be instigated to enable fundamental design concepts to be derived with the geotextile as a qualified component. Such an approach being more cost effective than merely adding the geotextile as a solution to a problem that need not have occured.

ACKNOWLEDGMENTS

Our gratitude is expressed to the following companies for their permission to include technical details relating to their products.

FLUVIO LABOR and SICALEX	BELGIUM
V.O.R.	BELGIUM
ROOK-KRIMPEN	THE NETHERLANDS

T5 Revetment construction at Port of Belawan, Indonesia

E. LOEWY, A. C. BURDALL and A. G. PRENTICE, Sir William Halcrow and Partners

SYNOPSIS. This paper describes the revetments used to protect a fine sand reclamation situated in the estuary of the Belawan river in Indonesia. A substantial length of the revetment is situated under a piled quay where grouted mattresses have been used to protect the 1:2.3 sand slope. Significant post construction settlement of the sand slope is expected and special measures were taken to enable the mattresses to accommodate differential settlement. The installation method in difficult environmental conditions and resulting modifications are presented.

INTRODUCTION

Background

1. Belawan is situated on the north-east coast of Sumatra,(See Figure 1). The present port and township is bounded by the River Belawan to the north and the River Deli to the south. The rivers share a common estuary but the main and deeper channel is formed by the Belawan River. The coastal areas surrounding the estuary are low-lying mangrove swamps intersected by a network of small creeks.

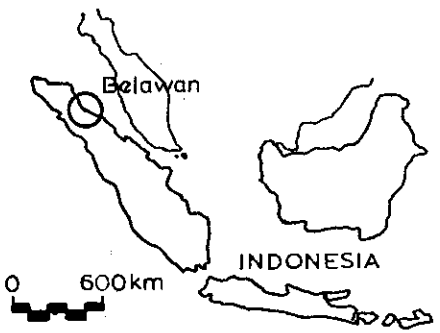


Figure 1. Location map for Belawan

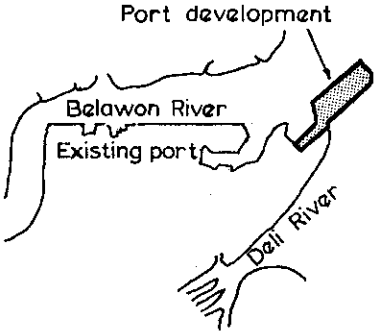
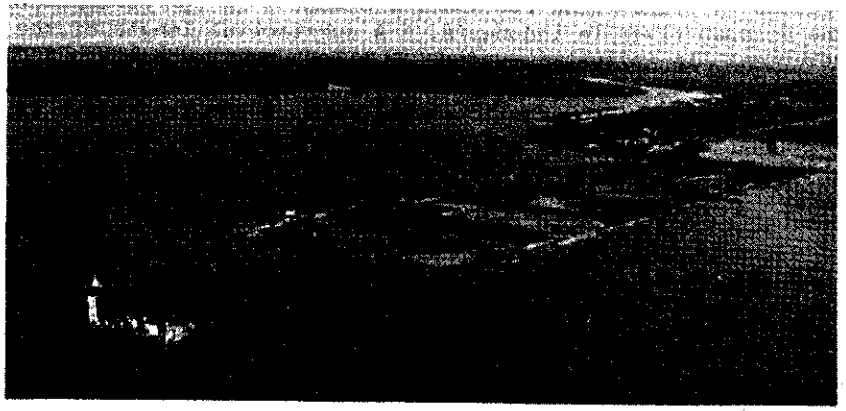


Figure 2. Port layout

2. The port of Belawan is the third largest port in Indonesia and currently handles around 5 million tonnes of cargo annually. To accommodate increasing trade the facilities for handling dry cargo and container traffic are being extended. The first phase of the extension will provide 850m of additional deepwater quay with associated access, cargo storage and handling areas. The layout of the existing port and the planned extension work is shown on Figure 2.

