IABSE SYMPOSIUM

VANCOUVER, 2017

Engineering the Future

REPORT

International Association for Bridge and Structural Engineering IABSE

Publisher

IABSE
c/o ETH Hönggerberg
C H - 8093 Z ür ich, Switzer land

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ISBN 978-3-85748-150-5

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Preface

Welcome to the 39th IABSE Symposium in Vancouver 2017. The built environment is becoming increasingly complex, and we face ever growing expectations by society that our infrastructure and buildings must provide exceptional performance over a long service life. The 39th IABSE Symposium provides a platform to the world's structural engineers to share their experiences with contemporary structures and their vision for the future. The conference theme "Engineering the Future" is highly relevant today when the solutions have to be engineered using innovative technologies and past experience in a way that is economical, robust and enhances the sustainability of the built environment. The Symposium enables the participants to actively discuss practical topics related to the structural engineering of buildings, bridges and other civil infrastructure.

The Symposium was organized by the Canadian Group of IABSE in collaboration with the Structural Engineers Association of British Columbia. These proceedings contain over 450 papers presented at the Symposium, which were written by an impressive roster of keynote presenters, panellists, and industry stakeholders representing design, research, construction, and socio-economic and political aspects of structural engineering. In addition, several unique workshops, tours and social events provided the participants with an enriching and engaging experience.

Located on Canada's spectacular West Coast, the host city Vancouver is one of the most beautiful and vibrant cities in the world. Its prominent location combines nature with urban life, making it an exciting conference and travel location. The Vancouver region has seen remarkable growth in recent years, with an explosion of new residential and commercial construction in the walkable Downtown core while preserving the city's varied past. Considerable rehabilitation and expansion to Vancouver's landmark bridges, transit structures and other civil infrastructure has also occurred in recent years.

This Symposium would not have been possible without the sustained effort and the hard work of many people. Obviously, the authors, the committee members, and the reviewers are essential to the success of the Symposium. In particular, we thank the dedication of the core group of the Scientific Committee for their efforts in handling of the papers and preparing an engaging technical program, and the members of the Local Organizing Committee for making the Symposium a memorable event.

We hope that you enjoyed the Symposium and find the technical program and the proceedings interesting and stimulating.

Maria Anna Polak Chair, Scientific Committee	Peter Taylor Honorary Chair Organizing Committee	Katrin Habel Co-Chair, Organizing Committee	Adam Lubell Co-Chair, Organizing Committee

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Seismic Assessment and rational renovation of the structural heritage

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Abstract

Pliny the Elder was possibly the first "engineer" trying to give suggestions on how to construct seismic resisting buildings, but even after gigantic steps in understanding ground motion demand and structural response, any strong earthquake results in casualties and economical losses, in most cases beyond expectations.
It is thus evident that the intelligent application of Newton's and Hooke's laws, the development of response and design spectra and of capacity design principles have not been sufficient to protect human life and the constructed environment from nature's whims.
Today's frontiers are related to the impossible reconciliation of resources and needs, and consequently to the best use of the available resources, in terms of funding, but as well of time, manpower, advanced techniques.
A first difficulty is associated with the problem of defining a common measure of risk, for different kind of structures and infrastructures, including apparently distant effects, such as business interruption, traffic detour, increased pollution, value of the cultural heritage.
A second basic problem relates to our capacity of appropriately evaluating the effect of different, traditional and innovative, strengthening techniques, in the same terms of global economical benefits.
This presentation will discuss these subjects from a critical viewpoint, emphasizing the possible *criteria* for the mitigation of seismic risk and some of the *alternative choices* that may be adopted for strengthening, with reference to:

(a) the modification of damage and collapse modes, comma strengthening individual elements or locally increasing the deformation capacity;
(b) the insertion of additional systems resisting eliminate to horizontal actions;
(c) the introduction of base isolation, with the objective of capacity-protecting the existing structure;
(d) the reduction of displacement demand by added damping or introducing tuned mass systems.

Examples will refer to major bridges and historical buildings, with the aim of discussing eliminate how B*ringing Existing Structures into the Future*, with an intelligent and sustainable approach.

Developments in the wind engineering of tall buildings

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Abstract

The number of tall buildings above 200 m in height has been growing exponentially in the last two decades, largely due to mass migration of populations around the world into cities where land is at a premium. There is no sign that this trend will end soon. A large number are now in the 200 m to 600 m range and the tallest are approaching 1000 m. The importance of wind loading and serviceability under wind action has grown along with the increasingly extreme heights and slenderness of many of these structures. Whereas wind loading used to be taken as something to be determined after most of the important design decisions had already been taken, it is now recognized (as it has been for a while for very long span bridges) as something that needs to be accounted for right from the outset. It is common now for shaping workshops to be undertaken in the wind tunnel soon after commencement of design so as to avoid difficult and expensive to solve problems emerging late in the process. As well as shaping the building aerodynamically, the use of supplementary damping has become much more common and is often acknowledges as a crucial part of structural optimization. The paper will provide examples of how wind engineering influenced the design of a number of tall buildings.

A recent development in wind engineering is the proposed adoption of Performance Based Design principles that have proven very beneficial in seismic engineering. The capability now exists to undertake full time history analysis of a tall building during a severe storm and to use Incremental Dynamic Analysis to explore its final collapse mode. This allows the true wind performance of buildings of buildings to be assessed in much greater detail than before, an important consideration if tall buildings are to be used a shelter in place along hurricane ocean lines. Findings from these studies indicate tall buildings, currently designed to remain fully elastic even at ultimate wind loading, have considerable untapped reserves of structural strength. The biggest challenges lie in the area of serviceability and cladding rather than structural strength. Serviceability issues can be largely resolved by supplementary damping systems but the current reliability of cladding under impact from wind loads, debris and wind driven rain appears to be in need of improvement.

Measuring, Monitoring and Evaluating Community Resilience using Remote Sensing Technologies

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Abstract

In many instances, disasters act as catalysts in the adoption of new and emerging technologies. Spawned by the need to rapidly collect vital information for disaster management, technology innovations have often helped emergency responders to assess the impact of large disasters more efficiently and rapidly, and to track and monitor progress in critical response and recovery operations. Some examples of where technology implementation has been driven by the occurrence of a major disaster include the 2010 Haiti Earthquake (where satellite and airborne imagery of all types was captured and studied and used to rapidly assess the extent of damage after this event), the 2011 Tohoku, Japan earthquake (where drone technologies were used to assess damage both within and outside of the Fukushima Nuclear Power Plant), and the 2015 Nepal earthquake (where the social and economic impacts of this devastating event were captured through remote sensing, crowdsourcing and GIS technologies). All of these events underscore the opportunities that emerge when time-critical information can be delivered more efficiently to users making critical decisions during the disaster.

One technology which has had an enormous impact on disaster management has been remote sensing. In the past several decades, this technology has been used extensively to explain the extent of impacts caused by earthquakes, tsunamis, hurricanes, floods, wildfires and terrorist attacks. Through high- resolution optical imagery and active sensors (e.g., synthetic aperture radar, or more commonly known as SAR, and light detection and ranging or In-situ and airborne LIDAR), remote sensing technologies have demonstrated significant efficacies in quantifying post-disaster damage, monitoring recovery and reconstruction progress after significant disasters, and more recently, in developing important exposure information on our urban infrastructure. One main reason for this rapid progress has been the introduction of high-resolution, commercially-available satellite imagery. Where these technologies used to be available to mainly government agencies (mostly military), they have now become readily accessible to the public. The impact of this development has been most noticeable in the disaster management area.

Remote sensing technologies are also playing a major role in helping to understand the vulnerability and resilience of many emerging economies around the world. Currently, there are substantial activities taking place in Africa where detailed risk profiles from natural hazards are being constructed in order to prioritize natural hazard mitigation efforts. The notion of investing in mitigation before a disaster occurs is key in reversing the trend of ever increasing losses from natural disasters that are especially prevalent in developing countries. On a global scale, the research community is doing a reasonable job in identifying and mapping a variety of natural hazards. However, in order to determine the impact that these hazards have on communities, better

information and data must be generated on exposures, i.e., what assets are at risk to these hazards. In the past several years, NASA has sponsored focused research on how to use earth observation (EO) imagery to delineate areas of urban development as well as the locations of critical infrastructure, e.g., roads, highways, bridges. Using a variety of satellite sensors (both active and passive) and combining this information with local field information (including census data), researchers have been able to construct inventories of buildings with regional profiles of building construction type, size and occupancy. This information has allowed analysts to quantify the expected damage or loss to communities from a wide range of natural hazards. These risk profiles are now allowing in-country policy makers to consider in a consistent and systematic way how best to address these risks for both urban and rural exposures.

In summary, this presentation will show through examples how remote sensing technologies have changed the way in which we measure, monitor and evaluate community resilience to natural hazards worldwide. We will also discuss that even with this demonstrable progress, remote sensing technologies still have the potential to be even more valuable in enhancing resilience. For example, key areas of development include timely and affordable access to images around the world, ensuring robust methodologies for exposure development and risk analysis, adequate documentation of successes and failures with respect to the use and adoption of remote sensing technologies, and areas where government support – especially in the research area – is needed to design, develop and test methodologies, systems, platforms and other components, so that robust disaster management tools can be developed and deployed throughout the world.

Challenge and Innovation of Long Span Bridges in China and over the World

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Abstract

The challenges and achievements of long span bridges in girder, arch, cable-stayed and suspension types are briefly introduced as the background of bridging capacity innovations in China and over the world. The challenging problems encountered in girder bridges are related to extreme bending moment, PC girder excessive deflection and orthotropic steel deck cracking, and the corresponding innovative techniques include hybrid structures, corrugated steel webs or steel truss webs composite girder and steel-UHPC composite deck. The most recent achievements of arch bridges can be attributed to steel box arch ribs for maintenance convenience and life-cycle durability and concrete-filled-steel-tube arch ribs for saving steel and concrete consumption and construction costs. The current cable-stayed bridge types with spatial cable planes and closed box girder have supported to enlarged span length up to 1,400 m or 1,500 m in near future if the challenging problems of deck lateral bucking and stay cable vibration can be overcome. Suspension bridges have been identified with the most challenging problem to have super long span length, and one of three kinds of control measures, including stabilizers, slot and the combination of slot and stabilizer, has to be adopted for aerodynamic stability. For suspension bridges with multiple or at least double main spans, the most important design concept is to select the proper longitudinal bending stiffness of the central pylon.

Keywords: Long span; girder bridge; arch bridge; cable-stayed bridge; suspension bridge; challenge; innovation.

Monitoring intrinsic forces of a steel multi-girder bridge with frozen expansion bearings through rehabilitation

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Abstract

A Structural Health Monitoring (SHM) system was designed and installed on a steel two-span continuous multi-girder bridge to track key performance metrics during construction of a nearby major industrial complex. The goals of the monitoring system focused on identifying and tracking performance of the bridge's unique movement mechanisms and variation of intrinsic forces within the girders. During the pre- construction monitoring period, the structure's temperature-based response signature was evaluated for each performance metric. This analysis showed that the original expansion bearings at the bridge's single abutment were frozen. After one year of monitoring, the owner of the bridge decided to carry out a rehabilitation project. The rehabilitation allowed for the opportunity to compare the bridge's response signatures before and after bearing replacement. The main objective of the paper is to present the findings related to how the bridge performed after the replacement of expansion bearings, specifically how the development of intrinsic forces in the steel girders was altered.

Keywords: Structural Health Monitoring, Periodic Temperature-Based-Assessment, Expansion Bearing, Steel Multi-Girder Bridge

Innovative Bearing Design for Bridges

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Abstract

Bridge bearings represent a small percentage of the overall cost of a bridge, however if improperly designed or installed they can result in the majority of the problems. As a result it is imperative that bridge bearings be easy to install and have a trouble free design. Many types of bridge bearings have been utilized over the years with a mixture of success and failure. One type of device that has had an impressive performance history for over 40 years is the disk bearing. The disk bearing has undergone extensive testing and offers engineers several different innovative design features for curved girders, uplift restraint, high horizontal loading and high rotations.

Keywords: bearings; bridges; cost effective; multi-rotational; polyurethane; PTFE; sliding.

Expansion Joints and Bridge Bearings as Smart Monitoring Devices

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Abstract

Expansion joints and bridge bearings are ideal devices for Smart Structural Health Monitoring.

Expansion joints are suitable for the determination of actual vehicle loads, as they are installed in all large span bridges and are directly loaded by overrolling traffic. Knowing the precise traffic loading is crucial for e.g. determination of the remaining bridge service life for the numerous bridges in need of rehabilitation measures.

Bridge bearings enable a pooled load transfer and movements and rotations with small restraining effects. The majority of changes in the state of the bridge have a direct effect on the loading and the rotation and displacement of bearings. E.g. a change of stiffness will lead to a change of the bearing load and the bearing rotation resp. displacement. Monitoring the reactions and loading of bridge bearing is a cost-effective monitoring measure for the primary structural system. If the bearing system is completely replaced by smart monitoring bearings it is feasible to determine the exact dead load which allows a reduction of the partial safety factor γ_G [4].

This paper describes a smart monitoring expansion joint and two smart monitoring spherical bearings, which are installed in a real bridge, i.e. the German pilot project "Smart Bridge in the Digital Motorway Test Bed". The devices have been extensively tested in laboratory tests and on a test bed, but it is the first application of both smart monitoring devices in a real bridge with normal traffic.

Keywords: bridge monitoring; expansion joints; load, rotation, displacement measurements; traffic load measurement; spherical bearings for monitoring; smart bridge

Innovative Expansion Joint Replacement for Burlington Bay Skyway

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Abstract

The innovative expansion joint replacement design for the Burlington Bay Skyway Northbound Structure in Hamilton, Ontario resulted in substantial economic and social benefits. The existing modular expansion joints were distressed and at the end of their service lives. Joint replacement was complicated by several constraints, including high traffic volumes, limited detour options, a restriction against full closures of the bridge, a moratorium by the client agency on splicing modular joint assemblies, and the limited available load capacity of the structure. The bridge articulation was modified and the existing breather joints were mobilized to reduce movement at 16 modular expansion joints. This allowed these joints to be successfully replaced with an innovative prefabricated module expansion joint assembly incorporating a single strip seal. The design minimized traffic closures and disturbance to the public, while also realizing substantial cost savings.

Keywords: expansion joint, innovative, modular, prefabricated, bridge design

Lions Gate Suspension Bridge Tower Joints and Bearings Renewal

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Abstract

A unique collaborative approach was utilised for the renewal of these major components of the bridge. It was a combination of input from the engineer, contractor, material specialist, manufacture and the owner that enabled a process of renewal which was innovative, constructible, utilised new materials and maintainable. An important consideration was to establish the causes for the observed early deterioration of components. A small scale model of the joint in particular was constructed out of wood and based on the 3-D FEM analyses that were carried out on the bridge, for failure mode analysis. Solutions were developed in a joint effort of all parties involved, leading to a novel approach for the restoration of the existing structural component. The installation was time sensitive and took place without any interruption of traffic

Keywords: modular expansion joint, modelling, wind load, wear, restoration, repair, bearing, spring, elastomer, polyurethane.

Lead Rubber Bearings for Seismic Isolation of Structures in Cold Climates - New Developments

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Abstract

Nowadays, even in areas that have not been well known for the application of seismic protective measures, there is a growing tendency to design highway bridges, especially curved ones, to withstand strong seismic demands. A commonly adopted earthquake protection strategy consists of using seismic isolation bearings instead of seismically vulnerable conventional bearings, to isolate the supported bridge deck from the ground movements below. Among the great variety of seismic isolation systems available, the lead rubber bearing (LRB), in particular, has found wide application in highway bridge structures. However, conventional LRBs, which are manufactured from standard natural rubber and lead, display a significant vulnerability to low temperatures.

This paper describes the challenge faced in the seismic isolation using LRBs of a curved highway viaduct where low temperatures must be considered in the design. Specifically, the LRBs must be able to withstand temperatures as low as -30 °C for up to 72 hours, while displaying only minor variations in their effective stiffness. This extreme condition required the development of a new rubber mixture, and the optimization of the general design of the isolators. Since the relevant specifications such as AASHTO Guide Specifications for Seismic Isolation Design and EN 15129: Anti-Seismic Devices contain only limited test data relating to low-temperature performance, extensive full-scale low-temperature dynamic testing was carried out. This testing, which sheds new light on the performance of LRBs at low temperatures, will be described, in the context of the overall challenge to seismically isolate curved highway bridges.

Keywords: seismic isolation; full-scale testing; low temperature; lead rubber bearings.

Experimental Investigation of Post-cracked Flexural Behavior for PC Girder Bridges

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Abstract

Extended studies are more and more needed for evaluating the post-cracked flexural behavior of PC (prestressed concrete) bridges where the design concept of eliminating cracks cannot be satisfied. In this paper, an experimental program is provided with six scaled specimens to analyze post-cracked flexural behavior of prestressed concrete girders. Mechanical properties, such as ductility, flexural rigidity and load-bearing capacity, are examined according to grouting, loading types and deflections at midspan. The results reveal that grouting provides better behavior by increasing ductility and crack resistance for PC structures. Load cycles have insignificant influence on cracking, ultimate loads and flexural rigidity of the prestressed concrete beams. However, load cycles may decrease non-prestress reinforcement (NPR) yielding loads by 5-12% and will reduce ductility by decreasing ultimate deflection. Furthermore, empirical equations have been presented and validated for evaluating flexural rigidity and load-bearing capacity for PC beams with cracks.

Keywords: Post-cracked flexural behavior; PC bridges; Flexural rigidity; Loading types; Load-bearing capacity.

Experimental Performance of Composite Box Girder Bridges Decked with Full-Depth Precast Panels

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Abstract

Box-girder composite bridges using prefabricated full-depth deck panels allow modular construction, greatly minimizing traffic impacts as well as providing longer span capability and better aesthetics when comparing with conventional plate girder systems. Shear stud clusters embedded in shear pockets are usually used to create composite action between concrete deck slabs and steel box girders. For accelerated bridge construction, it is advantageous to extend the spacing between the stud clusters. As a result, concerns have been raised about the effectiveness of composite action between the precast panels and the supporting girders. In this study, four composite box girders with a length of 5400-mm and a height of 380-mm were fabricated. The slab and the steel box were made composite by using closely-spaced studs over the full span length of beam. The arrangement of stud clusters of beams is respectively 2×3@400mm, 2×3@600mm, 2×2@800mm and 2×3@800mm, resulting in different degree of shear connection between 0.65 and 1.22. The specimen beams were tested to failure under two-point concentrated loads. It can be concluded from the experimental study that: (1) Shear stud clusters in the composite girder design can provide the necessary shear connection at the interface of steel box-girders and precast concrete slab bridge construction to achieve full composite action; (2) The degree of shear connection has little influence on the elastic behavior of composite box girders, and it has limited influence on the ultimate bending capacity; and (3) The testing has proven that full composite action between precast concrete panels and steel box girders can be achieved when the degree of shear connection is not less than 0.7.

Keywords: composite box girder bridge; precast deck panel; accelerated bridge construction; shear connection degree; partial shear connection

Experimental Study on Ductility and Hysteretic Energy of CIP and Precast Bridge Piers with High Strength Rebar

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Abstract

In order to minimize the construction cost and improve the seismic performance of structures, the high strength steel bar (≥500MPa) with sufficient ductility has begun to find application in construction industry around the world. Taking the cast-in-place and the precast segmental bridge piers with HRB600E into consideration, the pseudo-static experimental study of four large-scale specimens was carried out in this paper. The results showed that two types of the reinforced pier columns with HRB600E and different reinforcement ratio exhibited typical flexural failure mode where column bottom appeared concrete crushed seriously at the compressive toes or even extended into the core concrete encased by stirrup, and longitudinal bars buckled and subsequent fractured. The hysteretic loop for the CIP piers was plumper than the precast ones, but the resilience of precast pier was better than the CIP piers. The energy dissipation of the CIP piers for each cycle measured was larger than the one of the precast piers, which had relatively severer damage. The displacement ductility of the precast piers was relatively larger than the CIP piers. The energy dissipation bars fractured earlier in the cast-in-place piers than in the precast segmental ones when the reinforcement ratio was low.

Keywords: seismic design; bridge piers; high strength steel bar; reinforcement ratio; hysteretic energy dissipation.

Experimental Studies on a Novel Structural Detailing of RC Frames to Resist Earthquake and Progressive Collapse

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Abstract

Conventional structural design methods mainly concern the demands of individual hazards, while a multi-hazard oriented design method is in great need in the ever-complex multi-hazard building environment. Earthquake and progressive collapse, which are the two most critical encountered threats of reinforced concrete (RC) frames, are considered in this study. Previous study indicates that the newly added reinforcement in progressive collapse design may weaken the structural seismic resistance due to “strong-beam-weak-column” failure mode. To resolve such confliction, a novel structural detailing is proposed. Both cyclic and progressive collapse tests are conducted to validate the performance of the newly proposed reinforcement arrangement. The experimental results showed that the proposed RC frame structural detailing can maintain satisfying progressive collapse resistance and efficiently mitigate the column and joint damage under cyclic load.

Keywords: Experimental tests, RC frame, Structural detailing, Earthquake, Progressive collapse

Load carrying behaviour of beams with bent-up bars as shear reinforcement

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Abstract

During the second half of the last century it was common in Europe to use bent-up bars of the longitudinal flexural reinforcement near the support of one-way slab bridges to strengthen their shear capacity. As current codes do not offer clear concepts for evaluating the capacity of those structures, many of them have to be strengthened with expensive measures to comply with the standards. Therefore, an experimental series was conducted at TU Wien which included seven slab strips with the dimensions of 6.50/0.55/0.40 meters. The investigated parameters were the position and number of bent-up bars and the point of load introduction. The results exhibited that the activation of these bars is strongly dependent on the reinforcement layout as well as on the loading point. This is confirmed by the crack patterns and the covered development of the cracks.

Keywords: shear behaviour; bent-up bars; slab bridges; testing

Experimental Study on a Precast SRC Rock Shed

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Abstract

To understand the dynamic behavior of a precast SRC rock shed and to examine an analysis method for the dynamic behavior of precast rock sheds, a weight-drop test was done using a field-scale roof model. This model consists of a precast SRC girder, SRC slabs (beams), and a cast-in-place concrete slab. The results of this test were compared with those of nonlinear dynamic framework analysis in which fiber elements were assumed. The results clarified that, with the analysis done within the range of elasticity limit, 1) the analysis was able to accurately reproduce the test results under the proposed load input condition, and 2) the joint conditions for the main girder and the slab, which were one-point rigid joint, one-point pin joint, and two-point pin joint, did not result in considerable differences in the analysis.

Keywords: Rock-shed, Weight-drop test, SRC, Nonlinear dynamic framework analysis

A New Pulse-Based E-R-μ Method for Predicting the Peak Seismic Response of Highly Nonlinear Bridge Structures

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Abstract

Simplified analysis methods used in AASHTO, CAN/CSA-S6 and EC8 codes for the seismic design of isolated structures typically rely on a linearization of nonlinear systems and assume that the peak response can be obtained from a steady-state dynamic response centered about the origin of the force-deflection response of the system. This assumption, while adequate for a certain range of nonlinear systems, leads to potentially large inaccuracies, especially for highly nonlinear systems. The article presents a new pulse-based *E-R-μ* method that was developed to overcome these limitations and achieve better peak response predictions. The method is based on the response of nonlinear systems to single acceleration pulses which more realistically reflects the effects of ground motions on seismically isolated structures. In addition, the method does not require iterations, which represents a major advantage compared to current iterative linearization approaches. In the article, assumptions of current code methods are summarized. Energy based concepts forming the basis of the new *E-R-μ* method are introduced. The method is then described and validated against the results from nonlinear time history analyses for a large number of isolated bridge models. The method is also applied and validated for an archetype isolated bridge case. For this structure, the proposed *E-R-μ* method is found to give an upper bound prediction of the displacement demand that is obtained from nonlinear dynamic analysis.

Keywords: Seismic design; Bridge structures; Seismic isolation and supplemental damping devices.

Innovative Solutions to Seismic Design Challenges for the SFOBB I-80 WB Ramps at Yerba Buena Island

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Abstract

The I-80 Westbound (WB) ramps at Yerba Buena Island (YBI) are comprised of five complex curved structures that were designed to provide access to the new east-span of San Francesco Bay Bridge (SFOBB). The construction contract of the project was awarded in late 2013. Yerba Buena Island is located in very high seismic zone within the San Francisco Bay. Two major earthquake sources are the Hayward fault at about 12 km east of the project site and the San Andrea faults at 18 km west of the project site. The terrain at the bridge site highly varies with the ground surface elevations, which make seismic design very challenging. This paper discusses a number of innovative design solutions; foundation, superstructure, seismic deck joints, in-span hinges, spherical bearings, and etc. to deal with the stringent seismic design challenges.

Keywords: SFOBB; concrete-box; post-tensioning; steel-box; GFRC; seismic joints

Seismic Performance and Failure Mechanism Study of Double Deck Bridges by Pushover Analysis

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Abstract

Double deck bridges are increasingly adopted to alleviate the overcrowded traffic in China. However, its seismic performance is more complicated and less well-studied, comparing with ordinary standard bridges. In this paper, pushover analysis is employed to investigate influence of structural parameters on the seismic performance of double deck bridges. Analysis results show that a relative small column reinforcement ratio is feasible for double deck bridges, as cap beams and joints are likely to damage if the column reinforcement ratio is too high. The failure mode of double deck bridges can be categorized into two types according to the height of upper column and columns. One type is that plastic hinges appear in both upper and lower columns, and the other type is that plastic hinge just appear in the upper or lower column. Cap beams with relative large cross section dimension are favourable, as the strong beam-weak column mechanism is achieved.

Keywords: double deck bridges; seismic performance; failure modes; column longitudinal reinforcement; height of the pier; beam cross section

Comparative Study of a Set of Codes for the Seismic Design of Buildings

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Abstract

A comparative study of codes from seismically active regions of various countries is presented covering US, European, Italian, Greek, Romanian, Brazilian and Bulgarian Standards. The study focuses on the comparison of certain critical points: recurrence periods; seismic zonation and design ground motion parameter values; shape of the response spectrum; soil amplification; importance levels; seismic force-resisting systems; behavior factors; structural irregularities; story drift limits; procedures for seismic analysis. Following the comparison of the text of the codes, their application on the seismic design of an ordinary reinforced concrete structure is presented. The structure is subjected to the seismic input according to the above set of codes and obtained results are compared highlighting the differences between the codes. Overall this study aims to assist to the future improvement of the various seismic standards.

Keywords: Seismic codes, seismic analysis, comparative analysis

An efficient seismic retrofit for the Capodichino viaduct

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Abstract

Built environment in Europe has become dense with infrastructures and buildings packed in a restricted space. In many countries the laws explicitly promote the cities densification to avoid further urban sprawl. For many years the densification was debated without taking into account the need for a general seismic update of infrastructure and the protection of the cultural heritage. The Capodichino viaduct is a remarkable case of seismic retrofitting in a highly urbanized, seismic area. This paper presents the concept and the installation of new piers cap system that permitted to retrofit the bridge without any modification of the piers and foundations capacity, while the structure was in use.

Keywords: Pier caps, bridge engineering, construction process, urban construction

Seismic assessment of a vernacular rammed earth building

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Abstract

Rammed earth constructions represent a valuable cultural heritage of vernacular architecture, whose significance has acquired even more importance in the last years with the renovated interest for this sustainable building technique. The aim of this work is to develop a FEM model typologically representative of a Portuguese vernacular rammed earth construction in order to characterize numerically its seismic performance and raise awareness about the level of improvement introduced by two compatible strengthening techniques: textile reinforced mortar (TRM) and a ring beam applied at the top of the walls.

Keywords: rammed earth; seismic assessment; pushover analysis; retrofitting; TRM

Wind-induced Modal Identification of the Bosphorus Bridge using SHM-Structural Health Monitoring Data

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Abstract

Wind vibration characteristics of the Bosphorus Bridge is investigated using SHM data. The Bosphorus Bridge with the main span length of 1074 m and two side spans was instrumented due to the critical event in 2004 leading to damage to a hanger element. Totally 168 sensors were mounted on the bridge for its monitoring system. Due to the geographic location of Istanbul, strong winds are not expected for the bridges. However, the Bosphorus Bridge experienced a critical wind load in 2012, resulting in large displacement in transverse direction. During the event, wind speed reached to approximately 100 km/h from the average speed of 20 km/h within a short duration of 10 min. Therefore, it is significant to determine the influence of this event on the response of the bridge. For this objective, the data pre-processing including windowing and overlapping is first done to get rid of distorting effects of noise content on the data. The refined data, afterwards, is considered for structural identification of the bridge. Implementing the fundamental identification method of FFT, mode shapes and corresponding frequencies of the bridge are obtained. The comparison of the results during strong wind with those from after the extreme event showed that strong wind led to higher modal period values in the transverse and vertical modes, which can be attributed to a more flexible bridge behavior under this event. Along with the low modal frequencies obtained during the strong wind, the bridge is estimated to have high damping capacity under extreme loading. In addition, the modal frequencies obtained after the strong wind proves no damage to the bridge since these values are equal to natural vibration values of the bridge under normal operation conditions.

Keywords: suspension bridge; SHM; wind vibration characteristics; modal identification.

Thermal behaviour of a concrete cable-stayed bridge in Algeria

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Abstract

The Salah Bey Viaduct located in the city of Constantine, Algeria, is a cable-stayed bridge with a total length of 756 m and a 259 m main span. Its two pylons have a total height of 130 m and the deck is a prestressed box-girder 3.75 m high with large lateral cantilevers.

A comprehensive structural health monitoring system was set up during construction, including a large number of sensors and covering different aspects, as the weather conditions or the static, dynamic and seismic structural behaviours.

Since the environmental conditions in Constantine involve large daily and seasonal thermal amplitudes, this paper has the purpose to characterize these thermal variations and to analyse its structural effects.

Keywords: Cable-stayed Bridge; prestressed concrete bridge; structural health monitoring, thermal behaviour.

Tunneling Appropriate Computational Models from Laser Scanning Data

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Abstract

Tunneling projects often require computational models of existing structures. To this end, this paper demonstrates the viability of automatically, robustly reconstructing an individual building model from laser scanning data for further computational modeling without any manual intervention. The resulting model is appropriate for immediate importation into a commercial finite element method (FEM) program. The method combines a voxel-based technique with an angle criterion. Initially, the voxelization model is used to represent the façade model, while an angle criterion is implemented to determine boundaries of the façade and its openings (doors and windows). The algorithm overcomes common problems of occlusions or artefacts that arise during data acquisition. The resulting relative errors of overall dimensions and opening areas of geometric models were less 2% and 6%, respectively, which are generally within industry standards for this type of building modeling.

Keywords: Laser scanning, voxelization model, angle criterion, building reconstruction, finite element analysis, building damage, tunneling-induced settlement

Structural Monitoring of a Closure Strip in the Staged Construction of a Slab-on-Girder Bridge on Highway 401

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Abstract

Highway bridges are routinely rehabilitated or replaced in stages to avoid lane reductions. In recent years, the Ontario Ministry of Transportation (MTO) has seen an increase in inquiries and concerns from engineers and contractors related to staging. Some of the potential problems relate to settlement and movement of plastic concrete due to live load vibration, and shear and rotation at the construction joint, resulting in compromised reinforcement bond and reduced concrete quality at the construction joint. In support of a recent guideline advising designers of issues that shall be considered when designing bridges rehabilitated or replaced in stages, the MTO monitored the Hwy 401 Westbound Collectors Bridge over the Ramp from the Hwy 401 WBL Express to DVP/Hwy 404, during replacement. The paper describes the bridge's behaviour as the closure strip concrete sets up. The relative ratio of strain between girders across the closure strip provides an indication of the development of load transfer over time.

Keywords: monitoring; closure strips; staged bridge rehabilitation; cast-in-place concrete.

Traffic Response Pattern of Cable-Stayed Bridge as a Comparison Tool for SHM

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Abstract

A cable-stayed bridge across the Danube in Bratislava, Slovakia with a 303 m length of the main span was monitored and subsequently the data were used for Structural Health Monitoring (SHM). It was necessary to record the traffic in order to be able to incorporate it into the numerical analyses of the dynamic response of the bridge subjected to a well described dynamic load synchronized with the camera records. For the test's purposes a 28 channel National Instrument system has been used. The vibrations – displacements time series of a few control points on the bottom of the bridge deck have been also acquired using an interferometric radar IBIS-S located below the bridge. A precise FEM model was used to compare the measured values - accelerations and displacements with those from the time history analyses. Response spectra have been compared as well. A specific traffic situation (pattern) was selected from the traffic stream that can be used as a comparison tool for future SHM of the bridge.

Keywords: Structural health monitoring; cable-stayed bridge; NI measurement system; interferometric radar; FEM model; time/history analysis, traffic pattern.

A frequency domain tool for investigation of wind response of TLP suspension bridges

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The TLP suspension bridge concept is a new design proposed for crossing the wide and deep fjords along the E39 highway on the west coast of Norway. Recently sophisticated time domain analysis tools have been developed for accurate and reliable results taking into account different dynamic nonlinear effects. Calculation is computationally very demanding and requires special data management; therefore, a frequency domain tool is typically preferred for the initial phase of design. This paper presents basic concepts and assumptions used in the frequency domain analysis. The linearized dynamic system is simplified as a modal-decomposed system taking frequency-dependent hydrodynamic added mass and radiation damping into account. Different combinations of wind and wave can be efficiently used for screening of responses under different environmental loads. This newly developed frequency domain analysis tool is specially designed for TLP suspension bridges. Results of several practical example analyses are presented.

Keywords: Multi-span suspension bridge; frequency domain analysis; wind buffeting analyses; hydrodynamics.

Experimental and Numerical Studies on Post-Facture Behavior of Simply Supported Composite Twin I-Girder Bridges

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Abstract

This study is carried out to investigate the post-fracture behavior of the composite twin I-girder bridge systems. In the experimental program, one intact specimen and one damage specimen were tested under static load with displacement control method. Different cases of fractures are performed in numerical analyses based on finite element method and nonlinear analyses. Significant reduction of system stiffness and load carrying capacity is observed in post-fracture condition. The failure modes of both intact and damage specimen are governed by the crush of the concrete slab. Nevertheless, composite twin I-girder bridge system will not collapse under dead load and be able to carry a certain level of live load. Numerical analyses for different damage conditions proved that the fracture at mid-span section is the most fracture critical location for composite twin I-girder bridge system.

Keywords: post-fracture behavior, composite twin I-girder bridge, fracture critical location

A New Improved Type of Friction Connection – An Experimental Study

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Abstract

By inserting small hard indenters into the slip planes of a bolted lap joint, the effective friction coefficient of the joint can be increased and the joint can thus withstand a larger shear force. This research is an experimental study conducted at the Luleå University of Technology, Sweden. Indenters inserted uniformly between two plates have been subjected to compression tests and also been loaded in shear in a bolted lap joint. The necessary pre-load to impress a 2.5 mm diameter indenter 2.3 mm into two plates is 11 kN. With stainless steel indenters the effective friction coefficient (μ) of the friction connection is improved. In a reference test with two shear planes and plain as rolled plate surface conditions, no indenters and an M30 bolt with a pre-loading force of 320 kN, the slip resistance was 54.5 kN and the effective friction coefficient μ=0.09. For the same arrangement but with 29 indenters per shear plane, and the same pre-loading, the slip resistance can be expected to slightly exceed 250 kN and the effective friction coefficient to be close to μ=0.40, at the acceptable joint slip of 0.15 mm, according to the current Eurocode. The work described in the article is a part of the European R&D project PROLIFE, RFCS 2015-00025.

Keywords: Friction connection; hardness; indenter; slip resistance; pre-loading.

Structural Efficiency of Cold-Formed Steel Beams with Stiffeners in the Web

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Abstract

This paper reports a series of flexural tests at ambient and fire conditions on simply supported cold-formed steel (CFS) beams using two different configurations – with and without web stiffeners. The main objective of these tests at ambient temperatures was to assess the ultimate strength of the beams and to provide a reference for the fire tests. On the other hand, the major purposes of these tests under fire conditions were to assess their critical temperature and critical time as well as to observe the effect of the stiffeners on the beams under different restraining conditions, including no restraints, partial axial restraint to the thermal elongation of the beam and partial rotational restraint at the beam supports. In addition, a comparison of both experimental results at ambient and fire conditions with predictions from currently available design rules is shown. Finally, it is worth mentioning that the use of CFS beams with web stiffeners might not be always a good solution, depending on their slenderness and boundary conditions.

Keywords: cold-formed, steel, sigma, beam, flexural test, ambient, fire, buckling.

Simulating composite bridges with corrugated steel webs using spatial grid model

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Abstract

This paper proposes a method for simulating the structural response of composite bridges with corrugated steel webs. Numerical modelling methods with various model dimensionalities have been widely used in the simulation of this type of structure. Among these methods, one-dimensional finite element model can satisfactorily capture the general reponse but it fails to give the stress result in the structure, which is necessary for refinement design. Also, the intensive computation and convergence issue of 3D solid model make this model less attractive, though it might be more capable of accurately simulating the local response of composite bridges. The spatial grid model is proposed as a simple but accurate solution to model the general and local responses of the composite bridges with corrugated steel webs. In this model, top slabs, bottom slabs and webs are characterized by orthogonal beam elements, wherein the stiffness of these beam elements are determined by the principle of equivalent displacements. For simplicity, the corrugated steel webs were modelled by steel plates of the same depth as the original webs. The folding effect of the corrugated steel webs was simulated by the reduction of the elastic moduli of the longitudinal element for webs. Thorough comparison was carried out between the proposed model and 3D solid model in terms of the vertical displacements, normal stresses, shear stresses under various loading cases. The shear lag effect in the concrete slabs was also investigated by the proposed model. The result verifies the applicability and precision of the proposed method in the refinement design of composite bridges with corrugated steel webs.

Keywords: Spatial grid model; composite bridge; corrugated steel webs; refinement design

The Fatigue Research on Long Span Steel Bridge for High Speed Railway in China

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Abstract

The paper firstly describes the application of the new type of structures to long span steel bridge for high speed railway in China, and then mainly introduces the technique research of fatigue design for long span steel bridges. The research is divided into two parts. One is fatigue load research on new type of long span railway steel bridge, the other is fatigue strength on new type of structure details. Through systematic investigation of fatigue load and fatigue strength with long span railway steel bridges, the fatigue load regulation parameters are obtained, and based on the fatigue test results with more than 40 new kinds of structure details, the S-N diagrams are also obtained. The research results play an important part in the technology upgrade for the design of long span railway steel bridges in China.

Keywords: fatigue, long span, steel bridge, high speed.

Experimental Study on Mechanical Behavior of T-shape Stiffened Orthotropic Steel-concrete Composite Bridge Decks

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Abstract

A new-type of orthotropic steel-concrete composite bridge deck system was developed, by casting the concrete overlay on the top of the orthotropic steel deck ribbed with T-shape steel member. To study its mechanical behavior, two new-type orthotropic steel-concrete composite bridge decks with different section dimensions were experimentally investigated and two reference decks (reinforced concrete deck and orthotropic steel deck) were also involved in the research for comparison. For the new-type orthotropic steel-concrete composite decks, the average value of the ultimate load per width is 885.7kN, which are 2.35 and 1.61 times respectively for that of the concrete and steel reference decks with almost the same section height. Experimental results proved that the composite deck can effectively control the crack initiation and propagation in the concrete and postpone the yielding of the steel bars and steel plates.

Keywords: new-type orthotropic steel-concrete composite bridge decks; T-shape steel ribs; field test; failure mode; concrete crack

Modal parameter identification of a curved cable-stayed model bridge based on EDA and DATA-SSI

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Abstract

For bridge health monitoring, the measured data may be unreliable due to various interferences. In order to get a reliable modal parameter identification result of a bridge, it is vital to have an inspection and a pre-processing on the bridge health monitoring data. Firstly, exploratory data analysis (EDA) was adopted to inspect the data quality, and the unreliable data measured from malfunctioning sensor was removed. Then, outlier analysis was performed to eliminate the abnormal data points from the data set. In the end, data driven stochastic subspace identification (DATA-SSI) combined with stabilization diagram was applied to identify the bridge modal parameters. A large scale curved cable-stayed model bridge was taken as an instance to verify the proposed method. The comparison of the modal parameter identification results of the original and the pre-processed data shows that the proposed method is effective, accurate and valuable.

Keywords: curved cable-stayed bridge; exploratory data analysis; outlier analysis; data driven stochastic subspace identification.

A tensioning-belt-cable-bridge above the Kaponiggraben in Austria – design and realization

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Abstract

Future-oriented infrastructure buildings not only fulfill their function, but also enter into a special symbiosis with the environment. From the user's point of view, these particular structures are harmoniously integrated into the respective location. This special attention in the design of infrastructure structures is characterized by the interaction of nature, ethics and aesthetics and is to be applied in the future as the NEA-principle for further engineering tasks. The projected ensemble with the brand name *THE BOND®* was submitted for the first time as an official approval project in Austria and is about to be realized. The high technological and aesthetic quality and identity of the ensemble with the location promises a high marketing value, which means that the bridge, which was originally designed as a purely engineering task, offers much more possibilities than just the connection of two places and is a trend-setting design for further tasks for engineers.

Keywords: *THE BOND®*; cable bridge; concrete; steel; aluminium; bubbles; bungee jumping.

Feasibility of timber-concrete composite road bridges with under-deck stay cables

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Abstract

Timber-concrete composite (TCC) bridges represent an attractive structural system due to the synergistic use of wood and reinforced-concrete. However, the benefits of TCC bridges can be hampered by their relatively large flexibility that limits their application to long spans. This paper presents an alternative solution for TCC bridges that incorporates post-tensioned under-deck tendons. These steel tendons are deviated by two struts and anchored to the diaphragms at the support section, effectively subdividing the total span of the TCC bridge into three sub-spans. The advantages of the newly proposed system are evaluated for 60 m span TCC bridges. This paper shows that the incorporation of under-deck post-tensioning effectively changes the critical limit states governing the design of TCC bridges. In addition, the application of post-tensioned tendons leads to a significant increase in the allowable slenderness and efficiency of structures.

Keywords: design, timber-concrete composite, post-tensioning, critical limit states, bridge.

Third Bosphorus Bridge-An Overview

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Abstract

The Third Bosphorus, a stiffened suspension bridge with a main span of 1408m, overall length 2250m and width 59.4m, is believed to be the first of its type. The innovative hybrid suspension-stay cable supported deck is designed and constructed to carry 8 lanes of road traffic and twin track heavy rail, all on the same deck level.

The bridge is situated in a seismic region and exposed to a severe wind climate. The bridge was required to be constructed to a tight timeframe. These factors posed technical and planning challenges. The technical innovations featured in the paper include tower saddles, dehumidification, and structural health monitoring system.

From a Lenders' Technical Advisor perspective, this paper gives an overview of the technical challenges and how these were successfully addressed in bringing to fruition this truly unique crossing by the design.

Keywords:

stiffened suspension; cable stay; seismic; aerodynamics; hybrid; heavy rail; tower saddles; Pendle bearings; dehumidification; structural health monitoring.

The 2nd Wuhu Yangzi River Bridge: a 806m Span Cable-stayed Bridge use U-Shape Anchoring System

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Abstract

The U shape anchoring system is a brand-new anchoring system. It is developed on the basis of saddle anchorage. In this paper, a super long cable–stayed bridge that uses U shape anchoring is introduced.

The 2nd Wuhu Yangzi River Bridge is a super long span cable-stayed bridge under construction. It is a double-pylon cable-stayed bridge with an 806m main span. The main girder of it adopted separate steel box girder and four cable planes arrangement.

U-shape cable system is used on the pylon, which can make the pylon slimmer and the width of middle groove can be reduced. It is also the key to the whole structure system's establishment.

U-shape saddle is the core component of the U-shape cable system. It transmits the cable forces to the pylon, avoiding the tensile stress in the pylon. It expands the usage of traditional saddle. With the results of finite element analysis and theoretical analysis, its rationality has been proved. Using the integral saddle installation method, the construction becomes more efficient and gets higher construction quality.

Now, the construction is being carried out at full speed, and is expected to be finished at the end of 2017.

Keywords: cable-stayed bridge; anchor area; durability; U-shape cable system.

Risk Based Inspection Method for Cable Supported Bridges

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Abstract

There is recognition that inspecting all elements of a complex bridge at the same set frequency is not suitable for these types of structures and an inspection regime that uses a risk based approach is more appropriate. However, there is no formal method or guidance on how such an approach should be applied to complex bridges. This paper sets out a method of inspecting complex bridges based on the evaluation of risk. An assessment of the criticality, vulnerability and current condition of each bridge component or groups of components is carried out to determine the frequency of inspection based on the risk of failure. This assessment also takes into account the degree of difficulty of detection by inspection. This method reduces the risk of failure, optimizes resources and can help reduce risk to the public. This risk based approach can also be developed for use in maintenance and capital works planning and this will be introduced in this paper.

Keywords: Complex suspension, cable stayed bridges; inspection; risk based approach.

Updating Life-Cycle Performance Model of Bridge based on Inspection Data

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Abstract

For the bridge maintenance strategy and planning, prediction of future performance based on the current performance must be required and it is possible more rational decision-making through the higher accuracy of the prediction model. While performing a detailed inspection of the entire bridge can reduce a significant part of the uncertainty, it is impossible to reduce the uncertainty of inspection result and it is always evaluated by probability. In this study, to solve this problem, a Bayesian update method is applied to the optimal maintenance strategy in Bridge Management System (BMS) considering the uncertainty of inspection data. Also, examples of application are presented, showing the effects of inspection and updating on the bridge maintenance strategies. In this study, application possibility and availability of domestic bridge management system are evaluated by referring to the proposed method in the existing trends.

Keywords: bridge; maintenance; decision-making; uncertainty; inspection; bayesian; updating.

COST TU1406 – An overview of European Standardization on Quality Control of Road Bridges

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Abstract

Road asset management is a task of great responsibility, since it involves vital assets to the community. An efficient transportation network is essential for the modern society from the economic, societal and environmental point of view. Today, it is a challenge for operators to manage road infrastructures under their responsibility in an efficient way, meeting the present and future needs of the community they serve. For this purpose, authorities need to produce an asset management plan which should not only define the goals to be achieved by exploiting the roadway bridge network, but should also identify investment needs and priorities based on a life cycle cost criteria. In addition, a proper condition assessment of these assets must be conducted to support the decision-making process regarding their preservation. COST Action TU1406 aims to quantify performance indicators, define standardized performance goals and develop a guideline to establish quality control plans at a European level.

Keywords: roadway; bridges; performance; indicators; goals; standardization.

A novel Quality Control Framework for the management of existing bridges

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Abstract

The paper presents a framework to evaluate key performance indicators (KPIs) in qualitative manner. This framework is the basis for establishment of Quality Control plans for existing bridges. It addresses the dynamics of the damage processes that allows predicting the point in time, from which the performance goals are not met anymore. The KPIs are defined to address not only road users' but also owner's or operator's perspective as well as environmental and societal concerns. To this end the RAMSSHE€P approach gas been modified. The proposed framework is also illus- trated on a simple example.

Keywords: Quality Control plans, performance indicators, damage processes, demand processes, inspection, maintenance, Bridge Management

Performance Indicators for assessing RAMS SHEEP performance

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Abstract

Bridge management strategies need to specify maintenance actions, which are required in order to keep a desired performance level. This paper presents the structure and basic ideas for the development of a guideline incorporating different aspects of bridge performance goals, which may vary according to technical, environmental, economic and social factors. Furthermore it discusses the need for agencies to measure bridge performance against objectives on structure and network level. The paper is based on activities in the COST Action TU 1406, which aims to bring together both research and practicing community in order to accelerate the establishment of a European guideline for bridge management.

Keywords: Bridge management strategies, performance level, -indicators, -goals, COST TU1406.

A proposal for classification of key performance indicators for road bridges

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Abstract

Because of the competing demands for scarce resources (funds, manpower, etc) national road owners are required to monitor the condition and performance of infrastructure elements through an effective inspection and assessment regime as part of an overall asset management strategy. COST Action TU1406 aims to bring together research and practicing communities in order to establish a European guideline in this issue. In this context, this paper proposes a framework to classify research-based performance indicators related to highway bridge life-cycle analyses according to a parameter readiness level (PRL). Such a method examines program concepts, technology requirements, and demonstrated capabilities to rate the level of maturity of different categories of indicators. This approach is illustrated with some examples.

Keywords: Performance indicators; parameter readiness level (PRL); maintenance; road bridges; COST TU1406.

Decision support for maintenance and upgrading of existing bridges

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Abstract

Maintenance of transportation infrastructure assets can be relatively expensive, since it does not only include the direct cost of interventions, but also the indirect consequences of traffic disruptions. To make optimal decisions about maintenance actions, including rehabilitation and upgrading, reliable information about the performance of existing structures is needed. However, obtaining such information might require significant efforts and can be done in various ways. The purpose of an ongoing Swedish research project BIG BRO is to develop a framework for a decision support methodology that can be used for implementing maintenance strategies for bridges on a rational basis. The present paper provides a brief overview about the project as well as describes some of the ongoing work.

Keywords: maintenance; rehabilitation; upgrading; infrastructure; bridges; decision support.

Recommendations for proof load testing of reinforced concrete slab bridges

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Abstract

Proof loading of existing bridges is an option to study the capacity when crucial information about the structure is lacking. To define the loading criteria for proof load testing, a review of the literature has been made, finite element models of existing viaducts have been made, and on these viaducts, proof loading tests have been carried out. These bridges were heavily instrumented, to learn as much as possible about the structural behaviour during proof loading. Additional laboratory experiments have been used to develop controlled loading protocols, and to identify which stop criteria can be used for which case. As a result of the analysis and experiments, recommendations are given for proof loading of bridges with respect to the required maximum load and the stop criteria. These recommendations have resulted in a guideline for proof loading of existing reinforced concrete slab bridges for The Netherlands.

Keywords: guidelines; proof load testing; slab bridges; reinforced concrete; field testing; stop criteria; flexure; shear.

Development of a modular footbridge system with pre-tensioned CFRP reinforcement

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Abstract

A common problem of concrete bridges are corrosion damages of the steel reinforcement. The related loss of capacity as well as visual effects often require expensive and elaborate refurbishment or even reconstruction. To overcome these drawbacks, a modular footbridge system without steel reinforcement is developed. The application of non-corrosive carbon fiber reinforced polymer (CFRP) reinforcement is suitable for building slender constructions which are durable and long-lasting. To enhance the durability and reduce costs, high strength concrete (HSC) with high density is applied. Hence, no additional surface is required. The modular construction method allows for fast assembly and disassembly of the footbridge. This paper presents the dimensioning and flexural pre-design of the modular footbridge system.

Keywords: bridges; CFRP; new materials; pre-tensioning; durability; sustainability.

EXPERIMENTAL THIN-WALLED U-PROFILE FOOTBRIDGE MADE OF UHPFRC

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Abstract

This paper presents design, production and installation of an experimental thin-walled U-profile footbridge made of ultra-high performance fiber reinforced concrete (UHPFRC) with dispersed steel fibers without any conventional reinforcement. Properties of UHPFRC leads to the design of very thin structures. In this case an experimental thin-walled U-profile footbridge with horizontal and vertical curvature was designed and manufactured. Single-span bridge has span of 10 m, clear width of 1.5 m with thickness of shell structure of 30 mm on the side guards and 45 mm on the deck. The paper presents a lots of calculation versions for optimization of the proposal bridge. Self-compacting character of UHPFRC with high flowability allowed casting the final structure in one piece without any vibration. Extensive research was done before production of footbridge. Large-scale specimens were casted and tested in laboratory. A technology of casting and production of formwork were tested and optimized many times because of complexity of whole experiment. Finally the paper presents detailed course on installation of the bridge in landscape and setting and results of static loading tests.

Keywords: footbridge, UHPFRC, shell structure, arch bridge.

STRUCTURAL PERFORMANCE OF MODERN TIMBER BRIDGES IN JAPAN

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Abstract

Author has experimented actual modern timber bridges used glulam timber to investigate structural rigidity and static and dynamic characteristic on structural performance over about 24 years, and then has been evaluated structural performance of modern timber bridges based on field test data accumulated and three dimensional static and eigenvalue analyses. This study is investigated structural characteristics measured by field test immediately after the complation to modern 23modern timber bridges, and then evaluated actual structural performance for those bridges based on the static and dynamic characteristics such as static deflection static rigidity, natural frequency, damping coefficient, dynamic increment factor (impact factor), vibration serviceability and so on. As the results, the actual condition of modern timber bridges became clear that static flexural rigidity was bigger than the rigidity in the design, and that fundamental vertical natural frequency was almost equivalent to general highway bridges as steel and concrete bridges.

Keywords: modern timber bridge; structural performance; field test; structural analysis.

IZMIT Bay Suspension Bridge – Wind Induced Vibrations

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Abstract

This paper describes the studies and the countermeasures against the vibrations on the cables of IZMIT Bay bridge (now named "Osman Gazi Bridge") in Turkey. First, the vibrations observed in the structure are summarized together with the data measured on site by accelerometers, GPS etc. Through studies about the efficiency of possible anti-vibration devices, appropriate considerations have been adopted and those are working very properly so far.

Keywords: IZMIT Bay Bridge, Cable system, Wind-induced vibration, Anti-vibration device

Filling of strand corrosion products in cracked concrete based on accelerating corrosion method

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Abstract

An experimental study is proposed to investigate the filling extent of strand corrosion products during concrete cracking. A prediction model of crack width is developed incorporating the filling of corrosion products and geometric properties of strand. The relationship between the rust filling ratio and crack width is addressed. The restraint effects of stirrups on the rust filling ratio also are discussed. Twelve concrete beams were designed and accelerated toward corrosion-induced cracking. The proposed model is verified with the experimental results. Results show that the rust filling ratio increases with increasing crack widths before a critical value. After crack beyond the critical width, the rust filling ratio varies around the constant. The critical widths of maximum rust filling ratio in specimens with stirrups and without stirrups are 0.48 mm and 0.56 mm, respectively. The critical crack width of maximum rust filling ratio decreases 14.3% by using stirrups. Stirrups can restrict the corrosion-induced crack propagation and reduce the rust filling ratio.

Keywords: concrete beam; strand corrosion; stirrups; corrosion products; concrete cracking.

Rehabilitation of Deteriorated Timber Piles with Fiber Reinforced Polymer Composites

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Abstract

Louisiana has a large inventory of timber bridges in service. The timber piles in these bridges are succumbing to the effects of biological degradation that initiates in the wet-dry zones. Replacing these deteriorated piles is a costly process and in-situ repair of the piles with fiber reinforced polymers (FRP) is an economic alternative. An experimental program was conducted to evaluate the capacity of FRP strengthened deteriorated timber piles under axial loads with different lengths and depths of deterioration zone. A total of 11 monotonic tests were conducted. The investigated repair technique increases the capacity of damaged piles by 98% to 383% and enhances the capacity of undamaged piles by 3% to 22%. All failure modes were observed in the wooden portion of the pile outside the repaired region. Strain gage measurements indicate that the FRP shell is mobilized more when the annular void is smaller.

Keywords: Timber piles; deterioration; fiber reinforced polymer composites; grout; repair; testing.

Continuously welded rails on temporary bridge decks

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Abstract

The possibility of omitting rail expansion devices from the track configuration, when continuously welded rail is continued over temporary bridge decks, is investigated in detail. More specifically, the related rail track to temporary bridge interaction phenomena are analysed using finite element modelling. A parametric analysis assesses the additional rail stresses due to moving trainloads and temperature variations, based on stipulations provided in the unit identification code 774-3R. In addition, the model is expanded to a more complex structure that is able to simulate the buckling behaviour of the rail track using non-linear methods. It can be concluded that, depending on the magnitude of two main factors, the lateral ballast resistance and the amplitude of the initial track misalignment, a considerable reduction of the track stability might arise.

Keywords: railway track design, simulation, railway technology

Method for placing Prefabricated Slab Elements on Bridge Decks

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Abstract

The Institute of Structural Engineering of TU Wien is working on a new method for the construction of deck slabs for bridges, using partial depth precast concrete elements with an in-situ concrete layer. This construction method can be used for all types of bridges, but in this paper, the application for steel- concrete- composite bridges is shown.

Building the slab with partial depth precast elements are used. These elements will be delivered from the precast factory to the building site, where they are stored next to the abutment. An installation carriage with vertically adjustable steel bars is picking up the elements from the assembly area and carrying them to the installation site where the elements are situated in their final position. The additional reinforcement will be placed and a concrete layer will be applied.

Keywords: precast concrete elements, deck slab, installation carriage, fatigue tests

Effect of residual stresses on the overall buckling behaviour of welded box-section columns under axial compression loading

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Abstract

Owing to progressively increased demands of high-strength steels (e.g. S460, S690 and S960) in steel construction, an experimental program was developed to study welded box-section steel columns under compression accounting for residual stress distribution. In this paper, a series of numerical analyses were performed to identify the effect of residual stresses on the overall buckling loads of the welded box-section columns. At the end of the study, it was observed that residual stress distributions have little influence on the overall buckling loads of the welded box-section steel columns. It was also observed that dimensional properties and residual stress ratio α/β have a minor and a significant influence respectively on the overall stability coefficient of welded box-section steel columns.

Keywords: residual stress; welded box-section columns; buckling loads; axially compressed; stability behavior.

Rosedale Overhead: Functional Upgrades, Structural Rehabilitation and Seismic Retrofit

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Abstract

The Rosedale Overhead is a 77m long two-lane crossing of BC's Highway 9 over a busy railway track. Built in 1956, the current improvements include widening, new barriers, seismic retrofit and structural rehabilitation, including full concrete deck replacement. The initial design considered retaining and over-coating the existing girders. However, the final design was the outright replacement of the existing girders, with the new girders configured as continuous spans. This concept was preferred because of the lower costs, a savings partly attributed to the reduced number of girder lines from eight to five and bearings by more than half. A reliable seismic load path was established by infilling the bents either side of the rail tracks and locking the bridge ends with new semi-integral abutments. All other bents were left un-retrofitted with low-friction PTFE bearings to reduce lateral bent demands and avoid foundation upgrades.

