Paper No. 6456

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Proc. Instn civ. Engrs, vol. 18, pp. 121–148
February 1961

PUBLISHED BY

THE INSTITUTION OF CIVIL ENGINEERS

Great George Street · Westminster · London, S.W.1

1967

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For discussion at an Ordinary Meeting on Tuesday, 14 March, 1961, at 5.30 p.m., and for subsequent written discussion

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SYNOPSIS

The construction of refineries at Bombay necessitated rapid improvements to the Port's oil-handling facilities. After extensive site investigation it was decided to build an entirely new Marine Oil Terminal at Butcher Island, connected to the mainland by 2¼ miles of submarine pipeline.

A tidal model was used to study the best alignment for the berths and breakwater. Reinforced concrete was used in the construction of the pier-heads, berthing dolphins, and pipe gantries; rock rubble was used for the breakwater and pipeband causeways. Reasons for the choice of materials are given.

Pier-heads and pipe gantries were supported on precast columns stepped and grouted into holes cut in the rock floor of the harbour by the "Benoto" process. This was the first use of the "Benoto" equipment from floating support; the system is fully described, and its effectiveness discussed.

The site chosen is exposed to monsoon swells, and a novel type of berthing dolphin, carrying a 650-ton concrete gravity fender, was developed to enable tankers to use the berths in any weather without damage. The dolphins were constructed in dry dock and sunk in position on prepared rubble beds.

The design and installation of the pipeline system, including the launching and sinking of the submarine section, is described. Ancillary works at Butcher Island, fire-fighting arrangements, and electrical and mechanical contracts are also mentioned.

Work started in October 1953 and the first tanker was berthed in February 1955. The total cost of the project was £6,460,000.

INTRODUCTION

SITES at Trombay, on the north side of Bombay Harbour (Fig. 1), were selected in 1950 for the construction of refineries by the Standard Vacuum Oil Co. and the Burmah Shell Oil Co. As a result, the Government of India requested the Bombay Port Trust to improve the existing facilities for the import of crude oil and export of refined products. The Bombay Port Trust asked their Consulting Engineers, Sir Bruce White, Wolfe Barry & Partners, to examine and report on the problem.

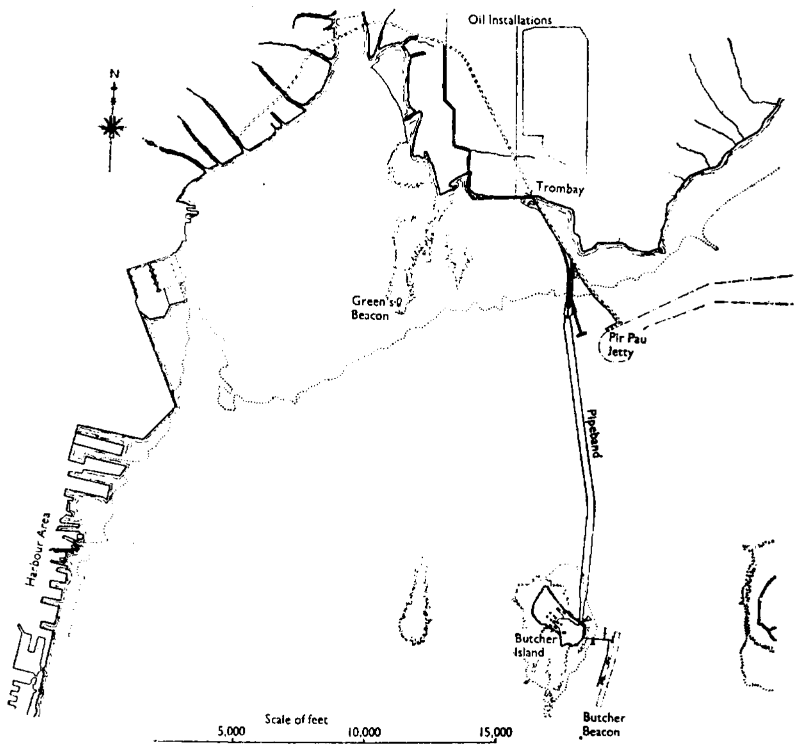

FIG. 1.—SITE PLAN

2. At that time, oil products for Bombay were imported over the Port Trust jetty situated off Trombay Island in the Pir Pau Deep, which tankers approached through a channel dredged to a depth of 20 ft. The Consultants, in their report of 1951 concerning the dredging policy of the port, had already considered the advisability of deepening the approach channel to Pir Pau for the larger tankers known to be under construction. This channel was attracting a considerable charge for maintenance dredging, and the Consultants had recommended that a suitable site for an entirely new oil port existed in the deep water between Butcher Island and Elephanta Island, and that this could be connected to the mainland by a submarine pipeline. They had suggested that future expansion

of the oil industry in India might justify the development of this site, which it was thought would be free of maintenance dredging.

3. Accordingly, a survey party was sent to examine the site in detail and an extensive programme of trial borings was instituted. As a result of the information obtained and of discussions with the oil companies concerned, preliminary designs and estimates were prepared. The scheme was approved by the Port Trust and sanctioned by the Government of India; the Consultants were entrusted with the design and supervision of the work.

SITE INVESTIGATION

4. A detailed hydrographic survey, carried out between November 1952 and April 1953, involved a basic survey to control the trial boring, echo-sounding, the plotting of float tracks, current-meter readings, and the examination of samples of the sea-bed and observations of waves and winds. About 700 borings and deep soundings were made in the area of the proposed oil berths and on several alternative routes for the submarine pipeline. A topographical survey was made of Butcher Island, where it was proposed to establish a tank farm and pumping station to serve the berths.

5. Information was obtained in sufficient detail to enable the Consultants to construct in London a mobile bed hydraulic model of the harbour, and this proved of great value in siting the new works.

6. Geologically the sea-bed was found to be an extension of the Deccan Trap with an overburden of viscous mud of a vaseline consistency varying in depth to about 12 ft. The rock floor has the characteristic stepped formation due to the eroded laminations of successive lava flows, and has a westerly dip of the order of 5°. At the surface the rock varies considerably in hardness; also, the surface has, at some time, been incised with a complex system of stream channels, later filled in with conglomerates or disintegrated basalt. Thus, there are appreciable changes in depth to sound rock within short distances; when structural foundations are being considered in such formations the value of close borings and probings cannot be too strongly emphasized.

SITING THE BERTHS

7. It is hardly necessary to describe the magnificent natural deep-water harbour of Bombay, which provides an anchorage of about 70 square miles. The main climatic influence is the south-west monsoon which breaks in early June, and blows, with short intermissions, until mid-September. Colaba peninsula provides a natural breakwater against the seas associated with the south-west monsoon winds, and development of the Port has taken place in the past along the western shore of the harbour where protection from the south-west is almost complete.

8. The choice of Butcher Island as a site for the new oil terminal was dictated primarily by the fact that it provides the nearest natural deep water to the refineries at Pir Pau, although it is to some extent open to swells entering the harbour when the south-west monsoon is blowing. Experience and observations of the site selected indicated that a measure of protection would be provided by the reef running in a southerly direction from Butcher Island to Butcher Beacon, and it was considered that conditions would never be so severe that tankers

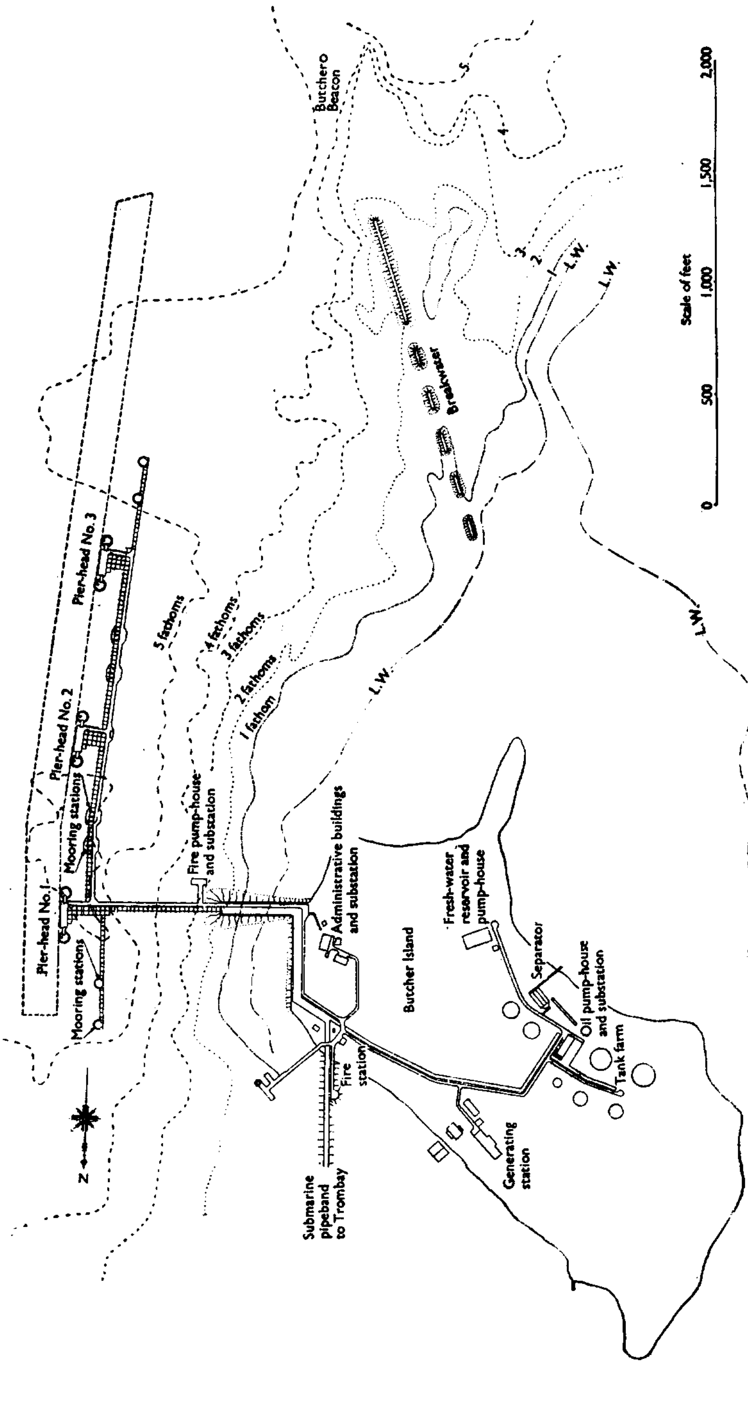

FIG. 2.—GENERAL ARRANGEMENT OF BERTHS AT BUTCHER ISLAND

could not lie at suitably designed dolphins. This opinion has been amply borne out in practice; the Butcher Island berths are in fact more tenable in monsoon swells than is the old berth at Pir Pau.

9. The oil companies were asked to state their requirements and, following discussions with the individual companies and finally at joint meetings, it was decided to provide three berths, each capable of accommodating tankers up to 32,000 tons in capacity and drawing 34 ft of water, which at that time were the largest contemplated. Since there was insufficient water in the outer reaches of the harbour to allow vessels of this draught to approach the berths at all states of the tide, it was agreed that tidal approach to the berths would be acceptable.

