Possible solution to past CM examination question

Question 3 - April 2007

Opening Access Bridge

by Kirsten Morris

Question 3. Access Bridge with opening span

Client's requirements

1. A bridge carrying two 4.0m-wide traffic lanes and a 2.0m-wide footpath over a canal to provide access to a new waterside development: see Figure Q3.
2. The minimum headroom required above water level is 4.5m when the bridge is closed and 15.0m when the bridge is open.
3. The minimum clear channel width required is 10.0m. The water depth in the clear channel is 3.0m. The clear channel must not be closer than 5.0m to either bank.
4. There are no restrictions to the overall size or height of the bridge in either the open or closed positions.
5. The minimum headroom required for road vehicles is 5.7m
6. Approach ramps should be kept to a minimum height with a maximum gradient of 1:12.

Imposed Loading

7. Vertical traffic loading 10.0 kN/m^2
   Footpath loading 5.0 kN/m^2

Site Conditions

8. The site is located in a marine environment adjacent to a seaside town. Basic wind speed is 46m/s based on a 3-second gust; the equivalent mean hourly wind speed is 23m/s.
9. Ground Conditions:

East side	Existing ground level to 0.2 m depth	Made Ground
	0.2 m to 10.0 m	Limestone, allowable safe bearing pressure 1000kN/m^2
West side	Borehole No. 1	
	0.0 to 2.0m	Topsoil
	2.0m – 30.0m	Loose Sand and Gravel, N=5 to 10
	30.0m	Limestone

Groundwater was encountered at 2.0m below ground level.

Omit from consideration

10. Detailed consideration of the mechanical means of opening and closing the bridge.
    Accidental impact on bridge and supports.

SECTION 1 **(50 marks)**

a. Prepare a design appraisal with appropriate sketches indicating two distinct and viable solutions for the proposed structure. 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. The client has asked you to consider increasing the headroom above water level to 6.0m when the bridge is closed. Write a letter to your client explaining how this could be achieved. (10 marks)

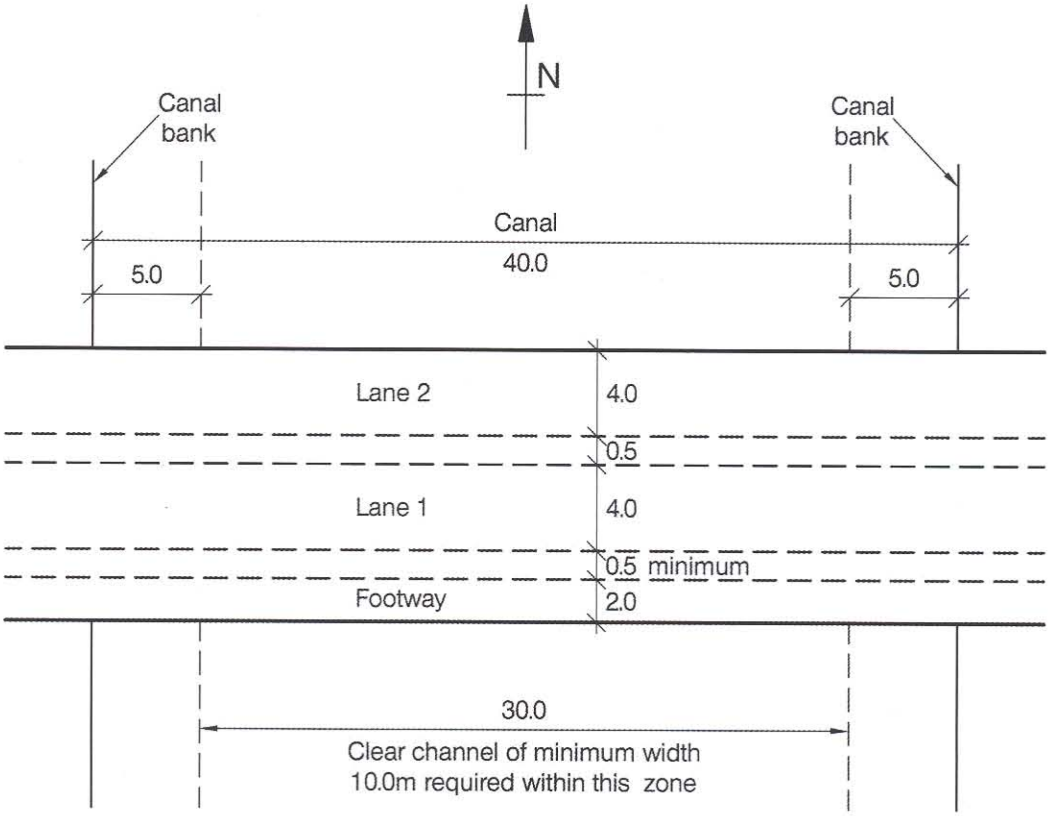
SECTION 2 **(50 marks)**

For the solution recommended in Section 1(a):

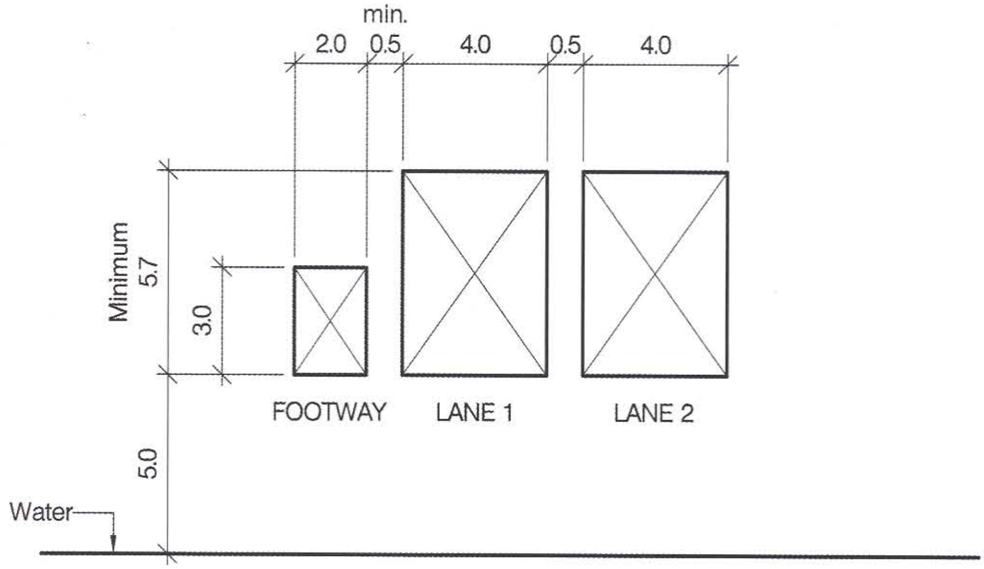
c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. (20 marks)