Keywords: railway overhead, structural rehabilitation, functional widening, safety upgrade, seismic retrofit

Seismic Performance of Cross Laminated Timber (CLT) Platform Building by Incremental Dynamic Analysis

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Abstract

The present study performed Incremental Dynamic Analysis on a case study Cross-laminated timber (CLT) platform building. The building was designed for the seismic modification factors of R_d=2.0 and R_o=1.5 for the soil Class C in Vancouver, BC, Canada. A 2D non-linear finite element model was developed in OpenSees. CLT panels were modelled as orthotropic elastic shell elements and the connections were modelled as non-linear springs that account for both uplift and shear deformation. The connections and wall parameters for hysteresis models were calibrated from test results. The seismic performance of the building was evaluated using the 22 bi-axial ground motions. The seismic demand was recorded in terms of inter-storey drift ratio. The results indicated that the case study CLT platform building has a sufficient factor of safety against collapse (Collapse Margin Ratio of 3.1) under a Maximum Credible Earthquake.

Keywords: Cross-Laminated Timber; Shear Wall; Seismic Loading; Incremental Dynamic Analysis; Finite Element; Collapse Margin Ratio.

Performance Analysis of Recycled and Natural Aggregate Concrete Column with Varying Design Parameters

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Abstract

An analytical approach is made to show the performance of recycled aggregate concrete (RAC) columns with varying design parameters and to compare these with natural aggregate concrete (NAC) columns. The design parameters taken into consideration include concrete compressive strength, steel yield strength, longitudinal reinforcement ratio, and applied axial load. These factors were considered for two different aspect ratios which ensure flexural failure behaviour of column. A two-level factorial analysis was performed, and the columns were modelled and analysed using SeismoStruct, a finite element analysis software. The observed responses include: base shear capacity and displacement at first cracking; first yielding of steel; first crushing of concrete; and the ductility of the column. The pushover analysis was used to determine the performance of each column and statistical software R was used for the analysis of variance (ANOVA), which determines the percent contribution of each design parameter and their interactions on various performance criteria. The analysis shows that, RAC columns perform with improved ductility compared to NAC column.

Keywords: Recycled Aggregate Concrete; Recycled Concrete Column; Factorial Analysis; Pushover Analysis; R; Ductility.

A monolithic approach for modeling viscoelastic materials in civil engineering

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Abstract

This paper presents a methodology called 'GUSTL' [1], which is designed to efficiently estimate the parameters of a Prony-series representation of linear-viscoelastic material behaviour using measured data of the complex modulus $\boldsymbol{E}^*(f)$ obtained in a dynamic mechanical thermal analysis. 'GUSTL' is based on the idea of solving an inverse problem, established as a physically motivated system of linear equations, by a nonnegative least-squares procedure. The whole methodology is validated against sample data from an epoxy-coated carbon reinforcement grid for concrete structures.

Keywords: viscoelasticity, material theory, Prony-series, inverse material modelling, dynamic mechanical thermal analysis (DMTA)

Fire Resistance Performance of Prefabricated Composite Floor System Infilled with Phase Change Material

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Abstract

In South Korea, the most common floor system installed on steel frames have been deck slab system. Disadvantage of this system is increasing construction duration due to concrete curing and additional fireproofing protection works. As fireproofing protection installed by people handwork had low quality and material wastes, floor systems that had fire resistance performance and easily applied to steel frames started being developed. Prefabricated Composite Floor System was also developed to apply to steel structures without fireproofing protection and features of this system were largely influenced by Phase Change Material filled inside the system. Phase Change Material could be differently made by additives and some materials were developed to enhance the fire resistance performance of systems by changing additives. In this research, the fire resistance performance of Prefabricated Composite Floor system with infilled different Phase Change Material was evaluated and predicted by using finite element analysis program ABAQUS/CAE 6.10-1. In addition, the effect of wire meshes and the type of PCM were investigated by using temperature distributions and displacements during 2 hours fire test modelled at finite element program.

Keywords: Fire Resistance; Finite Element Analysis; Phase Change Material; Heat Transfer Analysis; Floor System; Prefabricated; Composite System.

Energy Absorbing Connectors for Blast Resistant Design

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Abstract

Structural components are typically designed to resist blast loads with rigid connections. An innovative approach for blast design is to support blast-loaded cladding components on a building with energy absorbing connections (EACs), which deform as they resist the dynamic reaction load from the component. The EACs and the structural component both deform dynamically to absorb the energy applied by the blast load. The EACs can limit the peak dynamic reaction load transmitted into the supporting structure and reduce the damage to the supported component compared to a traditional rigid support if they are designed optimally, as a system accounting for their interactive responses. This paper will discuss static and dynamic testing that has been conducted on steel and aluminium honeycomb EACs and a simplified dynamic design approach for the EACs and the supported component.

Keywords: energy absorbing connections, blast loads

The effect of constraining measures for road traffic on highway bridges

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Abstract

The current German guideline for reassessment of existing road bridges (*Nachrechnungsrichtlinie*) allows for constraining measures for road traffic in order to reduce the load impact on bridge structures. However, quantification of this reduction is specified only for selected cases in the guideline. This paper presents results from analysis of the effect of different constraining measures for unidirectional road traffic, such as no passing of motor trucks, minimum inter-vehicular distance regulation, and modification of traffic routing, on the resulting structural demands for selected highway bridges. The results are compared to the reference case of normal, unconstrained traffic to demonstrate the effectivity of different constraining measures. Findings from this analysis can serve as base for calibration of modified load models for bridge reassessment when enforcing the respective constraining measures for road traffic.

Keywords: constraining measures, reassessment, road traffic, load model, traffic simulation, extreme load effect, highway bridge

Harnessing Results of Nonlinear Dynamic Soil Structure Interaction Analysis in Reinforcement Design of an Underground Rail Station

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Abstract

Underground structures located in highly active seismic regions can experience significant earthquake demands. Non-Linear Dynamic Soil Structure Interaction (NLDSSI) analysis using multiple earthquake records is becoming more prevalent method of assessment of those demands and is included in Design Criteria of many American transportation agencies. This paper will explain the advantages and challenges of NLDSSI compared to traditional seismic design methods of underground structures and an example of application on an underground station located in Los Angeles. To deal with the amount of data generated by NLDSSI the design team developed a semi-automated post-processing tool for reinforcement design using LS-Dyna model results, MySQL database, post-processing and custom visualization in Rhinoceros 3D and Grasshopper.

Keywords: Concrete, Underground Structures, Seismic Design and Response, Information Technology, Computational Methods, LS-Dyna

Northeast Anthony Henday Drive / Yellowhead Trail System Interchange – Design Challenges and Innovative Solutions

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Abstract

The Northeast segment of Anthony Henday drive is the final leg Edmonton's ring road. The project was delivered on a Public-Private-Partnership (P3) basis and was opened to traffic on October 1, 2016. Yellowhead Trail (Hwy 16) is the northern leg of the TransCanada Highway and connects to Anthony Henday Drive via a three level systems interchange that required the construction of fourteen bridges including two free flowing, third level curved directional ramps. Complicating the design already challenged by the interchange geometry was the proximity to adjacent rail yards and to numerous oil refineries. The adjacent refineries require a large number of supply pipelines that restricted pier placement, with one site having 17 large diameter pipelines crossing on various alignments under a single bridge. Further complicating the site was the presence of an abandoned coal mine under two of the bridges. The challenge was to design all of these structures while accommodating these numerous constraints using a P3 delivery model where construction needed to begin prior to the completion of the final design. This paper will review the numerous design challenges that were encountered and identify the innovative solutions that were used to solve these challenges.

Keywords: curved, bridge, concrete, steel, coal mines, P3, public-private-partnership.

Rehabilitation and Superstructure Replacement of the Miles Canyon Timber Suspension Bridge

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Abstract

The Miles Canyon suspension bridge is a 40 m long historic wooden suspension pedestrian bridge across the Yukon River near Whitehorse, Yukon, Canada. The bridge is owned and maintained by the Government of Yukon (GY). The bridge forms an important link in the local trail system and is important for tourism access to some of the historic sites of the Klondike Gold Rush. Non-destructive testing in winter 2015 revealed advanced decay in many members, necessitating full superstructure replacement. A temporary rehabilitation was performed to allow the bridge to temporarily reopen for the summer 2016 tourist season, with a full superstructure replacement in fall 2016. Replacement timber members were carefully selected, detailed, and prefabricated, giving the rehabilitated structure an extended lease on life with proper upkeep and maintenance. Construction of both phases of the work were completed on time and on budget.

Keywords: pedestrian bridge; timber; wood; rehabilitation; durability; suspension; prefabrication

Full Live Load Test of a Cable-Stayed Bridge

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Abstract

In March 2016, the cable-stayed Atal Setu Bridge, newly completed in northern India, was load tested with 42 trucks representing the full design live load of 854 tonnes. Load tests are routine in India and their objective is to assure the owner that the bridge had been built to the required quality. Test trucks were positioned in four phases; after each phase, the elevations of 26 control points on each side of the bridge, as well as coordinates of four control points on each pylon, were surveyed to track deflections. The survey results were corrected for thermal movements using a reference set of hourly survey results from the preceding five days. Surveyed deflections were compared to analytical predictions and a go/no-go decision was made for the next phase of trucks. All trucks were successfully positioned and at 24 hours after load removal, 97% of the deflection was recovered, satisfying the 85% limit of the Indian Roads Congress code.

Keywords: Load test; performance evaluation; cable-stayed; hybrid bridge; finite element method.

Multi span suspension bridge on floating foundations – behaviour under operation

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Abstract

A multi-span suspension bridge on floating supports has been evaluated and found to be a suitable option for the crossing of Bjørnafjorden on the West Coast of Norway. The proposed concept combines known technologies such a multi-span suspension system, floating supports inspired by the tension-leg platforms technology commonly used in the offshore industry and a top cable connecting the top of the four pylons.

Such a construction would pioneer the field of strait crossings at extreme depths for which conventional bridges are not suitable. The absence of similar constructions and therefore the lack of references constitute significant challenges for the design group.

The present article describes the global behaviour of the structure under normal operating conditions and summarizes the main findings from the investigations carried out in the initial study phases.

Keywords: Bridges, offshore structures, suspension bridges, floating bridges

Life-Cycle Cost Analysis of Super Long-Span Cable-Stayed Bridges with Steel or CFRP Cables

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Abstract

Concrete and steel are conventional construction materials for bridges. To achieve longer span and longer life expectancy, bridge engineers are urged to seek the novel material and new technology. Carbon Fibre Reinforced Polymer (CFRP) is a promising composite material attracting increasing attention in civil engineering. CFRP has advantages in high strength, light weight, durability, anti-corrosion performance and low maintenance, which make it suitable for cables in super long cable supported bridges. This paper intends to compare the Life-Cycle Cost (LCC) of a super long-span cable-stayed bridge using CFRP cables with the same bridge using conventional steel cables. The result indicates that, although the super long CFRP cable-stayed bridge shows a higher initial cost, its overall cost from the whole life-cycle perspective is more favourable comparing to the conventional steel ones.

Keywords: life-cycle-cost; long span; cable-stayed bridge; CFRP; steel.

Polyurethane flexible plug expansion joints – Characteristics, benefits and case studies

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Abstract

Polyurethane flexible plug expansion joints, the modern alternative to the traditional asphaltic type, have in recent years proven their value to bridge engineers all around the world, thanks to their numerous advantages over other expansion joint types in many situations. They offer all the benefits of asphaltic plug joint, including smooth, safe, low-noise surface, great adaptability and easy installation, but offer greatly improved reliability, strength, elasticity and durability. The immediate outlook for this type of joint remains exciting, with testing of a new, further improved design, in connection with the renewal of the joint's European Technical Approval, to be completed in early 2017. The installation, characteristics and benefits of this joint type are described, and its use is illustrated by a diverse range of application examples.

Keywords: flexible plug expansion joint; polyurethane; non-asphaltic; installation; maintenance; replacement; durability; ETAG 032.

The Ordsall Chord, Manchester, UK – an overview

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Abstract

The Ordsall Chord is a new railway link which for the first time connects Manchester Piccadilly and Victorian stations, cutting rail service congestion, and allowing new rail services to be introduced. The project has been undertaken in a heavily developed city centre environment, interfacing with several important heritage assets including the Liverpool to Manchester railway, the world's first inter-city passenger railway, dating from 1830.

The scheme comprises over 30 new and widened spans in a variety of structural forms, supporting nearly 700m of track, including major structures spanning the River Irwell and the Trinity Way dual carriageway highway. The structures are united visually by an architectural "ribbon" concept which has significantly affected the nature and complexity of the structural designs.

Significant features of the works include the UK's first network arch bridge; innovative structural monitoring; geometrically complex concrete arch structures; partial reconstruction of a critical heritage asset; and state-of-the-art BIM processes, including the UK's first bridge to be built from the 3d design model without the use of conventional 2d design drawings.

Keywords: Bridges; railways; railroads; steel; concrete; BIM; heritage; network arch; structural monitoring.

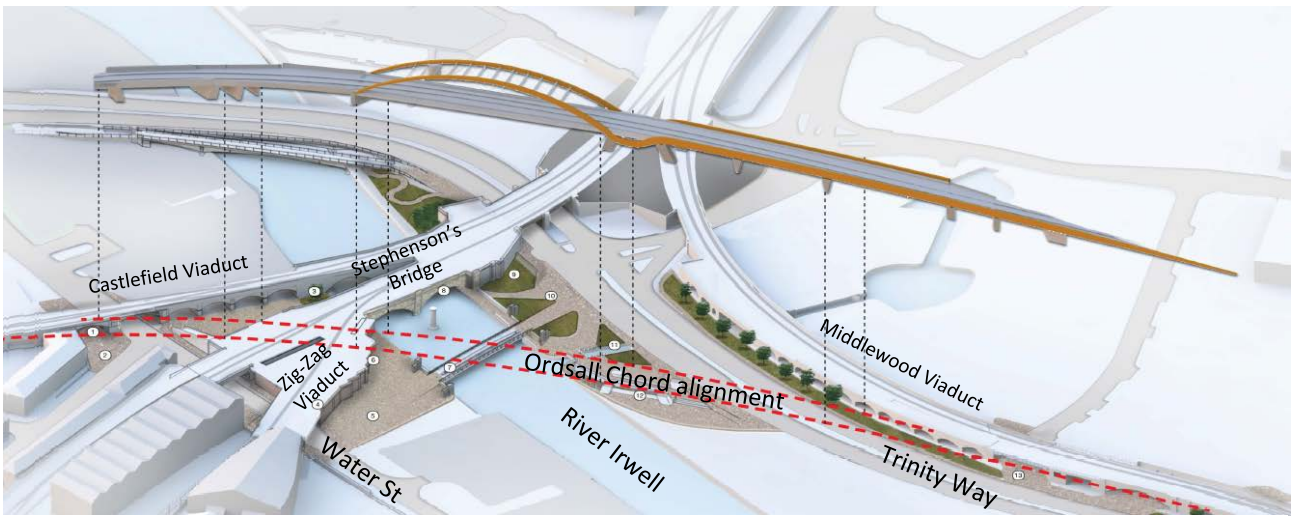

Figure 1: The Ordsall Chord

Design and Erection of the Arrah-Chhapra Bridge

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Abstract

The Arrah-Chhapra Bridge represents an evolution of bridge technology and construction processes in the Indian State of Bihar. The bridge will be an important link in the 117m-person state; increasing the road transportation capacity over the Ganges River by 66%. The original plan called for 36 approach spans that were to be erected span-by-span as precast box girder segments, whereas the 16 navigation spans were to be cast-in-place with variable depths of up to 8m. To reduce the construction schedule, while also creating a flexible construction sequence, McElhanney Consulting Services Ltd. engineers proposed an alternative extradosed system that permitted free-cantilevering segments of only 3.4m deep; enabling multiple spans to be erected simultaneously and rapidly. Through detailed construction stage analysis, rigorous geometry control, and exhaustive efforts in the riverbed, the new bridge is entering its final stages of construction.

Keywords: Extradosed; cable; free-cantilevering; erection engineering; construction stage analysis.

Static and Dynamic Study of a 700 m Long Catenary Bridge

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Abstract

Catenary pedestrian bridges are spreading all over the world with larger and larger span lengths. These engineering structures are extremely slender; therefore the wind effects seem to be the boundary to the span length maximization. There is apparently a strong need to increase the span length of such bridges, which makes it important to assess the feasibility of super-long spans. In this paper a pedestrian catenary bridge is investigated. The crossing would be built in an adventure park between two hills. The span of the main catenary cables would be 700 m, nearly twice as much as the longest bridge of its kind. The feasibility study comprises static and dynamic calculation of the structure. Catenary structures are geometrical nonlinear in nature, which requires third-order theory to follow. A program was written to conveniently model the structural behaviour. Nonlinear static calculation was used to determine the stiffness properties of the completed bridge, from which the tangential stiffness matrix could be compiled. The dynamic calculations were performed based on modal analysis via the extracted dynamic mode shapes and natural frequencies. The bridge structure was assessed with special attention on the wind effects; buffeting and coupled flutter phenomena were considered the most relevant wind related oscillation cases to deal with. Buffeting was handled by generated artificial wind loading in the time domain. The critical flutter wind velocity was determined based on a complex eigenvalue as well as time domain analysis. A parametric study was carried out in order to find the optimal wind-cable spatial geometry for the best buffeting and flutter performance.

Keywords: Catenary, geometrical non-linearity, wind effects.

Comparison of methods for determination of load-bearing capacity of I-73 and KA-73 precast concrete bridge beams

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Abstract

A comprehensive procedure to determine a load-bearing capacity I-73 and KA-73 precast concrete bridge beams using the advanced methods of statistical analysis based on simulation technique of Monte Carlo type in combination with nonlinear finite element method analysis is presented in the paper. Degradation processes over time caused by carbonation of concrete and chloride ingress together with consequent corrosion of prestressing tendons are taken into account. Mathematical modelling of these phenomena is based on information about the current state of the investigated bridges obtained from diagnostic surveys, including the degree to which building materials have deteriorated. Results of probabilistic approach are compared with those obtained using a global safety factor method according to the Eurocode 2 and the fib Model Code 2010 method called Estimate of Coefficient of Variation. Shortcomings and advantages of all utilized design/assessment methods are discussed.

Keywords: reliability assessment; bridges; I-73 beams; KA-73 beams; uncertainties; load-bearing capacity; lifetime assessment; reliability index.

HagwilgetBridge, Canada: Replacement of entire truss nodes under live traffic.

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Abstract

This paper discusses the concept development, detailed design and execution of the stiffening truss node replacement under live traffic for the Hagwilget Bridge. This complex rehabilitation project will extend the bridge service life by 40 years. Hagwilget Bridge is an 85-year old, 140 m (460') suspension bridge across the Bulkley River near Hazleton, BC. The bridge connects a First Nation community and the local hospital to the main highway with the only alternative route being a 4-hour drive on dirt roads. An innovative system was designed to allow replacement of entire stiffening truss nodes in 2 days, with no more than two, 20-minute traffic interruptions. This paper describes the design of temporary works and the complex construction procedures.

Keywords: suspension bridge, cables, refurbishment, repair, temporary works, truss, construction

Figure 1: Hagwilget Bridge at the start of repair works.

US 60 Smithland Bridge – Navigation Modeling

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Abstract

As part of the bridge type study for this major bridge replacement project over the Cumberland River, an innovative approach to addressing the needs of the navigation industry and expediting the new bridge span arrangement and Coast Guard approval process was used. Realistic 3-D virtual environment navigation modelling was utilized to quickly come to a decision on the necessary span length of the bridge, which would not have been foreseen during the bridge span arrangement/type study phase. The Seamen's Church Institute's world-class navigation simulation facility was utilized to leverage multiple pier placement locations and the expertise of experienced barge captains to evaluate various bridge span arrangement options. Significant project re-design time and costs were saved while achieving early concurrence on the required navigation clearances by the US Coast Guard. The new bridge features a 700-ft main span.

Keywords: Barge, navigation, simulation, modelling, long span bridge, truss

Modelling of structures and joints for performance-based design

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Abstract

In this article some particular case studies of using innovative solutions regarding structures and joints are presented with the purpose of pointing out those solutions which are used in construction, but which have lead to sad consequences due to their failure or being prone to failure due to their high sensitivity to overloading or to changes in loading arrangements between the connected members. The subject under revision is hard loaded Warren trusses made of I-profiles including end-plate joints with bolts in tensioned chords. The solution when using Warren trusses with support diagonals loaded in tension and made of glue laminated timber comes under criticism regarding the specifics of anisotropic wood material. The design models examined are presented in order to disclose the redistribution of internal forces after the detailing of joints.

This study is aimed at avoiding the risks in structural design and failures of structures.

Keywords: structural design; performance-based design, design models; joints; timber structures; steel structures.

Rational Reinforcement utilizing Post-tensioning Anchorage Devices in Horizontal Force Adjustment for Closure Pour

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Abstract

One of the solutions for constructing the rigid structure of the multi-span prestressed concrete (PC) continuous box girder bridge with low-height piers is the horizontal force adjustment for closure pour that can improve the stress at the base of side piers. However, in order to apply a large horizontal force to the thin member of cross section, there is a problem that it requires much time to reinforce the force application part and jacking force application work. Therefore, the author devised a rational reinforcement of the force application part in concrete structure by using post-tensioning anchorage devices which were embedded as reinforcement materials. This newly proposed method was adopted in the construction of the Onahama Marine Bridge. In this paper, the rationalization of the force application and construction in the horizontal force adjustment for closure pour of this bridge is presented.

Keywords: horizontal force adjustment for closure pour; extradosed prestressed concrete bridge; post-tensioning anchorage device.

Modelling Beam-Column Joints for Progressive Collapse Analysis

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Abstract

When a reinforced concrete frame is subjected to a progressive collapse due to the loss of a structural column, the surrounding elements are subjected to high stress state that may lead to their collapse. The rotational capacity of beams and, consequently, the beam-column connections is a critical factor determining the structural resiliency. Numerical models developed to assess the structural response under a progressive collapse situation must incorporate beam-column joint effects. In this study, state-of-the-art beam-column joint constitutive models are utilized to model a previously-tested reinforced concrete frame. A review of the beam-column joint modelling approaches, constitutive models, and the ease of their numerical implementation are presented. The calculated structural responses are compared to the experimental results, and the accuracy of each constitutive model is discussed.

Keywords: beam-column joints, progressive collapse, reinforced concrete, finite element analysis, frame elements, component models, rotational hinge model.

Formulated Tension Design for Post-tensioned Anchorage Zones and Relevant Equations in Chinese Concrete Bridge Design Code

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Abstract

In post-tensioned concrete bridges, issues of the anchorage zone may occur due to high compressive stresses immediately ahead of the anchorage device and substantial tensile stresses normal to the tendon axis. The versatility of post-tensioned concrete zone still requires more researches to develop systematic and practical design procedures. Based on the compression dispersion model, unified expressions for the bursting stresses and bursting force are formulated. Compared with the bursting force expression in AASHTO highway bridge design specification, the proposed equation has more advantageous by taking the parameters of anchor force eccentricity and inclined angle into consideration. The research results have been adopted as specified equations for computing the tension effects of post-tensioned anchorage zones in the newly updated Chinese concrete bridge design code.

Keywords: concrete bridge design code; post-tensioned anchorage zone; STM; bursting stress; bursting force.

Enhanced strut-and-tie model for reinforced concrete pile caps

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Abstract

Strut-and-tie models provide a simple and rational way to design discontinuity regions in reinforced concrete structures. However, when it comes to three-dimensional reinforced concrete elements such as pile caps, enhancements are needed to ensure a reliable and not overly conservative design. This paper presents an enhanced strut-and-tie model adapted to the analysis and design of reinforced concrete pile caps. The model is based on consistent geometries of three-dimensional nodal zones and struts and integrates a strength criterion for confined bottle-shaped struts. An iterative process is used in order to optimize the position of the members by refining the dimensions of the nodal zones. The model is validated by experimental results from tests on four-pile caps reported in the literature, showing effective predictions of their ultimate capacities. This enhanced strut-and-tie model can lead to safe and less conservative design of pile caps.

Keywords: strut-and-tie model, pile caps, reinforced concrete, three-dimensional.

Refined Stress Check of SpecialConcrete Box Girder Bridges at Serviceability Limit State

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Abstract

For shallow beams, stick models are frequently used to perform the stress check at serviceability limit state with the plane section assumption. However, the behaviour of specialprestressed concrete box girder bridges, such as multi-cell box and curved box girder bridges, is more complicated than shallow beams and does not comply with the plane section assumption exactly. As a result, the load distributions and spatial effects in the structure should be analysed clearly when doing the stress check at serviceability limit state. A proper spatial model called spatial grid model is used in this paper for the behaviour analysis of specialprestressed concrete box girders. Two examples are listedin this paper.In the last part, a refined stress check method based on plate elements is proposed to ensure the safety of specialthin-walled structures.

Keywords:prestessed concrete; special box girder; stress check; serviceability limit state; spatial grid model.

Modular steel lamella roofs by Hugo Junkers
A lightweight structure from the 1920s

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Abstract

In the mid-1920s, the German engineer Hugo Junkers (1859-1935) designed an innovative roof construction that is regarded a milestone in the development of lightweight structures. A rhomboid framework of slender steel elements forms a barrel vault that covers a span of up to 50 meters. More than 200 of these roofs – and associated patents – have been commercialized and built all over the world. Unfortunately, most of them do not exist anymore or are in bad condition.

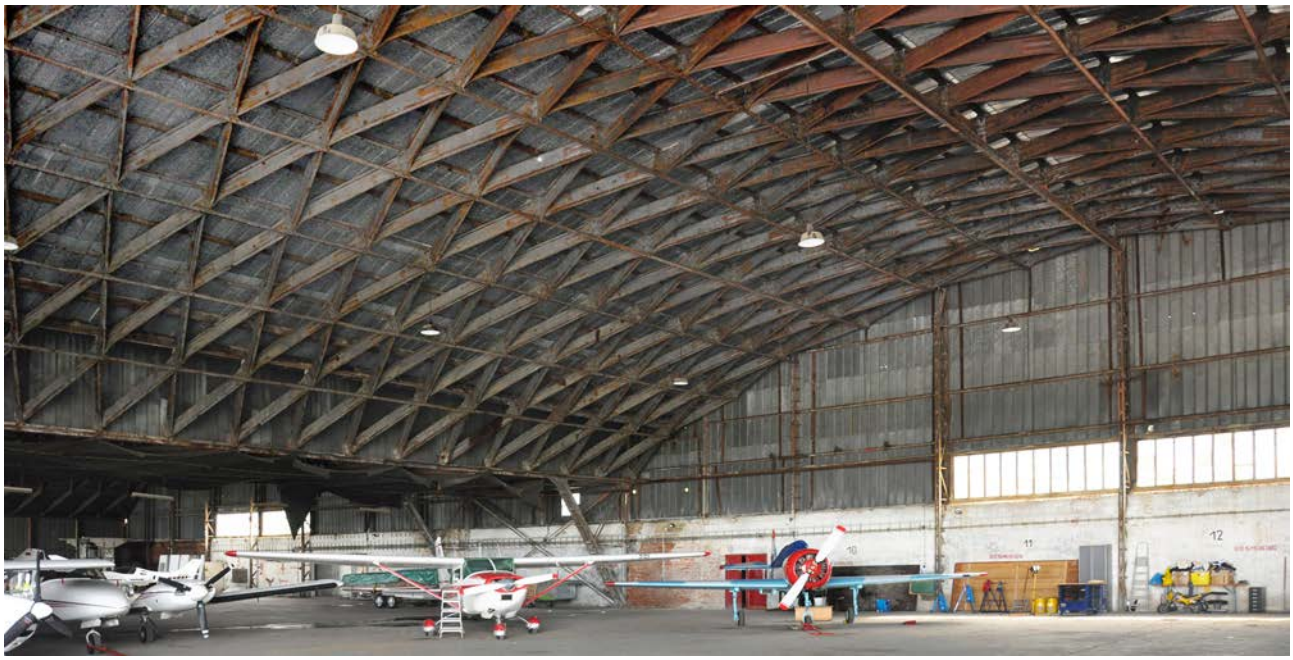

Figure 1. Inner view of hangar with Junkers roof in northern Munich (Tutsch, 2013)

This paper describes the historical steps of the technical development of the construction (in Chapter 1). The framework is designed along strict geometric rules, which in turn have a large influence on the load-bearing behaviour. Both geometry and structure are systematically analysed (in Chapter 2 and 3).

Finally, an example of the investigations and the analysis of a hangar from 1934 (Fig. 1) in northern Munich is presented (in Chapter 4).

Keywords: listed building; lightweight structures; lamella roof; steel; modular; barrel vault; load-bearing; maintenance.

Complexity Meets Craft: Fabrication and Erection Issues in Non Orthogonal Steel Structures

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Abstract

The past 20 years have witnessed remarkable advances in the digital design of structures. This includes the ability to *imagine* a diverse range of chaotic, curved and parametric structures. Where early software offered no interoperability between architectural design, engineering and fabrication software and the associated technical requirements, more recently the level of interoperability has soared. At this point Cloud based systems permit architects, engineers and steel fabricators to simultaneously create a comprehensive set of documents for structures. This level of communication has the potential to speed up the design and detailing process as well as minimize conflicts in all aspects of the construction process.

Many physical tools have been invented that are increasingly being employed to automate the processes used in the fabrication of more normative, orthogonal, structures. However, to a certain extent the actual fabrication of the steel used in complex structures has not changed appreciably over the same time. Although some computer assistance is used to cut complex shapes (particularly plate material) and control repetitive procedures such as the drilling of holes, the majority of the process has remained a craft that is carried out by the ironworker. This means that the success of the project still largely rests on the expertise of the welder and the judgment of those involved in the erection process.

As computation methods evolve at such a rate as to make much printed discussion of them rapidly out of date, this paper instead looks at the important lag between the design and fabrication of complex steel structures. Highlighted are issues of the increased importance for tight tolerances, achieving uniformity, and team coordination/communication in this yet largely craft based system and important accommodations that are required to ensure the proper fabrication and erection of Architecturally Exposed Structural Steel.

Keywords: complex structures, steel, fabrication, Architecturally Exposed Structural Steel, AESS, BIM.

The steel roof of the new Lille Stadium. Its mechanical scheme, assembly and erection sequences

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Abstract

The steel roof of the stadium of Lille, whose total area is approximately 50,000 m², is generated by simple cylindrical and spherical shapes. The stadium is able to welcome fully indoor or partly covered events thanks to a 120 x 80 m² movable roof. Valode & Pistre and Pierre Ferret are the architects of the project, Greisch, the engineering office and Eiffage Metal, the steel construction company.

The roof is supported by two 200 meter long and 16 meter high mega-trusses. The main characteristics of the project are the technique used to assemble the mega-trusses members (single pins and prestressed steel members) and the erection method (lifting). Both were chosen with the same goal: saving time. The new stadium was completed in only 2 years.

Keywords: stadium; structural schema; joints; contact; pins; post-tensioning; erection

Load Rating of a Steel Bridge by Inclination Measurement

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Abstract

Bridges are aging in Japan and the maintenance of these structures has become a major issue. In this current research work, in order to fully exploit in-service data obtained from structural monitoring, a methodology for evaluation of an existing steel bridge has been proposed to update live load effects and improve structural performance evaluation. Inclination data are chosen as a live load effect for all limit states then processed using extreme value theory and reliability theory. Incorporating the results from finite element analysis for resistance represented by inclination, the reliability index of the structural member is deduced by utilizing Second Order Reliability Method (SORM) together with its rating factor by Load and Resistance Factor Rating (LRFR). Rating factor results show higher rating than the procedure detailed in the AASHTO Manual for Bridge Evaluation (MBE), which is majorly based on design condition assumptions.

Keywords: load rating; inclination; finite element analysis; measurement.

Designing the River Irwell Crossing – the UK's first network arch bridge

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Abstract

The first railway network arch bridge in the UK is due for completion in the summer of 2017 and will support a new railway line that connects the Piccadilly and Victoria Stations in the heart of Manchester. Set alongside heritage structures of huge significance, aesthetics is paramount and has led to an asymmetric network arch form to satisfy the aspiration for a landmark bridge. The highly constrained site necessitated an unconventional piecemeal erection sequence over the river on asymmetric temporary towers. This required a detailed erection analysis of a complex methodology and special measures had to be taken to facilitate erection within acceptable construction tolerances. The paper provides an outline description of the design challenges that the project posed and how they were addressed.

Keywords: Network arch; erection engineering; advanced analysis; landmark bridge.

Figure 1. Visualisation of the network arch

Edge Distance for Mechanical Fastening of Steel Fatigue Cracks

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Abstract

Fatigue cracks of steel structural members applied by overload, repeated load occur. As a countermeasure, there are some repair methods of steel fatigue cracks such as a stiffening plate method, a weld repair method, a stop-hole method, and a mechanical fastening method, and they are used corresponding to the characteristics. Among them, a mechanical fastening method repairs steel fatigue cracks without welding. Crack progress after this construction is less and the thermal strains by welding do not occur.

In this paper, tensile test and FEM analysis of steel structural members using the mechanical fastening system are conducted. Fracture behavior affected by the edge distance of the mechanical fastening components is simulated using FEM analysis and the effective edge distance of the mechanical fastening is discussed.

Keywords: Steel structural member; Mechanical fastening; Steel fatigue crack; Tensile test, FEM analysis, Edge distance.

Cloud Accelerated Performance Based Seismic Design

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Abstract

Non-linear Time History Analysis (NLTHA) is a key enabler of Performance Based Seismic Design (PBSD). Arup Los Angeles office typically performs these simulations in LS-Dyna solver. In order to respond to the demands of concurrent design projects, the authors have adopted a cloud centric approach to accelerate our workflows and to enable the use of non-linear time history analysis as a design tool as opposed to a verification tool. This paper will present our custom workflow which enable a dramatic compression of the time required for these analysis. The workflow generates LS-Dyna models in parametric fashion via Rhino- Grasshopper. Since a single design iteration of analysis can result in 48 to 110 models from a range of ground motions and input parameters these models are typically executed on a compute cluster with a large number of compute cores. The resulting number of analyses generates a large amount of data (8-16TB) which we post process leveraging "Big Data" approaches typically used by other industries (financial or retail firms).

Keywords: Computational Methods, Information Technology, Seismic Design and Response, Performance Based Design, Cloud Computing

Calli Extradosed Bridge: Fast track project for an extradosed bridge in seismic area

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Abstract

Calli Bridge, in Antalya city center, is the first extradosed bridge in Turkey. This 180m long bridge is composed of an 80m main span and two side spans of 50m. The concrete deck is a twin pi-section of 2.5m in depth and 15m wide, making the bridge 30m wide. The extradosed PT cables are composed of 2 sets of 4 cables 31HDE15 per pi-section that will go through 3 pylons of 7m height, using Freyssinet saddles and cohestrand technology. For the first time worldwide, a 1,960MPa ultimate tensile strength strand is used, which has a direct impact on pylon's dimensions. As Antalya is located in high seismic hazard zone, a base isolation using LRB has been proposed. Thanks to this innovative concept for Calli Bridge of combining extradosed cables with base isolation and high strength strands, a cost effective solution has been reached. With the control of the overall supply chain of specific equipments, conception and construction were managed in only 7 months.

Keywords: bridge; extradosed; seismic; LRB; post-tension; isolation.

Performance Based Seismic Design of Shape Memory Alloy Reinforced Concrete Bridge Pier

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Abstract

Recent advancements in numerical analysis and computational power have pushed the current bridge design specifications towards a more descriptive performance-based seismic design (PBSD) approach as compared to the conventional force-based method. Shape memory alloy (SMA), with its distinct superelasticity, shape memory effect and hysteretic damping, is a promising material for the application in bridge piers to attain the objectives of PBSD. Despite few experimental testing to demonstrate the efficacy of SMA as reinforcement in bridge pier, there has been a lack of comprehensive guidance for potential designers of SMA-RC bridge piers. This paper proposes a performance-based design methodology for SMA-RC bridge piers, which consists of defining the performance objectives, developing performance based damage states and formulating a performance based design guideline considering maximum and residual drift. The procedure anticipates the allowable residual drift based on target performance level, calculates the maximum allowable drift, and ensures that those deformation demands remain below the allowable residual and maximum drift. Guidelines to determine the target drift and effective damping properties for SMA-RC bridge piers are also provided. The proposed procedure and guidelines are used in a trial application to design a SMA-RC bridge pier and analysed using a suite of selected earthquake records. The nonlinear analyses showed that the designed pier behave according to design expectations and provided very promising results in terms of the effectiveness and applicability of the proposed design method.

Keywords: Performance-based design, Shape memory alloy, Residual drift, Damping, Ductility.

Comparing Seismic and Tsunami Load Demands on Reinforced Concrete and Concrete Filled Steel Tube Bridges

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Abstract

In recent years, earthquakes and subsequent tsunami impacts on coastal communities have resulted in significant loss of life and damage to infrastructure. The impact of the ground shaking and tsunami damage was exacerbated by the failure of the transportation infrastructure, which delayed emergency services and had significant long-term impacts on local economies. These events have prompted an increased interest in updating structural design codes for bridge structures and informing retrofit strategies for the existing bridge infrastructure. One of the primary challenges for researchers is to differentiate between damage sustained during an earthquake and damage sustained during an ensuing tsunami. State-of-the-art numerical modeling procedures exist for both seismic analysis and damage prediction of structural systems as well as high-fidelity tsunami force prediction on large-scale structures, but these models are typically quite disparate in nature and require some coupling mechanism for multihazard analysis. In this work, the open-source structural analysis software OpenSees was used in-tandem with the open-source computation fluid dynamics software OpenFOAM to predict the damage susceptibility of reinforced concrete (RC) and concrete filled steel tube (CFST) bridges subjected to seismic and tsunami loading scenarios. For the seismic hazard analysis, a suite of near-field ground motions was scaled to predict the representative response of the two structures to a maximum considered seismic event (MCE). In parallel, a series of tsunami loading scenarios, including bore-type tsunami impact and rising steady-state flows, were developed using OpenFOAM models; these loading scenarios were applied to the structural models in OpenSees to evaluate the performance of the structures for a tsunami-only loading scenario to allow for a direct comparison of the seismic and tsunami demands and response. Preliminary results highlight the severity of the tsunami hazard, as both structures adequately resisted the MCE seismic hazard, but demonstrated a high collapse potential for all tsunami loading scenarios.

Keywords: Bridges, Concrete Filled Steel Tubes, Tsunami, Seismic

Prediction of Post-Earthquake Damage of Reinforced Concrete Highway Bridges

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Abstract

The prediction of earthquake damage to highway bridges is essential for informed decision on the post-earthquake bridge functionality. This paper presents a simplified method based on the development of fragility functions of typical reinforced concrete highway bridges and its validation. The concept of fragility functions represents a probabilistic relationship between the seismic intensity measure IM (e.g. spectral acceleration) and the degree of bridge damage. Median IMs of the fragility functions for the assumed damage states are developed using closed-form relationships based on the capacity spectrum method for seismic demand assessment. For each damage state, these relationships correlate the displacement threshold to the corresponding median IMs in terms of the input spectral acceleration at 1.0 sec. The simplified fragility assessment method was validated with dynamic analyses of an existing three span continuous girder reinforced concrete bridge in Quebec. The method revealed particularly useful for rapid vulnerability evaluation of a portfolio of bridges.

Keywords: Reinforced concrete highway bridges, earthquake damage assessment, fragility functions, seismic response analysis, bridge functionality.

Seismic Retrofitting of Existing Structures – Common Strategies and Case Studies

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Abstract

The design of critical structures to withstand the effects of earthquakes continues to gain importance all over the world. Most recently, several countries in Latin America have started to implement advanced seismic protection systems. The main objective of these systems is always the people's safety. However, the integrity of the structures and their serviceability immediately after an earthquake play an important role in the speed of the emergency response, particularly bridges, hospitals and schools. Additionally, the cost associated with repair or reconstruction of damaged structures is likely to be small compared to the economic impact caused by disruption of serviceability after an earthquake and during the long reconstruction phase.

Seismic isolation systems provide an alternative to conventional earthquake resistance design such as strengthening of structural elements (columns or beams), and have the potential for significantly reducing seismic risk without compromising safety, reliability, and economy of structures. As an alternative to seismic isolation, energy dissipation becomes essential in terms of seismic protection. The use of effective devices able to dissipate high amounts of energy ensures that other structural elements do not undergo excessive demands that could cause significant damage.

This paper presents some of the recent applications of seismic retrofitting in Mexico and Venezuela. These two countries are in active seismic areas that have experienced strong earthquakes. The development of the engineering expertise in the region, together with the availability of affordable and effective systems have encourage the use of advance seismic protection technologies, such as elastomeric isolators, as well as viscous dampers. The study cases presented in this paper serve as evidence of the increasing interest of designers, contractors and owners for safer and efficient structures, which above all ensure the safety of the population, and mitigate structural damage.

Keywords: seismic isolation; energy dissipation; Latin America; applications

Structural Evaluation and Load Rating of Lorne Bridge: A Historic Open-Spandrel Arch Bridge-Case Study

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Abstract

Open-spandrel arch bridges possess a unique combination of elegant architectural aesthetics and robust structural behaviour. While classified as such, Lorne Bridge, further, presents a historic icon and landmark of the city of Brantford, Ontario, Canada. The bridge was built in 1923 with three continuous arch spans that range between 42m and 47m, crossing the Grand River, and annexed to a 20m single span railway overhead structure. The steel-reinforced concrete superstructure of each of the main bridge spans consists of an arch and variable height solid spandrel walls supporting the bridge deck. Massive plain concrete piers and abutments carry the superstructure and are ultimately founded on bedrock.

Recently, a broad study including site inspection, condition survey and structural evaluation was carried out as a step towards maintaining both the heritage and function of the bridge in the future. The age, condition and complexity of the bridge warranted a sophisticated analysis method in order to achieve reliable evaluation conclusions. Therefore, the bridge was analyzed using a non-linear three Dimensional Finite Element Modelling (3D-EFM). The analysis represented the major surveyed concrete cracks of the bridge as well as investigating the influence of post-steel yielding of various individual superstructure components on the global behaviour and strength of the bridge.

The evaluation concluded that specific loads such as temperature, which only marginally utilize the strength of most structures, can dictate the load rating herein. Moreover, utilizing two dimensional/simplified methods of analysis for such bridges can neither predict the actual structural behaviour nor interpret the associated deficiencies. Finally, the study recommends that future design standards mandate more stringent requirements for evaluating open-spandrel arch bridges.

Keywords: structural evaluation, finite element modelling (FEM), open-spandrel arch, historic bridge.

Stabilisation of the gravity structure of the Romanesque Abbey of Payerne Switzerland

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Abstract

The gravity structure of the Romanesque Abbey of Payerne in Switzerland showed structural disorders indicating a delicate state of equilibrium. Consequently, the structure was stabilized by installing inclined tendons inside the walls of the side-naves that were anchored up to 10 m below the foundation in the ground. The implemented concept is original, invisible and allowed to avoid the horizontal steel bars (to take the horizontal thrust force of arches) that, in such cases, usually are installed, however significantly impair the perception of space inside the church.

Keywords: heritage structure, Romanesque architecture, natural stone masonry, gravity structure, inclined post-tensioning tendon, strengthening intervention.

Historical Arched Stone Bridges and Their Long Lasting History in Turkey and Balkans

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Abstract

It is one of the primary tasks of the General Directorate of Highways to repair and maintain the historical bridges which are of great importance in view of our cultural history in accordance with the projects to be developed or caused to be developed, apart from the recently constructed roads and bridges. In this paper, the restoration works carried out on the stone bridges with arches which are proven to be durable against the factors such as earthquakes, dams, variable water flows and heavy traffic over the centuries as a consequence of the analysis made specifically for the original construction techniques and the interaction between soil, foundation and river, shall be discussed.

Keywords: Stone Arched Bridges, Restoration, and Earthquake.

Reviving and Repurposing the Iconic TWA Flight Center

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Abstract

The Trans World Airlines (TWA) Flight Center, at John F Kennedy International Airport, New York is one of the most iconic buildings of the 20th Century. Designed by architect Eero Saarinen, the futuristic design was widely considered symbolic of the Jet Age.

This paper presents a brief overview of the historic building structure, and describes how a series of structural alterations are being made to transform the former airline terminal head-house into the lobby and reception areas within a new hotel and conference centre development. It details how creative design can be used to deliver adaptive re-use projects which move beyond basic restoration to deliver elegant structural solutions to address the future and continued life of existing buildings.

The latest 3D technology was leveraged throughout the project, including point cloud scanning, combined with Revit models of the structure constructed from record drawing information.

Keywords: Concrete Shell, Eero Saarinen, Historic Structures, Extending Service Life of Existing Structures, Strengthening and Repurposing of Structures, Underpinning, BIM, Aviation

Preserving a Well-loved Heritage Structure

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Abstract

One of Metro Vancouver's oldest, most interesting and historic structures, the Westham Island Bridge is the single gateway onto Westham Island in Delta, BC, which is home to key agricultural developments, a sports club, and popular local tourist attractions. Now entering its 106th year, the Westham Island Bridge needs a comprehensive structural assessment and rehabilitation study that will consider extending the structure's life for another 20 to 25 years such that it can continue to provide safe and reliable access to the island. Mott MacDonald has been retained by the Owner to undertake this asset preservation work in three phases comprising a comprehensive structural assessment and rehabilitation plan, detailed design of the rehabilitation works and construction support. This paper describes the recent work undertaken in Phase 1 to formulate a cost effective rehabilitation strategy for the bridge.

Keywords: Condition assessment; live load evaluation; quantitative analysis; qualitative analysis; rehabilitation plan

Current Status and Thinking of Chinese Ancient Bridges Protection

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Abstract

Since China is one of the major origins of human civilization, the wisdom of the ancients plays a prominent role in the field of bridge construction. On one hand, many ancient bridges on behalf of the construction level, historical features and architectural arts in different historical periods vanished because of structural degradation, natural disasters, man-made destruction or other reasons. On the other hand, the existing ancient bridges are faced with repair, reinforcement and renovation in varying degrees. There can be little doubt about the historical value of the existing ancient bridges, which can be seen as the walking encyclopedia of bridge construction. Therefore, it has become a heated issue on how to protect the ancient bridges to make it permanent and how to utilize their potential values. The history of Chinese ancient bridges is combed and the technical contribution to the world about bridge development are expounded in this article. According to investigation of existing ancient bridges, especially the bridges served as cultural relics, technical status is reflected and major problems faced in process of protection as well as restoration are proposed. Then, with the introduction to actual cases of protecting and utilizing ancient bridges, the experiences and lessons are summarized, which simulates the public discussion of ancient bridges protection. Finally, consideration and suggestions about ancient bridges protection are proposed regarding legislation, principles, techniques and culture.

Keywords: Chinese ancient bridges; repair; reinforcement; protection; case study.

The Use of Crossing Stay Cables to Add Stability to Towers of Multi Span Cable Stayed Bridges

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Abstract

Cable stay bridges with more than two towers have a particular issue with the stability of the central tower or towers. This study explores the recent development of using stay cables that cross over in the mid-section of spans to stabilise the tower. This technique provides an exciting new way of adding stability to the towers. This study investigates how the technique could be expanded for used on future bridges.

Keywords: Cable-Stay, Crossing Cables, Tower Stability

Study on Tensional Countermeasures for the Parallel Strand Stayed Cable Based on the Equivalent Model with Series-parallel Connected Springs

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Abstract

For easily calculating the cable tension force of cable-stayed bridges with parallel strand stayed cables, the cable-stayed bridges were simplified as a equivalent model consisting of serially or parallelly interconnected springs which were employed to instead of bridge elements such as towers, cables, and beams. . For this equivalent model, simplified formulas for calculating the tension force were deduced, and a corresponded calculation process was presented. The comparison of these proposed formulas with other calculation methods showed that the proposed formulas are reliable. A parametric study centralized on the proposed formulas was carried out in order to understand the characteristics of them. The study results suggested that stiffness ratio and tension coefficient had significant effects on the discrepancy of calculation, and the tension coefficient was more sensitive to the discrete discrepancy and total discrepancy of the final cable's force; equivalent tension has many advantages in practical construction operations, so a reasonable tensional countermeasure should be chosen according to the structural stiffness and the right tension coefficient should be estimated according to the tension range of jack at the same time.

Keywords: the equivalent model of series-parallel connected springs; simplified algorithm; variance analysis; ratio of stiffness; coefficient of tension; tensional countermeasures

Parametric simulation of non-symmetric cable-stayed bridges

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Abstract

The rapid bloom of cable-stayed bridges has been propitiated by the development of erection techniques and improvements of construction materials. Nevertheless, the economic boom of the last decade has deflected attention from economic cost to iconic aesthetical appearance increasing significantly designer's freedom. This structural freedom has enabled the proliferation of a number of non-symmetric cable-stayed bridges. Despite of the number of built examples, the analysis of non-symmetrical cable-stayed bridges has not received considerable attention from the researchers. In fact, the effects of the main design parameters in the structural behavior of these bridges are not addressed in detail in the literature. To fill this gap, this paper studies the structural response of a number of non-symmetrical cable-stayed bridges. With this aim, a parametric analysis is performed to evaluate the effect of each of the main design parameters (the ratio between the main and the back span length, the pylon, the deck and backstay stiffnesses, the pylon inclination, and the stay configuration) of this kind of bridges. Furthermore, the role of the geometrical nonlinearity and the steel consumption in stays are evaluated.

Keywords: Cable-stayed bridge; asymmetric; simulation; structural behavior.

Analysis of cable-stayed bridge construction

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Abstract

One of the most important causes of the rapid progress of cable-stayed bridges in recent decades is the development of the construction techniques that made their erection possible. Cantilever method and temporary support method are the most common procedures to build such bridges. The temporary support method is the fastest way of building cable-stayed bridges because conventional construction techniques may be used. This fact simplifies the erection task and leads to lower costs. However, when environmental factors or the requirements of the foundations or the sea or river crossing prevent the placement of temporary supports during construction, the cantilever erection method is commonly used. Focus on the research has been mainly devoted to the structural behavior of these structures under construction or service conditions, but the erection procedures and their calculations are not so studied. This paper aims to present practical tools to be used by the designer or the contractor for construction control of the tensioning process of the stays. Namely, a procedure to calculate the stress to be given to the first strand when the strand by strand tensioning technique is used and a procedure to update rationally the tensioning process of a cable stayed bridge when divergence between the foreseen stresses in the stays and the actual ones are noticeable.

Keywords: Cable-stayed bridge; strand by strand technique; construction control; prestressing; objective service state; tensioning process.

Influence of Curvature Radius on Static and Dynamic Characteristics of Curved Cable- stayed bridge

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Abstract

Curvature radius is one of the key design parameters of curved cable-stayed bridges. In order to obtain the influence law of curvature radius on the static and dynamic characteristics of curved concrete cable-stayed bridge with Π-shaped girder, taking a long span curved cable-stayed bridge as the engineering background, one spatial beam and plate mixed finite element model was established. Based on the theoretical model, the influence of the curvature radius on the structural static characteristics and the dynamic characteristics was analyzed by comparing curved cable-stayed bridges with different curvature radius and straight cable-stayed bridge with the same span. The results show that there is a big influence of curvature radius on the static and dynamic characteristics. The research results can provide some reference for the design of similar bridge structures.

Keywords: Bridge Engineering; Curved cable-stayed bridge; Curvature radius; Parameter Analysis; Static characteristics; Dynamic characteristics.

Numerical Study on 1200m-span Railway Cable-stayed Bridges with Four Different Girder Sections

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Abstract

The longest railway cable-stayed bridge, Hutong Bridge, with a 1092m main span, is going to be finished construction in 2019. It is no doubt that a railway cable-stayed bridge with main span over 1200m will come into being in the near future. This paper, basing on the design method of Hutong Bridge, extends a numerical study on cable-stayed bridges with 1204m main span. The numerical models adopt four different girder sections which are truss girder, orthotropic truss girder, box truss girder and box girder, aiming to find out the most suitable girder for the bridge. The advantages and disadvantages of these four kinds of sections will be valued by the effects on the pylons and piers, the stiffness of the girders, the effects on the railway and manufacturing cost. In conclusion, the mechanical characters of the box truss girder is better than other three sections and the cost of it ranks the third among these sections.

Keywords: Railway cable-stayed bridge; numerical analysis; truss; box; orthotropic truss.

Surrogate Modelling For Fatigue Damage of Wind-Turbine Blades Using Polynomial Chaos Expansions And Non-Negative Matrix Factorization

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Abstract

A computational approach for the estimation of fatigue degradation of composite wind turbine blades by means of time domain aero-servo-elastic simulations is proposed. Wind turbine blades are subjected throughout their lifetime to highly stochastic loading. Fatigue damage of the composite reinforcement of the wind turbine blades has been identified early on in the wind turbine design practice as a factor driving design. A simple fatigue accumulation model is utilized for the spar cap reinforcement of a wind-turbine blade. Non-Negative Matrix Factorization (**NMF**) for the damage accumulation random field is used for dimensionality reduction. An approximate computationally efficient model, relying on Polynomial Chaos Expansion (**PCE**) of the damage state with respect to probabilistically modelled mean wind and turbulence intensity is derived. The framework is exemplified in a case-study of a 1.5MW wind turbine.

Keywords: Composite fatigue; long term fatigue assessment; fatigue degradation; Wind Turbine; thin walled composite beam; Aero-elastic simulation; Gram-Schmidt PCE; NMF.

Fatigue assessment and damage detection of wind turbine structures by continuous health monitoring

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Abstract

In order to maximize power production, wind turbines (WTs) are continuously emerging as bigger and taller structures, built in more challenging environments. This development however decreases the reliability of wind turbine (WT) infrastructures. In addition, the dynamic nature of the loads typical for WT structures result in an excessive number of stress cycles during their operation lifetime. This might significantly differ from the fatigue loading design assumptions, which is a determinant factor for limiting the design lifetime of WTs to a minimum target period of 20 years.

Installed Structural Health Monitoring (SHM) system on an operating WT structure provides invaluable insight to the structural performance and can contribute to early damage detection, thus eventually leading to reduced maintenance costs and extension of operation life time. In this paper, a four- year continuously recorded SHM data of an Enercon E40 - 500 kW type WT is utilized for assessing its consumed fatigue life time at a welded connection. The monitoring system was implemented on the WT located in Dortmund, Germany, as part of a DFG-funded research project with cooperation to Ruhr-University Bochum.

Keywords: Structural Health Monitoring, Wind turbine, Rain flow counting, Fatigue analysis

Challenges for tower structures of modern wind turbines

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Abstract

Wind energy is already significant and will become even more important among the renewable energies in the future. The development of modern wind turbines provides new challenges for tower structures. Modern wind turbines are designed for a service life time of 20 to 25 years and the whole turbine has to withstand high dynamic loads. Typical tower heights of modern wind turbines are between 100 m and 160 m. The towers are usually made of steel. However, hybrid towers are also common for high towers. This paper focuses on recent developments and future trends of the design of tower structures for modern wind turbines. Firstly, steel and hybrid tower concepts of modern wind turbines are presented. Then, challenges of modern wind turbines are described; particularly the behaviour of concrete under fatigue loading. Furthermore, possible cases of damage of tower structures are presented.

Keywords: Wind turbines, hybrid towers, fatigue, multiaxial stress states, fire, damages.

Concrete towers out of semi-precast elements - erection of a prototype tower section

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Abstract

The further the transition from fossil to renewable energy generation is advancing the more wind turbines are build. Cites on-land with high wind speeds get more and more exploited, therefore cites with moderate and low wind speeds are getting more often in the focus for a wind turbine erection. At such cites, turbines need bigger rotors and higher towers in order to generate economical energy. That is why new construction methods for higher towers are of interested. Therefore, a new tower erection procedure was invented. The method is characterized by the use of standard and plain double wall elements, which are available all over the world. These elements are assembled to load bearing segments. The segments are stacked over each other as long as they are hollow and the hollow core of the double walls is filled with concrete, whereby all joints are reinforced therefore a monolithic and continuously reinforced tower structures is gained. Such a tower can be erected fast, while providing a structural resistance similar to a cast-in-place structure. The method was already tested in the erection of a prototype tower section where it demonstrated its practical feasibility.

Keywords: precast; double walls; high towers; wind turbine

Dynamic Analysis of Innovative Hybrid Wind Mill Tower Considering Soil Structure Interaction

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Abstract

The wind mill towers are constructed using monopoles or lattice type tower. As the height of tower increases it gives more power but it becomes uneconomical, so in the present research work innovative hybrid wind mill tower such as combination of monopole and lattice tower is analyzed using FEM software. When the tall structures are constructed on soft soil it becomes dynamically sensitive so 3 types of soil such as hard, medium and soft soil is also modelled and the innovative hybrid tower is studied for different operating frequencies of wind turbine. From study it is concluded that the innovative hybrid tower will reduce resonance condition considering soil structure interaction.

Keywords: Wind mill Tower, Dynamic Analysis, Resonance Conditions, Soil Structure interactio

The Gamechanger: How BIM for Bridges triumphs over the competition and revolutionizes design workflows.

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Abstract

Pennoni realized that times are changing in the bridge design industry. With the advent of new technologies, the firm sought a more efficient workflow than the traditional 2D design process. Uncertainties within this time worn approach had engineers performing redundant tasks, reworking tedious calculations and spending time updating plan sheets when unanticipated design changes occurred. This resulted in less competitive project proposals and inflated project budgets. After careful planning, it was decided that a BIM approach would be used on new bridge design projects. This approach develops a design model early in the concept and proposal phase – with the added benefit that the same model can evolve with the project as it is advanced through TS&L and subsequent milestone submissions. Developing 3D design models early on has allowed engineers and designers to visualize the entire design. Pennoni engineers are also able to better identify problems during design, instead of being uncovered later in construction, where costs from unforeseen delays can escalate. This approach has resulted in streamlined preliminary designs and higher quality visualizations and proposals, resulting in more project wins. Post award, the efficient use of the same models has reduced project man-hours and improved project budgets. Additionally, the BIM process also acts as secondary quality control – helping to minimize errors and increase overall level of quality in the project deliverables. Discussion will include the benefits of using the 3D design models to develop the 2D plan sheets, developing a refined structural analysis, generating accurate quantities and the ability to produce stunning visualizations which are used in client outreach and public planning events.

