The Institution of StructuralEngineers

Chief Examiner critique – Jul '24

Q3 – New coastal path cycleway and pedestrian bridge

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Contents

Introduction

The Examinations Panel has produced this additional preparation guidance document to show what the Chief Examiner (the person who writes the question) was expecting candidates to consider when answering the question.

The critique does not cover all possible solutions for the question but details the fundamental design challenges and shows examples of how these could have been answered. Candidates are encouraged to consider all potential options as part of their preparation work.

No part of this document should be reproduced by candidates in their answers for future exams.

Question Text

Client’s requirements

1. An existing path runs around the edge of an ancient slope failure from a coastal cliff system. Access around the back of the slope failure is limited by a hill and has been deemed to be unsafe to users due to rockfall risk from the steep hill slopes and the client requires that a new pedestrian and cycle bridge is designed to span across the slope failure zone.
2. The material from the slope failure has long since eroded away and has left a sandy shelf that has been protected by an existing sheet pile wall that supported by rock anchors at 15 m centres. Owing to limited knowledge of the construction of these anchors, no temporary or permanent load may be placed above any rock anchor, or 4m laterally either side of the rock anchor centreline. The extend of the anchors is shown on the plan view and section B-B of Figure Q3.
3. The site is also one of high environmental interest and therefore the client requires that the footprint of the new bridge must be reduced to the barest minimum, both permanently and temporarily.
4. The edge of the slope failure runs parallel to the coast and has been found to be stable except at the east and west edges where zones of exclusion have been defined. These are shown on Figure Q3. The zones of exclusion contain rock strengths of variable quality and therefore no structure may be supported in these zones either permanently or temporarily. Abutments must be placed outside these zones.
5. The new bridge is to contain two carriageways, the northern one for cyclists and the southern one for pedestrians: each is to be 2.5m wide. To maximise the view from the carriageways, both are to be staggered in elevation such that the southerly carriageway is 1.5m in elevation below the northern carriageway for the spans of the bridge between the zones of exclusion. Each carriageway may be offset laterally from the bridge centreline by up to 1.5m in plan.
6. Parapet heights are to be 1.4 m for the cycleway and 1.1 m for the pedestrian deck.

Imposed loadings

7. Both carriageways: Live Load intensity 5 kPa

Site conditions

8. Basic wind speed is 40.0m/s based on a 3-second gust; the equivalent mean hourly speed is 20.0m/s in the British Standard. Candidates using other codes and standards should choose an appropriate wind speed.

Ground conditions

9. The sandstone is of a uniform bearing condition with an allowable bearing pressure of 2000 kPa in any direction. The soft sands have N = 5

Omit from consideration

10. Design of parapets

SECTION 1 50 marks

a. Prepare a design appraisal with appropriate sketches indicating two distinct, viable and sustainable solutions for the proposed structure including the foundations. Clearly indicate the functional framing, load transfer, serviceability, and stability aspects of each scheme. Using sustainability as a key criterion, review and critically appraise the schemes, and identify the solution you recommend, giving reasons for your choice. (40 marks)

b. After the scheme design has been completed, the client asks whether changes could be made to the brief to reduce the material usage while maintaining the bridge requirements. Write to your client proposing possible changes. As part of any proposals made, explain the effect this may have on the design. (10 marks)