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 with diagrams showing the key elements of temporary works for the safe construction of the bridge. (10 marks)



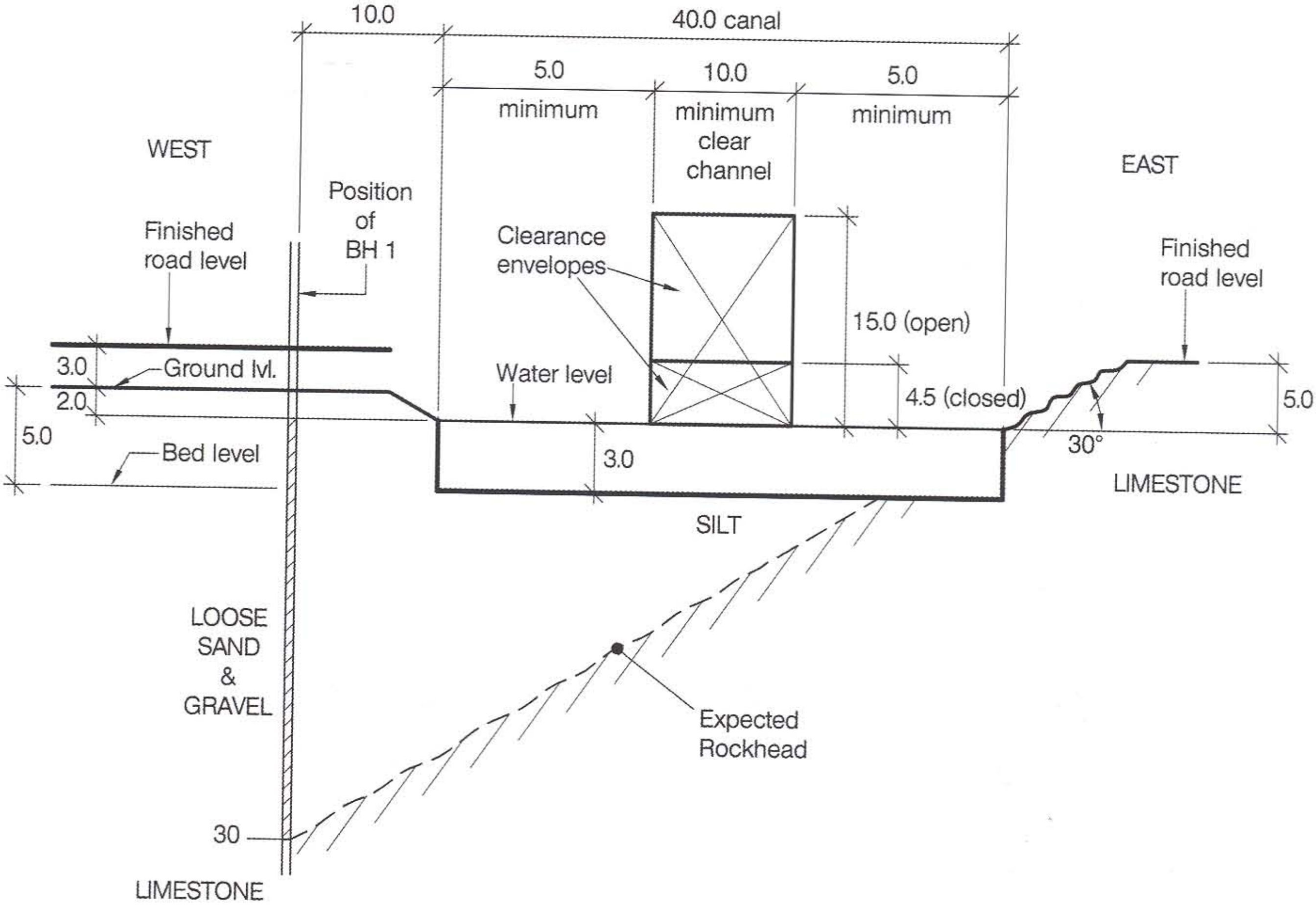
PLAN



CROSS SECTION

NOTE: All dimensions are in metres

FIGURE Q3 (Sheet 1 of 2)



LONGITUDINAL SECTION

NOTE: All dimensions are in metres

FIGURE Q3 (Sheet 2 of 2)

The problem is to design a structure to provide access over a canal with an opening span. This is outside the experience of most bridge designers but it should not be seen as a major problem after careful study as the question specifically excludes consideration of the mechanical means of opening. A question that at first glance appears difficult is often the one that provides the best opportunity to gain marks and show the candidates understanding of a variety of structural issues. i.e. You are required to demonstrate understanding of key structural principles and be able to design key elements of the structure.

The key to understanding this question is to appreciate that there are at least two distinctly separate but equally critical load conditions: in the closed and open positions partly because it is likely some reversal of load effects may occur. It is also important to consider the temporary state during erection which can also be critical. For an efficient design the moving part of the structure should be as small and lightweight as possible and the loading on bascules/ swings should be balanced to minimise lifting effort/ overturning moments respectively.

The ground conditions are very different on each side of the canal with Limestone close to the surface on the east side and at a depth of 30m on the west side with loose sands and gravels on top. This is pointing towards a possible asymmetrical arrangement for the structure and foundation construction which should at least be discussed in section a. The question also allows some flexibility in the position of the clearance envelope within the canal. There are benefits in building the larger foundation to support the fulcrum of the swing or sliding structure close to the rock embankment to minimise its' size and the amount of construction in the water. It will mean that a deeper piled foundation will be required on the other side for the approach viaduct.

Part a:

There are a number of possible options for solving this question and providing elegant structure. The lifting span could be achieved in a number of ways:

- Swing bridge using a balanced cantilever or cable stayed system. A single swing with the foundation as near as possible to the rock embankment with a longer lightweight span across the water and a heavy short back span to balance towards the embankment.
- Bascule lifting bridge. A single bascule again near the rock embankment would be most efficient. A counterweight span at road level is likely to dip into the water which is not ideal for a durability point of view so it would be preferable to have an overhead bascule with cables to lift the bridge or a decorative counterweight that rises above road level when the bridge is closed. Note that the closer the pin is to the clearance the greater angle of lift required but the smaller the span.
- Sliding bridge (sideways or longitudinal). This would be harder to set up as all the elements of the moving part would have to clear the road before sliding can be achieved. Sliding in line would need a cantilever involving uplift as well as vertical loading on the sliding bearings.
- Direct lifting. This would require two piers of similar construction in the canal so is likely to be expensive compared to alternative options. Also both sides would need to be lifted simultaneously. Wind loading in the raised condition may be a critical issue as it needs to be a lightweight structure lifted high.