3. Site Description. The reclamation covers some 30ha over an area where the existing sea bed was at a depth of up to 6 m below mean sea level but was largely within the tidal zone. It is located some 15km from the open sea and the dredged approach channel is maintained to a depth of 8m (see Photograph 1).



Photograph 1. Aerial view from the north of the reclaimed area

4. Extensive soils investigations had been carried out to determine the nature of the compressible clays and the volcanic ash and sand, which underlie the reclamation. The clays are highly plastic, lightly over-consolidated and are soft at the surface becoming firm to stiff at depth.

5. Vertical drains were installed to depths of up to 45mand centres of 1.5 m and 2 m of sand surcharge was placed over the reclamation to speed up the settlement. Nevertheless some further long term settlement of the reclamation is anticipated after construction has been completed.

DESIGN REQUIREMENTS

6. The reclamation was formed using hydraulically placed fine sand won from the upper reaches of the Belawan River. Slope protection is required to prevent erosion by tidal current, ship wash and rainfall runoff.

7. The reclamation material is a fine sand with a silt content typically between 10% and 15%. Hydraulic placing achieved a relative density of 40% to 50% and along the edge of the reclamation to be occupied by the quay, vibroflotation and dynamic compaction was carried out to achieve a minimum relative density of 60%.

8. The spring tidal range is 1.0 m and the maximum tidal currents observed during the various hydraulic investigations were of the order of 1.0 m/sec. Wave action due to winds is usually negligible but for brief periods with waves of up to 0.5 m are experienced. Bow waves from fast moving vessels also reach heights of 0.5 m. Underwater visibility was virtually zero because of the sediment content.

9. Rainfall records indicate six hour maximum rainfall intensities of 14mm/hour with the highest monthly rainfall during the monsoon season towards the end of the year.

10. To accommodate the anticipated post construction settlement the revetment was designed to accept,

- Up to 500mm general settlement
- Up to 200mm more settlement along the rear edge of the quay compared with the toe of the slope (i.e. a differential settlement of the top of the slope relative to the toe)
- a 250mm differential settlement midway between the pile bents relative to the area adjacent to the piles (i.e a 'dishing' of the slope between the piles).

11. The final revetment had to withstand this movement whilst retaining its structural integrity and prevent leaching out of fines from the reclamation material.

ORIGINAL DESIGN

12. During the design phase consideration was given to alternative forms of revetment both for under the quay and elsewhere. For the underquay slopes the selected revetment was specified to be synthetic filter cloth, overlain by 300mm of filter rock and 750mm of armour rock. The rock was required to be angular with 85% of the filter rock being between 5 and 20kg. Armour rock was to be between 50 and 200kg. Filter cloth was specified as Nicholon 66475 and was required to be lapped to adjacent sheets and at piles. The remainder of the reclamation perimeter was to be protected by rock filled gabions on Nicholon 66475.

ALTERNATIVE DESIGN

13. Subsequent to the award of the contract, to overcome the difficulties of obtaining suitable rock, the Contractor proposed the use of fabriform mattresses filled with concrete as an alternative to the filter and armour rock on the underquay slope. No change to the underlying filter fabric was envisaged (see Figure 3).