Digital Delivery with Building Information Modeling for Bridges

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Abstract

Digital delivery using Building Information Modelling (BIM) for bridges is growing in prominence nationally and in the United States (US). New software tools enable broader adoption of BIM-based bridge design production. Contractors are increasingly making use of BIM in planning site logistics and lifts, sometimes with construction simulations, and also for fabrication. Bridge data standards are moving forward through international and US efforts focused on the Industry Foundation Class (IFC) standard. The remaining issues to resolve for digital delivery are metadata, which is required to clearly communicate the responsibility for, limitations of, and reliable uses for digital data, as well as contract language and quality control processes. While many bridge owner agencies are moving forward with digital delivery, the Michigan Department of Transportation is currently pursuing a framework to close the metadata gap and bring the agency further along towards its vision for comprehensive digital delivery.

Keywords: Digital delivery; building information modelling; bridge information modelling, bridge design.

What happens in BIM, stays in BIM

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Abstract

HNTB has been an early adopter of everything BIM throughout its entire operations. More recently, the implementation of BIM for bridges has proven to provide significant advantages. Using Bentley's OpenBridge Modeler, projects can be modeled very quickly – it's like rapid prototyping in virtual space – allowing for quicker visualization, quantity computations, and clearance checks.

Using this approach in the conceptual engineering phase, engineers can spend more time on considering and weighing different alternatives and less time creating exhibits or visualizations of the alternatives.

In addition, using the direct interoperability with the analysis/design software, engineers can take advantage of the speed of the integrated process building the necessary engineering judgement directly into the process, and without taking the engineer out of the equation.

The presentation will also address how this type of workflow can be highly productive – like saving time copying data from one software to another – providing more time for actual engineering. Moreover, the presentation will address some important points related to overcoming BIM for bridges misconceptions, like how the process of quality control can be used to check the model and the data from it, because the model is not just a pretty picture, but an intelligent physical representation of the structure.

Going Digital: Increase Performance and Productivity Using A Common Data Environment

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Abstract

Interoperable design, modeling and analysis are keys to the success of today's bridge projects. The next generation of bridge modeling software requires that it be purpose-built for bridge designers and contractors who need to create, construct, maintain, and document a wide variety of bridge information throughout the lifecycle of the asset.

Building and exchanging information in a common data environment using information-rich 3D model increases data quality, collaboration, constructability and operational aspects including asset management. Reduction in the project's overall costs for the entire ecosystem are important for all stakeholders and the availability of intelligent 3D models are a key component in providing accelerated project delivery and information mobility.

How much is too much information and to what is our goal? Can we shorten the construction schedule? Are we designing for construction and can we meet the expectations of the travelling public during construction with the proposed design? A true data model addresses these questions and progresses the integrity of our engineering profession. This is when vision meets reality.

The purpose of this presentation will be to provide an overview of how technology can provide cost savings with the ability to interoperate with all stakeholders during design, construction and beyond on bridge projects of all sizes.

Optimizing Performance of Concrete Structures with Zinc Coated Reinforcing Steel

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Abstract

Corrosion of reinforcing steel bar is a significant cause of concrete failure, causing expensive repairs and premature structure replacements. Galvanizing provides proven corrosion protection for reinforcing steel significantly extending the life of concrete bridge structures. Whether applied by the traditional batch hot dip process or the new continuous galvanizing process, zinc coatings protect reinforcing steel both as a barrier coating and as a sacrificial anode. The properties of galvanized reinforcing steel and its contribution to improvement of concrete performance of bridges will be presented together with the status of related product standards.

Keywords: Corrosion, Galvanizing, Batch-hot-dip-galvanizing, Continuous-hot-dip-galvanizing, Zinc-coatings, reinforcing-steel, Rebar, concrete-failure.

Remaining Strength Evaluations and Reinforcement Methods of Plate Girders with Corrosion near Supports

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Abstract

In Japan, a lot of steel railway bridges were constructed during the period of rapid economic growth in the 1960s. Now, since over 50 years have passed, the aging of these structures has become conspicuous and a major social problem. In particular, for steel plate girders with open deck system, deterioration and damage due to corrosion are becoming pronounced. Nevertheless, the remaining strength evaluation and its reinforcement methods of corroded structures are not always sufficient. Therefore the purpose of this study is to propose an analytically-based evaluation method and a reliable measure to reinforce in the maintenance field of steel railway bridges. The following are noted: 1) Regarding the shear capacity of plate girders with corrosion near supports, the remaining strength depends on the corroded surface condition of each component such as a web or a vertical stiffener. And, according to the form and degree of corrosion, the fracture mode also changes from the buckling of web to the buckling of cross-shape column consisting of the web and vertical stiffener. The result shows that the corroded web has more effect on the shear capacity than the vertical stiffener. 2) Regarding the separation between the web and bottom flange due to corrosion near supports, the remaining strength is deteriorated more rapidly than above case 1, when the separation range lengthens more than the sole plate area. 3) For the reduction of the remaining shear capacity in the above cases 1 and 2, the load bearing capacity can be improved dramatically by unsophisticated attachments as reinforced members.

Keywords: shear capacity; local buckling; web; vertical stiffener; separation; strength recovery.

Effect of corrosion on bond performance of corroded pretensioned prestressed concrete beams

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Abstract

The bond behaviour between corroded strand and concrete in pre-tensioned prestressed concrete beam is investigated experimentally in the present paper. A total of nine pre-tensioned beams are fabricated and eight of them are accelerated to concrete cracking, with one uncorroded beam as control. Data on the distribution of corrosion-induced crack, force-slip responses, and failure modes are obtained. Effects of strand corrosion on the load-slip curves are studied. At last, the final failure modes and the ultimate strength of the beams are analysed. Experimental results show that the bond stiffness and strength do not decrease until the corrosion loss and crack width exceeds 5.1% and 0.27 mm, respectively. The failure mode of beams change with the increasing of strand corrosion. When the corrosion loss is less than 5.1%， beams PS0-PS4 fail in concrete crushing, accompanying with strand yielding. When the corrosion loss exceeds 6.91%, the beams fail in strand rupturing without detecting yielding plateau. The degradation of strand tensile strength plays a more important role than degradation of bond strength when strand reaches certain corrosion loss.

Keywords: strand corrosion; prestressed; bond stiffness; bond strength; failure mode.

Non-Destructive Testing for Detecting the Corrosions of External Post-Tensioned Tendons

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Abstract

Recently, a failure of external post-tensioning strands was found in JeongNeungCheon bridge in Seoul, Korea. It was the first time that the failure of tendon in PSC box girder bridges was reported in South Korea. A variety of attempts to find out the reason of tendon failure and to improve tendon maintenance system of PSC box girder bridges have been made after the failure. Out of many attempts, two types of NDT(Non-destructive testing) methods, MMFM(Magnetic Main Flux Method) and MFL(Magnetic Flux Leakage) were applied and compared to evaluate the capability and the effectiveness of the two methods to detect and quantify the deterioration associated with corrosion of strands. Two steps were taken to do so. First, both of the two NDT technologies were carried out for calibration and blind test, with damaged tendons in a laboratory environment. Afterwards, the external tendons were examined by the NDT systems inside the actual PSC box girders of the two bridges. This paper summarized the laboratory and on-site NDT test results to share the experiences.

Keywords: tendon failure; non-destructive test; corrosion; external post-tensioned tendons; PSC box girder bridge.

Life-cycle cost analysis of concrete structures reinforced with stainless steel reinforcing bars

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Abstract

The durability of reinforced concrete highway bridges is significantly affected by heavy road salt applications that are prevalent in parts of Canada and regions of the world with cold winter climates. Over time, chlorides migrate through the concrete to the reinforcing steel (rebar), resulting in corrosion and eventual loss of structural performance due to concrete spalling and loss of bond between the rebar and concrete. This causes significant reductions the service life of the structure. To address this issue, recent efforts have been undertaken to evaluate the use of corrosion resistant alternatives to traditional reinforcing steel, including stainless steel rebar. Along with assessing the increased durability that can be achieved, cost comparisons have been performed to identify conditions under which the increased cost associated with stainless steel rebar is warranted. In this paper, the results of recent analytical studies performed on the benefits of stainless steel rebar use will be presented. A significant gap identified in the literature has been the limited extent to which the effect of cracks in the concrete has been considered in assessing the corrosion performance of the rebar. In the current study, a probabilistic model for predicting the service life of reinforced concrete elements exposed to chlorides by Hartt (2012) has been modified to consider the effect of cracks on the diffusion coefficient, using a simplified approach proposed by Lu et al. (2011). In this paper, the modified model is described and used to demonstrate the effects of surface chloride concentration and the presence of cracks on rebar performance. This performance is characterized using a "critical cost ratio" below which it is economically appropriate, from a life-cycle cost perspective, to use stainless steel rather than black steel rebar.

Keywords: Reinforced Concrete, Corrosion, Stainless Steel, Service Life Modelling, Chloride Diffusion.

The durability and service life benefits of Stainless steel rebar and the properties and features which are responsible – A stainless industry primer for owner's, planners, specifiers, and designers on the technical and market realities

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Abstract

The tremendous cost of deteriorating infrastructure as caused by the corrosive effects of chlorides in North America is well documented as being in the billions of dollars annually. Owners, planners, specifiers, operators and designers of reinforced concrete structures faced with solving the problem of deteriorating concrete caused by chloride attack of the steel rebar from chlorides are looking for long term, low cost solutions and to solve the heavy cost burden of premature replacement of structures, excessive repair and maintenance costs, traffic congestion and reduced utilization. This paper makes the case that the fundamental and unique properties and features of stainless steel reinforcement are the underpinnings of the vast body of indisputable evidence pointing to stainless steel reinforcement as being a significant positive contributor to extending the service life of existing structures and enhancing the durability of new structures exposed to chloride attack. The author offers his engineering and product/market development perspective as a stainless steel reinforcement industry insider providing details regarding the chemistry of this product, the unique mechanical properties and the benefits which can be leveraged, the evolvement of historic to the current types of stainless steel reinforcement most in use, a summary of various corrosion resistance studies presenting the relative performance of various types of corrosion resistant reinforcement compared to stainless steel reinforcement, an overview of the important aspects of the ASTM standard for mill production, an overview of the purpose and summary of the recently released ANSI / CRSI IPG4.1 document "Standard Practice for Stainless Steel Reinforcing Bar Fabrication Facilities", the cost effectiveness of the use of stainless steel reinforcement as represented by a life cycle costing analysis, a historical and current day perspective of the applications of this product, the primary users of stainless steel reinforcement in North America, their specification formats and best practices.

Keywords: Stainless Steel, Corrosion Resistance

Assessing the Impact of Improper Placement on Reinforced Concrete Beam Behaviour

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Abstract

The recent construction booms in Dubai and China have often required the use of unskilled labour, which can lead to defects in the structure such as voids in reinforced concrete members. The goal of this research was to use sensors to explore the impact of poor concrete placement on reinforced concrete behaviour. Two beam specimens were constructed: a control, which was well vibrated, and a defective beam, which was not well vibrated resulting in extensive voids. Distributed fibre optic strain sensors were installed on both the longitudinal and transverse reinforcement bars. Digital image correlation was used to track crack development. It was found that the poor concrete placement had no impact on stiffness, capacity or failure mode. The distributed strain and digital image correlation data highlighted subtle differences in strain and cracking behaviour between the two specimens.

Keywords: reinforced concrete, beams, fibre optic sensors, digital image correlation, honeycombing, construction defects.

Use of Extra Coating Thickness on Epoxy-Coated Bars in Concrete Deck Replacement

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Abstract

Current standard specification for epoxy-coated steel reinforcing bars (ASTM A775/A775M) allows coating thicknesses between 175 to 400 µm. This paper presents an experimental program conducted to evaluate the bond performance in normal-weight concrete of epoxy-coated bars with coating thickness up to 460 µm. Two different bar sizes were investigated, No. 16 and No. 29 bars. Single splices as well as splices of bundled bars were evaluated in the experimental program. The results of the study were implemented in the form of design recommendations for bond of epoxy-coated bars with thicker coatings. The goal is to enhance the future sustainability of concrete bridges by improving the performance of epoxy-coated bars as a corrosion protection system.

Keywords: bond strength; bridge deck; epoxy-coating; thickness; reinforcing bars.

Concrete Structure Assessment using ACI 562: History and Possible Next Steps

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Abstract

This paper briefly summarizes the development of the structural safety provisions of ACI 562-16 "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures". An initial proposal to specify factored load combinations that depend on the desired Reliability Level of the element being assessed was not implemented. Instead, for cases where the required structural element dimensions, reinforcement locations and material properties are measured by the evaluator, the specified strength reduction factors are identical to those specified for Analytical Strength Evaluation in Chapter 27 of ACI 318-14. In all other cases, the strength reduction factors for assessment are identical to those specified for design in Chapter 21 of ACI 318-14. The reliability indices associated with these proposals are quantified and critically reviewed, and possible new directions for a future edition of ACI 562 are considered. The currently specified strength reduction factors yield higher reliability indices for tied or spirally reinforced columns than they do for beams subjected to bending, which is appropriate. The use of the assessment strength reduction factors yields a specified rating load that is markedly greater for columns than for beams with respect to the original design value, however: the associated 50-year probabilities of failure increase by a factor of roughly 25 for beams and by a factor of roughly 4300 for columns with spiral reinforcement. A preliminary procedure for building assessment is presented where the resistance factor is selected instead of the factored load combination to achieve a desired target reliability index. This simplifies the assessment as the structural analysis would be conducted using a single set of factored load combinations and the impact of different consequences of failure could be reflected in the resistance factor selected.

Keywords: code calibration, existing structure assessment, reinforced concrete, reliability index, strength reduction factors, structural safety.

Investigation of Causes of Cracks in a Precast Concrete Closed Spandrel Arch Bridge with Corrugated Section

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Abstract

A structural system of precast concrete closed spandrel arch bridge with corrugated section has been developed and used in a bridge project in Malaysia. During the process of construction, longitudinal cracks were found over the soffit of upper flange at haunch part of the 20 m-span precast arch panels. In order to investigate the causes of these cracks and their effects on the precast arch bridge structures concerned, a series of structural assessment was carried out. 3D analysis considering soil-structure interaction using StaadPro software was carried out in order to understand the behaviour of the arch with corrugated section in longitudinal and transverse direction. Verification of 3D analysis results with 2D Analysis softwares (LUSAS, PLAXIS and StaadPro) under self-weight conditions was also carried out. Results of analysis showed that the corrugated section possesses sufficient capacity in longitudinal direction (major direction) to withstand the design loads. Since the upper flange of corrugated section is singly reinforced, the longitudinal cracks at haunch part of the arch panel are likely to occur during installation and backfilling stages.

Keywords: precast concrete closed spandrel arch bridge, corrugated section, structural assessment, longitudinal cracks.

Bridge deck deflection: importance of early shrinkage

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Abstract

The construction of the viaduct over the A9 highway, a semi-integral prestressed concrete bridge with a total span of 351.60 m, was accompanied by uncertainties about the importance of long-term effects on the deck deformations. To clarify these, deformation measurements have been carried out using optical fibers, which turned out to be a powerful measurement tool enabling the recording of the whole construction process.

The measurements of the deck allowed identifying the various causes of deformation: an expansion period caused by the hydration heat release, a contraction due to early shrinkage; some deformations due to construction stages such as prestressing of the deck and lowering the formwork, and deformation due to creep.

Analysing the early stages of deformations allowed the development of a structural model for concrete which distinguishes the point of zero deformation and the one of zero stress. The point of zero deformation occurs after the dormant phase, some hours after concreting, when concrete is transforming from liquid to solid state. The point of zero stress occurs few days after concreting when the deformations reach a clear peak value defined as the "birth of the concrete structure". Up to this point of birth, the deformations occurring in the structure induce stress. Distinguishing these two points allows matching the experimental measurements and explaining the early cracking observed in concrete structures.

It is shown that prediction of the deformations with numerical models is possible as long as the construction stages, the long-term effects and early shrinkage are considered. However, early shrinkage occurring after the birth of the concrete structure, which reaches values around 0.3 ‰ during the first weeks, has to be added to the currently used strain values of shrinkage. Generally speaking, early shrinkage has to be considered in the design to explain and avoid early age cracking in concrete structures.

Keywords: bridge behavior, deformations measurements, early shrinkage, fibre optic sensor, creep and shrinkage, numerical simulation, construction stages, birth of concrete structure.

End Diaphragm Cracking of Box Girder Bridges due to Post-tensioning: Case Study

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Abstract

Adequate dimensioning and detailing of box girders end diaphragm is critical for proper performance of post-tensioned bridges. Current design methods have led to highly congested anchorage zones with construction issues and cracking problems. In order to study the performance of anchorage zones, box girders end diaphragms were instrumented in the field. Strain gauges were used in order to capture stresses in reinforcing bars and strains within the concrete elements. End diaphragm cracking was observed during post-tensioning for one of the investigated bridges. These cracks were not noticed during regular inspection because they occurred on the inner face of the diaphragm inside the box section. Skew angle of the end diaphragm is a governing factor affecting cracks distribution. The paper will discuss reasons for the developed cracks and highlight design recommendations.

Keywords: anchorage zone; general zone; field investigation; post-tensioned box girder; end diaphragm; concrete cracking

IZMIT Bay Suspension Bridge – Advanced Post tensioning system

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Abstract

This paper introduces the advanced post-tensioning system adopted in the anchorage for IZMIT Bay Suspension bridge (now named "Osman Gasi Bridge") in Turkey. The system is based on unbonded tendon instead of the conventional grout solution. The reliable long-term durability is provided by the dehumidification system and the condition inside a tube is continuously monitored. In addition, "strand-by-strand" method gives the possibility to replace strands in the feature. The method has been verified by a mock-up test. Major steps of strand replacement are also described in this paper together with some notable key issues.

Keywords: IZMIT Bay Bridge, Anchorage, PT strand, Dehumidification system, Replacement

Replacement of the Macdonald Bridge Suspended Spans: Fabrication and Field Construction Works

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Abstract

The Angus L. Macdonald Bridge, completed in 1955, connects Dartmouth and downtown Halifax, Nova Scotia, Canada. This suspension bridge is 762 m long, with a 441 m long main span. The deck of the suspended spans reached the end of its functional life and the entire superstructure was replaced segment-by-segment during full weekend and evening closures of the bridge, with traffic using the bridge during weekdays. The new deck segments were fully prefabricated, including an initial thin layer of wearing surface, and erected in a way that allowed traffic to use the bridge immediately following the replacement of an existing deck segment. This paper describes some aspects of the complex fabrication of the bridge superstructure. It further describes how the deck segments were replaced and explains unique challenges encountered during segment replacement and how they were addressed.

Keywords: suspension bridge; superstructure replacement; erection; fabrication; steel; deck segment replacement.

Wind Load Evaluation based on the Field Measurement Data for the Design of a Suspension Bridge

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Abstract

This study has been performed to evaluate the wind load for the design of a suspended bridge. A meteorological station was installed at each pylon area and the data was collected. Additionally, wind data from other weather stations located nearby the site was also considered.

The basis wind speed has been estimated by extreme wind analysis using historical extreme wind records, which are measured nearby two representative meteorological stations. In order to estimate the basis wind speed for 100 years, the Gumbel's extreme statistical analysis is performed.

The turbulence properties of fluctuating wind speeds such as turbulence intensity, spectrum and coherence also have been verified based on the field measurement data. The evaluated turbulence intensities are compared with the engineering model. Turbulence spectra were calculated using the high wind speed recordings and compared to the Kaimal Spectrum.

Keywords: Wind Load; Suspension Bridge; Basis Wind Speed; Turbulence Intensity; Turbulence Spectrum; Coherence Function; Field Measurement; Anemometer.

Spreading suspension cable at the Rhinebridge Emmerich, Germany

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Abstract

The Rhinebridge Emmerich of 1962 is a suspension bridge, with two 77 m high steel pylons, and 500 m long. The suspending cables consist of 61 parallel locked coil strands. The hangers are fixed to the suspension package by an iron cast saddle-clamp each. Corrosion products had spilled from the inside of the suspension cable at the lowest point. In order to investigate the corrosion of the cable in the interior, the suspension cable was opened under terms of running traffic using a special device with grippers. As a result, the strands of the cable could have been inspected all around. It was found, that the more than 50 years old strands are in very good condition. After documentation the strands have been cleaned, coated and lead back into the suspension package. The old saddle-clamp was fixed again and suspension cables were replaced.

Keywords: Suspension bridge, spreading of cable, saddle-clamp, maintenance.

Cable Erection of Triple Pylons (multi-span) Suspension bridge, New Millennium Bridge

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Abstract

The triple pylons suspension bridge in Korea, New Millennium Bridge, has triple pylons and multi-span. For the erection of main cables with 21 strands and 2,667 wires, the Prefabricated Parallel Wire Strand (PPWS) method has been adapted, and the cable erection work will be conducted from June to August in 2017. The paper describes the installation and design of catwalk and pylon saddle and erection of main cable of New Millennium Bridge.

Keywords: multi-span suspension bridge; cable erection; PPWS method; triple pylons; catwalk system; pylon saddle;

Dehumidification – An Effective Strategy for Preserving the Cables of Suspension Bridges

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Abstract

The majority of suspension bridge cables consist of thousands of high-strength galvanized steel wires typically around 5mm in diameter. The wires are compacted into a near-circular shape then traditionally protected by externally applied red lead or zinc paste, galvanized wrapping wire, and paint. As evidenced by cable inspections, water inevitably intrudes into the interstices of the cable causing atmospheric corrosion, hydrogen-induced stress corrosion cracking and broken wires.

Since its first application on the Akashi-Kaikyo Bridge in Japan, cable dehumidification has emerged as an effective method of protecting cables from the damaging effects of water. This paper will discuss the types of suspension cables, traditional cable protection systems, typical findings from internal cable inspections, and the history and effectiveness of dehumidification as a technique for protecting the main cables of suspension bridges.

Keywords: Bridge, Suspension, Cable, Dehumidification, Corrosion, Preservation.

The Mersey Gateway Project, UK – Delivery to completion

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Abstract

The Mersey Gateway Crossing is due to open to traffic in the autumn of 2017. This will mark the second road crossing over the River Mersey estuary, in the North West of the UK. At its centre piece a spectacular new double span 1km long cable stayed bridge. The end of construction, and beginning of the operational phase of the 30 year DBFO contract, brings the opportunity to reflect on the challenges presented during delivery of the project infrastructure.

Keywords: Major Crossing, Cable Stay Bridge, DBFO, Project Delivery, PPP, Post Tensioned Box Girder

Lessons learned from construction of several extradosed bridges

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Abstract

The creation of the concept and denomination of the extradosed bridge is attributed to the French engineer Jacques Mathivat, who, in 1988, coined this term for the first time referring to the solution he proposed for the Àrret Darré Viaduct. In that proposal, prestressing cables extended out from the upper part of the deck were anchored to a low tower in order to gain eccentricity. Even though this option implied material savings with regard to other more conventional solutions, it was rejected. Nevertheless, Mathivat's proposal inspired the Japanese who, in 1994, built Odawara Blueway Bridge in Japan. Since then, approximately one hundred extradosed bridges have been built all over the world.

Keywords: extradosed, pylon, cable stays, saddle, cantilever, prestressing

Considering constructability in precast construction

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Abstract

The construction industry in South Africa has traditionally relied upon in-situ concrete construction for much of its infrastructure development. However, prefabrication of concrete elements have the advantage that it can accelerate the project schedule, improve quality and increase durability of a structure. More extensive use of use of concrete prefabrication can support the Government's goal of providing infrastructure to eradicate poverty and unemployment, and to provide citizens with quality education by 2030. By using suitable engineering concepts, provision can be made to provide a better life for future generations.

This paper reports on a research project which is aimed at the compilation of information to help projects teams to consider prefabrication as a project alternative. Several parameters can influence such a decision, including time, cost, safety, quality, labour, aesthetics, location, and technical aspects. In this paper technical aspects are considered in the decision process, and specifically the choice of connections between precast elements.

Although much information is available in international literature on typical connection details, it may not necessarily be relevant to the local industry, which relies much on unskilled labour, with resultant quality management challenges. The choice of connections by designers therefore needs to comply with specific requirements, which include ease of construction, low material costs, and the potential for rework.

Early contractor involvement is seldom possible, and a new approach is needed to guide designers towards suitable choices which will enhance constructability. This paper presents the results of a study which identified the parameters to be considered for connection design in the local industry. It also identifies advanced concrete technologies which can benefit connection design in the local market. By making the correct design choices, the project constructability is improved. This information is also of value to other developing countries who can benefit from this construction method.

Keywords: pre-fabrication, modular construction, concrete, connections, quality management

Constructing the Abraham Lincoln Bridge

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Abstract

The Abraham Lincoln Bridge is a 3-tower cable-stayed bridge connecting Louisville, Kentucky to Jeffersonville, Indiana. The design included an innovative foundation layout, cable-stayed detailing that simplified construction, and probabilistic 100 year service life design. The design contemplated the construction approach preferred by the Design Build contractor. This collaborative approach between the designer and contractor was critical to achieving efficient design elements such as the anchor box, anchorages at the deck level, and tie downs. Yet, despite careful planning, challenges presented themselves during construction, such as deficiencies of concrete materials and difficulties during shaft construction. This paper takes an in depth look at these challenges that arose during construction as we endeavour to share the knowledge gained, not from what went well, but rather from our collective failures.

Keywords: Drilled Shaft Retrofit, Stay Anchorages, Tie Downs, Service Life, Durability

Innovative Technology of Yavuz Sultan Selim Bridge Design and Construction

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Abstract

This study dealt with innovative technologies developed for the structural design and construction of a new hybrid cable bridge named Yavuz Sultan Selim Bridge. It is a cable-stayed suspension bridge under the combined road and rail loading which is located in the northern side of the Bosphorus strait. It was proposed at an initial stage as a conventional suspension bridge type with truss double deck which has the sufficient rigidity to ensure its stability in an extreme environment and serviceability in a railway operation status. However, a new bridge in the Bosphorus strait was required to be aesthetically harmonized with existing two suspension bridges. For this reason, a hybrid bridge type in a high rigidity composing of a cable arrangement with orthogonal single box was developed for achieving good aesthetic view and serviceability in rail operation status. The techniques reported in this paper were focused on a hybrid system for the high-rigidity suspension bridge, a pendulum bearing for an additional rigidity and a newly developed fatigue test criteria for stiffening cable and damper designs. In addition, a plan of temporary struts and a Tower top beam(TTB) installation, special measures to resist against wind effects during the construction and for deck closures were enunciated in the paper.

Keywords : 3rd bosphorus bridge, Cable stayed suspension bridge, Hybrid cable, Rigidity

Atal Bridge: Efficient Delivery of Construction Engineering Services Using Information Communication Technology

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Abstract

India has massively increased investment in transportation infrastructure over the last decade, including the deployment of advanced technologies such as cable-stayed bridges. To relieve a domestic skills shortage, the services of foreign civil engineering consultants are often engaged, especially on technologically advanced projects. This paper presents a case study of the cable-stayed Atal Setu Bridge, a new link to the state of Jammu & Kashmir; recounting the diverse ways that foreign consultants assisted in the construction phase; and how newly available communication technologies made this process more efficient, even in an area with poor communication infrastructure. The geometry control during the complex erection sequence is described, including the methods of communication employed in this process. These communication channels assisted the transfer of both 'hard' technical knowledge and 'soft' organizational skills which are essential to civil engineering projects.

Contribution to Restoration Process of Structural Analysis Studies on Historic Bridges

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Abstract

In addition to making new roads and bridges maintenance and repair of historical bridges is one of the main duties of General Directorate of Highways, Restoration Implementation Project was prepared for 538 historical bridges and Restoration Implementation studies on 196 historical bridges between 2003 and 2016. In this paper, among the 70 historical bridges, the restoration projects were prepared; The contribution to the restoration projects and implementations of the structural analysis studies of the four different historical bridges constructed using the structural system, construction material and practice will be explained through examples, the different features of all historic bridges that were the subject of the examination required the preparation of separate technical specifications for each, all project and implementation studies were carried out in this direction.

Keywords: Historical bridges; restoration; structural analysis studies.

Engineering the Oculus – World Trade Center Transportation Hub

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Abstract

The Oculus structure is the centerpiece of the World Trade Center PATH Transportation Hub in downtown New York City. The main structure consists of two inclined steel arches supported by steel columns, which are anchored onto cantilevers embedded in the transit hall's concrete slabs below. A segmental erection method was proposed to erect the Oculus arches, which significantly reduced the amount of temporary shoring required and allowed construction to proceed at a faster pace. During erection, a detailed geometry control procedure was developed involving multiple survey targets to ensure erection proceeded on the correct path. Bolted connections were proposed in lieu of welding in many locations to accelerate erection. The methodology for bolting such large pieces of steel was developed and designed, then optimized to achieve further schedule improvements.

Keywords: erection engineering, segmental construction, analysis, steel, innovation, architecture, World Trade Center.

Back to the Future – Reconstruction and Revitalization of the BIKINI House in the Centre of Berlin

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Abstract

The BIKINI House, originally completed in 1957, is a listed building complex consisting of five buildings in the center of the West-City of Berlin, adjacent to the renowned Gedächtniskirche and the zoo. The entire ensemble was recently refurbished as a shopping mall, hotel and multi-screen cinema. The revitalization of the listed building complex is based on high standards of energy efficiency for energetically optimized buildings and on sophisticated design having to be realized against tight deadlines, which resulted in innovative constructional design details being developed, amongst others due to the quick construction work. The BIKINI House was completely gutted during the refurbishment and was rebuilt except for the bare concrete work. The new shopping mall connected with the historic building has a 240 m wide-span roof structure, which is a big artwork. This steel construction has a sheet thickness of 160 mm like a design construction for large bridges.

Keywords: Innovative design, steel construction, WU-structure, water impermeable concrete.

Figure 1. BIKINI Berlin. Complex of five listed buildings, carefully revitalized to meet modern shopping and entertainment demands

On the use minor and non-destructive methods for the safety evaluation of an historic RC bridge: the Bôco Bridge

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Abstract

Currently in use, the Bôco Reinforced Concrete (RC) Bridge, built in the early of 20th century, is one of the oldest RC bridges in Portugal. Its initial structural system, erected following the Hennebique system, was retrofitted in the 1960s to support heavy traffic, increasing the section of its structural components. However, the low quality of implemented retrofitting solution has promoted the presence of pathological processes, mainly concrete spalling and steel corrosion. In this context, the present paper shows the first results obtained during the second experimental campaign carried out on the bridge. This campaign comprised the use of several minor and non-destructive methods (laser scanning, operational modal analysis, and laboratory material characterization and mechanical tests), with the aim of improving the knowledge of the bridge and create an accurate numerical simulation (by means of Finite Element Model) to evaluate the safety level of this bridge. Results derived from this campaign, show a bridge with high load capacity, verifying the Ultimate Limit State.

Keywords: Historical construction; Reinforced concrete; Laser Scanning; Ambient Vibration Tests; Finite Element Model Updating; Safety analysis.

Dangerous synergies causing failures of historical structures

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Abstract

The safety and reliability of historical structures or structures generally are typically assessed under "ideal" load or environmental service conditions. However, natural events and human activity or intervention during the life of historical structures may generate synergic effects which decrease their safety and even cause serious defects or failures. This paper presents selected situations involving combined time dependent degradation and sudden impacts of natural or artificial loads or human activity, identifies problems involved in coupling incompatible materials with weather or climate effects and incompatible remedial or strengthening work on historical structures. It further deals with a common problem: inadequate design, harmful interventions, and inadequate protection or preservation treatments. Lessons learned in practice and basic recommendations for preventing catastrophic results are presented.

Keywords: historical structures; safety assessment; climate action; temperature and moisture; material degradation; windstorm; flood; earthquake; environmental fatigue; maintenance.

Analysis of Confederation Bridge Pier Behaviour Following Blizzard Using Pier Tiltmeter Monitoring System

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Abstract

The pier tiltmeter monitoring system for the Confederation Bridge was developed for continuous positional monitoring of all 44 main bridge piers to aid in operational management decisions. All piers were instrumented with digital, biaxial tiltmeters in early 2014, permitting the ability to measure certain response characteristics over 11 kilometers of bridge and 21 portal frame substructures. This was one of the first structures to have an extensive real-time, accessible tiltmeter system as part of a long-term monitoring project. The first major event occurring once the tiltmeters were functional was a blizzard in February of 2015. This event was used for analysis to demonstrate the monitoring system was able to confirm that all main bridge piers returned to their initial position following the event and also, that the behaviour of the piers had not changed or suffered any damage. The maximum increase in traverse tilt during the blizzard was found to be 680 microradians. This pier rotation was found to vary across the structure (i.e. from pier to pier), although a correlation with pier height was found. The peak mean wind speed logged by the weather station during the event was 127 km/h (15 minute average). The transverse behaviour of all piers during the blizzard with respect to wind was examined; results found were in agreement with those from other major storms logged, especially when only winds nearly normal to the structure were considered. Within one week of the blizzard event, the transverse position of all bridge piers was confirmed to be within 2-3 mm of the position recorded before the storm.

Keywords: Structural health monitoring; Confederation Bridge; tiltmeter; pier rotation; positional monitoring; operational management; blizzard.

Finite element investigation of the compressive membrane action effect on concrete slabs

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Abstract

The current design codes for punching shear resistance of flat slabs are based on empirical formulations derived from test results of isolated slab-column connections, where the compressive membrane action was ignored. Testing continuous slab systems is very uneconomical and in most cases not possible. In this paper, finite element analyses (FEA) are performed to investigate the structural performance of continuous slabs. A previously tested and analysed isolated slab with larger in-plane dimensions and different boundary conditions is considered. The FEA results indicate that the shear capacity of the continuous slab is much higher compared to the capacity of the isolated slab. The numerical models are used to examine the effect of low reinforcement ratio in the response of the continuous slabs. Finally, a comparison between analytical results and code provisions indicates the conservatism of the design codes.

Keywords: membrane action; concrete slabs; punching shear; crack pattern; finite element analysis; reinforcement ratio; design codes.

Field Testing and Computational Model Verification for Spread Slab Beam Bridges

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Abstract

Slab beam bridges are commonly used in Texas for short spans in low clearance areas where precast prestressed concrete slab beams are placed in a side-by-side configuration. A new bridge type called a spread slab beam bridge was recently developed using the same concept as spread box beam bridges except the precast slab beams are spaced apart to improve their economy. This paper presents field testing results for spread slab beam bridges, and evaluates different computational methods. One of the challenging geometries with widely spaced slab beams and the longest possible span length was constructed at full-scale. The bridge was field tested using vehicular service loads to evaluate structural performance and measure load distribution between girders for developing load distribution factors. The experimental results were used to validate computational modeling techniques including orthotropic plate, grillage, and finite element analysis.

Based on the research findings, it was concluded that spread slab beam bridges that utilize precast concrete panels with a cast-in-place concrete deck provide a viable construction method for short-span bridges. For the tested bridge, the desired performance was achieved for in-service loading. During field testing the beam live load deflections were within the design limits and no significant cracking or reduction in the overall stiffness of the bridge was observed. Bridge responses under dynamic loads were larger compared to the static values. All three computational methods had reasonably good agreement in terms of estimating load distribution between girders. However, the finite element method was superior in terms of predicting deflection profiles, modal frequencies, and mode shapes.

Keywords: Precast Prestressed Concrete, Bridge Girders, Spread Slab Beam Bridge, Load Distribution Factors, Finite Element Method, Grillage Method, Orthotropic Plate Theory

Experimental Research on Concentrated Load Transfer between Steel and Slender Reinforced Concrete Slabs by High Performance Saw-Tooth Connectors

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Abstract

This paper presents the results of an experimental study on saw-tooth connectors. One main application of these connectors is in hybrid structures, where they connect steel struts or cables to slender concrete decks. In these connections huge and concentrated forces are transferred from steel into concrete. According to the structural system, these connections may occur in the middle or on the edge of the reinforced concrete deck. Depending on the location within the main structure the rc-deck itself is exposed to compression or tension. Therefore, four different build-in situations are being investigated on slender rc-slabs. The presented experiments assess the distribution of the shear force along the connector. A preliminary FE-analysis based on the elasticity theory is compared with the observed load-bearing behavior. The tests show that the loading of the rc-slab in compression or tension has a high impact on the load capacity. All the tests show brittle failure in the concrete. This issue is addressed and investigated during this study.

Keywords: composite structures; concrete; steel; slabs; bearings; joints; bridges; buildings; fatigue; testing

Parametric study and reliability-based evaluation of alternate load path design in reinforced concrete slabs

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Abstract

In normal design situations, RC slabs are in general designed using small deformation theories while taking into account linear elastic behaviour. However as indicated by previous large structural failures the importance of considering the behaviour of RC slabs at large deformations is as important. Based on multiple experimental studies it is clear that RC slabs can develop alternate load paths and consequently generate a significant strength reserve by membrane action once large deformations occur due to the removal of a load-bearing element. This strength reserve is of major importance as this could result in an important increase of the structural robustness for RC buildings. In this contribution a parametric study with a numerical model is performed to investigate the design possibilities on membrane action in RC slabs. Next the reliability of the developed membrane action and alternate load path is calculated for a reference case which is subjected to the removal of a central support considering the static and pseudo-static behaviour.

Keywords: Alternate load paths, membrane action, structural robustness, parametric study, reliability study, RC slabs

Fundamental study on half-width slab deck replacement method for an existing composite steel girder bridge

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Abstract

Currently in Japan, RC deck of steel girder bridges suffers significant damage due to the heavy traffic / increasing the traffic load and leakage. Therefore, it becomes a time to renewal the slab deck especially the aged bridges designed based on recent codes. To avoid the traffic congestions during construction, it is hardly demanded to propose a new design method to shortening the construction period, as well as reducing the cost to retrofitting of the bridge. In this study, we focused on the amount of retrofit needed to replace the RC deck composite steel girder bridge to precast PC deck non-composite steel girder bridge, under half-traffic servicing state. To clarify the subject, frame analysis and FEM analysis were conducted. It is known from the frame analysis that, remove the load distribution crossbeam during construction may reduce the amount of girder's retrofitting. It is also revealed that, the slab deck should be partially replaced rather than fully replaced by FEM analysis.

Keywords: composite steel girder bridge; replacement slab; large-scale replacement; load distribution crossbeam; reinforcement amount; frame analysis; FEM analysis.

Toward Practical Modelling of Reinforced Concrete Flat Slab Systems

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Abstract

There is increasing demand for practical modelling procedures that can be used to assess the performance of reinforced concrete (RC) structures. The numerical assessment of RC slabs at the system level typically involves one of two modelling procedures: i) models constructed with the use of three-dimensional solid finite elements, or ii) models constructed using some form of layered element, usually developed on the basis of the plane sections assumption. The use of solids has been shown to provide good structural performance estimates for RC flat plates; however, the investigation of even a single slab-column connection can be extremely costly as fine meshes consisting of many degrees of freedom are usually required. Conversely, while layered elements are computationally more efficient, they typically provide extremely coarse estimates of the out-of-plane (through-thickness) shear response and generally cannot capture the influence of disturbances developed in slab-column connection regions.

This paper presents the application of an alternative RC slab system modelling procedure. Low-cost layered thick-shell finite elements that can adequately model through-thickness shearing effects were used to capture global slab system behaviour and a simple sectional analysis modification procedure was used to accommodate strength enhancements attributed to slab disturbances. Employing the formulations of the Disturbed Stress Field Model (DSFM), the thick-shell finite element analysis procedure was used to model the response of RC slab-column connections under concentric shear loading conditions. Shell element-based numerical responses were compared with those obtained using more conventional modelling procedures (e.g., solid continuum), and were contrasted with experimental data. Further, the validated RC slab modelling procedure was used to analyze the response of a slab subsystem test available in the current database of experimental literature, and was shown to provide good agreement with test results.

Keywords: Punching shear; nonlinear finite element analysis; shell element; disturbed region.

Building-Integrated Photovoltaic – Standardization and Testing

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Abstract

Opaque surfaces of buildings offer large-area spaces for generating energy. Today, sustainable façade systems contribute to produce high-performance buildings that are economical and energy-efficient. Furthermore, PV integrated in the building skin as building integrated photovoltaic (BIPV) produce energy. They play an important and leading role in achieving the future goals of an emission free energy consumption. Several requirements by national building laws and regulations need to be considered since PV modules are integrated into the façade as building products. In order to realize a BIPV project properly a detailed knowledge of building codes is required. Therefore, the EU-research project "Construct PV" aims for a common and European-wide applicability of BIPV. This paper presents the legal situation of building codes in Europe and selected national regulations. This will set a basis for future BIPV design in achieving the goals of an emission-free source of renewable energy.

Keywords: BIPV; buildings; sustainability; renewable energy; standards and tests; building codes.

Intelligent Future Building Skins – Studies on a Flat Plate Photobioreactor Prototype

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Abstract

Algae growth on building facades would usually be a cause for frustration among the majority of building owners. But what if microalgae were cultivated intentionally on facades as a future building concept for energy or domestic warm water supply? A team of German scientists and technicians consisting of ADCO Technik GmbH, ARUP Deutschland GmbH, Frener & Reifer GmbH, SSC Strategic Science Consult GmbH and Technische Universität Dresden is developing flat panel bioreactors made of glass for building skins. This paper presents the construction of a photobioreactor prototype. It describes the design approach including the structural design and flow simulations. The mechanical, physical and chemical loads are characterized and experimental studies on adhesive materials are presented.

Keywords: glass, facade, photobioreactor, CFD simulation, structural adhesives, tensile tests.

Assessing climate impact on reinforced concrete durability with a multi-physics model

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Abstract

A framework for performance-based durability engineering can incorporate climate impacts in its assessment of the lifetime sustainability of built infrastructure. Most performance-based durability and climate impact assessments have used simplified deterioration models, which are insensitive to shorter-term fluctuations in boundary conditions and therefore may underestimate climate change impacts. A highly sensitive fully-coupled, validated, multi-physics model for heat, moisture and ion transport and corrosion was used to assess a reinforced concrete structure located in coastal Norfolk, Virginia. Deterioration was predicted using tidal exposure conditions obtained from statistically downscaled global climate model output under two emissions scenarios. Deterioration, repair, and decision metrics under the emissions scenarios were compared using the performance-based framework to assess the influence of climate change.

Keywords: durability; performance-based; reinforced concrete; corrosion; climate change; hygrothermal; chlorides.

Timber bridges – Load carrying behaviour according to climate changes

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Abstract

Timber road bridges have been built worldwide for centuries. The high performance of wood as structural material is approved. However the influence of moisture induced stresses in cross sections according to the varied ambient climate are still questioned. Results observed in the long term monitoring of six timber bridges provide first guidelines for practitioners. Further on, first numerical simulations are carried out for the assessment of the long term behaviour of timber bridges over the life cycle. The numerical simulations include the moisture diffusion transport in wood as well as the resulting stress strain behaviour of the timber member. The research results provide new guidelines for the planning engineers, the definition of an active or passive zone of the cross sections, and provide a differentiation of the service class over the cross section.

Keywords: Road bridges, moisture content, stresses, service classes.

Climate impact optimization in concrete bridge construction

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Abstract

Estimates indicate that the total climate impact, from a lifecycle perspective, generated by Swedish construction processes reaches the same magnitude as emissions from all passenger cars in Sweden. A large part of the emissions from construction of roads and railways arise from production of steel and concrete used in bridges and other infrastructure structures. In this research, several cases of existing concrete bridges have been investigated. The case studies are in a very firm way analyzed, and then opportunities for reducing climate gas emissions are described and elaborated upon. Accordingly, design and dimensioning through the use of today's technology and material selection are discussed. Without developing new ways to construct bridges, or comparing concrete with other materials, a useful guide on how to use technology and opportunities that are available for constructing climate smarter versions of standard bridges today is developed and described.

Keywords: climate smart; concrete bridge; optimization; sustainable construction; integrated design

Climate Change: impact on snow load on structures and consequences on built environment

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Abstract

The effect of climate change could significantly affect, in the mid-term future, climatic actions and then the design of new structures as well as the reliability of existing ones, designed according the provisions of current or past codes. In this wok, a suitable procedure to derive snow loads on ground under non-stationary climate conditions is proposed, combining data provided by observational dataset and outputs of climate models. The analyses are performed for the Italian Mediterranean region and the results in terms of updated snow load maps are presented for movable 30 year time windows till 2100 according different greenhouse gas emission scenarios.

Keywords: Climate Change; Snow Loads; Extreme Values; Bayesian Methods; Structural Safety

Repair, Strengthening and Upgrading of Steel Bridges in The Netherlands

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Abstract

After World War II, many steel bridges were designed and built in The Netherlands. Many of these bridges are now of a substantial age and were designed for static and fatigue loading less severe than eventually present during their lifetime. Many of these bridges now show (fatigue) damage. Depending on the nature of the damage, these bridges can either be replaced, or a reinforcing substructure can be added, or the visible damage can be repaired and the bridge can be locally strengthened. In many cases, it has to be shown that the bridge is fit for purpose for future use, meaning that upgrading may be necessary. These bridges are now being reassessed and any possible conservatism in these assessments needs to be excluded to avoid unnecessary strengthening. The paper gives practical examples of repair, strengthening and upgrading techniques for steel bridges.

Keywords: steel; bridges; assessment; repair; strengthening; upgrading; fatigue; codes; standards.

Prolife: Recalculating a steel railway bridge for determining strengthening measures, using an updated FEM model and site measurements.

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Abstract

Under funding of the European Union's Research Fund for Coal & Steel (Grant agreement no. RFSR-CT-2015-00025) the project ProLife (Prolonging lifetime of old steel and steel-concrete bridges) is undertaken to find innovative new ways how to extend the lifetime of existing bridges. Within ProLife many different strategies for strengthening old road and rail bridges are researched by different partners in the project. The goal of the project is to look at different strengthening measures and their influence on the remaining lifetime and life cycle costs of a bridge.

We will focus on rehabilitating a steel rail bridge with steel deck sections to strengthen the stringers and cross beams. These are the governing elements for the lifetime of regular bridges, since the main (truss) girders generally have a high enough capacity to cope with today's loads. As a case study for this strengthening method the bridge over the river Waal in the Netherlands near Zaltbommel is used. This is an old (1932) truss girder bridge in a busy railway line with both passenger and freight trains. The methodology for strengthening this type of bridge is described using this case study.

In this paper we will give an insight in the way the FEM model was made. On-site measurements have been taken to verify and calibrate the model of which the results will be presented. It was found that for a detailed and accurate assessment of this kind of bridge on-site measurements are very important.

Keywords: Strengthening; recalculate; bridge; measurements; assessment; FEM updating

Innovative strengthening of steel truss nodes by Ultra-High Performance Concrete

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Abstract

The paper presents one innovative idea for strengthening of steel truss nodes by UHFRPC. The nodes are totally encased in the UHFRPC with no additional conventional reinforcement. The connection between steel and UHFRPC is realized by epoxy resin only without any shear connectors. For proving the efficiency of this strengthening method five specimens are going to be tested in laboratory, one reference bare steel node, and four encased. The parameters that are going to be varied during the tests are the concrete cover and encasement length of the elements entering the node. The very promising results from the preliminary FEM of the nodes are presented here in as well as the description of the experiments envisaged.

Keywords: steel truss bridges; nodes; strengthening; encasing; UHPFRC; laboratory tests.

Monitoring of a bridge strengthened with post-installed coiled spring pins

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Abstract

Many existing bridges were not originally designed for the traffic loads and the number of load cycles which they now experience. In order to increase the load capacity of non-composite steel-concrete bridges, post installed shear connectors can be used. This paper describes a field monitoring of a steel-concrete bridge which have been strengthened with post-installed coiled spring pins as shear connectors. During the monitoring, the bridge was loaded with a 31 tonnes truck placed in specific positions while strains were measured in the steel main girders, together with the horizontal slip at the steel-concrete interface. The results indicate that the coiled spring pins prevent the slip and that they can be used for strengthening purpose. It is also observed that the friction in the steel-concrete interface can contribute quite a lot to the composite action, even though that effect cannot be accounted for in the design.

Keywords: Shear connector; bridge monitoring; composite bridge; composite action; coiled spring pin; shear studs; bridge strengthening; rehabilitation;

Testing of coiled spring pins as shear connectors

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Abstract

A few decades ago, steel-concrete composite bridges were quite rare structures, whereas steel girder bridges with non-composite concrete decks were rather common. For the latter type of structure, composite action can be obtained long after the bridges were constructed by post installation of shear connectors. Most installation procedures involve reconstruction of pavement and concrete deck, which will result in traffic disturbance. There are however some types of shear connectors that can be installed from underneath, connecting the top flanges to the concrete deck, without affecting the upper surface. This means that the bridge can be strengthened during traffic. One type of such a shear connector is the coiled spring pin, which is an interference fit connector. This paper presents the results from push-out tests conducted in order to find the static capacity and the load-slip behaviour of coiled spring pins used as shear connectors.

Keywords: Shear connector; push out test; composite bridge; composite action; coiled spring pin; shear studs; bridge strengthening; rehabilitation;

A Technique for Strengthening Existing Continuous Non-Composite Steel Girder Bridges Using Post-Installed Shear Connectors and Inelastic Moment Redistribution

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Abstract

Many older bridges are constructed with floor systems consisting of a non-composite concrete deck over steel girders. A potentially economical method for strengthening these bridges is to develop composite action by attaching the existing concrete deck to the steel beams using post-installed shear connectors. The current paper discusses this method based on the findings from a large-scale research study aimed at strengthening existing non-composite continuous steel girder bridges. The results of this research indicate that post-installed shear connectors are a feasible and efficient method of extending the useful service life of a non-composite steel girder bridge. Increases of more than 60-percent in the ultimate strength of the bridge girders tested in this study were attained by strengthening to a composite ratio of only 30-percent. The test program also exhibited excellent fatigue resistance for the post-installed shear connectors.

Keywords: Post-Installed; Shear Connectors; Composite; Steel Bridge; Inelastic Moment Redistribution; Fatigue; Strengthening; Large-Scale.

Dynamic Analyses of Ship Impact to the New Bridge over Storstrømmen

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Abstract

Ship impacts to bridges are relatively rare and therefore treated as accidental loads. Due to the low probability of occurrence, it is logical to allow some degree of plastic behaviour of the impinged structure, since the alternative, a completely elastic response, may lead to disproportionally large material usage.

This paper presents the principle of, and results from, numerical analyses conducted for the illustrative design of the new bridge over Storstrømmen in Denmark. This is an approximately 4km long bridge consisting of 80m viaduct spans and two navigations spans of 160m in a single-pylon cable-stayed configuration. The girder is a continuous, post-tensioned concrete box girder carrying two railway tracks, two road lanes and a combined pedestrian/bicycle path.

Since ship impact is a transient event, the numerical analyses conducted consist of dynamic analyses in the form of time-series that include relevant non-linearities of the ship, soil and bridge bearings. Hereby a realistic picture of the bridge response during, and after, impact is obtained allowing the comparison between pre-defined failure modes and the bridge response.

In addition, the time-series produced are used to calibrate a linear model for train safety/runability calculations in conjunction with ship impact to define design criteria's for maximum bridge accelerations levels at ship impact, in order to prevent trains from overturning.

The runability model itself have be tested against the Danish Great Belt West Bridge, a comparable railway concrete girder bridge, in order to justify that the model gives correct acceleration levels for the train/structure interaction and subsequently acceleration levels at ship impact.

Based upon the investigations made also risk analysis have been carried out, in order to show the overall risk complies with railway authorities and Eurocode requirements.

Keywords: cable stayed bridge, ship impact, train/structure interaction, dynamic analysis, train runability.

Assessment of the Structural Safety of the Schiphol Railway Tunnel

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Abstract

The planned extension of the parking garage P1 in the centre of Schiphol Airport, in which a third storey would be build on top of the existing two, demanded a reassessment of the Schiphol Railway Tunnel underneath it. The assessment was based on the Eurocodes, on the Dutch standard NEN 8700 and on the Dutch guideline RBK. The major goal was to avoid or minimize strengthening measures. This is achieved by minimizing the calculated construction forces, by using 3D FEM plate models, by accurately determining the load from the parking garage and using the adjusted load factors for the safety level "Reconstruction". Also the capacity of the construction elements was calculated as accurately as possible. Additional design shear capacity was gained using the benefits of the RBK, of the haunches and thickenings. The ULS was reviewed and strengthening measures were designed, mainly to locally increase the shear capacity.

Keywords: tunnel, assessment, structural safety, shear capacity, strengthening.

Renovation of the Existing Lighthouse for New Radar System in the Gulf of Thailand

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Abstract

The new radar system mainly consists of a 5.7-meter-long SCANTER antenna, a 1.2-meter-diameter microwave dish and a 5.0-meter-high lightning protection rod, which are supported by a new steel structure located on the roof of the lighthouse. These additional loads are transferred directly to the existing interior columns under the roof. Ultrasonic Pulse Velocity (UPV) testing was conducted to investigate the strength and reliability of the existing lighthouse structures, and found that certain improvements to the existing structures had to be made. Ultimately, the structural engineer decided to strengthen these structures by covering them with glass fibre reinforcements in order to extend the lifespan of these structures for the new radar system.

Keywords: renovation; existing lighthouse; new radar system; strengthen; glass fibre reinforced polymer; marine condition; additional loads.

Design and Launching of a Redundant Truss over a Busy Rail Yard

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Abstract

Five deteriorating Warren trusses over the busy BNSF Northtown rail yard in Minneapolis need replacement. The new structure consists of a skewed 305-foot (92.96 m) truss and two-span steel girder structure to meet the RR's desire to eliminate two piers in their yard. The new truss incorporates unique load path and internal redundancy measures including eliminating fracture critical steel truss members and gusset plates and using a post-tensioned concrete bottom chord. Removal of the two existing truss spans over BNSF's main line tracks and the installation of the new truss span is accomplished using a launching system.

Keywords: truss; accelerated bridge construction; redundancy; launching; construction over rail roads; post-tensioning.

Multi-span suspension bridge on floating foundations - behaviour under ship impact

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Abstract

The multi-span suspension bridge on floating Tension Leg Platform (TLP) foundations is one of the proposed concepts for the crossing of the E39 Bjørnafjord in Norway. One of the challenges in the design of the fixed link is to ensure sufficient robustness with respect to ship impact. In this work, the structural response to a ship impact event is evaluated using nonlinear finite element analysis. The simulations are based on a bow model of a 186 m length over all container vessel, which is estimated to transit the bridge crossing weekly. Impacts from a conventional container vessel bow without ice reinforcements cause minor damage to the floater hull. Most of the energy is dissipated in the striking vessel. Impacts from an ice-reinforced vessel gives considerable more damage to the floater hull. The damage extent for all the simulated impacts are repairable on site. However, impacts from the conventional vessel cause only minor denting and can be repaired at a convenient time, whereas impacts from the ice-reinforced vessels necessitates major repair work.

Keywords: Multi-span suspension bridge, floating foundations, ship impact, nonlinear FEA, steel, fracture.

Numerical simulation of protection barriers for bridge piers against ship collision

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Abstract

In the design of bridges across waterways, the importance of a protection system for the bridge piers against ship collisions increases with the increased traffic passing along the channel. To estimate the behaviour of reinforced concrete protection members in steel-concrete composite bridges and to define the failure load of the structures is a challenge due to the complexity of material interfaces, member behaviour and size of structure.

In order to evaluate the ultimate strength and energy absorption capacity of a pier protection system, an advanced finite element model using concrete damaged plasticity model provided in ABAQUS has been utilized and presented in this paper. A possible ship collision to the pier protection barriers is simulated using displacement-induced loading and considering plasticity of steel as well as concrete damage plasticity including the post-peak behaviour. The results from the simulation reveal that the pier protection barriers have sufficient capacity to absorb energy from a ship impact.

Keywords: Nonlinear analysis, pier protection, concreted damaged plasticity, post-peak behaviour

Seismic Fragility Curves using Natural and Synthetic Ground Motions

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Abstract

Fragility curves are useful tools for the probabilistic assessment of the seismic performance of buildings. Nonlinear structural analyses with uncertainties in load and resistance are required to develop fragility curves. A statistically sufficient number of earthquake ground motion records should ideally be obtained from past records of the region of interest to have a satisfying fragility curve. However, the number of available earthquake records in many seismically active zones is limited. In such a situation, use of the synthetic ground motions is an accepted alternative for fragility analyses of buildings. This paper compares the seismic fragility curves obtained from synthetic and natural ground motion records. It is found that synthetic ground motions result in conservative fragility curves with lesser dispersion in drift demand when compared with natural recorded ground motions.

Keywords: synthetic ground motion, uncertainty, fragility curve; performance level; dispersion.

Seismic Performance of Concrete-Filled Double-Layer Steel Tubular Column under High Axial Load

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Abstract

Concrete-filled steel tubular (CFT) columns have been widely used in building structures because of excellent earthquake-resistant properties such as high stiffness, high strength, good ductility and large energy absorption capacity. In past years, a special cross-section of column with the concrete-filled double-skin steel tubes (CFDSTs), was proposed by several researchers due to some advantages in respect of CFT column, which include reducing total dead load of structure, lowering concrete consumption, increase in section modulus and improving cyclic performance. However, the hollow part of cross-section can lead to significant axial compressive strain under high axial load. In this study, a different cross-section of column with concrete-filled double-layer steel tubes (CFDLTs), transforming from the CFDST column by filling the hollow part of cross-section with concrete, is proposed to decrease the axial compressive strain. Quasi-static cyclic tests of the CFDST and CFDLT column specimens were carried out under constant axial force ratio of 0.5 to investigate the effect of hollow section of column and solid section of column on the seismic performance. The experimental results showed that the CFDLT column specimen exhibits higher lateral load capacity and ductility. It is clarified that progress of axial compressive strain can be remarkably prevented for the CFDLT column specimen.

Keywords: CFT column; CFDST column; CFDLT column; hollow section; solid section; seismic performance; high axial load; axial compressive strain.

A New Seismic Retrofitting Method for Steel Bridge Piers in Japan

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Abstract

Japanese highway bridge design codes have been modified a lot since the Hyogoken-Nanbu Earthquake in 1995, but only used for designing new bridges. The aged steel piers constructed with old design code should be strengthened appropriately to adopt with current design code. With the purpose of improving the seismic performance of existing steel piers, a preventive seismic retrofit method by using GFRP plate, rapid hardening concrete, rubber-latex mortar, and reinforcement is proposed in this paper. The static loading tests on the steel piers before and after strengthening were performed to confirm the effects of the present strengthening method. Moreover, three-dimensional FE models were built to make a comparison study between the strengthened and the original steel piers. Load versus deflection relationship and sectional strain distribution on the piers were measured and compared between original piers and strengthened piers. Both experimental and numerical results indicate that the present strengthening method can greatly enhance the stiffness and reduce the stress levels of steel pier, resulting in the extension service life and improvement of the seismic performance of aged steel piers.

