DESIGN AND CONSTRUCTION OF THE QUEEN ELIZABETH QUAY
CONTAINER TERMINAL - PORT OF COLOMBO

by

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Introduction

The extension of Queen Elizabeth Quay was planned to provide a multi-purpose alongside berth for handling of bulk cargo including fertilizer, yard cargo and containerised cargo. This item was included in the Technical Development Scheme of the Colombo Port in 1967. As it appeared in the original proposal, the extension of the quay by 180m (600 ft) with an alongside depth of 11m (36 ft) was estimated to cost Rs. 4.55 million.

The primary object of this proposal as then envisaged was to provide an additional alongside berth similar to other Queen Elizabeth Quay berths. Then it was felt that with the big development of containerised cargo in other Ports of the world, that Colombo Port may be caught unprepared if it was unable to provide facilities for handling container traffic when the necessity arises. Although there were no figures available to forecast the volume of containerised cargo to and from Sri Lanka, the container revolution had begun to change the pattern of world shipping.

The world shipping industry entered into an era of container ships when the first full container ship was placed on New York - Europe run in April 1966. Since then gradually almost all the world's main sea lanes have been successfully containerised. Thus the need to construct a container terminal in Colombo was recognised and it was agreed that the bulk handling berth proposal should be modified to meet the requirements of container handling.

Also taking advantage of the proposal to deepen Colombo Harbour for the accommodation of larger tankers, the new amended proposal was to construct a quay 300m (1000 ft) long with an alongside depth of 12.5m (41 ft) of water. This proposal was estimated in 1969 to cost Rs. 10.5 million, and this estimate received approval only in July 1972. The location of this project is shown in Fig. 1.

Though the preliminary site works started in June 1968, on the initiative of the then Colombo Port Commission, there were no proper plans to construct these works. Due to lack of priority, public sector red tape, acute shortage of foreign exchange and insufficient fund allocation, the project progressed at a snail's pace. On several occasions engineers recommended as far back as in 1971 to close this work site due to lack of satisfactory progress. The expenditure over the period of project is shown in Fig. 2.

Nearly 180m of the quay was partially completed by 1977 to inaugurate a containerised RO-RO service to Australia by Ceylon Shipping Corporation with the arrival of M.V. 'Turquoise Bounty' on 17.12.1977.

In August 1978 on a directive from the Minister of Shipping, Aviation and Tourism, international tenders were called to contract the balance 120m (400 ft) of the quay, estimated to cost Rs. 25 million but was later suspended by the then Minister of Trade & Shipping. With the formation of the Sri Lanka Ports Authority on the 1st August 1979 highest priority was given to this project and instructions were given for the Authority to complete the balance works by end of May 1980. The work progressed rapidly and it was possible to complete the project in early 1980.

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The terminal was ceremonially inaugurated by His Excellency the President J.R. Jayewardene on the 1st August 1980, opening a new era in container operations in Colombo and the Port of Colombo became one of the first Ports in South Asia to offer a container berth to the Shipping in the region. There was a steady rise in container traffic since then and in 1984 Colombo handled 187,000 TEU's which surpassed the forecast for 1988.

This being one of the single major items of maritime engineering works in Sri Lanka designed and constructed by the Port personnel without any form of foreign assistance, it is considered appropriate to place on record some of the design and construction aspects of this project.

Design Evolution

Because of the familiarity that the Port engineers had in the use of concrete cylinders in maritime structures, large diameter cylinders were considered suitable for this project. The construction using concrete cylinders was found to be cheaper than the mass concrete block-work construction. Moreover the cylinder construction would require much lesser diver time as compared with the latter at a time when divers were a scarce resource. Large diameter concrete cylinders had been used successfully in the construction of quay walls at Le Havre and Toulon in France.

The initial concept of the design was by Mr. (now Dr.) A.N.S. Kulasinghe who was Deputy Chief Engineer at that time. The detailed designs including the later modifications were directed and supervised by him. Right through his subsequent period in the Colombo Port Commission as Chief Engineer (Ports) and until he retired from the post of Port Commissioner at the end of 1971, he was involved in the works and directed the execution of the project.