10. These decisions having been reached, the remaining factors influencing the exact site of the berths were the tidal currents and the avoidance of siltation.

11. The flood tidal stream sets in a north-easterly direction, separating about 2 miles to the south-west of Butcher Island to provide two well-defined currents; one swings east towards Butcher Island, and the other north along the western shore of the bay, to reunite midway between Butcher Island and Pir Pau and continue in a north-easterly direction along the shore of Trombay Island. Between Butcher Island and Elephanta Island the flood sets east by north, reaching an average speed of 1½ knot at springs. The ebb tidal stream, setting in a south-westerly direction, follows much the same course in reverse but predominates in strength. Between Butcher and Elephanta Islands the ebb sets in a south-westerly direction at an average speed at springs of 2½ knots. However, the tidal streams are complex and are much affected by winds and heavy rains. In the area of the new works the ebb current can reach 3½ knots, and in the rainy season very little effect is felt from the flood current.

12. The site finally chosen for the three new oil berths is on the south-east side of Butcher Island (Fig. 2). The berths have been positioned to suit the dominant ebb current which, as the model experiment showed and experience suggested, would keep them free of siltation, while allowing tankers to approach and ride easily at the dolphins. The model experiments also showed that at certain stages of the flood eddy currents were produced at right angles to the berth alignment. Various training works to improve conditions at the berths during the flood tide were tried out in the model. An intermittent half-tide rubble breakwater, running from the southernmost point of Butcher Island out towards Butcher Beacon, was found to be the most successful in preventing the worst effects of flood eddies without encouraging siltation. This was incorporated in the works.

Layout of the oil terminal

13. The general arrangement of the new works is shown in Fig. 2.

14. Each of the three oil berths consists of two berthing dolphins 200 ft apart, at which the tankers lie while loading or unloading their cargoes at the pier-head in between. The pier-head is of reinforced concrete construction and carries the roadway, pipeband terminal, and hose-handling gear. Fire-fighting towers are provided on the dolphins, which are connected to the pier-heads by bridges. Timber fendering protects the pier-heads from accidental damage and use by small craft.

15. The pier-heads are connected to one another and to the shore by means

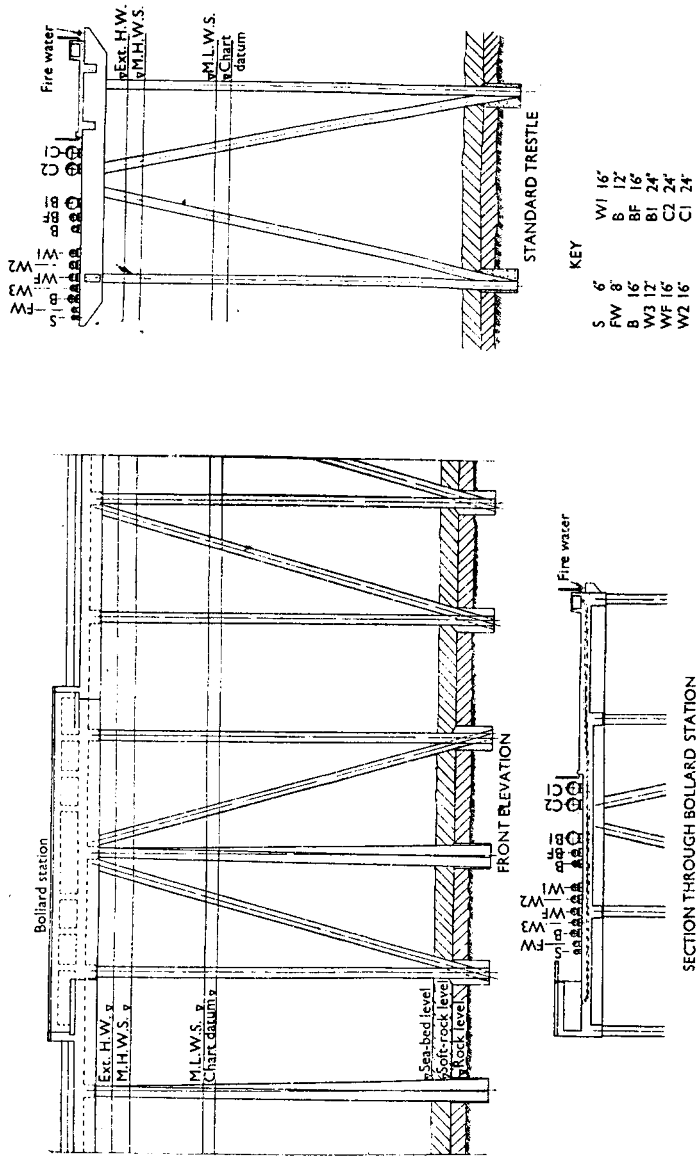

FIG. 5.—STANDARD TRESTLE AND BOLLARD STATION

of a reinforced concrete gantry which carries the pipelines and the roadway. The gantry, as it approaches shallow water off Butcher Island, gives way to a rock bund construction, the extent of which was determined by equating bund cost per unit length with that of the reinforced concrete trestle structure.

16. Originally it was intended as a measure of economy that tankers lying at the northern and southern berths should have their outer lines made fast to buoyed moorings, while bollards mounted on the gantry at intermediate positions were provided for their inner lines and for lines from tankers at the central berth.

17. To obviate boat work special mooring caissons were subsequently provided instead of the buoys, and 10-ton capstans were requested at each of the mooring points so that a damaged ship, which could not use its own winches, could be berthed safely. To accommodate the capstans at the bollard stations on the gantry the design was modified to increase the size and strength of the stations.

18. The submarine pipeline from Trombay is brought ashore on the north-east side of the island over a rock bund 600 ft long, from where it is carried along the eastern shore of the island to the approach gantry and out to the berths. Connexions are made to a tank farm which has been built on the west side of the island. Other ancillary works established on Butcher Island include a Diesel power station serving all installations on the island, an oil pump-house for bunkering and pipeline flushing duties, ballast-disposal facilities, and a fresh-water reservoir and associated pumping station. Administration buildings and accommodation on the island for personnel operating the terminal were designed and built departmentally by the Port Authority.

Design of the berths

19. Three principal factors influenced the design of the berths. First, the necessity for speed of construction so that crude-oil tankers could be brought in and discharged at dates to suit the progressive starting up of the refineries. Secondly, structural steelwork, which has been proved to corrode rapidly in the Bombay atmosphere when in contact with salt water or spray, was to be used as little as possible. Thirdly, it was required that tankers should be able to use the berths in any weather.

20. The first factor, speed of construction, made it necessary to minimize work between tides, which in Bombay have a range of 17 ft. In the event the only tidal work in the whole design is the half-tide beam bracing at the front of the pier-heads, which can be seen in Fig. 3, Plate 1. The rakers transmitting the thrust from this beam were precast, but the beam was cast in situ. The dolphins, which were designed as reinforced concrete caissons to be built on a slipway or in dry dock, were floated to the site and sunk in position. The rubble bunds carrying the pipeband at Butcher Island and the breakwater were placed from barges by floating or land-based cranes. The bund at the Pir Pau end of the submarine pipeline (Fig. 4, Plate 1) was placed from the land by Euclids tipping rubble in advance of themselves to a height above M.H.W.S.

21. The second decision, to use reinforced concrete generally throughout the marine construction, led to the standard trestle design shown in Fig. 5. These trestles, 49 ft wide and pitched at 20-ft centres, carry the pipeband, a 12-ft roadway, and cable duct. It was not considered possible to drive piles into the rock

floor of the harbour, and the problem of providing a satisfactory foundation for the trestles was solved by boring 49-in.-dia. holes into the solid rock into which precast columns were stepped and grouted. The holes were cut by the "Benoto" process from floating craft. So far as is known, the first use of this equipment from floating support was in the construction of the Bombay Marine Oil Terminal and in similar work being done simultaneously for the Burmah Shell Oil Company and the Tata Power Company at Trombay, for which the Consultants were also responsible. The system proved entirely satisfactory and is described in detail in § 33. Pier-heads and bollard stations are variations of the basic trestle design.

22. It has already been stated that the Butcher Island site is sometimes open to a heavy swell during the south-west monsoon. In view of the requirement that tankers should be able to use the berths in any weather it was decided that each berth should consist of two berthing dolphins at which the tanker could lie clear of the pier-head in between, and which would be capable of absorbing berthing impacts from vessels having displacements of up to 40,000 tons and approaching at a velocity of 1 ft/sec. The construction of the dolphins was to be such that vessels would not suffer when lying alongside under conditions of swell. The design finally adopted consisted essentially of a heavy reinforced concrete ring suspended by a linkage system from a circular concrete caisson and is described in detail below. Its development was materially assisted by the study of scale models.

MATERIALS

23. To ensure that the very dense high-quality concrete necessary for satisfactory marine works would be obtained, all available aggregates were sent to London by the survey party for analysis.

24. After considerable research river sand from Karsalia, which is about 200 miles from Bombay, and a crushed microgranite, of which there is an intrusion of limited extent at Chandivali, were specified for all concrete in the marine work. This microgranite was chosen in preference to the regional basalts because of the better shape produced in crushing and because of its freedom from chlorophaeite and allied unstable constituents. The Karsalia sand was somewhat deficient in fines but this was offset by an excess of fine particles in the coarse aggregate which was obtained by jaw-crushing. A black sand from Mumbra and basalt aggregates were used for low-grade concretes in work on dry land.

25. The specified strengths of the two high-quality concrete mixes used were: Grade A, 4,500 lb/sq. in. and Grade B, 3,750 lb/sq. in., both at 28 days. The Grade A quality was used in the columns and the Grade B quality in the deck construction and caissons. All site concrete was consolidated by internal vibration. The average cube strength of Grade B concrete at 28 days was 6,500 lb/sq. in. Ordinary Portland cement manufactured in India to British Standard specifications was used throughout.

26. For the construction of the rock bunds and breakwater four grades of rubble were specified:—

Grade A: blocks from 0·5 ton to 3 tons.
,, B: ,, ,, 0·5 cwt ,, 1 ton.
,, C: ,, ,, 0·1 cwt ,, 3 cwt.
,, D: quarry run from 0·1 cwt to 1 cwt.

The percentage of the various sizes within each grade was also laid down to ensure a sufficiency of large boulders with reasonable compaction. For instance, in the Grade A rubble which was used for armouring the bunds 50% of the stones were in the 2–3-ton range. Rubble for the construction at Butcher Island was quarried from trap rock at Elephanta Island, and rubble for the submarine pipeline take-off bund at Pir Pau was brought from similar quarries at Trombay.

27. The Port Authority were anxious that Indian materials and products should be used in the works wherever possible, and many small supply and fabrication contracts were advertised and awarded in India. However, the timber fendering for the pier-heads was greenheart imported from British Guiana; this proved to be cheaper than teak grown in India.

28. Steel pipes were purchased principally from British suppliers. Pumping plant, tankage, valves, and pipe fittings were procured under separate contracts from specialist suppliers in Britain, India, the United States, and Western Germany.

