The Institution of Structural Engineers

Possible solution to past CM examination question

Question 3 - April 2010

Footbridge

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Footbridge question

Client's requirements

1. A new footbridge is required to cross a major urban highway to provide access to a commercial centre: see Fig. Q3
2. The footbridge is to cross the highway at an angle of 30 degrees. At the east end of the bridge a ramp is required to descend to ground level. Provision is to be made for a future extension of the bridge further to the east.
3. No loading may be transferred from the footbridge to the commercial centre building and an expansion joint is required at this junction. Column supports to the footbridge are permitted only within the highway planting strips and the central carriageway divider. No columns are permitted under the east end of the bridge.
4. The maximum permitted gradient of the ramp is 1:12. Horizontal landings are required in the ramp at vertical intervals of not more than 3.5m, and the length of each landing must be not less than 2.0 m.
5. A 1.0m high parapet is required for both the footbridge and the ramp. The clear widths of the footbridge and ramp are to be 6.0m and 4.0m respectively.
6. A minimum clearance of 0.8m is required from the edge of carriageway to the face of any structure. The minimum required headroom under the footbridge is 5.1m above the carriageway level.
7. Temporary access to the highway carriageways is available each night between midnight and 5:00am.

Imposed loading

8. Footbridge loading 5.0kN/m^2

Site conditions

9. The site is located in the centre of a city. Basic wind speed is 46m/s based on a 3 second gust; the equivalent mean hourly wind speed is 23m/s.
10. Ground Conditions Ground level - 0.5m Made ground 0.5m – 30.0m Sandstone. Allowable bearing pressure 1000kN/m^2

Omit from consideration

11. Detailed structural design of the footings for the ramp.

SECTION 1 ***(50 marks)***

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure including the foundations. Indicate clearly the functional framing, load transfer and stability aspects of each scheme. Identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After the design has been completed, the client advises that he wishes to create a garden under the west end of the footbridge and wishes to avoid any columns in this area (shown as the dotted line in Figure Q3). Write a letter to the client explaining how your design could be modified to accommodate this change. (10 marks)

