

DESIGN AND CONSTRUCTION OF HAORA OFFSHORE
COAL UNLOADING TERMINAL

by

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INTRODUCTION

A new coal fired power plant constructed by the Israel Electric Corporation on the Mediterranean coast off Hadera, Israel, requires the import of 3.3 million tons of coal per year.

As there is no port on the Israeli Mediterranean coast capable of handling the 60,000 to 140,000 DWT bulk carriers required for transferring of coal, several studies were conducted in order to decide on the most feasible facility for mooring and unloading these boats.

Rather than expand existing ports or build a new protected port, a decision was finally taken to construct an unprotected offshore terminal at the power plant site.

The terminal was designed to accommodate bulk carriers of up to 140,000 DWT in the first stage, and up to 170,000 DWT with future expansion.

The design of the coal unloading terminal in an unprotected environment created the need to develop design criteria as well as operational and structural systems that will respond to problems arising from unloading bulk in the open sea. As there was no known precedent of an unprotected unloading terminal, the criteria was based on experience in existing offshore loading terminals, laboratory tests and engineering judgement.

The construction of an unprotected offshore terminal, at a cost of \$60 million (excluding mechanical equipment), represents a considerable saving of time and money in comparison to the expansion of existing ports or construction of a new protected facility.

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PRELIMINARY CONSIDERATIONS

Initial studies were conducted for development of the existing Haifa port. This port, situated 50 km north of the Hadera power plant is in the bay of Haifa, and can presently accommodate boats of up to 35,000 DWT. It is not suitable for handling bulk carriers of the designated size without a substantial investment in port expansion and land transportation systems.

This investment was estimated to be twice as high as the cost of building the unprotected facility in Hadera.

Other options for building a new protected port at the power plant site in Hadera were investigated as well. These options included several harbour layouts with breakwater protection. The various layouts and types of breakwaters (Fig. 1) were tested in a marine laboratory in order to find the feasibility and efficiency of the proposed harbours.

Laboratory tests showed that placing a breakwater in the open sea did not provide sufficient protection against heavy storms and did not provide sufficient berth availability for the ships. Capital investments in each of these solutions was also very substantial, as costs and risks of building breakwaters at water depths of 24 to 27 meters are very large.

In addition, soil investigations performed at that time showed that the soil does not provide a good foundation for the various types of breakwaters. The soil found at the site is characterized by a 5 meter top layer of loose sand, overlying a 5 meter layer of soft clay which can develop circular shear failure modes under breakwater loads. The soil in general was more suitable to pile foundations than other methods of load transfer.

These considerations led to the belief that a "finger" type, pile supported pier, connected to the shore by a pile trestle (Fig. 2), will provide the sufficient berth availability needed for unloading the required quantity of coal and at much lower costs.

Operational analyses were conducted in order to estimate the required berth occupancy for importing 3.3 million tons of coal annually. These analyses, which used as parameters various possibilities of unloading equipment and various sizes of bulk carrying boats, showed that a 50% berth occupancy when unloading operation is continuous, or 65% if no unloading is performed Saturdays and holidays, would be sufficient for unloading the necessary amount of coal.