Trestle and pier-heads

29. Reference has already been made to the development of the standard trestles (Fig. 5) which, spaced at 20-ft centres, form the approach to the oil berths and the connexion between the pier-heads. Each bent consists of four precast columns, two of which are raked to brace the frame laterally in the shape of a "W", connected at deck level by a cast-in-situ transom beam. The columns are hollow and two sizes were used, depending on the length required; 16 in. square with a 4-in.-dia. grout-hole running the whole length of the column, for lengths up to 60 ft; and 19 in. square with a 6-in.-dia. grout-hole for lengths between 60 and 80 ft. The trestle is designed to carry the operating pipe loads and a 12-ft roadway with a loading equivalent to a 10-ton truck in each bay. The pipes are supported at the transoms only. The trestle is designed to be stable against 10-ft waves exerting a force of $\frac{1}{2}$ ton/sq. ft against the projected area of the columns in the zone of orbital motion. The level of the roadway and of the pier-head deck is 7 ft above the maximum recorded high water. Expansion bays are provided in the trestle structure on each side of the pier-heads, and the central bays of the resulting trestle sections are braced longitudinally by means of additional raking columns localized at one position only in each bay.

30. The pier-heads are 112 ft long and formed of similar bents, with the addition of the half-tide beam bracing and raking struts already mentioned (Fig. 3). The pier-head area is decked with an in-situ slab 8 in. thick, and is provided with drip trays under hose connexions. Hose-handling operations are carried out from a platform 12 ft 6 in. above the pier-head deck, equipped with a 2-ton crane and hose racks.

31. The trestle is widened by the addition of two extra vertical columns (Fig. 5) at the bollard stations, and a heavy deck slab, 1 ft 6 in. thick, provided to increase stability and avoid tension under bollard pull. The mooring stations are connected to the main trestle by a 10-ft roadway carried on two-column bents again at 20-ft centres. These columns are raked inwards to form a series of A frames (Fig. 6).

32. All the columns were cast at Carnac Basin, which was hired by the Contractor from the Port Authority and converted into a very effective casting yard.

An overhead gantry crane was installed to serve the yard and barge berth, and was equipped with a traversing skip which enabled columns to be cast rapidly and continuously. When the columns had been stripped and inspected they were numbered and marked for various parts of the work before being stacked for maturing. When ready for use the columns were loaded on to barges by the

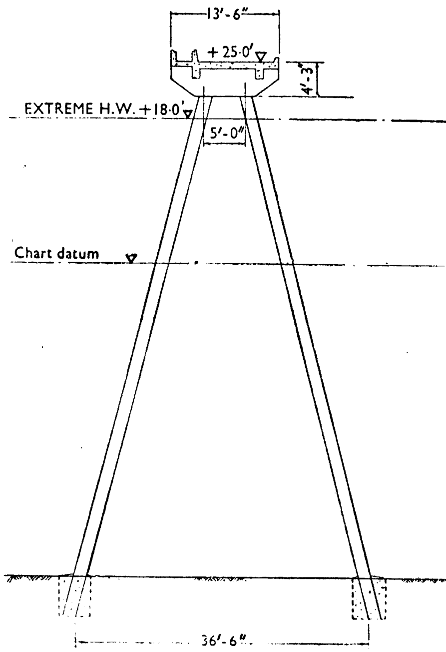

FIG. 6.

travelling crane and towed out to the site. At the site they were handled by a floating crane or by sheer-legs, all possible precautions being taken to avoid hair cracks.

33. The "Benoto" system has been developed since 1932 for the construction of large-diameter in-situ piles, and for sinking deep shafts in the search for water and mineral deposits. The process consists of dropping a special type of heavy grab which, working inside a steel guide tube, first breaks up the bed-rock and then removes the spoil. This "hammer-grab" is essentially a heavy hammer with a head in the form of a strong "orange-peel" type of digging bucket; it has two or three jaws which can be locked open to form a chopping bit, then unlocked to permit the jaws to be operated for removal of the broken material. Various sizes are made, ranging in weight from 216 to 1,250 lb. and in diameter from 14 to 55 in. The cutting heads are made of very tough nickel-chrome steel, and different types of jaws are available to suit different materials

encountered in excavation. When the excavation has been completed, piles can be cast in the usual way inside the boring tube which is withdrawn by a combination of jacking and rotation.

34. In the Marine Oil Terminal the "Benoto" plant was required only to excavate holes in the rock floor of the harbour, in which precast columns were to be founded. The machine was mounted on a specially designed pontoon having two projecting arms, which embraced the boring tube over which the hammer-grab was centered. The pontoon measured 46 × 26 ft and was 4 ft 3 in. deep, with a working draught of 1 ft 7 in.; mounted on the pontoon were six hand winches for handling the anchor cables. The pontoon was moored on four or six concrete clump anchors to ensure that it could be accurately held in position against the fast currents while boring proceeded. The heaviest type of hammer-grab was employed. This is normally fitted with a 47-in.-dia. cutting ring for operation inside a 49-in.-dia. boring tube. However, it was found that the loss of momentum, caused by the cushioning effect of the water in the tube, was reduced when the smaller 37-in.-dia. cutting head was used. With this grab the water could pass freely between the grab and the walls of the tube during the fall of the hammer, and so a heavier blow was struck. In addition, time was saved because the operator did not have to position the smaller grab so accurately over the guide tube before letting it fall.

35. At the site the typical column-setting operation required the seating of one vertical column and one raking column in the same borehole in the rock. The following construction procedure was therefore adopted.

36. A 49-in.-dia. open-ended tubular steel casing was sunk through the silt to the rock floor at the site of the proposed borehole. The casing was held in position by a light lattice-work box girder supported on, and run out from, the columns already placed. Operating within the casing and through the water, the hammer-grab was used to excavate the silt and then to break and excavate the rock to the required depth. Two precast concrete columns were then lowered through the tube into the excavation. The tube was then removed, the columns being supported temporarily by the box-girder guide. The raking column was then pulled over into its correct position and both columns were braced in place with a system of R.S.Js clamped to, and run out from, the columns already placed. Finally, the hole in the rock was filled with a colloidal grout, which was forced down the hollow columns until the rock excavation was filled. This method of construction is illustrated in Fig. 7.

37. Grout was produced by the "Colgrout" process, the machine being mounted on a separate pontoon complete with its own supply of sand, cement, and fresh water. A standard double-drum mixer, with a grout-capacity of 150–160 cu. ft/hour was used. The grout mix was 1 cwt of cement to 1½ cu. ft of specially screened sand and 6½ gal of water. Delivery was effected at a head of 25 ft of grout (equivalent to 50 ft of water) through a rubber hose of 2¼-in. internal diameter. Before the columns were placed, the holes were cleaned by air-lift and careful records were made of the depth and of the materials excavated; samples of broken rock taken out of each hole were stored in airtight tins for reference. In every case the grouting was inspected by diver and, where necessary, the diver was required to grout up the excavation through a pipe introduced beside the columns. As a precaution against vibration transmitted through the guide frame to the newly grouted columns during the subsequent boring process,

the grout was allowed a period of 12 hours to set before excavation of the next set of holes was permitted.

38. Occasionally, groundrock irregularities encountered during excavation caused the "Benoto" tube to shift off the correct position or to go down on a slight rake. Once the hole had been cut it was found that, with the size of column in use, very little adjustment of the position of the columns could be made. In future operations of this type it would be an advantage to allow more clearance for the columns by using a casing of larger diameter.

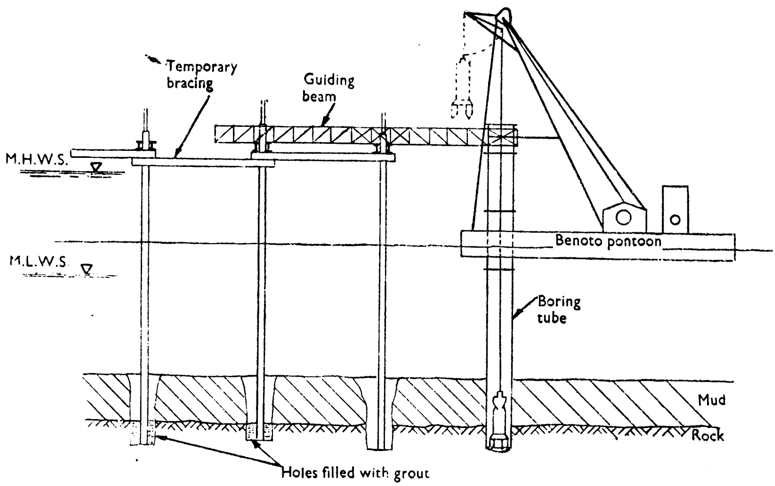

FIG. 7.—METHOD OF BORING HOLES IN HARBOUR FLOOR

39. The depth specified for the penetration of the columns was 3 ft into hard rock. The rock surface, however, in some places is decomposed or of soft structure. At such locations the boreholes were carried to greater depth and, so that the raking column could be pulled into position, a plug of concrete was placed in the bottom of the hole, where necessary, to bring it up to the desired level for stepping the raker. This was done by inserting the vertical column, lowering a cage of reinforcement over it into the bottom of the hole, and filling the annular space around the column with suitably graded aggregate to the level required. The aggregate was then grouted through the hole in the column and the raker stepped at the higher level. Since the columns were precast in a limited number of lengths the tops were trimmed to the proper elevation after setting. This was a matter of routine.

40. The use of the "Benoto" hammer-grab proved very satisfactory. The only breakdowns experienced were occasional fractures of the cutting blades in the hardest rock, and failures of the pulley cable. By using the grab, the broken blade could usually be recovered from the bottom of the hole and then welded up; the pulley cable had to be replaced. It took some time to familiarize the

operators with the special equipment and the marine conditions, but once this had been achieved progress in sound basalt averaged about 1 ft/hour, i.e. twelve holes per week. Because of special measures occasioned by soft rock, and for other reasons, this average was not always realized. In all, about 450 holes 3–10 ft deep were excavated in the rock floor of the harbour in tidal waters down to 50 ft deep under all but the worst weather conditions without any major difficulties.

41. Timber shuttering for the beams and deck slabs was supported by strutting from the R.S.Js which were employed to brace the columns in position before grouting. Concreting ships, equipped with steam cranes or fixed gantries carrying overhead conveyors, were used for placing concrete, and were kept supplied by a fleet of barges. A general view of the work, showing concreting in progress at Pier-head No. 2, is given in Fig. 8.*

BERTHING DOLPHINS

42. Fig. 9, Plate 2 shows the general arrangement of one of the berthing dolphins. The gravity fender consists of a reinforced concrete ring. Since Bombay Harbour experiences a tidal range up to 17 ft the effective weight of the fender at high tide would be substantially less than at low tide. This was compensated by making the fender ring hollow and of triangular section with small openings at the bottom, so that a berthing shock raising the fender would also raise the contained water which would increase in quantity with tide level. The structure supporting the fender is a circular reinforced concrete caisson with a conical upper section. A heavily reinforced capping slab to the conical section carries eighteen projecting suspension arms. These suspension arms carry housings from which the gravity fender is hung by means of the multiple linkage system shown in Fig. 10, Plate 2. The linkage system, which is entirely above water, allows the fender to move inwards and upwards, and also to rotate. This offers progressively increasing resistance and thereby absorbs the impact of vessels berthing against it. The travel of the fender is 3 ft horizontally and 1 ft vertically in which the full kinetic energy of a 40,000-ton vessel approaching at 1 ft/sec can be absorbed. The linkage system, which is specially designed to avoid sudden changes in link load due to combined lateral and rotational movement of the fender, is connected to the suspension arms and the fender ring through housings provided with heavy rubber bushes which effectively damp small irregularities of loading and prevent oscillatory movement due to wave action or tidal pressure on the fender. Shortly after installation the rubber bushes showed signs of cracking; this was attributed to ozone attack and has fortunately proved to be only superficial. All metal parts were zinc coated and any one link can be removed for inspection or maintenance without putting a berth out of service. The berthing face of the concrete fender ring is protected by heavy rubber tubing hung on chains; this also ensures that ships' plating is not subject to damage while moored at the dolphins.