Keywords: Steel piers, seismic retrofit, loading test, numerical analysis.

Structural design of a seismic isolated building in Matsumoto city

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Abstract

This paper reports under construction project of a seismic isolated building designed by Toyo Ito Architects and Associates. In the structural planning, for function maintenance of post-disaster, seismic isolation structure which is capital seismic isolation at basement floor has been adopted. All seismic isolators are on the capital of SRC and RC columns. By adopting capital seismic isolation at basement floor, the depth of the foundation can be made shallow and drilling cost is reduced. And for realization of open space, the upper is planned as steel rigid frame structure which CFT columns and H-section steel beams are utilized. First, this paper describes about the architectural plan. Next, structural planning with respect to mainly seismic isolation structure is explained. After explanation of the structural planning, the detail of the structural design (verification by using time history response analysis) is shown.

Keywords: seismic isolation structure, capital seismic isolation, steel rigid frame structure, response spectrum analysis, time history response analysis

Pretensioned, Rocking Bridge Columns for Accelerated Construction and Enhanced Seismic Performance

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Abstract

A new precast bridge bent system has been developed that accelerates on-site construction activities, minimizes residual displacements even after large seismic events and reduces post-earthquake damage. The connections are the key to the system's seismic performance. They were tested under quasi-static conditions and found to perform exceptionally well with nearly zero strength degradation and little concrete damage, even after being loaded cyclically up to drift ratios of 10%. The restoring properties of the system were evaluated through multi-shaking table tests conducted on a quarter-scale, two-span bridge specimen. The maximum residual drift ratio during testing was 0.4%, even after excursions to drift ratios exceeding 13%. This paper describes the new system, compares its performance to that of more conventional cast-in-place construction, and describes key aspects of its design philosophy.

Keywords: bridges, rapid construction, shake-table, pretensioned concrete, connection, precast concrete, seismic, residual displacements, low-damage, rocking structures

Seismic Performance of Perforated Steel Plate Shear Walls Designed According to Canadian Seismic Provisions

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Abstract

Perforated Steel Plate Shear Wall (P-SPSW) is a relatively new lateral load resisting system. Research on P-SPSW is in the initial stage, and to the best of these researchers' knowledge, no seismic performance of code designed P-SPSWs has been studied yet. The main objective of this study is to evaluate the seismic performance of code designed P-SPSWs. Three multi-storeys (4-, 8-, and 12-storey) P-SPSWs were designed according to the seismic provisions of NBCC 2010 and CAN/CSA S16-14. Nonlinear time history (NTH) analysis was conducted using detailed finite element (FE) modeling techniques for a series of ground motion records which were compatible with Vancouver response spectrum. All the perforated shear walls exhibited excellent seismic behavior including high stiffness, stable ductility, good energy dissipation capability and also current code equation provides a good estimation of the shear strength of the perforated plate when the infill plate is fully yielded. The applicability of the modified strip model (MSM) was also evaluated in this research for unstiffened P-SPSW. It was observed that the modified strip model captures the inelastic behavior of multi-storey unstiffened P-SPSWs with adequate accuracy. The ultimate strength was predicted well, and the initial stiffness was slightly underestimated.

Keywords: Lateral load resisting system, Nonlinear time history analysis, Response spectrum, modified strip model.

Three-Dimensional Non-Linear Analyses of Special Reinforced Concrete Moment Frames

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Abstract

The design of special reinforced concrete moment frames (SMFs) requires the consideration of both strength and stiffness. SMFs are proportioned and detailed to allow for extensive inelastic deformations, but most frames are designed using elastic (or modified elastic) two-dimensional models. Two concepts not included in design are the increased lateral stiffness of axially loaded compressive columns (and by contrast, the loss of stiffness of columns in tension) and the increased displacement of leeward columns due to concrete beam elongations. In this paper, shear-force distribution between columns and corresponding beam elongations will be presented using three-dimensional non-linear finite element analyses (3DFEAs). Analyses include load-to-displacement results and associated changes in beam stiffnesses from the 3D-FEA and compare those results to two-dimensional finite element analyses.

Keywords: bridge; building; column; ductility; earthquake-resistant; flexural strength; shear strength.

Influences on Determining Structural Reliability

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Abstract

The influences to investigate when trying to assess the reliability of structures are manifold. Even if all the relevant stochastic parameters and data for establishing a typical reliability model are known, there are uncertainties to be considered which cannot be covered by probabilistic methods only. In a probabilistic analysis, the basic variables of a design problem, such as e.g. material strength or load effects, have to be modelled as random variables. From there, the failure probability of a member can be determined by use of methods of reliability analysis.

This relatively straightforward procedure reaches its limits when additional influences like the simplification and/or linearization of the design problem, the model-reality-antagonism, the paper-building site transformation or human error are to be considered. Especially the three latter are not tangible by stochastic methods only. As the nature of these issues is predominantly human, individual competence or its opposite deprive a purely mathematical approach to achieving sufficient reliability.

Keywords: reliability, design checking, design supervision, human error, model uncertainty

Live Load Distribution Factors for a Lightweight Movable Bridge Deck System

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Abstract

Louisiana has approximately 160 movable bridges, mostly in the southern part of the state. The typical deck systems in these movable bridges are steel grids. Records show that steel grids have had maintenance issues. A precast lightweight concrete deck system for Louisiana's movable bridges is presented. The deck configuration features a multi-rib T-beam configuration. Live load distribution factors (LLDFs) for flexure and shear are quantified so that the deck system can be designed using the traditional beam line analysis method. Several nonlinear finite element analyses were conducted to quantify worst case LLDFs for interior and exterior ribs. A variety of load positions and span configurations are examined. LLDFs for moment and shear vary from 0.63 to 0.87, and from 0.64 to 0.86, respectively. The LLDFs for flexure and shear provided in this paper offer a practical approach for designing this new deck system for movable bridges.

Keywords: Movable bridge decks; live load distribution factors; finite element analysis

Column Removal Analysis of Bare Steel Gravity Frames Using Connection Behaviour from Physical Tests

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Abstract

This paper investigates the dynamic response of bare steel framing systems with commonly-used shear connections under several column removal scenarios. The analysis follows the Imperial College London method for progressive collapse assessment, which provides a simplified approach that accounts for the dynamic effects associated with instantaneous column removal and a practical framework for assessing the collapse resistance of a structure. Load–deformation relationships and failure limits for beam-to-column connections under combined moment, shear, and tension used for this study are taken directly from physical test data, providing realistic connection behaviour for the prediction and assessment of dynamic response. The robustness of various shear connections is quantified and compared, and connection parameters that significantly affect performance under dynamic loading are discussed.

Keywords: column removal; dynamic response; progressive collapse; robustness; steel structures; shear connections.

Numerical Analysis of Stress Concentration Factors of CFRP-Strengthened Fillet Welded T-joints

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Abstract

A few past studies indicated that fatigue behaviour of welded joints in steel bridge strengthened using carbon fiber reinforced polymer (CFRP) sheet could be improved obviously. The authors in this paper try to verify the issue of how CFRP decreasing stress concentration at weld toe in fillet welded T-joints through numerical analysis. Stress concentration factors (SCFs) in fillet welded T-joints before and after CFRP strengthening were investigated respectively by 1560 finite element models using ABAQUS, with different parameters varying, such as fillet weld toe radius, CFRP reinforcing ratio and CFRP elastic modulus. It is concluded that all the parameters are important affecting the SCF of fillet welded T-joint, and using high elastic modulus CFRP can be the most efficient approach to decrease SCF. Parametric equations were proposed to calculate SCFs of fillet welded T-joints with and without CFRP strengthening.

Keywords: fillet welded T-joint; carbon fiber reinforced polymer (CFRP); strengthening; stress concentration factor (SCF); numerical analysis; parametric equation; fatigue.

Design Challenges Related to Providing Lateral Load Resistance to Existing Buildings in Accordance with Current Building Codes

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Abstract

The evaluation and retrofit of existing buildings using current Building Codes can present a variety of challenges to structural engineers. There is a substantial inventory of buildings throughout the United States that predate modern Codes in regards to wind and seismic demands. The state-of-engineering practice has also evolved considerably since the time these buildings were constructed. This paper examines the existing deficiencies, the analysis of these deficiencies, and the proposed retrofit solutions for a precast reinforced concrete warehouse constructed in the mid-1950's. The building has been subjected to multiple design-level wind events during its service life, including Hurricane Katrina in 2005, and exhibited satisfactory performance. The ASCE 7-10 and 2012 IBC Building Code were the applicable standards at the time of our analysis in 2016. The Southern Building Code was the applicable building code prior to the adoption of the IBC Code. The seismic demands based on the current standards were determined to be up to ten times greater than the wind demands, which raised some compelling questions regarding the applicability of the current ASCE 7 and IBC seismic provisions in a geographical area where the design lateral loading has been historically controlled by wind. It was also observed that the connectivity between the lateral load resistant elements and structural diaphragm was poor to non-existent, which required creative solutions to connect the structural elements in a manner that produced a reliable lateral load path.

Keywords: reinforced concrete; precast; retrofit; seismic load demands; wind load demands.

Shaping Forces; the symbiotic relation between structure and architecture

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Abstract

Over the past two decades architects are finding their way into the bridge design practice. Ever since the 90's we have seen an exponential growth of the involvement of architects in bridge design. Many beautiful and well integrated designs have been realized all over the world, but an equal amount of farfetched bridge designs have seen the light of day.

What are the key design considerations to achieve a beautiful and yet structurally sound bridge? Does a structure always need to follow the most efficient form, according to the laws of mechanics and of finance? Or is there such a thing as symbiosis between Form and Force, a way of working that ensures that the final result becomes greater than the sum of its parts?

Best practices in bridge design from the authors architectural office demonstrate the belief that structure and architecture are involved in a symbiotic relationship. One cannot be successful without the other. Just how this successful interaction is achieved is the subject of this paper.

The Shenzhong Link – A synthesis of architectural and structural design

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Abstract

In March 2016 COWI with Dissing+Weitling architecture won the international competition for a fixed link between Shenzhen on the east side and Zhongshan on the west side of the Pearl River Estuary near Guangzhou in China. The Shenzhong Link is 24km long and includes 7km immersed tunnel, 4km cable supported bridges, 12km approach bridges and an artificial island. The link will serve the transit traffic of a 2 x 4 lane expressway and local traffic to a terminal building on the artificial island. Engineers and architects jointly developed the bridge structures, artificial island and tunnel with the overall objective to achieve an iconic, yet harmonious and elegant link from one end to the other. The award of the 1st price of the competition was followed by these words of the Client's: "The design philosophy of the concept is advanced. The overall design of the link is magnificent, elegant and concise. The design of main bridges, the approach bridges and the artificial island is integrated, the holistic impression and iconic landmark of the link is prominent, the whole link is in harmony with the surrounding environment, the Y-shaped pier shaft of approach bridges give a very strong sense of rhythm." The teamwork of the engineers and architects is supposed to be exceptionally successful. This paper describes the innovative bridge concepts of the fixed link, their justification in terms of structural strength, durability, economy and architecture, and how they were developed. The basic demands of strength, stability and durability actually go well hand-in-hand with elegant and slender bridge structures, that are yet inexpensive. The engineers and architects worked in close collaboration from the very beginning of the competition, pro's and con's of different design options were discussed by the team, and by joint efforts, the concepts were changed or modified into their final shape.

Keywords: design competition, bridges, architecture, structural design, winning concept, harmony

Plus-Energy façades with smart materials for future building envelopes

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Abstract

Façade constructions and their opaque areas show great potential for generating energy by using photovoltaics (PV). The performance of PV modules decreases with increasing cell temperature. To reach lower module temperatures even in insulated façade constructions without rear ventilation, a composite construction using smart materials was examined. By mounting phase change materials (PCM) on the backside of the PV module, the PCM can absorb thermal energy from the PV module by melting from solid to liquid during the day. Rising module temperatures can thus be buffered. At night, the thermal energy in the PCM is released back into the ambient air.

For future applications, the article outlines an approach of integrating hybrid panels in façade constructions. These elements combine PV modules and thermal collectors in order to generate thermal and electrical energy with a high efficiency due to the low temperatures of the PV cells.

Keywords: phase change materials (PCM); photovoltaics (PV); PV module; energy; mullion-transom façade; monitoring; hybrid-panel; thermal collector.

Securing visual quality and architectural intent while aiming for an affordable tender design - the procurement of the Mersey Gateway Crossing

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Abstract

Since its announcement in 2005, the Mersey Gateway Crossing Project between Runcorn and Widnes is getting close to its completion. The 9.5km long bypass corridor project, featuring a 1000m long three pylon cable stay bridge, becomes a precedent on a procurement route that allowed its client, Halton Borough Council, to maintain a high quality design intent while controlling the budget of a project, which was under increasing pressure as regards affordability, due to economic downturn. With the help of infrastructure specialist Knight Architects the client managed to outline areas of greater flexibility and key design requirements. The resulting descriptive Design and Access Statement, was a key reference document in the subsequent Competitive Dialogue. Using the Mersey Gateway as an example, the paper will explore how the choice of the right procurement route enables to realise a major infrastructure project of high functional and architectural quality, while allowing the client to remain in control of both budget and design, significantly improving its chances to be supported by the public.

Keywords: procurement, competitive dialogue, tender, cable-stayed bridge.

Enabling a New Architectural Paradigm with Performance Based Design of a Base Isolated Sculptural Office Tower

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Abstract

Due its height and expressive architectural design the (W)rapper Tower is set to become a landmark building in Los Angeles, CA. The structure is architecturally driven and features exterior curved steel boxes "Bands", an eccentric Steel Plate Shear Wall (SPSW) core and Seismic Base Isolation. Performance Base Design (PBD) using LATBSDC guidance was adopted for the design and the performance of the Tower. The structure was assessed using Non-Linear Time History Analysis (NLTHA) in LS-Dyna with 63 earthquake simulations (nine suites of seven ground motions each). The analysis and post-processing used an automated workflow relying on cloud computing and custom database post-processing. This paper describes the development of the structural system and the analysis process employing numerous advanced modelling and visualization techniques.

Keywords: Steel, Bearings/Joints/Seismic Device, Buildings, Spatial Structures, Seismic Design and Response, Innovative Structural Systems, Information Technology, Performance Based Design, Tower/High-Rise

Bridge Aesthetics: Two examples from India

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Abstract

On seeing aesthetically pleasing structures, we are touched if we are sensitive to beauty. Such structures do enrich us and elevate our soul. Aesthetic quality of design (beauty for an artist) in form and shape is defined & there are rules for achieving the beauty. However, simple application of rules may not be enough, an artistic talent and sense of beauty matters, which designer has been bestowed upon by HIM. When proportion, Order and symmetry are applied well, the object so produced has aesthetic value. Five important aspects form, character, detail, scale and proportion must be considered from first principles. [1]

Two Arch bridges have been recently completed / nearing completion in North East India, which will pave way for changing preferences for accepting aesthetics as preferred solution:

- Sanjenthong Bridge at Imphal: 4 lane Bow String Arch bridge, span 56m
- Bridge over river Wahrew in Meghalaya: Steel latticed arch bridge, span 150m.

Principles devised by Dr Fritz Leonhardt, which are very effective in objectively assessing the aesthetical appeal of a bridge are used.

Sound Engineering is necessary for good design of lasting value, but may not lead to beauty in itself. Beyond rational thinking of an Engineer, objective must be there to create beauty. Artist, when engaged, should work for purpose of the structure rather styling it! Beauty of design will reach lasting value only if the bridge achieves its purpose.

Key words: Aesthetics; Bridges; Arch; Steel trussed arch; Bridge design; Composite deck; Steel box section arch; Hangers; HTS bars; Steel Bow String Girder

Cross-Sections of long Composite Bridges – Performance based Design

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Abstract

Steel-concrete composite bridges play an important role in building motorway bridges of small and of long spans. The paper puts the focus on large span bridges of the construction type deck bridge. Today, four different cross-sections are built regularly. These four cross-section types are investigated and the adequate area of use is proposed considering life cycle performance. Possibilities of further development are discussed.

Keywords: steel-concrete composite bridges; deck bridges; cross-section types; comparative study; performance based design; options for development;

Sir Ambrose Shea Lift Bridge – Newfoundland and Labrador, Canada

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Abstract

The new Sir Ambrose Shea Vertical Lift Bridge is located in the Province of Newfoundland and Labrador on the east coast of Canada, and was built as a replacement to an existing structure constructed in 1961 that had reached the end of its useful life. It is a three-span structure, with a movable centre span (vertical lift span) flanked by two simple fixed composite plate girder spans. The towers for this lift bridge consist of a three dimensional steel truss, shaped representative of sails. Each tower component is connected by a three dimensional exoskeleton truss which houses the machinery to operate the lift span. The new bridge was designed to be durable, efficient, and reliable as well as being an aesthetically pleasing structure with architecture to reflect the local culture and tourism potential of the region. The new bridge was constructed adjacent to the existing bridge in order to minimize disruption to the local fishing boats and road traffic.

Keywords: movable bridge; durability; tubular sections; vertical lift bridge; aesthetics; constructability.

Conceptual Design, Detailed Design, and Construction of the Terwillegar Park Stressed Ribbon Footbridge

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Abstract

In January 2013, the City of Edmonton called for proposals for a new 300 m footbridge across the North Saskatchewan River in Edmonton, Alberta, Canada. Consultants were challenged to develop concepts that were innovative, fit the context of the deep natural river valley, and meet strict budgetary and schedule requirements. In October 2016, the longest and first multi-span stressed ribbon bridge in Canada was opened to the public. The Terwillegar Park Footbridge was designed by Stantec Consulting Ltd for the City of Edmonton and forms a key link in the river valley park system in that city. Stressed ribbon bridges can be described as precast concrete structures that are erected segmentally on cables and post-tensioned to achieve a continuous, slender, prestressed concrete structure. In this paper, the conceptual and preliminary design process of the Terwillegar Park Footbridge is described and challenges encountered in the design and construction of this elegant and innovative structure are shared.

Keywords: stressed ribbon; footbridge; precast; concrete; post-tensioned; segmental; cable; ground anchors

A Baseline Study of a Major Viaduct in Toronto, Canada, for Strategic Planning for the Superstructure Replacement/Rehabilitation of Elevated Structures

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Abstract

The F.G. Gardiner Expressway (Gardiner) is a major transportation artery in the City of Toronto, Ontario, Canada and has an "Elevated" section, a 6 km long viaduct structure of over 500 spans. The City constructed the viaduct in segments between 1955 to 1964, and since then the viaduct has undergone over 100 rehabilitation projects to keep it continuously operating. Recent plans for the "Elevated" section involved a complete realignment and replacement of a 2-km long section at its east end, and a superstructure replacement for the remaining 400 spans as the bulk of the substructure will remain. This has posed questions concerning the disparity of life expectancy and maintenance efforts of the existing substructures, and those of the new superstructure, and the correctness of this method of rehabilitation. This paper is a case study to describe an approach to assess and recommend an overall strategy in addressing this challenging question.

Keywords: Rehabilitation; service life; structural evaluation; substructure; chloride penetration.

Veterans Home Bridge Rehabilitation

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Abstract

Bridge rehabilitation projects are completed to permit current design loads and State legal loads on existing structures. This paper presents a rehabilitation case study of the Veterans Home Bridge, a historic orthotropic steel deck arch structure that was constructed with distinctive aesthetics and in an era that warrants its listing in the National Register of Historic Places (NRHP) as a contributing element to the Minnesota Soldiers' Home Historic District. Following a fracture critical inspection which identified critical deficiencies that required urgent repairs, a load rating analysis was completed for the steel truss, which resulted in a 12 Ton G.V.W. load posting requirement. Because minimum emergency vehicle G.V.W.s exceed this load restriction, the bridge was closed to the public. Multiple repair options were evaluated and a detailed rehabilitation design was completed to facilitate American Association of State Highway Officials (AASHTO) HS-20 Design Truck loading and to meet the aesthetic requirements of the Minnesota State Historic Preservation Office (SHPO).

Keywords: bridge; historic bridge; truss; arch truss; load rating; rehabilitation; repair; structural strengthening; steel design.

Construction of the Terwillegar Park Stressed-Ribbon Footbridge

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Abstract

The recently completed Terwillegar Park Footbridge is a new stressed ribbon bridge located in Edmonton's river valley. The bridge is 262 m in length and is one of the longest stress-ribbon bridges in the world. This bridge type comprises a thin deck, supported on highly stressed bearing strands, and post-tensioned to achieve the necessary stiffness and desired geometric shape.

Associated Engineering, working as an erection engineer for Graham Infrastructure developed methodology to construct this bridge, described in this paper. One innovative accelerated construction method used was the creation of the 'messenger' loop system that facilitated bearing strand and precast panel installation. Furthermore, the construction erection team was required to provide geometric set-out during construction and involved modelling, monitoring and reporting of the bridge during construction.

Keywords: pre-stressing, post-tensioning, cable structure, stressed ribbon, accelerated construction.

Performance assessment of embedded distributed optical fiber sensors in reinforced concrete structures

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Abstract

In this paper, an experiment where distributed optical fiber sensors (DOFS) were implemented in two small concrete beams subjected to a three-point load test is outlined. Here, an optical backscatter reflectometry based DOFS is implemented simultaneously embedded in the concrete (glued to the steel rebar) and attached to the outer surface of the concrete after its hardening. For comparison purposes, three electrical strain gauges are also used in the rebar. The main objectives with this experiment, is to analyze the feasibility of installation of DOFS directly on the rebar element of a reinforced concrete beam and compare the measured strain at rebar and surface of the concrete.

Keywords: distributed optical fiber sensors, structural health monitoring, crack detection, concrete structures.

Distributed Deflection Measurement of Reinforced Concrete Elements Using Fibre Optic Sensors

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Abstract

The construction of new infrastructure required to meet the demands of a growing global population has substantial negative impacts on the environment. Structural engineers can help reduce these negative impacts through efficient material use in reinforced concrete (RC) design, as steel and concrete production accounts for a significant portion of global greenhouse gas emissions. In RC design, stiffness and support condition assumptions often lead to large discrepancies between design models and true behaviour. Critical insight would be captured if the deflected shape of RC beams could be practically measured. A method of measuring the deflected shape of RC beams using distributed fibre optic sensors (FOS) is presented. Six RC beams were tested in three-point bending. The FOS results were evaluated against displacement transducers and were found to capture deflected shapes accurately until loading exceeded 50% of the beams' ultimate capacities.

Keywords: Reinforced concrete; fibre optic sensors; displacement; deflected shape; distributed sensors; concrete cracking; strain.

Distributed Sensing to Assess the Impact of Support Conditions on Slab Behaviour

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Abstract

Support conditions, specifically axial restraint, have a significant impact on the behaviour and load carrying capacity of flexural members such as slabs. However, in conventional design these beneficial effects are ignored since they cannot be accurately quantified. In the current work two reinforced concrete one-way slab specimens were tested in three point bending with and without axial restraint. Each specimen was instrumented with distributed fibre optic strain sensors to assess the impact of the support conditions on the internal strain behaviour. The load deflection data for the two specimens is used to assess the impact of the support conditions on stiffness and capacity. The internal strain data is used to evaluate the degree of support restraint and the impact on the internal stress state for each specimen.

Keywords: slabs; reinforced concrete; arching action; end restraints; fibre optic sensing; digital image correlation.

Distributed fibre optic sensor system to measure the progressive axial shortening of a high-rise building during construction

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Abstract

A novel approach is being used to measure the progressive axial shortening of key structural elements of Principal Tower, a 50-storey reinforced concrete building in London, as it is being built. Distributed fibre optic sensor (DFOS) cables are embedded inside two columns and two core walls, from which the axial strain profile can be measured along the whole height of the constructed elements. Measurements are being taken regularly throughout the construction process, making it possible to observe the change in strain, and thus the axial shortening, within these elements at any stage of the construction. This helps the design engineers and contractor verify the predicted differential shortening and adjust the column height presets if necessary. The purpose of this paper is to describe the monitoring system and to present initial data recorded from the first five levels of the building.

Keywords: axial shortening; high-rise; tall buildings; jumpform; monitoring; distributed fibre optic sensors; Brillouin sensing.

Prestress Loss Monitoring Using Long-Gauge Fiber Optic Sensors

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Abstract

Prestressed concrete is an important building material due to its economy and superior performance compared to reinforced concrete. Given the current attention to infrastructure monitoring and condition assessment, creating methods for monitoring prestressed concrete specifically is increasingly important. Assessment of prestress losses in the field, an important parameter in prestressed concrete, is required in order to ensure safety, and allow designers to better understand the evolution of losses particularly as they pertain to new concrete mixes. This paper presents a method for the monitoring prestress losses using strain measurements collected from sensors embedded in the concrete. The method is applied to measurements from Streicker Bridge, a prestressed concrete bridge on the Princeton University campus. The method shows promising results and can be used for monitoring more complex beam-like structures.

Keywords: prestressed concrete; post-tensioning; structural health monitoring; fiber optic sensors; prestress loss.

Method for Validation of long-term Temperature Measurements from Sensors

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Abstract

Structural Health Monitoring (SHM), which holds promise for quick and reliable assessment of structural condition, requires reliable long-term measurements. While commercially available sensors can provide accurate measurements, none have been tested on longer timescales to ensure stability. This study deals with the creation of a method for the validation of temperature measurements without the use of a redundant monitoring system. Reliability of temperature measurements is particularly important because they are often used for the compensation of other measurements, such as strain. The method is based on comparison of measurements to easily obtainable public data, such as data from meteorological agencies, and is presented through application to measurements from sensors installed on Streicker Bridge in Princeton, NJ. It was successfully used to confirm stability of multiple sensors and detect malfunction of other sensors.

Keywords: structural health monitoring, temperature validation, FBG sensors, long-term monitoring, temperature measurements, measurement drift

The Existing Champlain Bridge - Overview of Issues – The Owner's Perspective

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Abstract

Montreal's Champlain Bridge was the first large scale use of prestressed concrete in Canada. A lack of understanding of corrosive effects from the long term use of de-icing salts has, over the decades, led to severe corrosion of the concrete girders. A poor drainage system and water infiltration through the pre-stressing anchors contributed to accelerating deterioration. A decision to replace the bridge was taken in 2011 only 49 years after its opening.

Today, the most vulnerable girders are instrumented and the owner, The Jacques Cartier and Champlain Bridges Incorporated, has installed steel trusses beneath the exterior concrete girders as a risk management strategy.

Keywords: Pre-stressed concrete; trusses; queen post; corrosion; risk management

The Existing Champlain Bridge – Instrumentation, Monitoring and Load Tests

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Abstract

This paper describes the instrumentation and monitoring of the 50 spans of the Champlain Bridge in Montreal using optical sensors at mid-span for recording flexural strains on the exterior post tensioned girders. These girders were subjected to structural degradation due to corrosion of the strands. Presently over 320 optical sensors are installed on the bridge to record data on a continuous basis at 50Hz. Such data contains invaluable information for monitoring the bridge response and condition after each monthly Load Test. In addition, the daily dynamic traffic loading is analysed to detect any sign of degradation in the post tensioned girders.

Keywords: Bridges, monitoring, instrumentation, load tests, flexural strain, traffic loading, trends.

The Existing Champlain Bridge – Assessment Using Refined Analyses

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Abstract

In order to evaluate the performance of the post-tensioned I-girders and diaphragms in the existing Champlain Bridge, a combination of 3D linear and 2D non-linear finite element analyses were carried out. After 55 years in service, many girders are experiencing deterioration. The results from the 3D analyses enabled the determination of the loads applied to individual girders and diaphragms for the non-linear analyses. The 3D analyses also enabled the determination of the redistribution of forces in the structure due to different degrees of corrosion of the tendons in the girders. The 2D non-linear finite element analyses captured the responses of the girders and diaphragms and enabled an assessment of the performance under service and factored loads. The degrees of corrosion of the tendons and the stirrups were estimated from inspection results. The effects of different strengthening measures were also assessed using this approach.

Keywords: bridge girders; post-tensioning; deterioration; corrosion; evaluation; strengthening; finite element analysis; non-linear analysis.

The Existing Champlain Bridge - Assessment of Structural Deficiencies

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Abstract

The 50 approach spans of the Champlain Bridge each consist of seven precast post-tensioned girders. Deterioration of the PT tendons is observed in the girders at multiple locations, raising concerns about the integrity of the remaining tendons. Due to the uncertainties involved in determining the number of tendons that have become ineffective due to corrosion, multiple inputs are used in a comprehensive assessment program to determine the condition of the girders and establish the load carrying capacity of the Bridge. The assessment allows the corporation managing the bridge to plan rehabilitation and strengthening programs to ensure user safety and that will ensure the structure remains open to traffic. The comprehensive assessment program includes visual inspections, exploratory openings, monthly load tests and daily monitoring. The program represents a proactive and preventative approach using multiple inputs identify critical deficiencies and address them through a comprehensive rehabilitation program.

Keywords: post-tensioning; concrete; girders; corrosion; deterioration; condition assessment; bridge; monitoring

The Existing Champlain Bridge - Strengthening Measures

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Abstract

The superstructure of the 50 approach spans of the Champlain Bridge consists of a highly integrated system with seven deep precast post-tensioned girders, transversely post-tensioned diaphragms and cast-in-place infill deck slabs. Deterioration and signs of corrosion observed in many of the girder PT tendons led the corporation managing the Bridge to initiate a major girder strengthening campaign to ensure user safety and that the structure remains open to traffic. Six strengthening systems were designed to secure all 100 edge girders, each system having a specific rehabilitation purpose and designed to address multiple constraints. For each system, the main principles behind the design, its intended purpose (emergency or permanent repair) as well as the many considerations in developing each system are described.

Keywords: post-tensioning; concrete; girders; corrosion; deterioration; strengthening; rehabilitation; bridge

The Existing Champlain Bridge – Developing a Customized Inspection and Assessment Methodology

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Abstract

A bridge at the end of its lifespan tends to deteriorate at an exponential rate. Given the unique challenges of the Champlain Bridge located in Montréal, a customized inspection program was developed to monitor the condition and behaviour of the bridge approach spans. The cornerstone of this program is a set of customized inspection criteria to assess the degraded superstructure elements and the installed strengthening systems. An Integrated Grading System (IGS) rating the overall performance of a reinforced superstructure element was also developed. The IGS rating is based on an algorithm that feeds on inspection data from each individual component and considers the complexity of the interactions between the original structure and the added strengthening systems. This paper presents an example of the inspection criteria and IGS rating system developed specifically for the approach spans of the Champlain Bridge.

Keywords: corrosion; degradation; inspection criteria; defect; strengthening; integrated grading system; evaluation.

Design of instrumented bearings for direct measure of bridge live loads

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Abstract

A long span steel through truss was scheduled for expansion bearing replacement as part of an overall rehabilitation project. At the time, a Structural Health Monitoring (SHM) system was being designed to investigate how overloaded trucks were affecting the performance of the bridge. Due to the opportunity presented by the bearing replacement project, the concept of instrumenting the new bearings with load cells was accepted by the bridge owner and a formal design was commissioned. A prototype bearing was constructed and evaluated through rigorous testing in a laboratory setting to ensure that the addition of sensors in the load path of the bearings would not compromise the integrity or safety of the bridge. Upon completion of the acceptance testing of the prototype bearing, the full construction of the bearing assemblies and their subsequent installation was started. The paper discusses the various challenges associated with the design, construction, maintenance, and processing/interpretation of the measurements for such a system.

Keywords: Steel, truss, load cell, bearings, structural health monitoring, instrumentation

Extending Building Façade Performance Requirements for Blast: Hazard and Injury Assessment Investigations

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Abstract

Existing criteria for protection of occupants in government owned and/or occupied facilities in the US is largely based on estimates of damage limits for conventional façade structures and materials such as concrete, brick and concrete masonry, and glass. These damage limits are commonly based on extent of damage as a function of lateral deformation or ductility and the extent to which that deformation requires subsequent repairs or allows re-use. This approach works well for new construction where modest strength and mass increases can provide sufficient capacity at minimal cost so as to not exceed deformation limits. For existing buildings and historic facades, the approach can be onerous and inefficient, since retrofits to large sections of the façade may be required.

This paper describes initial efforts to define blast performance requirements for existing buildings in terms of occupant hazard based on injury potential rather than on deformation limits. Existing injury data and simplified façade failure and debris kinematics and analytics are used to relate applied blast load to actual occupant hazards. The approach provides information to building owners and stake holders that can provide much more efficient and cost effective extents for façade retrofits. The retrofits required are also more efficiently localized to lower levels and higher threat locations near the building.

Keywords: Performance Based Design, Natural and Man-made Hazards, Design Criteria, Resilient Infrastructure.

Aerodynamics challenges and solutions for structures of unique architecture

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Abstract

The paper examines aerodynamic characteristics of close and parallel automobile and rail bridge arches. Aeroelastic stability of the bridge arches is investigated in a specialized wind-tunnel. It is found that the automobile bridge span is subject to vortex-induced oscillations. These oscillations are reduced by arrangement of a fairing on the bridge-span stiffening girder. Possibility of a buffet-type aerodynamic instability is examined in detail.

Keywords: aerodynamics of bridges, aeroelastic vibrations, vortex excitation, reducing vibrations.

The Ordsall Chord, Manchester, UK – digital delivery of design

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Abstract

The Ordsall Chord is a new railway link which for the first time connects all five of Manchester's city centre railway stations. It involves extensive and varied structures supporting nearly 700m of track, many of which are highly complex geometrically to satisfy architectural requirements.

The design across all engineering disciplines has been undertaken using extensive state-of-the-art Building Information Modelling (BIM). Federated 3d models produced by all disciplines are integrated in a common data environment, compliant with UK government BIM Level 2 requirements.

The level of detail developed for the civil and structural engineering design is unprecedented for a transport infrastructure project in the north of England, with modelling down to the level of individual reinforcement bars. Software interoperability issues were encountered and resolved.

Early involvement of the main contractor and steel fabrication subcontractor has allowed conventional roles and processes to be challenged. The design models and drawings have been produced on the designer's behalf by the steelwork subcontractor, although the structural designer still owns these deliverables. For one structure, drawings were dispensed with entirely and this structure was built directly from the 3d model, prepared in collaboration between fabricator and designer.

Adoption of these methodologies has supported successful delivery of structures with challenging geometric interfaces between steelwork, concrete, and existing brickwork arches. This has reduced programme and safety risks during fabrication and installation, and will provide a platform for enhanced management of the structural assets in the future.

Keywords: Building information modelling; bridges; steel fabrication; collaboration; reinforced concrete.

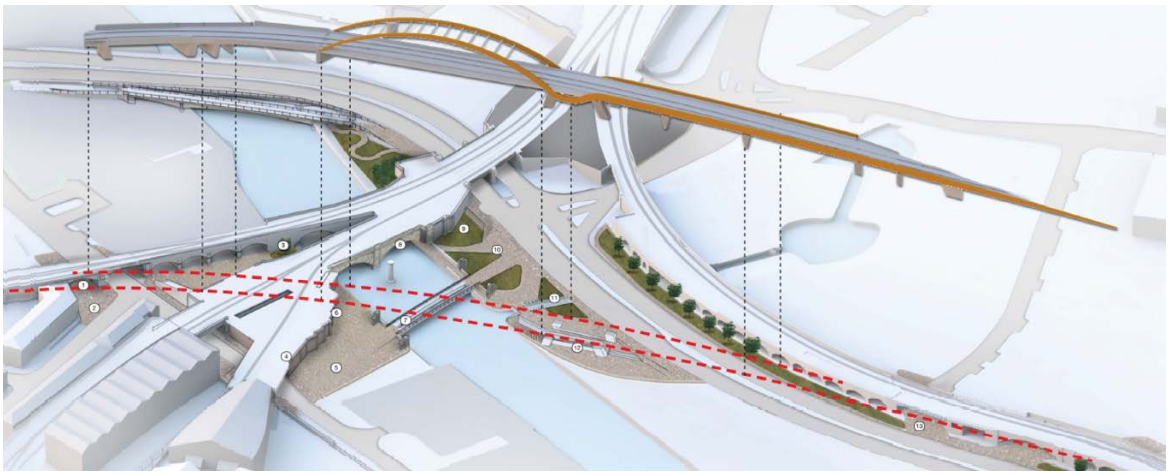

Figure 1: The Ordsall Chord

Flexural Performance of Two-Way Concrete Slabs Reinforced with Carbon Fiber Grid

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Abstract

Fiber-reinforced polymers (FRP) were recently used as a replacing reinforcement in concrete structures in view of their excellent resistance to corrosion, light weight, and high specific strength. A state of art of using carbon fiber grids as an internal reinforcement with self-consolidate concrete in two-way slab systems is presented here. The experimental program included studying the flexural performance of the carbon fiber grid as in comparison with the conversional welded steel wire mesh. This work is expected to find its application in parking garages to enhance the durability performance and extend the service life of the concrete slab members. The load –deflection curves, ultimate loads, energy absorption, and failure mode of simply supported slabs with different aspect ratios are discussed. The test results for simply supported slabs with aspect ratio of (1:1) showed that the FRP grid tended to fall within the criteria of minimum load requirements per ASCE7 as the steel wire reinforcement did. In addition, the slabs observed a limit of deflection (L/360) at approximately 50% of their ultimate loads.

Keywords: CFRP grid; Steel wire; SCC concrete; Flexure; Floor slabs.

Key Techniques for Performance-based design of metro depot covered structure

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Abstract

The challenges of developing superstructures on metro train depots include abrupt changes of structural stiffness, discontinuities of vertical structural elements, out-of-current codes, different architectural types, and different construction sequences. This study analyses design process of superstructures on a metro train depot in Shanghai area. The performance-based seismic design is used to design the key structural components. The laboratory shaking table tests are used to simulate seismic responses of depot and superstructure subject to earthquakes. The theoretical analysis and shaking table simulations show the superstructure and depot deformed elastically in moderate earthquakes and will not fail in strong earthquakes. The main factors affecting development of superstructure above metro train depot are analysed. The paper provides useful insights to similar projects.

Keywords: Metro train depot; superstructure above depot; performance-based design, shaking table tests

The Third Bosporus Bridge - Its longitudinal and transversal behaviour

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Abstract

The Third Bosporus Bridge is a highly rigid suspended bridge with a main span length of 1'408 m and a total length of 2'260 m located at the north of Istanbul near the Black Sea.

The cable system is a combination between stiffening cables (stay system) and classical suspension. The towers are 320 m high. The steel deck, on the main span, is 5.50 m high and 58.50 m wide with 4 road lanes in each direction, 2 railway tracks and 2 sidewalks.

Of course, for such huge spans, the wind loads and seismic hazard are very important, but with the addition of two railway tracks, the effects of the large and combined loads have to be examined in detail.

For railway traffic, it was very important to check that the vertical displacements were limited. But this hybrid suspension induces non negligible longitudinal displacements leading to a large distension of several stay cables. Then, if classically, the support scheme is important in the vertical and transversal directions, for this bridge, the longitudinal direction had also to be examined in detail.

Different solutions have been studied for the transversal and longitudinal supports. Pendular bearings have been chosen for the longitudinal direction. The paper will explain the interest of the different support schemes.

Keywords: Cable Bridge, design, longitudinal behaviour, transversal behaviour.

Derailment of an overhead gantry for the erection of precast concrete girders

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Abstract

This article explores the reasons for the derailment of an overhead gantry during construction of a precast concrete girder viaduct. Inasmuch as the accident occurred on the last out of 13 spans on one of two nominally identical parallel bridges in which no prior anomalies had been detected, a detailed forensic investigation was in order. The parallels among numerical calculations, experimental findings, eyewitness accounts and reconstruction of the accident sequence lent support to the identification of the most likely hazard scenario. The underlying causes were associated with less than optimal interfacing and data exchange among the actors involved in viaduct construction. The study showed that in addition to efficient quality assurance strategies, clearly defining each actor's tasks and responsibilities is of cardinal importance in preventing construction worksite accidents.

Keywords: bridge construction; bridge building equipment; temporary structures; ancillary elements; overhead gantry; precast concrete girders; forensic engineering

Retrofit of concrete Members with CFRP Rod Panels (CRP 195)

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Abstract

Recently, a novel technique comprising small diameter carbon FRP (CFRP) rods arranged in a panel form (known as CRPs) has been developed and deployed. One of the technique's advantages is the segmental construction, achieved by using short-length rod panels made continuous via an overlap (or finger joint). In this study, four-point bending tests were performed to assess the effectiveness of the rod panel system in strengthening RC beams. The rod panel investigated here is called CRP 195 and is fabricated from CFRP rods with diameter of 4 mm (0.16 in.) and spacing between rods of 9.4 mm (0.4 in.). The tests include: a control beam; and three beams strengthened with one of the following reinforcements: continuous CRP 195; overlapped CRP 195; and overlapped CRP 195 anchored at ends with U-shaped FRP fabrics. Results showed that the capacity increase of strengthened specimens as compared to the control beam is as follows: 104% for the continuous CRP 195; 95% for the overlapped CRP 195; and 195% for the overlapped CRP 195 with end anchorage.

Keywords: concrete, rehabilitation, FRP, laminate, Rod panels, four-point bending.

Unique access system engineering innovation leads to important milestone at MLC Centre

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Abstract

Sydney's MLC Centre, an iconic building on the city's skyline was the tallest reinforced concrete structure in Australia when it was built in 1978. The building deteriorated over time and needed a full range of treatments to its façade. To conduct repairs to the 220 m tall octagonal skyscraper, a unique site access method was designed for the project consisting of four (4) fully enclosed climbing work platforms.

When the concrete remedial repair works on one side of the building were completed all four platforms required relocation to the opposite side of the building. Hence, the Monorail relocation solution was developed. The suspended monorail system was designed and installed allowing for the platforms to be rotated on the other side of the building without dismantling.

Keywords: Concrete Remedial works; Temporary steel structures; Temporary works design; high-rise buildings.

Comparative Study between Reversely and Forwardly Constrained Optimal Design Method for Tall building Structure

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Abstract

Optimal design is attracting increasing interest due to the huge energy and material consumption for tall steel structures. The optimization of certain structure is based on primitive design, which is commonly obtained by traditional design process. The design results obtained from the optimization of primitive design is called optimal design. Traditional optimal design method commonly starts with a primitive design which is greatly over constrained. The over constrained primitive design has great design redundancies, and further optimization process will successively reduce the design redundancies until the controlling constraints are properly constrained. There is another optimization process, however, which starts with a primitive design which is under constrained. The under constrained primitive design will be effectively upgraded in successive optimization process using minimum structural material increments until the controlling constraints are properly constrained. The first optimization process, which starts with over constrained primitive design is called forwardly constrained optimal design (FCOD) method. The second optimization process, which starts with under constrained primitive design is called reversely constrained optimal design (RCOD) method. In this paper, the RCOD method is applied to a 10-storys steel frame structure to investigate the superiority of the RCOD method when compared with the FCOD method.

Keywords: primitive design; redundancy; forwardly constrained optimal design; reversely constrained optimal design.

Numerical Evaluation of Moment Live Load Distribution Factors in NEXT D Beam Bridge

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Abstract

NEXT D beam bridges have often been preferred for short and medium span bridges due to ease and speed of construction, and elimination of the intermediate diaphragms. The NEXT D beam is the integral full depth flange that also acts as the structural bridge deck. However, there is a concern about the live load distribution factors (LLDFs) for this type of bridges. There are no design specifications addressed in the current AASHTO Load and Resistance Factor Design (LRFD) Specifications. A conservative approach is suggested by the PCI Northeast Bridge Technical Committee to calculate the live load distribution factors. In this research, a three dimensional (3D) finite element (FE) model was created using ABAQUS software for a 3 m (10 ft) wide single NEXT D beam and verified with manual calculations based on AASHTO LRFD specifications. After verification, the model was applied to a typical bridge, comprised of NEXT D beams, and used to calculate the LLDFs. The results were compared with the LLDFs calculated using AASHTO LRFD and PCI Northeast recommendations. FE model results compared well with the manual calculations, indicating that the model can be used to predict the LLDFs of the NEXT D beam bridge. Furthermore, LLDFs for interior beams are: 0.74 from the FE model, 0.81 from the AASHTO LRFD computations, and 1.04 from the PCI Northeast calculations. While for exterior beams, LLDFs are: 0.79 from the FE model, 1.03 from the AASHTO LRFD computations, and 0.96 from the PCI Northeast calculations.

Keywords: Live load distribution factors; NEXT D beam; Finite element method; AASHTO LRFD; bridge

Northeast Anthony Henday Drive / Yellowhead Trail Interchange Flyover Ramp Bridges

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Abstract

The three level system interchange connecting Northeast Anthony Henday Drive and Yellowhead Trail implement two flyover ramp bridges. To improve construction efficiencies, the contractor team sought implementation of continuous chorded (kinked) girders rather than conventionally curved girders to accommodate the curved ramp geometry. The multi-span structures comprised of kinked straight I-girders, forming horizontally curved alignments, imposed unique design challenges that were not explicitly addressed within the Canadian bridge code. This paper showcases the two flyover bridges; a 315 m long five span bridge with a radius of 340 m and a 415 m long six span bridge with a 347 m radius. Design challenges and considerations encountered during the design and construction are presented.

Keywords: kinked; chorded; segmentally curved; steel I-girders; straddle-bent.

Assessment of efficiency of intensity measures for performance-based travelling fire design

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Abstract

Current fire design methods assume a uniform temperature distribution in building compartments, which is unrealistic for large compartments. In contrast, travelling fire models account for the non-uniform distribution of temperatures in large compartments. However, an adequate fire intensity measure (IM) is important to properly define the severity of the fire, especially within the context of a performance-based design. This paper presents an assessment of IM as related to various engineering demand parameters (EDP) in order to establish the most efficient IM for performance-based travelling fire design. Non-linear analyses were carried out on generalised steel frame models to determine their structural response. Regression analysis was also carried out and it was observed that the length of fire was the most efficient IM in the range of EDPs considered. The results will be useful in the performance-based fire design of steel structures.

Keywords: Travelling fire, intensity measure, engineering demand parameter, performance-based design, length of fire.

Finite Element Analysis of Bearing Plinth in Different Sizes

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Abstract

Bearing plinth is the key to connecting superstructure and substructure of the bridge. Once there's damage, the safety of bridge structures will be in danger. As a result, it is necessary to design rational size of bearing plinth. This paper takes several kinds of common bearing plinth in high speed railway bridges as examples to make nonlinear finite element analysis through ANSYS finite element software. It illustrates in detail the selection of unit and material, the layout of rebar and the contact analysis among bearing and bearing plinth in numerical simulation. Moreover, under the load of various high-speed railways, the stress and deformation of different-size bearing plinths are analyzed and discussed. Expectedly, the result indicates that it is reasonable to simulate the actual stress distribution of bearing plinth by using ANSYS software. It also shows that bearing plinth in different sizes have corresponding distinctions in its stress and deformation, so that the influence of various aspects should be considered in the design of bearing plinth. The research contents and results of this paper can provide reference for the design of the bridge bearing plinth.

Keywords: Bearing plinth; high speed railway bridges; nonlinear finite element analysis.

Deflection estimation of a steel box girder bridge using multi-channel acceleration measurement

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Abstract

The deflection of a bridge is an important physical quantity, which is usually specified in design. The deflection can also be utilized in the estimation of traffic load. However, the measurement is oftentimes not practical. Reference points for displacement sensor are usually not available. While deflection estimation by double-integration of acceleration measurement provides a simple and inexpensive deflection estimation, this approach suffers from large integration errors. In this study, deflection estimation without the integration errors only using accelerometers is proposed. The acceleration signals are used to estimate girder inclination. By combining this inclination and the vertical acceleration through a Kalman filter, the bridge deflection is evaluated. A steel box girder bridge is instrumented with wireless tri-axial accelerometers. The deflection estimated through the Kalman filtering is compared with references.

Keywords: bridge deflection; inclination; acceleration; Kalman filter; field measurement

A Study on Parameter of Steel Strain of Precast Reinforced Concrete with Joint

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Abstract

Currently, the fabricated precast concrete construction is actively applied. It constructs a number of modules to complete the structural member, resulting joint occurs between each module. These connections need to identify its behaviour due to safety and serviceability. However, the prediction accuracy of deflection is not guaranteed. Because of the traditional methods cannot be reflected characteristics of an initial crack of the joint interface and difference of strength of grouting materials. Therefore, a new proposal for deflection evaluation is required to reflect the joint characteristics of precast flexural member. In this study, the mean steel strain characteristics were analysed for three variables; load, concrete compressive strength and rebar ratio. In the result, mean steel strain of rebar is proportional to load and inversely proportional to concrete compressive strength and rebar ratio.

Keywords: precast concrete; prefabricated construct; joint; deflection; mean steel strain; tension stiffening effect; curvature; load; concrete compressive strength; rebar ratio.

Ultimate load of cylindrically curved panels under uniform compression at straight edge and the influence of curvature

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Abstract

Curved panels are widely used in modern novel steel bridges and buildings. Stability shall be considered for these structures under compressive loads. While it still has many challenges on how to consider stability since there are no guidelines in specifications. In this paper, ultimate load of the cylindrically curved panels were studied. First, accuracy of numerical model was verified by theory and model test. Then the influence of curvature on ultimate load at the straight edge of curved panel was studied. Results showed that the deformation of curved panel was obvious in the direction perpendicular to the panel. The position of maximum deformation was located near the central region and perpendicular to the curved panel. Ultimate load of curved panel is smaller than the straight one. And the ultimate load decreases as the curvature increases with a linear relationship between the reduction factor of local stability and the curvature.

Keywords: curved panel; stability; steel pylon of cable-stayed bridge; elasto-plastic buckling; full-scale model test; ultimate load; curvature; reduction factor; empirical formula.

Experience of duplex stainless steels as construction materials in bridges: Results of seven inspections

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Abstract

Duplex stainless steel (DSS) usage in bridge construction has increased significantly in the last twenty years because of the material's exceptional mechanical properties, good corrosion resistance, negligible need of maintenance and thereby low life cycle costs. Three suitable DSS grades used in bridge structures are EN 1.4462, 1.4362 and 1.4162. It is important to choose a DSS grade which is appropriate for the intended service environment, not least because the price of the material generally increases with the corrosion resistance. This work presents the results from various bridge inspections where DSS has been used for the main structure in environments which were retrospectively classified in accordance with EN 1993-1-4 Annex A. The results illustrate successful application of DSS structures and could also be used to provide data for future design standard revision, for example EN 1993-1-4, Annex A, relating to material selection.

Keywords: duplex stainless steel (DSS); corrosion resistance; long term durability; bridge; inspection; EN 1993-1-4.

Hybrid structure for the ArtLab EPFL pavilion

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Abstract

The ArtLab pavilion groups three distinct buildings under one same roof. This project, developed by the Japanese architect Kengo Kuma, winner of the 2012 competition, was built on the EPFL campus, next to the Rolex Learning Center, from 2014 until 2016.

The pavilions, with their unifying roof, create a contrast between traditional slate roofing and contemporary design with their dramatic length and various inclined planes as proposed by the architect. But, this contrast also characterizes the structure: while it is made of simple frames, each of them have a specific geometry which calls for modern construction methods and innovation.

The variable geometries of the frames were generated using a 3D model of the pavilions to guaranty the continuity of the different roof planes. To obtain constant cross-sectional frames, a hybrid structure composed of a wooden frame coupled by two frames made of perforated steel plates was developed. Using non-linear material laws, a numerical model was validated with experimental results of bending tests and then used to design of these hybrid frames.

Finally, the northern roof cantilever was created with a three-dimensional pleated structure made of solid wood. The behaviour of this structure was modelled with shell finite elements and verified on site by monitoring the displacements of the roof during construction.

These pavilions demonstrate that innovation can improve the quality of construction.

Keywords: glued laminated timber, perforated steel plates, hybrid structure, innovation, 3D modelling, experimental study, bending tests, , wooden pavilion

Using game engines in visualizations and simulations of the bridges in the E39 fjord crossings project.

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Abstract

As part of the design, development and planning of the E39 fjord crossing project, the Norwegian Public Roads Administration (NPRA) is looking at the possibility of using game engines for real time rendering and animations of the bridge concepts. The development of the visualization tools in the gaming industry, with the likes of Virtual Reality (VR), Augmented Reality (AR) and more advanced game engines, enables much more detailed models than what has been possible before. The NPRA would like to use these tools as an aid in the design, construction, maintenance and operation of the fjord crossings. By introducing 3D-models of the constructions and the terrain in all stages of the project, the models can be imported and further developed in 3d-modelling programs and game engines used by the game industry in order to create advanced visualizations and simulations. This paper demonstrates how game engines can be used as a tool to incorporate scientific data and analysis and display these data through real time visualizations and simulations. In this case, the horizontal mode of the two TLPs due to wind, current and wave forces.

Keywords: 3D, visualizations, simulations, terrain models, multi-span suspension bridge, texture, modelling, programming.

Explanation: 3d-modelling program and game engines, programs used by the game industry and include programs as 3D Studio Max, Blender, Maya, Unity 3D, Unreal etc.

5th LNG TANK IN ZEEBRUGGE TERMINAL (BELGIUM)

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Abstract

ESTEYCO has been contracted by BALZOLA contractors to provide civil engineering works within the Engineering – Procurement – Construction – Commissioning (EPCC) contract for the 5th LNG Tank in Zeebrugge (Belgium) to FLUXYS.

The project comprises two main structural items.

- The full containment (type H4) high capacity LNG Tank (180,000 m3).
- A cylindrical shell (diaphragm wall) with 102.1 m of inner diameter where LNG tank is enclosed, semi-buried.

Both, the foreseen high capacity and the maximum height limitation due to Belgian Environmental and Visual Impact legislation, lead to define the cylindrical shell where the LNG Tank shall be erected.

Keywords: LNG, Tank, Diaphragm Wall, Aquifer, Boulders, Concrete, Post-tensioning, Belgium.

Conceptual Design of Salmon River Replacement Bridge

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Abstract

Replacing an existing narrow two-lane truss bridge constructed in 1954 with a wider modern day girder bridge while keeping the existing roadway alignment and maintaining two lanes of traffic throughout the construction period presents some interesting challenges. The Salmon River Bridge is a 180' (54.9 m) long single span steel Pratt truss structure located approximately 27 km north of the City of Prince George on Highway 97. McElhanney reviewed a number of conceptual bridge replacement designs including single span and multi-span configurations utilizing steel and/or concrete structures and reviewed existing, upstream and downstream road alignments. After considering environmental impacts, constructability, detour requirements and the need for under bridge walkways it was decided to design and construct a new 66.5 m long single span bridge on the existing roadway alignment utilizing steel girders and a concrete to-grade deck.

Keywords: replacement; bridge; I-girders; steel; concrete; deck; piles; abutments; detour

Pendulum-type bearings / seismic isolators – solutions and case studies

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Abstract

Pendulum-type bearings, or curved surface sliders, have much to offer in bridge construction, particularly as a means of seismic isolation in earthquake-prone areas, but also, for example, in supporting the decks of bridges that are designed for heavy railway loading. A number of variations of this type of bearing have been developed – with non-spherical sliding surfaces, for example, or multiple sliding / rotation interfaces. The features and benefits of these different types are described, with reference to illustrative case studies.

Keywords: Bearings; pendulum isolators; curved surface sliders.

Opening effect on punching shear strength of RC slabs

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Abstract

Punching shear failure can happen in reinforced concrete flat slabs due to the development of high shear stresses in the slab-column connection area. These shear stresses are increased when openings are created, since the presence of openings reduce the concrete area that sustains the shear stresses. In this paper, finite element analysis (FEA) with the damaged plasticity model for concrete in ABAQUS is performed to simulate the opening effect in reinforced concrete slabs without shear reinforcement. A previously tested and analyzed interior slab-column connections is considered. The effect of the location and the size of the opening on the punching shear resistance are investigated. The punching shear capacity of the analyzed specimens is calculated using the equations of two current design provisions for punching shear (ACI 318-14, Eurocode2-2004) and compared with the numerical results. A probabilistic analysis using Monte Carlo simulation for both design codes is considered. Finally, fragility analysis is performed in order to estimate the probability of the estimated punching shear resistance related with the opening size and distance.

Keywords: opening effect; concrete slabs; punching shear; crack pattern; finite element analysis; design codes; Monte Carlo simulation; Fragility analysis.

A Critical Take on Eurocode 2 Concerning the Assessment of Shear Capacity of Reinforced and Prestressed Concrete

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Abstract

Most of the infrastructure in Europe dates back to the midst of the 20th century. In recent years it became more and more important to conserve and revamp this existing network of traffic roads and bridges to meet the actual and future requirements of the society. With the introduction of the DIN 1045-1 in 2001 and the actual generation of the Eurocodes in 2012-2013 the re-evaluation of existing structures, i.e. especially bridges, became more difficult when using these technical rules as a base. In many cases the new calculations resulted in a significant smaller load-bearing capacity than the constructions were designed for back in the day. In particular, re-evaluations of the shear capacity of these structures show big discrepancies between the amount of steel that is needed depending on the old regulations or the new Eurocodes. These discrepancies are shown by typical examples and possible ways to handle the results will be discussed. By looking at advanced shear models and non-linear finite element calculations possible further developments of the shear-limit-state formulation are suggested.

Keywords: Eurocode 2; shear; existing structures; advanced shear models

Punching/Shear Strength of a Full-scale Tested Bridge Deck Slab

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Abstract

For reinforced concrete (RC) slabs without shear reinforcement, shear and punching can be the governing failure mode at ultimate limit state if subjected to large concentrated loads. Punching of RC slabs without shear reinforcement has been a challenging problem in assessment based on current standards. To examine a previously developed enhanced analysis approach, this study was conducted by applying continuum FE analyses to a 55-year old RC bridge deck slab subjected to concentrated loads near the main girder in a field failure test. The influence of parameters such as boundary conditions, location of concentrated loads and shear force distribution were investigated.