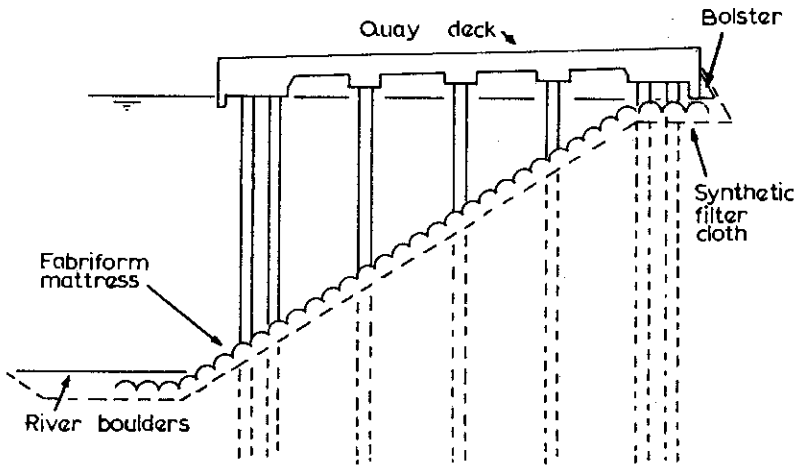


Figure 3. A cross-section of the protected under quay slope using fabriform mattress

14. The fabriform mattresses were to be made up from woven panels of filter fabric connected to the fabric of adjacent mattresses by means of zip fasteners. Construction of the mattress would be such that, on filling, a mechanical joint would be developed between adjacent panels which takes the form of continuous "ball and socket" joints. In addition, a quilt pattern appears on the surface of the panel caused by fastening together the upper and lower layers of the envelope at regular intervals. This, apart from acting as a control on mattress thickness, allows the insertion of a coarser meshed material to create "filter points" at the nodes. The arrangement of the mattresses is illustrated in Figure 4 and on Photograph 2.

15. Filling of the mattresses was to be with a pumpable small aggregate concrete mix, known as micro concrete, with excess water being expelled through the fabriform material. The filling of the mattress results in a reduction in the length and breadth dimensions of the mattress and this reduction has been termed "shrinkage". The proposed 100mm nominal thickness of the mattress gives rise to a consequential 17% shrinkage which had to be allowed for in the fabrication of the mattresses.

16. Various panel and collar arrangements were considered for the underquay works at Belawan to allow the mattresses to be fitted around the piles, and to provide the necessary flexibility to accommodate the anticipated settlement. Initially it was intended that slope protection works would commence ahead of deck construction and advantage would be taken of this by lowering the mattress panels onto the slope, with preformed holes for piles. This arrangement was revised to include a horizontal joint on one side of each pile to

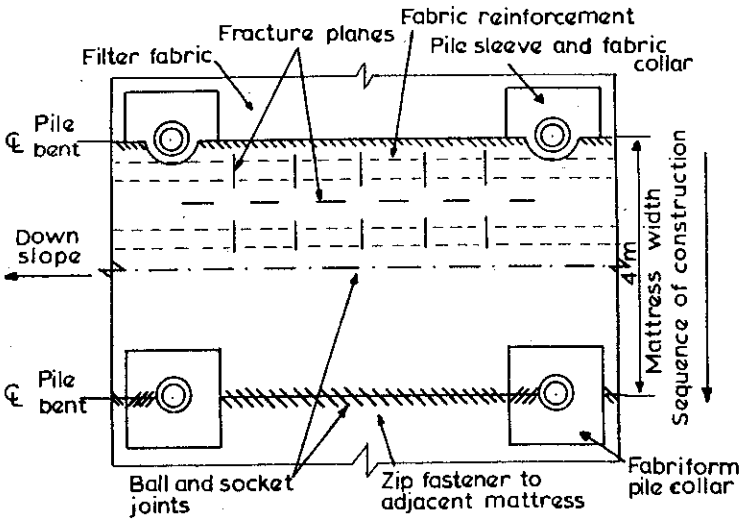
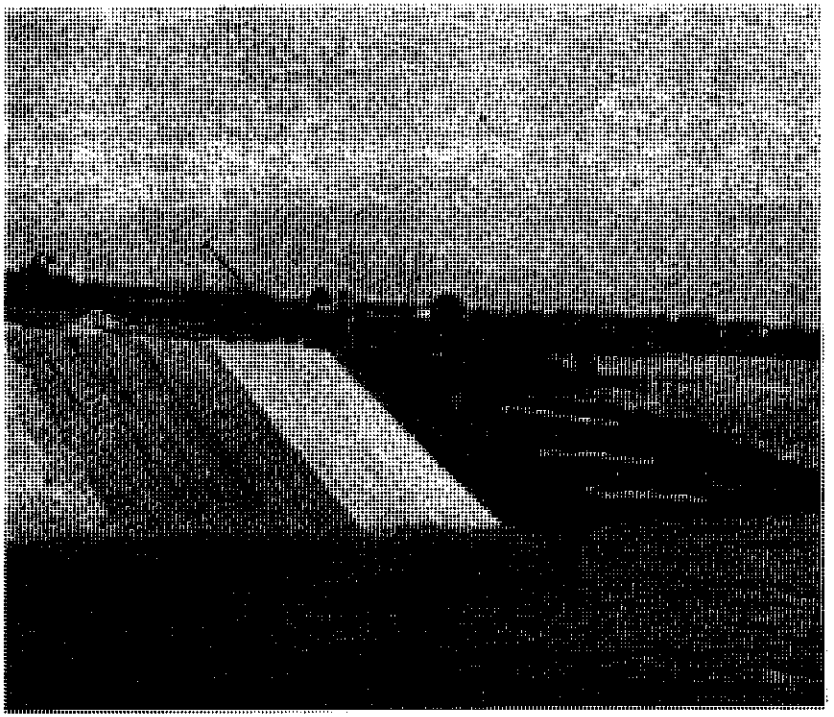