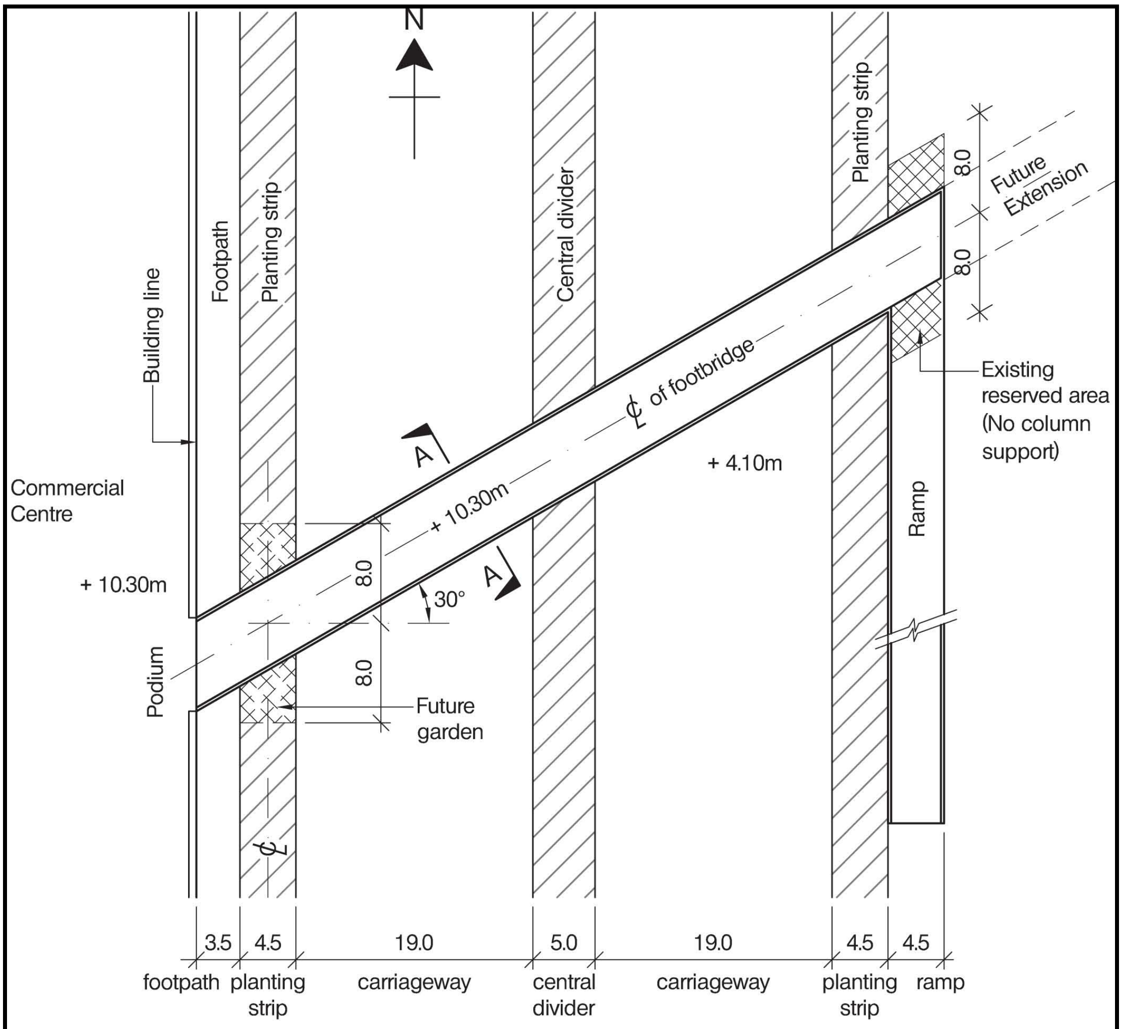
SECTION 2 ***(50 marks)***

For the solution recommended in Section 1(a):

c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the bridge foundations and the ramp. (20 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimating purposes. (20 marks)

e. Prepare a detailed method statement for the safe construction of the footbridge and its ramp and an outline construction programme. (10 marks)



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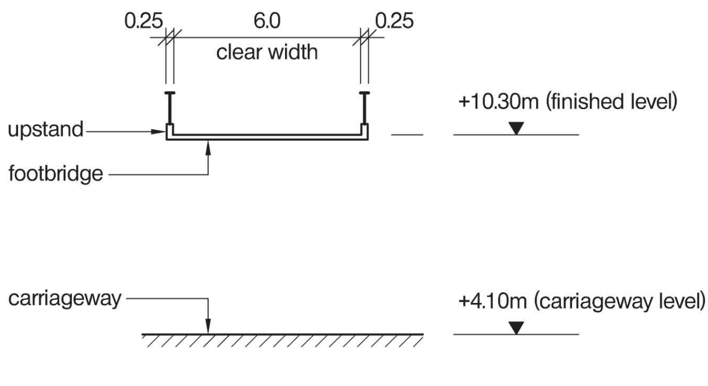

SECTION A-A

NOTE: All dimensions are in metres

FIGURE Q3

Introduction:

Initial response to this question reminds any bridge engineer the footbridges over busy motorway or trunk road in urban areas of various part of UK. For example Ely Road footbridge in London over A406 as shown in Figure A & B (Footbridge at Hong Kong):

Figure A: Ely Road footbridge over A406 North Circular next to the shopping centres.

Figure B: Footbridge at Hong Kong

Understanding the question and visualisation of the site in three dimensions is the most important step to solve the problem. An imaginary view of the site is shown in the Figure C below:

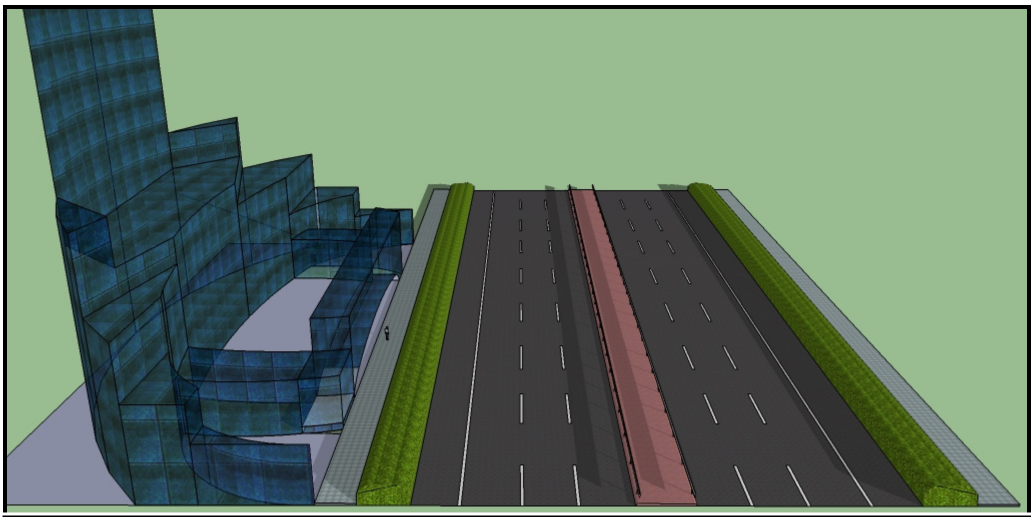

Figure C: An imaginary three dimensional view of the site as in question

<u>Key observations from Client's requirement => *constraints*</u>

- Major urban highway, temporary access to the highway carriageways is available each night between midnight and 5:00am :
    - *Least (as above) / no disruption acceptable*
    - *Prefabricated / Pre-cast form of deck only acceptable*
    - *Cast in situ deck only possible if permanent formwork is used*
- 30° Skewed Alignment:
    - *Detailing is affected throughout, especially at the connection with ramp*
    - *Effect of skew on the proposed form of superstructure's behaviour.*
- No load to be transmitted to the commercial building:
    - *Superstructure must be cantilevered / overhanged from either end supports*
    - *Expansion joint at west end shall be designed to accommodate the possible movement*
- Column supports to the footbridge are permitted only within the highway planting strips and the central carriageway divider with a minimum clearance of 0.8m is required from the edge of carriageway to the face of any structure:
    - *Limited space for substructure & foundation*
    - *Lighter superstructure is more appropriate to avoid skew effect on the substructure.*
- The clear widths of the footbridge and ramp are to be 6.0m and 4.0m respectively:
    - *Much wider than UK's standard width for foot bridges and approach ramps*
    - *Omission of central support using a longer superstructure will be extremely difficult.*
    - *Transport of prefabricated superstructure shall be planned since design stage.*
    - *Erection of the major components of the superstructure shall be considered in design.*
- The minimum required headroom under the footbridge is 5.1m above the carriageway level. The maximum permitted gradient of the ramp is 1:12. Horizontal landings are required in the ramp at vertical intervals of not more than 3.5m, and the length of each landing must be not less than 2.0 m.
    - *It is lesser than UK standard of 5.7m, but for a ramp in 1:12, less than 70m long with one landing would be required.*

- *Considering the width of each carriageway, spans are to be determined and their allowable deflection limit will have to be added on top of the permissible headroom.*

All the above points are better visualised by the following three dimensional figure D

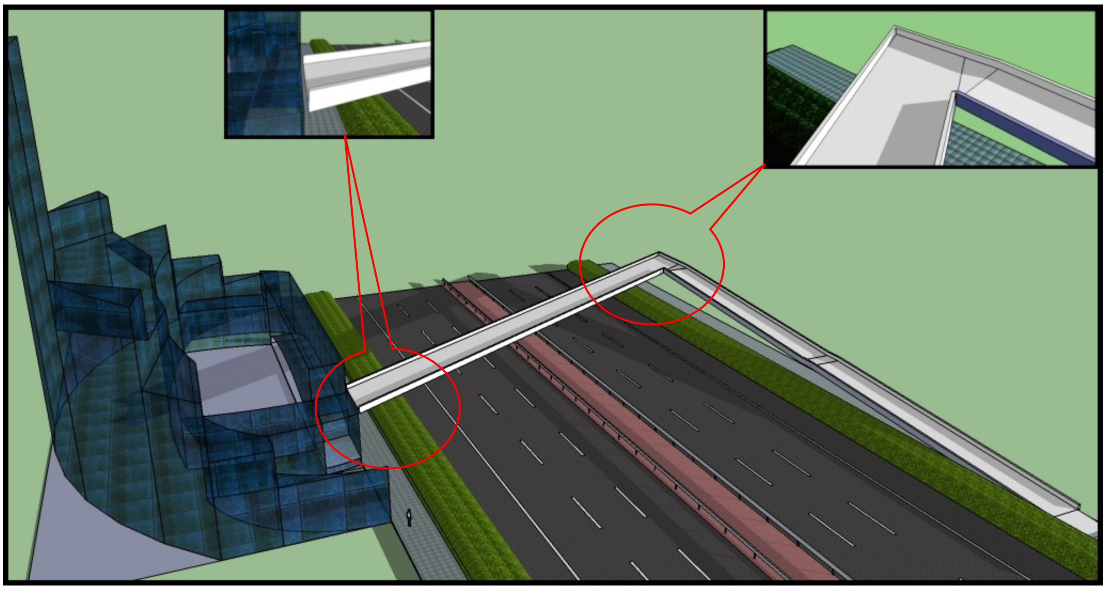

Figure D: A 3D representation of the client's requirements leading to the constraints

A complete three dimensional visualisation of what is described in the question and particularly the client's requirements are the most important to the person whoever will attempt it. Any solution is put forward has to be cross checked to all the above constraints.

