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Design and construction of the Terratrel Ro-Ro ramp for Second Severn Crossing

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ABSTRACT: The Severn Bridge construction in the United Kingdom required a 12m high jetty ramp to allow the transportation of caissons and crawlers up to 2600 tonnes weight to waiting sea barges. These loads are the heaviest ever transported in Europe and the ramp is inundated throughout its life by the second highest tide in the world and is located in a severe windswept marine estuary. Reinforced Earth ramps were chosen as the safest, most economical and least damaging to the environment of the sea bed. Terratrel facing of steel grid supported by High Adherence earth reinforcing strips provided an optimum solution. The structure is the largest marine Terratrel structure in the world and is the first reinforced soil structure of any description to support such large moving loads. Fig 1. The Reinforced Earth Company, UK won the Highly Commended Award in the British Construction Industry Awards, 1993 "for this creative, bold and cost effective solution", said the judges.

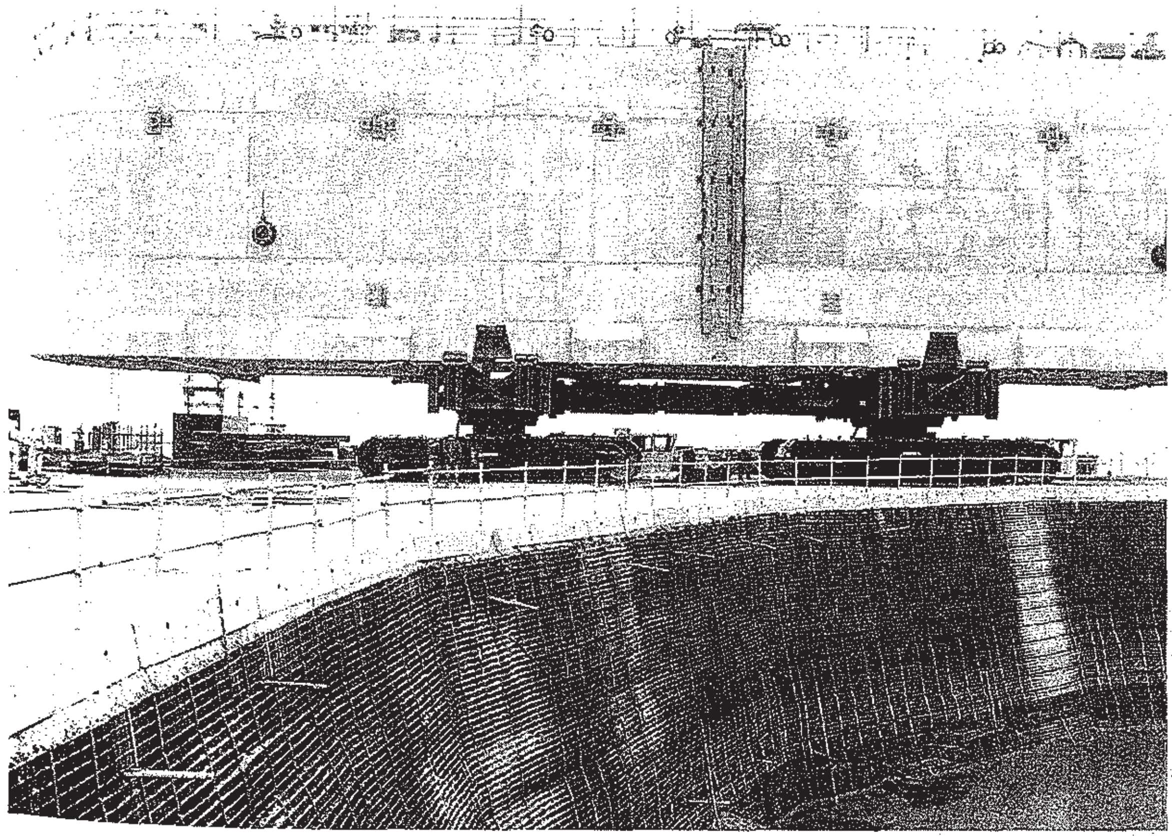

Fig 1. Reinforced Earth Ro-Ro ramp with Terratrel steel grid facing and High Adherence strips

1 BRIDGING THE RIVER SEVERN

The estuary of the Severn between South Wales and the south west of England has been a hazardous crossing ever since the ferry in pre-Victorian times. The prosperity of South Wales is dependent in part upon a good crossing to the rest of the country and at first there was only the long detour inland by road and across the bridge at Gloucester.

