Earth Reinforcement Practice, Ochiai, Hayashi & Otani (eds) © 1992 Balkema, Rotterdam. ISBN 90 5410 093 1

Underwater construction techniques using Reinforced Earth

D.Weinreb
Reinforced Earth Company Limited, Canada

M.S. Boyd
Reinforced Earth Pty Limited, Australia

ABSTRACT: The Reinforced Earth technology has been applied to many structures which are partially underwater. These structures have been constructed in the dry. Two techniques have been developed, one in Australia and the other in Canada, to construct these structures underwater. These techniques are presented.

1. INTRODUCTION

In river and marine environments, Reinforced Earth has been adopted successfully for river walls, sea walls, wharves and reclamation works using the standard technology developed for land based structures and construction in the dry. Many of these structures were designed for, and subject to, inundation and flooding both under construction and in service. The behaviour of Reinforced Earth under such conditions is well understood and predictable, provided that the structure is well drained and protected against scour,. The practicality of erecting such structures below water level, however, is limited.

In the Asian/Pacific region and in North America a considerable market potential exists for economic, durable land backed wharf structures to service remote resource developments. In South East Asia, flood control schemes in many areas require river training walls to be built underwater .

Two techniques have been developed and implemented, one, in the Asian/Pacific region by the Australian Reinforced Earth Company and, one, in the North America region by the Canadian Reinforced Earth Company, which both retain the essential technical advantages of Reinforced Earth while addressing the practical needs of underwater construction.

2. DESIGN AND CONSTRUCTION

Design factors to be considered included the effect of buoyancy, draw down, corrosion, strip loading and construction method. Construction factors to be considered included the placement of panels, connection of reinforcement and backfilling.

The most significant construction problem was seen to be the placement of panels and the connection of reinforcement while maintaining the flexibility which is desirable for variable foundationand which is necessary for Reinforced Earth ehaviour to be properly mobilised within the Reinforced Earth block.

The two techniques differ essentially with respect to the connection of the elements. the Australian technique is based on the use of divers of facilitate the placement and connection of reinforcement to the panels using a simplified large tolerance flexible connection system. The Canadian technique maximised the above water operations by the use of guide piles and preconnected elements to minimise the use of divers.

3. THE AUSTRALIAN TECHNIQUE

A new wharf structure was built at the Copra Wharf at Honiara in the Solomon Islands, where an existing steel sheet piled wharf had been severely corroded. (Boyd & Ryan, 1988).

The face of the Reinforced Earth forms the vertical face to the wharf structure. The structure is 82.5 metres long and varies in height between 3 and 6 metres. The reinforcement length in the Reinforced Earth block is 6 metres. See Fig. 1

Bollards, with design ratings of 10T, 20T and 50T were required to be supported on top of the wall. A seismic design factor of 0.15 g was applied and the design analysed using the seismic design criteria developed by the New Zealand Ministry of Works. General surcharge loading was 15 kN per square metre over the top of the structure.

The facing panels were plain concrete units 2.0 m 2.25m x 0.55m thick (Fig. 2). A site specific durability requirement that no embedded steel be used in the panels resulted in the development of a recessed keyway for the strip/panel connection to