SECTION 2 50 marks

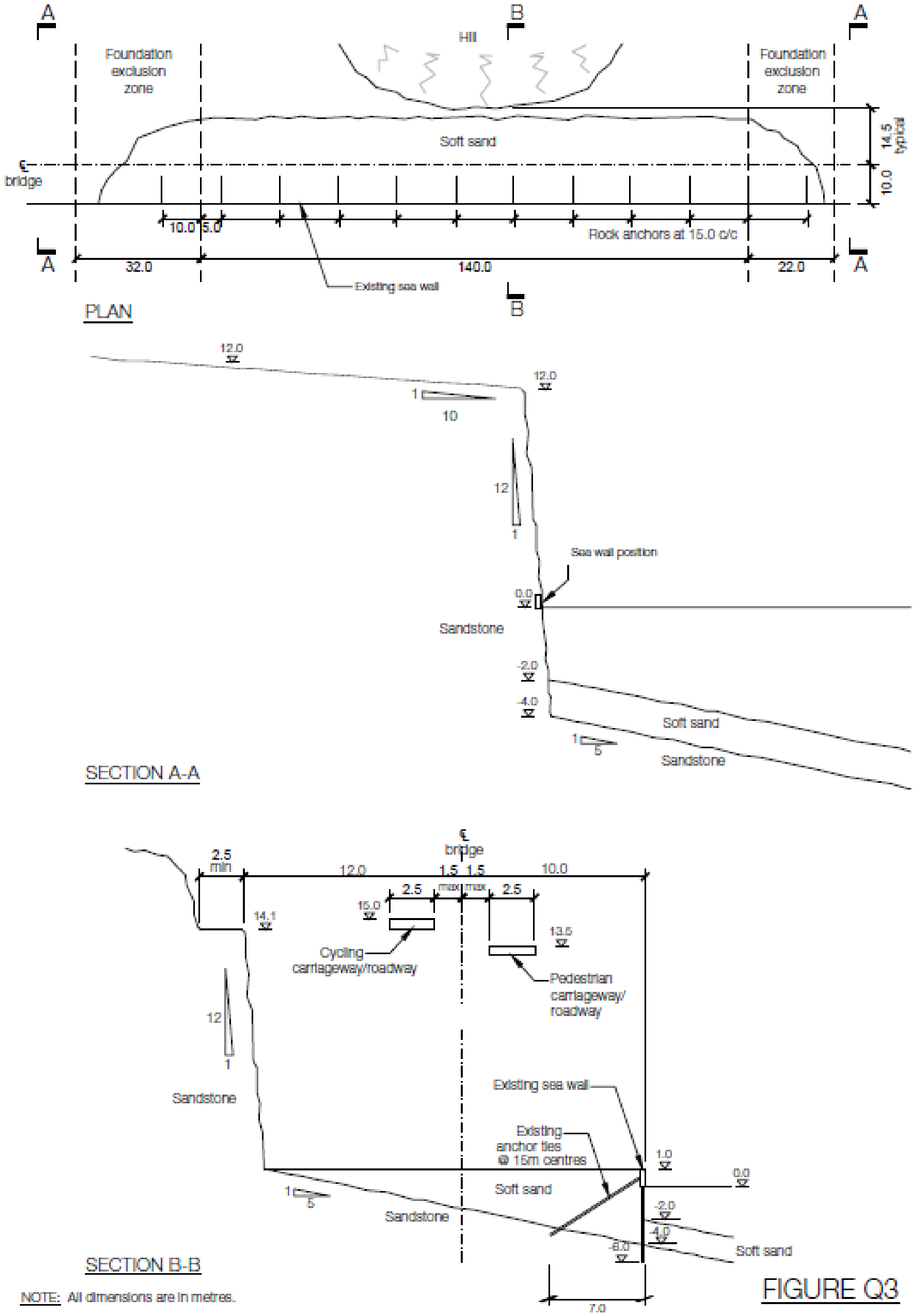
For the solution recommended in Section 1(a):

c. Prepare sufficient design calculations to establish the form and size of all the principal structural elements including the foundations. Include approximate A1-A3 carbon calculations for each of your principal elements. (22 marks)

d. Prepare general arrangement drawings which may include 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 works. (8 marks)

Question Figure



NOTE: All dimensions are in metres.

FIGURE Q3

Critique

Section 1a – scheme designs

What are the main challenges? Why have certain constraints been introduced and how are candidates expected to deal with them?

Key challenges

The paper is based on having a largely historic failure of part of a cliff slope and that the narrow opening that is left is not safe because of falling rocks and therefore a new bridge is required. The failure of the cliff slope happened thousands of years ago and as a result all of the fallen material has essentially been washed away and what is left is a scallop out of the cliff and the soft sand at the bottom. The sandy shelf has been protected from further erosion by the construction of a protective sea wall which is of environmental interest and therefore construction across it needs to be minimised.

Furthermore, the seawall contains a series of rock anchors and there are zones of exclusion for both permanent and temporary construction around these anchors which are at 15 metre centres. It is possible to place structure between the anchors but there is a zone of 8m wide above each anchor where no structure may be placed.

The client requirement is to build a new bridge across this gap (including exclusion zones) of 194 m. These exclusion zones, where no structure may be placed arise due to residual concerns over the strength of the two ends of the slope failure. (We will have to add a note to say that it is possible to excavate in the zones to allow clearance of the deck to the apartments).

The client has requested that the two decks are offset vertically so that both decks will have a view of the sea to the South off the bridge. The client has permitted an offset of the decks laterally which may assist the designer with options for a centrally supported tower to support the bridge.