It would be good practice to avoid any part of the mechanics / moving parts to be sited permanently or temporarily in the water or inside confined spaces as this presents a durability and a hazard for maintenance activities.

The loose sands that may be subject to settlement under the approach embankments so some discussion of differential settlement gained marks. Keeping the channel close to the east side will reduce the fill on the east and reduce the rock excavation on the west.

The available depth of construction with a horizontal vertical alignment is 500mm which is adequate for a number of structural solutions to span 10m clear. The road alignment does not have to be horizontal but must be within the given limits for the slope. There are no restrictions on the road level or length of the approach – other than those dictated by economy. If in doubt in exam situations you are permitted to state your understanding of the question and the examiner should mark accordingly. It is generally NOT a good idea to try to simplify the question as it is likely to limit your opportunity to gain marks. Remember you are trying to show the examiner how much you know and not just present a solution that works. Some of the options would be more complex with a sloping alignment.

The stability of the structure in the open condition must be considered and to check that the moving parts will not clash with static elements of the structure.

The key to the solution for a swing bridge is to balance the dead loads to minimise the moments around the pivot point and for a bascule is to balance the dead loading so the effort required to move the bridge is minimal.

It is suggested that candidates come to the exam with a checklist that can be described in one paragraph or even one sentence per option, as follows:

- sketch elevation and cross section (not to scale) to explain structural type adopted
- column types and abutment types
- foundation types
- articulation
- load path
- constructability
- durability and maintenance
- aesthetics

The above points can then be summarised in a table before the recommendation is made.

Part b: The question requires an increase in the clearances - the scope of the response depends on the solution chosen. It is best to aim to get as many issues as possible for discussion so do not select your option to avoid problems in part b or you may limit your opportunity to gain marks. There are a number of issues to discuss for a rise in the vertical profile. Raising the approach embankment on the west will increase fill and possible settlement. Raising on the east will reduce rock excavation on the approach. The height of the substructures will be increased as will the visual impact. Greater cost, longer construction time, possible affect on the moving mechanism, increased wind loading for the temporary condition. It may also be worth noting where your design is beneficial in this regard – i.e. Issues that will not be a problem such as no change to the lifting mechanism,

Part c: It is a good idea to do an outline calculation for the balance of loading at an early stage to allow preliminary sizing of the length of cantilever and backspan. This will allow final layout of the piers and moving section to be fixed. The size of the main beams and cantilever elements, lifting cables, and the pier and abutment needs to be established along with two types of foundations (piled and direct on rock). Two load cases must be considered for the open and closed situations. The open condition should consider wind loading effects. If the bridge is to be launched the temporary reverse loading and cantilever effects during launching must be included in the design of critical members since this can be the critical load condition. Lateral buckling / u frame action to restrain the compression members/ flanges of compression members is a critical issue in truss solutions.

Part d: Plan, elevations section, details of significant elements – bearings, joints etc.

Part e: There is a great opportunity in this question to show your knowledge of special construction issues and temporary works but make sure the basic sequence makes sense. It is helpful to be familiar with Health and Safety and environment issues but you must be able to describe temporary works required to construct their design. There are lots of issues to discuss for example:

- Working in and over water (piling/ caisson)
- Access across water
- Possible pollution to sea with debris / construction materials
- Possible sensitive area with tourists, residents etc.
- Siting a crane on soft ground.

You don't need to be familiar with methods of construction over / in water but you should be able to recognise the problems and understand basic principles.

<u>Figures:</u>

Fig 1 Outline scheme - Option 1
Fig 2 Outline scheme - Option 2
Fig 3 Load transfer - Option 1
Fig 4 Load transfer - Option 2
Fig 5 Bearing layout - options 1 & 2

<u>Commentary on the figures</u>

Figures 1 – 5 with notes

<u>References & examples:</u>

NCE 22/11/07 insert “The historic bridges & Infrastructure awards 2007 page 21 Wellington St Swing Bridge Kingston Upon Hull.

http://www.bardaglea.org.uk/bridges/bridge-types/bridge-types-intro.html

Tower Bridge London.

Peros Bridge Bristol

OPTION 1 - SWING BRIDGE

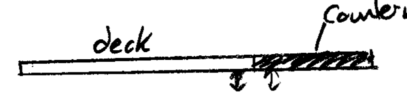
Location of main foundation : close as possible to Rock => minimise depth / Cost / Risks

Alternative large foundation in middle with 2 equal spans => no other piers in water

Approach ~~ramp~~ span precast / steel lifted in => minimise risk working over water

Construction depth ≈ Cantilever span/8 at bearing. - but can be reduced as only DL.
=> likely to raise level above that shown.
simply supported span/16 for DL+LL.