The original design of 1968 for the quay wall was based on an alongside water depth of 11m. The sub-structure used 8.24m (27 ft) diameter cylinders. Precast rings were to be assembled and stressed together in a drydock using H.T. wire to form 15m high cylinders which were to be floated to position. This design was not accepted as it required a large quantity of H.T. wire and the use of a drydock. Therefore it was considered that a redesign was required and the design of 1969 utilized 8.24m diameter cylinders with a relieving platform. The designed water depth was 12.8m. This design had significant advantages over the previous design in that it didn't require the use of a drydock, so that ship repair activity in Colombo would not be interfered. It eliminated the use of H.T. wire thus saving quite a lot of foreign exchange.

Both these designs did not consider container gantry crane loads. Thus in 1970, the design was further reviewed to take into account the loads imposed by container gantry cranes. It was revealed that the factor of safety against lateral stability was fairly low. A, 10.37m (34 ft) diameter cylinder was found to overcome this weakness. In 1971, Faculty of Engineering of the University of Peradeniya was requested to analyse the structure and they suggested that 10.37m diameter cylinder should be adopted. By this time, work was already progressing using 8.24m diameter cylinders. Therefore the finally adopted design consisted of 8.24m diameter cylinders on the quay wall tied-back to anchors which were 10.37m in diameter incorporating a diaphragm.

Investigations

The existing structure of Queen Elizabeth Quay was of concrete blockwork in sloping bond on random rubble foundations. In order to proceed with cylinder type construction it was necessary to find out the nature of seabed and sub-surface materials along the proposed line of quay. A line of air jet probing was conducted by divers at intervals of 33m (100 ft) along the line of quay. Except at the first 33m point, the probe descended to more than 16.5m below LWOST. The probe struck a hard layer at the first point with similar results when attempting to probe around that point. It was considered to be the end of existing rubble and boulder foundation of blockwork quay wall. After the findings of these investigations, plans were prepared to sink the first cylinder beyond the existing rubble foundation and to fill the gap between the existing end of quay and the first cylinder with mass concrete blockwork.

The investigations also revealed that about a 3m thick layer of soft silt and clay existed at the seabed over a distance of about 200m along the line of quay. This layer had to be dredged out and replaced with coarse sand brought
from outside harbour area.

The results of further bore-hole investigations carried out in 1970 during construction and in 1980 after completion of works to determine the suitability of the structure to support a heavy container handling gantry crane are summarised in Fig. 5.

Design Aspects

The quay wall structure was designed as a tied-back, precast reinforced concrete cylinder wall with beam and slab superstructure. Each cylinder was made up of eighteen precast concrete rings each 0.9m (3 ft) high and stacked one over the other. The cylinders were to be sunk by counter-grabbing on the average to a depth of 15.9m below LWOST. The sub-structure of the quay wall consisted of 28 cylinders. (Fig. 3).

Each precast ring (Fig. 7) had an external diameter of 8.24m (27 ft), wall thickness of 0.6m (2 ft) and a height of 0.9m (3 ft) weighing approximately 25 Tons. Its wall was provided with 40 vertical holes each 0.33m (13 inches) in diameter placed symmetrically around the circumference and extending the entire height of the cylinder. They were included to reduce the weight of cylinder and to permit in-situ concreting of holes to make the cylinder monolithic while resisting horizontal shear force. The weight of cylinder units was critical as they had to be lifted using the available cranes. Each ring was reinforced with 900 kg. of reinforcing steel to cater mainly for torsional and flexural effects during lifting and handling. The bottom edge of the lowermost cylinder unit had the holes enlarged to a conical shape terminating in a steel cutting edge made of steel flats. The object of this shape was to help penetration through the sand. The circumferential interlocking key between cylinders is shown in Fig. 7. The circumferential seal was provided to prevent the leaking of sand fill from inside.