<u>The most appropriate two distinct viable solutions possible for this problem:</u>

For the two distinct and viable solutions there are many examples for the structural forms in the common design offices. Cast in situ deck slab (using pre-cast formwork) on top of simple or continuous beams or even simple through truss, overhanged at either side to meet client's requirement should be the most appropriate solutions since there is no aesthetic requirement from client. However both the solutions shall be designed and detailed keeping all the above constraints in consideration.

Solution 1:

Cast in situ deck slab on top of continuous steel beams as shown in Figure E below:

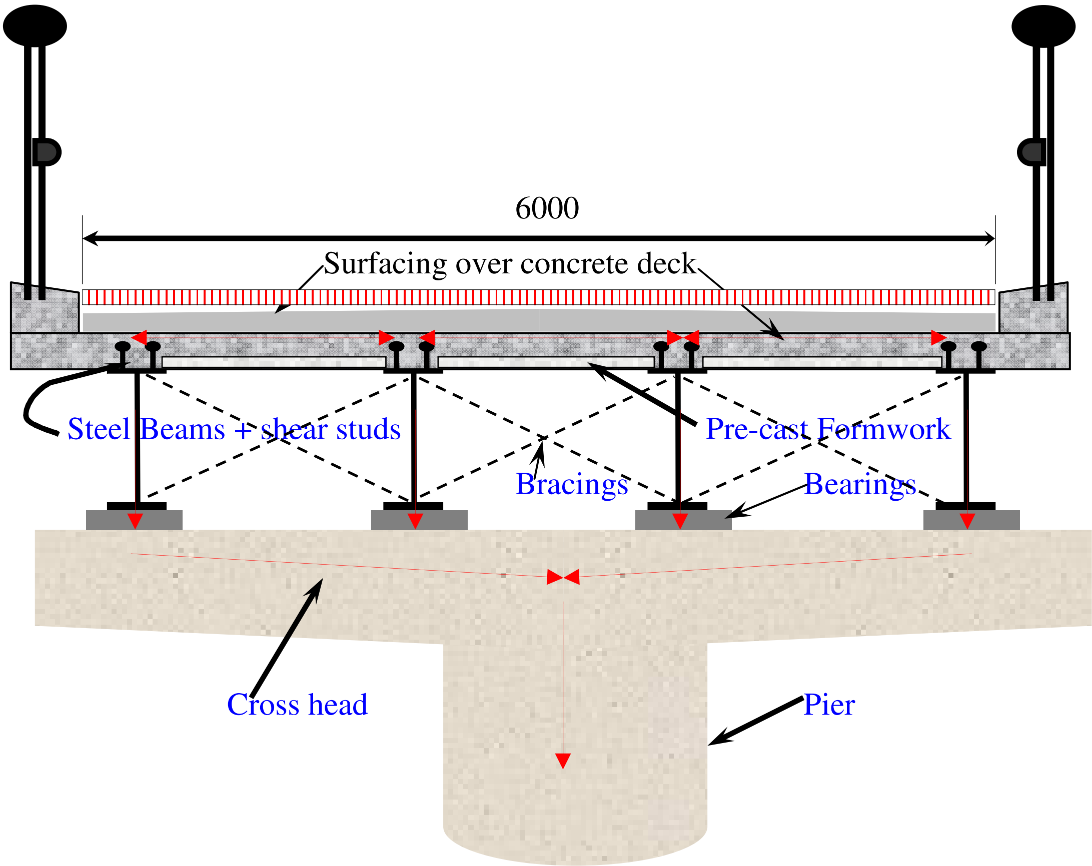

Figure E: Typical cross section of the solution 1 with load & load path

This is the simplest possible solution for the given problem. In the table below it is shown how it overcomes the above mentioned constrains

List of Constraints	**Ways to overcome them**
Least / no disruption Prefabricated / Pre-cast form of deck Cast in situ deck on permanent formwork	Erection of pair of pre fabricated girders and casting of slab on top of the pre-cast formwork will minimise disruption.
Detailing to accommodate 30 degree skew Superstructure's behaviour due to the skew. Superstructure to be cantilevered / overhanged No load to be transferred to the Commercial building.	Beams used underside of deck to accommodate the triangular portion to match the ramp slope. Skew induced behaviour is dealt with by pair of steel composite plate girders. Provision of expansion joint between the cantilever end and building will ensure no load is transferred to the building.