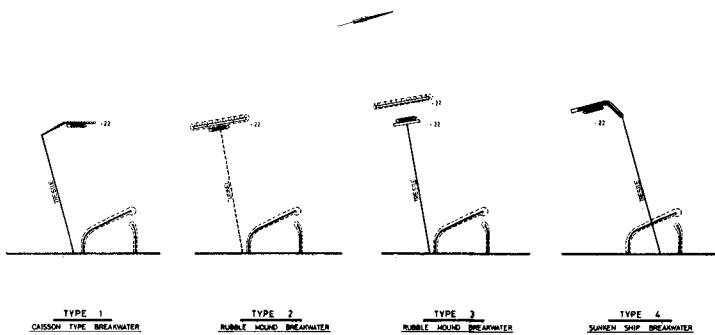


Fig. 1. Layout of Protected Harbours

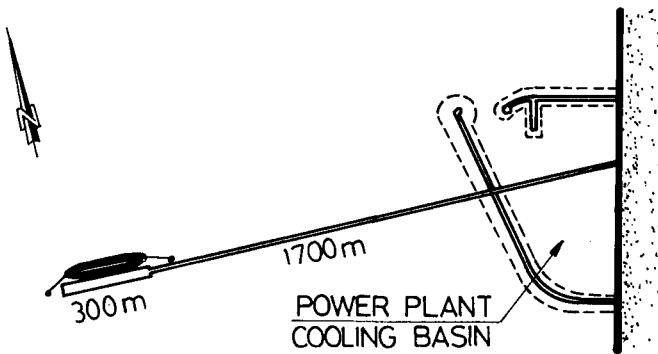


Fig. 2. Unprotected Pier

MODEL TESTS:

In order to test the berth availability of the "finger" pier, operational criteria had to be established. Limiting criteria were set for boat movements at the pier, for safe berthing and mooring and for maneuvering procedures at approach and departure of boats (see Ref. 1).

These criteria were established by consulting with ship captains and unloading equipment operators, as well as by comparing accelerations and velocities of ship movements with those of the unloader bucket movements.

Model tests were conducted on two ship models, a 60,000 DWT and 120,000 OWT. Each boat was tested in full load and in light ballast conditions.

The model tests indicated the optimum mooring fendering system that provides maximum berth availability and berth operability at the existing sea states in the location of the terminal.

These tests showed that the expected yearly unloading operability will be about 80% to 90%, depending on ship size and load. The expected yearly average berth availability will be 80% to 85%.

TERMINAL DESCRIPTION

The pier is a 300x24 meters structure, heading due west into the main direction of the waves. It is a pile supported open structure which absorbs very little impact from the waves and causes little or no reflection of waves between the pier and the boats moored along its side. The boats are moored against dolphins adjacent to the pier, bow heading into the main direction of the waves (Fig. 3). Mooring lines are connected to a quick release hook system placed on the mooring and breasting dolphins. Breastlines can be tied either to near breasting dolphins, or under the pier deck to far breasting dolphins (Figs. 3 & 4).

The pier is located at water depths of 20 to 40 meters and is connected to shore by a 1700 meters long 12 meters wide approach jetty. The approach jetty is built of 200 meters long sections.

The approach jetty deck is a composite construction of pre-fabricated concrete slabs on steel girders, supported on pile bents placed every 40 meters. Typical pile bents have two battered piles that provide the transverse stability. Longitudinal stability is provided by fixed points, with four battered piles, placed at the middle of the 200 meters trestle sections.