43. The caisson was designed to avoid tidal work at the site, and to provide the mass required to ensure stability both during the various stages of construction and under operating conditions. It was originally intended to construct the caissons to a height of 38 ft on a slipway to be built at Butcher Island for the

* Figs 8, 11a and b, 15, 16, and 17 are photographs and are printed between pp. 128 and 129.

purpose. In the event the contractors were able to hire Hughes Dry Dock from the Port Authority, and all the ten caissons used in the work were constructed there.

44. A light steel sectional cofferdam, 21 ft high, was specially designed to be fitted to the top of the caisson before launching. The conical top section and the gravity fender were to be constructed inside after the caisson had been sunk in its correct position.

45. While the caissons were being built in the dry dock, the caisson beds were prepared at the site. The area was first dredged to remove most of the overlying silt and mud, and the rock surface was then cleaned by air-lift. After a careful survey of the rock levels rubble was dumped and levelled to form the caisson foundation. When the rubble was within 6 in. of its full height a grid of rails was lowered on to the bed and carefully set to the final levels, which were calculated from the levels of the underlying rock to allow for settlement on an empirical basis of 1 in. per 15 in. depth of rubble. The foundation was then completed by carefully screeding rubble to the level of the rails. The whole operation was controlled by divers. The rubble beds were 68 ft in dia. and varied in depth from 4 to 8 ft. The allowance for settlement worked very well in practice.

46. When the first stage of the caisson construction had been completed and the cofferdam fitted, the caisson was floated out of the dry dock and towed to the site on the next neap tides. When moored in its final position, a further 2 ft of concrete was added to the caisson floor bringing its thickness to 5 ft. Sand ballast was then added to bring the caisson within 2 ft of the prepared bed at low water. Control of its position during sinking was by pontoon-mounted winches. The caisson was positioned as closely as possible during the flood tide and was finally positioned and sunk during slack water. After the caisson's seating on the foundation had been checked by the divers, a protecting apron of large stone rubble, 10 ft wide, was dumped around the caisson to a depth of 4 ft.

47. The dolphin cone, cap, suspension arms, and gravity fender were then constructed within the cofferdam, and the caisson filled with sand. Finally, the fender ring was raised by jacks, hung from the linkage system, and the cofferdam removed. A completed fender, and a fender under construction in cofferdam, can be seen at the ends of Pier-head No. 2 at low water in Fig. 11a. Fig. 11b shows the completed fender at high water under monsoon conditions.

PIPELINE SYSTEM

48. The pipeline system posed a number of problems not encountered in the majority of installations where a tanker terminal serves only one refinery. In this instance the pipelines are a common-user facility serving two independent refining and marketing organizations, while at the same time constituting an extension to the earlier port facilities available to all commercial interests for import of dangerous petroleum products.

49. The composition of the main pipeband is listed in Appendix I, together with details of the principal service pipes between Butcher Island tank farm and the berths. Except for fresh-water services, all pipelines are of welded steel with a wall thickness of $\frac{7}{16}$ in. throughout for pipes of 12 in. dia. and larger. This was determined on the basis of life expectancy in the face of inevitable corrosion rather than from stress considerations.

50. Owing to common use of the pipelines by several operators, the scheme includes pumping plant and storage tanks to enable the return to their respective refineries of products left in the lines after loading operations. Bunkering and ballast-water disposal facilities are also provided on the island. The latter includes a settling tank and a 600-ton/hour twin-bay oil and water separator, with provision for future installation of a second tank should this become necessary in the event of increased trade, or if the need arises for special facilities for breakdown of oil and water emulsions.

51. Hose-handling arrangements are orthodox, since it was considered that the more sophisticated equipment now becoming popular was not at that time sufficiently developed to ensure trouble-free operation in Bombay. To present the hoses to the tanker manifolds and also for transferring them between the vertical storage racks and the working areas, each berth is equipped with a post-type electric jib crane designed to lift 2 tons to 35 ft above the deck level at radii between 8 ft and 50 ft. All motions can be controlled from a remote push-button station on the pier-head main deck as well as from the elevated driver's platform. Additionally, to facilitate coupling the hoses to the pipe terminations there are two 15-cwt hand tackles on a runway carried below the upper deck. Details of the hoses are given in Table 3, Appendix I. Each hose is 75 ft long comprising three units of 25 ft with flanged connexions. During use, the bight is supported by the tanker's derrick with a loop remaining on the pier-head main deck. With this arrangement changes of tide and of tanker draught during pumping are catered for without need for constant adjustment of the hose slings.

52. Draining down of hoses is by gravity, and slops are returned to a settling tank on Butcher Island by screw-type pumps located at each pier-head. Waste oil collected in the settling tank is ultimately returned to the refineries by pumping into one of the crude lines.

53. At the Pir Pau end of the system comprehensive manifolding facilities have been provided. These connect the pipelines from the new berths with the two refineries and with the Port Trust pipelines running to the storage installations in Bombay. At this manifold a new pump-house is also being constructed for the dual purpose of replacing the old booster pumps associated with the original Pir Pau oil jetty, and for the return of flushing water used in connexion with the new 12-in.-dia. special-products line.

54. The oil companies stipulated that it should be possible to pump scrapers ("pigs") through the whole length of the main pipeband, including the submarine section, to free any deposits which might form inside the pipes. This requirement led to the incorporation of large-radius bends throughout, and on the Pir Pau bund precluded the use of orthodox forms of expansion loop. On this section, therefore, hydraulically formed molybdenum-steel bellows-type expansion units with internal liners were employed. This necessitated: (*a*) substantial anchors at each end of the Pir Pau section, associated with relatively light intermediate anchors at the expansion points; and (*b*) the adoption of a castellated form of pipe support to discourage misalignment of the pipes caused by the internal operating pressures.

55. The effect of expansion forces on the gantry connecting the pier-heads with Butcher Island was given special study, in order that the lightest type of concrete structure might be used. It was fortunate that the relative positions

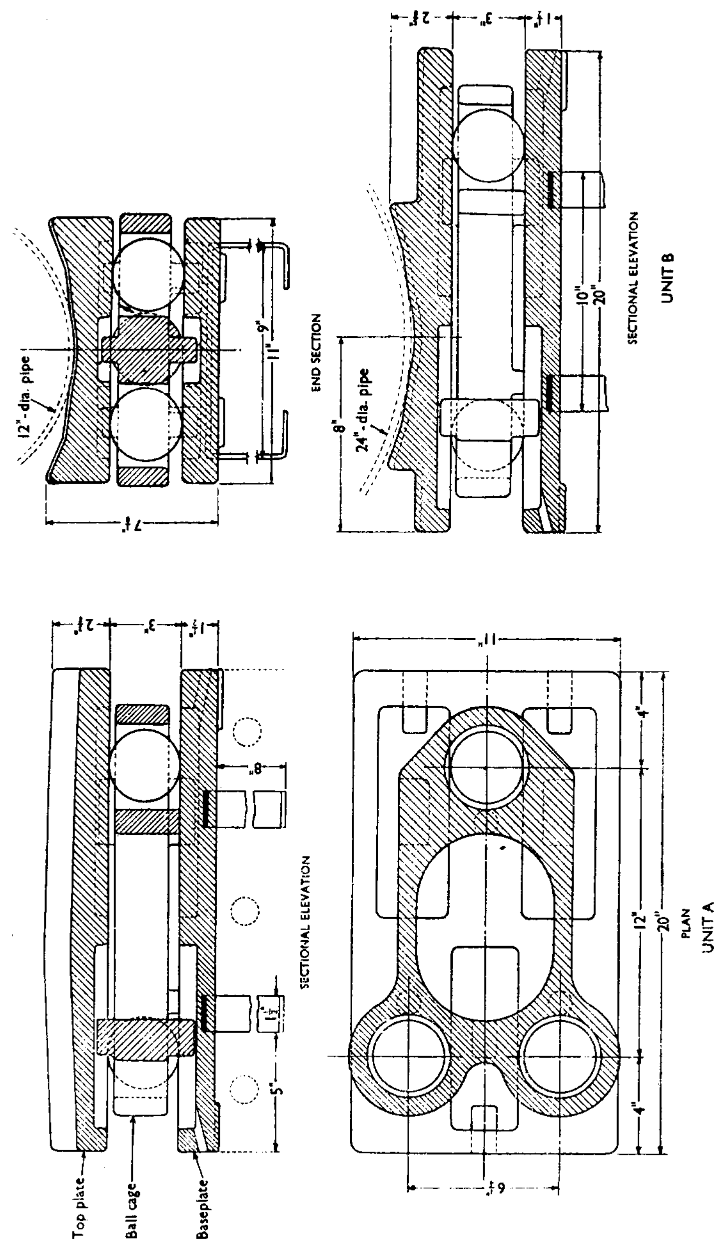

Fig. 12.—Anti-friction pipe support

of the berths and the island resulted in a gantry and pipeline layout which permitted the accommodation of thermal expansion within the natural configuration of the system. Even so, the normal method of pipe support, employing rubbing strips cast into the tops of the supporting beams, was found to result in transfer of considerable forces to the gantry, particularly where the pipes passed over expansion joints in the structure. Strengthening the structure to accept these forces would have resulted in a considerable additional expenditure, and accordingly the special anti-friction pipe supports illustrated in Fig. 12 were

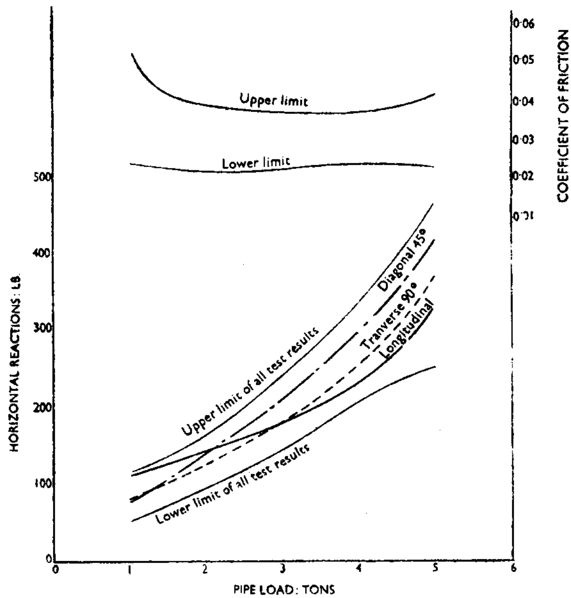

FIG. 13.—PERFORMANCE CURVES: PIPE SUPPORTS

developed. These units were constructed in India from high-duty cast iron and their effectiveness may be judged from the fact that with the exception of a short section of one 24-in.-dia. pipe at the root of the approach bund, all pipes on the gantry which are supported in this way have remained in their design alignments without need for additional guides. Fig. 13, showing the results of tests carried out on one of these supports, illustrates the very considerable reduction of friction achieved in comparison with the normal rubbing strip. A worth-while saving in the cost of the reinforced concrete structure resulted.