Limited space for substructure & foundation Lighter superstructure is more appropriate to avoid skew effect on the substructure.	Single circular pier with cross head supporting the light weight superstructure will be least affected by the skewed superstructure.
6m wide foot bridge and 4m wide ramp Omission of central support using a longer superstructure will be extremely difficult. Transport of prefabricated superstructure shall be planned since design stage. Erection of the major components of the superstructure shall be considered in design.	Two pairs of girders for footbridge and a pair of girders for ramp are enough for the spans. Use of central pier support and the introduction of splice at the point of contra-flexure at either side, will make it easier for transportation and erection of prefabricated steel girders leading to a very simple solution.

Solution 2:

Cast in situ deck slab through simply supported Warren Truss Girders as shown in Figure F below:

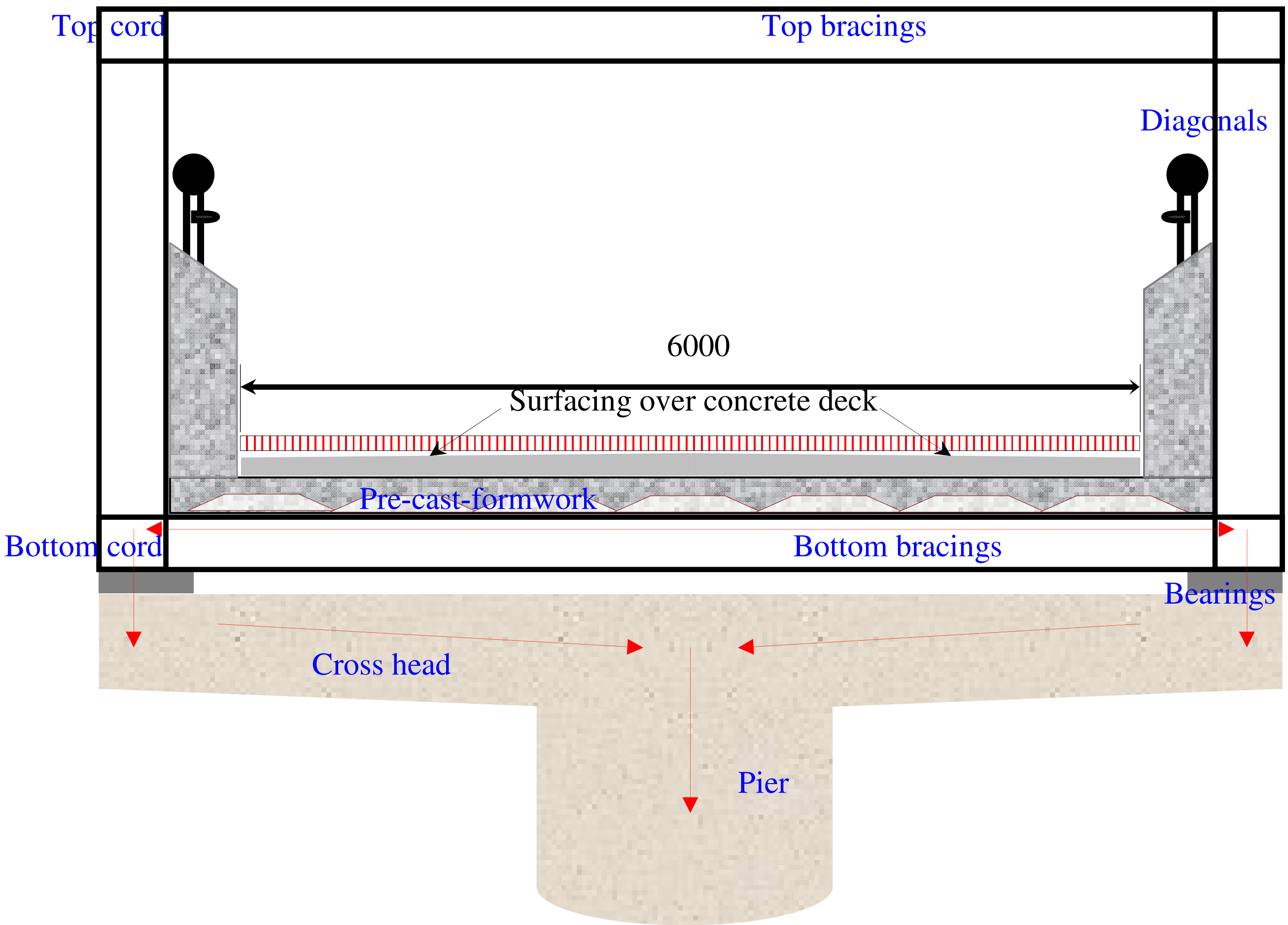

Figure F: Typical cross section of the solution 2 with load & load path

This is another simple possible solution for the given problem. In the table below it is shown how it overcomes the above mentioned constrains:

Constraints as listed	How the solution overcomes them
Least / no disruption Prefabricated / Pre-cast form of deck Cast in situ deck on permanent formwork	Transportation of prefabricated Warren truss individually, erecting them in place by tying them each other at top and bottom using transverse members and casting of deck slab on top of the permanent formwork shown above will minimise the disruption.
Detailing to accommodate 30 degree skew Superstructure's behaviour due to the skew. Superstructure to be cantilevered / overhanged No load to be transferred to the Commercial building.	Trusses are simply supported on piers at the central reserve & either end of carriageway. The trough shape concrete deck is cantilevered to the either end with appropriate detail at the connection with ramp / commercial building will overcome all these constrains easily.
Limited space for substructure & foundation Lighter superstructure is more appropriate to avoid skew effect on the substructure.	Single circular pier with cross head supporting two trusses at either side on bearings and the concrete deck on prefabricated formwork will be considerably light superstructure and stiff enough to deal with the constrains listed.
6m wide foot bridge and 4m wide ramp Omission of central support using a longer superstructure will be extremely difficult. Transport of prefabricated superstructure shall be planned since design stage. Erection of the major components of the superstructure shall be considered in design.	Two pairs of trusses and one pair of them over each carriageway is enough for 6m wide foot bridge. 4m wide concrete ramp supported on intermediate piers joining the footbridge RC deck with a triangular wedge, is a very simple arrangement for joining slope with skew deck. Best use of central reserve pier support Transportation and erection of Warren girders shall not be difficult for this solution.