Figure 4. Typical fabriform mattress arrangement



Photograph 2. A length of fabriform mattress during construction

allow the mattress to be unrolled down the slope and unfolded to encompass the piles. After the commencement of construction the mattress arrangement was further revised to place mattress joints on the bent line as indicated on Figure 4.

17. To secure a close fit between the slope protection and the pile while permitting mattress movement due to shrinkage, a fabriform collar was proposed which was initially intended to fill the annulus around the pile. However, after further consideration of the expected relative settlement of mattress relative to quay the structure, a steel sleeve and "top hat" of filter fabric were proposed with a collar of fabriform laid on top of the mattress and tight to the sleeve as indicated on Figure 5 and shown in Photograph 3. As relative settlement occurs the sleeve was expected to slide down the pile and the "top hat" to expand, bellow fashion with a collar for protection.

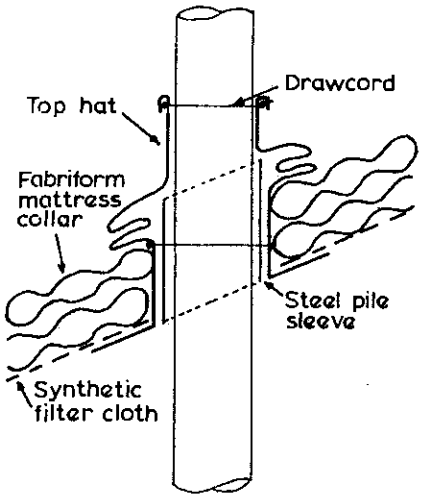
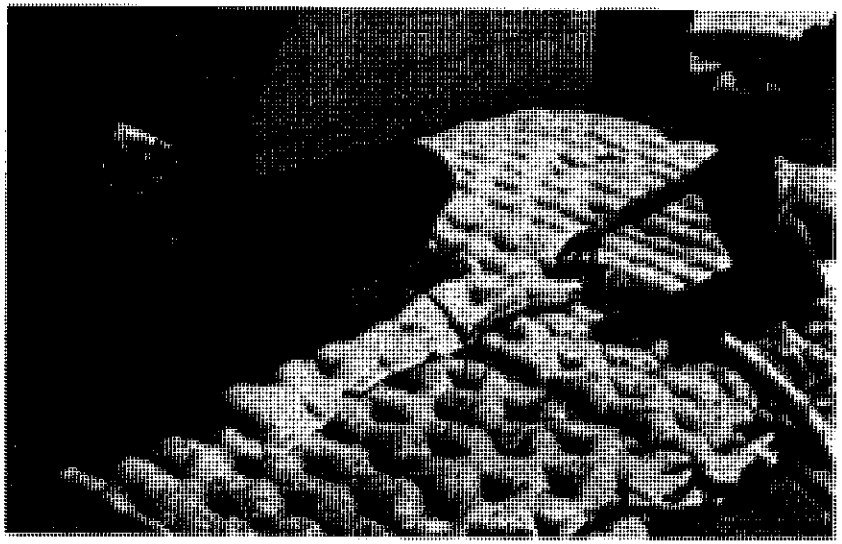