56. The installation of the submarine portion of the pipeband also introduced some interesting problems. It was known that marine rock-boring molluscs, of the Pholas family, were present in the waters of Bombay Harbour, and from reports of experience in other Indian ports it was thought that they might not be

averse to drilling through the submarine pipelines. These creatures obtain oxygen by circulating water through their bodies by means of two siphon tubes, and, so far as is known, they cannot operate below about 8 ft of mud. It was decided, therefore, to trench the submarine pipelines into the mud of the harbour floor. The sections of the pipeband between high and low water, where it is carried up on to the rock bunds at either end, were also buried in mud contained in specially constructed "mud-ponds", which serve the additional purpose of increasing the effectiveness of the cathodic protection system where the pipes pass through the tide range.

57. Trenching the pipelines into the mud also gives reasonable protection from damage by the anchors of country craft—a hazard not entirely eliminated by charting the area as a prohibited anchorage.

58. External protection against corrosion for the pipes in the submarine section consists of a cold tar primer followed by three flood coats of hot-applied cold tar enamel reinforced by spiral laps of fibreglass tissue. Additionally, an impressed current cathodic protection system has been installed as an integral part of the overall design.

59. To give mechanical protection for the anti-corrosive coating, and to provide a measure of negative buoyancy, an overall coat of gunite of 1½-in. minimum thickness was specified. Some modifications to these requirements were later allowed to suit the mechanical coating plant set up by the pipe-laying contractor, but in general the quality of coating obtained proved to be the equal of, or better than, the specified minimum. It was originally intended that prepared lengths of pipe should be assembled and launched off the end of the new rock bund at Pir Pau. However, owing to a decision, dealt with in § 72, to make use of this bund for two cooling-water pipes, the pipeline contractor elected to construct a separate launchway which enabled him to process the pipes and carry out launching operations without interference with other works.

60. Jointers, comprising two pipe lengths welded together, were cleaned and wrapped by means of Crose CPC cleaning and priming machines and Crose LR coating and wrapping machines. These machines are of the rolling-rig type. Some initial difficulty was experienced in obtaining a satisfactory coating with the LR machine and in consequence, after trials, it was found preferable to employ only one wrap of fibreglass lapped 50% instead of the two single non-lapped wraps originally specified. After the enamel coatings had hardened and any defects located by the "holiday detector" had been patched, mechanical protection was applied by an American "Heavy Coat" machine. This plant is also of the rolling-rig variety, applying the cement/sand mix by means of contra-rotating brushes and at the same time pulling in a wire mesh reinforcement. An extremely dense and satisfactory coating was produced. The coated jointers were then transferred to the assembly line and butt welded into approximately 2,000-ft lengths. Following hydraulic testing of each length the exposed joints were wrapped and coated by hand to ensure continuity of the anti-corrosion and mechanical protection. All butt welds on the submarine section were subject to 100% radiographic inspection.

61. The pipes were launched by means of the pipeline contractor's specialized roller launchway incorporating an equalizer assembly at the seaward end to control the reverse curve as the pipes entered the water. In the case of the

16-in. and smaller pipes, buoyancy tanks were attached at regular intervals; successive lengths were jointed and the joints wrapped and coated as launching proceeded, until individual lengths of up to 11,000 ft were assembled for towing into position. Joints between floating sections were made over water from a specially adapted barge, and the coatings were made good at this joint before the pipe was sunk into position on to the sea-bed by selective release of the buoyancy tanks.

62. Since the 24-in. pipes still had positive buoyancy after the gunite coating had been applied, it was the contractor's original intention to proceed in a manner similar to that described above, but to handle each 2,000-ft length separately and to sink the pipe in position by pumping in water. This operation proved to be unsuccessful owing to inability to hold the pipe on its correct alignment against the very considerable transverse tidal forces acting on the pipe, and also because it was found impossible to control the position of the water introduced for sinking, even though rubber "pigs" were inserted at intervals for this purpose.

63. By the onset of the 1954 monsoon, one 12- and two 16-in.-dia. pipes had been laid, but owing to the difficulties described approximately 10,000 ft of 24-in.-dia. pipe had been lost or damaged without the completion of a successful crossing. The monsoon period gave an opportunity for re-assessing the technique for laying the larger pipes. At the suggestion of the consulting engineers, it was decided to give the 24-in.-dia. pipes a negative buoyancy of about 10 lb/ft run by increasing the thickness of the gunite coating to 2¼ in.; to employ regularly spaced buoyancy tanks as had been done with the smaller pipes; and to install concrete anchor blocks on each side of the pipeband to ensure positive location of the pipes, before and during sinking, against the effects of sudden changes in the strengths of the tidal current between Butcher Island and Pir Pau. So that the additional concrete coating should not introduce excessive rigidity, and thus cause difficulties during the sinking operation, it was "ringed" at intervals down to the original 1½-in. thickness.

64. These measures proved entirely successful and the remainder of the pipes were successfully laid during November and December 1954. Pipes salvaged from the earlier unsuccessful launchings were stripped and undamaged lengths were used in the overland sections.

65. The procedure for preparing and launching the lined fresh-water pipe was similar to that already described, except that joints were made with screwed couplings equipped with a short extension to relieve some of the stress on the roots of the threads on the pipe ends during laying. A special mastic inside the coupling ensured continuity of the internal lining. Lengths of about 1,750 ft were prepared on the launchway, and the joints over water were made with bolted flanges and metallic joint rings.

66. When the first section was launched it was found that the pipe turned in the couplings owing to a couple produced by the buoyancy tanks. This resulted in damage to the coating. The Contractor was much concerned lest further damage of this kind might occur during the laying operation, and a local decision was taken to spot-weld the couplings to the pipe. This action proved disastrous. When laying was resumed the bending stresses inseparable from such an undertaking caused the couplings to split longitudinally, allowing the pipe ends to spring free.

67. The couplings were made in N.80 steel, and it was immediately obvious that local hardening and cracking had been produced at ends of the couplings in the area of the tack welds. After tests had been made at the manufacturer's works it was decided to secure the joints against turning by using glycerine and litharge as a jointing paste. This set rapidly by polymerization in less than 2 hours and produced joints which were quite immovable. As a further precaution additional flanged joints were introduced, reducing the individual lengths launched to approximately 1,000 ft.

68. After the 1954 monsoon the pipeline was layed without further incident. Ironically, it was found that couplings made originally with normal jointing paste, but not tack-welded, proved equally resistant to twisting after lying in the sun for several months.

69. When the pipelines had all been laid on the sea-bed, they were lowered into the mud with the Collins submarine trenching machine. This consists of a tubular steel cage, equipped with high-pressure air and water jets, fitted over the pipe to be trenched in and towed by a tug carrying the necessary pumps and compressors. This machine proved ideal for the fine material on the floor of Bombay Harbour. Divers reported that after the requisite number of passes, the pipes were found to be lying at the bottom of a steep-sided trench. Except at the two ends of the submarine section, backfilling of the trench was left to the action of natural forces.

70. Having been laid, each pipe in the submarine section was filled with fresh water, pending the commissioning of the system. With the exception of the 8-in.-dia. lined pipe, the water used was treated with 0·2% of sodium nitrite to inhibit internal corrosion.

71. A treatment tank has been installed at Butcher Island pump-house to permit the controlled introduction of this chemical inhibitor into the flushing water used for displacing products from the white oil lines. It is hoped that by this means internal corrosion will be greatly discouraged.

JOINT BUND AT PIR PAU

72. Fig. 4 shows the general arrangement and cross-sections of the submarine pipeband take-off bund at Pir Pau. In the initial design stage it was decided to carry the pipeband out to sea on a rock bund, both to provide a launching platform for the submarine section, and to limit the length of pipeline that would be in the tidal range and therefore liable to damage. There was an existing rubble bund at Pir Pau forming the approach to the old Pir Pau oil jetty, and the original idea was to widen this bund sufficiently to carry the new pipeband out to deep water. The Consultants were then approached separately by the Burmah Shell Refinery and the Tata Power Co., who were building a new power station at Trombay, with a request to design and construct cooling-water intake systems at Pir Pau. Discussion between the interested parties soon showed that there were considerable advantages to be had from the installation of a composite system, both in reduction of costs to the participants and in avoidance of interference between them.

73. The scheme finally adopted comprised 3,800 ft of jointly owned rock bund which carries a 12-ft roadway, the Marine Oil Terminal pipeband, and the Burmah Shell and Tata cooling-water lines to a point where the systems diverge,

the cooling-water lines being taken a further 1,600 ft seawards to the intake stations and the pipeband becoming submarine. This arrangement was tried out in the tidal model to make sure that there was no disturbance of the tidal currents which might lead to siltation of the cooling-water intakes.

74. The bund has a top width of 75 ft and the cross-section is zoned, the rubble sizes running from Grade D with 4–12-in. stones to Grade A with blocks 18–36 in. in least dimension, each zone having prescribed proportions. The Grade A rock constitutes the protective facing against wave action on side slopes of 1 in 1½. The zoning is not symmetrical about the centre-line of the cross-section because of a construction programme which required that the westerly portion of the fill be constructed first in order to meet the pipe-laying schedules of the Marine Oil Terminal and the Burmah Shell Refinery. The top of the fill is 5 ft above maximum recorded high tide.

75. Material was quarried from the trap rock in the adjacent hills, graded, and transported to the site in Euclids. The initial fill was extended by end dumping and was carried to 3 ft below its final level, leaving this depth for later special consolidation. Hand-placing of rock was limited to the pitching of the side slopes. At the point where the systems diverge, the bund is gradually widened and falls to the level of the sea-bed between two wing walls which form the "mud pond" for the protection of the oil pipelines. The Burmah Shell and Tata cooling-water lines continue at the higher level, formed by one of the wing walls.

76. The depth of silt overlying the rock bottom of the harbour varied considerably along the line of the bund. It was found that the Grade A dumped rock would satisfactorily displace 6–8 ft of silt to provide a solid foundation for the fill. Where the silt was deeper than this it was dredged out before the stone was placed. The bund was well consolidated by the passage of the Euclids constructing it and by the side-boom tractors subsequently used by the contractors for the various pipelines. Maximum observed settlement was 3½ in. after 5 months.

77. Separate contracts were awarded locally for the construction of the pipe supports, roadway, and cable ducts.

Breakwater and rock bunds at Butcher Island

78. The elevation and the plan of the half-tide rubble breakwater situated to the south-west of the oil berths are shown in Fig. 14, Plate 2. The breakwater is finished at a level of 8·5 ft above chart datum, is 15 ft wide at the top with side slopes of 1 in 1½, and is armoured with a 4-ft-thick blanket of Grade A rock.

79. The rock bund and mud pond which receive the submarine pipeband at Butcher Island, and the rubble causeway which carries it round the north-east side of the Island and out to meet the pipe gantry, are essentially similar in construction to the Pir Pau joint bund.