<u>Comparison and selection of the more appropriate solution</u>

Three important points stand out for option 1 over 2:

- Least disruption to the road under.
- Easier to transport and erect in place
- Much simpler detail for connection with ramp.

Important points for the letter to client:

- Pier near commercial building cannot be used, but without a support the bridge cannot be built as a cantilever from central reserve support.
- Instead of single cylindrical pier with cantilevered crossheads a pair of piers at least 16m apart will have to support the superstructure by its monolithic crosshead in between.

The letter should discuss the impact of these two important points to the design and nothing else.

Calculation:

For the chosen option calculation is required for principal structural elements;

Standard 250mm thick deck slab with B20 -150c/c T&B both direction can easily be considered for this particular case based on minor calculation or even engineering judgement is acceptable. Standard plate girders or even rolled sections at high end of the steel section table can easily be demonstrated as capable of carrying quarter of entire load with little amount of calculation (using appropriate references to the available information from various guidance notes etc). Since the structure is continuous, so hogging moment will govern the section design. Therefore neglecting composite effect will not be grossly uneconomical as the section has to satisfy the requirements in combined effect of bending and shear. Hence the calculation should demonstrate the need.

Though wind may not be governing but minimum calculation is needed in line with the question. Calculation for the sizing of substructure, foundation and ramp are also equally important, which are often forgotten. For this particular solution other than working out of the ramp geometry minimum amount of calculation or at least a design statement is necessary for its sizing purpose.

Drawings:

As mentioned in the question the answer script must include general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements and critical details for estimation purpose. For this extremely simple solution other than plan, elevation and section, it is desirable that the expansion joint with the commercial building and the triangular slab to act as a transition between the deck slab and ramp must be included. Detailed three dimensional views of both the proposed solutions are provided in the appendix.

Method of Statement and outline construction programme:

The detailed method statement for the safe construction of the footbridge and its ramp and an outline construction programme should include various stages of construction and the anticipated time required for each of them. This can be done by putting bullet points accompanied with free hand sketches and a bar chart, but health and safety aspect of each activity and reasonable understanding of the time involved for respective activity has to be well demonstrated.