The quay was designed for the following superimposed loads: uniformly distributed load of 3 Tons per sq.m, crane wheel load of 50 Tons on each of six wheels at a corner, bollard pull of 50 Tons per bollard at every 26m and a berthing impact force of 90 Tons.

The complete cylinder (Fig. 4) was analysed as a flexible pile subject to bending and thrust. The factor of safety of the cylinder against sliding and topping was found to be low. Therefore in order to increase the factor of safety a tie force was applied 1.4m below the finished level of quay. The anchor constituted a 10.37m (34 ft) diameter cylinder having a wall thickness of 0.75m (30 inches) extending from -2.6m LWOST level to +2.4m LWOST level (Fig. 6). Two of the quay wall cylinders were tied to one anchor cylinder using post-tensioned tie beams each applying a force of 260 Tons (Fig. 3). This tie force was transmitted to the anchor cylinder through a horizontal diaphragm 0.6m thick. The holes in the cylinder were to be filled with concrete or sand. In order to resist the maximum shear of 350 Tons, 14 holes were to be concreted with reinforcement while other 26 holes were filled with sand. The inside cavity of the cylinder was to be filled with sand.

The space between each pair of adjacent cylinders had to be properly closed to prevent seepage of sand to outside. This had been a frequent problem with cylinder type walls. The precast sealing unit had a length of 3m and 0.45m thick with the two long sides having the curvature of cylinders. The width of the unit at the waist was to be adjusted to suit the size of the individual gap.

The superstructure of quay wall was designed with two cope beams placed on top of the cylinders, two transverse beams per cylinder 0.9m wide by 1.5m high, and 30cm thick R.C. deck slab. The cope beams were 2.9m high having a width of 1.5m on the landside and 1.8m on the seaside. The seaside crane beam is placed 4.25m behind the quay face supported on transverse beams which are spaced 4.4m (14.5 ft) apart.

Initially there were no gantry cranes installed. Later when decision was made on the cranes whose gauge was 27m, the landside crane beam foundation was designed using 530mm (21 inches) diameter cast-in-situ reinforced concrete piles supported on bedrock at an average depth of 19.8m below LWOST with a design load of 130 Tons. The total length of crane track was 305m and 53m length was designed without piles as pilling was not possible due to existence of a boulder layer underground. A spread footing in the form of an inverted 'T' was proposed for this section to be supported on sand fill after ground...
improvement.

The distance of first cylinder from scar end of existing quay measured 26m at cope level and 9.8m at toe level. This gap was designed to be filled with slant blockwork to complete the slices and horizontal blockwork to cover the balance, the horizontal blockwork being founded on a mass concrete foundation 1.25m thick. These mass concrete blocks weighed 10 - 20 tons. A total of 247 such blocks were needed to fill this gap and the extent of this blockwork construction is shown in Fig. 8.

The northern end of the berth had a width of 108m (354 ft) up to the South-West breakwater. The first 45m length on the harbour side was designed to form a vertical wall with same cylinders as on the main quay so that a harbour tug or a small vessel could be berthed on this face. The balance 63m constituted a trapezoidal boulder wall.

Construcional Aspects

Preliminary site works started in June 1968. in an area of 90m x 30m at the end of existing quay. One of the initial items of work undertaken was to erect a 20 year old rail-mounted block-setting crane and modify it from 15 Ton lifting capacity to 30 Ton at 17.0m radius. This crane was to be used for lifting precast cylinder units which weighed 25 Tons each.

The precasting of 8.24m diameter cylinders was so planned that each cylinder could be lifted out using this crane. Several casting beds were prepared with the bases moulded in concrete. Steel shutters were used and the casting of cylinders commenced in May 1969. This precasting work did not pose any problem except for the lack of storage space for completed cylinder units as cylinder sinking was not progressing as planned. While the monthly target for production of precast ring units was fifteen the actual output did not exceed seven units for most of the period.