Figure 5. Fabriform mattress arrangement at a pile



Photograph 3. Fabriform collar installation

18. To give the mattress more flexibility, crack inducers were provided within the panels. Crack inducers comprised lengths of sewn seams joining upper and lower layers of the mattresses giving rise to a section weak in bending and these are indicated on Figure 6.

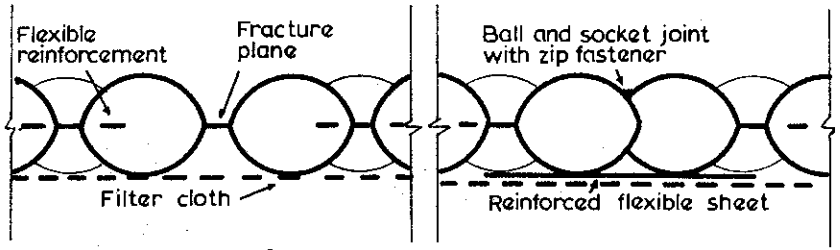


Figure 6. Fabriform mattress details

19. A concrete filled fabric bolster was proposed for installation behind the rear beam to accommodate settlement without loss of material around the beam.

20. The use of a grouted mattress was initially considered for the river bed, in the berthing area where armouring is required to prevent undercutting of the quay slope due to ship wash. However, the original design was retained except that since the area was horizontal, rounded river boulders were substituted for angular rock.

INSTALLATION PROCEDURES

21. The installation of the mattresses, onto the prepared slope, was planned to be carried out after pile driving but before construction of the suspended deck. However, for various reasons deck construction commenced before mattress installation and, as a result, approximately one-third of the underquay slope protection was placed below a framework of precast beams and some 50 m were installed below the completed deck (see Photograph 4).

Photograph 4. Quay construction

22. After excavation of the slope by clamshell grabs sand pumps and, hand trimming was undertaken by divers using water jet for removal of surplus material and gravel filled bags for filling low areas. Care in trimming proved essential to avoid distortions of the mattress with consequent unsatisfactory panel joints. Sleeves, previously placed over the piles were set in position and the slope was finally checked by divers and sounding before the filter fabric was unrolled down the slope. The filter fabric was weighted with bags of gravel to avoid flotation. "Top hats" of filter fabric were placed around the piles and sleeves and secured with steel pins approximately 500mm long pushed into the sand slope.

23. The fabriform panels were drawn out from the shore by divers each new panel being secured to the free end of the previous panel by a zip fastner.

To hold and control the position of the mattresses while they were being filled, steel poles were inserted into sleeves on the mattresses and the poles were held in position by ropes attached to anchors at the top of the slope. As the mattresses shrank in plan during filling, the poles were progressively allowed to move down the slope to allow the mattresses to attain their designed shape.

Micro concrete was pumped into panels through tubular inlets set at intervals down each half panel. Several half panels were filled concurrently, filling commencing at the toe of the slope and progressing up the slope. The leading half panel was not filled until the next panel had been attached.

Subsequently to filling of the main mattresses, overlaying collars of fabriform were placed round the piles and pumped full of micro concrete. The fabric "top hat" was then adjusted to provide slack material which could be taken up as settlement occurred.