a) deck balanced Cantilever



b) Cable stay

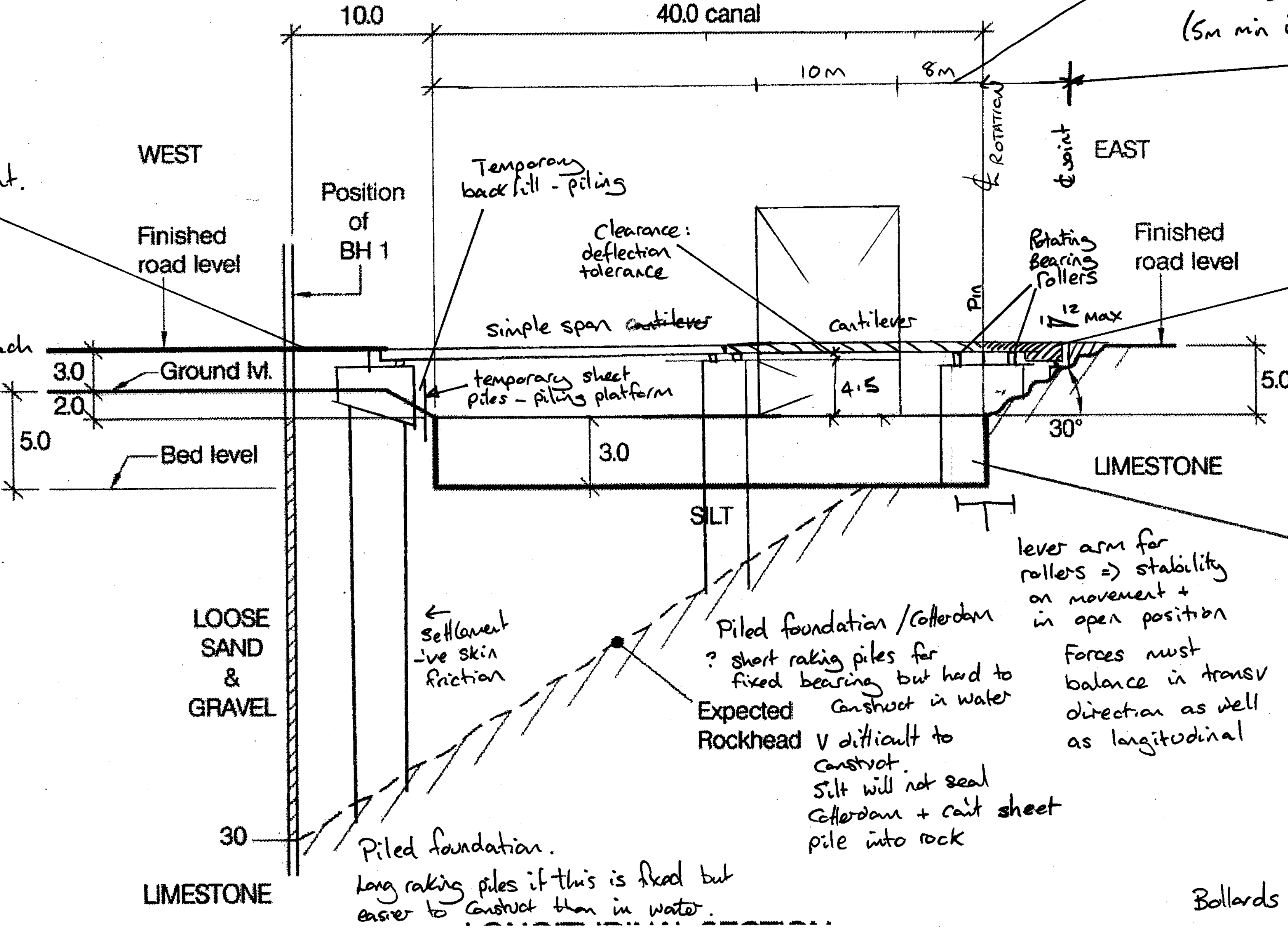
Clearance when open:
width = 11m min →
Allow $\frac{16m}{2}$ = 8m
(5m min in Question)

Min distance to joint to ensure clearance during rotation.
note joint at slight angle to prevent jamming

Roller bearings => must be Controlled
Locked in position in open position
=> wind loading.

Possible run on slab to deal with settlement.

Early Construction of approach embankment: settlement prior to abutment construction



Piled foundation / Cofferdam
? short raking piles for fixed bearing but hard to construct in water
v difficult to construct.
Silt will not seal Cofferdam + can't sheet pile into rock

lever arm for rollers => stability on movement + in open position
Forces must balance in transv direction as well as longitudinal

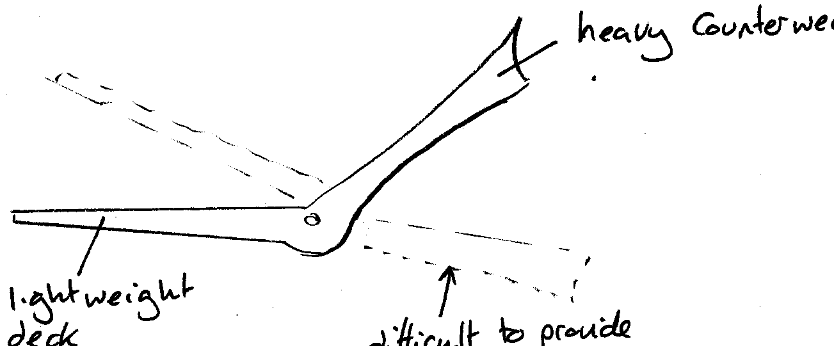
PIER / ABUTMENT
Built in caisson / cofferdam
Hollow to minimise Concrete ?
Fixed for horiz loads.
Access for machines maintenance
Avoid Confined spaces
: spaces likely to flood

Approach span.
Cost alternative choices for fixed end : And Compare CDM risks.
Decision not obvious

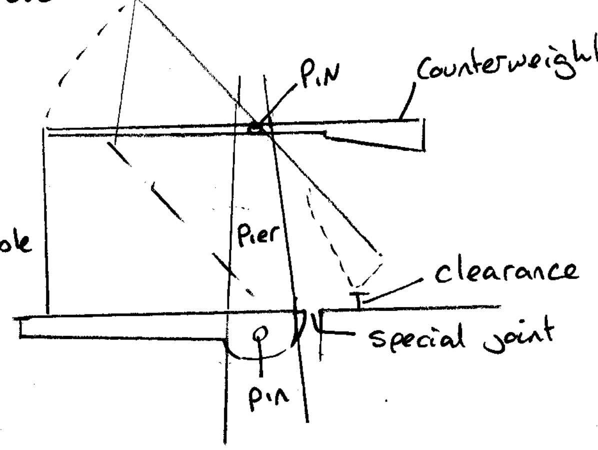
Piled foundation.
Long raking piles if this is fixed but easier to construct than in water.

Bollards to prevent ship impact.