Keywords: Shear and punching of RC slabs, Bridges, FE analysis, full-scale bridge test

Punching shear behaviour of edge column connections in continuous flat slabs

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Abstract

This paper deals with the behaviour of reinforced concrete flat slabs around their connections to edge columns. Using a non-linear finite element model with shell elements and simple assumptions regarding flexural and shear response, this study investigates the magnitude of unbalanced moments transferred between the slab and the column as well as the distribution of shear forces in the slab around the connection. The influence of distribution of reinforcement between hogging (around the columns) and sagging (in the mid-span) areas as well as in the directions parallel and perpendicular to the slab edge are analysed. The behaviour of continuous slabs is compared to that of typical test specimens. It is shown that the distribution of shear stresses in test specimens may be significantly less uniform which can lead to lower punching capacities in the tests than in actual continuous slabs.

Keywords: Reinforced concrete; slabs; punching shear; edge columns; non-axisymmetric conditions; non-linear finite element analysis.

Comparison of Shear Design Provisions Used in Various Approaches

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Abstract

As multiple one-way shear design provisions for structural concrete members appeared in the recent decades and have been adopted by various design codes, it is important to assess how the design would be influenced by these approaches. A few approaches were selected from the most widely used national code provisions and other relationships proposed by researchers. This paper overviewed the mechanisms of shear resistance considered in each approach, and a thorough review and summarization was made. The application of the three principles of shear design in each approach is discussed. The factors affect the concrete and the steel contributions in each approach are compared. And the influence of prestressing force on shear resistance is also studied.

Keywords: shear design provisions; design database; shear resistance; mechanisms; concrete contribution; shear reinforcement

Discrete modeling of reinforced and prestressed concrete beams under shear loads

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Abstract

Conventional finite element software and associated numerical models are usually used to analyze the mechanical behavior of structural scale concrete beams. However, they lack the ability of accounting for concrete heterogeneity or including concrete aging and deterioration effects. This paper introduces the advanced techniques to model the behavior of reinforced and prestressed concrete beams under shear loads utilizing a discrete particle model incorporating effects from creep, shrinkage and prestress loss. Five-meter long concrete beams with full reinforcement and different prestress levels were tested under shear loads. Material tests of the concrete, including unconfined compression, uniaxial tests to measure modulus of elasticity, and splitting tests, were carried out on the day of shear testing. Concrete creep and shrinkage measurements were also conducted to study their effect on prestress loss and consequently shear response. The model constructs the beam with concrete as discrete particles and the steel rebars/tendons as beam elements. The concrete behavior is defined by constitutive laws with its material properties calibrated based on standard experimental tests. The behavior of reinforced rebars and prestressing tendons follow the elasto-plastic law of typical steel with known Young's modulus and yielding strength. The rebar beam elements and solid concrete elements interact with each other using penalty constraints. Before the shear load is applied, creep and shrinkage losses of concrete are evaluated, of which the parameters were calibrated based on the experimental measurements. The results of the predictive shear simulations for the reinforced and prestressed beams resemble those of the tested specimens including but not limited to the force-displacement curves, the failure types, and the crack patterns. These analysis-and-modeling techniques hold great significance to innovations in structures.

Keywords: prestressed concrete; reinforced concrete; discrete modeling; shear; creep; shrinkage; prestress loss.

Effectiveness of FRCM System in Strengthening Reinforced Masonry Walls Subjected to Cyclic Loading

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Abstract

Much of the research on the strengthening of masonry structures has focused on strengthening of *unreinforced* masonry structures; as a result, most strengthening design guidelines are limited to this type of structural strengthening. In addition, only a limited experimental database of reinforced masonry structures with strengthening is available. The main purpose of this research is to study the behavior of fully grouted reinforced masonry walls strengthened with Fiber Reinforced Cementitious Matrix (FRCM) system under out-of-plane action. Seven reinforced masonry walls strengthened in flexure using (FRCM) were built as a part of this study. Two reinforced walls constructed in running and stack bond pattern were investigated as control specimens and the other specimens were strengthened using different types of fibers. FRCM strengthening composite materials consisted of one or two plies of fabric embedded in cementitious mortar. The test results indicated that the FRCM system is a very effective technique for upgrading flexural capacity of masonry walls and improve the behavior of stack wall.

Keywords: Strengthening, FRCM, reinforced masonry, cyclic load.

Shaking Table Test Using Scaled Model of Reinforced Concrete Column Considering Time Variation from Similitude Conditions

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Abstract

In a scaled model test of RC column, mortar and micro concrete are broadly used as model concrete whose material characteristics are different to that of ordinary concrete for prototype. In this case strain ratio which denotes scale factor of strain becomes not unity, and this is so called strain distortion. Furthermore, from nonlinear material characteristics of concrete, the strain ratio becomes not constant but variable during model tests.

In similitude law, strain ratio is related to scale factor of time. It indicates that time of input ground acceleration used for model tests should be different to that used for prototype tests when variation of strain ratio is occurred. However, many researches on dynamic test using RC model have not considered this similitude requirements and this can cause errors in predictions for responses of prototype.

In this study, shaking table tests using RC scaled model considering the strain distortion and the variation of strain ratio were conducted. Predicting the variation of strain ratio by a developed analytical procedure, input ground acceleration of model was modified by following the similitude requirements. Test results shows that accuracy of prediction for response of prototype is significantly improved when using the modified input ground acceleration.

Keywords: similitude law, scaled model test, strain ratio, RC column, shaking table test.

Role of the Floor System in the Cyclic Response of Steel Gravity Framing

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Abstract

In typical U.S. design practice for steel buildings, lateral loads are assumed to be resisted by a small number of lateral-force-resisting frames, while the rest of the structure consists of gravity framing, typically assumed to have no flexural resistance. It has long been recognized that the simple shear connections used in gravity framing do possess some flexural strength. However, there is little experimental data on the cyclic loading response of these connections. This paper details ongoing experimental research into the response of such connections. Full scale cruciform composite beam-column subassemblies were tested under large cyclic inter-story drifts. These tests have shown that simple shear connections can develop significant moments under large drifts, largely due to the formation of large tensile forces in the floor system. Given the large number of shear connections in most structures, this capacity could significantly enhance the seismic resistance of a structure.

Keywords: seismic behaviour; composite connections; steel buildings; cyclic loads;

Analysis on Fabricated Concrete Frame with Replaceable Energy Dissipation Connectors

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Abstract

A new type of fabricated concrete frame with replaceable energy dissipation connectors (REDC-FCF) is presented in this paper. The replaceable energy dissipation connector (REDC) is a kind of damping member, which is installed under the concrete cover instead of the ordinary rebars in the top and bottom of the beam end. The structural type and construction method of the REDC-FCF is introduced. The seismic performance of the REDC-FCF and the ordinary reinforced concrete frame (RCF) are analyzed and compared by the time history analysis, and the seismic responses between the two structures are contrasted. The results indicate that the inter-story displacement of the structure is basically consistence with that of the ordinary reinforced concrete frame (RCF) under moderate and rarely met earthquakes. A stable hysteretic property is seen in the REDC members, which indicates that the REDC can be effectively applied in seismic resistance. The analysis results indicate that this kind of structure could be used in high seismic zones.

Keywords: Replaceable Energy Dissipation Connector; Fabricated Concrete Frame; Seismic Performance; Seismic Rehabilitation

Improving seismic performance of the non-structural light steel framing systems using sliding bolted connections

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Abstract

Non-structural façade systems are very sensitive to damage because the shake intensities that cause damage in these systems are much lower than those for structural components. A proper detailing and configuration of the connections between non-structural system and primary structure can be crucial to reach a good global behaviour of the both non-structural components and structural system.

At the present study structural systems of a high rise building and non-structural facade are completely being isolated by means of proposed friction-slip mechanism/connections. The sliding bolted connection is placed between exterior light steel framing façade and primary structure such that sliding occurs parallel to the lateral load resisting movement plane. The effectiveness of the proposed connection in responding lateral force demand is evaluated by a series of finite element (FE) study on moment resisting frames equipped with the friction-slip connection.

The FE study results exhibit that the sliding bolted joint is able to carry inelastic deformation higher than maximum inter story movement of the special moment frames.

The numerical results exhibited that the large portion of plastic deformation is dissipated by the connection while the entire CFS members remain elastic. As a consequence, this type of connection can be very ductile and performs in a very desirable manner. The comparison of results indicated that depending on the section geometry, the inelastic bending capacity of CFS beams with slip-critical connection can improved and reach M_p.

KeyWords: Non-structural facade, Slip-friction connections, Inter story drift, Lateral resisting system, Light steel framing system

Seismic Performance of Columns with Grouted Couplers in Idaho Bridges

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Abstract

Accelerated Bridge Construction (ABC) methods have been limited in moderate-to-high seismic regions because of concerns about the performance of connections. A study was carried out for the Idaho Transportation Department (ITD) on the seismic performance of precast columns with grouted couplers versus the conventional cast-in-place columns. Experimental data provided the necessary input to model the grouted couplers. Using the OpenSees finite element analysis program, selected bridges were subjected to the seismic conditions of the most seismically active location in Idaho. The stresses in both the longitudinal reinforcing bars and the grouted coupler regions are found to be well within acceptable ranges. The largest column drift, using a combination of orthogonal displacements, is about 1.6 percent. Furthermore, grouted couplers may be used to connect precast columns to footings or cap beams for columns with less than 4 percent drift.

Keywords: bridge, column, cast-in-place, precast, grouted couplers, seismic response.

Development, testing and construction of the hybrid FRP composite – concrete road bridge

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Abstract

Fibre reinforced polymer (FRP) composites have become an integral part of the construction industry because of their versatility, high strength-to-weight ratio, enhanced durability, resistance to fatigue and corrosion, accelerated construction and lower maintenance and life-cycle costs. However, all-composite structural bridge systems have specific shortcomings such as high initial costs, low stiffness and the existence of brittle failure modes. To make the best use of materials and to overcome the above shortcomings, combinations of FRP and conventional materials have recently been investigated. The innovative hybrid idea of a "FRP composite – concrete" structural system for bridges is proposed. The objective of this paper is the description of the new bridge system itself and the presentation of research results related to its development, as well as a demonstrative bridge construction.

Keywords: FRP composites; bridge; hybrid structure; FEM analysis; testing; construction.

Durable design of a 42m full FRP footbridge for Bergen, Norway.

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Abstract

A tender design was prepared for a bridge at Paradis, Bergen, Norway. It is a full Fiber Reinforced Polymer (FRP) structure. The material and detailing have been optimised for the application in the Norwegian wet and cold climate. With its free span of 42m, this bridge is one of the longest spans for bridges in full FRP worldwide. In close cooperation with the Client, Statens vegvesen, a design for a pedestrian bridge was prepared by the team consisting of architects and engineers of RoyalHaskoningDHV. Statens vegvesen requires a low maintenance solution to minimise life cycle costs and hindrance for traffic on road and rail. The choice for FRP was made to prevent durability issues due to thermal fatigue and salting in winter times. This paper presents the interaction of design, material and manufacturing process. It describes the results of the structural analysis and highlights the principle of the solutions for reliable and easy to assemble connections.

Keywords: Glass Fiber Reinforced Polymer (GFRP), bridge, low maintenance, design, lightweight engineering, structural analyses.

FRP composite bridges provide optimal solutions in urban areas

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Abstract

The city of Rotterdam has fully embraced Fibre Reinforced Polymers (FRP), otherwise known as composites, as building material and uses it extensively for city wide bridge replacements. Over ninety bridge have been realised. FRP has reduced the costs of ownership for asset managers and significantly improved on building nuisance. As a front runner with the application of composites Rotterdam has gained valuable experience on how to deal with a new upcoming market and a material which has not yet earned its place among conventional building materials.

Keywords: composites; fibre reinforced polymers; bridges; new materials; lightweight structures

Member Stiffness for Frame Analysis of GFRP Reinforced Concrete Structures

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Abstract

The ACI 318 Building Code provides flexural EI stiffness values for elastic analysis of steel reinforced concrete buildings, with a moment of inertia I equal to $0.7I_g$ for columns, $0.35I_g$ for beams, and $0.25I_g$ for flat slabs at factored loads ($1.0I_g$ for columns, $0.5I_g$ for beams, and $0.35I_g$ for flat slabs at service loads). This paper recommends design values of the moment of inertia for analysis of glass fibre reinforced polymer (GFRP) reinforced concrete members based on current ACI 440 design requirements. Results at the factored load level suggest using a value of I equal to $0.4I_g$ for columns and $0.15I_g$ for beams and slabs. At the service load level, recommended values are increased by 50 percent to give $0.6I_g$ for columns and $0.225I_g$ for beams and slabs.

Keywords: analysis; beams; columns; moment of inertia; slabs; stiffness; FRP reinforcement.

Bracing of large GFRP frames with very slender GFRP panels

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Abstract

Glass fibre reinforced polymers (GFRP) were developed in the first half of the 20th century. They have high strength (especially for tensile stresses), low density, high resistance in corrosive environments, and free formability. Despite these advantages, GFRP materials are not widely used in construction yet. The main reasons are low stiffness of GFRP (relative to its strength) and the absence of codified and generally accepted design standards. Structural engineers typically have limited knowledge and experience with these materials. In this study, an approach to design slender GRFP bracing panels with methods similar to those used for plated steel girders is developed and compared to results of full-size shear tests.

Keywords: Composites, Lightweight Structures, Plate Buckling, Panel-Braced Frame

Static and dynamic performance of an orthotropic-deck pultruded fibre-reinforced polymer footbridge

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Abstract

Pultruded glass fibre reinforced polymer (GFRP) is a strong, light, and durable material that is very well suited to modular structural forms. The replacement of aged and deteriorated small footbridges is an ideal use for such structures. However, GFRP has low stiffness; this and the typical low mass of GFRP structures, mean that they can be susceptible to human-induced vibration. Further, the vibration design rules for footbridges have evolved over the years from experience with steel and concrete structural forms. Consequently there is a need to investigate the suitability of GFRP footbridges and the applicability of current design rules. A team at Monash University has recently constructed a 9 m long orthotropic deck pultruded bonded GFRP footbridge to investigate these issues. Extensive material testing and full-scale structure testing has been carried out to establish the overall structural behaviour accurately. This paper explains the design and construction of the footbridge, and reports the results of the static performance assessments. Bond performance, shear lag, and deck-beam composite action are all examined under uniform load and four-point bending tests. This paper also reports the results of extensive experimental modal testing and numerical modelling of the structure. Further, a novel sequence of human walking trials has been performed to assess the vibration performance under real loading conditions. The modelling of human-induced vibration and the response of the structure is also considered in this work. The results will assist in developing improved guidelines for the design and construction of such structures.

Keywords: pultruded fibre-reinforced polymer; FRP; footbridge; vibration; human

Designing with big DATA – Design, Analysis and Fabrication of a Complex Geometry Grid Shell

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Abstract

This paper will examine the impact of big Data on structural engineering design. With continuing advancements that liberate the geometrical form, as well as the increasing structural efficiency created by digital fabrication, structural engineers are dealing with unprecedented amount of data related to both geometry and analysis.

Taking as a case study the work done on Jewel, a 12,500m^2 grid shell at Changi Airport in Singapore, we will examine strategies and opportunities for new ways of working with the large amount of data generated by this project.

Project Jewel at Changi Airport includes a triangulated gridshell roof describing an ovoid shape with a dramatic central opening. This will be one of the largest gridshells ever built and is a significant engineering and construction endeavour.

The paper will explore the challenges with regard to:

Geometry – the strength of a shell structure is directly related to its form. Parametric generation and dynamic relaxation of the shape allowed for the geometrical rationalization of this form in the face of design drivers that included, architectural constraints, fabrication limitation on glass, drainage and ponding, and airport radar concerns.

Element and nodal discretization – As a steel gridshell, the location and size of the steel elements will have a direct impact on the strength of the shell structure. Additionally the connection of these elements gives rise to nodal "families" that can be grouped to facilitate fabrication. We will explore the studies and parameters that were used to find optimal solutions to these problems.

Keywords: Geometry, Grid Shell, Steel, Complex Forms, Dynamic Relaxation, Form Finding, Node Construction, Glass, Airport

Methodology for selection of production method in an early stage - improved conceptual design process.

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Abstract

The design of buildings and load carrying structures in early stages is a challenging task for a number of reasons; scant information generally exists and several different requirements involving building structures should be managed, including technical, environmental and financial requirements. However, this phase of the design process is important and will fundamentally influence the following construction phase, as well as the entire life of building structures. It is particularly important that the construction phase is properly considered already in the design phase and that the production method selected is suitable for the design of building structures. The purpose of this research has been to improve the design process in the conceptual phase. The findings will highlight the benefits of design for production in bridge engineering. The aim has been to identify examples of practices and work methodologies that are of good caliber in the Swedish bridge construction sector. Early findings show that there exists a divergence between research findings and current practices. The research community has presented several participatory methodologies for the design process, such as Early Contractor Involvement (ECI) and Integrated Project Delivery (IPD) for the potential of improving effectiveness in bridge engineering. However, studies of current practices in industry show that these methodologies are difficult to implement and that there are hidden consequences. The processes developed should manage several requirements simultaneously, including technical, environmental, health and safety, and financial. Competencies involved include Structural Engineering, Architecture and Production Management, in addition to expertise in health and safety, materials science, environmental impact and procurement. Further, the intention is for the processes to deal with verification methods for the proposed conceptual solutions and risk analyses based on quality assurance. Both new and existing building structures should be considered.

Keywords: Early Contractor Involvement, Integrated Design Process, Integrated Project Delivery, Form of Remuneration, Public Infrastructure Projects, Bridge Design

The imminent Future of Parametric Nodes

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Abstract

Complex geometries are undeniable nowadays, according to the enormous progress in parametric software. Giving a close look to the complex geometries; one can easily define the most critical points of any geometry, which are the connecting nodes. These represent a challenge for any project, based on the flow of geometry mesh; each connecting node could have a completely different form.

Accordingly integrating additive manufacturing to the process of facade manufacturing will have prosperous results. Additive manufacturing is a growing trend based on what it could offer. Some claim that Additive manufacturing has severe limitations to be applied in facade industry. On the other hand, the question should be; how should facade engineers/manufacturers expand their horizons so they could get into the process and start to trust and utilize.

The author claims that what is missing is the tool that can be utilized during the planning phase of any project. The absence of the tool that can solve the intersecting points/nodes of any project leads to certain repetitive workload.

The tool from the author point of view is defined as the parametric node, which could adapt to any geometrical condition. The first idea was to design a parametric node that could be manufactured traditionally. The idea achieved a success reaching the point that "parametric node" is conceivable. The challenge showed up in the kernel of the node as it could only adapt to clear geometrical forms, which presented a mind shifting strategy starting to look at Additive manufacturing and topology optimization to ease the developing process of the node.

The effect of connection type (Bolted – Welded) had been done to check the effect on the topology optimization process – as a factor of cost reduction - and Material testing for 3d printed steel specimens is in progress.

Keywords: Parametric, Nodes, Mesh, Skin, Additive manufacturing, Topology Optimization, Digital fabrication.

Long term deflections of Paudèze Bridges

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Abstract

The Paudèze bridges are two parallel bridges, each with a total length of around 400 m and a maximal span of 104 m. They were built using the balanced cantilever method between 1971 and 1974. After construction, a continuous increase in the deck deflections was observed. Since 1988, mid-span deck deflections of one of the two bridges are monitored using a hydrostatic levelling system. The continuous increase in deflections of the deck was measured from 14 years to 36 years of age of the bridge. In 2010, the deflections were reduced and stabilized by placing additional prestressing cables inside the box girder.

In preparation for the rehabilitation project planned for 2017, material properties were measured, crack patterns were recorded and the remaining prestressing forces were measured in some cables.

A detailed analysis was carried on the bridge which had been monitored using the finite element method. The purpose of this analysis is to understand the bridge behaviour so that the impact of the rehabilitation project can be analysed and optimized. Two different models were built: a viscoelastic beam model and a non-linear shell model using the fictitious crack model for concrete with a plasticity based formulation.

These finite element models and the comparison with the measured values allow the following conclusions. First, it is shown that the viscoelastic beam model and the non-linear shell model allowed approaching the instant deflections of the bridge. Second, it is shown that the non-linear shell model could reproduce the cracking pattern observed in the bottom slab of the box girder. Third, it is shown that the prestressing losses are higher than usually assumed. Finally, it is demonstrated that long-term deflections of the bridge deck could not be reproduced by the viscoelastic beam model. This is due to the available creep models according to which deflections and strains stabilize after 20 years. However, the measured deflections in the bridges continuously increased for 36 years. This clearly shows that the creep models given in codes are not adequate for predicting deflections of balanced cantilever bridges.

Keywords: balanced cantilever bridge, long term deflection, crack pattern, creep model, prestressing losses.

Analytical Study Assessment of a Bridge with Pretensioned Rocking Columns for Rapid Construction

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Abstract

A two-span, quarter-scale, precast concrete bridge with pretensioned rocking columns was tested on the shaking tables at the University of Nevada, Reno in 2014. The columns were designed with partially unbonded strands to provide re-centering; locally debonded reinforcing steel to delay bar fracture; and confining steel tubes at their ends to protect the concrete against spalling. The residual drift ratios in the bridge were never larger than 0.4%, even after peak drift ratios more than 12%. The only major damage observed during testing was the fracture of the deformed bar reinforcement, first occurring at a drift ratio of 5.7%. To investigate methods to delay bar fracture in this bridge, analytical models were developed and calibrated using the experimental results. These models suggest that low-cycle fatigue likely caused reinforcement fracture in the tests and fracture could be delayed by using a longer debonded length of the reinforcement.

Keywords: bridges; rapid construction; shake-table; pre-tensioned concrete; connection; precast concrete; seismic; low cycle fatigue; analytical modelling; rocking structures

Smartcoco Research Project

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Abstract

The SMARTCOCO research project was developed to fill gaps in knowledge and provide design guidance for specific types of composite steel concrete structural elements used in high rise or heavily loaded structures. Those composite elements belong to structures defined as "hybrid" because they are neither reinforced concrete structures covered by Eurocode 2, nor composite steel concrete structures covered by Eurocode 4. A generic design approach based on the logics of composite sections and of reinforced concrete sections, like equivalent sections and struts and ties mechanisms, was first developed and used to design test specimens. These ones were tested in physical and/or numerical experimentations. The results were used to calibrate or correct the initial proposal for design. The output is written as a design guide which intends to complement Eurocode 2 and 4.

Keywords: steel profile, composite, hybrid, encased section, embedded section, columns, walls.

Composite Beams of Steel and Timber

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Abstract

Composite steel-concrete buildings are commonplace, but they are incompatible with low-carbon construction technologies. This is because the manufacture of the cement used in the flooring slabs, which is cast *in-situ* around headed stud connectors, is associated with the production significant CO_2 emissions, and deconstruction of such a building is environmentally intrusive with little possibility of re-use of the structural elements. The use of engineered timber in lieu of cast *in-situ* concrete is proposed, connected to a bolted steel frame by shear connectors. A series of short-term tests are reported on composite steel-timber beams, and it is shown that the shear connection is robust and associated with ductile and predictable modes of failure. Numerical modelling of the beams, verified and validated against the results of the tests, is also undertaken and used for a parametric study that demonstrates the potential of this innovative use of steel and timber in composite construction.

Keywords: bending test, composite, CLT, ductility, numerical analysis, steel-timber beam.

Structural Performance of Modern Timber Bridges In Japan

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Abstract

Author has experimented actual modern timber bridges used glulam timber to investigate structural rigidity and static and dynamic characteristic on structural performance over about 24 years, and then has been evaluated structural performance of modern timber bridges based on field test data accumulated and three dimensional static and eigenvalue analyses. This study is investigated structural characteristics measured by field test immediately after the complation to modern 23modern timber bridges, and then evaluated actual structural performance for those bridges based on the static and dynamic characteristics such as static deflection static rigidity, natural frequency, damping coefficient, dynamic increment factor (impact factor), vibration serviceability and so on. As the results, the actual condition of modern timber bridges became clear that static flexural rigidity was bigger than the rigidity in the design, and that fundamental vertical natural frequency was almost equivalent to general highway bridges as steel and concrete bridges.

Keywords: modern timber bridge; structural performance; field test; structural analysis.

Robustness of Multi-Storey Timber Buildings

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Abstract

This paper investigates the probability of disproportionate collapse for a nine-storey mass-timber building designed for gravity and lateral loads. This is a static analysis which accounts for both geometric and material nonlinearities. Considering 32 different scenarios, the proposed building is subjected to removal of ground floor columns, one or two at a time, to compute the reliability index. As limit state functions, the results take into account the residual capacity of the building, in terms of bending moment resistance and shear stress within Cross-laminated timber panels, as well as the resulting deformations. Results indicate that failure is dictated by the imposed deflections rather than the capacity of the timber elements. The investigation shows that the proposed building does not have sufficient robustness to redistribute the load to the undamaged part of the building after the considered removal scenarios.

Keywords: Disproportionate Collapse; Progressive Collapse; Flat-Plates System; Extreme Events; Mid-Rise Timber Buildings; Structural Integrity.

Innovative Solutions for Mid-rise Residential Passive House Wood Structure

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Abstract

The SFU Passivhaus is a proposed residential project that will target Passive House certification. It comprises two mid-rise wood frame buildings, one of which is located on top of a concrete parkade. Key challenges include the mitigation of vertical shrinkage effects for the wood structure, and the need for a super-insulated envelope around each of the residential structures. A number of innovative solutions are being considered, including the use of engineered wood components to reduce the anticipated shrinkage, detailing of components to accommodate vertical movement, and a base isolation concept that helps maintain the continuity of the thermal envelope at the interface with the concrete parkade. At this time, the project is still in design development phase, so the solutions are only presented and discussed at a preliminary concept level, without significant numerical data or analysis.

Keywords: mid-rise wood building; passive house; wood frame; wood shrinkage; engineered wood; base isolation

Comparison of CLT Design Methods to Composite Beam Theory

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Abstract

Cross-laminated timber (CLT) is increasingly being used as a primary structural material. Since about 60-70% of structural material is associated with the floor system, sustainability gains are efficiently realized by use of CLT floor plates. Most floors can be modelled as 1-way slabs and idealized via beam theory; however, increasingly complicated composite beam and plate theories are being proposed for CLT design. This research compares methods from the US CLT Handbook to a composite beam design equation derived from elasticity theory. All deflection and stress results are compared to a benchmarked finite element model. Results show that CLT Handbook methods provide stresses and deflections within 5% of the FEA and composite beam theory. However, results indicate the shear analogy method over-estimates required laminate thickness for 4.6m span by up to 30% for deflection-governed design compared to the composite beam theory.

Keywords: Cross-laminated timber, composite, beam theory, elasticity, wood design, rolling shear

Development of a Two-way Column-supported Flat Plate in Cross Laminated Timber

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Abstract

Chicago Horizon is a pavilion for the 2015 Chicago Architecture Biennial that is composed of a flat roof made entirely out of Cross-Laminated Timber (CLT). The application of two-way column-supported flat plate in timber (for both the gravity system and as part of the lateral-load-resisting system) is possibly unique to this structure. This paper details the analysis, design, detailing and fabrication of the structure relating each to the translation of the flat plate structural type to CLT. This paper highlights: the comparison between two conceptual options for flat plate realization; the application of fasteners at 45 degrees to provide shear reinforcement of CLT locally; and the use of the laminated timber columns moment connected to the CLT flat plate to form the pavilion's lateral-load-resisting. This unique application was developed through a close collaboration between the authors (architects, engineers and fabricators) and is the development of a new structural type in mass timber.

Keywords: mass timber; cross laminated timber; flat plate timber; timber moment frames

Wind Response of the New Varodd Bridge Balanced Cantilever

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Abstract

The New Varodd Bridge is a 655m concrete girder bridge with four main spans with a maximum length of 260m. The bridge will be located in a very narrow position between the existing Varodd suspension bridge on the southern side and the existing Varodd girder bridge on the northern side. The new bridge will be constructed as a balanced cantilever with a connection to the existing girder bridge that connects the bridges in transverse displacements but not in vertical displacements. During this phase the bridge is very sensitive to wind effects. An additional complication lies in the proximity of the existing bridges which highly impact the flow around the new structure. This paper addresses the coverage of these aspects, through a combination of wind response calculations in both frequency domain and time domain, as well as wind tunnel tests performed on a 1:160 scale aeroelastic model of the balanced cantilever.

Keywords: Structural dynamics; wind engineering; frequency and time domain response calculations; wind tunnel testing; balanced cantilever; concrete bridge.

Ambient Vibration Testing of the Hawkshaw Bridge

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Abstract

This paper presents the ambient vibration tests that were conducted on the Hawkshaw Bridge, a three-span cable-stayed bridge located in New Brunswick, Canada. Tri-axial wireless sensors were installed on the bridge girders to capture the bridge acceleration due to the normal traffic condition. Challenges that were faced during the tests and the post-processing of the data are discussed in this paper. The natural vibration frequencies were extracted using Operational Modal Analysis. The vibration frequencies were compared with the finite element analysis results of the original designed bridge and the discrepancies were discussed.

Keywords: ambient vibration testing; cable-stayed bridge; operational modal analysis; finite element method; full-scale bridge testing

Vibration Testing of Scaled Cable-Stayed Bridges

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Abstract

In this article, the development of a 1/75 dynamic small-scale model of the Hawkshaw Bridge and its modal identification are presented. The results are also compared with the vibration tests performed on the prototype structure. The Hawkshaw Bridge is a cable-stayed bridge in New Brunswick. The scaled model is 4.4 metres long compared to the actual length of 332 metres. The scale model was designed to stay within the elastic limits under the performed tests. Similitude laws were strictly followed to develop a structural model that complies with the dynamic similitude requirements. Random vibration sources were introduced to the scaled structure to simulate operational dynamic loads that the prototype structure experience. The response of the model was recorded using five tri-axial accelerometers. Using operational modal analysis, modal properties of the scaled model are estimated. The results were used to correlate the field vibration test data to the laboratory experiments.

Keywords: scale model; similitude theory; cable-stayed bridge; vibration testing; modal analysis

Transverse Acceleration causing damage in a masonry arch bridge

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Abstract

A change in the form and type of traffic utilizing masonry arch bridges has been reported in the literature to cause an unexplained level of transverse damage in the bridges, even when the vehicle loading is within the accepted limits. Of the three most probable causes for this problem, the issue of transverse acceleration on the bridge is investigated here. Acceleration response on the bridge can be measured using standard 3 axis accelerometers with ambient vibration providing the minor test loads and vehicle loads providing the major test loads. A method is developed for testing the masonry arch bridges for detecting damage caused by transverse acceleration specific in the bridge and an example from measurements of masonry arch bridges in the UK is used to demonstrate the problem and solution.

Keywords: masonry arch bridges, accelerometer.

Flutter derivatives identification on a very large scale aeroelastic deck model

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Abstract

A large scale aeroelastic model of the Third Bosporus bridge deck was designed and built to measure the aeroelastic response under different incoming flow conditions and to validate numerical models for the buffeting response of Super-long Span Bridge. The 8 m long model, with a deck chord of 1.17m, can reproduce the multi-modal dynamic response of the deck in a range of reduced velocities V*=V/(fB) between 1 and 10. The model is intended to overcome the limitations on aerodynamic similarity of traditional small scale aeroelastic models (typically 1:200 – 1:400), for validation of numerical codes to study the aeroelastic and buffeting response of long span bridges. The model allows to contemporary measure the dynamic response and the aerodynamic forces acting on the deck using 2 instrumented sections equipped with pressure taps. In the present paper, a procedure to measure the flutter derivatives coefficients of the deck, at different reduced velocities, on the large scale aeroelastic model, using forced motion tests, is presented. The research is aimed at investigating the feasibility to measure the aerodynamic properties of the deck directly on the large scale aeroelastic model presenting aeroelastic coupling among vertical and torsional modes. These results will be used in the validation procedure of numerical codes relying on the aerodynamic coefficient data set coming from the rigid model.

Keywords: wind tunnel testing; large scale aeroelastic model; steady coefficients; flutter derivatives.

Changing Bridge Aerodynamics under Nonstationary Winds

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Abstract

The nonstationary features of winds during tropical cyclones and non-synoptic events have been recently observed and analysed. However, the significance of nonstationarity in the consideration of wind load effects has not been extensively investigated yet. The effects of nonstationarity on bridge aerodynamics could be discussed from both linear and nonlinear viewpoints. For linear aerodynamics change, the conventional 1-D indicial response function could be extended to a 2-D case since an additional time scale is introduced in the wind-structure interaction system due to the time-varying transient nonstationarity. Buffeting response of a bridge deck based on the time-domain linear analysis framework associated with 2-D and 1-D indicial response functions, representing non-synoptic winds and corresponding synoptic equivalents, should be carried out. For nonlinear aerodynamics change, the modification of effective angle of attack (resulting from a combination of the structural motions and approaching low-frequency turbulence) due to the time-varying mean wind speed and its contribution to wind-induced nonlinear effects on buffeting needs to be comprehensively examined. In this study, the effects of nonstationarity on the bridge aerodynamics have been investigated based on a semi-empirical linear, hybrid and generalized hybrid models, where the significant contribution of the time-varying mean wind speed to the effective angle of attack and hence to the nonlinear bridge buffeting response is highlighted. The results demonstrated the important effects of the transient nature on the nonstationary wind-induced structural response. This study could facilitate more appropriate design of flexible structures considering non-synoptic or tropical-cyclone wind loads.

Keywords: Nonstationary; nonlinear; bridge aerodynamics; buffeting.

Fatigue Damage Assessment of Stay Cables for Light Rail Transit Bridges

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Abstract

The use of cable stayed structures for long span bridges gained popularity in the late 20th century with the development of advanced construction materials and equipment, and advancement of sophisticated structural design and modelling capabilities. There are many light rail transit (LRT) cable-stayed bridges in use today. Due to the repetitive cycling loading from passage of similar trains, the potential risk of fatigue-induced damage to stay cables is significantly higher for LRT bridges than roadway bridges. As LRT bridges carry heavier trains and provide increased levels of service, the fatigue induced damage to stay cables and its impact on the remaining service life has been frequently raised by transit authorities. This paper presents a recent study completed on assessing fatigue induced damage to stay cable for a LRT bridge including numerical analysis, processing of historic and future train data, and field investigation of the bridge's response.

Keywords: cables; concrete; bridges; fatigue; assessment / repair; dynamic effects / vibrations.

Fatigue inspection for orthotropic steel deck with infrared thermography

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Abstract

An efficient inspection method for detecting fatigue cracks on orthotropic steel decks was developed. The bead-penetrating crack between a deck plate and trough rib can be detected remotely with high degree of accuracy by this method. This method is called “temperature gap method”, since the fatigue crack is identified by detecting the temperature gap at the crack with an infrared thermography. The inspection with this method is done in a systematic manner with priority of the bridges set from the data of cumulative traffic volume of large vehicles. The infrared camera system and the crack detection system were also developed for the efficient inspection. This paper is to report on the inspection for orthotropic steel decks with the infrared thermography.

Keywords: infrared thermography, orthotropic steel deck, fatigue, inspection method

Fatigue Performance Evaluation of Severely Corroded Steel Strands

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Abstract

Recently, one of the external tendons in Jung-reung-cheon Bridge in Seoul was failed after 17 years of service due to severe corrosion in strands. As a part of the in-depth investigation, fatigue tests for the corroded strands were conducted to check the structural safety and serviceability of the defected tendons. Nine corroded strand specimens were collected from the replaced tendons. All corroded strands demonstrated very poor fatigue performance. All the specimens could not satisfy the minimum requirement of two million cycles at the stress range of 190 MPa recommended by Eurocode. Section loss in each specimen was measured at the fractured section and found that there is little correlation between section loss and fatigue life. It may be little fatigue life remaining once corrosion occurred in strands.

Keywords: fatigue; corrosion; external tendon; strand; durability; section loss; post-tensioning.

A Critical Fatigue Crack in a Long-Span Truss Bridge; Cause Investigation and Measures

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Abstract

This paper presents a report on a critical fatigue crack in a long-span truss bridge and a series of measures from cause investigation to preventive retrofit for the damage. The severe damage occurred and propagated due to a fatigue crack at the bottom of a diagonal member of the bridge. The findings obtained by the web-based long-term monitoring reveals that the member being mainly investigated and the other several diagonal members have excited in two wind velocity ranges. Wind directions of both the case are approximately perpendicular to the bridge axis. Componential analysis of vibration suggests that in-plane vibrations are vortex-induced and vibration out-of-plane is buffeting due to strong wind. The vibration induced by the strong wind was the main cause of the crack. Based on the findings, a preventive measure has been taken to suppress wind-induced vibration by changing the dynamic characteristic of diagonal members.

Keywords: fatigue damage; wind-induced vibration; truss bridge; long-term monitoring

Optimal Design and Fatigue Performances of Innovative Corrugated Orthotropic Steel Deck Plate-RPC Layer Composite Deck Structure

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Abstract

Fatigue problem of orthotropic steel deck posed great challenges to the sustainable development of bridges all over the world. Improving mechanical performance, increasing local rigidity, and decreasing stress concentration at the fatigue-prone details were the foundation to solve fatigue problem. Developing innovative composite deck structure was one of the promising solutions. An innovative composite deck structure was investigated, which composed of corrugated orthotropic steel deck plate, reactive powder concrete (RPC) layer and stud shear connectors. To explore the mechanical performance of the composite deck structure under different parameter combinations, an optimal design method was presented based on the BP (Back Propagation) artificial neural network. And a multi-object design optimal model was established to achieve the optimal structure design. The fatigue performance of the presented deck system under the typical fatigue vehicle load was analyzed by finite-element model. The fatigue stress amplitudes of the fatigue-prone details of the steel deck were decreased obviously. The results indicate that the presented optimal design method is feasible in determining the optimal structure design. The controlling fatigue-prone detail of steel structure is the cross weld between the corrugated deck plate and diaphragm. The innovative composite deck structure possesses excellent mechanical properties and fatigue performance.

Keywords: composite bridge deck; orthotropic steel deck; reactive powder concrete (RPC); optimal design; fatigue performance.

Fretting Fatigue Analysis of Bridge Stay Cables at Saddle Supports using Multiaxial Stress-Based Approaches

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Abstract

Saddle systems have been used in recent projects to support the cables in cable-stayed and extradosed bridge structures. With this approach, the cable is anchored to the bridge deck on one side of the pylon, extended over a "saddle" within the pylon, and then fixed on the other end to the deck on the opposite side. A major design consideration for this type of anchorage system, where several significant gaps in the current state-of-knowledge have recently been identified, is the in-service fretting fatigue behaviour of the cables within the pylon saddle. In order to begin to address these knowledge gaps, a research project was recently undertaken at Technische Universität Berlin, wherein analytical tools for understanding and calculating the displacements and contact forces were developed, fatigue tests were performed on large-scale test specimens of cables draped over a round saddle, and fretting fatigue analysis was performed using various models, including several employing multiaxial stress-based approaches. In this paper, these fatigue models are described, and the input parameters required for their application are discussed. Predictions made using the described models are then presented. The paper concludes by identifying the future work needed to further develop this modelling approach, so that it may serve as a useful tool for tasks such as: optimizing design parameters including the saddle radius and contact surface material, and developing improved, reliability-based design guidelines, which will enable the safe and economic design of this connection type, while at the same time reducing the number of large-scale proof tests required at the design stage by the current standards.

Keywords: cable-stayed; extradosed; bridges; saddle supports; fretting fatigue, multiaxial stress

The New Champlain Bridge Corridor Project – Needs, Owner Objectives and Delivery Method Used for a World Class Project

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Abstract

A rapidly deteriorating condition of the existing Champlain Bridge in Montreal, led the Government of Canada to accelerate its replacement and ultimately award a $3.98 billion CDN contract to Signature on the Saint Lawrence Group to deliver a new replacement crossing.

Entailing a 3.4 km long structure over the St. Lawrence River with some 193,000 m^2 of new deck construction, the works represent one of the largest infrastructure projects currently underway in North America and will produce Canada's biggest bridge.

The first of six related papers submitted to this symposium, this paper explains the need for an accelerated schedule, describes the delivery method used, summarizes the imposed requirements to ensure delivery of a highly durable structure (125-year design life) and key architectural features of the bridge required to endow Montreal with an elegant world class transportation infrastructure.

Keywords: cable-stayed; bridge; Champlain; durability; deterioration; PPP; delivery; architectural; light-rail.

The New Champlain Bridge – Performance and Design Criteria

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Abstract

The New Champlain Bridge, designated as a life-line structure, is one of the highest profile infrastructure projects in North America due to its critical economic importance, the premature deterioration of the existing structure, and its visibility throughout the metropolitan area.

The new bridge is comprised of three bridges: a 529 m Signature Span comprised of a asymmetric Cable-Stayed Bridge with a main span of 240 m; a 762 m East Approach with a maximum span of 109 m; and 2044 m West Approach with a typical span of 80.4 m.

This paper discusses the performance and design criteria used in the design of the bridge, including those defined in the Project Agreement (PA) and the various site-specific investigations and hazard assessments.

Keywords: cable-stayed; bridge; Champlain; wind hazard; aerodynamic; wind tunnel; seismic hazard; vessel collision; ice loading; durability.

Design of the Cable-Stayed Bridge Signature Span of the New Champlain Bridge

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Abstract

The cable-stayed bridge for the New Champlain Bridge Project (the "Project") is the signature crossing. The asymmetrical structure features a 124 m back span and a 240 m main span. The 170 m high single-pylon consists of a tuning-fork configuration of twin masts. Inclined concrete tower legs and "W" shaped steel pier caps supporting the deck define the unique aesthetics of this bridge.

The focus of this paper is to provide a detailed description of the bridge including a discussion of the superstructure, main span tower, supporting piers and cable-stay system. It also describes the erection techniques used. Working alongside the Contractor, the design team made innovative use of pre-casting, modular segments, and non-traditional erection sequencing to meet the Project's fast-track schedule of only 42 months, while overcoming the severe winters in Montréal.

Keywords: cable-stayed; bridge; Champlain; main span tower, stay cables, pier bents, superstructure, pier caps, erection.

The New Champlain Bridge: Technical Challenges in Design of the Approach Viaducts

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Abstract

The New Champlain Bridge is an iconic structure, being delivered on an extremely fast tracked schedule. Add to that numerous limitations on construction activities arising from the sensitive river environment, difficult climatic conditions, and concerns over existing regional infrastructure. Finally, throw in strict visual quality requirements to achieve a pre-published architectural concept. This paper discusses how the above conditions guided decision making and design concepts for the approach structures and specific design challenges encountered while meeting the expectations of the constructor, concessionaire and the Authority.

Keywords: Champlain, bridge, precast, concrete, segmental, box-girder, modular, winter, durability, fast-track.

Highway Approaches of the New Champlain Bridge Corridor

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Abstract

The New Champlain Bridge project corridor extends over a length of approximately 8.5 km.

The highway approaches of the bridge corridor include the reconstruction of two major interchanges in Montreal and the widening and reconstructing of both Highways 15 and 10 over 4.5-kilometers in highly urbanized neighbourhoods within Montreal and its suburbs. Highways are equipped with aesthetically pleasing retaining walls, EPS walls as well as noise barriers to satisfy the needs of the community. Furthermore, the construction of a new 470-metre bridge connecting Montreal Island to Ile des Sœurs (Nuns' Island) represents one of the highlights of the highway approach corridor structures.

Both cyclists and pedestrians will be able to safely travel over the project corridor on a multiple-use path and stop at one of the many belvederes to gain an exceptional view of the city.

Durability is also a key design consideration, with a 125-year design life set as design criteria.

Keywords: Champlain; highway interchanges; aesthetically; noise barriers; retaining walls; nun's island bridge; multiple use path; durability.

Innovative Means and Methods for the New Champlain Bridge

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Abstract

Signature on the Saint Lawrence Construction (SSLC), a consortium comprised of SNC-Lavalin inc., Flatiron Constructors Canada, Dragados USA and EBC, is mandated to build the New Champlain Bridge Corridor Project (NCBCP). Significant challenges include:

1) Construction schedule: The Bridge must be in service by December 2018.
2) Navigation restrictions: The Seaway traffic must be maintained during the main span's construction.

This paper discusses the following innovative construction methods used for the New Champlain Bridge (NCB):

i) A custom-built gantry to install the precast footings/pier starters in the river;
ii) The delivery system for the segments to the tip of the deck in the main span.

These erection systems were developed and selected to suit the specific challenges of the project, including speed of construction, maintenance of shipping and environmental protection areas.

Keywords: Champlain, heavy-lifting, precast, footing, survey, cable-stayed, gantry, Seaway, erection.

Shear Strengthening of Pile Cap Girders Using Carbon Fiber Reinforced Polymer (CFRP) Strips

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Abstract

Five large-scale reinforced concrete (RC) pile cap girders were tested to investigate the feasibility of strengthening wide-webbed RC members in shear using Carbon Fiber Reinforced Polymer (CFRP) strips that wrapped around the girder and U-wrap strips with CFRP anchors. CFRP strips were applied to uncracked and pre-cracked 813 mm deep by 813 mm wide pile cap girders to determine the shear performance of strengthened members. The test results indicated that the CFRP anchors developed the fracture strength of the CFRP strips even though some anchors were placed in tension zones. The CFRP shear strengthening improved the shear capacity of the pile cap girders by as much as 56%. Strengthening uncracked and pre-cracked specimens resulted in comparable peak shear capacities. However, the pre-existing shear crack caused the average CFRP fracture strain to be lower than in the uncracked girder.

Keywords: carbon fiber reinforced polymer (CFRP); CFRP anchors; shear strengthening; reinforced concrete (RC); shear performance.

Numerical simulation of long-term creep tests on prestressed beams

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Abstract

The deformations of concrete elements can increase significantly over time as a result of creep and shrinkage. Different material models, which have been calibrated on large datasets, are available in literature in order to predict this time-dependent behaviour. A cross-sectional calculation tool which employs the age-adjusted effective modulus has been developed to verify the accuracy of six models with respect to creep data available for 24 prestressed beams. These prestressed beams with a span of 8 m were loaded up until 4.5 years in a four point bending configuration. This paper reports on the comparison between the measured and calculated compression strains and deflections. It was observed that the mid-span deflection of the prestressed beams at the end of loading is best prescribed by the model B3 and the Gardner Lockmann 2000 model.

Keywords: prestressed beams; time-dependent deformations; creep models; large-scale test

Assessment of the shear strength of existing post-tensioned bridges

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Abstract

The assessment of existing structures is becoming more and more important in the field of activity of a structural engineer. To get more information about the load-carrying behaviour of shear critical bridge structures an experimental campaign on large-scale post-tensioned specimen was carried out. With the aid of DIC it was possible to measure the crack kinematics of the critical shear crack during the whole test. Thus, an evaluation of different shear-transfer actions were performed. Based on these results a shear design concept – including different shear models – for post-tensioned bridge girders with a very low amount of transverse reinforcement was proposed. The approach was used to evaluate the shear strength of a real existing post-tensioned bridge. Based on the suggested concept a cost-extensive strengthening of the webs were prevented.

Keywords: Assessment, shear strength, bridges, post-tensioning, experiments.

Experimental and Numerical Investigations on the Shear Capacity of Existing Prestressed Concrete Bridges

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Abstract

Systematic re-analyses of prestressed concrete bridges in Germany show, that only some 5% can fulfil all requirements given by current design standards whereas more than 60% of the bridges exhibit relevant or severe deficits. Hereby, the majority of the deficiencies are related to insufficient shear capacity. In order to more realistically assess the actual shear capacity, several research projects have been launched comprising numerical and theoretical investigations as well as extensive experimental testing. The present paper will firstly illustrate typical deficiencies of existing concrete bridges and will then discuss current research activities on the shear capacity. In doing so, experiments using an innovative laboratory setup will be described allowing a realistic testing of concrete beams at a reduced length utilizing the substructure technique. Finally, full-scale experiments on a prestressed 7-span continuous road bridge will be presented and discussed.

Keywords: Existing concrete bridges; assessment of bearing capacity; re-analysis; shear capacity; numerical modelling; experimental testing; full-scale experiments.

Adaptive Prestressed Structures realized by utilization of Artificial Intelligence Techniques

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Abstract

Safety, economy and aesthetics are principal criteria for structural design. Involved contradictions between rising design demands and increasing influences provoke new challenges in the field of engineering and therefor innovative strategies and construction techniques. The conventional passive design principle of prestressed concrete is significantly improved by equipping the structure with appropriate control processes. Adaptive Prestressing is characterized by an active self-adjustment of the construction featuring various potentials. Benefits are verified by previous projects covering self-adjusting prestressed structures. A new implementation approach is based on application of AI-techniques like Fuzzy Logic, expert knowledge and machine learning. By means of experiments on two different prototypes the developed system's applicability is verified and potential of Adaptive Prestressing is emphasized.

Keywords: Adaptive Prestressing; self-optimization; Fuzzy control; adaptive control; structural optimization; artificial intelligence; machine learning; adaptive structures.

Seismic collapse safety of RC circular bridge pier retrofitted with fibre reinforced polymer

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Abstract

In recent years, the use of fibre reinforced polymer (FRP) composites sheets used to enhance the lateral confinement for improved ductility and strength of reinforced concrete (RC) bridge piers. The collapses of bridge structures in past and recent seismic events have raised concerns regarding the adequacy of lateral confinement of existing bridges to prevent the partial or total collapse. This research deals the seismic collapse safety of existing RC bridge piers retrofitted with FRP and compares with existing old RC bridge piers designed without consideration of seismic design guidelines. The collapse safety performance of FRP retrofitted RC bridge pier was evaluated using 20 different ground motions to compare the performance of FRP retrofitting system. Using incremental dynamic time history analysis, the collapse risk of the FRP retrofitted bridge piers was evaluated considering uncertainties in ground motion characteristic and structural modelling. The outcome of the research will provide an estimate of the dynamic capacity of the FRP retrofitted bridge piers and demonstrate the effectiveness of FRP-retrofitting technique as an external reinforcement.

Keywords: fiber reinforced polymer; bridge piers; base shear; displacement; stiffness; confinement ratio; nonlinear analyses

Research on the dynamic properties of piled structures using the neural networks and the support vector machines

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Abstract

A simplified method is proposed to analyse the dynamic properties of piled structures. Superstructures are modelled as generalized single degree of freedom systems using the virtual displacement principle, and the impedance functions of pile groups are solved based on the thin-layer method. Six dimensionless parameters are selected to characterize the soil-pile-structure systems and extensive parametric analyses are performed. A mathematical model for the seismic analysis of soil-pile-structure system is built in the neural network based on the outcomes of parametric analyses. The data of the analyses are divided into three different parts which are used for training, testing and validating of the artificial neural network(ANN) model. In order to validate the accuracy of ANN model, another analysis technique of the support vector machine is used. The outcomes show that the model can predict the dynamic properties of the soil-pile-structure system with good accuracy and less time which contribute to solve the dynamic characteristics of piled structures without performing complex analysis.

Keywords: soil-pile-structure interaction, dynamic property, artificial neural network, support vector machine

Botín Art Center in Santander, Spain

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Abstract

Botín Art Center is a remarkable work of Engineering and Architecture design in the north of Spain, in the beautiful front seaside of Santander bay.

This multipurpose building, signed by Renzo Piano, will be open to the public in 2017.

The building is a real challenge from a structural point of view. Minimizing the number of supports on the ground floor and flying over the sea, the structure is designed in order to accommodate all the architectural requirements.

Botín Art Center is composed by two building with a common underground basement and elevated footbridge connections. The West Building is conceived as a Gallery Exhibition Center with external dimensions of 80,0m*30,0m. The East Building is a multipurpose building of 48,0m*27,5m, with Educational areas and a Auditorium for conferences or music concerts.

Keywords: Botín Art Center, singular structure, slenderness, steel trusses, Santander, Renzo Piano, Architecturally Exposed Structural Steel (AESS), Fundación Botín.

Calgary Airport Trail Tunnel Temperature Monitoring

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Abstract

The Calgary Airport Trail Tunnel (CATT) is a 620-m-long roadway tunnel constructed under the Calgary International Airport's (YYC's) new parallel runway and three associated taxiways owned by The City of Calgary (The City) on land leased from YYC. The CATT was designed according to the Canadian Highway Bridge Design Code (CHBDC). The question arose during the design stage if the tunnel, which is a buried structure, would be subjected to the same temperature effects (range and gradient) given in CHBDC for bridges. To investigate this question for future designs, a system of wireless sensors was installed in the CATT to monitor temperatures with data being collected remotely. The paper includes an overall explanation of the CATT's design, temperature monitoring instrumentation, and initial findings, including comparisons with temperatures recorded outside the tunnel, and the temperature range and differential provided by the CHBDC.

Keywords: Tunnel; temperature; monitoring; wireless sensors; reinforced concrete.

A Unique Approach to Rejuvenating a High Rise Building with Deteriorating Precast Cladding

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Abstract

Extending the life of aging buildings and reinvigorating the appearance to reposition assets is very valuable to building owners. This is a sustainable approach to preserve property, keep it in good working condition, not only on the exterior, but also the interior of the building. This becomes more challenging for high rise buildings with high occupancy. The average age of downtown core high rises in metropolitan North American cities is reaching or exceeding 50 years, where major intervention on the building façade is likely required to extend its service life. The subject of this paper is a 50 year old high rise building with exterior precast concrete cladding on a concrete frame structure.

In 2013, WSP was retained to perform a condition assessment of the precast cladding of the subject building. Following an extensive study, option analysis for the precast cladding ranged from restoration as a minimum, to the extreme case of over-cladding or re-cladding. The latter options were intended to renew the façade and minimize maintenance and repair of the existing cladding. A significant concern for the client in addition to life-cycle costs was the impact on building operation and occupants.

After careful considerations, over-cladding was selected as the preferred option. For the precast panels, this required stabilization and introduction of an external structural steel framing directly attached to the building structural frame using specialty anchoring systems. The system supported not only the existing precast, but also the new metal and glass cladding. The intent of the new structural support was to make the existing precast connections to the structure redundant.

A practical design was developed to accommodate constructability and the likely variables anticipated during construction while working on building exterior and minimizing impact on occupants. Preplanning, and developing detail variations, simplified the design solution and made them more economical. The subject project is under construction and is expected to be completed in early Fall 2018.

Given the age and type of construction of many buildings built over 40+ years ago, this is anticipated to be a relatively common issue for building owners in the future. This paper will offer a unique engineering solution addressing the challenges with renewing these building stocks.

Keywords: grout anchor; precast; cladding; concrete; curtain wall; high-rise building.

Design and Construction of a Lagoon Bank Protection Structure with Precast Counterfort Wall System

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Abstract

A precast counterfort wall system developed for bank protection structure for a large lagoon and waterfront development in Nusajaya, in the state of Johor of Malaysia is presented. The 5.25m high vertical earth retaining walls with 4.05m submerged depth below sea water level and 4500m total length of irregular layout were to be completed within 12 months together with massive cut-and-fill earthworks. Conventional in-situ reinforced concrete construction has been ruled out due to time and cost factors, and uncertainty in finished quality. A structurally efficient precast section with sloping "Tee" stiffener integrated with wall and base in manageable size was conceptualised, designed and developed with special considerations to aspect of construction. The economically viable solution adopted was a retaining wall system made of precast counterfort wall unit, strengthened with precast tie-slab and in-situ toe-beam, and finished with in-situ capping beam. Some 82.7% of concreting works were precast off-site, enabling site clearing and preparation works to commence simultaneously. The challenges of product design, manufacturing and installation are highlighted.

Keywords: precast concrete retaining wall; counterfort wall; lagoon bank protection.

Structural Widening of 2-Span Continuous Prestressed Concrete Bridge: Structural and Seismic Implications

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Abstract

Widening of existing bridge structures to accommodate a capacity upgrade on roads each side are becoming more frequent for bridges that are still relatively young. Such widening must consider the interaction of new and existing structures during and after construction and the overall seismic performance and associated issues when an updated seismic code has to be applied. Here, the widening of the existing 208 Street Overpass across Highway #1 in Langley, British Columbia is presented explaining the evaluation and assessment techniques used to determine the constraints, design risks, seismic performance and the subsequent development of novel structural systems, innovative construction methods and advances in seismic design to complete the new structural design and seismic retrofit of the existing bridge.

Keywords: Superstructure widening; seismic retrofit; post-tensioning; shear walls; pile caps; strut-and-tie.

A Novel Methodology for Optimum Seismic Performance-based Design of Friction Energy Dissipation Devices

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Abstract

Friction-based supplemental devices have been extensively used for seismic strengthening of existing substandard structures, however, the conventional use of these dampers may not necessarily lead to an optimum structural performance. Conventionally designed friction dampers usually follow a uniform height-wise distribution pattern of slip load values mainly for simplicity of implementation. This can lead to localizing structural damage in certain storey levels, while the other storeys accommodate lower relative displacement demands. In this study, a practical performance-based optimisation methodology is developed to tackle with structural damage localization of RC frame buildings with friction energy dissipation devices under severe earthquakes. The proposed optimisation is aiming at redistributing the slip loads of the friction wall dampers so as a uniform height-wise distribution of inter-storey drifts is achieved. The efficacy of the method is evaluated through the optimum design of five different low to high-rise RC frames equipped with friction wall dampers under six real spebctrum-compatible design earthquakes. The effects of different design parameters including number of storeys, convergence factor and design seismic excitations are also evaluated on the efficiency of the adopted optimisation approach. The results indicate that compared to the conventional design, using the suggested methodology to design friction wall systems can result in up to 40% reduction of maximum inter-storey drift and considerably more uniform height-wise distribution of relative displacement demands under the design earthquakes.

Keywords: Friction damper; Non-linear optimisation; Seismic performance; Slip load distribution; Structural damage.

Numerical Study of the Seismic Behaviour of Variable Friction Base Isolation Systems

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Abstract

Variable Friction Systems (VFS) have been recently proposed as alternatives to traditional friction devices. VFS come with an extra design "degree of freedom", in the form of coexisting multiple friction coefficients across the sliding surface, so that the properties of the base isolators can be adjusted to achieve enhanced seismic performance. In particular, the principal benefit of VFS is their capacity of dissipating a larger amount of energy with respect to their constant-friction counterparts, reducing the displacement demand on the system, and the lateral forces and accelerations transmitted to the isolated structure.

This paper presents the results of more than 450,000 non-linear time history analyses, illustrating key differences in the response of VFS as a function of the systems' properties and showing that generic VFS can be capable of high seismic performance.

Keywords: Base Isolation; Friction Pendulum; Variable Friction; Time History; Single Degree.