80. Rock for these works was quarried at Elephanta Island where it was sorted and loaded into barges for direct pumping. The armouring was placed in the breakwater by floating cranes and in the causeways by cranes working out from the land.

Electrical installations

81. All of the electrical power required at Butcher Island is provided by a new Diesel power station. There is also a 60-kW 415/240-V house set. Cooling is by evaporators mounted on the roof.

82. Primary distribution to two main substations on the Island and to the fire-pump substation is at 3·3 kV by means of paper-insulated, lead-alloy sheathed, wire-armoured cables laid in concrete sand-filled ducts following the roadways. Pump motors exceeding 100 b.h.p. are supplied at 3·3 kV. All other secondary distribution is at 415/240 V derived from delta/star transformers with neutral points solidly earthed at the sub-stations.

83. Owing to its dangerous location the tank farm substation is pressurized; this avoids the problem of high-voltage flameproof switchgear.

84. Cables supplying the pier-heads are carried in a sand-filled concrete trough along the roadway on the side remote from the pipeband, and the installation generally conforms with the Institute of Petroleum Safety Code. Flameproof construction has been adopted in all dangerous locations, and sub-circuit wiring has been carried out principally in mineral-insulated cable.

85. Owing to the very large individual pump loads of up to 500 b.h.p./unit installed in the tank farm pump-house, a supervisory remote control from the power station has been incorporated. This ensures that there is sufficient generator capacity on the station bus-bars before a large pump is started.

86. The principal load at the berths consists of the eight mooring capstans each capable of a 10 ton pull. These have torque-limiting characteristics achieved by means of fluid couplings.

87. Lighting generally follows standard practice in oil installations. The fire towers at the berths provide a convenient location for long-range flood lighting of pier-head working areas.

Telecommunications

88. The project includes comprehensive telecommunication facilities consisting of:—

- (*a*) VHF radio-telephone communication between Butcher Island and the mainland.
- (*b*) A complete supervisory telephone system.
- (*c*) A commercial (public) telephone system forming part of the Indian Government Posts and Telegraphs system.
- (*d*) Separate fire-alarm networks on Butcher Island and at Pir Pau.

89. The telephone systems necessitated two submarine cables connecting Butcher Island with Pir Pau. These cables are of the polythene-insulated and armoured wet type and were so installed as to be outside the influence of the cathodic protection system of the main pipeline.

90. Cathodic protection for the submarine pipeband is provided by two multiple-graphite-anode systems installed off-shore about 1,000 yd from each of the pipeline landfalls. Separate, impressed current, rectifier sets, and test points are installed in special buildings located at the two shore ends of the pipeline. Cathodic protection is also provided for the bottoms of the tanks on Butcher Island.

FIRE-FIGHTING SERVICES

91. The isolated position of Butcher Island made the establishment of a self-sufficient fire-fighting service a matter of prime importance. Fire pumps, monitors, and foam generators are standard equipment on all tugs at Bombay, and in addition the Port Trust have provided a new fire float for service at the Oil Terminal. It was also appreciated at the preliminary design stage that a fully integrated land-based fire-fighting system would be essential and that the very small First Aid force maintained by the Port Trust would require considerable augmentation.

92. The Port Trust sent their two senior fire officers to England for training in the latest techniques, and the Consultants prepared a separate report on the organization and equipment of an expanded fire-fighting force, appropriate to the new responsibility, which has been implemented as part of the project.

93. The fire water main extends the whole length of the gantry and follows the pipe track on Butcher Island into the tank farm area. It is supplied by three vertical-spindle submerged multi-stage pumps, established on a separate piled structure near the approach gantry. Hydrant outlets with reducing valves are located at 200-ft centres on the gantry and at strategic positions throughout the system.

94. The pier-heads' and tankers' hose manifolds are commanded by monitors, capable of discharging 1,500 cu. ft/min of mechanical foam, situated on fire-fighting towers at each dolphin. The monitors are arranged for remote control from deck level, and sufficient foam compound is stored for not less than 30 min continuous operation. Fixed piping carried back to a safe distance permits the replenishment of foam compound by means of portable pumps during fire attack.

95. All storage tanks are equipped with foam pourers and fixed dry foam risers terminating adjacent to the service roads, so that portable foam-making equipment can be readily coupled between the fire water hydrants and the risers. Mechanical foam can be injected into the oil storage tanks at a rate of more than 1 cu. ft/min for each square foot of free oil surface, without the aid of portable foam towers.

96. Mobile appliances consist of four specially designed compact towing and personnel vehicles on Land-Rover chassis, backed up by eight purpose-made trailers fully equipped for dealing with specific fire risks. Two of the towing vehicles are equipped with light-duty pumps and first-aid hose reels for use in areas remote from the fire water main, and two additional heavy trailer pumps were also ordered to reinforce existing pump appliances. The majority of the appliances are located on Butcher Island.

97. A comprehensive alarm system has also been ordered.

CONTRACTS

98. Tenders were invited in May 1953, and the principal civil engineering contract was awarded in July 1953 to the Royal Netherlands Harbour Works Company Ltd and Shapoorji Pallonji Ltd, a consortium formed specifically to undertake the work. The installation of the pipeline system and ancillary plant was entrusted to a similarly formed consortium, The Merritt Chapman & Scott

Corporation and The Hindustan Construction Company of India Ltd, with whom the Collins Construction Company of Houston, Texas, was associated for the specialized work of laying the submarine pipelines. The contract for the Pir Pau Joint Bund was awarded to Patel & Motichand Ltd.

99. The entire works, including the electrical, mechanical, and communication contracts, were supervised by the Consulting Engineers who appointed Mr M. L. Wolfe Barry, A.M.I.C.E., as Resident Engineer with a specialist site staff who were assisted by engineers seconded from the Bombay Port Trust.

100. The work of construction began in October 1953. The first berth came into use for import of crude oil in February 1955, and thereafter the facilities of the terminal were progressively commissioned on completion, the third berth coming into full operation in December 1956. The total cost of the project was £6,460,000; the civil works accounted for £3,130,000, and the pipelines, tankage, and mechanical and electrical services for the balance of £3,330,000. A breakdown of these costs is given in Appendix III.

CONCLUSIONS

101. Now that the Oil Terminal has been in continuous use for 5 years, it is possible to draw conclusions on the success of the project. In this whole period there has been no occasion when a vessel has been unable to use a berth or has suffered damage of any account through the process of berthing or lying alongside. The use of these berths has sustained full output of the two refineries as far as the supply of crude oil is concerned, and has dealt sufficiently with the disposal of the finished products.

102. In the design particular attention was given to the avoidance of high maintenance costs, and to date there have been none of any significance.

ACKNOWLEDGEMENTS

103. The Authors express their thanks to the Government of India and the Bombay Port Trust for permission to present this Paper, and in particular to the Engineers of the Port Trust and the departments under their control for their willing assistance throughout the project from the earliest design stages to the completion of site work.

104. They are indebted for some of their facts to a Paper[1] by Mr W. Wallace, A.M.I.C.E., and Mr G. E. Archibald, A.M.A.S.C.E. They would like to thank Mr J. W. T. Tapp, A.M.I.C.E., who was Resident Engineer on the Burmah Shell, Tata, and B.P.T. works at Trombay, for his assistance in the preparation of this Paper; and Mr H. D. Taylor, A.M.I.E.E., and Mr C. T. Payn, Assoc.I.E.E., for contributions concerning the pipeline system and electrical installations for which they were respectively responsible.

[1] William Wallace and G. E. Archibald, "Trombay Power Station: Cooling water system". Proc. Amer. Soc. civ. Engrs, Power Div., vol. 82, No. PO1, Paper 896 (Feb. 1956).

APPENDIX 1

PARTICULARS OF PIPELINES AND HOSES

TABLE 1.—MAIN PIPEBAND: BUTCHER ISLAND TO TROMBAY

Designation	Purpose	Diameter: inches	Approximate route length: feet	Designed capacity: tons/hour
C1	Crude import	24 O.D.	20,400	2,000 } 3,000 coupled
C2	Crude import	24 O.D.	20,400	2,000 }
B1	Black export	24 O.D.	20,400	2,000
W1	White export	16 O.D.	20,400	800
W2	White export	16 O.D.	20,400	800
W3	White import (special products)	12 N.B.	20,400	250
FW	Fresh-water supply	8 N.B.	19,400	100

Note.—Table 1 includes 11,300 ft in submarine section.

TABLE 2.—SERVICE PIPELINES: BERTHS AND BUTCHER ISLAND INSTALLATIONS

Designation	Purpose	Diameter: inches	Approximate route length: feet	Designed capacity: tons/hour
SB	Ballast disposal	16 O.D.	4,800	2,000
BF	Back-flushing B1	16 O.D.	4,900	900
WF	Back-flushing W1, W2, and W3	16 O.D.	5,000	550
B2	Bunkers loading	12 N.B.	5,000	300
SR	Slop return	12 N.B.	1,400	170
BS	Bunker storage	16 O.D.	1,300	1,000
S	Slop	6 N.B.	4,700	—
FW	Fresh-water loading	8 N.B.	4,400	200
H	Fire water	8 N.B.	5,200	345

TABLE 3.—HOSE COMPLEMENT AT EACH BERTH

Line designation Tables 1 and 2	Maximum hose size: inches I.D.	Actual hose size: inches I.D.	Number that can be used simultaneously	Rating
C1	10	8	4	Heavy-duty 200 lb/sq. in. working: 600 lb/sq. in. test (C1–W3)
C2	10	8	4	
B1	10	8	4	
B2	6	4	2	
W1	8	8	2	
W2	8	8	2	
W3	8	8	1	
SB	10	8	2	150 lb/sq. in. working; 450 lb/sq. in. test
FW	6		1	
		2½ (Rubber-lined canvas)	3	100 lb/sq. in. working

APPENDIX II

TABLE 4.—PUMPS

Duty	Number	Type	Number of stages	Capacity: gal/min	Total head: lb/sq. in.	Motor b.h.p.
Black-oil flushing	2	Centrifugal	1	3,500	148	500
White-oil flushing	2	,,	2	2,200	175	250
Boosting and flushing water return*	3	,,	2	1,050	175	140
Bunker loading	2	,,	1	650	55	110
Waste-oil return	1	,,	1	650	40	60
Slop handling	11	Screw	—	130	83	15
Fresh-water loading	2	Centrifugal	1	750	60	50
Fresh-water supply	2	,,	1	375	74	40
Fire water†	3	Borehole centrifugal	5	650	216	166

* Equipped with scoop-type fluid couplings for variable-speed operation.
† One with 230-b.h.p. Diesel engine.

TABLE 5.—OIL AND WATER STORAGE

Location	Contents	Type of tank	Number	Capacity: tons of water
Butcher Island	Flushing water	Fixed-roof, welded steel	1	7,000
,, ,,	Flushing oil*	,, ,,	1	6,500
,, ,,	Tanker ballast	,, ,,	1	4,500
,, ,,	Bunker storage	,, ,,	2	2,500
,, ,,	Waste oil	,, ,,	1	800
,, ,,	Power-house Diesel oil	,, ,,	2	90
,, ,,	Fresh water	R.C. reservoir	1	2,000
Trombay	Flushing water	Fixed-roof, welded steel	1	2,200
,,	Fresh water	R.C. reservoir	1	250

* Now used for furnace-oil bunkers.