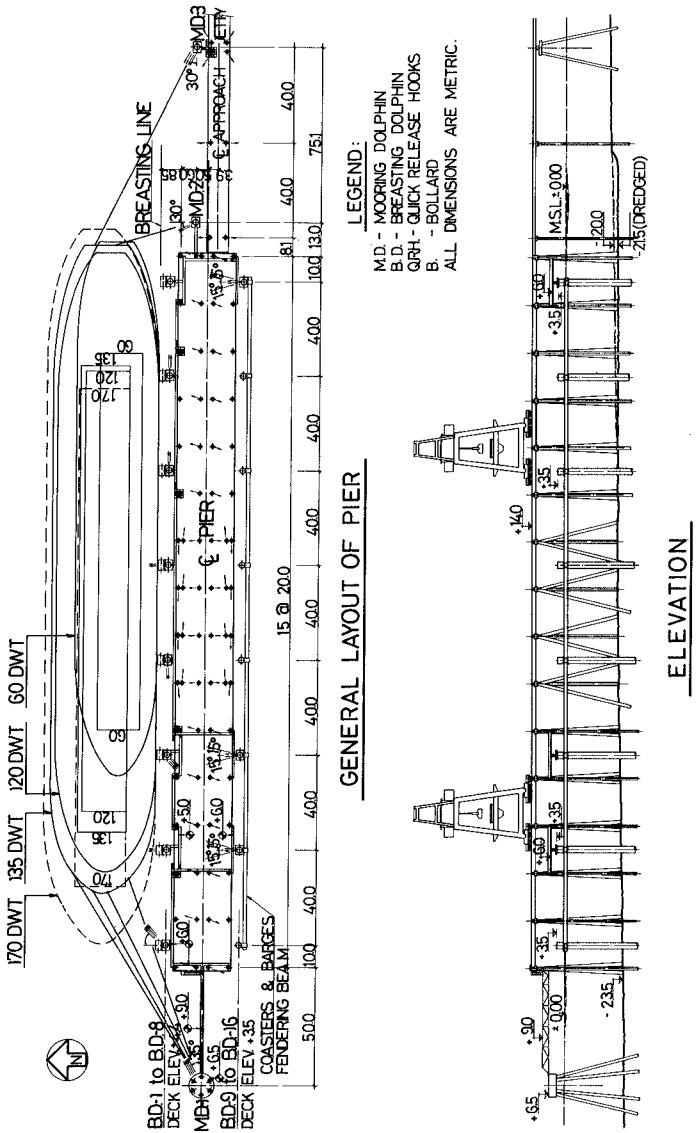


Fig. 3. General Layout of Pier

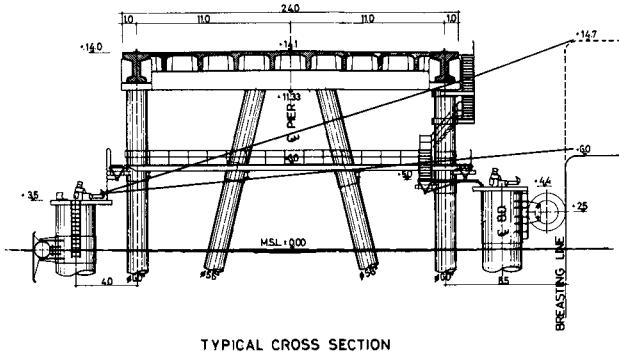


Fig. 4. Typical Cross Section

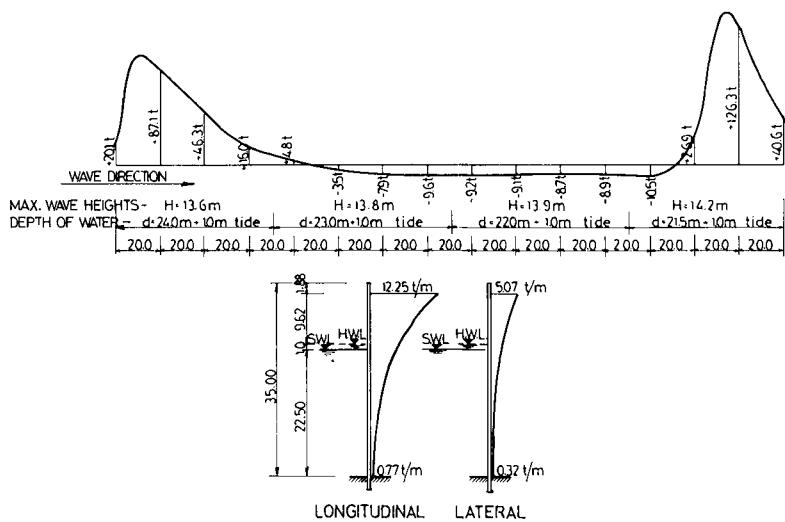


Fig. 5 Wave Shape and Forces on Pier Piles

Pier and approach jetty deck are at +14.0 meters above M.S.L.

SEA STATE AND DESIGN CONSIDERATIONS

Two groups of sea states are essentially considered in the design of the terminal. The lower sea state is the state at which the pier is operable. In this sea state the boats can be moored and unloaded, and the general layout is based on behaviour of the boats at this sea state.