a) Counterweight deck bascule



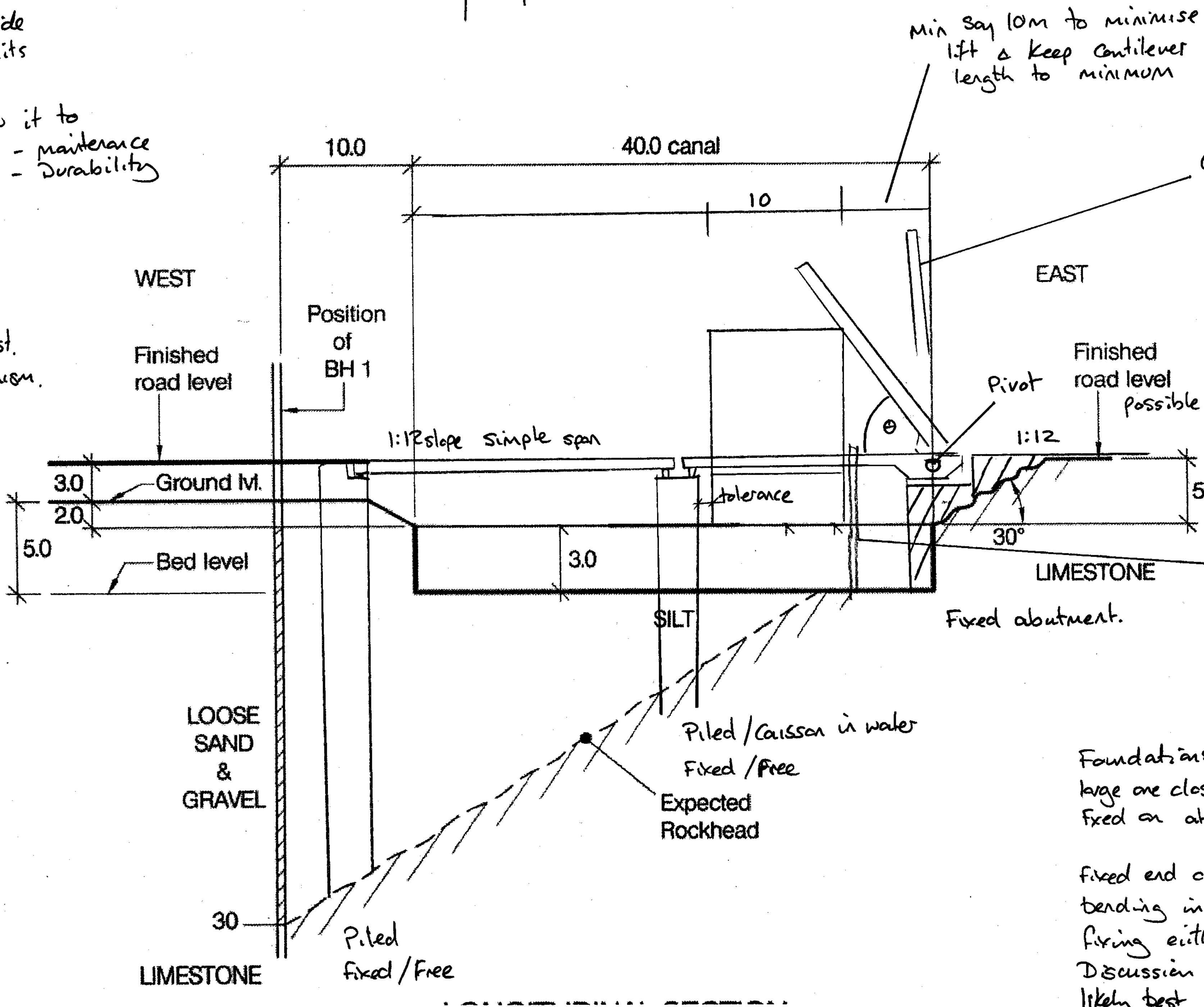
b) overhead bascule



OPTION 2 Bascule

Depth of deck ≃ L/16 overhead bascule. } Cantilever depth can be reduced as only supports DL but stiffness required during lifting.
≃ L/8 cantilever bascule }

In plane stiffness during lift in case drive mechanism not aligned, vibrations
~~possible~~ Need to look at wind causing twist when open. and load on hinge and mechanism.



Greater angle θ harder to lift:
backspan clearance of counterweight
movement of mechanism / drive
overhead bascule becomes less effective
=> more clear channel to allow
sensible limit ≃ 45° say

Bollards to protect from ship impact & prevent encroachment out of clearance zone (impact on raised deck)

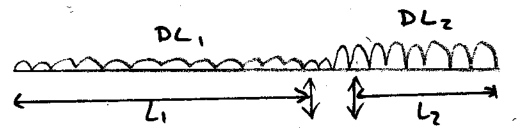
Foundations:
large one close to Rock => reduce cost / depth / CDM.
Fixed on at pivot for bascule.

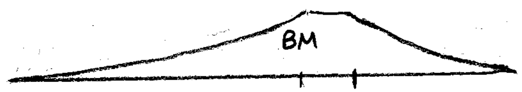
Fixed end of approach span requires raking piles / soil resistance / bending in piles : Balance costs + risks of fixing either one will direct choice :=>
Discussion with piling contractor essential in practice
likely best option to fix at abutment.

LOAD TRANSFER - SWING BRIDGE OPTION 1

Balanced Cantilever:

open



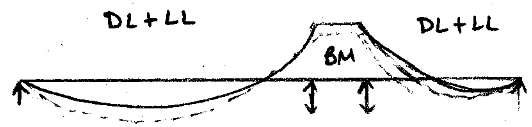


MAX BM = $\frac{wL_1^2}{2} \simeq \frac{wL_2^2}{2}$

Minor corrections to balance taken by bearing reactions preferably all in compression : ie forces close to balance

BM diagram curved due to effect of UDL

closed



DL as above

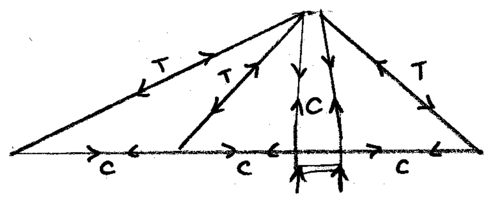
LL each span separate + Both together

⇒ Max sag in each span, max hogg, max bearing load

⇒ envelope of BM.

wind not significant in closed position

Cable stay



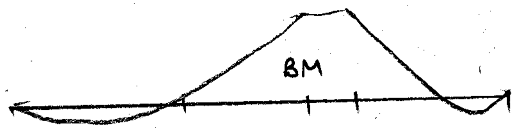
T - tension

c - Compression

Bridge should lock down onto end bearings in closed position to avoid bounce/uplift

single cable.

open

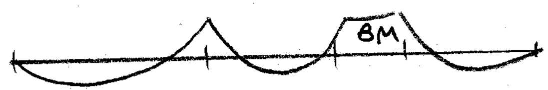


Longitudinal + transv loads in pin

Transv loads at abutment/pier when closed.

Multiple cable

open

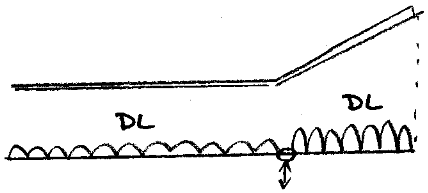


closed ⇒ similar but vertical end reactions will modify envelope

LOAD TRANSFER - BASCULE

OPTION 2.

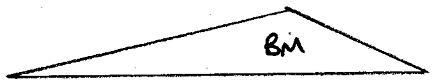
BASCULE DECK



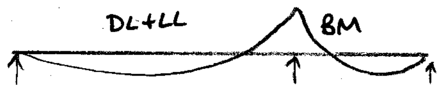
$WL^2/2$

OPEN: wind load on bearings + drive mechanism (both options)

open

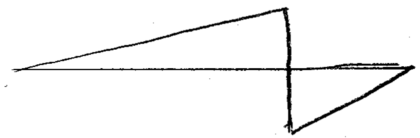


closed



DL + LL Envelope loadcases as option 1.