Seismic isolation of La Meynard Hospital, Martinique

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Abstract

The new technical support center of La Meynard hospital is meant to be operational just after an earthquake. This lead to design an isolation system. Rubber bearings have been used together with viscous dampers, which enable to decrease the building acceleration from 12.6 m/s² down to 1.6 m/s². A non-linear time history analysis of a simplified model was used to pre-design the isolation and damping system. The detailed calculations, was done by the company NECS on a 3D finite elements model of the structure, which took into account isolators and dampers. This analysis enabled to improve the design, particularly concerning the dampers orientation. The devices were manufactured by Freyssinet and tested according to NF EN 15129 standard. The installation of the devices was performed at the beginning of the construction. Works lasted forty four months from March 2013 to November 2016.

Keywords: Hospital; seismic isolation; NF EN 15129; finite elements; time history analysis.

Seismic Protection of the Eskişehir City Hospital in Turkey

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Abstract

The Eskişehir City Hospital with four main building blocks is located 250 km south east of Istanbul in a rather highly seismic zone of Turkey with up to 0,6 g PGA. To avoid any fatalities or damages to the structure and enable absolute continued functionality even after the MCE event, it was decided to apply seismic isolation with pendulum isolators.

This paper will show the design considerations to limit the base shear within the isolated building blocks for the MCE event down to less than 0.13 W (W = seismic weight = Dead Load + 0.3 Live Load) on isolator top level and max. 0.2 W on the upper floor building levels of the structure and the realization with suitable seismic pendulum isolators.

For these low shear level requirements the isolator performance was adjusted to 3.5 s effective period and 26 % damping.

Keywords: Isolation; earthquake protection; low base shear; no damages; pendulum isolator.

Shaking Table Test on a Super Long-span Cable-stayed Bridge Subjected to Spatially Varying Ground Motions

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Abstract

A 1/70 scaled model of a trial designed super long-span cable-stayed bridge with a central span of 1,400 m, including group piles foundation and site soil modelled by utilizing laminar shear box, was designed, constructed and tested using a multiple shaking tables array system at Tongji University. The influences of different traveling wave velocity on the seismic response of the scale model with different structural systems, such as floating structural system, elastically constrained structural system and energy dissipation supporting pier structural system, were investigated under spatially varying ground excitations with considering traveling wave effects in the longitudinal direction. And the influence mechanism of input wavers with various traveling wave velocity on the seismic response of different structural systems are further clarified under non-uniform excitations in the longitudinal direction. The experimental results show that pile-soil-structure interaction (PSSI) has significant effect on the seismic responses of the towers and piers for three structural systems under non-uniform excitations; the seismic responses of different structural systems of the cable-stayed bridge scaled model is sensitive to the traveling wave velocity of earthquake waves, which suggests that traveling wave effects should be considered in the seismic design of the super long span cable-stayed bridges. This kind of shaking table test can help to improve understanding on dynamic performance, and is very useful for seismic design and analysis for a super long span cable-stayed bridges excited spatially varying earthquakes, especially for a super long span cable-stayed bridges considering with PSSI.

Keywords: Super-long cable-stayed bridge; shaking table test; traveling wave effects; structural system; pile-soil-structure interaction; laminar shear box.

Seismic Retrofit of the McIlraith Bridge

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Abstract

The McIlraith Bridge is a 202 m long six-span variable depth steel plate girder structure located in Ottawa, Ontario, with in-span joints in each girder at the second span from each end separating the structure into three segments. The seismic evaluation and retrofit design was completed to the newly adopted CSA S6-14 and based on the Seismic Performance Category of the structure, Performance Based Design was required. To decrease the demand on the substructure elements and increase the durability of the structure, seismic isolation bearings and flexible link slabs were selected as the preferred seismic retrofit scheme. Time History Analysis was performed to verify the results of the Elastic Dynamic Analysis.

Keywords: seismic, evaluation, retrofit, isolation, link slab, durability, performance based design

Former Dominion Archives Building Seismic Upgrade Case Study

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Abstract

The former Dominion Archives building at 330 Sussex Drive in Ottawa, Canada is a three-storey historic stone masonry building that was built in two stages between 1904 and 1924. The perimeter masonry walls form the lateral load resisting system of the building; however, the walls of the 1904 section were in poor condition with soft and deteriorated mortar, the terra-cotta flat arch floors of the 1904 section did not form a proper diaphragm system, and the floor diaphragms were not adequately anchored to the perimeter walls. This case study will present the seismic upgrade and retrofit work that was undertaken to extend the life of the building, including an innovative solution to restore the structural integrity of deteriorated stone masonry walls, providing new lightweight reinforced concrete topping floor diaphragms in the 1904 section and connecting the concrete floor diaphragms to the historic masonry walls with stainless steel grouted anchors.

Keywords: historic masonry; seismic upgrade; concrete diaphragm; building envelope.

Vibration control of footbridges under pedestrian loading using tuned mass damper systems with eddy current damper technology

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Abstract

Footbridges are prone to vibrations induced by pedestrians depending on the bridge`s natural frequencies. Well-known measures to increase the structural damping of a footbridge and hence control the risk of vibrations are Tuned Mass Dampers (TMD). One of the main parameters defining the overall effectiveness of a TMD is its damping mechanism; for this purpose eddy current dampers are an innovative solution, which can improve TMD performance significantly.

This paper describes the design of an eddy current damper as part of a passive tuned mass damper. First, the theoretical potential is analysed analytically. A detailed discussion on the optimization of TMD parameters combined with the characteristics of eddy current dampers shows its advantages. In the second part a TMD construction using an eddy current damper is designed based on a case study of a footbridge.

Keywords: Footbridge; Vibration control; Tuned mass damper; Eddy current damper.

New Pedestrian Overpass at Husum Station

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Abstract

This paper presents the design of a potentially dynamic sensitive pedestrian bridge crossing a railway at Husum Station in the Copenhagen area.

Due to narrow access roads to the bridge, the project team proposed a very light prefabricated steel superstructure comprising three longitudinal steel beams and pre-installed glass fiber slabs as the bridge deck. The light superstructure and low construction height made the superstructure sensitive to pedestrian introduced vibrations. Dynamic analyses were conducted and the result was that tuned mass dampers (TMD) were required. However, measurements on site after erection of the bridge has shown that the dampers are not needed to fulfil the requirements. In the paper the reasons for the deviation between the analysis and the on-site measurements are analysed and discussed.

Keywords:. Composite structures, Fibre Reinforced Polymers, Structural Dynamics, Tuned Mass Dampers

US Olympic Museum

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Abstract

The US Olympic Museum (USOM) Footbridge is a 245ft clear spanning footbridge over Union Pacific Rail Road. This bridge is situated at the foothills of Rocky Mountains in Colorado Springs, Colorado. The dramatic and unique Rip-Curl concept will enhance the landscape between future US Olympic Museum and America the Beautiful Park. The footbridge is designed in collaboration with AMD architects, DS+R architects, UP Rail Road and City of Colorado Springs.

The Rip Curl superstructure is a sweeping asymmetrical steel shell morphed from an arched 70 ksi steel top chord and a "stressed skin" web. The concept is designed to both integrate with the aesthetic vision for the US Olympic Museum and to minimize impact on busy rail operations during construction as well as reduce maintenance for the client. This paper describes the rigorous analysis and design behind this unique concept

Keywords: innovative structural systems; architecture; bridges; steel.

Reliability under the Serviceability Limit State of Footbridges Subjected to Human-Induced Vibrations

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Abstract

Codes of practices aim to achieve a relatively consistent and sufficient level of safety for structural members with minimum total costs over a design working life. Traditionally, reliability-based calibration of the design codes is performed to ensure an acceptable level of safety, usually represented by a target reliability index. Specification of the target reliabilities is one of the key steps required for the calibration process. Target reliabilities for ultimate limit state (ULS) design are well explored by the international codes, which suggest a wide range of target reliabilities depending on the reference period and failure consequence. On the other hand, little research has been undertaken towards establishing target reliabilities for serviceability limit state (SLS) design of structures under normal use. International standards suggest the use of a single target reliability index under SLS design, which is independent of the reference period. The design of lightweight footbridges is often dominated by SLS under human-induced vibrations rather than the ULS. In the current study, the sufficiency of the target reliability for SLS under excessive vibrations is investigated for footbridges designed using the SÉTRA guideline. With this objective in mind, reliabilities for different footbridge classes such as suburban and urban are evaluated under the design as well as non-frequent traffic loadings and the results are compared with existing target indices for SLS design. The results point towards the specification of higher reliability indices for different footbridge classes under their respective design traffics in order to achieve sufficient reliability under non-frequently occurring heavy traffic loadings. The possibility for overdesign that may result can be mitigated by adopting traffic dependent comfort limits.

Keywords: footbridges; serviceability design; human-induced vibration; reliability

Test and Simulation of Pedestrian-induced Vibrations in a Double-arch Footbridge with Curved Girder

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Abstract

This article carries out the dynamic tests and analyses based on a special-shaped footbridge of Guangzhou Science City. The experiment of pedestrians crossing the footbridge contains these cases: a pedestrian crossing the footbridge at different speeds, several pedestrians in line crossing the footbridge at a specific speed. After comparison, the FEA calculate results are quite close to the measured responses of the footbridge. It shows that the response of the footbridge is increased by the foot frequency. It also finds that, when the foot frequency is higher than 3Hz, the vertical vibration of left span and right span goes opposite phase. The lateral vibration of left span and right span affect each other a lot. The higher foot frequency is, the more obvious it becomes. The forced vibration frequency of the footbridge is closed to the exciting frequency while the resonance doesn't occur.

Keywords: Footbridge; special-shaped; dynamic analysis.

The dynamic evaluation of composite materials footbridges

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Abstract

The dynamic analyses of two examples of composite footbridges are presented in this paper. The investigation focussed on the comparison of dynamic responses to different types of dynamic load – specifically, pedestrian movement, traffic loads and rail loads. For dynamic analyses, a set of 3D models of the footbridges was prepared using the ABAQUS software program. The first step of the analysis was to determine the dynamic characteristics of the structure, i.e. its mode shapes and natural frequencies. Modal analyses revealed that the lowest natural frequency of one footbridge coincides with the frequency of pedestrian steps while walking or running; therefore, an evaluation of the dynamic response to these types of human actions was performed in order to identify the possible resonance phenomena. In the next stage, the authors assessed the dynamic response of the footbridges to typical traffic loads; these types of load are transmitted to the structure through the ground and foundations. Such an assessment appears to be necessary due to potential increases in the number of vibration sources arising from changes in the types and volume of traffic over time. It should be noted that traffic loads, which are a source of vibration for footbridges that are located over highways or railways, constitute an interesting yet still under-recognised problem concerning footbridges. For the analyses, representative time histories relating to the passage of a heavy goods vehicle and a train were used. The results of the analyses were compared with acceptability limits, with regard to levels of acceleration, in order to assess levels of vibration serviceability. The analyses revealed that the dynamic responses to both road traffic and rail loads are of a lower magnitude than the responses to the movements of human users.

Keywords: footbridges; dynamic analysis; vibration comfort criteria assessment; advanced composite material; fibre-reinforced plastic (FRP); glass-fibre-reinforced polymer (GFRP); ABAQUS

Long-Term Performance of PresLam Frames: Are Post-Tensioning Losses really an Issue?

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Abstract

Several post-tensioned timber buildings have been already constructed in New Zealand and overseas starting from 2010. The construction technology relies on unbonded post-tensioning tendons or bars passing through internal ducks in beams, frames or walls to create moment resisting connections. Supplemental energy dissipation can be obtained by introducing replaceable mild steel bars or other types of dissipation devices at the rocking interface generally called "dissipaters".

This paper resumes an up to date review on all the available information in terms of post-tensioning loss. Data coming from operative building under monitoring are presented and compared with respect to the beam-column joint detailing solution. Furthermore, the influence of different post-tensioning loss scenarios on the building seismic response is showed by analytical and numerical procedures.

Results show that interstorey drifts in case of earthquake might significantly increase with post-tensioning loss when dissipaters are not provided. However, floor displacements remain constant when additional damping devices are used even in case of extreme loss scenarios.

Keywords: PresLam, post-tensioning, timber, creep, long-term

Bending, vibration and long-term performance of timber-concrete-composites floors

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Abstract

There is much potential for engineered wood products (EWP) to be used beyond low-rise residential construction when incorporating the notion of hybrid systems like timber-concrete-composites (TCC). The research presented in this paper experimentally determined the bending, vibration and long-term performance for a range of TCC systems in several EWPs. Strength and stiffness properties were validated on small-scale shear tests. Subsequently, full-size floor panels were tested for elastic stiffness and dynamic properties under quasi-static loading. Furthermore, floor panels are subjected to serviceability loads since summer 2015 with the environmental conditions and the deflections being monitored. This research provides insight to engineers into safely designing TCC floor systems for bending, vibration and long-term performance.

Keywords: Timber-concrete-composite; Hybrid construction; Multi-functionality.

The development of timber as a construction material for bridges in Norway

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Abstract

Throughout the nineties, a new generation of wooden bridges were born in Norway. This was the result of mixing traditional knowledge about the use of wood with the use of modern glulam technology and innovative solutions regarding connections. In addition, the use of preservatives in combination with constructive protection made the bridges more durable. In the past two decades there has been a continuous development of bridge technology. It is not an important target to use as much timber as possible, but rather to exploit the best characteristics of every material, including steel and concrete. This has led to that we can push the limits of the use of this environmentally friendly material. This paper shows some examples of bridges that have been built and presents a record-breaking bridge that may be the next step in the timber bridge era

Keywords: Timber Bridge, glulam, arch bridge, truss bridge, network arch bridge.

Uncertainty of Visual Inspection on the Reliability Analysis of Timber Elements

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Abstract

In this work, the uncertainty related to the process of visual inspection of timber elements as a method to define different strength classes is quantified. For that aim, visual inspection was made to different chestnut timber elements at local and global scales. The inspection was made by sixteen different inspectors, with low experience, and by an expert for benchmark analysis. The uncertainty of the visual inspection process was measured by the analysis of these independent observations obtained under the same conditions of measurement, resulting in the quantification of the experimental standard deviation to characterize the variability of the observed values and of the experimental standard deviation of the mean to characterize the uncertainty of the process. A reliability analysis was also made using random samples including the uncertainty from the visual inspection process, obtaining reduction factors for a specific case study.

Keywords: visual inspection; timber; uncertainty; reliability.

Case Study: University of British Columbia's 18-storey TallWood House at Brock Commons

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Abstract

The TallWood House at Brock Commons is an 18-storey mass timber hybrid student residence under construction at the University of British Columbia in Vancouver, Canada. When completed in the spring of 2017 it will be 53m high – the tallest contemporary mass timber hybrid building in the world. Structural engineers at Fast + Epp collaborated with Acton Ostry Architects and Hermann Kaufmann Architekten. This paper will outline some of the unique structural engineering challenges associated with this mass timber building and the design strategies used to overcome them. Specific topics include two-way point supported CLT floor slabs, axial column shortening, CLT diaphragm design, tolerances, as well as dynamic wind induced vibrations. It will also review the project's pre-fabrication process, on-site construction sequencing, and lessons learned.

Keywords: Tall wood, CLT, Diaphragm design, Tolerances, Axial column shortening

Simplifying Complex Problems: Use of Parametric Tools to Design and Build Complex Wood Structures

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Abstract

This paper presents the design, fabrication and construction techniques used to build an off-site fabricated, modular, free-form wooden ceiling soffit for a building in Honolulu, Hawai'i. This architectural feature ceiling used wood in an unconventional way, calling for innovation at all stages of the Project: modelling, structural analysis, fabrication, transportation and installation.

Dynamic relaxation was used to define the architectural surface, Grasshopper for the generation of a fully customisable 3D model, real time Finite Element Analysis for structural checks, and CNC machining for fabrication. The panels were shipped in containers and chain-hoisted into place.

Keywords: Freeform; Complex Geometry; Timber; Parametric Design; Rhino; Grasshopper; CNC; Modular; Prefabrication

Extending Glass Façade Performance Predictions for Natural and Man-made Hazards Using Accessible High Fidelity Formulations

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Abstract

Current design approaches for glass hazards generated by natural and man-made insults typically use single degree of freedom (SDOF) methods to analyze the performance of window glazing and mullions. SDOF methods have significant limitations when used for analysis of complex glazing systems such as storefronts and curtain walls. Coupling effects are ignored in SDOF methods, and only single assumed modes of response can be considered. Additionally, more complex support conditions (point supported glass), thermally efficient designs (triple glazed units), and geometrically playful designs (curved glass) are difficult to represent as SDOF systems.

This paper describes the implementation of a statistical glass fracture modeling approach into a "cloud-based" finite element formulation for glass, laminated glass and structural and nonstructural elements (mullions, muntins and connections).

Computational features include advanced user-defined constitutive models (UMATs) that have been implemented in parallel processing structures within the multi-physics finite element code LS-DYNA. These computational features are driven by advanced numerical formulations that include a new Glass Failure Prediction Model (GFPM) based UMAT with an elastic constitutive model with flaw-based probabilistic failure criterion, a new PVB interlayer UMAT, and a new structural silicone LS-DYNA UMAT.

Shock tube tests have been conducted for validation. DIC (digital image correlation) was used for surface displacement measurement in the validation tests. An example of an application to a geometrically and materially complex façade is presented at the conclusion of the paper.

Keywords: high-performance facades, glass hazards, dynamic response, blast loading, impact loading, natural hazards.

Case Studies of Reinforced and Post-tensioned Glass Beams

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Abstract

Glass and concrete share basic material characteristics. They are strong in compression but rather weak in tension. Moreover, both show a linear stress-strain relation in bending until brittle failure caused by tensile loads. Therefore, it is reasonable to construct glass beams using the principles of reinforced and pre-compressed concrete design. Future glass projects will be more material efficient as the reinforcement replaces uneconomical oversizing approaches in conventional glass beams. This will reduce the amount of flat base material and decrease the energy needed to produce it. Additionally, the reinforcement allows for a redundant load path during a post-breakage situation, which is a compulsory design criterion. Lastly, the pre-compression of the glass permits larger bending loads and may provide an initial uplift to neutralize any dead-load deflection beforehand.

The paper introduces into the design of reinforced and post-tensioned glass beams by applying the terminology of Eurocode 2. The article summarizes six existing reinforced glass beam projects in Germany and international research activities in this field. During a case study, the presented structural options are compared. The paper includes an assessment of a probable choice of materials. Furthermore, it presents a comprehensive approach to systematize reinforced glass beams as a basis for future design. Finally, this will open the topic for further discussion and outlook into future research activities.

Keywords: structural glass; glass beam; post-tensioning; post-tensioned glass; redundancy.

Figure 1. Spannglass Bridge at glasstec 2014 Düsseldorf, Germany (photo: Messe Düsseldorf/Tillmann).

Effect of Regrinding on the Edge Strength of Tempered Glass

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Abstract

Laminated glass can have an edge displacement of the individual glass panes resulting from the lamination process. With regard to visible or exposed edges, this displacement reduces the optical quality of the glass component. The regrinding of the edge after lamination compensates the displacement and thus creates a highly transparent surface. However, regrinding tempered glass leads to a reduction of the compression zone near the edge and bears the risk of reducing the load-bearing capacity. The degree of this reduction was experimentally determined and evaluated at the Institute of Building Construction with the aid of both single-glass panes and structural component tests.

Glass Failure Prediction Model for Out-of-Plane Bending of Waterjet-Drilled Holes

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Abstract

Use of fully tempered (FT), point-supported glass (PSG) as structural elements has become increasingly common. However, current US glass design charts and analytical methods found in ASTM E1300 are only applicable to rectangular lites with continuous line supports along one or more edges. As a result, practitioners use finite element analysis to determine maximum principle stress that dictates glass thickness. However, sole reliance on the single largest maximum principle tensile stress (SLMPTS) may not always be representative of actual performance as surface flaws often precipitate failure at lower stresses and different locations from the SLMPTS. This paper analyzes the experimental data for 10 FT specimens with waterjet holes subject to out-of-plane bending. Experimental time histories are converted to the to 3-second failure loads for determination of best fit m- and k- values for use with the glass failure prediction model to determine stresses for a probability of breakage of 1 in 1,000 and 8 in 1,000 lites.

Keywords: point supported glass; failure prediction model; fully tempered; allowable stress.

Building with Glass as Structural Element in Alpine Areas

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Abstract

Building with glass as structural element becomes more and more common. Under special boundary conditions like in alpine areas this might become a challenge concerning design and execution at the building site. Important points are the climatic conditions in alpine regions, like extreme wind loads and extreme pressures for insulating glass units due to the difference in altitude, narrow installation situations and a narrow time slot. Basics and applications of glass constructions in these extreme boundary conditions are presented. Two summit stations with glass applications, the Nebelhorn (2224m) and the Zugspitze (2962m) are presented.

Keywords: Glass, railings, facades, curved glass, insulating glass unit.

Comparison of Unconventional Testing Methods for Mechanical Characterization of Polymeric Materials in Modern Glass Structures

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Abstract

Designing with glass always includes the use of polymeric materials. Since polymers can undergo large deformations, nonlinear constitutive laws have to be applied in numerical simulations accounting for the hyperelastic material behaviour. Here, the challenge is to identify hyperelastic material parameters by more than one experiment in order to represent the structural behaviour of polymeric materials under arbitrary loading conditions as well as to relate one experiment to one material parameter. That is why in addition to common uniaxial tensile tests, other experiments, such as biaxial tensile tests have to be performed. Based on this idea, the present paper discusses the principle of the material parameter identification under a simultaneously multi-experiment data fit for hyperelastic materials with the focus on two different test set-ups for biaxial tensile tests, where two different types of polymers will be analysed.

Keywords: polymeric material; hyperelasticity; biaxial tensile test; multi-experiment data fit

Sustainable Bridges – Implementing Owner Sustainability Requirements

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Abstract

In recent years, significant steps have been taken to improve the sustainability performance of buildings, most commonly by defining mandatory requirements through laws and regulations in a 'top down' approach. But how are the principles of sustainability being brought into the world of bridges? Are similar 'top down' approaches being used? After setting out the subject of the paper and defining the 'top down' approach to implementation of new practices within the construction industry, a case study is presented which reviews how requirements for sustainability have been introduced into the existing framework for the technical approval of bridges in the United Kingdom. The advantages and disadvantages of such an approach are discussed.

Keywords: Bridges; sustainability; technical approval; case study.

Low Level Road Bridges: A Sustainable Project

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Abstract

The Low Level Road (LLR) Project is a $101.6 Million strategic transportation infrastructure improvement in North Vancouver, BC that has been recognized for multiple engineering design and sustainability awards to date. This paper is a case study that discusses the innovative design features, sustainability attributes, and construction challenges encountered for each of the three main bridges involved with the LLR project, which have become landmarks in the surrounding community. The three bridges discussed in the paper include the 78m long Neptune/Cargill Overpass, 42m long Spirit Trail Overpass at East 3rd Street, and 58m long Spirit Trail Woodland (Moodyville) Suspension Bridge. In each case a unique sustainable structure solution was developed, which required engineering innovation to meet the project goals.

Keywords: sustainability; bridges; transportation; environmental; liquefiable soil; steel-tied arch; integral deck; joint-less bridge construction; suspension bridge; Envision

Holistic Consideration of the Sustainability on Steel-Concrete-Composite Motorway and Railway Bridges

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Abstract

Nowadays, sustainability is a key issue for the design of constructions, especially relevant for bridges with a service life of 100 years and where all the life-cycle stages need to be considered. Therefore, at the tender stage decision making should no longer be only based on construction costs but on a holistic assessment of sustainability aspects along the whole lifespan of the bridge.

In the European research project "SBRI" and the German research project "NaBrüEIS" a holistic approach of the sustainability on bridges has been developed. "SBRI" is devoted to the analysis of realistic case studies on motorway and crossing motorway bridges, while "NaBrüEIS" has the focus on the holistic evaluation of railway bridges. In both projects, environmental and economic aspects were assessed with the methods of LCA (Life-Cycle Assessment) and LCC (Life-Cycle Costing) together with external effects.

An important difference between the motorway bridges and the railway bridges is the external effects due to the traffic interruption, that play a crucial role on the holistic approach of the bridge. In motorway bridges, the external effects relate to the impact on the traffic flow in terms of user costs whereas in railway bridges, the external effects refer to the operation encumbrance costs linked to the operation of the railway net.

Keywords: Sustainability Assessment, Life-Cycle Assessment (LCA), Life-Cycle Costs (LCC), Holistic Approach, Motorway Bridge, Railway Bridge

How can a Bridge Engineer contribute to a sustainable infrastructure?

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Abstract

As Bridge Engineers we have a significant leverage to influence our built environment, but all too often we choose to stay with established solutions instead of striving for new and better alternatives. When designing for sustainability, we should have the following aspects in mind:

- Environmental impact of our design over its whole life, locally and globally.
- The possibility for our structures to grow with increased traffic – but also to shrink where population is on decline.
- Plan for environmental friendly means of transport and make their use more comfortable, i.e. wide bike lanes, widening for light rail addition.
- Minimize traffic obstruction during construction.
- Design for a long service life.
- Design for dismantling and re-use of structural parts.

This presentation will show examples where a sustainable design could be achieved and explains possibilities how the engineer can convince the client to agree on better than the traditional solutions.

Keywords: sustainability, fast erection schemes, bridges, prefabrication, long service life, new materials, professional ethics

Adding value through innovation in structural design: 1 – Introduction, with reference to innovation in bridge design

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Abstract

Innovation is vital in any developing and growing society. It undoubtedly adds value in structural design, but the engineer's appointment needs to be such as to allow it to occur. The issues touched on briefly in this paper, and the four other associated papers, will be debated at the Seminar on this topic at the conference.

Keywords: Innovation, radical change, added value, incremental improvement, bridge design, seminar introduction.

Adding value through innovation in structural design: 2 – Innovative design of timber structures

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This short paper will focus on opportunities for innovative thinking in the creation of hybrid structures and how this innovation can add value – the theme of an open forum discussion seminar led by the Institution of Structural Engineers at the 2017 IABSE Symposium in Vancouver.

During the past century, steel and concrete have dominated as primary building materials for structural designers. Timber has – for many years – remained the neglected child; when it is used, its design is often relegated to timber manufacturing firms. This paper and subsequent presentation will address emerging factors in our industry that will increase opportunities for structural designers to sensibly introduce wood into their design repertoires, often in combination with steel and concrete, to create functionally and cost-efficient structures that address the sustainability concerns of our day. Drawing on the collective wisdom of engineers who were 'out of the box' thinkers, it will also provide some foundational thought and stimulating discussion that assesses what it takes to become a fresh thinking engineer who considers all material combinations when designing structures.

Keywords: *hybrid structures; timber; mass timber; innovation; sustainability*

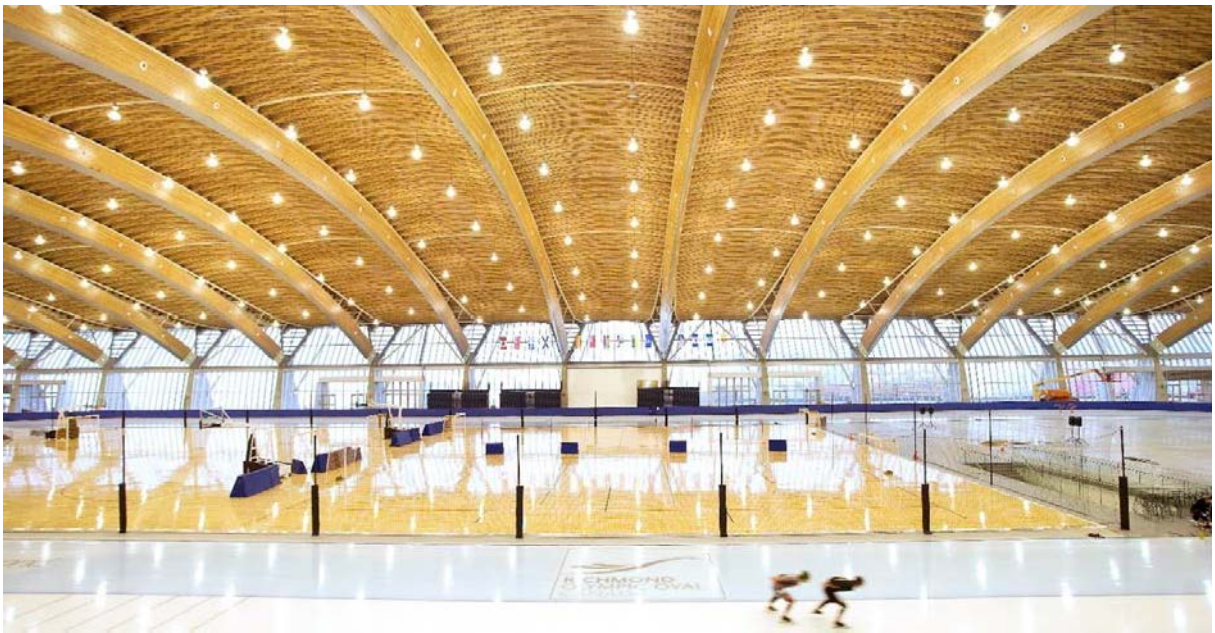

Figure 1. Richmond Olympic Oval Roof. Photo by Stephanie Tracey.

Adding value through innovation in structural design: 3 – Creativity and innovation in building structures

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Abstract

This paper is part of a series on the subject of adding value through innovation in structural design – the theme of an open forum discussion seminar organised at the conference by the Institution of Structural Engineers.

It explores different routes which can lead to creativity and innovation in building structures. It also identifies key drivers and enablers of innovation and the wider design philosophy that is needed for it to flourish.

Keywords: innovation; creativity; new materials and fabrication techniques; cross industry transfer of knowledge; collaboration; communication; mentoring

Adding value through innovation in structural design: 4 – Three Novel Applications of Bridge Isolation Bearings near Vancouver, BC

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Abstract

Seismic Isolation Bearings can be used for a diverse range of applications including new and existing bridges. This paper presents three non-traditional applications of base-isolation to bridges in South Western British Columbia. The three applications consist of a new trestle structure, retrofit of an existing bridge, and a new pedestrian bridge. The Fraser Heights Bridge is a new 472 m long twin trestle-bridge that was base-isolated to meet stringent seismic performance-based design criteria and to facilitate rapid construction. The Nicolum River Bridge is a three-span 178 m long bridge built in 1985. The original modular expansion joint had failed and re-articulation with isolation bearings was adopted to share thermal strains between the abutment joints. Isolation of the superstructure also redistributed lateral restraint between the substructure elements, and this added benefit was used to upgrade the bridge seismically. The Tynehead Pedestrian Bridge is a new three-span 120 m long steel arch pedestrian bridge. Base isolation bearings were adopted for this bridge to meet the performance-based seismic design criteria, and also to increase damping to mitigate the risk of pedestrian-induced vibration. This paper presents the performance criteria, design considerations and construction details for three non-traditional applications of isolation technology, highlighting the differences in the design approach and the benefits of base isolation in each instance. Construction of the three bridges is discussed.

Keywords: Base isolation; laminated elastomeric bearing; shear strain; damping; expansion joints; seismic demands; seismic modelling; seismic performance; pedestrian-induced vibration

Adding Value through Innovation in Structural Design: 5 – Digital Workflows and Emerging Computational Design Tools

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Abstract

This paper is part of a series on the subject of adding value through innovation in structural design – the theme of an open forum discussion seminar organised at the conference by the Institution of Structural Engineers.

Digital workflows and computational design are revolutionising the way we design, build, operate and experience structures and the built environment. Interoperability and changes in how we use software are key to the successful implementation of these workflows, and this is explored further in this paper through two case studies.

Keywords: digital workflows, parametric design, interoperability, augmented reality

Sustainable retrofitting of existing buildings in peripheral residential districts of big European cities

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Abstract

Construction and operation of buildings have a serious contribution to the environmental impact. That is the reason to consider the building retrofit as a good demonstration of sustainable development. The contemporary trends in the construction sector include the increasing rate of rehabilitation and strengthening of existing structures compared with construction of new structures. The design approaches for retrofit of existing buildings have an important contribution to guaranteeing the high quality of the life with respect of the contemporary requirements. Analysis of two of the most popular structural systems in the peripheral European residential districts: "Large-panel system" and "Large area formwork", are presented. Based on the conclusions of this analysis and on the presented realized projects for rehabilitation, some general considerations and recommendations for sustainable retrofit of residential buildings are given.

Keywords: Existing buildings, "Large-panel system", "Large area formwork", retrofit, sustainability.

A Meso-scale Numerical Model for Predicting Chloride Diffusivity in Concrete

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Abstract

Chloride-induced corrosion of reinforcing steel is the most important factor affecting reinforced concrete (RC) structures subjected to saline environments, and thus it is needed to understand how chloride ions ingress in concrete. In this study, firstly, an experiment of chloride ingress in specimens under chloride diffusion is conducted in a climate chamber and profiles of chloride concentration along the depth are obtained. Then, a mesoscopic model, which considers the temperature, relative humidity, and time effect, is developed to investigate the chloride diffusivity in concrete. Concrete is treated as a heterogeneous material composed of cement paste, aggregates, and the Interfacial Transition Zones (ITZ). It is assumed that the chloride diffusivity can take place only in the cement paste and the ITZ and the aggregate is considered as impermeable. Influence of the ITZ thickness, i.e., 0, 50 and 80 µm, on the chloride diffusivity in concrete is calculated. Chloride concentrations, which are simulated with the mesoscopic model with consideration of temperature, humidity, and time effect are compared to the test data. The results show that the chloride concentration with consideration of the ITZ thickness at the same depth is higher than that without consideration of it. However, different thickness of the ITZ, i.e., 50 and 80 µm, has a small impact on the chloride diffusivity in concrete, hence, the thickness of the ITZ is recommended as 80 µm for efficiency. The simulation results with consideration of temperature, humidity, and time effect are in good agreement with the test data.

Keywords: concrete; chloride diffusion; mesoscopic model; temperature effect; humidity effect; time effect.

Concepts for Durable Post-Tensioned Bridges over Highways in Ontario, Canada

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Abstract

Cast-in-place post-tensioned concrete bridges present certain advantages over slab-on-girder bridges and they make up 20% of the Ontario Ministry of Transportation's bridge inventory. Despite their excellent performance, relatively few are currently built. This paper presents two concepts for cast-in-place post-tensioned concrete bridge replacements over existing highways which overcome some perceived shortcomings. The first concept is two-span cast-in-place voided slab underpass with monolithic pier columns and integral abutments on caissons. The superstructure is cast 1.2 m above the final profile to allow for falsework clearance over three lanes of highway in each direction, and jacked down to the final alignment. The second concept is a single-cell box girder underpass with two spans of 37.5 m, monolithic pier column, and integral abutments.

Keywords: prestressed concrete; post-tensioning; integral abutments; bridge aesthetics; jacking; sustainability; cast-in-place concrete.

Short and long-term behaviour of RC slabs strengthened with prestressed CFRP laminate strips

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Abstract

In the context of strengthening reinforced concrete (RC) structures with fiber reinforced polymer (FRP) materials, the externally bonded reinforcement (EBR) technique is the most widely used strategy. By prestressing the FRP materials attached to the concrete substrate, the advantages of external prestressing and of the EBR technique are combined. The solutions adopting carbon FRP (CFRP) laminates have been mostly used.

Special end-anchorage systems are required at the ends of the prestressed CFRP laminate to transfer the high shear stresses developed from the FRP to concrete, in order to avoid a premature FRP peeling-off failure. From all the proposed systems, two of them have been prevailed, mainly: the mechanical anchorage (MA) fixed to the ends of the FRP reinforcement and the gradient anchorage (GA).

The present work investigates the short and long-term behaviour, including the durability issues, of reinforced concrete (RC) slabs strengthened with prestressed CFRP strips according the EBR technique. Two different anchorage systems were studied: (i) MA and (ii) GA. The experimental program carried out included of the effects of environmental actions such as water, water with chlorides and wet-dry cycles on the global performance of these slabs. This paper presents the general description of the experimental program, the analysis of the main results, as well as the retained conclusions.

Keywords: EBR; CFRP; prestress; Anchorage; durability; long-term behaviour; RC structures

The 5% Solution

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Abstract

Opportunities abound in the field of structural design to make a meaningful contribution towards the reduction of our carbon footprint. Typical construction materials—steel and concrete—are among the highest CO2-emitting materials during their production. Production of one tonne of steel emits 1.8 tonnes of CO2, and production of one cubic meter of concrete, on average, emits 250 kg of CO2. A modest reduction in the use of steel and concrete in structural designs will go a long way in reducing CO2 emissions. The analysis of structural designs by us and other authorities shows that a reduction of 5% of steel and 5% of concrete in a building can be achieved without impacting the structural integrity by just being a little more judicious while designing. Being environmentally mindful while designing structural elements is what we call the 5% Solution.

Keywords: buildings; sustainability; greenhouse gas emissions; concrete; cement; steel

Durability assessment of reinforced concrete structures due to chloride ingress up and beyond induction period

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Abstract

Chloride ingress in reinforced concrete structures is the main cause for the corrosion of reinforcing steel. This paper presents chemo-mechanical material models up and beyond induction period, taking into account concrete mix design, supplementary cementitious materials, concrete cover, effect of cracking, and environmental conditions. The 1D model of transient problem of chloride ingress is extended for crack effects, which accelerates propagation. Fracture–plastic constitutive model is used for the modelling of externally induced cracks. The influence of cracks is significant, e.g. crack width 0.3 mm decreases the induction time approximately five times when compared to intact concrete. Once the end of the induction period is reached, progressive corrosion stage takes place. The corrosion current density i_{corr} is used for calculating time of concrete spalling due to chlorides. After concrete spalling, reinforcement is subjected to corrosion without any protection.

The above-mentioned models are implemented in a finite element software, using multi-physics approach, i.e. combining transport and mechanical analysis. They predict induction time, extent of corrosion for chloride ingress, and calculate remaining steel area. The presented chemo-mechanical approach is validated on several engineering structures suffering from chloride ingress, e.g. Nougawa bridge, Japan, or concrete strut of a prestressed bridge in Prague, Czech Republic. The present models are applied for ULS analysis, while assessing load-bearing capacity of a structure in dependence on the state of reinforcement corrosion.

Keywords: Chloride ingress, induction period, reinforcement corrosion, service life, durability

Shear and flexural strengthening of existing bridges with textile reinforced mortar

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Abstract

Increasing traffic loads and changes in code provisions cause deficits in shear and flexural capacity of many highway bridges. Therefore, a lot of structures in Europe and North America are expected to require refurbishment and strengthening soon. This projection is based on the current conditions of many older road bridges. Many different strengthening methods have been established, all having specific advantages and disadvantages. By applying a thin layer of textile reinforced concrete (TRC) to bridge deck slabs and the webs of prestressed concrete beams the load carrying capacities of those members can be increased significantly. This new method has been investigated experimentally. The TRC layer is a combination of a corrosion resistant carbon fibre reinforced polymer (CFRP) fabric and an efficient mortar. In this paper, the strengthening method and the test results obtained at RWTH Aachen University are presented.

Keywords: existing concrete bridges, textile reinforced concrete, carbon fibre reinforced polymer, shear strengthening, flexural strengthening, experimental investigation.

Innovative solutions for Bridge strengthening (widening and compliance to new codes) by modification of initial static scheme

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Abstract

Strengthening of bridges for compliance to new codes is nowadays quite usual, but some innovative solutions have to be found for economic reasons, when loads increase due to widening or seismic actions is huge and has a strong impact on foundations, or when other parameters such as vibrations need to be considered. Freyssinet's solution on 2 projects, Binh Trieu Bridge in Vietnam and Ayala Bridge in Philippines is a complete change of static scheme: isostatic bridges are transformed into hyperstatic bridges or portal frame mixing together: new elements of concrete, additional prestressing, dampers, change of bearing conditions, with only one goal "reduction of global cost of strengthening solution."

Keywords: strengthening; retrofitting; post-tensioning; dampers

Condition Assessment and Renewal Options Analysis for the Queensborough Bridge

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Abstract

The 41 span, 920m long Queensborough Bridge, constructed in 1960, provides a strategic daily link for 90,000 vehicles over the north arm of the Fraser River connecting New Westminster, BC. The Owner, the BC Ministry of Transportation (Ministry), initiated an in-depth scoping study to assess its current condition, as well as identify and analyze renewal treatment options to enable them to make informed decisions on managing the asset. The importance of limiting user delays was essential when evaluating potential treatment options. Multiple options for rehabilitation of the concrete deck as well as encapsulation and recoating scenarios for the steel girder coating was investigated. Life cycle cost analysis and conceptual traffic staging strategies were prepared. A qualitative assessment matrix, accounting for economics, traffic disruption and risk, was an effective tool in understanding, evaluating, and conveying recommendations.

Keywords: Condition assessment; bridge rehabilitation plan; renewal analysis

Post-Earthquake Analysis, Retrofit, and Future Performance of the Centinela Building

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Abstract

In April 2016, a M_w 7.8 earthquake struck the coast of Ecuador, causing major destruction in the cities located near the epicenter. Most of the residential buildings did not collapse but they experienced substantial damage of the non-structural components and some structural elements. The design for life safety and collapse prevention criteria were satisfied; however, the damage level prohibited their subsequent occupancy. As a result, all social activities of the affected cities cannot normalize until this infrastructure is reconstructed. In this paper, the Centinela building, a structure affected by the earthquake, is investigated to determine the damage level and retrofit alternatives. In addition, a risk assessment is conducted to predict the response of the building during future events, considering both the structural and non-structural components. In the future, these types of assessments may serve as a decision-making tool for government agencies and owners.

Keywords: Ecuador; Muisne earthquake; Bahia de Caraquez; seismic performance; seismic retrofit; risk assessment; non-structural element damage

Strengthening of a Twin Arch Bridge in Goa, India for Stability

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Abstract

A recently constructed bridge comprising parallel twin tied arches were observed tilted on one side soon after the cast-in-place concrete deck was poured. A three dimensional (3D) analysis of the as-built structure including both the material non-linearity and the initial imperfections demonstrated that the stiffness and strength of the existing Vierendeel lateral bracing between the arches were inadequate for developing the design capacity of the structure subjected to dead, live and wind loads. A retrofit of the structure by replacing the Vierendeel-bracing with X-bracing was proposed, which increased the limit load of the structure many folds. A step-by-step retrofit scheme for replacing bracing system was developed through virtual simulation. The study enabled developing a cost-effective retrofit measure for the bridge, and identified the need for stability bracing design guidelines for steel arches within the existing design specifications.

Keywords: steel arch; stability; retrofit; non-linear analysis; Vierendeel bracing.

Fort Nelson River Bridge Superstructure Replacement & Substructure Strengthening

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Abstract

Whether it's to accommodate an increase in traffic volumes, a need to satisfy new design standards and loading requirements, or a need to extend the service life, utilizing existing infrastructure is an attractive consideration for owners in order to minimize throw away costs. The existing single lane 430 m long Fort Nelson River Bridge on the Liard Highway No. 77, built in 1984, needed an upgrade to replace the temporary superstructure with a permanent one for increased traffic volumes and to eliminate delays. This paper presents the transformation of the existing single lane ACROW bridge to a modern two lane composite steel girder bridge, describing the evaluation of the various superstructure types during conceptual design, the opportunity to utilize the existing piers and the challenges and risks associated with this, the impact of Canada's northern climate, and the innovative thinking that allowed the design team to overcome the many site specific constraints. Cost is always key criteria when evaluating different bridge options, but in this case constructability, durability, and the northern climate all carried significant weight in the evaluation process. Although utilizing the existing piers and alignment saved costs, it also created design constraints and construction and strengthening challenges in the piers themselves. It did, however, allow the contractor to use the existing bridge as a temporary detour bridge by sliding the existing superstructure downstream so the new bridge could be built along the existing alignment. Designing for Canada's northern climate requires innovative thinking to facilitate both construction and the service life of the bridge due to the extreme weather patterns. Pre-fabricated elements such as steel girders and full-depth precast deck panels were configured for modular on-site assembly to achieve accelerated construction and improved durability. Deck continuity over the entire superstructure through a novel articulation scheme was provided to improve the service life of below deck components and minimizes routine maintenance.

Keywords: Composite steel girder bridge; multi account analysis; northern climate; pre-fabricated elements; jointless deck, superstructure continuity, modular design; incremental launch; bridge slide; construction staging for traffic management; remote location

Simulating ductile crack growth in carbon steel using an extended finite element method (XFEM)

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Abstract

A novel methodology for simulation of crack growth in a 3D steel model is presented. This methodology is vital for the safe and full design of steel elements under harsh environment. The methodology, which is based on the extended finite element method (XFEM), neither requires the updating mesh over the course of the analysis, nor the priori definition of a crack length. Many other methods require the definition of crack and/or location of the crack to predict fracture. The methodology was validated against measurements from conventional static tests. The tests were carried out on the coupons of structural hollow tubes that are fabricated of 40x40x2.5SHS, 50x25x2.5RHS, 20x20x2.0SHS (mm) sections. Predictions of crack growth are used to study the behaviour of axially loaded steel to fracture. A major benefit is that the proposed method can be advanced for modelling fracture/fatigue of moderate to large structures to earthquakes.

Keywords: Extended finite element method; ductile fracture; steel coupons; structural hollow sections; steel braced frames.

Fatigue damage evaluation using S-N curves obtained by different data fitting methods

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Abstract

This paper investigates the differences in the predicted fatigue life of transverse butt weld joints and cover-plated beams considering statistically based fitting methods on fatigue test data and comparing the results with the S-N relation proposed in international standards. The test data fitting are performed by employing the Least Square Method (LSM) and the Maximum Likelihood Method (MLM) taking into account the contribution of the runouts. The Mean curve, the characteristic curve and the design curve have been derived. In order to consider the effect of Variable Amplitude loading, the S-N curves have been extended and the fatigue damage according to the Palmgren-Miner cumulative damage rule is evaluated for a load spectrum that follows a Rayleigh distribution. The results have been compared and discussed together with a Linear Elastic Fracture Mechanics (LEFM) based fatigue prediction.

Keywords: Steel; Bridges; Fatigue Damage; Welds; Fracture Mechanics;

Assessment of the brittle fracture behaviour of old mild steel structures

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Abstract

For the rehabilitation of steel structures from the 19th and the early 20th Century the assessment of the brittle fracture behaviour is essential for the structural safety. The methods used in EN 1993-1-10 were predominantly developed for welded structures made of current steel grades with more or less high toughness. The simplified method for the toughness check by using Table 2.1 [1] is not suitable for old mild steel structures with riveted and bolted connections. Notch effects and residual stresses are quite different in welded and riveted structures. The material properties of old mild steels are characterized by larger scatters, particularly due to the inhomogeneous distribution of tramp elements and higher contents of non-metallic inclusions. In this paper, experimental and analytical studies of the brittle fracture behaviour of structural elements with holes for riveted and bolted connections are presented (see also [2], [3], [4]).

Keywords: Brittle fracture; old mild steel; rived structures; fracture toughness; Master-Curve; Sanz-correllation; charpy-tests; transition temperature.

Fatigue Evaluation and Parametric Study on Orthotropic Steel Deck Composed of a New-Type of U-rib with Upset Webs

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Abstract

Fatigue cracks initiate at rib-to-deck welded joints play a significant part in issues with respect to the durability of orthotropic steel deck bridges. In general, the extremely highly local stress concentration induced by direct application of wheel load and geometric discontinuous are known as the primary reasons for this type of fatigue crack. In the purpose of improving the fatigue resistance of rib-to-deck joints by alleviating local stress concentration, an innovative orthotropic steel deck composed of a new type of U-rib with upset webs was proposed. Fatigue evaluation based on effective notch stress approach for the presented orthotropic steel deck was performed using finite element method. The investigative results indicate that the proposed orthotropic steel decks have preferable fatigue performance than that composed of conventional normal U-ribs. The presented new-type of U-rib is suitable for the enhancement of the structural durability of the orthotropic steel deck. A parametric study also showed that the deck plate thickness, rib wall thickness, and upset thickness have various degrees of effects on the fatigue resistance of the innovative rib-to-deck welded joint.

Keywords: orthotropic steel deck; rib-to-deck detail; U-rib with upset webs; effective notch stress; finite element method; parameter study

Fatigue Design of high stressed aluminium structures under cyclic loading

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Abstract

DIN EN 1999 provides static material datas and rules to design lightweight-structures with static and variable quasi-static loading until ultimate strength. Tensile and fatigue test with the aluminium alloy EN AW-6063 T66 are evaluated and discussed in relation to DIN EN 1999 and conducted numerical stress investigations.

Keywords: EN AW-6063 T66, Ramberg-Osgood, DIN EN 1999, Low-Cycle-Fatigue

Fatigue Performance of a Precast Hybrid FRP-Reinforced Bridge Truss Girder System

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Abstract

The fatigue behaviour of a novel precast hybrid bridge truss girder system is experimentally investigated. The girders consist of pretensioned top and bottom concrete chords connected by vertical and diagonal truss members made of concrete-filled fibre reinforced polymer (FRP) tubes. The truss members are connected to the top and bottom chords by means of long double-headed glass FRP (GFRP) bars. The chords are also reinforced with GFRP longitudinal bars and transverse stirrups. Six large-scale truss girders were fabricated and tested. All girders had identical cross-section dimensions with 1.32 m overall depth. Three of the girders were 2.83 m in length. The remaining three were 9.82 m long. One short and one long girder were tested under static loading up to failure. The remaining four girders were tested under cyclic fatigue loading of different levels and amplitudes. The tests showed excellent performance of the truss girders in terms of strength, stiffness, and fatigue life.

Keywords: bridges; concrete-filled FRP tubes (CFFT); fatigue; Fibre-Reinforced Polymers (FRP); headed bars; hybrid; truss girder.

Comparative Assessment of Bridges designed according to Balanced Lift Method and Balanced Cantilever Method

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Abstract

In recent years a new bridge construction method has been developed at the Institute of Structural Engineering of TU Wien. The so called Balanced Lift Method can be seen as an alternative to the Balanced Cantilever Method.

To compare these two construction methods, an alternative design using the Balanced Lift Method for the 210 m long San Leonardo Viaduct was prepared. Starting with building the pier and the vertical installation of prefabricated elements for the compression struts and the bridge girder, the construction is ready for the lifting process. A simple way to describe this lifting process is to compare it with opening an umbrella. To create a monolithic structure, all thin wall precast elements are then filled with in-situ concrete. Finally, it can be said that for the evaluated bridge a reduction up to 30 % of the concrete mass would be possible by using the Balanced Lift Method.

Keywords: bridge construction method, precast concrete elements, post-tensioning, Balanced Cantilever Method

Columbia River Skywalk – Turning a Need into a Landmark

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Abstract

The Columbia River Skywalk, designed by COWI North America Ltd., is a new pedestrian / pipeline suspension bridge located in the City of Trail, BC, Canada. The bridge carries pedestrians in addition to two utility pipelines. The bridge spans the Columbia River with a total length of 280 m (main span of 225 m). Aesthetics and cost were key objectives and were achieved through early communication with contractors, use of different construction materials, close work with the pipe designers, and attention to detail. This paper describes the design details developed to increase constructability and to address aesthetics in addition to discussion of the alternate materials, pipe design approach, and features included to address wind and pedestrian loading. In addition, the paper describes how the project evolved from a basic utilitarian pipe crossing to one that provides significant social value to the City of Trail, and COWI's role in it.

Keywords: pedestrian bridge; suspension bridge; cables; HDPE pipe; FRP deck panels; aesthetics; constructability; flexibility; wind; vibration.

ABC on LBJ Express Project – Innovative bent cap design and beam placement

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Abstract

The LBJ Express project rebuilt one of the most congested highways in Texas. Precasting most of the straddle bents that supported the 9-mile depressed section allowed for a fast construction and erection of the bents. In order to maintain the existing traffic at all times, some bent caps were constructed in several phases, and post-tensioning was used to connect different bent segments. For the IH-35E section, composite straddle bents were placed overnight in a single operation that allowed for a reduction of the original schedule. Existing cross bridges along I-635 created constructability issues because of low vertical clearance and crane placement constraints. An 82 meter long custom-built truss system enabled each beam to be carried transversely, moving across the bent cap to its final location, accelerating the bridge construction. This paper describes in detail some of these innovative designs and how they were implemented during construction.

Keywords: Bridges, Roads, Construction equipment for Bridges, Post-tensioning, Precast, Prestressing, Bent caps, Accelerated Bridge Construction, Innovative Structural Systems

Robust Bridge Design Framework to Blast, Fire, and other Extreme Threats

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Abstract

Recent bridge projects have incorporated multiple hazards (i.e., blast, fire, manual sabotage, RPG/mortar) as independent threats on the system. Traditional design methods to handle each threat separately are expensive and can lead to conflicting requirements. This paper will introduce the framework for a robustness-based design process. The outcomes are articulated through a series of generalized variables; topology (i.e., structural configuration relative to the site or location), geometry (i.e., layout of the structural load bearing elements), damage, and hazard intensity measures. A probabilistic framework permits consistent characterization of the inherent uncertainties through the process. This definition of resilience allows engineers to quantify resilience and robustness in more certain terms and provides a basis to better assess post-event structural behaviour.

Keywords: Blast, Fire, Resilience, Topology, Probability, Robustness, Bridge Protection.

Upgrading the Yellowhead Highway in Jasper National Park

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Abstract

The Yellowhead Highway (Highway 16) is a major east-west highway connection in Western Canada. A 77 km segment of the highway is located in Jasper National Park, including nine bridges, falls under the jurisdiction of Parks Canada. These bridges were built in the 1960s using two general forms, precast prestressed I-girders and precast prestressed inverted u-shaped girders (also known as FC girders). Following the identification of ongoing deterioration, a multi-year program was developed to upgrade the corridor for CL-800 loading. Two bridges were identified for strengthening and general rehabilitation, six bridges for partial (superstructure) replacement and the final bridge for full replacement. Designs were intended to enhance the expected service life of the structures, utilizing as much of the original structures as possible. Diligent planning was required to minimize the overall project environmental impact.

Keywords: Bridges, Concrete, Prestressing, Assessment / Repair, Rehabilitation, Structures and Environment.

Shrinkage and Creep of Mega Concrete Filled Steel Tubular Column in Super Tall Steel Building

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Abstract

Concrete filled steel tubular column (CFT) is popular in super tall building, since it has many advantages compared with ordinary steel or reinforced concrete system. CFT column is a combination of two traditional structural forms: steel tube and concrete filled in the hollow steel tube. It takes many researchers on the load carrying capacity of this composite member. However, not much has been done in relation to their time-dependent behavior especially for mega concrete filled steel tubular column employed in super tall steel buildings. In order to estimate the effects of shrinkage and creep of CFT column during the construction period, B3 model was applied to revealing the time-dependent behavior. The calculation results are compared with experiments. Then a real super tall steel building was employed to illustrate the shrinkage and creep of mega CFT column. The results show that the creep takes a significant effect on the column shortening during the construction. The value of shrinkage deformation is actually small and can be negligible in design.

Keywords: super tall steel building; concrete filled steel tubular column; shrinkage and creep; construction sequential analysis.

A manufacturing process approach to construction: design and application of a composite system for modular buildings

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Abstract

Singapore Authorities are actively promoting construction industrialisation through the Prefabricated Prefinished Volumetric Construction (PPVC) method so as to reduce the city-state's dependence on foreign labour. This paper features the technical options of the modular system that were engineered for the Ministry of Health Holdings' Woodlands Crescent Nursing Home in Singapore. This system, developed in response to constraints imposed by the design disciplines, factory fabrication, transport, and site erection can be used on a wide array of building types, including high rise hotels and apartments. The paper presents the choices taken in defining the modular system; unconventional structure design, especially on the influence of transfer floors and module layout; fire proofing and corrosion protection; the methodology used for the module construction as well as erection; and finally, the further development of this system.

Keywords: Modular and pre-fabricated construction, composite construction, innovative structural systems.

Creative Construction Method for an Attractive Tied Arch

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Abstract

The City of Chilliwack is replacing an important bridge over the Vedder River using the design build project delivery model. The winning design was an attractive 60m twin tied steel arch bridge with steel hanger roads in a "ray" arrangement. The longitudinal tie girders for the arch is a steel box section which connect the ends of the pipe arch ribs, and support transverse floor beams. The tie girders are made continuous through a 20m south side span. In-river works were undesirable due to fisheries windows schedule limitations. Launching was therefore chosen for the erection method. This presented unique challenges for an arch due to high abutment reactions on the underside of the tie girders during the launch. A temporary kingpost design was developed to support the midspan of the arch during the launch. The continuous south side span tie girders will act as a launching nose. The kingpost will also be used to support the old truss bridge during demolition.

Keywords: Design Build, Steel Structures, Bridges, Tied Arch, Construction, Launch, kingpost, Cables, Construction Equipment for Bridges

Accelerated Bridge Construction (ABC) in Idaho: The State-of-the-Art Bridge Technologies, Current Practice and Future Research

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1 Abstract

Accelerated Bridge Construction (ABC) can be defined as the process of prefabricating bridge elements in a factory, then transporting the components to the bridge site for subsequent assembly. ABC offers rapid construction, minimum traffic disruption, better quality control, improved work zone safety, maximum use of machinery, durability of bridge components, and less environmental impacts.

ABC is becoming a popular construction technique in the United States, Japan, New Zealand, and Europe. This paper begins with a literature review of the recent developments in ABC in the United States and New Zealand. It highlights past and recent applications of ABC in the State of Idaho including several bridge projects from the Idaho Department of Transportation (ITD) where incorporated ABC technologies are discussed.

A summary of the past research project on ABC at Idaho State University (ISU) is presented. This project investigated use of grouted splice coupler for column-to-footing and column-to-cap beam connections in regions of high seismicity in Idaho. The paper also presents an overview of an on-going research project on ABC that is funded by ITD and ISU (2017-2018). The project has experimental and analytical parts which investigate properties and performance of closure-pour materials between pretensioned Deck Bulb-T girders. The first phase of the project focuses on development of an optimum cost-effective closure-pour mix that would possess not only sufficient structural properties, but also would be durable and require lower maintenance. In the second phase of project, the structural performance of the closure-pour materials would be investigated experimentally using several beams. A typical beam specimen would represent a transverse strip of the superstructure composed of precast girders on sides and closure-pour in the middle. Results from experimental testing would be used in the third phase to create analytical models of the proposed closure-pour details. The models would be capable of assessing the connection strength under one-time truck load, providing an indication of fatigue performance under repeated loading, and indicating durability performance such as crack control and interface bond.