Model tests, as well as the short experience accumulated to date, show that the pier is operable at wave heights of up to 4.0 to 4.5 meters max. (2.5 meters significant waves). These waves are generally 9 to 12 seconds waves, and as such are shorter than the design ship lengths, and cause ship movements that are smaller than those set by the limiting criteria.

This sea state exists over 300 days per year. The other sea state considered is the high, 1:100 year sea state, which governs the structural design and stability of the facility. At this state no boats are moored at the pier and the maximum design waves act on the structure. The 1:100 year deep water design wave at the pier is an 8.7 meters significant wave with a respective maximum wave of 14.5 meters. In general, these waves have return periods of approximately 15 seconds. The maximum wave height at the pier location (water depths of 20 to 24 meters) corresponding to the deep water design wave, is 13.7 meters. The shape of the wave at this location is cnoidal (Fig. 5) with a crest height of approximately 9.5 meters above H.W.L. or 10.5 meters above M.S.L. Pier deck elevation was set at +14.0 meters above M.S.L. so that the underside of the deck will be above the crest line.

The maximum waves breaking zone is located in the approach jetty region approximately 100 to 400 meters east of the pier (1300 m. to 1600 m. from shore) at water depths of approximately 18 meters. The maximum wave at the breaking zone is best represented by a Modified Solitary wave shape with a crest level of approximately 11.4 meters above H.W.L. This crest level is app. 1.0 meter higher than the bottom of the pile cap beams and acts with a slamming force on the structure (Fig. 6). Lengths of approach jetty sections were set so that each section will absorb the impact of no more than one crest of the higher waves. Accordingly the sections of the approach jetty are 200 meters long with one or two fixed points for longitudinal stability. The fixed points at maximum waves breaking zone are also designed to absorb the slamming forces on the pile cap beams.

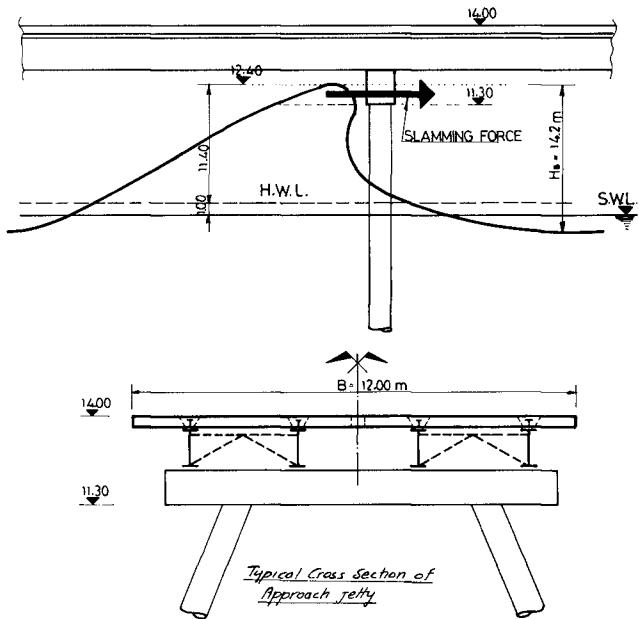


Fig. 6. Wave Forces on Approach Jetty Piles

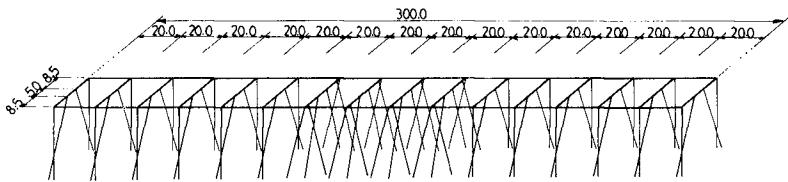


Fig. 7. Structural System of Pier

The design of the structural systems of the pier and approach jetty is based on a space frame analysis fully continuous in all directions with nonlinear soil-pile interaction (Fig. 7).