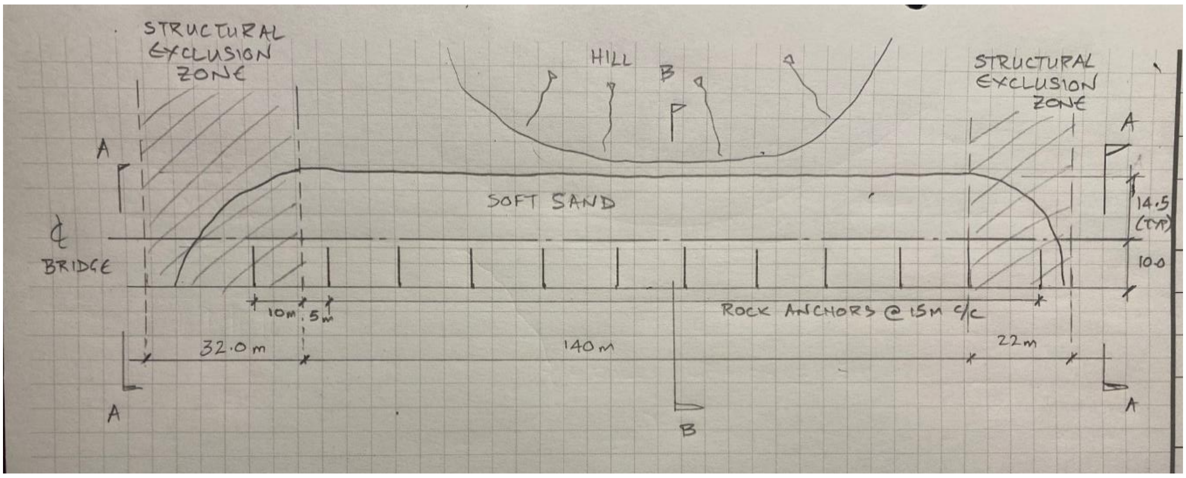
The sea is a very good means of access for construction and the water depth immediately adjacent to the seawall is sufficient to bring a barge in to deliver material to site.

At either end of the bridge there is the no structure zones which for spans of at least 35 metres at one end and 25 metres at the other end. The zones are 32 metres and 22 metres in length but clearly the abutments will need to be set back from this zone and there will need to be clearance for the foundations.

The clear challenges are that the rock anchors limit the foundations such that only a single pier can work if you want to run foundations outside of the anchors. Candidates must recognise that they will need to leave space for the excavation of the pile caps although a drilled shaft could be achieved which would help the single pier arrangement further.

If the candidate tries to use a twin pier arrangement, then they will need to locate the piers at "gaps" in the rock anchors as seen on the following sketch where the centre of the first pier will be at least 44.5 m from the eastern abutment. This would require piers at 60m to achieve a well-balanced structure, but these are big spans, but achievable.

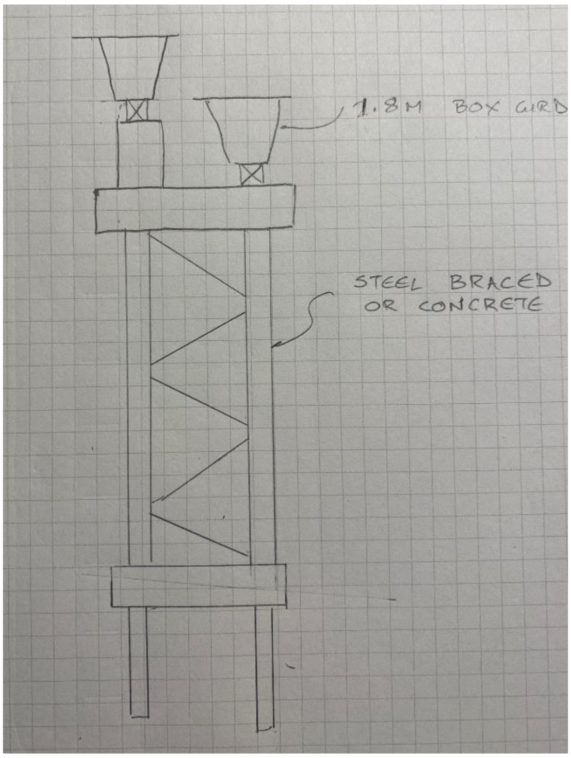
Thus the choice of foundations provide two different structural span arrangements. Let's look at the one that sits between the anchors.



Notional schemes

Here you should provide a minimum of three different scheme options that candidates could put forward to answer the question. Notes should accompany the sketches to help the Advisors understand your vision for how you expect this question's challenges to be addressed.