Keywords: precast; concrete bridges; Accelerated Bridge Construction; prefabrication; dissipative controlled rocking; prefabricated substructure; closure-pour; couplers; unbonded post-tensioning; seismic design

Quality Control Plans for Girder and Frame Bridges

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Abstract

Infrastructure managers works every day according to some kind of Quality Control Plan (QCP) in order to ensure a desired quality with minimum traffic interruption balancing cost, risks (implicit or explicit) and performance. These QCPs varies significantly among European countries, which urges the establishment of a common European guideline. COST TU1406 Working Group 3 has the aim of providing a detailed explanation of the steps towards the establishment of a QCP. The approach is generic and evaluates performance values with due attention to: 1) Structure and its constitutive element incl. background material such as birth certificates, 2) Time-dependent Performance Indicators (PI) from observations (e.g. spalling) with due reference to the underlying deterioration processes (e.g. alkali-silica reaction) and 3) Related Key Performance Indicators (KPI) based on the Dutch risk-driven maintenance concept RAMSSHE€P. This paper outlines QCP's for concrete girder and frame bridges.

Keywords: Quality control plans, performance indicators, deterioration processes, demand processes, inspection, maintenance.

3D Non-Linear FE Model for a high Capacity Saw-tooth Connector

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Abstract

This study explains the behavior of a high capacity saw-tooth connector integrated into a slender reinforced concrete slab. The connector is designed to transfer high shear forces into the slab, either from steel trusses or cables, as in truss bridges or cable stayed bridges. A 3D finite element model is developed to investigate the non-linear behavior of a connector positioned in the middle of a slender reinforced concrete slab. An elasto-plastic material model is employed to define the nonlinearities of the plain concrete with Menetrey-Willam failure criterion and non-associated flow rule. Power hardening function and fracture based function are adopted to obtain the hardening / softening law, which defines the behavior of concrete, based on the stress-strain relation. That relation is acquired by using the crack band theory, which relies on the dissipated energy and element size in the model. The model shows an excellent agreement with the experimental force – displacement relation, with a discrepancy of 1-3% only. The flow of forces along the saw - tooth connection is investigated in more detail with a second FE - model. In this model the load transfer is restricted to the saw teeth only, which are arranged along the sides of the connector. The experimental data demonstrate an excellent correlation with the results obtained from the model. It is found that the shear resistance of the saw-tooth connector is much higher than the resistance of conventional types of shear connectors, like shear studs. However, it has brittle failure behaviour governed by the strength of the concrete.

Keywords: 3D-nonlinear FEM, Reinforced concrete, Saw-tooth-connector, Multiplas

Construction monitoring and control for Jiaomen River arch bridge in Guangzhou

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Abstract

For novel arch rib, it is difficult to control the accuracy of the segments and whole bridge, especially for special shape bridge. It is also hard to balance the maximum lateral displacement (MLD) of arch rib and the maximum axis force (MAF) of jigs when removing temporary supports at high altitude. To address these issues, firstly, the derrick arch bridge with a total span of 231 meters is taken as the research object. Following the establishment of the finite element (FE) model of the bridge, an innovative criterion is proposed to consider both axis position and inclination angle, in which the error during the closure stage of the bridge is controlled availably. Secondly, among three potential plans modeled with FE model, one was chosen to remove the jigs, which effectively reducing the MAF and the MLD. Finally, the field monitor tests were proofread with FE model results to ensure the reasonable state of the bridge.

Keywords: novel arch; unsymmetrical; extroversive; orientation; assembling jig removed; monitoring.

Conceptual design and construction of lightweight R-UHPFRC bridges

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Abstract

This paper is addressed to structural engineers motivated to design and build R-UHPFRC structures as cost-effective lightweight structures of original aesthetic expression. Basic principles and essential UHPFRC properties are outlined first. The conceptual design is illustrated by means of two designs in precast segmental construction, one for a railway bridge and one for a pedestrian bridge. The pedestrian bridge has been built and is in service since 2015 in Switzerland.

Keywords: Ultra High Performance Fibre Reinforced Cementitious composite materials (UHPFRC), R-UHPFRC, lightweight structure, pedestrian bridge, railway bridge, conceptual design, segmental construction, accelerated construction.

Case Study of Two U.S. Bridge Projects Using Prefabricated Bridge Elements Connected with Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC)

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Abstract

Accelerated bridge construction (ABC) techniques were used to rehabilitate two notable bridge structures in the United States in 2016; a 16.5-meter (54-foot) long, single-span superstructure carrying U.S. Route 30 over Bessemer Avenue near Pittsburgh, Pennsylvania and; a 5-span 308-meter (1,011-foot) long historic concrete arch bridge carrying Franklin Avenue over the Mississippi River near Minneapolis, Minnesota. These projects utilized prefabricated bridge elements (PBEs) that were connected together on-site using Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC). Different UHPFRC mix designs, supplied by LafargeHolcim, were used for each project. A rapid-set mix used for the Pittsburgh project allowed the single-span superstructure to be replaced during a 57-hour weekend road closure, while the Minneapolis project utilized a standard-set mix. In both cases, UHPFRC was used for its ability to rapidly achieve high strength as well as provide simple, strong, durable connections between the prefabricated elements.

Keywords: ultra-high performance concrete; UHPC; fiber-reinforced; UHPFRC; prefabricated bridge elements; PBE; closure pour; connections; accelerated bridge construction; ABC

Punching resistance of flat slabs strengthened with an added layer of UHPFRC

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Abstract

Existing Reinforced Concrete (RC) slabs often show insufficient punching shear resistance when verified for updated loads. A simple and fast method to strengthen these slabs is casting a layer of Ultra-High Performance Fiber Reinforced cement-based Composite (UHPFRC), with or without reinforcing bars, on its top surface. This method has been shown to be very efficient, as the layer of UHPFRC does not only increase the flexural resistance of the slab but it also carries part of the shear.

This paper presents a recently developed model to predict the punching shear resistance of composite slabs strengthened with an added layer of UHPFRC. In this model, the contribution of the RC section is estimated with a new punching resistance model based on plasticity and fracture mechanics. A method is proposed to calculate the contribution of the UHPFRC layer to the punching resistance.

Keywords: composite slabs; flat slabs; punching resistance; Ultra-High Performance Fiber Reinforced cement-based Composite (UHPFRC); strengthening; near interface cracking; triaxial stress state; compression zone; plasticity.

Strengthened Unreinforced Masonry (URM) structures with Ultra High Performance Fibre Reinforced (UHPFRC) layers under axial in-plane and horizontal out-of-plane loading

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Abstract

The structural upgrade of existing Unreinforced Masonry (URM) buildings is an area with increasingly interest worldwide and especially in low-middle income countries and in earthquake prone areas. The deficiency of the existing URM has been highlighted through collapses and severe damages during recent earthquakes which could be considered as one of the greatest causes of fatalities and economic losses during major earthquakes.

The structural upgrade of existing URM has always been a quite challenging task which is mainly attributed to the relatively poor bond between the 'new' material and the existing structures. In this study a novel technique has been investigated by the addition of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) layer together with partial repointing of the conventional mortar in order to increase the shear strength at the interface between masonry and UHPFRC. Numerical analyses have been conducted using Finite Element Analysis (FEA) models that have been calibrated in previous studies using experimental data for UHPFRC. Analyses have been conducted using different values for the thickness of the layer while the mortar-to-bricks and the UHPFRC-to-masonry interfaces have also been simulated. Numerical analyses have been conducted to investigate the axial in-plane and the horizontal out-of-plane behaviour of the strengthened URM specimens.

The numerical results demonstrate that the proposed technique can considerably improve the axial load strength of URM elements. In case of out-of-plane loading, the addition of UHPFRC has been proved to be quite efficient for the improvement of the stiffness and the maximum strength of existing URM structures.

Keywords: UHPFRC, masonry, strengthening, walls, axial load, out-of- plane.

Strengthening of plain concrete beams using Strain Hardening Geopolymer Composites (SHGC) layers

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Abstract

In this paper the application of novel environmentally friendly, Strain Hardening Geopolymer Composites (SHGC) for the structural upgrade of existing concrete elements has been examined. The binder of these cement-free materials (SHGC) is different from that used in conventional cement based systems. Ternary geopolymer binder is used instead of Portland cement, which is activated by a low concentration and content of alkaline liquids (Potassium Silicate). The addition of two types of fibres (steel and PVA) has been examined in order to provide enhanced ductility and energy absorption characteristics. These novel materials have been used for the strengthening of concrete prisms. SHGC layers have been applied to conventional concrete elements and composite prisms with 100 mm breadth and depth and 500 mm span length, and have been tested through flexural tests. The experimental results indicate that the addition of SHGC layers to existing concrete elements can considerably improve the flexural response of normal concrete. The proposed technique can lead to significantly higher flexural loading carrying capacity, while at the same time the ductility can be considerably improved, especially by the addition of PVA fibres which can also provide strain hardening properties.

Keywords: Geopolymer, SHGC, PVA fibres, steel fibres, fly ash and slag.

Effectiveness of UHPFRC cover for the seismic strengthening of deficient bridge piers

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Abstract

The paper presents the results of an experimental and analytical research program aimed at developing an innovative seismic strengthening technique using Ultra-high Performance Fibre Reinforced Concrete (UHPFRC) cover applied to existing bridge piers with deficient reinforcement detailing. Experimental results on full-scale rectangular bridge pier specimens with cross-sectional aspect ratios of 4:1 and 2:1 subjected to weak or strong axis bending showed that the exceptional mechanical properties of UHPFRC allow eliminating concrete failure modes such as splitting cracks, spalling and crushing, thereby allowing transferring lapped bar forces through the surrounding UHPFRC, as well as failure modes associated with inadequate reinforcement detailing. Refined 3D nonlinear finite element models were developed to provide a numerical tool for evaluating the performance the strengthening technique.

Keywords: Seismic strengthening; UHPFRC; Bridge pier; Lap splice; Bond splitting strength; Nonlinear finite element modelling.

Design of Gothenburg's new landmark bridge

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Abstract

One of Gothenburg's three existing connections across the Göta älv river is to be replaced, as the *Götaälv* bridge, constructed in 1939, has reached the end of its service life. The bridge is an important part of Gothenburg's transportation infrastructure, with roadways, light rail track and cycle and pedestrian paths crossing the river fairway. The City of Gothenburg Urban Transport Administration held an international design completion to meet the city's ambition to create a new landmark for the city. The winning entry, *Arpeggio*, 440 m long and with a 42 m lift span, is part of the new *Hisings* bridge, which has a total length of approximately 800 m. The width of the bridge varies between 35-42 m and it runs parallel to the existing Götaälv bridge. The detailed design of the new bridge was produced by COWI Sweden together with the winning design team of *Arpeggio*.

One of the great challenges for the project comes from the ground conditions in Gothenburg, with great depths of soft clay often containing contaminations from historic heavy industry. Pipe piles with minimal mass displacement were chosen both to safeguard the function of the existing bascule bridge and to provide a solid foundation for the new lifting bridge. Keeping public transport in Gothenburg and the fairway open during the entire construction period of the new bridge requires well adapted technical solutions and meticulous planning. The construction of the bridge started in January 2017, but this paper presents the design phase which lasted for about four years.

Keywords: bridge; movable bridge; lift bridge; steel pipe piles; steel-concrete composite

Four High Performance Concrete Deck Configurations for Louisiana's Movable Bridges

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Abstract

Louisiana has approximately 160 movable bridges, mostly in the southern part of the state. The typical deck systems in these movable bridges are steel grids. Records show that steel grids have had maintenance issues. Four alternative high performance concrete (HPC) bridge deck configurations were developed for Louisiana's movable bridges using four unique concrete mixtures. The development of each concrete mixture is presented. Additionally, each mixture is characterized in terms of its compressive strength, tensile strength, modulus of elasticity, and Poisson's ratio. Several nonlinear finite element analyses are performed to simulate the behaviour of all four deck configurations from the onset of loading to failure. AASHTO's ultimate load demand is met regardless of which deck configuration is selected. The panel that features the LHWPC 130 mix exhibited the highest peak load and offers the simplest geometry.

Keywords:

Movable bridge decks; high-performance lightweight concrete; finite element analysis.

Grayston Pedestrian Bridge: A Shared Perspective of South Africa's Connectivity and the Challenges of Getting There

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Abstract

The Grayston Pedestrian Bridge forms part of a pedestrian and cycling corridor recently built to connect residents of the Alexandra Township to the wealthy business district in nearby Sandton in the Gauteng Province of South Africa. Alexandra is one of the poorest urban areas in South Africa whilst Sandton is one of the Country's most affluent. Previously separated by vehicle-centric infrastructure, the "Great Walk" project includes integrated bus rapid transit systems and provides unobstructed daily movement for the more than 10,000 people via a 6m wide sidewalk and bicycle lane with a 289m long cable-stayed pedestrian bridge over the busy M1 freeway at the Grayston Interchange. The project was envisaged as a community focused project incorporating sustainable best-practices such as local labour and design approaches intended to minimise future maintenance needs. While the project has achieved the original design goals, unforeseen challenges arose during the project's tender and construction process. This required the project team to identify innovative solutions during construction without impacting the project's bottom line. This paper intends to share the innovative ambitions from the challenges encountered on this important project for South Africa.

Keywords: pedestrian; bridge; post-tensioning; cable-stayed; concrete; box girder.

Bridge scour monitoring: challenges and opportunities

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Abstract

Scour and related hydraulic causes have been identified as the reason for almost 60% of over-water bridge failures in the United States. Hundreds of millions of dollars have been spent in direct repair costs. With increased frequency of flooding due to erratic rainfall patterns, scour-related damage to bridges is expected to increase. In the last few decades, several periodic and real-time scour monitoring systems have been developed. This state-of-the-art review introduces various contact and non-contact methods of bridge scour monitoring along with their strengths and limitations. Next, the challenges in installation and performance of some of the scour monitoring techniques in field applications are discussed. Indirect methods of monitoring bridge scour based on ambient and forced vibration analysis of the structure are also reviewed. Finally, the paper also provides some thoughts on novel methods of conditions assessment hitherto not tried for scour monitoring.

Keywords: Structural health monitoring, sensors, bridge Scour, hydraulic,

The 102nd Avenue Bridge over Groat Road – Design Concept and Challenges

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Abstract

The 102nd Avenue Bridge over Groat Road in Edmonton, Alberta, Canada is a 113 m long bridge that spans over Groat Road which is located in a 22 m deep ravine. The bridge replaced a 104 year old bridge on steel trestles. The selection of the replacement bridge had to take into account several factors including marginally stable steep ravine slopes and traffic disruptions in the urban environment. In addition, the client requested a "character" bridge which placed more emphasis on the aesthetic appearance of the bridge. Out of six options that were initially considered, a single span steel haunched girder design with integral concrete abutments on piles situated at the top of the slopes was selected to avoid foundations on the steep slopes. This required the development of an integral abutment bridge design concept, consisting of an 83 m long main steel span connected to 15.6 m long integral concrete abutments supported on hybrid steel and concrete piles at the back and sliding bearings at the front of each abutment. This concept created several design challenges:

- With a total length of 113 m and a design temperature range of over 70°C, the bridge is considered to be at the upper span limits for integral abutment bridges;
- Since the concrete abutments act as short back-spans to the main span, there was the potential for uplift at the back of the abutments;
- Force continuity between the 83 m steel span and the abutments required that the connection of the 83 m steel span to the concrete abutments had to be designed to transfer large moments; and
- The adopted design concept required a construction sequence that would not affect the integrity of the connection between the steel span and the concrete abutments.

This paper presents the design concept and approaches, and construction methods for this structure.

Keywords: bridge, bearing, composite, hybrid, integral abutment, fatigue.

Special Accommodation for Structural Steel Coating of Burlington Bay Skyway

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Abstract

The northbound structure of Burlington Bay Skyway in Hamilton, Ontario recently underwent major rehabilitation. This included a component for the recoating of the structural steel in the 150 m-long overhead main span arch. The primary operational constraint was that traffic lanes stay open throughout construction. The additional gravity loads and wind loads from the scaffolding and environmental enclosures posed serious structural overload concerns. Extensive computer analysis and scenario testing enabled the development of a staging arrangement, structural strengthening scheme, high wind closure protocol integrated with rapid lane closure gates, and an overheight vehicle detection advanced warning system. This rehabilitation of the bridge commenced in Spring 2014 and was completed on time in Fall 2016 with no significant traffic delays or disruptions. Structural integrity was successfully maintained throughout construction.

Keywords: steel coating, truss strengthening, construction staging, advanced modelling, wind design, traffic management, scenario testing

Latest Practices for Existing Long-Span Suspension Bridges

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Abstract

This paper discusses three latest practices applied to existing US long-span suspension bridges. The first is the moveable median barrier (MMB) along U.S. Highway 101 on the Golden Gate Bridge that was recently installed. This MMB system enhances traffic safety by providing a physical barrier to separate opposing directions of traffic, while at the same time allowing the reconfiguration of the lanes to meet peak capacity demands. The second is the suicide deterrent barrier system (SDS) to be installed on the Golden Gate Bridge, the first of its kind in the United States. The Net system was identified as the Preferred Alternate in the FEIR/EA process to be carried forward to final design. The third is the corrosion protection of main cables by dehumidification, first implemented in the United States on the William Preston Lane Jr. Memorial Bay Bridge and now being planned or implemented on other US main cable suspension bridges.

Keywords: suspension bridge; moveable barrier; suicide deterrent system; cable dehumidification.

Detail design of Chacao Bridge in Chile

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Abstract

The paper describes the design process of the Chacao Bridge in Chile, what have been the challenges in the design, and how these challenges are solved. The bridge is a multi-span suspension bridge with main spans of 1155m and 1055m and with a total length of approximately 2750m, making it the longest suspension bridge in South America, connecting the island of Chiloe to mainland Chile. The bridge site is subjected to severe environmental loads, and particular effort has been on ensuring seismic robustness, since the site is located in a high seismic zone. The detail design is performed by consultants Aas-Jakobsen from Norway and Systra from France for Consorcio Puente Chacao. The bridge owner is MOP Chile.

Keywords: suspension bridge, multi span, design challenges, pylons, approach bridge, saddles, main cable

Some aspects of Chacao Bridge design

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Abstract

The 2,750m-long Chacao Bridge, South America's longest suspension bridge, will connect mainland Chile with the country's largest island Chiloe. The three-tower suspension bridge will have main spans over 1km in length (one 1055 m and the other 1155 m). The central pylon with inverted V shape shown in the reference design has been modified by SYSTRA. The bridge being located close to an active seismic fault, particular care was considered on seismic robustness, and many specific seismic analysis were performed. The total length of the suspended steel superstructure is 2494 m and the weight about 21,000 tons. The bridge girder is continuous from the South pylon to the North abutment.

Keywords: suspension bridge, pylon, push-over

Service Life of Concrete Structures for the Longest Suspension Bridge in South America

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Abstract

It is widely recognized that service life can be economically extended with more robust and durable initial design and construction than in the future by rehabilitation of a deteriorated asset. In an effort to reduce life-cycle costs, new major concrete structures are designed for service lives of 100 years or more; longer than the 75 years typically assumed in structural design codes. To confidently achieve the required service life, engineers must go beyond current structural design codes and assess deterioration mechanisms and mitigation measures specific to each structure and its environment. Similar to modern structural design codes, a rational, reliability-based approach can be used. This paper presents a state-of-the-art durability design methodology that is used on the concrete components of the Chacao Bridge, required to achieve a 100-year service life.

Keywords: Service life design; durability; concrete; chloride-induced corrosion; bridges.

Challenges with Building the Longest Suspension Bridge in South America - Overview of Issues – The Owner's Perspective

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Abstract

The Chacao Bridge is the first major bridge project in Chile, and when built it will be the largest suspension bridge in South America. The 2,750 m-long structure will connect the island of Chiloé with mainland Chile across the Chacao Channel. The three-tower suspension bridge will have main spans over 1 km in length each. The project is being executed through a Design-Build procurement method, through the Department of Roads within the Ministry of Public Works.

It is expected that the bridge will improve tourism, increase investment and business opportunities on the island and provide better access to medical care.

The design faces many challenges related to the environment where the bridge is located; high seismicity, high wind, volcanos, tsunamis, sea waves, and potential erosion of the central island (Roca Remolinos) and the shores. There are also construction requirements and procedures that go beyond common local engineering practice.

This paper presents the design and construction challenges for the project from the Owner's perspective. Also, it discusses the interaction within the project team: owner (MOP), owner's engineer (RyQ and COWI NA) and the construction JV working together for successful delivery of this high profile project.

Keywords: Owner perspective, design, bidding process, suspension bridge.

Service Life Performance Design of Chacao Bridge

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Abstract

To ensure the service life performance of an exceptional bridge like the Chacao Bridge, it has been paramount to the owner MOP in the design to take care of all aspect of the future operation and maintenance of the bridge. The goal is to ensure a future service life with low operational costs and high and safe bridge availability for traffic. Therefore, unlike design of conventional bridges, the Chacao design build project integrates durability, access and future operation in the design process.

This paper described how an adequate service life performance design can be achieved in the design build contract for the Chacao Bridge. The overall goal is to minimize the life cycle costs of the bridge with a service life of more than 100 years. The bridge design applies modern durability design approaches, control and monitoring systems, access facilities – all aspect which will be documented in an Operation & Maintenance Manual with instructions on how to operate the bridge in the future.

Keywords: Suspension Bridge, performance design, enhancement of durability, operation and maintenance, structural health monitoring.

Proof load testing of the viaduct De Beek

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Proof load testing can be a suitable method to show that a bridge can carry the required loads from the code without distress. This paper addresses the preparation, execution, and analysis of a proof load test on a four-span reinforced concrete solid slab bridge, viaduct de Beek. The bridge has one lane in each direction, but was restricted to a single lane, since an assessment showed that the capacity is not sufficient to allow both lanes. For this proof load test, the bridge was heavily equipped with sensors, so that early signs of distress can be seen. The difficulty in this test was that, for safety reasons, only the first span could be tested, but that the lowest ratings were found in the second span. A direct approval of the viaduct by proof loading was thus not possible, and an analysis was necessary after the field test. The result of this analysis is that only by allowing 6.7% of plastic redistribution in the second span, sufficient capacity can be demonstrated.

Keywords: existing bridges; load testing; proof load testing; reinforced concrete bridges; bending moment capacity; sensors; slab bridges

Testing Bridges to Failure - Experiences

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Abstract

Four bridges of different types have been tested to failure and the results have been compared to the load-carrying capacity calculated using standard code models and advanced numerical methods. The results may help to make accurate assessments of similar existing bridges. Here it is necessary to know the real behaviour, weak points, and to be able to model the load-carrying capacity in a correct way.

The four bridges were: (1) a one span steel truss railway bridge; (2) a two span strengthened concrete trough railway bridge; (3) a one span concrete trough bridge tested in fatigue; and (4) a five span prestressed concrete road bridge.

The unique results in the paper are the experiences of the real failure types, the robustness/weakness of the bridges, and the accuracy of different codes and models.

Keywords: bridges, testing, assessment, load-carrying capacity, reinforced concrete, prestressed concrete, steel, analysis, codes.

The Åby Bridge placed beside the rail track for testing, Häggström et al (2017).

Determination of dynamic properties of railway bridges through forced excitation

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The determination of dynamic properties of railway bridges is important for the assessment of structures, for example, to show their suitability for changing operating conditions (e.g. new train types, higher train speeds). Besides the determination of natural frequencies and mode shapes the identification of damping and its non-linear behaviour can be a particularly challenging task when dealing with stiff structures (e.g. frame bridges with short spans) using conventional methods like ambient vibration monitoring or impact testing. Also the results of measurements conducted by different companies may differ due to different methods used during data evaluation.

The project "KOMET" (funded by the Austrian Federal Railways – Division ÖBB-Infrastruktur AG) carried out by the engineering company REVOTEC, the research institute AIT and the Technical University Vienna aims to show the potential and the benefits of assessing dynamic parameters and their non-linear behaviour using forced excitation. Another focus of the project is to improve the comparability of measurements carried out by different contractors by updating a current guideline.

The paper will present results of three bridges from a first monitoring campaign conducted on newly erected short to medium span railway bridges. By comparing results from different methods of excitation (ambient, sandbag, impulse hammer and different exciters) the advantages and applicability of the individual methods will be shown. If possible also the non-linear behaviour of dynamic parameters (especially for damping values) are determined from the results.

Keywords: bridges, damping, forced excitation, mode shapes, natural frequencies, short spans, railway

Robustness-based assessment of railway masonry arch bridges

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Abstract

In the past decades, structural robustness has gained major interest due to the collapse of remarkable structures, such as the Ronan Point tower and the World Trade Center. In both situations, a local damage lead to structural collapse, triggering research to restrain progressive collapse in structures. Masonry arch bridges are important historical structures, with many of them still in service. Over their long lifetime, deterioration and damage have affected their ultimate load-carrying capacity, which must be considered when evaluating the safety condition of these structures. This paper presents a methodology for robustness-based assessment of masonry arch railway bridges, by computation of the ultimate load-carrying capacity resorting to the limit analysis method. The main damage scenarios, namely their location and extension, will be presented and discussed. The influence of such damage is discussed in detail, as well as the most influencing structural parameters, being justified the robustness capacity in such cases. The developed methodology is then applied to a Portuguese railway masonry arch bridge.

Keywords: Masonry Bridges; Reliability; Structural Robustness; Damage; Vulnerability; Redundancy.

Behavior of transition plates crossing high-speed railway bridge joints in Germany

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Abstract

Great stresses at the continuously welded rails (CWR) and large fastener forces at bridge joints due to the deformation of bridge ends have been observed in German high-speed railway lines. In order to limit the influence of this localized track–bridge interaction, a novel structure with a transition plate crossing the bridge joints has been applied in the new German high-speed railway line. The utilization of transition plates reduces the restraint forces caused by the deformation of the bridge ends. It divides the large gap at the bridge ends to two smaller gaps at the transition plate ends and ensures that the tensile and compressive forces in the fasteners do not exceed the permitted values at the bridge ends. In this paper, the behavior of the transition plates crossing the bridge joints is discussed. Measured bearing settlements and the dynamic response of the transition plates crossing bridge joints under high-speed train loads are analyzed.

Keywords: Transition plates; bridge joints; track–bridge interaction; high-speed railway; bridge monitoring.

High toughness RC railway viaduct with columns reinforced by arranging a spiral rebar inside of the longitudinal bars

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Abstract

Since Japan is the land of earthquakes, the seismic design is very important for the design of civil engineering structures and the design of architectural structures in Japan. The seismic design standard has been revised by the damage of earthquakes in the past. After the 2011 off the Pacific coast of Tohoku Earthquake, there is the need for Anti-Catastrophe Performance and redundancy to have the measures for Unanticipated Earthquake in the seismic design of Japan.

Therefore, the authors developed the new method of the reinforcing bar arrangement. The new method can enhance dramatically ductility capacity in the RC column, so it is possible to give sufficient redundancy against Unanticipated Earthquake. The authors think that it is a very effective technique in the seismic design. In this report, we report the performance evaluation method of the RC column by the new method and the construction results.

Keywords: seismic design, RC rigid-framed viaduct, ductility, Anti-Catastrophe Performance, redundancy

Debris barrier design using energy-balance techniques

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Abstract

The design of structures that are intended to protect inhabited areas and infrastructure from debris mass movement events poses particular challenges. The impact of a debris flow places an energy demand on the structure and traditional quasi-static design approaches are limited by the arbitrary selection of dynamic impact factors. For debris barrier design, an energy-balance approach, that equates the internal work of the structural elements to the kinetic energy of impact, is appropriate. Two recent flexible grillage debris barrier projects near the Resort Municipality of Whistler illustrate the application of this technique.

Keywords: debris barrier structural design, debris flows, debris floods, impact loads, energy balance, strain energy analysis, flexible grillage debris barriers

Besiktas stadium roof : innovative design and construction method

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Abstract

Located nearby the historic part of the city, the Vodafone Arena Stadium, replacing the former Besiktas JK Inonu stadium, stands out thanks to its remarkable covering of 26000m² that can shelter up to 42 000 spectators. The big lift method, used successfully in the last decades to lift lightweight and flexible structures composed by cables only, has been adapted for this project to lift a mixed structure, allying the stiffness of a highly hyperstatic steel frame and the shape-depending behavior of a cable structure. After being assembled on the ground, the structure was lifted on a distance of approximately 21m with 42 strand jacks, developing a total towing force of 7000t. Strict control procedures and geodetic checks were necessary to coordinate the 42 lifting points.

The paper describes the general design approach and the specific site conditions; the construction method is detailed from both a calculation and an operational point of view.

Keywords: stadium roof; full-locked cables; big-lift; construction methods; strand jacks; distortions; geometric control.

Organic Prestressing Impact in Multi-Span Large Deck Construction

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Abstract

In the past decades, a "critical range of spans" – 70m to 100m - for multi-span viaducts with concrete decks has been identified. The most common construction methods adopted for that type of viaduct are 1) cast in situ free cantilever; 2) precast segmental free cantilever and 3) precast full segment. With recent technological developments, another possible 4th alternative may be considered and studied for certain bridge types within the mentioned span range: in situ, span by span construction. In this presentation its features and its limitations are discussed considering the involved technological challenges.

Keywords: Bridge Construction, MSS, large spans, OPS

Design, Construction and strengthening of folded plate structures made by folding

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Abstract

Modern high performance materials like Textile Reinforced Concrete (TRC) offer new possibilities for the construction of very filigree and lightweight structures. Prefabricated plate elements can be transformed into complex three-dimensional shapes by folding without a laborious construction of curved formworks. In order to exploit the design space within the envisioned technology a method was proposed involving form-finding, simulation of folding process, and production concepts, as well as an assessment of structural performance. Since inspiration for this approach was derived from the ancient art of paper folding origami (ori=folding; gami = paper), we call the method oricreate and its application to concrete oricrete (ori- and con**crete**). By using the design and manufacturing methods, several prototypes of folded plate structures have been realized and tested with sizes up to 2,4 m x 3 m. The design and manufacturing process of folded structures and experimental investigations are described and methods for strengthening proposed.

Keywords: form finding, textile reinforced concrete, folded plate structure, concrete shell, folding, light-weight construction, strengthening, prestressing.

New Dynamic Center Piece for Montréal Delivers on All Challenges

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Abstract

The Canal Lachine Bridge is the new signature structure in downtown Montréal, Québec, Canada. The curved cable stayed bridge is the center piece of the $1.5 billion Design-Build Turcot Project. The 350m long structure will be built in stages to accommodate the overall project construction schedule. Delivered within the fast-paced Design-Build environment, the design required close collaboration between designer, contractor, architect, fabricator and owner.

The 50m wide superstructure carries two independent carriageways with a total of six traffic lanes. The main span utilizes a pylon and single plane fan arrangement of stays to support the 88m main span over the Lachine canal. The unique design had to accommodate building one carriageway to carry traffic for two years without cable supports before the second carriageway could be erected. Both halves will be tied together at the lower cable anchorages and the pylon location after establishing composite action. In this stage, they will form a unique, highly redundant composite steel grillage system that achieves both, efficiency and elegance.

This innovative extradosed bridge utilizes multiple steel box girders connected by cross frames and transverse tie-beams to create a single superstructure type. Composite action is achieved using slender full-depth precast deck panels to accelerate construction. The continuous superstructure is fully isolated from the substructure to control seismic design forces on substructure elements and their foundations. This allowed single columns and mono-pile foundations.

Keywords: signature structure; extradosed bridge; seismic isolation; curved composite box girders; staged and accelerated bridge construction.

Concept, Realization and Monitoring of an advanced space structure

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Abstract

The development of space grid structures experienced its maximum momentum in the third quarter of the last century. The mathematical and structural principles were described and many thousands of steel space grid structures in different shapes built. An advancement of form and structure of double layer space grids therefore cannot occur in the structural principle but in the use of new materials replacing parts of the structure.

Today in 2016 the authors are pleased to announce that more than five years ago a space grid structure with an upper (compression) layer made of glass panes only, perfectly fulfils its task covering a courtyard in the German capital Berlin.

At this structure, on the basis of a traditional steel double layer grid all members in the compression layer are replaced by the glazing. The glazing fulfils a double function. It serves either as the primary load bearing system and transfers significant in-plane loads or as roof covering. The panes are connected by steel knots at their corners and transfer in-plane forces via adjustable contact blocks.

After the main research phase the first commercial project using this new concept was launched in 2007. With a dimension of 15 m x 21 m and an arch rise of 3.50 m it covers the courtyard of one of the Berlin palaces. In autumn 2009 the palace was going to be re-opened to the public.

The design process was attended with extensive testing to obtain an individual approval. This contribution describes the testing at single panes and at a full-scale arch of 15 m span. Plastics for the in-plane load application into the glass edge and their creeping behaviour were investigated in first tests. The stability behaviour against glass pane buckling was tested at relevant load combinations and the post breakage robustness and the walk-on ability of the overhead glazing ensured by suitable test. Load bearing tests with a total load of 13 tons were applied on one 15 m arch and finished the test series.

Within the last years the structure and its components were monitored. With these experiences valuable feedback to the testing and design steps and recommendations for further projects were gathered.

Keywords: glass, roof, space structure, transparent, load bearing glazing, in-plane load, monitoring

Analysis and optimization of a continuous composite bridge with uplift-restricted and slip-permitted connectors

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Abstract

To improve the cracking resistance of reinforced concrete (RC) slab at hogging moment region in continuous composite bridge system, a new connection concept called the uplift-restricted and slip-permitted (URSP) connection has been proposed. This paper presents both the design and analysis of a three span continuous composite bridge where URSP connectors were used. Based on design process of the project, some practical design guidelines and construction methods are proposed for the application of URSP connectors. Finite element model of the bridge considering construction process is established according to the case project. Simultaneously, another model of the same bridge with only stud connectors is built for comparison, the results show that URSP connectors can effectively improve the cracking resistance behavior of RC slab with little influence on the overall stiffness and strength of the composite beam. Furthermore, the optimization analysis of URSP connector at structure level is studied. The design guidelines and the analysis results in this paper can provide a reference for further study on the application of URSP connectors in continuous composite bridge system.

Keywords: continuous composite bridge; optimization analysis; cracking resistance; hogging moment region; uplift-restricted and slip-permitted.

Optimization of Sealing Plates for Hanger Connections at Tied Arch Bridges

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Abstract

Railway bridges are a central component of the rail network in Germany and all over the world. These bridges, particularly in the case of large spans, are often designed as tied arch bridges with flat steel hangers. There are several variations for the connection between these hangers and the main support elements (bows or stiffening girders), whereas the most common connection type is an intersection between the hanger extension and a partition plate located inside the main support element. In this case, the hanger has to transverse one of the flanges of the main support element which leads to a hole in the flange. Usually, a sealing plate of 6 to 12 mm thickness is used to close this hole in order to protect the main support element from humidity. The sealing plate is welded circumferentially to the hanger at its inner side and to the flange at the external edges.

In the past, several damages were noticed at the outside welds of such sealing plates. Therefore, the question arises, how to optimize the sealing plates in order to increase their robustness and lifetime. For this purpose, finite element simulations are carried out for this detail and different shapes of sealing plates are compared. Amongst other results, it is shown that roundings of the corners do not always lead to a reduction in the relevant structural stresses.

In order to validate the simulations, fatigue tests on scaled models are also carried out. The surface stresses are measured with strain gauges.

In this paper, the results of the simulations are compared with the results from the fatigue tests and recommendations for the shape and manufacturing of the sealing plates are given.

Keywords: Tied arch bridges; hanger connections; sealing plates; fatigue; finite element simulation, welding.

Rayleigh-Ritz/Finite Element Analysis Of Plates By Singularity Functions

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Abstract

A novel analysis method is developed for the analysis of Timoshenko type plate bending loaded by concentrated loads. A stiffness matrix and a consistent load vector are assembled via the minimum potential energy principle and solved for a set of unknown variables. The rules described herein for assembling such as matrix may yield a matrix that is rank deficient (the matrix column vectors do not span the space of dimension equal to the matrix size, there exists a null-space). Solution to the equations is possible by the use of the singular value decomposition, (s.v.d.). The original problem is thus transformed to one having less unknown variables that are all independent. The redundant transformed variables, that correspond to the null-space, are discarded. An industrial reinforced concrete raft on an elastic foundation is presented as a worked numerical example and compared to Strand7® software finite element analysis.

Keywords: reinforced concrete, slab, foundation, finite element analysis, Rayleigh-Ritz analysis

Finite Element Model Update of Cable Supported Bridges Using Large Scale Global Optimization Technique

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Abstract

An effective optimization method is introduced for the finite element model update of cable-supported bridges. When typical model update methods are applied, there are some difficulties in solving the optimization problem such as local, pre-matured, non-satisfactory solutions due to the large number of updating parameters. Thus, in order to solve the minimization problem effectively, we adopt a large scale global optimization technique which can utilize several algorithms simultaneously. The proposed method is based on the Multiple Offspring Sampling (MOS) framework in which multiple optimization algorithms including genetic algorithms and particle swarm optimization are dynamically combined to produce the global optimal solution. The application example of an existing suspension bridge shows that the proposed method can be effective to update dynamic finite element models.

Keywords: finite element model updating; suspension bridge; large scale global optimization; multiple offspring sampling; genetic algorithm; particle swarm optimization.

Optimization of the curved pylon

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Abstract

Thu Thiem 2 Bridge is a new crossing to be built over the Saigon River in the city center of Ho Chi Minh City in Vietnam. It will be a landmark for a new urban Thu Thiem area and for the whole city. The cable-stayed bridge has a single, well recognizable, backwards curved pylon and asymmetric span arrangement with lengths of 200 and 115 meters (Figure 1).

In the engineering design phase, the structure shall be optimised, including minimization of quantities, whilst ensuring constructability and safety of the works. Normally, the minimization of quantities brings about financial savings, however in a challenging construction the ease of erection may also be the key for economical success.

This paper discusses the design of the complex structural concept of the Thu Thiem 2 Bridge, with particular attention to the design of the pylon. Optimization, in big and complex bridge projects, is a chain of choices based on designers' experiences as well as understanding of the local environment and construction culture. This is not often a measureable task.

Keywords: cable-stayed; bridge; design; curved pylon; long span bridges; Signature bridge.

Figure 1. Thu Thiem 2 Bridge. View from north-east

Self-anchored Suspension Bridge Model Updating with Artificial Neural Network and Modified Particle Swarm Optimization

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Abstract

To yield an adequate FE model, a hybrid model updating method is proposed by using ANN, modified PSO and LHS. In this paper, firstly, the theories of ANN, modified PSO and LHS method are described; Secondly, the procedures of the proposed method is presented; Finally, the application to the model updating of a self-anchored suspension bridge with extra-width is conducted with two objective functions, Method A considers dynamic response and Method B considers both dynamic and static responses. The results show that frequency differences between test and modified model were narrowed compared to results between test and initial model after model updating using both methods as all the values are below 9% which are 25%-40% initially. The MACs increase a little illustrating that more agreeable mode shapes are obtained as all of the MACs are over 0.85. This indicates that a relatively more adequate FE model can be yielded with high efficiency without losing accuracy by the method. Through the comparison between two objective functions, it can be concluded that model updating of real structure should take both static and dynamic response into consideration as results of Method B is more reasonable that the static displacement is closer to the experimental value and the dynamic characteristic is within the acceptable limitation of engineering.

Keywords: model updating; BP neural network; Gaussian mutation; particle swarm optimization; Latin Hypercube Sampling; self-anchored suspension bridge.

Numerical analysis of vertical pipe damper

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Abstract

This paper proposes a new metallic energy dissipative device to mitigate structural damages under seismic excitations. In general, metallic dampers dissipate seismic energy through yielding. The inelastic cyclic deformation of the proposed damper, dissipates the seismic energy through yielding of the steel material. Herein, a three-dimensional finite element model of the damper is developed considering material nonlinearity, large displacement and contact. To aid the aim, the damper performance is studied through cyclic quasi-static tests. The parametric study is performed to find which parameters have higher influence on its performance. The results show that, the damper is exhibited excellent strength and ductility, stable hysteresis force-displacement behaviour with notable energy-absorbing capability to dissipate the seismic energy. Furthermore, it is found to have light weight, economical with ease of fabrication and implementation which used as a potential alternative for passive control of structures.

Keywords: passive energy dissipation; yielding damper; metallic damper; seismic control; hysterics curve; Vertical Pipe Damper

Signal stationarization technique in output-only damping identification

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Abstract

The aim of this study is to propose the enhanced damping estimation process with output-only system identification technique by signal stationarization algorithm using amplitude-modulating (AM) function. First, a series of field measured data was analysed to demonstrate the effect of nonstationarity in operational monitoring data from cable-supported bridge. Next, in order to eliminate an effect of nonstationarity due to a traffic loading, AM function was calculated by the temporal root-mean-square function of measured responses. The approximated stationary process was extracted by dividing the sample record by envelop AM function. For the verification of the proposed techniques, a signal stationarization algorithm was applied to the measured acceleration response from cable-stayed bridge. After then, a damping ratio of cable-stayed bridges was estimated by applying Natural Excitation Technique combined with Eigensystem Realization Algorithm (NExT-ERA) to the stationarized signal obtained from 3-day ambient vibration data. To show the enhanced performance of the proposed procedure for damping estimation, the mean and coefficient of variance (COV) of estimated damping ratio were compared with/without signal stationarization process. The amplitude-dependency of estimated damping ratios was also analysed according to applying a signal stationarization.

Keywords: damping estimation; operational modal analysis; nonstationary; signal stationarization; cable-supported bridge

Design and Commissioning of a New Liquid Damper System for Wind-Induced Vibrations of Buildings

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Abstract

An innovative damper to reduce wind-induced vibrations in tall buildings was developed by Thornton Tomasetti in collaboration with the National Aeronautics and Space Agency (NASA). The system is a collection of small liquid column dampers equipped with air springs and presents a number of performance, cost and practical advantages over traditional tuned mass dampers. A first implementation of the system was installed in 2016 on a residential building in Brooklyn, NY. This paper relates the design process of this prototype, which evolved during construction of the building as its dynamic properties became known with more certainty. The active and passive tests performed to tune and commission the damper are then described. The paper finally reports on the performance of the system measured after installation.

Keywords: tuned mass damper, vibration, acceleration, wind, serviceability, commissioning.

Development of post-installed mass damper for automated warehouse

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Abstract

A vibration control system for an automated warehouse was developed that can be applied to existing warehouses as well as newly built ones. The device used for this system is the "post-installed mass damper" that can be post installed on the cargo storage space in an automated warehouse. This damper has a large mass that causes a sustainable effect of reducing the response across a wide range of natural frequencies of an automated warehouse, which vary depending on the number of stacked cargoes and their weight. The results of the shaking table test demonstrated that the fall of cargoes by the earthquake ground motion could be prevented by using this damper because the accelerations of the rack were reduced to 50%-70%. Moreover, this effect was confirmed by the analysis conducted with the proposed model. The acceleration of the rack top was reduced to 80% and the maximum slip displacement of the cargoes was reduced to 25%.

Keywords: automated warehouse; post install; mass damper; cargoes fall; vibration control; shaking table test; response analysis.

Optimizing Nonlinear Damper Performance for Multi-Mode Cable Vibration Control based on Forced Vibration Responses

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Abstract

Nonlinear damper is promising to provide higher energy dissipation when attached to a stay cable at a near-anchorage position, compared to linear damper. This is because the nonlinear control force can induce significant participation of higher cable modes in vibration responses by which the vibrating energy is dissipated more quickly. However, the control performance of a nonlinear damper for a cable depends on both the vibration mode and amplitude, and there exists no explicit formula to predict the damping performance for such a nonlinear system. Numerical analysis is required, rendering the damper performance optimization for multi-mode vibration control difficult. This study proposes to optimize the nonlinear damper performance for multi-mode cable vibration control based on forced vibration responses of the system, in particular the system responses under harmonic excitations. This approach facilitates the optimization owing to the fact that the periodic responses of the nonlinear system can be efficiently solved using harmonic balance method; furthermore, a numerical continuation method is used for obtaining the frequency response functions over the concerned frequency range. Moreover, the nonlinear system partial differential equation is expressed in a dimensionless form and hence the numerically obtained frequency response function represents a subset of the dynamics of the general system. Consequently, the optimization of the nonlinear damper performance can be realized by minimizing the peaks of the system frequency response functions corresponding to varied modes and excitation amplitudes of practical significance, with respect to the damper parameters. A nonlinear viscous damper is chosen for illustrating the optimization procedure for multi-mode vibrations of the cable, demonstrating the effectiveness of this method.

Keywords: Cable stay; Multi-mode control; Nonlinear damper; Optimization; Forced vibration analysis; Harmonic balance method; Numerical continuation; Frequency response function.

Design example of mid-story-isolated skyscraper with the viscous dampers to reduce the response acceleration in lower part of the building

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Abstract

This paper introduces a design case of 230-meter-tall mid-story-isolation skyscraper in Roppongi, Tokyo. Since the response reduction by seismic isolation on buildings over 200-meter-tall is smaller than general low-rise buildings, these buildings hardly adopted mid-story-isolation structure. Mid-story-isolation buildings are adopted to reduce the response in the upper part of the building, but in actually, the response acceleration is often largest just below the isolation story. In this paper, we introduce the architectural and structural planning for adopting a mid-isolation structure for a skyscraper building and solution methods in this project. The realization of this building presents new possibilities for skyscrapers and mid-story isolation buildings.

Keywords: Skyscraper; mid-story-isolation; viscous material shear wall; oil damper; steel damper.

Basic design for a Submerged Floating Tube Bridge across the Digernessundet

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Abstract

This paper describes the basic structural design for a Submerged Floating Tube Bridge (from now on SFTB) across the Digernessund in Norway. The SFTB is proposed as part of a scheme for a new and improved fixed link along the E39 route, across the Bømlafjord in Norway. The existing fixed link consists of a 7.8 km long subsea rock tunnel below the main part of the Bømlafjord, and a 677 m long suspension bridge spanning across the Digernessund, which was too deep for a subsea rock tunnel. The two parts of the link meet at a small island named Føyno. The existing tunnel does not comply with new EU regulations for tunnels due to the high gradient, but an improved tunnel with a SFTB through the Digernessund will solve the problem.

The paper will discuss different structural solutions for the SFTB. A possible construction method will also be evaluated.

Keywords: Bridges, design, submerged structures

Hydrodynamic analysis of the submerged floating tunnels under irregular waves

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Abstract

Many concepts of the submerged floating tunnels, which consists of floating tunnel segments and mooring systems, have been continuously suggested for the new-type transportation system. Although the SFTs show structural effectiveness and economic efficiency compared to the conventional oversea transportation structures such as oversea bridges and underwater tunnels, there is still no real construction example due to lack of sufficient researches about hydrodynamic behavioural characteristics with rational global performance analysis methodologies. For designing the main structural members such as floating tunnel segments, mooring lines, and anchor systems, the engineer should apparently know the behavioural characteristics of the SFT under the design environmental loading conditions first. Because the SFT moored at the pre-defined underwater location with specific draft is affected by waves and currents, the submerged floating structure shows significant dynamic responses continuously. Therefore, rational hydrodynamic analysis should be conducted in order to evaluate the global performance of the SFT and calculate the structural responses such as motion, internal forces, and stresses under the governing design loads. In this paper, the methodology of rational global performance analysis is suggested based on time domain hydrodynamic analysis. Using the method, significant dynamic characteristics of the submerged structures under the irregular waves are studied.

Keywords: submerged floating tunnel; hydrodynamics; offshore; time-domain analysis; structural dynamics; fatigue; mooring

Dynamic Analysis of a Suspension Bridge with a Floating Girder

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Abstract

A continuum model for a three-span suspension bridge with a floating girder is presented to investigate its dynamic behavior under moving loads and vertical support motions. This model can consider hangers' extensibility. Coupled differential equations for the vertical displacements of a main cable and a girder subjected to external loads are presented. Equations of motion in matrix form are obtained by introducing the Galerkin method with shape functions for the main cable and the floating girder. A numerical example is used to verify the continuum model against a finite element model.

Keywords: suspension bridge; continuum model; floating girder; dynamic analysis; moving loads; vertical support motions.

Concept overview of a multi-span suspension bridge on floating foundations

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Abstract

A ground-breaking solution is envisaged for the crossing of Bjørnafjorden on the West coast of Norway. The proposed solution consists of a three span suspension bridge whose two central pylons rest on floaters. The floaters are inspired by the Tension-leg platform technology commonly used in the offshore industry in areas of extreme depths. Similarly to Tension-leg platforms, the floaters are anchored to the seabed by means of vertical tethers. Different floater geometries, both in concrete and steel, have been considered. A top cable has been introduced between the top pylons in order to provide the system with sufficient longitudinal stiffness to accommodate the asymmetric traffic load situations that would, otherwise, lead to large deflections in the loaded spans. The rest of the superstructure consists of the main suspension cables, pylons, hangers and an aero-dynamical bridge girder. Multi-span suspension bridges, tension-leg platforms and top cables are known and proven technologies however they are brought to an unprecedented scale and combined into a construction that could become one of the world's most innovative bridges.

Keywords: Strait crossing, floating bridge, suspension bridge, offshore structure

Effect of Triangle Cables Configuration on the Behavior of Reinforced Concrete Submerged Floating Tunnel under Hydrodynamic Load

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Abstract

This study aimed to perform a further analysis regarding the Reinforced Concrete Submerged Floating Tunnel of Triangle Cables Configuration (RC-SFT TCC) system fitting to attain the structure with the optimum configuration. The TCCs were inducted into several configurations, namely C1, C2, C3, and C4 that remined the two angle inclined cables of 36˚ and 45˚ respectively with a different pattern. Subsequently, a numerical modelling was also carried out using Finite Element Method (FEM) with the employment of SAP2000. Buoyancy Weight Ratio (BWR) of 1.3-1.5 were also added in this study to provide the optimum of the RC-SFT configuration. The modelling result showed that the C1 provided the most optimum configuration due to the maximum axial forces of 1145.1 kN. The C1 was also considered giving a better performance due to load-deformation behaviour than the C2, C3, and C4 models. Finally, it can be confirmed that RC-SFT is feasible to be applied as an alternative infrastructure due to its results.

Keywords: reinforced concrete, submerged floating tunnel, triangle cable configuration, numerical modelling, hydrodynamic load;

Coupled wind and wave load analyses of multi-span suspension bridge supported by floating foundations

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Abstract

The TLP suspension bridge concept is a novel design proposed for crossing the wide and deep fjords along the E39 highway on the west coast of Norway. The bridge concept consists of a multi-span suspension bridge supported by one or more tension leg platforms. An accurate and representative load formulation for wind and wave excitation is essential for design of these structures. This article presents time domain analysis of a TLP suspension bridge subject to wind and wave loading. Analyses are performed for both coupled and separate wind and wave loading, in order to investigate possible coupling effects between the two environmental loads. A fully coupled nonlinear Newmark time integration scheme is used, where structural geometric nonlinearities, frequency-dependent hydrodynamic radiation properties and wind interaction are included. New developed tools are used for parallel calculation of the time domain calculations. Presented study shows a coupled effect search strategy.

Keywords: Multi-span suspension bridge; time domain analysis; coupled wind and wave analyses; wind interaction; hydrodynamics; parallel calculation.

Sustainable Serviceability of Structural Concrete

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Abstract

Long-term deflection of concrete grids is predicted by iterative application of elastic analysis. The grid consists of short elements of prestressed concrete beams. The procedure applies to floors and bridge decks, including irregular solid slabs with beams or drop panels. The grid is assumed horizontal and is subjected to gravity loads and prestressing forces. The displacements are considered at five degrees-of-freedom: two translations and two rotations about horizontal cartesian axes and a downward deflection. The effects of cracking, creep and shrinkage of concrete and relaxation of prestressed reinforcement are analyzed by equilibrium and compatibility equations, avoiding the use of empirical multipliers. The analysis considers the effect on serviceability of cracking induced by construction loads at early age of concrete.

Keywords: concrete; cracking; creep; deflection; grid; linear elastic analysis; prestress; relaxation; shrinkage.

Anisotropic Concrete Compressive Strength

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Abstract

When the load carrying capacity of existing concrete structures is (re-)assessed it is often based on compressive strength of cores drilled out from the structure. Existing studies show that the core compressive strength is anisotropic; i.e. it depends on whether the cores are drilled parallel or perpendicular to the casting direction. Engineers may therefore misjudge the load carrying capacity. Thus structures may be strengthened or rebuilt unnecessarily or left in service with high failure probability.

This paper presents a literature review and an experimental study on the anisotropy and its correlation to the curing time. The experiments show no correlation between the anisotropy and the curing time and a small strength difference between the two drilling directions. The literature shows variations on which drilling direction that is strongest. Based on a Monto Carlo simulation of the expected variation it is argued that the variation of the anisotropy may be statistically coincidences.

Assessment of the crack propagation in reinforced concrete

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Abstract

Cracking of concrete is a complex phenomenon induced by direct loading or restraint which unavoidably affect reinforced concrete structures whenever the tensile strength of the concrete is exceeded. Hence it is important to predict where cracks will be located and how they will propagate.

Based on theoretical considerations of the crack initiation in plane reinforced concrete structures experimental studies have been carried out in the Laboratory for Structural Engineering at the University of the German Armed Forces in Munich. The first objects of the experiments were R/C-panels under in-plane tension loads. In a second step R/C-plates under uniaxial and biaxial bending moments were tested with different loading conditions and with different loading paths. [1], [2], [3], [4]. The results of these tests clearly showed the influence of the position, the spacing and the angle between longitudinal and transversal reinforcement on cracking. The future research at the chair of concrete construction will be focused on the modelling of the initiation and the crack propagation in reinforced concrete structures subjected to certain boundary conditions and quasi static loadings. This research is based on numerical calculations, the general theory of Linear Elastic Fracture Mechanics (LEFM) and models for cracking and simulation of the crack propagation.

This paper presents a short overview on the experiments on R/C-panels and slabs carried out in the Laboratory for Structural Engineering at the University of the German Armed Forces in Munich and on the results which have been achieved in the past. Afterwards the actual research is presented. To understand the stress distribution in the direct vicinity of the longitudinal and transversal reinforcement bars a small simplified section of a R/C slab was modeled in the finite element program ANSYS. The aim is to evaluate the capabilities and limitations of the extended Finite Element Method (XFEM) implemented in ANSYS to simulate crack growth and to determine where the crack will initiate and propagate in this region.

Keywords: reinforced concrete, experiments, LEFM, XFEM, cracks, crack-modelling, crack initiation, crack propagation

Geometric effects on Ultrasonic Pulse Velocity Method for Structural Assessment – Experimental Study on Mortar Specimens

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Abstract

Non-destructive ultrasonic evaluation (NDE) is commonly used for assessment of civil infrastructures and characterization of construction materials. Among the acoustic methods impact echo, ultrasonic pulse velocity (UPV), and surface waves analysis can be distinguished. The UPV method, as it is an ASTM standard test method for concrete specimens, is investigated in the article. The standard specifies the applications of UPV as: assessment of relative quality of concrete, presence of imperfections (i.e. voids, cracks, and the effectiveness of its repairs). UPV can be also applied to monitoring changes in the condition of a specimen. In spite of an easiness of the method the obtained results highly depend on the transducers used, the coupling quality, and the specimen dimensions. In this article the authors focus on the sensor and the dimensions effects. The results for UPV tests on 5 mortar specimens of different heights and diameters are presented. The specimens are tested with 54 kHz and 850 kHz resonant frequency (f_c) transducers and the state-of-the-art laser vibrometer (response measurements).

Keywords: Non-Destructive Testing, Ultrasonic Pulse Velocity, Laser Vibrometer, Size effects.

Aggregate effect in fastening applications

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Abstract

In the last decade, the construction industry saw a shift towards rehabilitation and modular construction in order to address the growing demand for faster construction on one side, and change in usage and sustainability on the other side. Consequently, post installed fastening systems have become an important part of civil engineering structures and see increasingly wider application. In the present paper, the experimental investigation of a potential aggregate effect on the concrete cone capacity is presented. Three concrete batches were cast aiming at the same mix design while varying the petrography of the aggregates. Pull-out tests for mechanical anchors were performed at two different ages. Each concrete was fully characterized in terms of compressive, tensile strength, and fracture properties. Based on the obtained data the current design codes for concrete cone capacity in tension are evaluated regarding their ability to predict the anchor capacity from concrete compressive strength only in spite of the differences in used coarse aggregate.

Keywords: mix design; concrete composition; fasteners; concrete cone failure; concrete capacity;

An experimental study of crack development in flexural reinforced concrete members

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Abstract

This paper presents the results of an experimental program of eight reinforced concrete beams carried out in order to investigate the development of cracks related to flexure. To be able to investigate possible size effects with respect to cracking, beams of two different depths were tested. The crack development was continuously measured based on digital image correlation. From observation of the tests, two crack systems was identified; the primary flexural cracks and local secondary cracks. The development of these two crack systems with respect to increasing load, within the service load range, was analyzed and illustrated. The analysis showed different characteristics for the two crack types depending on the depth of the members. The measured average crack spacings and crack widths of the the primary flexural cracks showed a linear proportionality to the member depth. The measured crack spacings, for both crack systems, were compared to existing tests as well as selected models estimating flexural cracking.

Keywords: cracking in flexural members, modeling of reinforced concrete, serviceability, spacing of cracks, test results, width of cracks.

Dynamic Response of Adjacent Prestressed Concrete Box Beam Bridge utilizing Reinforced UHPC Shear Keys

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Abstract

Adjacent precast pre-stressed concrete box beam bridges are popular for medium and short spans in North America due to ease and speed of construction and high torsional rigidity. However, longitudinal cracks in the shear keys, which can cause reflective cracks in an overlay or in a composite deck, are one of the most critical issues with these bridges. These cracks can lead to leakage and cause corrosion of the reinforcement, and in severe cases can lead to a reduction or loss of load transfer between beams. Many solutions have been used to eliminate or reduce the cracks in the shear keys. However, some adjacent box beam bridges still exhibit longitudinal cracks. Recently, Ultra High Performance Concrete (UHPC) has been used as a grout material in the connections between prefabricated bridge elements due to the superior mechanical, bonding, and durability properties. In this paper, the dynamic response of the first adjacent precast prestressed concrete box beam bridge in the United States utilizing partial depth reinforced UHPC shear keys was investigated. Instrumentation was installed at different locations, and the bridge behavior was monitored. The dynamic response was compared with the static response. Furthermore, the dynamic amplification factor (DAF) was determined and compared with AASHTO LRFD Design Specification. The results from the moving load showed that the bridge behaved as a unit which emphasize the ability of the new connection to transversally transfer the load. The results also show that the dynamic amplification factor (DAF) from the AASHTO LRFD Design Specification is conservative compared with the measured value.