For example in this chosen solution:

- Approval in Principle & designers risk assessment followed by the detailed design and preparation of fabrication / construction drawings should be an activity in the beginning of the project, which is often forgotten.
- Prior to any construction activity the site preparation and enabling works along with the site mobilisation with adequate fence to the construction area for safe construction is equally important.
- On completion of the project hand over of the structure with as built drawings and Health & Safety file to the owner client should not be ignored in the method of statement.

Appendix 1: Three dimensional view of the proposed two solutions.

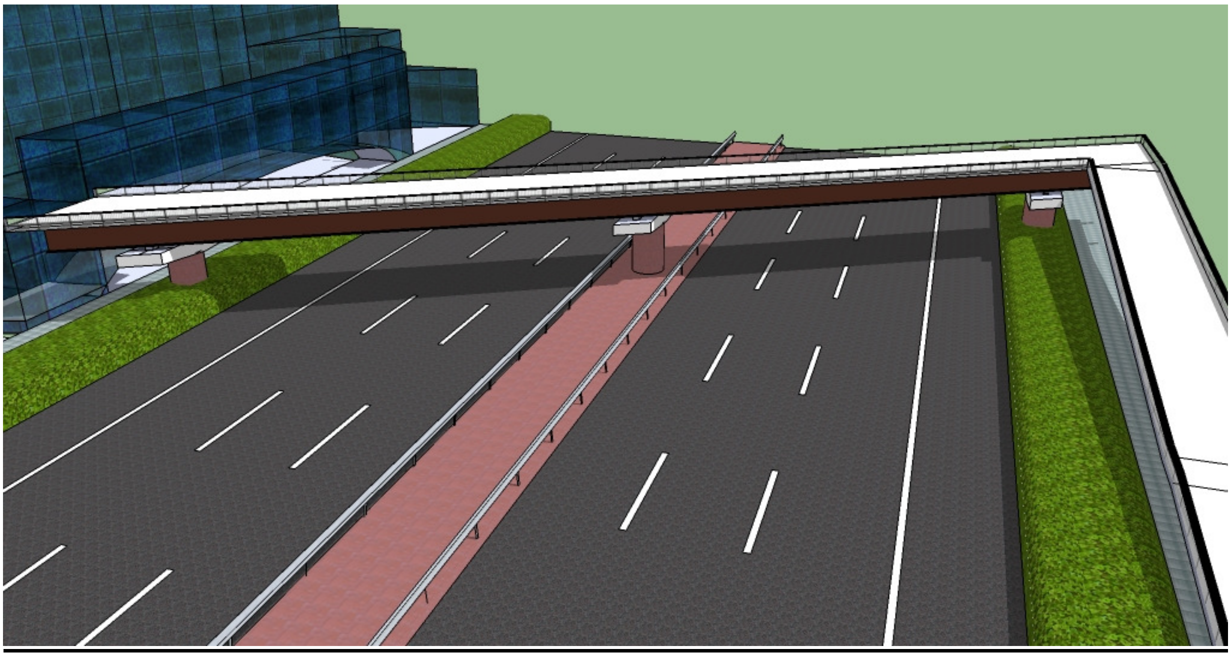

Figure 1A: Three dimensional view of the bridge and ramp made of RC slab on steel girders