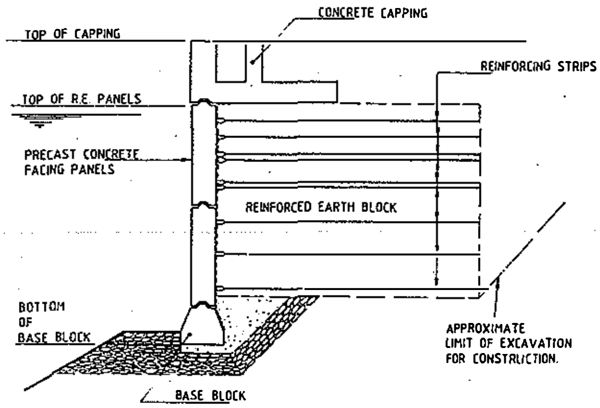

Fig 1 Section, Copra Wharf

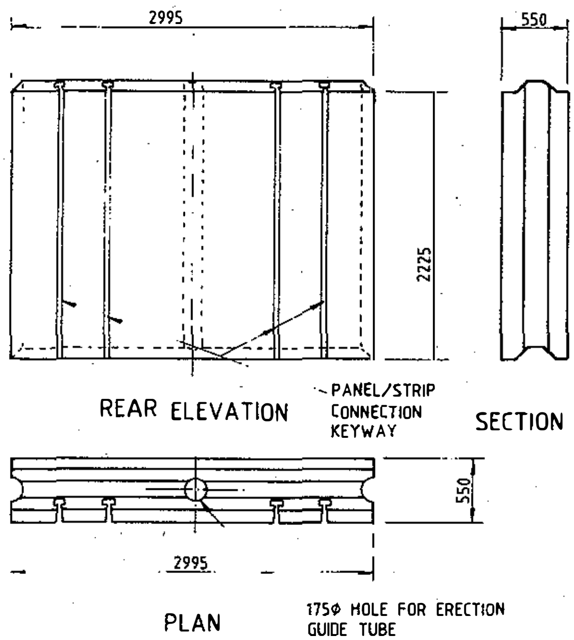

Fig 2 Facing Panel

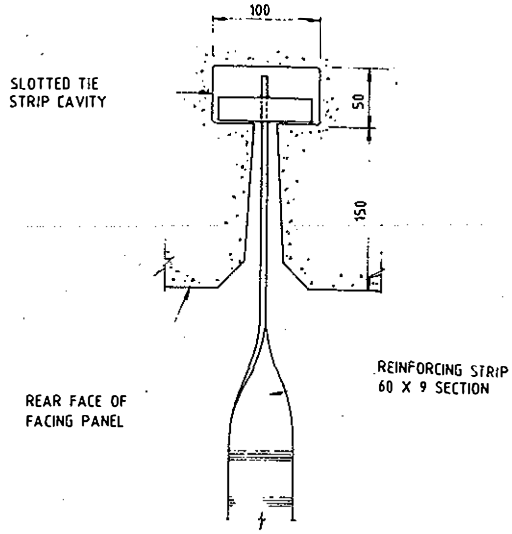

Fig 3 Strip/Panel connection

provide a void for the steel reinforcement and to ensure that there was an allowance for the variability in fill levels and the potential for differential settlement.

The horizontal panel joints were essentially a tongue-and-groove configuration which is designed to fulfil three functions:

- self alignment during placement
- support during construction.
- flexibility under compression.

The vertical joint is a standard gravel filled shear key based on the details derived for precast concrete block work in gravity sea wall construction.

The reinforcing strip section is standard High Adherence strip with increased thickness to provide a corrosion allowance. A section of 60 mm x 9 mm was used which incorporates a 2.5 mm corrosion allowance per surface (or 5 mm overall) for a 50 year design life. The strip/panel connection is provided by way of a plate welded to the end of the strip which is twisted by 90 degrees to allow it to fit into the slotted keyway. (Fig. 3)

The select backfill in the Reinforced Earth block is a sandy river gravel with less than % passing 75 um and a CU of approximately 6.5. The friction behaviour of this material was tested in a large direct shear box for a range of density achievable under water (very loose to dense) which confirmed that a minimum angle of internal friction of 35 degrees was appropriate for all conditions of the material (buoyant, saturated, dry).

Site works commenced in December 1985. The existing sheet pile facing was left in place during construction to provide some assistance by way of access and alignment control. The existence of this wall, however, proved to be an unnecessary restriction to the construction operation particularly as the site was already contained by the proximity of the Copra sheds and the need for phasing of construction.

At the base of the excavation, a probe was used to confirm the adequacy of the foundation and prior to placing the base blocks, layers of 40 mm and 20 mm aggregates were placed to provide firm and level support.

The facing panels (and base blocks) were provided with vertical hole in the centre into which a 150 mm steel pipe approximately 4.5 m long was inserted during erection. This pipe acted as a guide to position the incoming panel over the previous panel (or base block) and, during backfilling, it acted as a temporary panel support. Panel alignment was maintained by way of a clamp or saddle across the joint at the top of the panel.

Backfilling was achieved using a grab bucket. As each area was roughly completed, the fill was compacted by a diver (and support team above) using a concrete poker vibrator. Density was checked by way of a simple steel box which was buried and filled during the general earthworks, then removed and weighed.

On completion of the backfilling to each designed strip layer, the end plate of the reinforcing strips was inserted into the keyway slots at the of the panel and the strip guided down to the surface of the compacted fill by the diver.

The backfill operation (including the placement of fill to a depth of 750 mm over the width of the Reinforced Earth block and behind, compaction and placement of reinforcing strips) was completed at a rate of approximately 3 panel widths per day.

This cycle of operation was repeated throughout the structure, both in the shallow and the deep zones - panel placement, backfilling and compaction, strip placement, further backfilling and compaction and so on.

4. THE NORTH AMERICAN TECHNIQUE

A new marginal wharf, part of a new recreational area, was completed in Newcastle, New Brunswick, Canada at the Miramichi Historic Shipbuilding Centre in July 1991 (Fig. 4). The Miramichi River is known for its scenic shores. It is some 220 km long running from Juniper, N.B. to the Atlantic Ocean.

The wharf is 101.7 m long and 7.0 m high and consists of 108 prefabricated concrete panels with a total surface area of 692 m^2. The wharf was constructed underwater by using the Reinforced Earth technique.

The contract for the wharf was awarded in December 1990 by the Department of Supply and Services of New Brunswick.