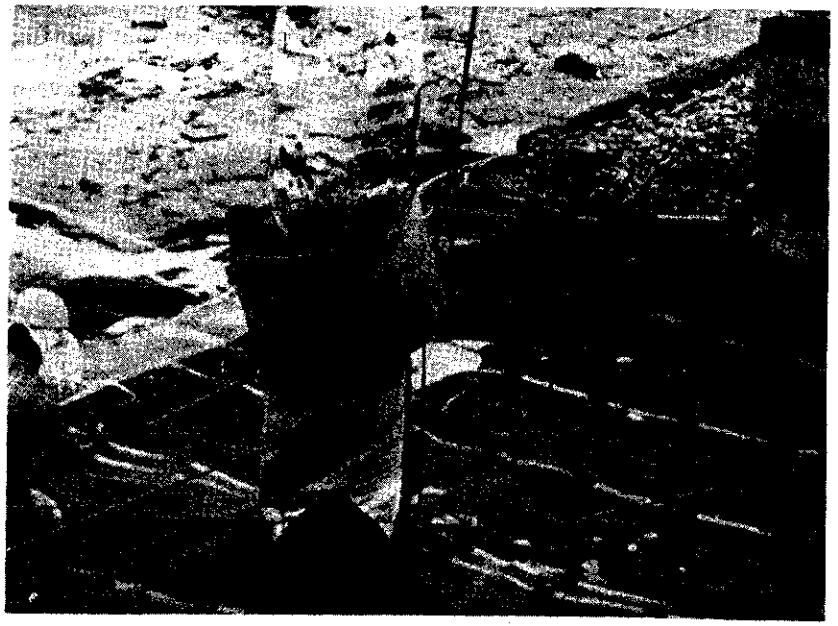
The construction sequence is illustrated in photographs 3 to 5.

INSTALLATION DIFFICULTIES

24. Difficulties arose when the first mattresses moved too far down the slope during filling.

25. Initially, the woven filter fabric was laid with the warp along the slope for reasons of economy. As a result of the problems with the first mattresses the filter fabric was rearranged with the warp down the slope as its coefficient of friction was much greater in this direction.

26. Mattress panel joints were initially placed mid-way between the pile bents. An advantage of this arrangement was that the piles would provide additional resistance to the movement of mattresses down the slope. During the early stages of the work a series of trials were carried out to check the sliding resistance between the filter fabric and completed mattress. From the full scale trials it was established that there would be adequate resistance even with the fabric laid down the slope. Ways of providing increased resistance during the temporary phase when the mattresses were being filled were devised. From then on the filter fabric was laid down the slope. Also the panel points were moved to the pile bent lines so that the shape became a simple rectangle with semi-circular cut outs for piles on each long face.



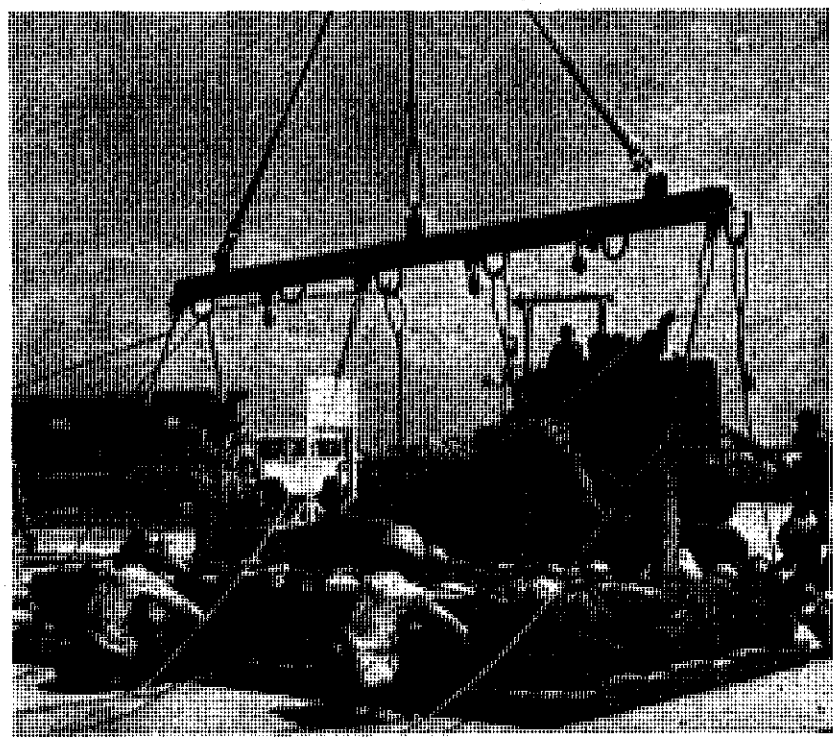
Photograph 5. Filter fabric and pile sleeves