The clearing of sunken obstructions and replacing of a layer of soft mud with sand preceded the cylinder sinking operation. The seabed was properly levelled by divers before placing of the first cylinder unit. Initially a prefabricated shutter 9m x 9m and 60cm high was placed by divers at seabed to correct level and then inside was levelled with sand. The use of this shutter was eliminated later and levelling was done without the shutter. The cutting-edge cylinder unit was placed on the prepared bed and several other units were stacked on it until the cylinder projected above the water level. Thereafter sinking was achieved by centre grabbing using a floating crane with a grab. More units were added until the cylinder was sunk to the required depth.

The first cylinder took over 8 months to complete due to several delays such as non-availability of required equipment. The second cylinder was completed in 2 months and the third cylinder took one month. The third cylinder was sunk in a location where the seabed was dredged to 15m below LWOST to remove certain sunken obstructions and backfilled with sand to 11m below LWOST, so that sinking into virgin ground was less than 1 metre.

The sinking of quay wall cylinders did not pose a problem except the No.9 cylinder which tilted towards land after it had been sunk to the required depth. The tilt was almost 6° to the vertical with the seabed at 11m below LWOST. The seaside edge of the cylinder was found to rest on a hard layer while the landside edge on a soft clay layer. In order to correct the cylinder following operations were performed: outside the cylinder on seaside dredged by 1.5m, outside the cylinder on landside filled up by 1.5m, inside the cylinder on seaside grabbed out and cut below the cutting edge with waterjet by divers seaside top edge of cylinder loaded with a weight of 65 Tons. After almost three months, in February 1973 the cylinder was almost vertical again but the cylinder penetrated further 1.9 metres.

When the penetration of a cylinder was completed, inside was filled with sand up to the cutting edge level and fourteen holes were filled with concrete, placed under water from bottom opening skips which passed through the cage of six 20mm reinforcing bars; the other holes were filled with sand. The central cavity of the cylinder was filled with sand.

The gap between each pair of adjacent cylinders measured about 60cm. Those gaps with the exception
of four were closed with precast concrete units made to suit the size of each gap. The measurement of the gap was made from the bottom to top at every cylinder ring unit by divers for this purpose. The sealing unit had a length of 3m and 0.45m (18 inches) thick with the two long sides formed to the curvature of cylinders. The units would press against the cylinders due to lateral earth pressure when installed in position and they were found to perform very satisfactorily. In the four gaps where these units would not work, two long shutters were fixed on either side of the gap approximately 3m apart and filled inside with concrete using canvas bags or bottom opening skips.

The superstructure of quay wall consisted of in-situ concreted cope beams, transverse beams and the seaside crane beam. The dock slabs on the cylinders which spanned between transverse beams were cast in-situ with provision to lift them to inspect the sand fill inside the cylinder, if it became necessary.

The existing scar end of the blockwork quay was as shown in Fig. B. The space between this end of blockwork and the first quay wall cylinder was filled with sliced blockwork and horizontal blockwork. The faces of blocks at the scar end covering about 185 sq.m were covered with barnacles which had to be scraped out by divers before setting of new blocks. The mass concrete blocks had a cross section of 5 ft. x 5 ft. and length varying from 6 ft. x 11 ft. After completing few slices with new blocks, it was necessary to construct the foundation for balance blockwork.

The horizontal blockwork is normally founded on a concrete foundation. After grabbing out about 4000m³ of material from seabed to 13.7m (45 ft) below LWOST, a prefabricated steel formwork was placed at the bottom and levelled. The formwork measured 8m long and 12.2m wide, into which 120m³ of concrete was placed using canvas bags to complete the foundation. A total of 241 blocks were placed in horizontal work and in slice work. In the eight horizontal courses where it was not convenient to make precast blocks, in-situ concrete was placed using canvas bags within a formwork. The blockwork that started in 1969 was completed in mid 1972 which required quite a lot of diving time. Subsequent inspection of the blockwork revealed gaps in between blocks upto 50mm and at few places upto 150mm. All these were caulked with oil coir rope, packed with concrete prior to backfilling with sand.