APPENDIX III

COSTS

	£	£
Main civil works		
Dolphins and pierheads	731,000	
Gantry	373,000	
Rubble causeway from Butcher Island to gantry	173,000	
		1,277,000
Rubble causeway on Butcher Island for submarine pipe-band	55,000	
Rubble in wing walls of mud pond	10,000	
		65,000
Mooring caissons		194,000
Half-tide breakwater		98,000
Floating constructional plant		842,000
Capstans and cables		40,000
		£2,516,000
Bund at Pir Pau:—		
Rubble in widening and lengthening; provision of pipe supports; construction of road; electric lighting, etc.	326,000	
Mud pond	194,000	
		520,000
Civil engineering works on Butcher Island. Demolition, excavation, and filling; permanent roads and drainage; minor bridge works; retaining walls, etc.		94,000
		£3,130,000

	£
Pipelines, tankage, and pumping plant	
Pipes, valves, fittings, supports, anchor blocks, expansion units, etc.	818,000
Hose-handling cranes and hose racks	30,000
Tanks, foundations, and containing walls	53,000
Oil pumps and water pumps	52,000
Foundations for pipes and for manifold at Pir Pau	23,000
Oil pump-house	16,000
Fresh-water pump-houses, one on Butcher Island, one at Pir Pau	5,000
Oil separators and ballast-water treatment	22,000
Pipeline instrumentation	16,000
Walkways	21,000
R.C. water-storage tank on Butcher Island	15,000
Reservoir for fresh water at Pir Pau	12,000
Shed over manifold at Pir Pau	5,000
Installation of pipelines, tanks, pumps, etc.	1,507,000
Miscellaneous works	7,000
White-oil flushing installations at Pir Pau	131,000
	£2,733,000

	£
Electric supply, distribution, and services	
Power house, including plant	119,000
Substations and switch houses, including transformers and switchgear	76,000
Cables, including trenching and covers	84,000
Lighting fittings, electrical equipment, and accessories, including erection	58,000
	£337,000

	£
Fire-fighting	
Fire water pump-house	29,000
Pumps	14,000
Fire-fighting equipment	46,000
Fire-alarm system	32,000
Fire-station buildings	13,000
	£133,000
Cathodic protection	
Buildings for equipment, one on Butcher Island and one at Pir Pau; 5-way test box building on Butcher Island	3,000
Equipment, including installation	23,000
	£26,000
Telecommunications	
Submarine cables	56,000
Land system	43,000
VHF radio network	2,000
	£101,000

Summary

	£	£
Civil works		3,130,000
Other works:—		
Pipelines, tankage, and pumping plant	2,733,000	
Electric supply, distribution, and services	337,000	
Fire-fighting	133,000	
Cathodic protection	26,000	
Telecommunications	101,000	
		3,330,000
		£6,460,000

The Paper, which was received on 4 February, 1960, is accompanied by six photographs and eleven sheets of drawings and diagrams, from which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared, and by three Appendices.

Written discussion on this Paper should be forwarded to reach the Institution before 15 April, 1961, and will be published in or after August 1961. Contributions should not exceed 1,200 words.—SEC.