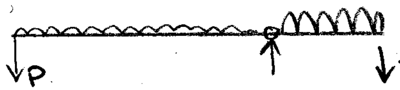
open



shear force diagram (more load on counterweight side)

Bascule high level

BOOM.

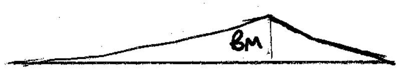


drive force?

open

$BM = P \times L_1 + \frac{wL_1^2}{2} = \frac{wL_2^2}{2}$ + drive force

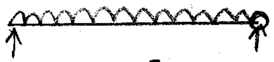
open + closed



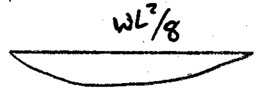
BM closed P=0 (or near 0) drive = 0

BM diagram slightly curved due to UDL

Deck



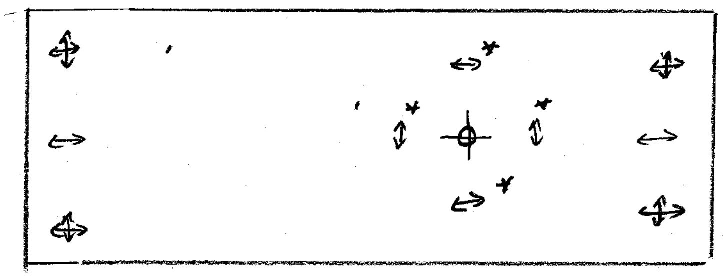
open + closed



BEARING LAYOUT.

SWING

Specialist rotating bearing - will be large



Guided bearings must be parallel to line of expansion to prevent locking

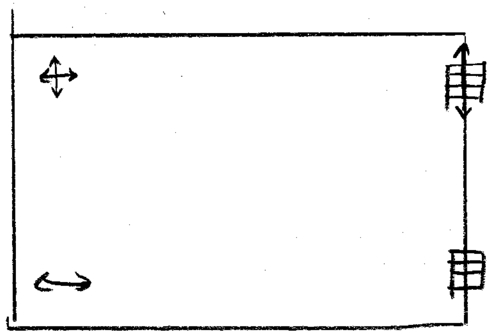
central pin - fixed both directions free to rotate.

MIN 4 roller bearings in circular channel - must take transv wind load + movement loads.

free bearings.

sliding guided bearings - transv wind load when closed.
(option to put combine with one side of free bearings)

Bascule



Roller bearing / pin specialist - free to rotate + slide transverse fixed longitudinal

Roller bearing / pin specialist - free to rotate fixed in plan

free bearing

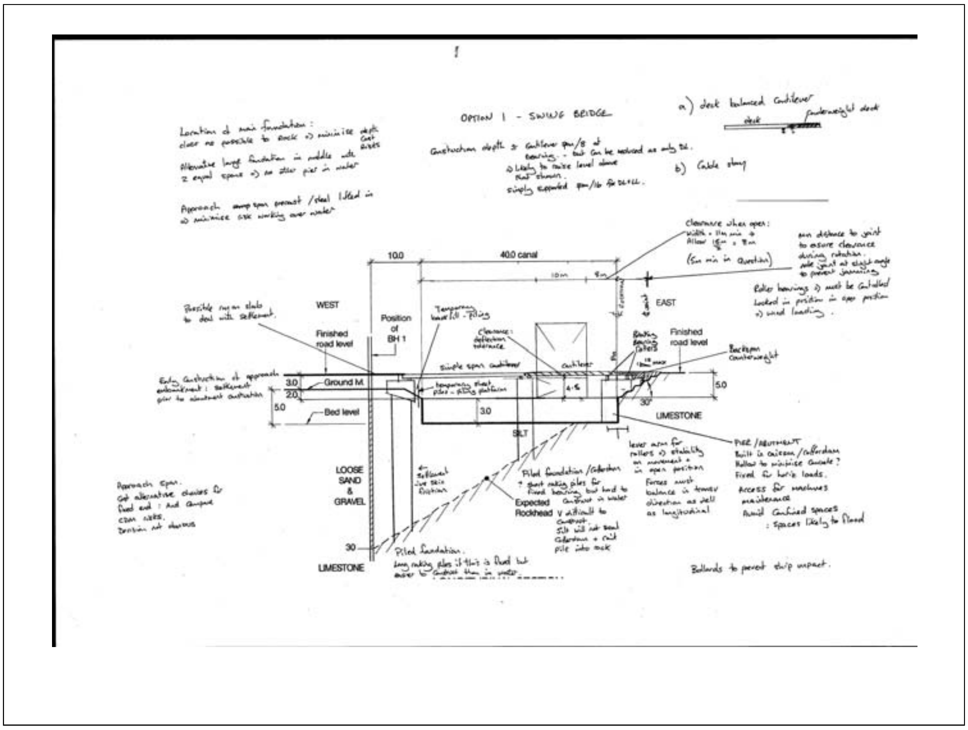
sliding line up with fixed roller to avoid locking.

- possible additional free bearings / free roller each end.

Commentary to accompany diagrams

Question 3, 2007

Access Bridge with Opening Span



At the beginning of the examination it is recommended that you start with drawing and writing notes in a rough plan to collect your thoughts and this will help develop your ideas. This is a quick way of setting out your ideas and, where you have been unable to finish, these notes can be invaluable to get marks. You will notice the volume of information on the sketches on the following slides and this will all count for marks. This form of presentation is much quicker to do and easier for the examiner to understand than lengthy essays. This is particularly relevant if English is not your first language. It is helpful to draw up the problem roughly to scale so you can try out ideas and check dimensions to make sure the solution will work. You cannot rely on the drawings in the question to be to scale. All of the notes above are likely to get marks for section a and some for e for the temporary works. The examiner is looking for you to show that you understand the issues around the problem and arguments for why certain solutions are better.

My initial idea was to put the pin of rotation well onto the east embankment but then realised that I was wasting the back span and having to cut into the rock. This type of issue can only be appreciated by drawing up the problem. It may be more cost efficient to provide a single large central pier to support the pin with two cantilevered spans to be supported on each abutment when closed.