A bridge site was first surveyed in 1845 and the location known as the English stones was chosen. In 1873 Charles Richardson one of Isanbard Brunel's pupils chose the English stones as the site of the famous Severn Rail Tunnel which still carries the Cardiff to London line. This same site was chosen for the Second Severn Crossing some 5km downstream of the first suspension bridge which was built some twenty years ago and is now showing its age.

The 6km wide Severn Estuary provides a real challenge to engineers with the second highest tidal range in the world 14m, currents of 10 knots and exposure to high winds often causing the closure of the first bridge.

1.1 *Bridge design concept and construction methods*

The cable stayed bridge has a 456m central span and two long multi-span viaducts. Haste (1995) has given a detailed account of the choices made by Laing/GTM in the development of the crossing leading to three basic features; minimise the amount of work done in the river, maximise the prefabrication or precasting and modularisation of as many bridge components as practical, fast construction methods based on extensive use of jack-up barges. These requirements together with the presence of load bearing sandstone on the bed of the estuary lead to the adoption of large precast concrete caissons to form the basis for the bridge piers.

1.2 *Ro-Ro ramp concept*

The caissons were cast on land and transported some 500 metres to a sea-going barge which carried it to the waiting crane on the jack-up barges. Fig 2. The caissons were then placed on the sea bed and concrete filled. The only means of transporting the 2100 tonne caissons from the precast yard were Lampson crawlers imported from the USA and as used to carry rockets in the US Space Programme.

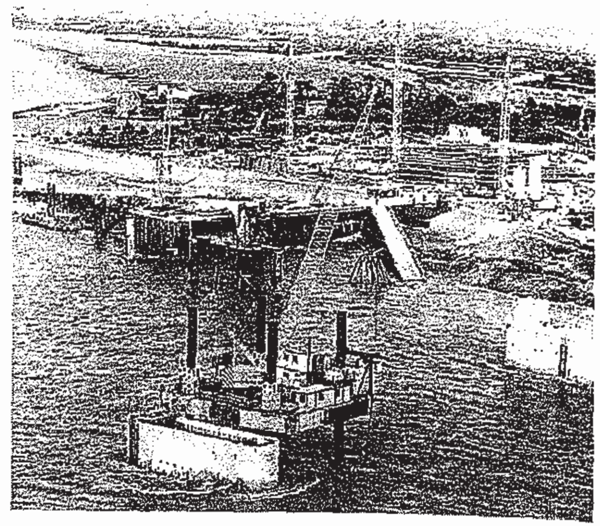

Fig 2 Ramp & jetty in background at left & centre

A jetty ramp was needed to give access for the crawlers to the waiting barges and Laing/GTM considered many options. They chose Reinforced Earth Company's proposal of a Reinforced Earth™ ramp formed by two back to back walls with a Terratrel™ facing of steel mesh panels backed by a layer of geotextile which allowed for evacuation from within the ramp of the water as the tide fell each day. Fig 3. The Terratrel structure offered the most economical solution and was built directly on the rock bed of the estuary thereby enabling the Contractor to comply with environmental requirements of no excavations into the bed. Fig 4.

Reinforced Earth construction usually consists of layers of galvanised High Adherence™ steel strips in layers of backfill and connected to cruciform concrete facing panels. The Terratrel system replaces the concrete panels with a steel grid backed by a layer of geotextile and for this marine structure black steel strips were used.

2 DESIGN OF RO-RO RAMP

The structure was needed for several tasks:-

- Materials jetty

For loading barges with construction materials using a NCK Ajax crawler crane 66 tonnes capacity. For loading 200 tonne pier section onto barges using a Manatowoc 4100W ringer crane on the barge.

- Ro-Ro ramp

To allow open top sea going barges to berth at its end and to be grounded at low tide. The ramp then provided access for 37 No caissons varying in

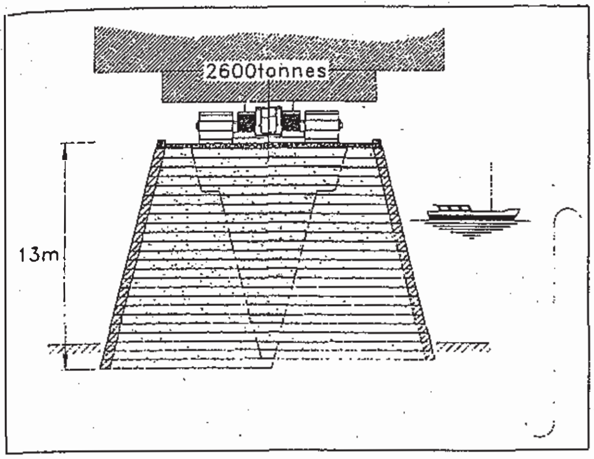

Fig 3 Cross section through Terratrel ramp

Fig 4 Placing first row Terratrel panels at low tide

weight from 1000 tonnes to 2100 tonnes and 40 No precast sections up to 1500 tonnes per load to be brought from the precast yard to the waiting barges.