The structural design was based on a combination of the following codes - DNV (Det Norske Veritas), "Rules for Design Construction and Inspection of Offshore Structures", API-RP2A, "Recommended Practice for Design Construction and Inspection of Fixed Offshore Structures", Israeli Codes for design of concrete and prestressed concrete structures and AISC specifications for steel design. Some of those codes are based on Ultimate Limit State (ULS) and some on serviceability Limit State (SLS). To enable the combined use of these codes, modifications had to be introduced.

All parts of the structure were designed for the 1:100 year wave loads with the exception of the walkway system under the pier deck. These walkways, at elevation +6.0, were designed for 25 year return period waves and are expected to be repaired periodically.

The supporting piles were designed for the following load combinations:

$$\begin{array}{ll} 1.3P + 1.3L + 1.0D + 0.7E & \text{(ordinary)} \\ 1.0P + 1.0L + 1.0D + 1.3E & \text{(extreme)} \end{array}$$

where P - Permanent loads
L - Live loads
D - Deformation loads
E - Environmental loads

The piles were designed with a factor of safety of 1.5 for both the ordinary and extreme load combinations, which allowed for a total factor of safety of 2.0 for the "theoretical working" loads. A reduction of 20% of the factor of safety was permitted in a few piles at the approach jetty fixed points when loaded by the extreme slamming forces caused by the maximum breaking waves.

SOIL CONDITIONS AND FOUNDATIONS

Extensive soil investigations were performed at the site. Over 30 borings were performed in order to enable the preliminary studies of the various alternative layouts. Of these more than 20 were directly on the pier and trestle alignment. The borings were performed in water depths of up to 26 meters, and generally to 40 meters penetration in the soil. Several additional borings were performed during construction to penetration of up to 100 meters in the sea bed.

The soil formation at the site is characterized by three different layers, a top layer of fine sand, approximately 5.0 meters thick, overlying a second layer of very soft clay, app. 4.0 to 6.0 meters thick, overlying medium to dense sand alternating with calcareous sandstone layers. The bottom layer showed high S.P.T. values, ranging from 40 to 100. Based on these soil investigations, the piles selected for the pier were 56" diameter, 7/8" thick, steel pipe piles and the piles selected for the approach jetty were 48" diameter, 3/4" thick steel pipe piles. The required ultimate capacity of the 56" pier piles was 1000 tons, and for the 48" diameter approach jetty piles - 600 tons. The contractor proposed a change in the vertical pier piles, using a single, 60" diameter, 1 1/8" thick steel pipe pile, with ultimate capacity of 1800 tons, instead of two 56" diameter piles used in the basic design put out for tender.

A load test was performed on the 60" pile with 31 meters penetration. The test pile failed at approximately 1100 tons instead of the required 1800 tons.

As changes in the design were impractical at this stage of construction, the contractor proposed to drive the piles until the required resistance was met. This was achieved at a penetration of approximately 70 meters and at very great costs. Since the construction was delayed at that time due to heavy damages to the contractor's equipment caused by a storm, time was available to find alternative solutions for increasing the pile capacities.

Analysis of the 60" test pile failure has shown the pile has not formed a sufficient soil plug, and has cut through the sand and calcareous layers like a "cooky cutter" through batter. In order to avoid this the piles were driven to approximately 35 meters penetration, the soil inside the pile was removed by a rotary drill, and a concrete plug was cast inside the pile (Fig. 8). When concrete has reached sufficient strength, the pile was redriven to the required resistance. Redriving the piles has increased the resistance from 8 to 10 blows/10 cm to 50 to 90 blows/10 cm over an additional penetration length of 50 to 70 cms, much more than the required resistance, which was calculated to be 35 blows/10 cm when using a menck 2500 pile driving hammer (delivering 31 ton meters energy) (see Fig. 9).