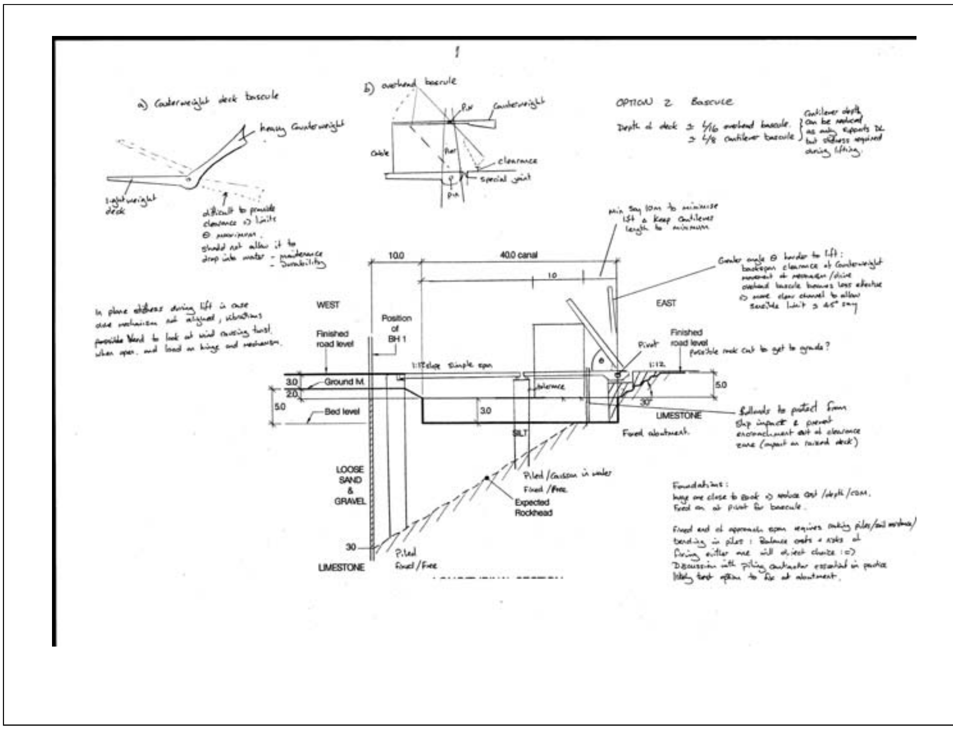
It is critical to look at the movement on plan. The back span cantilever is probably too short as drawn here to prevent the corner of the deck being obstructed by the abutment during rotation. The joints can either be curved (centre of curvature at the pin) or angled to ensure release of opening which is the cheaper / simpler option.

Note that the rough working shown here probably took slightly more time than people have in an exam but there are many points to be had from legible scribble. I don't think it is necessary to put much more description on the paper to pass part a other than some description of stability under various load conditions open / closed and reasons for your selection to follow up.

Deck construction. You can prepare span: depth tables for various types of construction to use as a lookup in the exam. This will save time deciding what solutions are viable. Note that the depth shown on these diagrams is probably too shallow. Preliminary rough sizing of the depth of construction using span : effective depth ratio's of 1:6 for a cantilever or 1:12 for a simply supported span or 1:15 for a continuous span can be helpful. IStructE "manual for the design of reinforced concrete building structures" gives these values which are a good start. You could of course use your own experience to prepare rules for different types of bridge structures.

It is a good idea to prepare folders with information on different bridge types such as railway, river, footbridges, motorway, aqueduct, moving etc. for quick reference in the exam. The same applies for construction types: truss, bow string, arch, composite steel beam & slab, prestressed beam, cable stay, suspension etc. and for different foundations. There are many websites and references you can use to give you information.

Study also construction methods and associated health and safety and environment issues: Launching, top down / bottom up, caissons, cofferdam, Lifting material delivery.



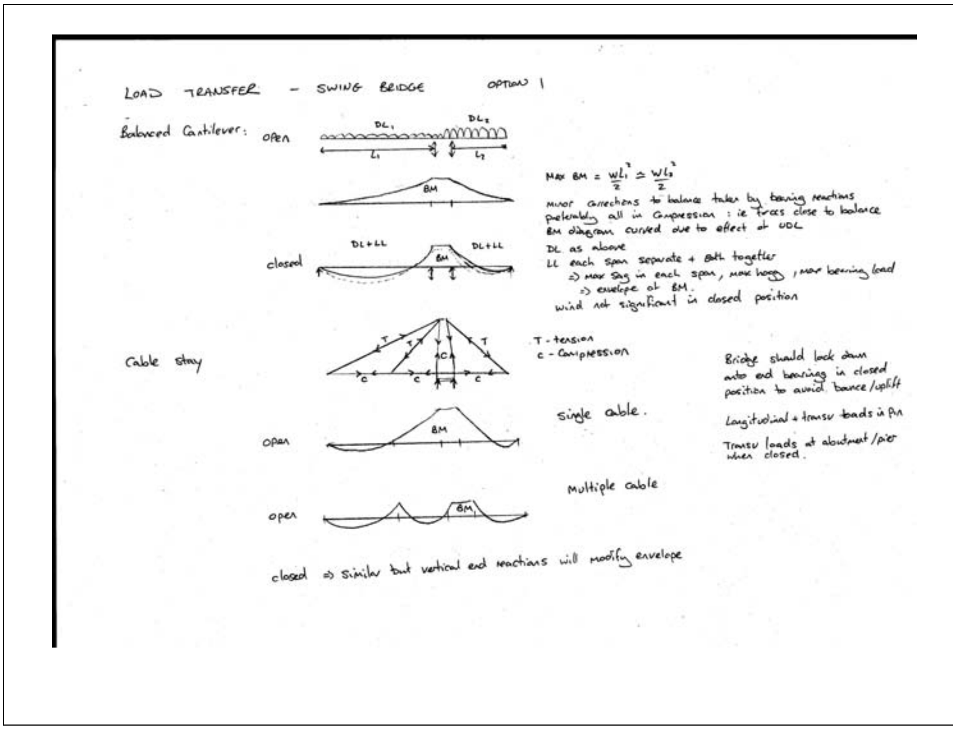
It is ideal if the second solution is significantly different to the first so you can show as much knowledge as possible

Do not bother to repeat issues mentioned in solution 1 as it will not get extra marks but it is worth mentioning where elements are the same/ similar.

I have ignored detail of the simply supported span but some marks can be gained by discussing it and it is better not to ignore issues. Certainly do not ignore issues deliberately because you don't know exactly how to solve them or try to simplify the question. This will limit your available marks as you will get some for recognising a problem even if you don't know the best solution and you could lose marks because the examiner thinks you haven't identified a key structural issue to the question.

The foundations options are subject to discussion as one end of the approach span must be fixed. It would be more structurally efficient to do this on the shorter piles but construction in the water is significantly more complex. You would not be expected to know the best answer but you will get marks for discussing the issues which would in practice be resolved by discussion with specialist contractors.