The Lampson transporters and connecting frame weighed 500 tonnes making the maximum transported load 2600 tonnes. The edge of the Lampson crawler track would be 1 metre from the face of the Terratrel structure and would travel at 1/3 mile per hour down the ramps 7% gradient. The structure had a steep slope face 1h:4r generally except at the materials jetty face which was vertical.

Two principal load configurations were identified for the separate sections of jetty and ramp. In each case the vehicle gross weights were converted into an equivalent UDL and a limit equilibrium analysis carried out for each reinforcement layer using the Coherent Gravity Method as in the French Ministry of Transport Recommendations (1979) and as now given in the British Standard BS 8006 (1995).

A detailed potential wedge failure analysis was made in which many potential wedges passing below

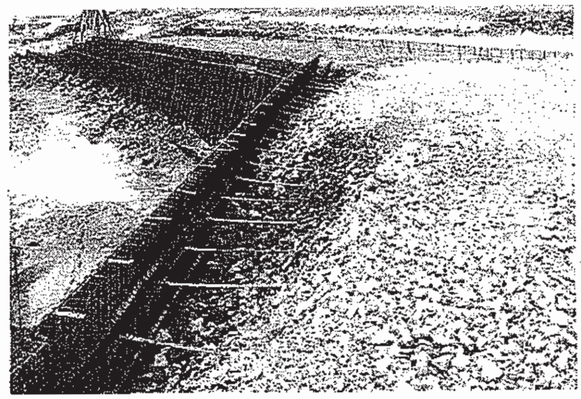

Fig 5 Coarse stone backfilling

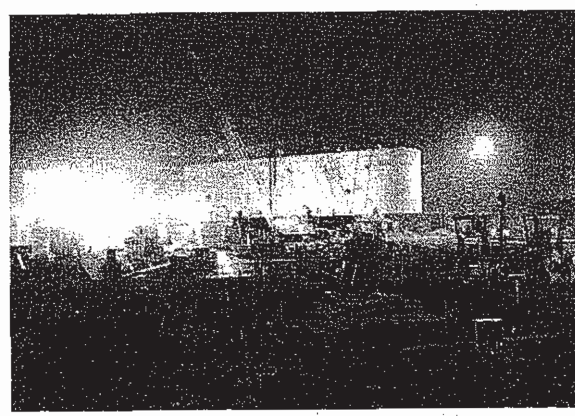

Fig 6 Caisson jacked up during night shift

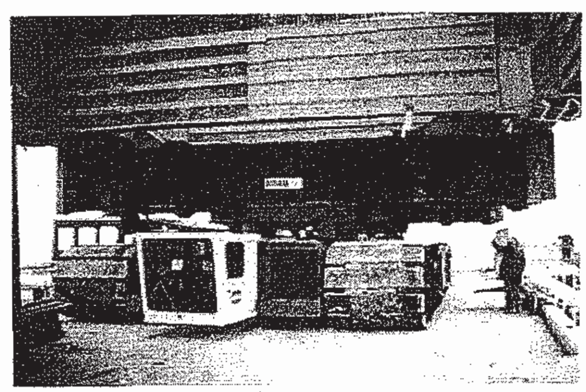

Fig 7 Lampson crawler positioned beneath caisson

the crawler tracks were individually examined for tensile and pull out capacity. The database of the Reinforced Earth Company's full scale tests were used to assess the pull out resistance of the High Adherence strips with the chosen 125mm to 20mm quarry rock backfill.