The concrete plug and redrive method could not be adopted easily to the 56" diameter battered piles used in the pier. These piles with ultimate capacities of up to 1350 tons, had also to be driven to 70 meters penetration in order to develop the required resistance. In order to reduce the penetration to approximately 35 meters, a steel annulus ring was welded into the pipe approximately 15 meters from the bottom tip (see Fig. 8). The introduction of this annulus ring assisted in forming a better soil plug and develop additional bearing

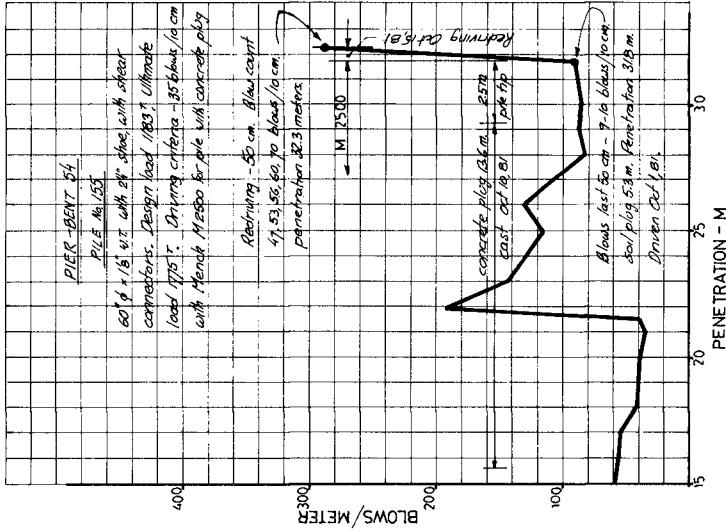


Fig. 9. Driving Record of a 60" Diameter Vertical Pile Before and After Concrete Plug Installation

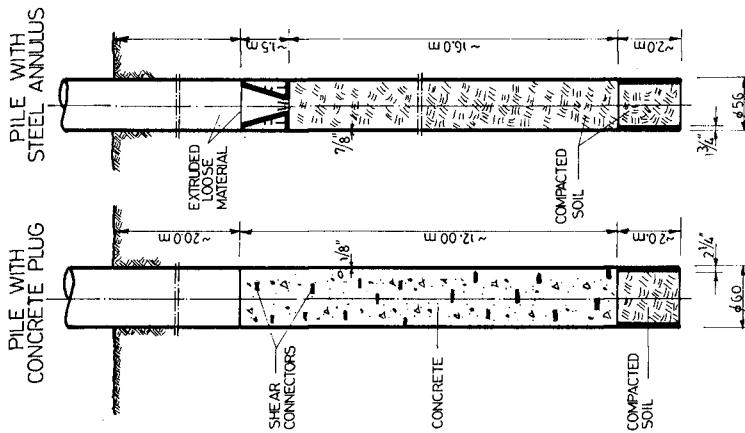


Fig. 8. Piles with Concrete and Steel Plugs

surface. The piles driven in that manner reached the required resistance at the expected penetration (Fig. 10).

These alternative solutions proved to be far less expensive than driving the piles to 70 meters penetration.

DOLPHINS

An important feature of the design is that the bulk carrying boats be berthed and moored to dolphins which are separated from the pier structure. These dolphins are designed to absorb the energy of the boats at approach and departure conditions, and take the forces of the mooring lines when the boats are moored.

For this purpose, the dolphins are designed as flexible cantilevered piles with large rubber fenders which help absorb the energy without developing large forces.

The tender documents called for a system of dolphin piles interconnected by hinged struts. The contractor has chosen to use single pile dolphins of 2600 mm. and 2800 mm. diameters with wall thickness ranging from 34 to 70 mm. The fenders used are "Vredenstein" jumbo type fenders, 2700 mm outside dia., 1350 inside dia. and 4000 mm long.