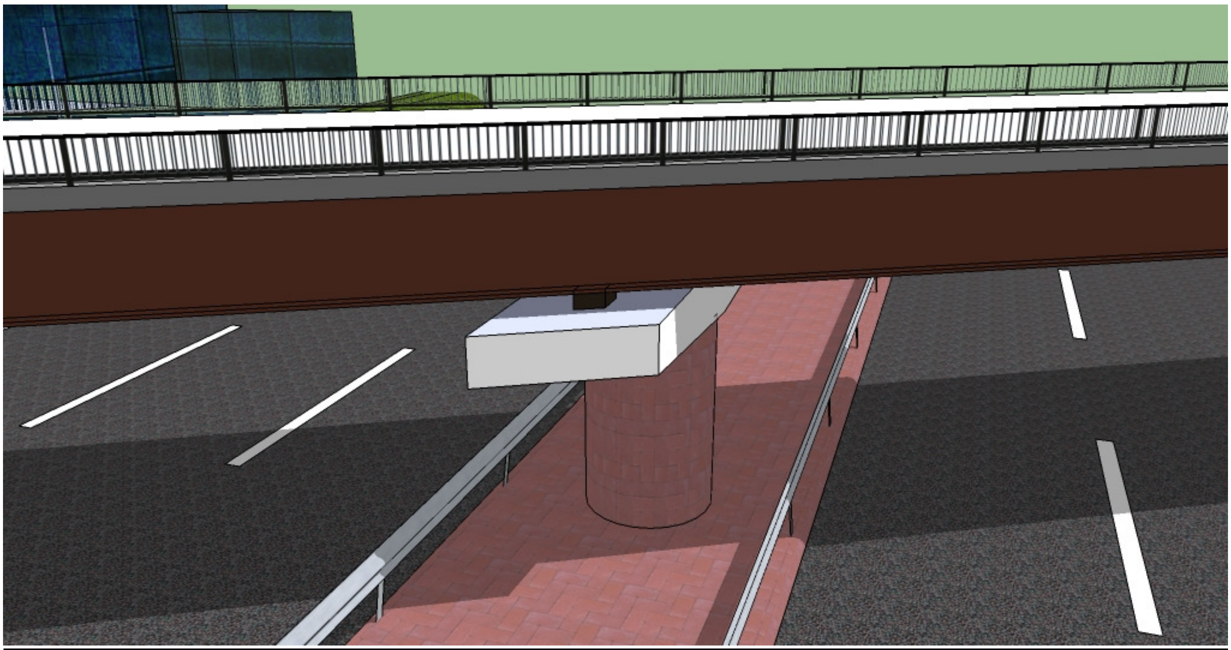

Figure 1B: Three dimensional view of the bridge deck slab on steel girders, bearings and parapets

SOLUTION1

Figure 2A: Three dimensional view of the bridge concrete deck on through warren truss & ramp

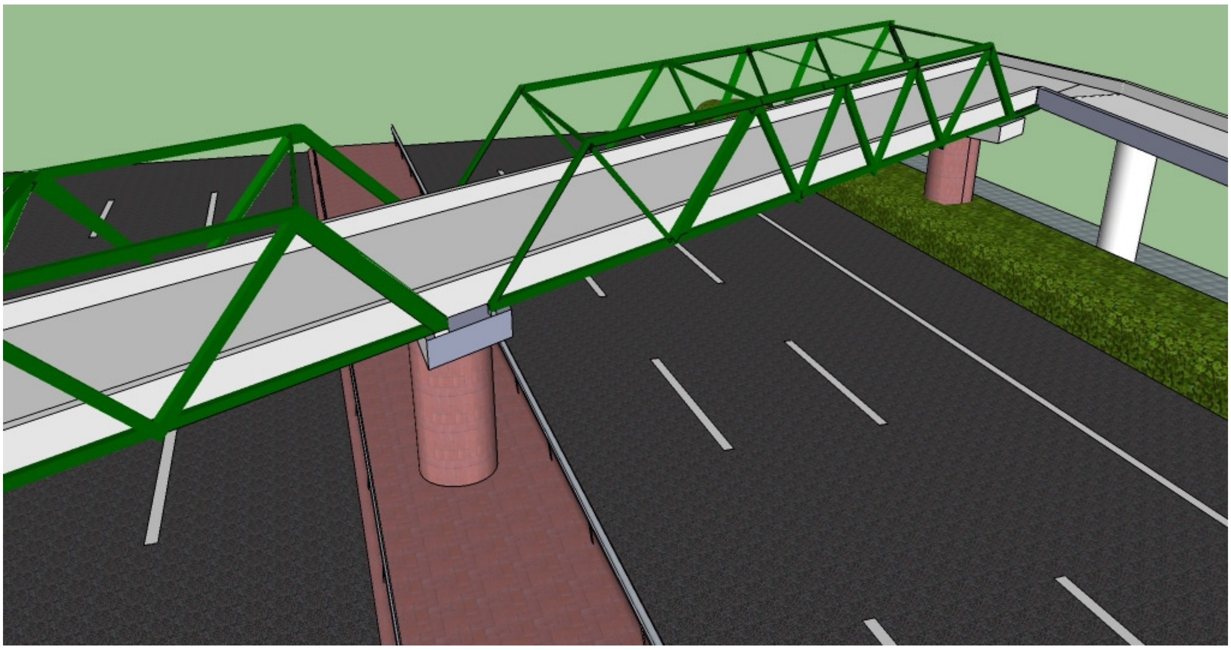

Figure 2B: Three dimensional view of the bridge deck on steel truss, bearings & ramp connection

SOLUTION2