The residual rupture strength of the steel strips in the marine environment were estimated using the Company's own monitoring and research database

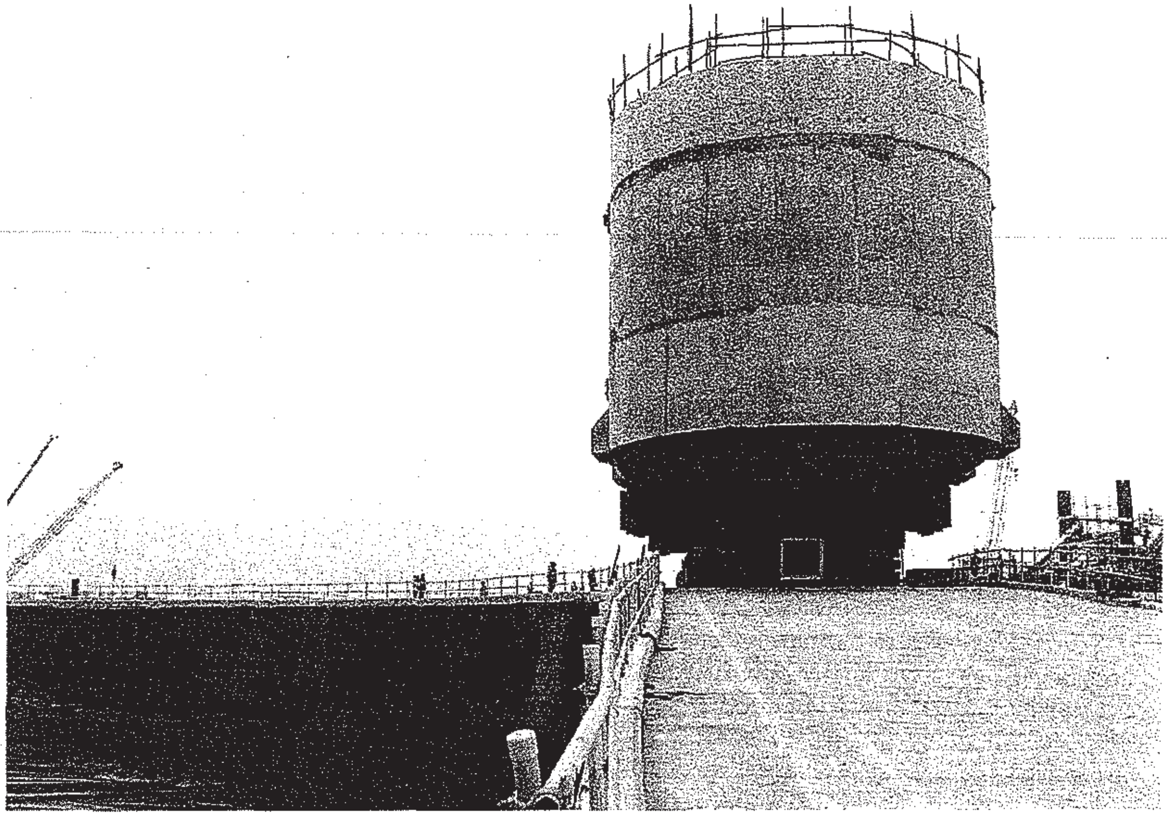

Fig 8 Caisson travels down ramp 1 metre away from edge of facing

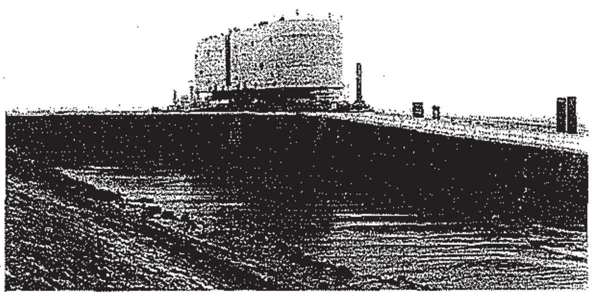

Fig 9 Caisson travels down ramp

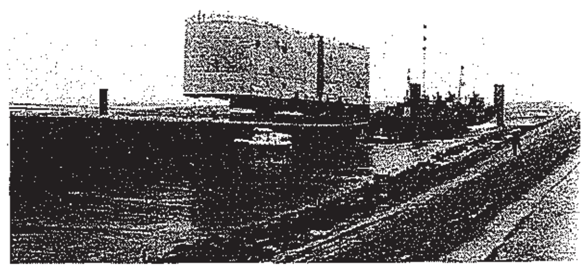

Fig 10 Caisson passes from ramp to barge

for similar works. Due to the onerous application a high risk partial safety factor was incorporated. The High Adherence reinforced strips used were 40x5mm & 40x8mm section and up to 10m in length.