Keywords: box beam bridge; UHPC; shear key; longitudinal crack; dowel bar; connection; field test dynamic response; dynamic amplification factor.

An innovative metro viaduct using UHPC

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Abstract

Systra had developed since 1996 a concept of U-shape viaduct, used for more than 300 km of metro viaducts throughout the world. In order to continuously improve the transportation infrastructures, SYSTRA has developed recently, with inputs from Lafarge Holcim, a new structural and architectural concept for metro viaducts, using UHPC.

The deck and the piers are made of a combination of UHPC and ordinary concrete. The lateral beams have openings in order to: clear the view from the metro passengers across the lateral beams, improve the architectural aspect and allow various esthetical expressions, and optimize the UHPC use. Thanks to this new design, the span between piers is about 45m to 50m (instead of formerly 35m for SYSTRA classical U-shape viaducts). Globally the carbon print of the UHPC viaduct is less important than the classical viaducts, due to a better durability of UHPC.

Keywords: UHPC, metro viaduct

Structural Behaviour of UHPC with Micro-Reinforcement

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Abstract

With intent to provide a ductile failure and to use Ultra High Performance Concrete (UHPC) to full capacity usually steel fibres are added during the mixing process. The impaired workability as well as random orientation and spreading of the fibres, the increased environmental pollution and the cost factor are beside the spots of corrosion resulting from near-surface fibres the main disadvantages in the use of micro steel fibres. Earlier studies primarily dealt with the replacement of the fibers concerning ductility, load bearing behaviour and durability by the application of a micro-reinforcement. Within this paper the development of a design concept for micro-reinforced UHPC is presented. Based on experimental investigations, main findings are transformed into analytical expressions, idealized and afterwards implemented into a design concept.

Keywords: UHPC, Micro-Reinforcement, Cracking, Design Concept, ULS.

Development of prestressed T-beams made of textile reinforced UHPC

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Abstract

In comparison to ordinary concrete beams, the reduction of the dead weight by using high performance materials leads to larger possible span to height ratios. However, to avoid excessive deformations, it is planned to applicate carbon fiber reinforced polymer (CFRP) bars as prestressing members. Due to the lack of valid codes for prestressed CFRP bars in UHPC, preliminary investigations are planned, including tests on the transfer length of different types of CFRP bars in UHPC. The main goal of these tests is to determine the necessary concrete cover needed to avoid splitting cracks at the load introduction. This paper contains a detailed description of the test specimens, the test setup as well as preliminary test results. Based on this investigation it is planned to develop innovative prestressed material-fitting T-beams made of textile reinforced UHPC.

Keywords: Textile reinforcement; Ultra-high performance concrete, FRP-bars, Prestressing

The new method strengthen U-shape girders by UHPC thin layer

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Abstract

As a new type of bridge structure, prestressed concrete U-shape girdbcers are extensively applied in urban elevated roads, railways and highways in China. However, there are problems remained for the structure of U-shape girders including large shear lag effect, poor torsional and integrity performance, which result in the emergence of various cracks on prefabricated bridge decks. Taking the strengthening of Hujia highway in Shanghai as a construction example, a strengthening method of U-shape girders by UHPC (ultra high performance concrete) is proposed in this paper. The UHPC layer was poured under the prefabricated bridge deck for repairing cracks and it has proved to improve the carrying capacity of the U-shape girders. In order to demonstrate the feasibility of UHPC layer strengthening method, a local plate finite element model is built to analyze the local effect. The UHPC plate bending experiment and in-field loading test are carried out to prove that the carrying capacity and strengthening effect of UHPC layer are remarkable.

Keywords: U-shape girder; UHPC; finite element analysis; bending capacity experiment; in-field loading test

Flexural Performance of the UHPC Deck in a Novel Steel-UHPC Composite Girder

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Abstract

This paper investigated the flexural performance of the UHPC deck based on Fifth Nanjing Yangtze River Bridge which is the first long-span cable-stayed bridge in China utilizing reinforced UHPC with basalt. Two types of specimens were used to reveal the longitudinal and transversal flexural performance of the UHPC deck, respectively. The load (stress)-deflection curves and load (stress)-crack width curves of the specimens were obtained from the experimental and theoretical studies. The results showed that the UHPC deck in the elastic stage exhibited adequate bending stiffness and cracking strength. In addition, the formulas in the recommendation of AFGC were used to calculate the maximum crack width of the UHPC deck. It showed that the formulas were not applicable to UHPC structures with coarse aggregates. Thus, there is a necessity to revise the formulas for UHPC structures with coarse aggregates.

Keywords: flexural performance; UHPC; load-deflection curve; FE analysis; crack width.

Innovative Design and Construction of Special Guideway Structures for Vancouver's New Evergreen Line SkyTrain Extension

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Abstract

The new Evergreen Line is an 11 kilometre extension to the existing SkyTrain advanced light rail transit system in Metro Vancouver, British Columbia, Canada. The project scope includes design and construction of six new stations, expansion of one existing station, nine kilometres of elevated and at-grade guideway, and a two-kilometre bored tunnel.

This paper focuses on innovative design of the elevated guideway "Special Structures" where the standard precast segmental construction was not suitable. The necessity of constructing Special Structures is primarily driven by the complexity of the guideway and station geometry, and constraints imposed by properties, municipal infrastructure, railway tracks, and by connecting to an existing station. Construction challenges included working in constrained linear corridors, through multiple municipal jurisdictions, and over private properties and active railway lines.

Keywords: elevated guideway structures, light rail transit, performance-based seismic design

A Case Study on Evaluating the Performance Criteria of the 2014 Canadian Highway Bridge Design Code

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Abstract

The performance based design provisions of the 2014 Canadian Highway Bridge Design Code (CSA S6-14) have been applied to assess the seismic design of a three-span prestressed reinforced concrete bridge in Vancouver Island, British Columbia. Response spectrum and nonlinear time-history analyses of the bridge at 10%, 5%, and 2% probabilities of exceedance in 50 years hazard levels, and a static pushover analysis were carried out. Soil-structure interaction was considered assuming two soil conditions, corresponding to site classes C and D of CSA S6-14. The seismic performance of the bridge was also evaluated using the recently updated performance criteria in the 2016 BC MoTI Supplement to CSA S6-14. It was observed that the bridge design satisfied all of the performance criteria in both documents at all hazard levels and for both soil conditions, except for the CSA S6-14 criteria at 10% in 50 years probability of exceedance hazard level on site class D.

Keywords: concrete bridges; performance criteria; performance-based design; force-based design; Canadian Highway Bridge Design Code, BC MoTI Supplement.

Canadian Code Framework for Performance Based Seismic Design of Bridges

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Abstract

The framework for the performance-based seismic design of bridges that was developed for the 2014 Canadian Highway Bridge Design Code (CSA S6-14) is presented. Three different earthquake return period motions are used for the analysis and the seismic hazard, site classifications and site coefficients developed for the 2015 National Building Code of Canada are used. Different seismic analysis procedures are used to predict the performance for the different levels of seismic input motions. Performance levels are prescribed to satisfy the required service states and damage states. Performance criteria, commensurate with the damage levels are given. The advantages of the performance-based design approach for the design of new bridges as well as the evaluation and retrofit of existing bridges are presented.

Keywords: seismic design; seismic hazard; performance-based design; analysis, performance criteria; importance category; evaluation; retrofit.

Opportunities in the Performance Based Seismic Design of Bridges in British Columbia

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Abstract

Performance-based seismic design was introduced formally in 2014 to the Canadian Highway Bridge Design Code (CHBDC). The most important motivation was to encourage and require bridge owners and engineers to consider and discuss the post-seismic performance expectations for new and existing bridges, and to provide a design framework in which performance could be measured and evaluated. The need to facilitate this discussion was underscored by recent damaging earthquakes, including the February 2011 Christchurch event, in which a disconnect in expectations for seismic performance of structures among owners, society at large and engineers was underscored.

In the PBD of bridges, post-seismic performance is described in terms of bridge function, damage, acceptable repair times and timing of the return to service to traffic. This differs from previous force-based design approaches, including simply designing for accepted levels of ductility. In PBD the structural engineering profession must wrestle with the methods and changes in approach inherent in the application of displacement-based structural analysis and assessment as well as damage and repair cost estimating. Once this hurdle is cleared, it is hoped that more designers then will then turn their attention to the range of opportunities available in the conceptual and detailed design of structural systems that PBD facilitates.

This paper outlines some of the design challenges and opportunities afforded by performance-based seismic design. It illustrates a low-damage bridge designs using a hybrid lateral load-resisting system in which performance would not be demonstrated adequately, if at all, using force-based design and its inherently limited design philosophy. It describes the performance assessments of a hybrid base isolation and sub-structure ductility on sites that include highly variable compressible soils. Seismic isolation limits damage from moderate to large earthquakes, but would not preclude some limited plastic hinging of a ductile extended-concrete-filled steel pipe pile substructure for the largest event. Part of the motivation was to provide a rational, low-maintenance bridge articulation scheme, which saves both first and ongoing life-cycle costs throughout the life of the bridge regardless of whether either ever experiences a large earthquake. The analyses, design process and performance measures for the multiple levels of seismic hazard are described. In addition, some design considerations and related issues including deterministic vs probabilistic approaches, design innovation and peer review, bridge articulation, consideration of aftershocks in damage, and return to service, and societal and contractual incentives are also provided.

Keywords: performance-based seismic design, PBD, seismic, low-damage, isolation, Canadian Highway Bridge Design Code, CHBDC, S6-14.

Application of Performance Based Design to Highway and Transit Structures

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Abstract

The latest Canadian Highway Bridge Design Code, S6-14, now requires Performance Based Design (PBD) for certain bridges. For engineers comfortable with the previous force based design approach, PBD appears to require additional, and more complicated non-linear analysis, to satisfy multiple performance objectives. A review of a displacement based design approach indicates that simple, existing tools can be used to implement PBD for a majority of highway bridges and transit structures. A parametric study is used to demonstrate that the minimal damage performance level will generally govern; thus the other levels only need to be verified after initial conceptual design is completed. The study also indicates that different strain limits can lead to different column designs for the same performance level.

Keywords: Performance Based Design; Displacement Based Design; Performance Criteria; Pushover Analysis; Concrete Columns.

Evergreen Line Performance Based Design – An Owner's and Designer's Perspective

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Abstract

The Ministry of Transportation and Infrastructure delivered the Evergreen Line through the Design Build project delivery method. The project specifications included Performance Based Design (PBD) seismic design criteria. Large design build projects are a testing ground for new design specification philosophies and there had been disagreements between the Owner and the Contractors' designers in past projects. The Ministry introduced a process to prevent potential disputes using a three member Seismic Design Peer Review panel. The project included a number of special structures and at-grade sections that were situated in poor, liquefiable soils subject to large lateral spreading deformations. The Panel vetted the seismic design strategies for each structure and dealt with a number of important issues including interpreting expected performance levels into useable deflection and strain limits, while amending the specified reinforcing steel strain limits. Analysis methodologies were also reviewed by the Panel.

Keywords: seismic; performance based design; liquefaction; strain limits.

Eglinton Crosstown and Evergreen Line LRTs - Structural Design on Mass Transit Projects

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Abstract

The structural design for urban transit projects has its unique challenges, such as train dynamic loadings and rail-structure interactions. Mass transit systems in an urban environment often involve guideway in tunnels, including bored tunnel and cut and cover tunnels. The tunnel structural design must take into consideration the integration of passenger train system requirements such as dynamic envelope, space for cables, emergency walkways, and train control.

Using the Eglinton Crosstown and Evergreen Line projects as examples, the structural design challenges and solutions for a light rail system are discussed, and lessons learned from past projects are summarized. The "Crosstown" is a light rail transit line currently under construction in Toronto, Ontario and will run across Eglinton Avenue between Mount Dennis and Kennedy Station. The 19-kilometre corridor includes a 10-kilometre underground portion, 25 stations and stops, and a maintenance and storage facility and operations and control centre.

The Evergreen Line is an 11-kilometre extension to the existing SkyTrain system in Metro Vancouver which was completed in 2016. It contains elevated guideway, at-grade guideway, bored tunnel and cut and cover tunnels, stations, and a vehicle storage facility.

Keywords: mass transit; structural design; dynamic loading; rail-structure interaction; dynamic envelope; train control system; emergency walkway; seismic design.

Incrementally launching method for bridges of Northern Marmara Motorway, Turkey

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Abstract

This paper presents the challenge of the incremental launching of three viaducts of the Northern Marmara Motorway project in Istanbul Turkey. The incremental launching method (ILM) was pushed at its own limit to be adapted to this Viaduct. The deck, with 55 meter long spans, was moved by sliding on piers up to 82 meter high through a complex vertical and horizontal alignment.

This paper gives an overview of this construction methods, and the specificity of these viaducts. In particular, specific procedures were implemented to control the behaviour of the piers during launching operations, due to their slenderness and their non-conventional anti-seismic design. Specific geometric checks were also necessary to follow the launching curve. Temporary structure associate to ILM will also be described in the paper: prefabrication yard, design and construction of the launching nose, choice and design of launching devices.

Replacing damaged PSC suspended span of Varsova Bridge across Vasai Creek on NH-8, Mumbai, India.

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Abstract

The existing Varsova Bridge across Vasai Creek, called as Bassein Creek Bridge when constructed, was opened to traffic in 1968. It is in Mumbai Ahmedabad section of NH-8, about 35 Km from Mumbai. Major cracks were noticed on 12th December 2013 in the West side girder of the penultimate span from Mumbai end. The site was inspected for assessment of the damage. It was decided to replace the said span.

The real task was to dismantle the existing PSC span without any debris falling in the creek while working in a very restricted work area as well as within a very short period. The head room over high tide was very small, water depth was about 8m and bed was with soft clay for 6 to 8 m. Use of scaffolding or heavy equipment was ruled out. One end was with halved joint and other on pier cap. Overall depth of deck had to be maintained along with total weight of the span. In this scenario only some sort of pre-cast girder and cast in-situ deck slab was feasible. In-situ construction was ruled out so was launching of any pre-cast concrete girder due to capacity limitations of existing deck. Only feasible option was use of composite construction. Use of steel girder allowed its transport over existing deck as well as provided support for holding damaged deck with supports on adjacent spans.

An innovative support and lowering system for dismantling span was devised. It consisted of a moving trolley over steel girders, suspenders from girders to hold cut segments, holding of segments with bolts in drilled holes in deck slab and lowering through strand jacks. The disposal was in environment friendly manner, without any debris left at site or spilled in creek.

The designs were completed in 2 weeks and entire execution in about 19 weeks smoothly. Paper discusses the design aspects, replacement details, accounting for the constraints imposed from the design, location and limitations of existing structure arrangement.

Keywords: Cracks, PSC span dismantling, Anchor bolts, Lowering segments, Light equipment, Steel girder.

Transforming the former Waterloo International Terminal for commuter services

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Abstract

Waterloo International Terminal is to be reopened as a domestic railway station offering high frequency commuter services from south west England into London as part of the Wessex Capacity Programme. Modifying the viaducts on the approach to the terminal while minimising disruption to passengers was critical to allow the necessary platform, track and signalling changes. This paper describes the challenges presented by the site and some of the innovative ideas our collaborative team implemented in order to deliver an efficient and effective solution.

Keywords: Alliancing; bridge assessment; bridge repurposing; conceptual design; Network Rail standards; Soil-Structure Interaction; Track-Bridge Interaction; Fast-Track Construction.

Design and Detailing of Advanced Composite Rehabilitation with and without Anchorage

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Abstract

Fiber-reinforced polymers (FRPs) are widely recognized as versatile materials for the retrofit and repair of structural members for a variety of existing deficiencies. As a supplement to the FRP, mechanical or composite anchorage is sometimes utilized to increase the performance of various FRP-reinforced structural members. With proper design and detailing, the use of composite anchors has proven to prevent premature debonding failure of externally bonded FRP. The performance of FRP-retrofitted concrete members continues to be cited as a high-priority topic for research and an assortment of tests have been completed to validate the use of composite anchors in different types of applications. This paper will review the performance of different tested assemblies using FRP with and without the use of composite anchorage, including state of the art testing on a beam-column assembly. In addition, there will be discussions on the variety of structural applications and specific detailing required on composite anchors to ensure a safe and durable strengthening system.

Keywords: FRP; composite; anchorage; beams; beam-column assembly; durability.

T3 Minneapolis – America's Largest Modern Mass Timber Building

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Abstract

Mass timber construction in America has been reborn with T3 Minneapolis (timber, transit, technology) – at 220,000 sqft and 7 stories, T3 is the largest modern mass timber building in North America. As a spec office building it is designed to attract the modern tenant, embracing green construction techniques and creating a warm interior environment with the timber superstructure. T3's rustic core-ten façade resembles its historic neighbours while its interior highlights simplicity, modernity and elegance through exposed engineered wood products and connections. Over 1000 CNC'd glulam beams and columns and over 1100 2x8 NLT panels were prefabricated offsite and sequentially delivered to site for just in time delivery. The T3 timber superstructure was erected in 9.5 weeks. The T3 success story began with a convinced developer and design team, and carried through with exceptional team communication, collaboration, and pre-planning and eventually delivery from StructureCraft. Every detail was carefully discussed and realized with the intent that T3 represent a successful and competitive model for future mass timber buildings in North America.

Keywords: Mass timber, heavy timber, offsite construction, prefabrication, modular construction, glulam, nail-laminated timber (NLT), timber engineering

Quantifying the value of monitoring for post-earthquake emergency management of bridges

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Abstract

SHM systems are widely installed to increase the knowledge of the structural state and in present practice it is implicitly assumed that the information they bring is beneficial for the structural integrity management. This may not always be the case since inappropriate use of monitoring data, leading to wrong decisions, may be detrimental for the structural safety or cause economic losses. In this paper, a framework based on the concept of Value of Information from the pre-posterior Bayesian analysis is applied to forecast the utility associated to the implementation of an SHM system for the case of emergency management of road bridges subjected to seismic risk. An optimization problem is formulated to identify the most efficient decisions regarding traffic restrictions after an earthquake defined as those corresponding to the minimum associated cost and consequences. The choice of a proper structural performance indicator and the methods for the computation of the prior probabilities of damage, of the likelihood functions and of the costs associated with the different possible traffic restrictions are also briefly discussed.

Keywords: Structural Health Monitoring, Value of Information, emergency management, road bridges, performance indicators, seismic risk

Identification of Bridge Surface Roughness Profile Using Drive-by Technique

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Abstract

As the surface roughness of a bridge has significant influence on the interaction between a moving vehicle and the bridge, it is one of the hurdles for the use of drive-by technique in the assessment of bridges. The proper identification of surface roughness of a bridge will be most useful to the minimization of associated uncertainties and improvement of accuracy of numerical simulation. This paper presents a novel method for estimation of the bridge surface roughness profile from the responses extracted from an instrumented vehicle based on vehicle-bridge interaction. By letting the vehicle run along the bridge with different added masses, an estimation of the roughness profile can be obtained. The feasibility and effectiveness of this method are studied by finite element simulation.

Keywords: drive-by technique; finite element method; roughness profile; vehicle-bridge interaction.

Error analysis of structural system identification by observability method

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Abstract

In structural system identification, measurement errors and simulation errors are closely related with the accuracy of the identification method. In this paper, the effects of these two types of errors on structural system identification by observability method(OM) are thorougly discussed. An example structure is analyzed step by step. For the very first time, the analytic expression of the flexural stiffness is given by the observability method. Using this expression, the effects of errors in a particular measurement, random errors in all measurements are analyzed. Also, two examples are used to illustrate the effect of simulation errors of observability method. It is observed that the estimations fluctuate during the recursive process. Also, the accuracy of the estimations decreases sharply at null curvature zone. For this reason, it is highly recommended to adopt different load cases to alleviate this situation.

Keywords: structural system identification; observability method; static; measurement errors; simulation errors;

Contributing human and organizational factors for damage of Bos & Lommer plaza in Amsterdam

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Abstract

The Bos & Lommer plaza complex in Amsterdam was completed in 2004. This complex consisted of apartments, shops and a parking for over 500 cars. In 2006, an 11 ton truck was positioned on the plaza deck and caused structural damage. Part of the load bearing structure had failed and the apartments were evacuated, until the deck was strutted.

Forensic investigations showed that detailing of the reinforcement was questionable and the amount of reinforcement was insufficient, or deviated from drawings. The whole complex was evacuated until measures were taken. Subsequently, investigations of the shops and apartments above the parking showed that the design of a 1 m thick transfer floor might have been erroneous.

Profound investigation of this case showed various human and organizational factors, that might have contributed to the failure. The stacking of various functions resulted in a complex load bearing structure. The building process was complex with over 50 subcontractors. The safety culture was not well developed, given heavily economizing on costs and very tight planning, fragmentation and no clear final responsibility. Risk analysis and checking procedures were lacking. Communication and collaboration could have been improved.

This paper will give insight in technical causes of the failure and in underlying contributing factors. These underlying factors will be systematically studied, by using a theoretical framework.

Keywords: Forensic Structural Engineering, Failures, Human and organizational factors

Practicability of New and Innovative Products – Method for the Evaluation of Innovative Façade Components

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Abstract

In construction, for general contractors the use of newly developed products is always a risk and therefore often leads to the rejection of innovative components. The reason is the lack of practical experience as well as normative regulations and test certificates. Furthermore, instructions and recommendations for the use under certain boundary conditions are also missing.

Due to this reason, a simple method was developed to review the practicability of new and innovative products in façade constructions. With specific technical questions developed with façade consultants the evaluation of innovative façade components for planning, erection, utilization, and demolition is possible. The aim was to make a substantial evaluation of innovative façade components regarding their practicability as well as the influence of the new product on resource efficiency and durability. Therefore, the cost-benefit analysis was chosen for the evaluation. The methodology was divided into two main process steps: in the first step the product is evaluated by means of predetermined selection answers and in the second step, a weighting ratio of the different criteria is set by the user. In total, the review consists of four main criteria, which are divided into 16 fine criteria with an overall of 40 evaluation questions. Thereby, the main criteria are differentiated according to the life cycle of a building and include planning, construction, operation, and removal of the building.

The results of the assessment of new and innovative façade components evaluate the potential of the new product to meet the requirements as part of future facade structures and identify weaknesses and risks of the products at an early stage. With this, the co-operation between manufacturers and executing companies can be tightened to optimize products before their market launch, especially in terms of practicability, durability and resource efficiency.

Keywords: façade components, innovation, durability, cost-benefit analysis

Fatigue Damage Identification in Precast Truss Girders Using Relative Wavelet Entropy

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Abstract

An experimental implementation of a relative wavelet entropy (RWE)-based structural damage identification technique (DIT) is presented. The technique is capable of detecting and localizing structural damage, as well as estimating its severity, without the need for any data to be collected from undamaged (reference) state of structure. The bases of this reference-free DIT are: (1) structural damage changes the energy distribution of bridges' vibrational signals; (2) these changes are detectable by means of discrete wavelet transforms (DWTs); and (3) the detected changes can be quantified using spectral entropy. The efficacy of the proposed RWE-based DIT in identification of structural damage has been verified through its application on a precast bridge truss girder system tested under fatigue loading. The girder consists of glass fibre-reinforced polymer (GFRP) tubes filled with concrete reinforced and connected to pretensioned top and bottom concrete chords by double-headed GFRP bars.

Keywords: bridges; fatigue; damage identification; FRP; relative wavelet entropy; vibration.

Artificial seabed; a mooring concept for crossing long and deep waterways

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Abstract

Based on the incentive from the Ministry of Transport and Communications in Norway of replacing ferry crossings with permanent fixed crossings, there is a need for new crossing technology for the deepest and widest fjords. The present paper presents a concept consisting of a floating pontoon bridge with a submerged floating tunnel at mid-span, the latter to facilitate ship traffic. These elements are further side moored down into a submerged anchoring system. The benefits with the presented concept are that there is no need for a tall bridge for the fairway, and the fairway is flexibly placed where it is needed for the specific crossing. The concept is independent of water depth and sea bottom conditions. The concept makes use of technology and element sizes known from both offshore oil- and gas and civil construction. The paper presents the overall concept and the global behavior of the structures.

Keywords: Floating bridge, submerged floating tunnel, mooring system, dynamic analysis, slender structure, artificial seabed.

Field Load Test of Cable Crane for a Record-breaking Cable-stayed Bridge

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Abstract

Yachihe Bridge is a record-breaking cable-stayed bridge with 800m steel truss deck of main span. It is the first time for cable crane used in the deck erection of cable-stayed bridge in the world. Unusually, the cable crane has no temporary towers but uses the bridge pylons directly. Field load tests are carried out before the cable crane putting into services. The cable crane load tests include static load test and dynamic load test, during which main cable forces, deformations of pylon tips, main cables and anchorages, etc. are measured in situ. Wherein, the cable crane is well instrumented with strain gauges at critical locations of the anchorages to record the main cable forces. This paper mainly describes the design, schemes and instrumentations of the cable crane load tests, meanwhile field measurements and numerical results are presented and compared.

Keywords: cable-stayed bridge; cable crane; load test; deformation; main cable force; strain gauge

Innovative bridge cables for the reduction of ice-shedding risk

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Abstract

Ice and snow accretions on bridges pose a hazard for motorists and pedestrians, as shedding accretions can have a significant mass associated with them. Various technologies have been tested on numerous bridges in an attempt to prevent accretion build-up or help mitigate the effects of the falling snow or ice on the traffic below. Most have been found to have problems with durability and cost-effectiveness though. In this paper, we present preliminary test results from ice shedding tests that have been performed on innovative cable surface modifications in the DTU/Force Technology Climatic Wind Tunnel (CWT) in Lyngby, Denmark. It is shown that contrary to the ice shedding of contemporary cable surfaces, the innovative surfaces retain the ice longer during the melting process, reducing the shedding ice mass and particle size, thus reducing the risk associated with the shedding ice.

Keywords: freezing rain; ice accretion; bridge cables; ice shedding; concave fillets.

Wind Buffeting in Time Domain Analysis of Long-Span Bridges using RM Bridge

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Abstract

Wind buffeting in time domain is an important consideration in the dynamic analysis of long-span bridges such as cable-stayed and suspension bridges subjected to turbulent wind fields. These bridges exhibit relatively large deflections and can oscillate strongly during the turbulent wind.

New functionality for including wind buffeting in time domain has been implemented in RM Bridge as part of Halsafjorden Floating Bridge project on the west coast of Norway. The buffeting and aerodynamic forces are expressed with Quasi-Steady State (QSS) coefficients theory. Typical wind load effects on structure include: constant mean wind velocity, turbulent dynamic wind buffeting load, and interaction of the moving structure with the aerodynamic damping and stiffness. The QSS aerodynamic stiffness and damping provide additional damping to the structure.

The analysis results generated by RM Bridge compare very well with a published design example. Time domain analysis is compared with the frequency domain analysis. A sensitivity analysis is performed to further validate the implementation with respect to different angles of wind attack, time and frequency discretization, random phase angles, and coherence.

Keywords: Time domain analysis; frequency domain analysis; long-span bridges; dynamic analysis; wind interaction; RM Bridge; floating bridges.

Radial Floating Ice Deflector: An Innovative Approach

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Abstract

A radial floating ice deflector (FID) was developed, designed and constructed for a cable ferry crossing in northern Manitoba, Canada. The purpose of the FID is to protect the ferry from future floe impacts. In this paper, the concept development process including the conceptual design of the FID is presented, the problems such as floe - FID interactions, design ice load and design constructability arising from the conceptual design are discussed, and the solutions for the problems are introduced. At the end of this paper, potential applications of the structural system reflected by the FID are discussed and recommendations are made for the design and construction of future similar ice control structures.

Keywords: cable ferry; radial floating ice deflector; float; strut; chain; chain anchor; bollard; floe; ice load; constructability

U Shape Anchoring System: Concept Design and Key Experiments

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Abstract

The anchoring zone of the pylon is the key partial design of cable-stayed bridges. Both the reliable transmission of enormous stay force and the convenience for structure and construction should be considered in design.

The U shape anchoring system is a brand-new anchoring system. It is developed on the basis of saddle anchorage. The steel strands pass through the saddle on one side of pylon cross section, then go around the pylon and come back to the anchor on the other side at the same cross section. This method mainly generates compressive force in pylons, avoids tensile stress from mechanism, and improves their stress performance.

To realize this concept in engineering, there are still some problems to handle, including arrangement of saddle space in pylons, specific structures for stays to rotate in pylons, guarantee for mechanical property of strands in the U shape anchoring system and construction plan in later period and so on.

These problems have been taken into full consideration in the concept design. And some tests about fatigue performance of cables, clamping performance of the V-shape pipes and construction techniques have been carried out to verify the system.

This paper will give a detail introduction about the concept design of this U shape anchoring system, and some key experiments.

Keywords: anchoring zone; u-shape anchoring; durability; design; experiment.

Modeling of Bonding for Epoxy Resins between Steel Rebar and Concrete at Elevated Temperatures

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Abstract

Epoxy resins have increasingly been used to bond steel rebars into existing cast-in-place or precast concrete structures due to the advantage of higher bond strength compared with mechanical steel-to-concrete anchors at normal temperature. At elevated temperatures, however, significant bond deterioration can be expected as the resin's modulus decreases with an increase of temperature. The decrease in the load bearing capacity of the bond can lead to collapse of the structural systems after exposure to high temperatures.

A mechanical model is proposed in this study to investigate the characteristics of the adhesive bonding stress between steel rebar and concrete interface at elevated temperatures. The model is calibrated with the results obtained from a series of pull-out tests using deformed bars with varying diameters of 12 mm, 16 mm, 20 mm and 25 mm. It is found that the model provides good prediction of the bond stress.

Keywords: epoxy resins; bonding; steel rebar; concrete; elevated temperatures.

Fire Design Methodology for Cold-Formed Steel C-Section Flexural Members

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Abstract

Fire design rules for cold-formed steel beams are commonly based on past research on hot-rolled steel beams. Hence this paper present a methodology for calculating the fire response of unrestrained cold-formed steel C-section flexural members, based on guidelines of Eurocode 3 Part 1.2 for fire design of steel beams and on results of experimental and numerical studies. European fire design rules were found to be unsafe or over-conservative, depending on their relative slenderness and serviceability load applied on the beams. Therefore, new formulae for lateral–torsional buckling of unrestrained cold-formed steel C-section flexural members, which approximate better their real behaviour in case of fire are proposed. Comparison with numerical moment capacities demonstrates the accuracy of the new design methodology.

Keywords: cold-formed, steel, beams, fire, finite element analyses, buckling, fire safety design.

Mechanical Properties of Stainless Steel Bolts at Elevated Temperatures

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Abstract

In order to promote fire resistance of bolts connections, this paper developed an experimental program for investigating mechanical properties of stainless bolts at elevated temperatures, in which standard coupon specimens were prepared and performed for two types of stainless bolts subjected to tensile loading. The research findings accomplished on fire resistant bolts have been reviewed carefully and compared with mechanical properties of stainless steel bolts in fire. In addition, stainless steels (EN 1.4401 and EN 1.4571) as their parent materials were included in this investigation. It can be found that strength and stiffness reduction of stainless bolt materials is almost in consistency with their parent materials in fire. A better performance in strength retention has been observed for these materials in the temperature range of 500 to 900℃, compared to fire resistant bolts. Relying on the experimental data, strength and stiffness reduction factors have been derived for stainless steel bolts for help with determination of their stress-strain relationships at elevated temperatures.

Keywords: Stainless bolts; elevated temperatures; stainless steel; bolt failure.

Performance-Based Assessment and Mitigation of Fire Hazard for Bridges

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Abstract

Several recent incidents have demonstrated vulnerability of bridges to fire hazard. Fire-induced damage or collapse of bridges can disrupt the functioning of infrastructure networks, leading to significant costs to public including business interruption from route closures as well as potential casualties. While application of fire protection in a selective manner might be necessary to achieve a resilient bridge design for bridges, an across the board fire-rating approach similar to what is used in building design practice is unrealistic and uneconomical. A performance-based approach can provide a better hazard assessment for each individual bridge, thus leading to a cost-effective fire protection scheme.

Although the benefits of a performance-based approach are well-known, attempts in practice face an efficiency challenge to go through the steps of hazard analysis and identification of realistic scenarios, fire simulation and determination of design variables while keeping the process repeatable. This paper presents an innovative computational approach that allows the engineer to evaluate a bridge for several possible fire scenarios in a generalized scheme to determine if there exists a scenario that can potentially threaten the integrity of the structure. If such a case is identified, advanced detailed computational methods can be used for a more accurate evaluation. An example study is conducted on fire retrofit of a highway interchange with interconnected bridges to showcase this approach. Various fire scenarios caused by tanker truck accidents are initially analysed using simple computational tools that account for direct radiative heat transfer and lumped mass heat conduction while the bridge is subjected to realistic temperature curves. Necessity of advanced Finite Element analysis is determined based on the results of initial evaluation.

Keywords: Performance-based fire engineering, bridges, fire hazard mitigation, fire protection

Numerical modelling of slab-column concrete connections at elevated temperatures

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Abstract

Flat slab-column concrete frames are an economical type of concrete building. The main advantages of this type of frame structure are that they are easy to construct, relatively cheap to build and offer flexible column arrangement. However, they are susceptible to a type of failure known as "punching shear", where columns "punch" through slabs. This is a particularly dangerous type of failure as it occurs suddenly. Punching shear occurring at high temperatures, such as in fire, is a clear concern. This condition has been studied experimentally but to date there has been very little numerical investigation of the topic. This paper presents a numerical study of the mechanics of punching shear failure at elevated temperatures, with a focus on the role of load induced thermal strain (LITS), which is shown to explain apparently anomalous experimental results.

Keywords: punching shear, fire, FEM, LITS, load induced thermal strain.

Performance-based fire design and the U.S. prescriptive guidelines: A comparative study

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Abstract

Current codes and standards for fire design of structures in the United States are mainly based on design at the component level using prescriptive approaches, while performance-based design for fire can be used to address the needs for designing modern buildings with cost-effective solutions. Previous research shows that, when system-level performance is considered, fire protection on secondary beam elements in composite steel-concrete floor systems is not necessary due to the development of a membrane action in the concrete slab during fire. This study compares the fire design of a 9-story office building using prescriptive and performance-based designs. The safety levels of the two designs are investigated and compared. It is shown that performance-based design can be used to achieve the required level of safety currently enforced in the U.S. prescriptive guidelines, while providing an opportunity for cost reduction in fire protection material.

Keywords: fire; building; prescriptive design; performance-based design; membrane action; SAFIR.

Safety level evaluation for existing rockfall protection gallery Rieinertobel

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Abstract

Within the coming decade many ageing rockfall protection galleries in the Swiss Alps will require rehabilitation measures to ensure their durability. Before a gallery is rehabilitated, its current safety level needs to be assessed to decide whether strengthening measures are also necessary. Generally, an assessment of structures several decades old with current design standards will result in a recommendation for expensive strengthening measures. However, design standards may offer the possibility for a risk-based assessment, e.g. Swiss standard SIA 269, which allows for evaluating strengthening measures in consideration of both safety and cost-efficiency. This paper describes a risk-based assessment for the rockfall protection gallery Rieinertobel and shows that target safety requirements can be met without strengthening measures. The described approach allows for managing ageing infrastructure in a cost-efficient manner without compromising safety.

Keywords: Existing structures; rockfall gallery; consequences of failure; target reliability; cost-efficiency; design loads; natural hazards.

Modified traffic load models for reassessment of short-span highway bridges

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Abstract

Towards the objective of a more differentiated and realistic approach for representing the actual traffic load impact on short-span structures for application in bridge reassessment, actual traffic load impact based on local traffic data, and the resulting structural demands on selected short-span bridge structures are analyzed. Structural models applied consider peculiarities of short-span bridges concerning bidirectional load carrying behavior due to a compact shape of their superstructure. To obtain robust results, additional scenarios are considered to simulate possible, unfavorable traffic constellations on the bridge. The resulting characteristic values of structural demand are used to calibrate a modified traffic load model. The paper presents results of this analysis for selected short-span bridge structures with varying span widths under different representative traffic types, and using different modelling assumptions.

Keywords: short-span bridge, reassessment, road traffic, load model, traffic simulation, extreme load effect, highway bridge

Seismic Risk Assessment of Bridges in Jakarta Transportation Networks using Incremental Dynamic Analysis

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Abstract

Jakarta is known as the most populated as well as most traffic-congested among capital cities in the world. The development of infrastructure facilities, such as bridge, is carried out to meet the high demand. Since the latest Indonesian Seismic Code has been released, retrofitting of existing bridges becomes an issue therefore it is important to investigate the performance of existing bridges under seismic catastrophe compared to corresponding design earthquake. To mitigate the condition and seismic risk of some vital bridges of Jakarta transportation, a simple procedure developed based on probabilistic approach. Incremental Dynamic Analysis is performed to have nonlinear response history by using artificial site-specific earthquake ground motion. The post-earthquake response is utilized to determine bridge damage level under various ground motion intensities. Seismic risk map is developed to classify the most critical bridge under earthquake and priorities the rehabilitation program according to its performance level.

Keywords: earthquake; incremental dynamic analysis; bridge; risk assessment.

CROSS International

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Abstract

CROSS - Confidential Reporting on Structural Safety – has been operated since 2005 by the UK Structural-Safety group to help engineers learn from the experiences of others to avoid structural failures. Reports are submitted confidentially by practitioners and comments are added from a panel of industry experts. Anonymised reports with comments are added to a data base and published in Newsletters which are widely circulated and read by designers and contractors. Whilst the system is primarily for the UK there have been expressions of interest in expanding it to other countries from organisations in Europe, Australia, the USA and South Africa. The aim is to set up an International arrangement whereby countries with equivalent confidential reporting schemes would add reports to a central data base. Experience on preventing failures and structural collapses, some with catastrophic consequences, would be freely shared amongst both developed and developing countries in a confidential, independent, and expert way. The paper will present proposals for how this can be achieved and the benefits that would be obtained.

Keywords: CROSS; SCOSS; Structural-Safety; International; confidential; reporting; learning

Resilience-based design and damage-resistant technologies for an enhanced seismic performance of bridges

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Abstract

Seismic codes do not currently focus on earthquake resilience. Resilience can be broadly defined as the ability of a system to quickly recover after a large earthquake. Traditionally, the main code objective has been only to prevent collapse and ensure life safety. Performance-based design (PBD) is a supplement to force-based design (FBD) and intends to demonstrate that pre-identified earthquake performance objectives for the structure are satisfied. Yet, neither FBD nor PBD include explicit verification of the expected functionality of the structure after the earthquake. Resilience-based design (RBD) appears as a holistic design process which identifies and mitigates earthquake-induced risks to enable rapid recovery in the aftermath of a major earthquake. Resilience explicitly requires design of structures to sustain less damage in earthquakes, therefore, damage-resistant technologies are a key component of RBD. This paper gives an overview on low damage design and the latest damage-resistant technologies; and subsequently, presents a framework for the quantification of seismic resilience for damage-resistant technologies for bridges. The framework introduces reparability as a key design criteria and resilience as a key performance indicator for seismic design. Applying the proposed framework on the design phase allows the estimation, by defining different recovery strategies, of final recovery times and preliminary costs of the bridge after an earthquake. Finally, since resilience allows the benefits of mitigation technologies to be translated into concise meaningful terms to owners and decision makers, such as expected closure time, RBD concepts can lead to an increased confidence in implementing low damage technologies as a method for reducing damage to bridges in an earthquake.

Keywords: resilience, bridge, pier, rocking, damage resistance, seismic design

The Probabilistic Analysis of Vienna Stadium Roof Structure

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Abstract

The paper deals with probabilistic analysis of the Ernst Happel stadium`s roof – roof of the biggest stadium in Austria. The presented contribution extends the analyses carried out after 25 years lifetime. The numerical model of the stadium`s roof was identified on the base of dynamical measurements and initially was analysed using deterministic approach. Considering the uncertainties of stiffness and loading of the roof, probabilistic analyses were carried out. The uncertainties were declared with help of truncated Gaussian distribution as statistical distribution function. The Monte Carlo Simulation and the Response Surface Method were applied. The output parameters which effect the dynamic behavior of the stadium roof were analyzed with help of response surface. The sensitivities of natural frequencies and modes on the uncertainties of stiffness and loading are presented.

Keywords: Stadium roof, finite element model, statics, dynamics, probabilistic analysis.

Figure 1. Ernst Happel Stadium in Prater - Vienna

Concrete arch stability by the nominal stiffness method

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Abstract

Verification of the load-carrying capacity of a series of historic concrete tied arch bridges, has shown that the nominal stiffness method of EC 2 may be applied successfully in determining the bridge's ultimate capacity. However, the code mentions a slenderness value, beyond which nonlinear analysis becomes imperative, this being the case for the aforementioned cases. Albeit the formulas strictly apply to straight columns, all cases have demonstrated that this limiting value is really conservative for arches. Nonlinearities include nonlinear material characteristics, cracking and creep, as well as large deformation and imperfections. The nominal stiffness method has been an effective way for dealing with the first type of nonlinear effects is, whereas large deformations and imperfections were included in the numerical simulation. A wide variety of concrete arch bridges was considered. This resulted in a clear almost linear relation between the ultimate load-carrying capacity and the effective modulus. Two definitions for slenderness and for a load carrying capacity factor have been taken from EC 3. The latter includes, large deformations and imperfections. A quadratic relation between these two quantities is derived, similar to buckling curves for steel arches. This might substitute the limiting slenderness from the code and constitute a more practical tool. The ultimate load-carrying factor thus obtained may also be used for a unity-check procedure.

Keywords: Arch slenderness, nonlinearity, nominal stiffness method, concrete arch buckling, imperfections.

Walton Bridge – a new arch bridge over the River Thames, UK

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Abstract

Walton Bridge comprises a steel thrust arch with pad foundations supporting a steel-concrete composite ladder deck. The arch ribs have parabolic profile and varying hexagonal cross-section, tapering from springing points to crown, and span 96.1 m. The total rise of the arch is 14.77 m with a span to rise ratio of 6.5. The bridge deck is suspended from the arch by bar-type hangers. Continuous end spans carry the bridge deck between the arch and end abutments, which are full height reinforced concrete. This paper discusses the method of design employed, including the impact of construction methodology and environmental constraints, together with analysis of aerodynamic effects. It focuses on a number of innovations that were introduced and challenges that were resolved. Two key issues were:

- Arch design utilising plastic section properties with reductions to account for the continuously curved steel plating making up the arch ribs;
- Design and specification of bar-type arch hangers for brittle fracture and fatigue, noting that there was insufficient industry guidance on either subject.

Keywords: Steel, arch dge, non-linear analysis, design, bar toughness, fatigue testing, curved plates.

Design of Kouchigawa Bridge on the Shin-Tomei Expressway - a Steel-Prestressed Concrete Composite Multiple-span Balanced Arch Bridge

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Abstract

A three-span composite balanced arch structure was adopted as the river-crossing section of the bridge, using a balanced truss cantilever erection method. The arch ribs were designed as prestressed concrete (PC) box girders and the stiffening girders were designed as steel box girders. PC box girders were also adopted on the approach spans. In order to improve driving comfort of passing traffic and minimize maintenance cost, the stiffening girders of the balanced arch are connected with the PC box girders of the approach spans without expansion joints. In order to increase the seismic resistance of the bridge, rigid connections were used at most joints between the substructures and superstructures, and between the vertical members and stiffening girders.

Keywords: balanced arch; arch rib; stiffening girder; steel-prestressed concrete composite structure; PC box girder; steel box girder; balanced truss cantilever erection method

Figure . Aerial view of kouchigawa bridge

The Lusail Feature Arch

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Abstract

"Engineering the Future" - Lusail City is a self-contained and comprehensively planned new city currently under construction in Qatar. The Lusail Feature Arch was designed to enhance the Marina Interchange and create a gateway to Lusail City, with an arch spanning 184m and rising 75m above the A1/A6 interchange. The concept and aesthetics were developed in conjunction with international bridge architects, Dissing+Weitling, and comprise a triangular section tapering with height and incorporating an anti-clockwise twist emanating from the springing, creating a shape which is continually changing in profile as it gains height. This paper describes the derivation of the design criteria of this very slender structure. The arch was susceptible to wind induced excitations, and the paper discusses the effects determined through wind tunnel testing which was undertaken to establish the aerodynamic performance of this unique structure.

Keywords: Design criteria; analysis; modelling; steel; aesthetics; wind engineering; aerodynamics.

A New Tied Arch to Replace a Rural Mississippi River Crossing

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Abstract

The US 52 bridge over the Mississippi River provides a crucial transportation link for the region, connecting Savanna, Illinois to Sabula, Iowa with the nearest alternate Mississippi River crossing located almost 32 kilometers to the south and is now rapidly approaching the end of its useful life. The proposed replacement consists of 12 spans totalling 748 meters from a causeway in the middle of the Upper Mississippi River Wildlife and Fish Refuge in the Mississippi River on the Iowa side to the high bluffs of the Mississippi Palisades in Illinois. The 166.4-meter main span steel tied-arch over the navigation channel incorporates a floating deck system and redundancy design concepts while simplifying details. The construction of deep cofferdams in the river is eliminated in favour of large diameter drilled shafts foundations with waterline footings, the first use of this construction method by the Illinois DOT.

Keywords: bridge replacement, steel girder, tied arch, internal redundancy, fracture critical, waterline footings, drilled shafts, steel detailing, galvanizing, Mississippi River.

Integrating Aesthetic Design and Structural Engineering on a Signature Bridge

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Abstract

The new Walterdale Bridge offers Edmonton a unique opportunity to create a striking new entrance into the downtown. The mandate of the Walterdale Bridge Replacement project for a functional signature bridge offers the opportunity to create a public place on the North Saskatchewan River.

The aesthetic goals of the structure played heavily into the structural systems chosen, which ultimately had a substantial impact on the overall structural design. This paper will explore how key aesthetic features were explored and influenced the structural design of the bridge and how that vision was maintained and protected through the construction phase, with focus on contract requirements for Architecturally Exposed Structural Steel and Architecturally Exposed Concrete.

Keywords: Bridges; Steel; Concrete; Cables; Aesthetics; Architecture; Conceptual Design and Realization

Composite Pile Foundation in Bridge: Code recommendation and Chilean experience

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Abstract

The design of deep foundation on Chilean traditional bridges, commonly considers a drilled reinforcement concrete or a drove tubular steel piles. A few experience has been developed on large span bridges (cable-stayed, suspension, among others) and composite piles (steel and concrete). Even more, the composite pile has never been used in Chilean bridges.

This paper presents a structural study about three alternatives of composite foundation piles applied in long span bridges, in order to be compared them under strength capacity conditions. A reinforced concrete pile, a steel-cased concrete pile (without steel reinforcement) and a steel-cased reinforced concrete pile are studied in order to show the benefits of implement these elements in a Chilean bridge.

A FE Model of each pile are carried out applying strength, service and extreme events (seismic) loads combination. Finally, discussion about the normative applied (international and Chilean codes) and assess the structural behaviour is presented.

Keywords: composite; pile; bridge; design.

Single Row Piles in Integral Bridge Foundations: Challenges and Solutions

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Abstract

This paper presents the challenges and their solutions adopted for the design of two-span continuous integral overbridges supported by single row pile foundations without any interfacing pile cap elements, as part of A14 Cambridge to Huntingdon development.

The paper highlights the geotechnical modelling limitations, construction requirements, contractor's preferences, and other constraints placed on pile configuration due to load demands and form of superstructure.

With respect to structural aspects of design, the paper discusses the design challenges and solutions associated with reinforcement detailing within the abutment and pier walls in absence of interfacing pile cap elements.

It also touches upon use of strut and tie approach, to propose a safe and buildable detail around the pile reinforcements, and the reinforcements of the substructure element.

Keywords: integral bridges, strain ratcheting, continuous flight auger, strut & tie, buildability.

Soil Structure Interaction and Performance Based Design for the Port Mann Cable Stayed Bridge

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Abstract

The performance based seismic design of the Port Mann Bridge, a 10 lane cable-stayed bridge located 30min outside of Vancouver, BC, is presented in detail. The Port Mann Bridge is the centerpiece of the Port Mann/Highway 1 Improvement Project. Located in a high seismic region, the design-build project includes the 850-meter-long Port Mann Bridge carrying the Trans Canada Highway over the Fraser River. With a 470-meter-long main span and 190-meter-long side spans, and 52-meter-wide deck, the Port Mann Bridge is the largest main span crossing in Western Canada, the second longest cable-stayed bridge in North America, and one of the widest bridges in the world. The geotechnical conditions varied along the 2 km bridge length, and included soil layers that are highly susceptible to liquefaction in the larger events. The geotechnical development of ground motions and the site-specific non-linear soil response are discussed. The three-dimensional modeling techniques used to capture the soil structure interaction (SSI) in the global seismic analysis of the Port Mann Bridge are described, with special focus on the approach to non-linear structural modeling and the implementation of a strain-based seismic design.

Keywords: Performance Based Design, Cable-Stayed Bridges, Soil-Structure Interaction

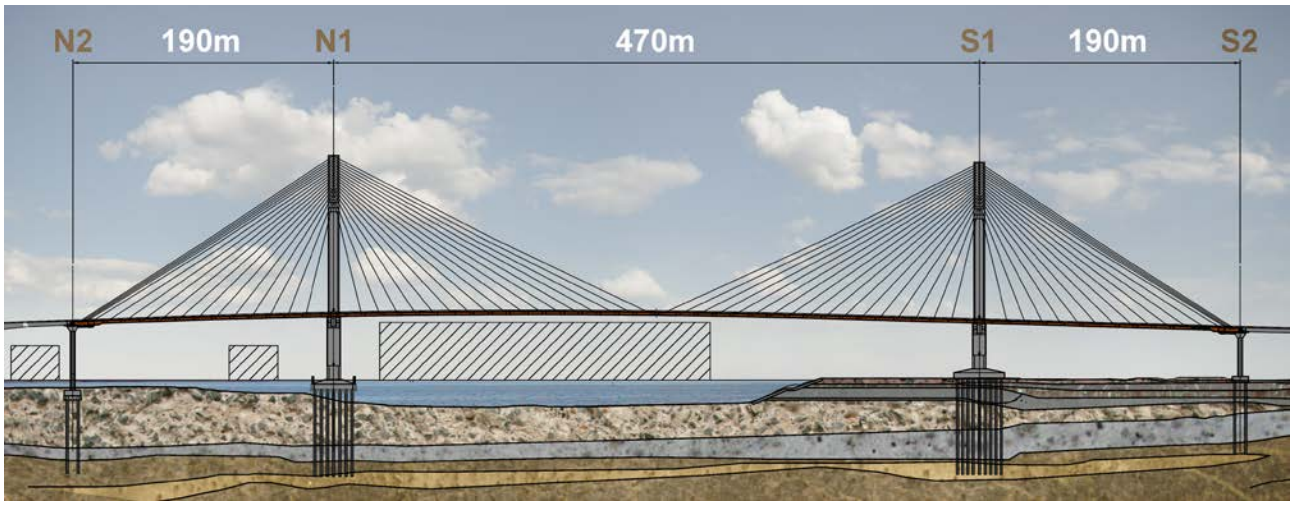

Figure 1. Cable-Stayed Bridge Layout

Soil-Structure-Pipe Interaction Analysis and Inelastic Design of the Port Mann Water Supply Tunnel Shaft and Pipe – Case Study

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Abstract

The new Port Mann Water Supply Tunnel in Metro Vancouver, BC, Canada is a 1km long, 60m deep, 2.1m diameter water main constructed under the Fraser River through liquefiable soil. The tunnel, shafts and pipe are designed to withstand ground motions with a 10,000 year return period and continue to deliver water. Non-linear time history analysis of the soils predicts approximately 6m of lateral movement for the design seismic event. Soil-structure interaction analyses indicated conventional design was ineffective for both the shaft and the 60m free-standing steel water pipe within one shaft. A unique hybrid inelastic design was used to enable the steel pipe to realize very high inelastic strains and the concrete shaft to yield to accommodate the soil induced demand. The design required special grades of high ductility steel and innovative details to de-couple the concrete shaft from concrete shoring walls to limit demands on the shaft.

Keywords: seismic, liquefaction, tunnel shaft, inelastic design, soil-structure interaction, steel pipe, concrete hinge, self-consolidating concrete, shear friction.

Unique Design Considerations for Mechanically Stabilized Earth Walls in Transportation Widening Applications

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Abstract

As many transportation corridors have exceeded design capacity, additional lanes are being constructed adjacent to existing traffic. The construction of new lanes often requires support of excavation or relies on existing retaining structures for temporary and permanent load relief on new MSE walls. Although various types of hybrid MSE structures using combinations of existing walls or multiple wall types have been successfully constructed for decades, minimal formal design guidance existed until 2006 when the US Federal Highway Administration issued a manual for Shored MSE walls (SMSE).

This paper will present case studies and best practice suggestions for the use of MSE walls in highway widening applications, including where new MSE walls are placed in close proximity to existing MSE walls or other retaining structures.

Keywords: MSE, Shored Mechanically Stabilized Earth, soil nail, reinforced soil

DETAILED DESIGN OF THE URBAN TUNNELS UNDER *LAS GLORIAS* SQUARE, BARCELONA

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Abstract

Barcelona´s urban planning foresees a big green pedestrian area at *Las Glorias* Square where, nowadays, a capital hub of rail and road communications is located. One of the most important access to the city is the Gran Via street, which nowadays runs through the square at the same level, and will become underground in the future under four of the main railway tunnels in the city. The tunnel, in urban ambit, is being built between diaphragm walls which are connected between them under the existing railway´s tunnels. The new tunnel will be built using an innovative method by jacking horizontal steel tubes, that will configure the horizontal protection during the digging works, and will allow to maintain the service of the existing railway tunnels without interruptions, that are daily used by thousands of citizens. The execution of the transverse box section is divided in two phases.

Keywords: Tunnel, urban, jacking, diaphragm wall, phreatic level

Structural Engineering Global Interoperability: What and Why

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Abstract

Like-minded structural engineering organizations should work together to allow participants in the design and construction industry to more readily operate on a global platform. We call this Global Interoperability, and in its most general sense it is a vision where our industry is structured to readily facilitate people, organizations, and systems to work across geographic and other boundaries.

Besides the obvious benefit of sharing of resources to achieve a common goal, Global Interoperability will be particularly advantageous for structural engineers who are highly qualified, globally adept, creative, and value-producing.

The idea of Global Interoperability does not imply a homogenization of education, licensure, standards, and language. Indeed, regional differences in approach are both expected and desirable to foster innovation. Instead, the goal of Global Interoperability should be to identify and break down unnecessary and wasteful barriers to collaboration and enable the advancement of the profession worldwide. Some elements of standards and practices may be common across boundaries. In other cases, say in codes and standards, it may be desirable to define a structure or framework for a global approach, which accommodates regional variations.

Global Interoperability is a long-term vision and results of deliberate collaboration with other professionals in the field of structural engineering, and will require a sustained, incremental progress to promote a successful structural engineering profession. Other industries such as medicine, law, and public safety are working towards Global Interoperability. To the author's knowledge no structural engineering organization has taken a leadership role in promoting Global Interoperability.

Structural Engineering Global Interoperability: Codes and Standards

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Abstract

This presentation reviews the systems in place for developing and administering building codes and standards in the United States, the European Union, and a few major countries around the world such as Canada, China, and India. Commonalities among the systems as well as major differences will be pointed out and discussed.

In the United States, there used to be three regional model codes, which are now unified into one *International Building Code*. The process by which this unification was accomplished will be briefly reviewed. Whether the lessons learned in that effort can be utilized to bring some unity to at least the structures of the building codes of the world will be explored.

Structural Engineering Global Interoperability: Knowledge Sharing

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Abstract

Design and engineering work for global projects has increased exponentially in the last two decades and will continue to grow as globalization accelerates. Structural engineers collaborate on projects worldwide to understand and implement local codes and practices, specific environmental hazards, unique construction materials, common building systems and construction sequencing. Efforts also extend to general contracting capabilities including cultural and legal systems' impact on procurement budget and project construction schedule.

This presentation will provide a synopsis and an overview of how engineering organizations can benefit from developing a framework for standard practices and requirements in forms that allow easy adoption with local modifications in any region of the world. A database of global codes and standards is envisioned to assist structural engineers with their practice to take into account resources required, cultural influences, legal system and customs on structural engineering practice. The presentation further explores steps planned by the Global Activity Division of SEI/ASCE to develop a sharing platform for Structural Engineers to access required resources and materials to efficiently execute projects worldwide. A review of recent and ongoing sharing efforts between SEI and other engineering organizations and local jurisdictions in different parts of the world will be provided. It is hoped these efforts continue to bridge the gap in engineering practices, required education, level of experience, and licensure standard towards a globally integrated and interoperable structural engineering profession. Knowledge sharing will serve to assert the value and importance of the structural engineer in global construction projects.

Structural Engineering Global Interoperability: Professional Qualifications and Licensure

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Abstract

Professional licensing requirements in the various jurisdictions in the United States are complicated and often stifling. Further, the multi-jurisdictional structure in the US is a clear impediment to international practice by US engineers, and practice in the US by engineers licensed elsewhere. It usually is very difficult, and sometimes impossible, for engineers with a professional license in the US to obtain a license by comity in another country, and vice versa. This restricts engineers wishing to practice across the US borders from working fluidly in the global engineering community.

In addition, the prerequisites for licensure sometimes differ significantly from jurisdiction to jurisdiction, and the licensing examinations necessary to qualify for licensure often follow entirely different philosophies, and sometimes are antiquated, from country to country.

These differences among the requirements for licensure around the world seem counterproductive and often arbitrary in the context of establishing credentials to practice structural engineering in jurisdictions other than one's home. International practice will be facilitated when authorities strive to establish mutual recognition and acceptance of the basic criteria for professional licensure.

This presentation will explore the present status of licensure requirements, and make an argument for working to coordinate and unify across jurisdictional boundaries.

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