Scheme option 1 - Foundations between anchors

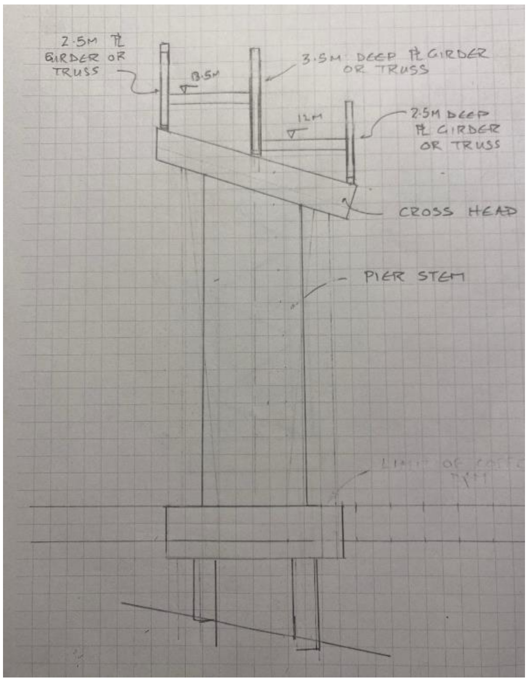


The foundations for these anchors will be piled (all solutions will require this) but with a pile cap sitting on top of it. The foundations have no restrictions placed on them when inside the rock anchors as there is a 5m space available which will be more than sufficient longitudinally. Width is also not an issue. The substructure could be either a concrete leaf pier, a steel braced section or individual columns supporting a pair of independent boxes (but they will need to consider the requirements for bearing replacement). Spans will be driven by the eastern span. The first western span will have to be around 45m. The candidate is then likely to be driven to 60 m spans to get balance with the end span but could consider 30 or 45m spacings.

The candidate will need to consider the tall piers and the significant overturning effect generated by a pair of boxes.

Longitudinal load effects will be small and limited to only bearing friction as I would envisage that the decks for all the schemes will be tied at one abutment and free to expand between the rest of the piers.

Construction would be by placing temporary decking onto the sand and driving a small excavating rig from a barge in the sea to the location for the two piers and boring into the rock. The piers could then be cast if they are concrete from concrete delivered from the sea or with steel columns erected individually and then tied by the bracing. The deck units would then need to be brought in by crane and lifted into place. This construction requirement is likely to restrict the span lengths so the first span will be a challenge. A clever candidate would recognise that the eastern span will be shorter and so construction would start here so that the longer western span could be spliced at the point of contraflexure.

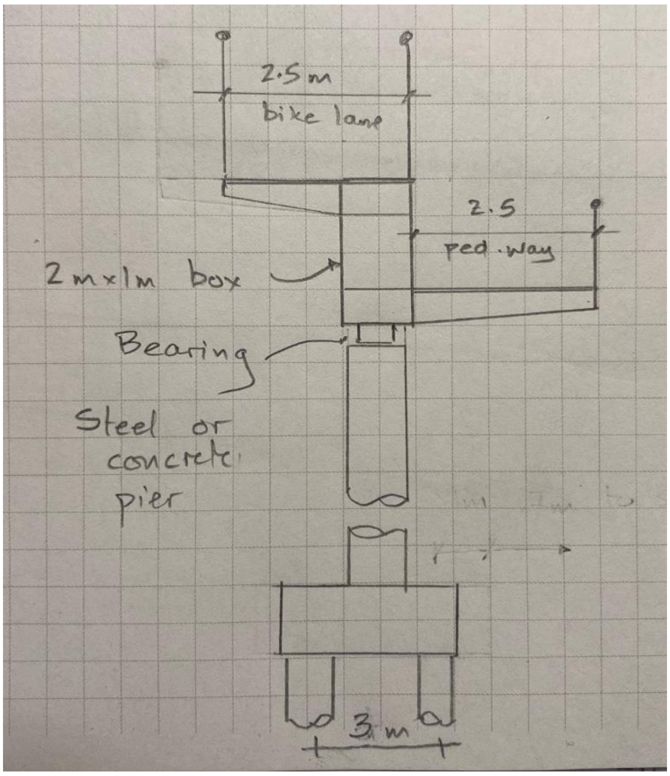


There is a section deck section option that could be used which would be three trusses that are tied together by the deck cross beams. A deeper truss could be used for the centre truss to suit the deck barrier arrangement for the higher parapets required for the cycleway (1.4m v 1.1m). The advantage of these is that the slope would reduce the U frame action moments but the differential truss stiffnesses would need to be taken into account.

The advantage of the pair of steel boxes will that they can be placed closer together than the trusses so the idea of using a single deeper truss for the central truss would be an attractive option.