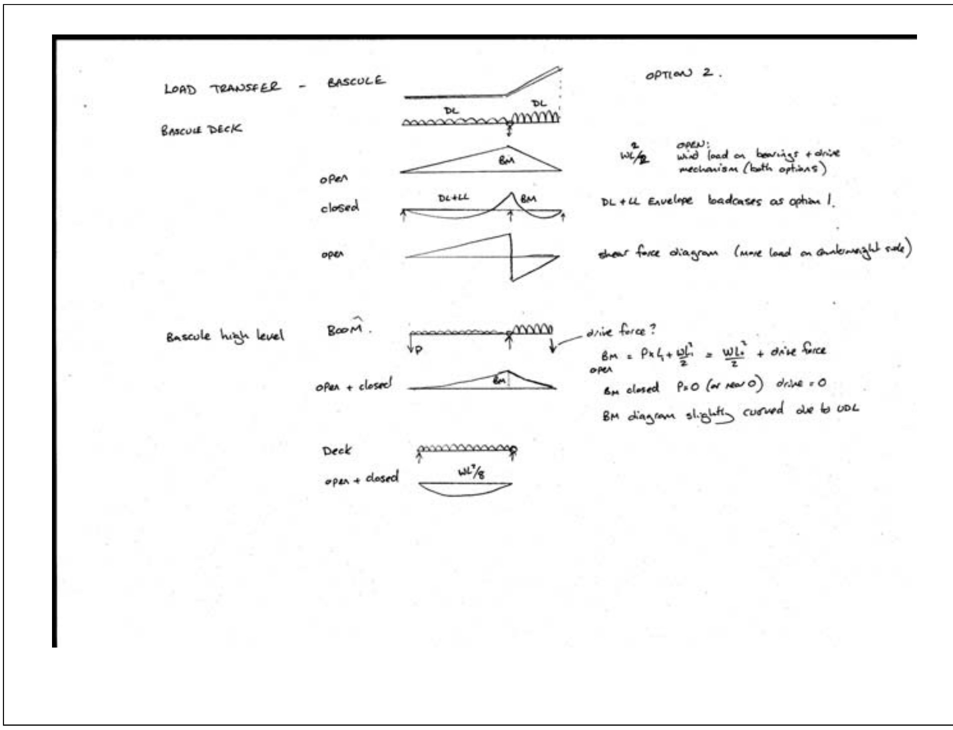
For this solution it is important to protect the headroom when open with bollards to prevent shipping getting too close. Generally ship impact should either be included in the design or prevented by the installation of barriers in the water.



The examiner will be looking for simple diagrams to show that you understand the structural behaviour of your structure. If you can't draw these simple diagrams for the main types of bridge structure then this is a key area for further study. The diagrams above clearly show how the load transfer is working within the deck.

Don't forget to discuss the foundations as well – particularly why they are different at each end. How are torsional loads carried by the deck, bearings. Longitudinal braking (each separate span), transverse loads from wind (each span).

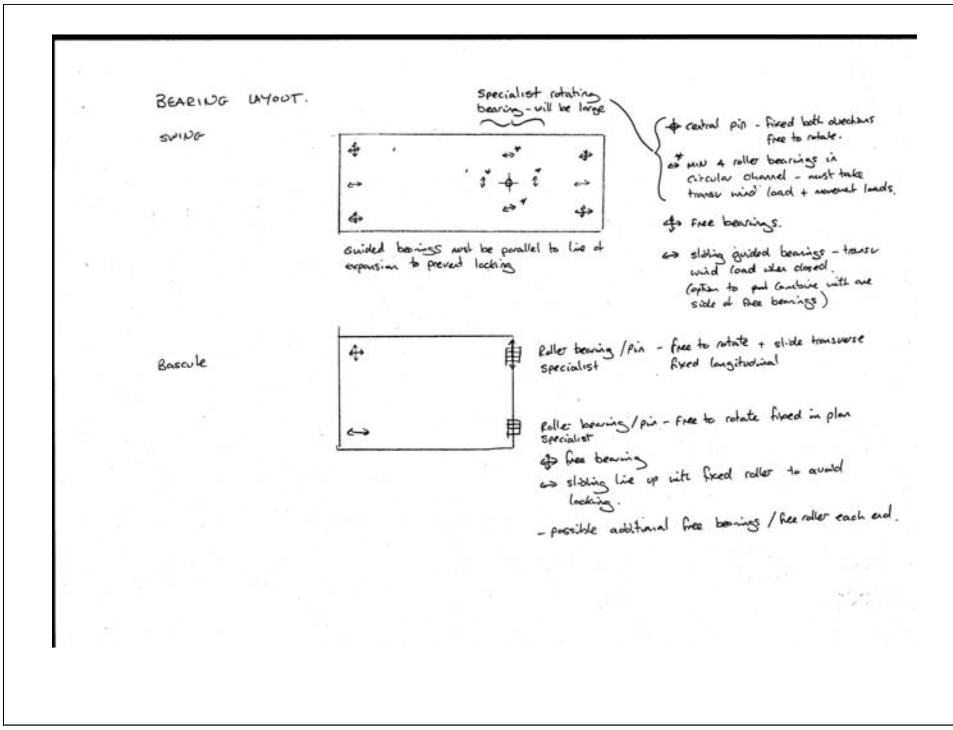
I originally drew the bending moment diagrams with straight lines but the UDL effect causes a slight curve. This is a minor effect and the formula is correct.



It is important in this question for you to show you understand the different load conditions both open and closed. The examiner will be confident in your abilities if you can present good bending and force diagrams.

These diagrams can also be helpful to assist your answer to section c calculations.

I originally drew the bending moment diagrams with straight lines but the udl effect causes a slight curve. This is a minor effect and the calculation is correct.



A bearing diagram is a useful way to gain additional marks but can also show lack of understanding. It is good to provide a key to your diagrams in case you mix up and draw them the wrong way round in haste. Each deck must be fixed at each end in each direction but too many points of fixity will prevent free movement on expansion of the deck. It is best to look at each direction separately. It is important if the deck is curved to make sure the direction of the sliding bearings is towards the fixed bearing and not on the tangent of the curvature. Uneven loads on the deck must be supported by a bearing that can support torsion or two bearings that create a couple. A single bearing at the end of a span is unlikely to be acceptable unless it can support torsion.

The swing bridge deck would probably need bearings that can resist uplift (unless sufficient kentledge is provided) to prevent it lifting with traffic loading / wind actions.

Due to the complex working of the problem it is likely that the above has taken a significant time so it would be better to set out some pro's and con's for the choice of structure and then tackle the rest of the question and return to tidy up text for section a if there is time.