Wharves, piers and somc scawalls are usually partially or totally submerged at all times and require varying depths of water.

In the Great Lakes and along the Atlantic and Pacific shores, visibility underwater is very limited and can be considered as "Zero Visibility" during and considerably long after backfill placement takes place. Consequently, a new method of installation of these underwater walls was developed to construct these underwater structures from above water and to minimize the use of divers. All works as well as guidance for vertical and horizontal alignment must be done from above water.

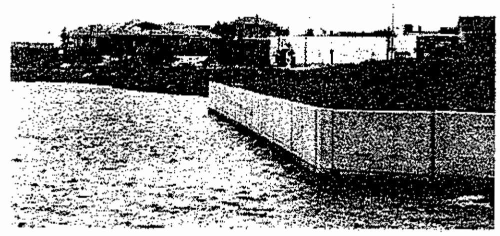

Fig.4 Miramichi Wharf - Completed Structure

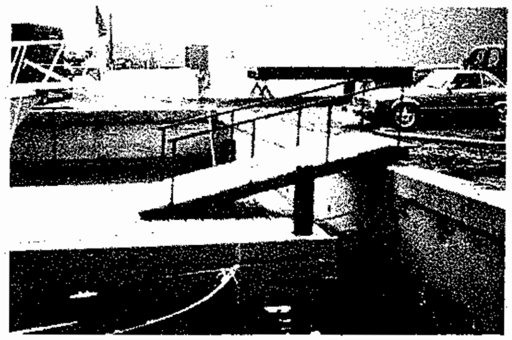

Fig.5 Pilot project built underwater.

The design accommodates the effects and behaviour of the reinforced earth mass under submerged conditions, hydrostatic pressures, wave, storm and ice forces, drainage, scour and impacts of marine crafts.

The components of Reinforced Earth wharves and piers are assembled on land and lowered below water in discrete units of concrete facing elements and reinforcing strips in one assembly.

A pilot structure was successfully built in Toronto, Canada in 1986 (Fig. 5) and followed by a structure on Canada's St. Lawrence River in 1988.

The submerged vertical wall built for Ontario Hydro (fig. 6) was for the use of an "ice boom" maintenance dock. The structure, located near Cornwall, Ontario, was 4.3 meters high and 52 meters in length, supporting a concrete load distribution slab for heavy maintenance equipment (Cragg, 1989).

After the foundation has been excavated to designed bottom of wall and levelled to within tolerances ($\pm$ 300), an assembly of two 8m long concrete beams, is lowered by "Guide Piles" (Fig. 7) below water level. This assembly is called "Base Panel" and it provides a "levelling pad" for subsequent placement of panels above it.

The side walls of the base panel provide a

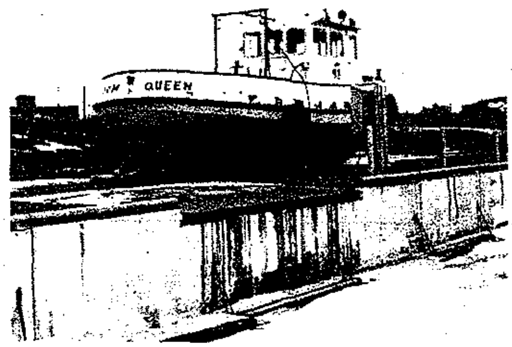

Fig 6 Wharf in Ontario, Canada

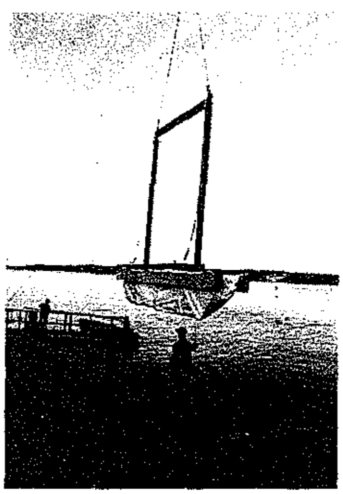

Fig 7 Base Panel

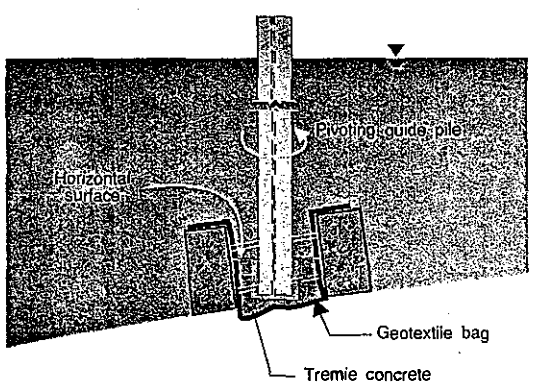

Fig 8 Detail at bottom of base panel

fornnwork for rapid hardening high workability concrete which is pumped to below water. Geotextile fabric, draped between the sides of the base panel, prevents the concrete from leaking out. The concrete, once hardened, provides a horizontal level and seals the bottom between the piles. (Fig. 8)

The base panel assembly is designed in a way in which the guide piles carry the concrete sideform beams during installation. The guide piles are then supported by the heavy concrete sideform beams after the base panel is in its final installed position and rests on the bottom.