3 CONSTRUCTION

Erection began in difficult conditions at low tide when soft deposits were cleaned off the founding stratum and Terratrel grid facings erected. Stone fill was placed and High Adherence reinforcing strips bolted to the face tie strips Fig 5. As the tide rose work stopped and resumed again after the falling tide. It was necessary to use hosepipes to wash off the mud layer brought in by the tide before resuming backfilling and strip placement. Erection and backfilling of the 4000 sqm structure took three months in the Autumn of 1992. Any mud remaining would have acted as a potential weak sliding layer. The use of coarse stone backfill reduced the risk of wave action removing fill during construction.

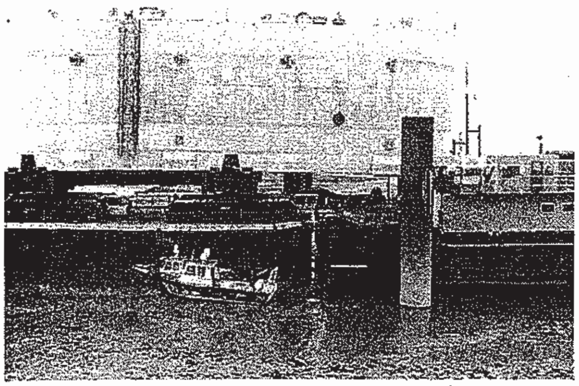

Fig 11 Caisson passes from ramp to barge

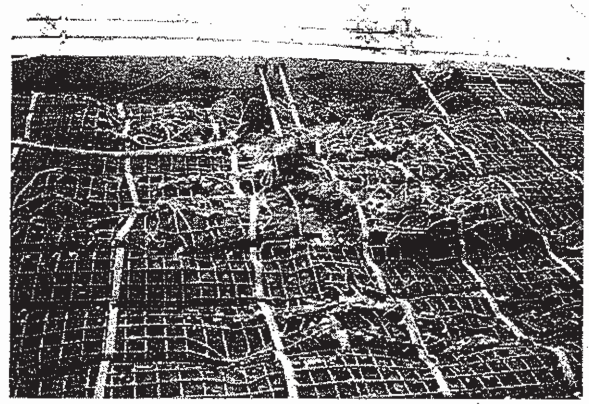

Fig 12 Breakaway barge damages face in storm

4 TRANSPORTATION OF CAISSONS

The 37 No caissons were in various sizes with the large ones being some 16m high x 45m long x 9m wide and weighing 2100 tonnes. In effect each one was the size of a 5 storey apartment block.

Upon completion of casting the caisson was jacked off its bed (Fig 6) and the Lampson crawlers positioned below. The caisson was lowered onto the crawlers which then moved onto the head of the ramp where the crawlers were slewed through 90° to then travel down the narrow ramp. Figs 7, 8, 9, 10 & 11.

For highway structures it is common to design for say 45 units of HB loading knowing that this load case will rarely occur. However, this design was unusual in the loads assumed were those actually applied by every caisson and the incoming tide.

4.1 *Storm damage to Ro-Ro ramp*

The first caisson was transported in January 1993 followed by many others before a storm one night caused a sea barge to break it's moorings. An area of facing of some 20sqm was ripped out of the structure causing many strips to be ruptured. Figs 12 to 14. Reinforced Earth Company engineers examined the damage and made repair recommendations. Expanded mesh was fixed over the holes in the facing, supported by shutter soldiers, and attached to the broken strips by welding. Openings were cut through the 150mm concrete road slab and the holes filled up by concrete. The ramp was operational within 24 hours and again carrying caissons.