27. During trimming of the underquay slope, a minor surface slip occurred affecting a 25 m length of slope. The cause of the failure was not immediately apparent and the progress of work was disrupted while investigations were made. It was concluded that failure occurred as a result of a combination of circumstances the dominant features being wave action from ships and local areas of silt. A second slope failure occurred adjacent to the standing edge of fabriform slope protection. In this case, 12 m of slope were affected but there was no evidence that the failure extended under the grouted mattress. No re-design of the permanent works was considered necessary. Repairs were effected by removing the loose surplus material and making good the hollows with gravel fill fabriform protection was then placed as elsewhere.

PLACING OF ROCK TOE

28. Removal of silt and trimming of the quay trench was carried out by a 200mm diameter submersible pump suspended from a barge. Placing of filter fabric and filter rock was

carried out together. Steel frames 2m x 4m were placed over rectangles of filter fabric laid on the quay deck. Filter rock was then placed in the frames to the required depth and the filter fabric temporarily secured to the frame sides. Frames were placed on the river bed by crane with divers assisting in locating frames against those previously placed. Lapping of filter fabric was achieved by laying out the leading edges. While frames were retained on the leading edge, others were subsequently retrieved as the work face advanced. The frame loaded ready for lowering into position is shown in Photograph 6.



Photograph 6. Frame loaded with river boulders and ready for lifting

29. Rock armouring was placed by net and levelling achieved by re-arranging armour using an orange peel grab and various weights.

PROGRAMME

30. Underquay slope protection works commenced in February 1983 and were programmed for completion in eleven months. Production rates for laying the fabriform mattress and grouting averaged two bays per day. Work on fabriform installation was normally based on an eight hour day, working alternate Sundays. Occasionally, early morning or late evening tidal work was carried out to take advantage of slack water.

31. Work was normally on only one leading edge although, for a period, up to three leading edges were being worked. The only leading edge allowed to stand for a substantial period of time was at the location where the second minor slip occurred.

32. Quay trench protection works commenced during July 1983 and section 1 (the first 350 m) was effectively completed by October of that year and work was continuing in section 2 at the time of writing this paper and was expected to be completed in early 1984. Placing of frames containing filter fabric and filter rock peaked at about 16 bays per week with work alternating between six and seven days each week. Placing of armour rock and its subsequent trimming to level generally kept pace with the frames.

CONCLUSIONS

33. This use of grouted mattresses and geotextiles is believed to be one of the largest yet carried out for underquay slope protection and it provided valuable experience on some of the construction difficulties that can be met in an estuarine situation. While environmental conditions hampered placing and monitoring, effective installation proved practicable after modifications had been made to the panel arrangement.

34. Placing of the slope protection is not yet completed under the quay but, for the finished areas, no erosion or instability is apparent. The berths have not yet been put into use and subject to the effects of shipwash. Post construction settlement to date has been small.

ACKNOWLEDGEMENTS

35. The authors wish to thank the Belawan Port Administrator for permission to publish this paper. The main contractor for the work was Dharsamrin Indonesia Group with specialist sub-contractor Dowsett Prepakt Limited for underquay slope protection work.