Scheme option 2 – torsion box with shorter spans

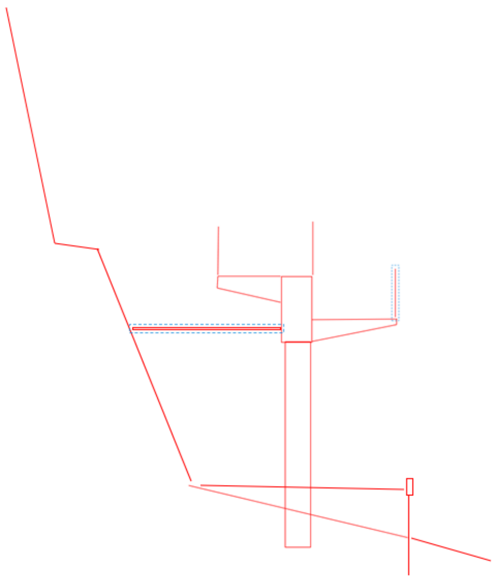
The attraction of this scheme is that the decks are cantilevered off a torsionally stiff central spine beam. What is attractive here is that this can then sit atop a single steel or concrete column and then sit on two piles at relatively close spacing so that it is not affected by the rock anchors. An added attraction is that the cycle deck can sit on the torsional box so that the centreline of the foundation is offset from the pier. This is not an issue with the foundations as the torsional restraints would be taken out at the abutments, as is always the case with any form of box girder. There will be a load case where one deck is loaded and the other is not. It is worse for the pedestrian deck being loaded but this is well within an 2m by 1m box. The other attraction of the single box is that the overturning on the piers from wind is much reduced by the lower profile of the deck as opposed to a pair of solid decks. Even a truss will have a higher porosity than the edge barriers required for cycle and pedestrian safety.



Span lengths are likely to be 35m for the first span and then could be slightly longer as the box beam could be brought in as a single unit and then the decks lifted in separately and attached to the box beam. Splices will be more difficult in all the box beams but if they are close to points of contraflexure then the demands for the flanges will be reduced.

The candidate would need to recognise that the torque in the box beam needs to be supported at either end of the abutments and would need to have either hold down bearings or outriggers so that the bearings are spread to ensure no lift off occurs.

Scheme option 3 – lateral bracing against the cliff wall



This is slightly more radical but allows for the candidates to use a pair of struts to brace the top of each column against the side of the Cliff wall. This then creates a very stable base for each of the piers and obviates the need for a rock socket at the base. This could be done with either scheme but is inherently more logical for the single box beam system. The construction sequence would be to build each of the piers with some form of temporary support during construction and then to tie in the pair of ties into the Cliff wall. Once this is done you have a very stable platform and again the bridge deck can then be lifted in by crane on a sea barge. The ties could also be rigidly connected to the deck and thereby reduce the torsion effects substantially.

Scheme comparison and selection

The abutments at either end should be relatively easy and I would expect that the candidates would read the question and recognise that in the final span the vertical separation is not needed over the full length of the span and so the deck can taper down and that essentially one would ramp both decks to the same median level of 12.75m. The ground slopes at one in 10 in that area so some minor adjustment of geometry will be required. Candidates will need to recognise that the bridge is secured at one end of the bridge and free to move at the far end. If a torsional box is used then they will have to deal with the torsion stresses at both ends (but it can still slide at one end).

Section 1b – changes to the brief for reduction in material usage options

What can the candidate do to change the original brief, whilst maintaining a key structural design feature (floor to ceiling height, column spacing/total count, floorplans)? There should be a minimum of three clear changes defined, with indications of other considerations.

- Decks at the same level
- Common deck structures (although this is achieved by the single torsion box)
- Reduced long span loading (crush loads cannot be maintained for long spans)
- Better investigations of the rock anchors
- Move the alignment further away from the rock anchors so spans are not constrained
- Better investigations of the end exclusion zones

Section 2c – calculations

What calculations are you expecting candidates to perform for principal elements? Have you carried out prelim calcs to check, for example, spans and foundation reactions against soil capacities to avoid only piled foundations and what can be done within exam time constraint, etc.

- Loadings
- Foundations
- Piers
- Decks for longitudinal effects
- Abutments

Section 2d - drawings

What do you expect candidates to detail here? What plans/part plans, sections, elevations are crucial to the scheme design?

Clarity of drawings is important particularly when candidates split/ combine plans. Drawings are expected to include the following but subject to the solution chosen:

- Elevations
- Foundation plans to show compliance with the constraints

- Deck cross sections
- 3 Key details from: deck to pier connections including local bearing stiffeners

Section 2e – method statement

What are the key aspects of the construction process candidates need to include?

For this structure the key issues include:

- Verifying ground conditions.
- Erection sequence for foundations including protection of anchors and not loading the soft sands.
- Lifting arrangements from barges
- Erection of temporary works