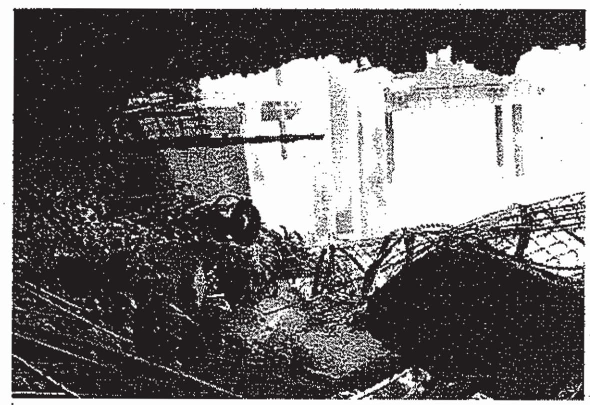

Fig 13 View from inside gouged hole

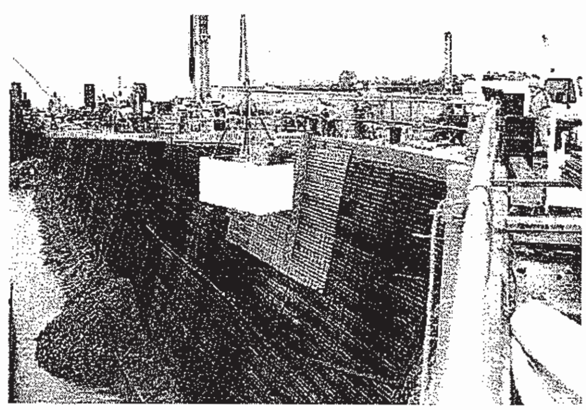

Fig 14 Repairs carried out at low tide

5. CONCLUSIONS

The experience gained in the design and construction of this major Reinforced Earth structure carrying the heaviest of loads in a difficult marine environment, has enabled engineers and owners to have confidence in the safe and economical application of this technique. Figs 15 & 16.

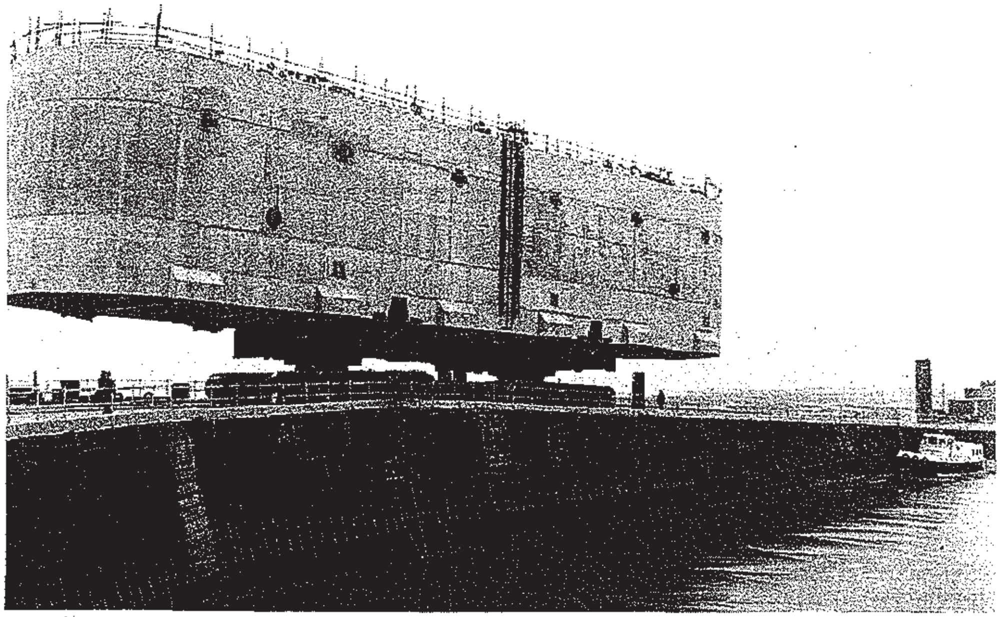

Fig 15 2600 tonne load supported by Reinforced Earth ramp

Following its successful operation the ramp was entered in the British Construction Industry Award Scheme alongside many architect designed buildings and elegant bridges. There were some doubts before entering a plain and functional piece of temporary works. However, NCE (1993) commented that "it is unusual for a temporary structure to be entered for an award, but the Reinforced Earth Ro-Ro ramp is no ordinary structure". "This is a creative, bold and cost effective solution", said the judges. "It is also a rare case of a structure for which the design loads - among the largest seen in this country - will in fact and not just possibly, be applied". The structure won the Highly Commended Award in 1993 due to it's intellectual elegance , economic advantages and it's low impact on the environment.

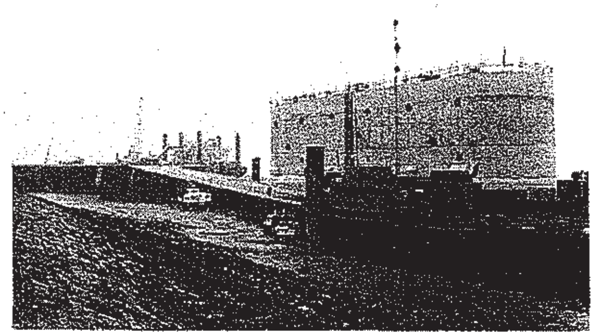

Fig 16 Transfer to barge made at low tide

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