The area behind the quay wall required approximately 240,000m³ of fill material for reclamation. Sand dredged from outside harbour for most part of it from the Shipping channel of the Port using the trailing suction dredger 'Diyakawa' was used for reclamation.

The anchor cylinders and tie-beams were constructed on the reclaimed land in-dry after the fill reached about 0.75m above LWOST. The anchor cylinder was cast in-situ using steel formwork and the tie beams were either precast or cast in-situ. The 10.37m diameter cylinder had a wall thickness of 0.76m (30 inches) and a total height of 5.0m. The horizontal diaphragm was concreted to a thickness of 0.6m to anchor the steel wire of the tie-beams. The tie-beams had a cross-section of 0.6m x 0.6m in concrete with ducts for high tensile wire cables.

Eight cables each having 12 Nos. 0.276 in diameter high tensile wire were used in the tie beams with the cable ends fanned out and concreted into the diaphragm of the anchor cylinder. The cables were stressed on the seaside end with four cables anchored on the inner coping and four on the outer coping.

The Northern end of the berth was constructed with the same cylinders as on the main quay for a distance of 45m. The balance length of 63m up to the South-West breakwater was constructed by directly dumping rock pieces of the size 5-150kg from tippers into the site to form into a trapezoidal section and allowed for settlement.

After the reclamation was over, the sub-grade was compacted prior to surface finishing. The surface was completed in rubble packed macadamised paving to an overall thickness of 40cm, with a grade of 1 in 100 for surface water drainage. The Terminal was completed with three 20m high illumination posts with high intensity lights.

The total cost of construction is Rs.33 million.

**Container Handling Gantry Cranes**

At the time of opening of the new Terminal in
1980, there were no gantry cranes available. But soon it became necessary to install cranes. Although Foreign Consultants who studied the construction concluded that an independent piled foundation is required on the quay wall side to carry the crane loads in view of inadequate bearing capacity of the quay wall, a group of port engineers reviewed the structure and concluded that a light-weight gantry crane could be safely installed on the quay. There was no landside crane beam constructed as the gauge of the crane to be installed was not final.

In 1982, an award was made to install two gantry cranes. The gauge of these cranes being 27m, it was then necessary to construct landside crane beam and foundation to carry the crane load. The foundation consisted of 21 inches diameter reinforced concrete piles spaced 5.9m and supported on bedrock. Single vertical piles were used for in-use condition loads while double verticals for storm bays. They were of two types: driven cast in-situ and bored cast in-situ piles.

The loading condition of the cranes installed are as follows - Maximum vertical load during use of crane of 30.4 Tons per wheel, during storm condition 36.1 Tons per wheel, having six wheels per corner.

Pile driving was not possible over a length of 53m of crane track due to the existence of a boulder layer underground. A spread footing having a base width of 2.4m was constructed on this length. The sand fill, however, had insufficient bearing capacity, N-value upto a depth of 1.5m below the foundation level being less than 9. Vibro-compaction of the fill improved the N-value to more than 20, on which the footing was founded.

The two gantry cranes were commissioned on 2nd September 1983. They had a safe working load of 35.5 Tons under the spreader, spreader weight being 8 Tons. The two cranes and the crane track costed Rs.140 million.

The commissioning of this berth in 1980 and subsequent installation of container handling gantry cranes has enabled the Port of Colombo to be a leading container handling port and a transhipment base in South Asia.

Acknowledgements

Finally it must be said that although this paper has been prepared and presented by the writer, the design and the successful construction of the project was unquestionably a team effort and thanks are due to everyone responsible.

The Author also wish to thank the Managing Director of the Sri Lanka Ports Authority, Mr. K.S.C. de Fonseka for the permission given to present this paper.
Fig. 1 LOCATION PLAN

Fig. 2 PROJECT EXPENDITURE
FIG 3 - PLAN OF QUAY

FIG 4 - DETAILS OF CYLINDER QUAY
FIG. 5  SOIL PROFILE.
(From south to north on new quay face.)
FIG. 7 - DETAILS OF CYLINDER.