The design of the base panel permits a limited pivot to the guide piles. While the guide piles remain perfectly vertical during placement of the base panel to ensure a perfect horizontal alignment, they can pivot slightly in their installed position.

It is obvious that the concrete sideform beams which rest on the bottom and adapt its irregular shape, can not be in perfect vertical alignment. However, the concrete pumped into the gap between the concrete beams of the base panel does become level and together with the pivoting guide piles it allows the first course of wall panels to assume correct horizontal and vertical alignment.

The guide piles are made of wide flange steel sections. They provide guidance during installation and a vertical link between panels (Fig. 9) preventing loss of backfill material through the joints. The guide piles do not, however, play any structural role of the in-service structure.

The horizontal joint between wall panels is formed by 100mm cork. It serves two purposes; to seal the horizontal joints and eliminate escape of backfill material and to enhance flexibility due to its compressibility.

The concrete wall panels are assembled on land. The reinforcing strips are attached to the panels and rest on support cages. The cork is then nailed onto the underside of the wall panel. The whole assembly of panels, reinforcing strips and cages are lifted by a specially designed installation beam (Fig. 10). The panels are then inserted between guide piles and lowered to below water to their final position.

Once a whole row of wall panels is in place, backfilling can commence by using either clam shell or backhoe. The backfill used is 20-50 mm crushed stone and is placed below water first at the support cage location (to minimize bending of the reinforcing strips) and then to the top of the panel. Backfilling below water is normally carried out using standard marine construction equipment such as clamshells or excavator buckets. Open mass dumping is not recommended due to lack of fill placement and distribution accuracy. Hydraulic delivery can also be employed if cost is effective.

Generally, the density of lower grade fill can be enhanced if desired by various vibro ground improvement technique. However, using permeable, low self settlingC uniforrn crushed stone backfill offsets the high costs of compaction improvement techniques.

The simple combined sequence of panel/strips

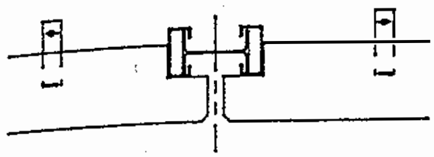

Fig.9 Section through guide pile

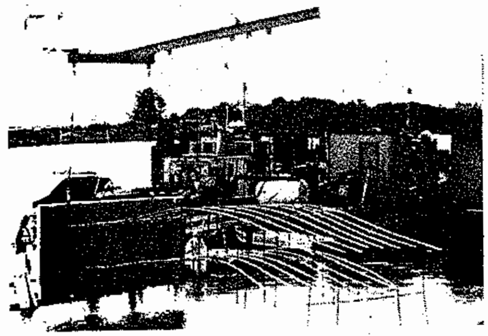

Fig.10 Wall panel assembly

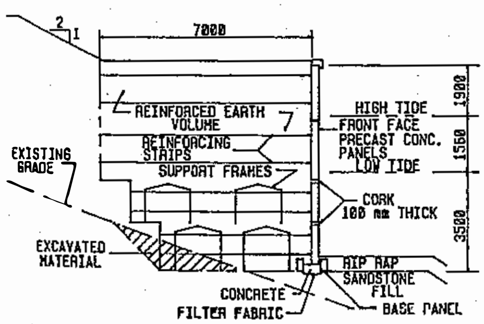

Fig. 11 Cross section - Miramichi Wall

arrangement and backfill placement as described is repeated until the wall height increases to above the water level.

Once a row is installed and backfill is placed, a new row can be installed in the same fashion until the structure daylights from the water.

Above water installation can continue without usage of the support cages. (Fig. 11)

5. CONCLUSION

The two techniques described have been successfully applied to the construction of prototype structures. The adoption of either technique will depend on local construction practice and costs. Both techniques respond to the demands of both construction simplification as well as the post construction flexibility with respect to Reinforced Earth behaviour. The practicality of constructing Reinforced Earth structures underwater is established and the adoption of such techniques is recommended for situations where dewatering is not practical or economic.

REFERENCES

Boyd, M.S. and Ryan., M.J. 1988 A Reinforced Earth Solution for Marine Structures, 2nd Australasian Port Harbour and Offshore Engineering Conf., Brisbane.

Cragg, C.B.H., Carmichael;, T.J. and Klym, T.W., 1989, Instrumentation of Reinforced Earth Wall, Internal Report of Ontario Hydro Research Division, Toronto, Ontario.