The dolphins are designed to absorb the impact of 170,000 DWT boats approaching at a maximum docking speed of 20 cm/sec.

CONSTRUCTION

Construction of the terminal began in March 1980 and was scheduled for completion January 1982. The contractor was permitted to make certain changes in the design that were more adaptable to his equipment and experience, provided that they do not influence the basic concept and layout of the terminal. The contractor was also required to perform the detailed design of these changes according to the design criteria that was specified in the contract documents.

Damages that were caused to the contractor's equipment by the severe storm mentioned above as well as the problems encountered with the piles that were proposed by the contractor, delayed the final completion of the terminal. Construction of the pier and dolphins was completed in January 1982 and construction of the approach jetty was completed in August 1982.

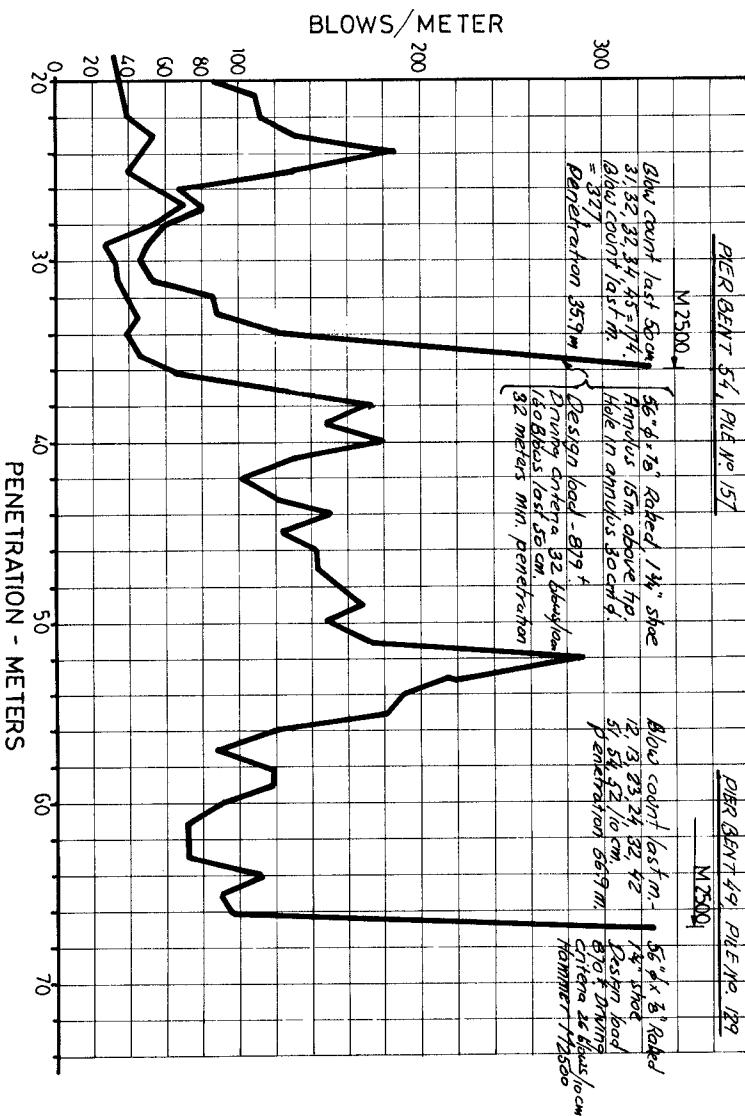


Fig. 10. Driving Records of Similarly Loaded 56" Diameter Piles With, and Without, Annulus

The first boat was unloaded at the pier in August 1982 into 500 DWT coasters that were moored at the opposite side of the pier and which delivered the coal to shore. With the completion of the approach jetty, the coal was temporarily unloaded to trucks running from the pier to shore. This will continue until the conveyor belt system is complete. To date, the behaviour of the boats at the pier was very much as expected from the model tests, with little interference from winter waves.

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