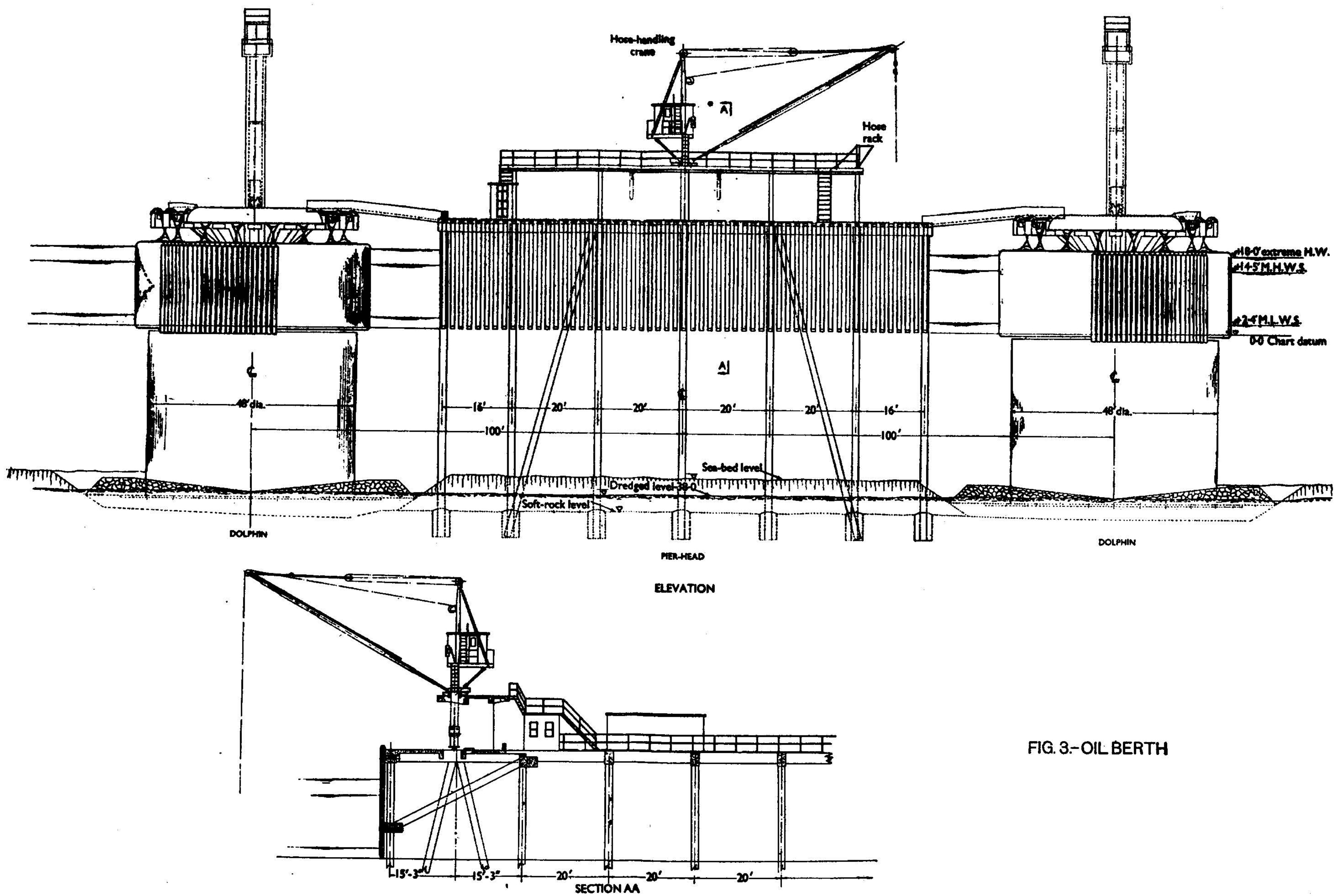

FIG. 3.-OIL BERTH

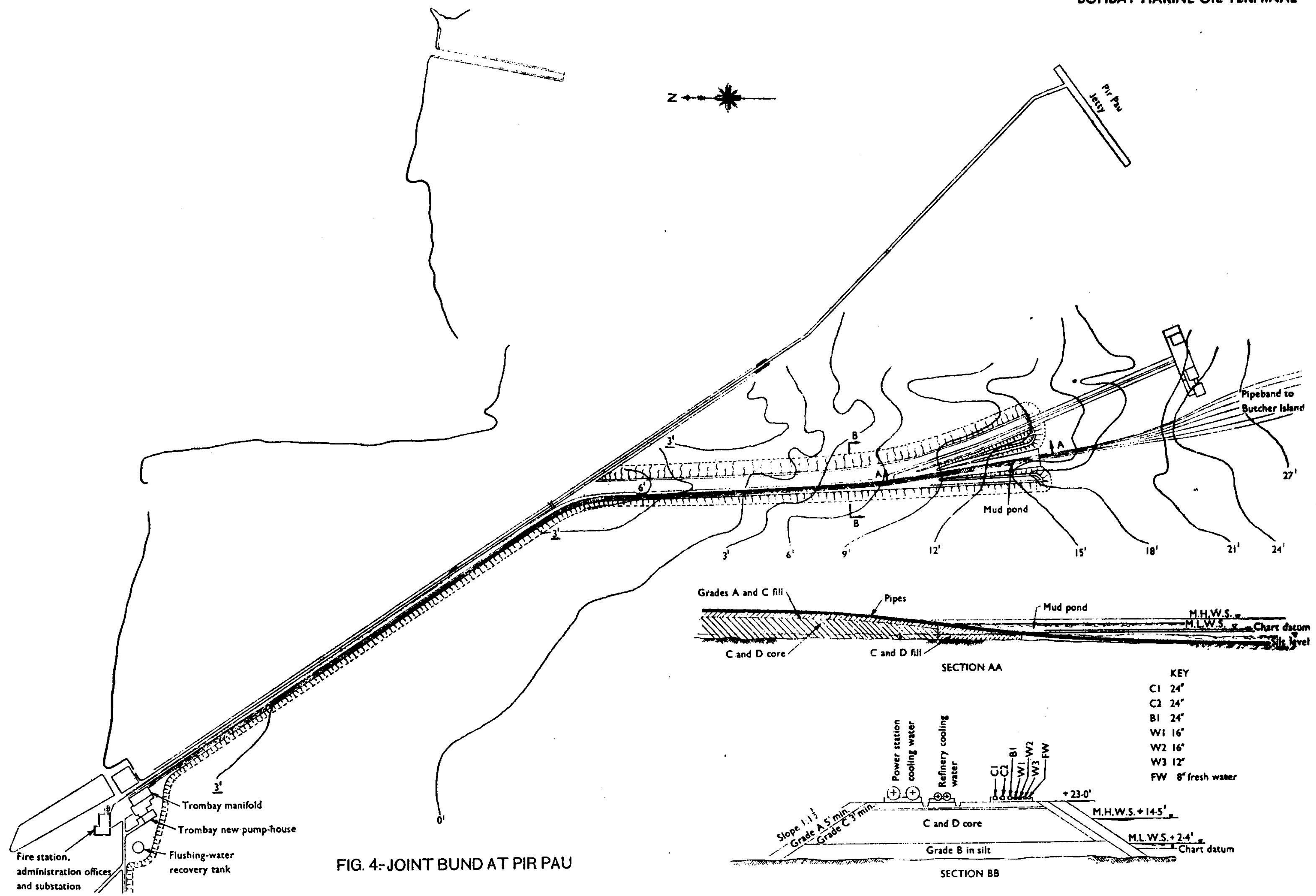

FIG. 4.- JOINT BUND AT PIR PAU

SIR BRUCE WHITE, C. R. WHITE,
A. H. BECKETT, AND P. E. GOLVALA

William Clowes & Sons, Limited: London

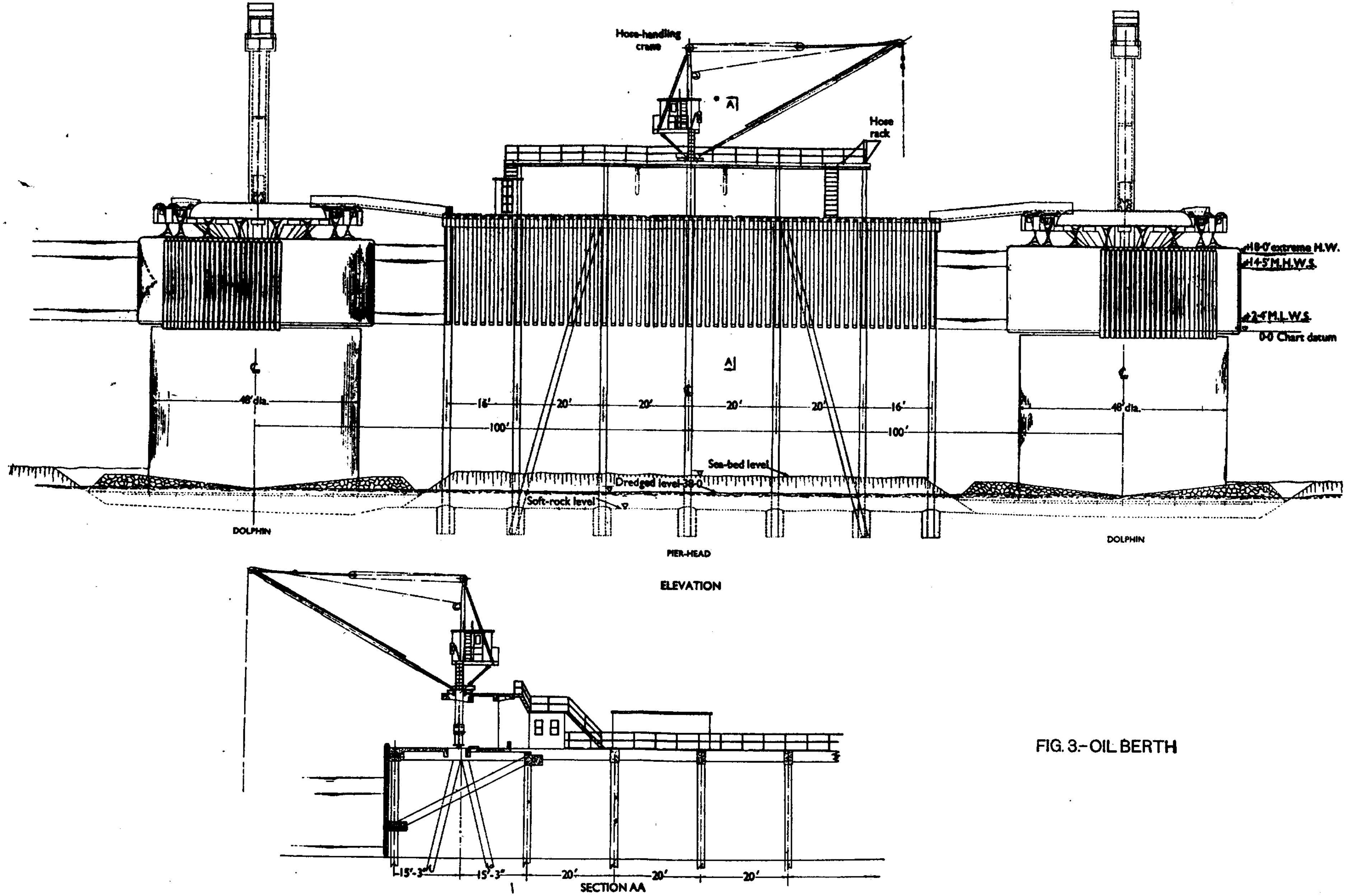

FIG. 3.–OIL BERTH

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William Clowes & Sons, Limited: London

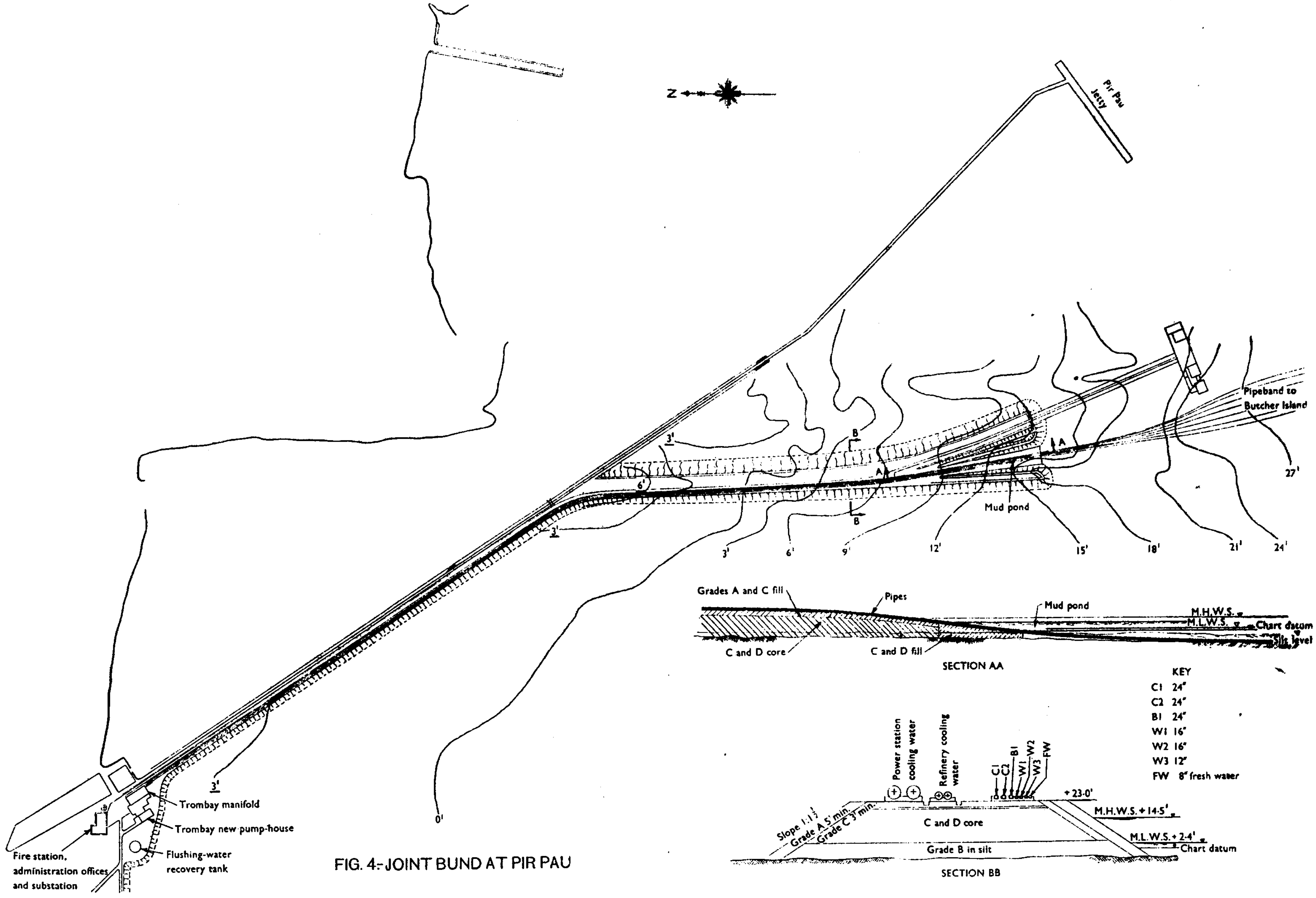

FIG. 4.- JOINT BUND AT PIR PAU

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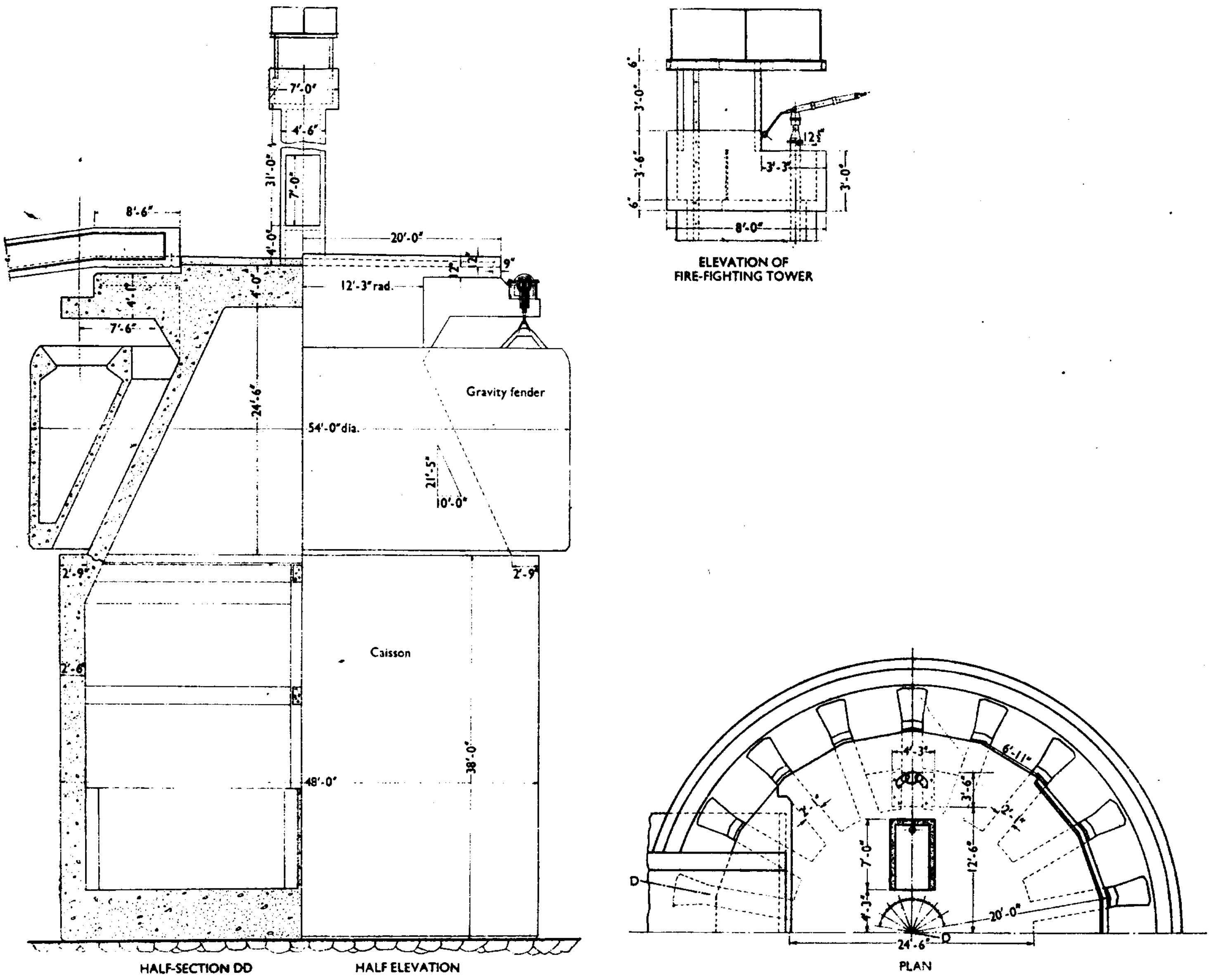
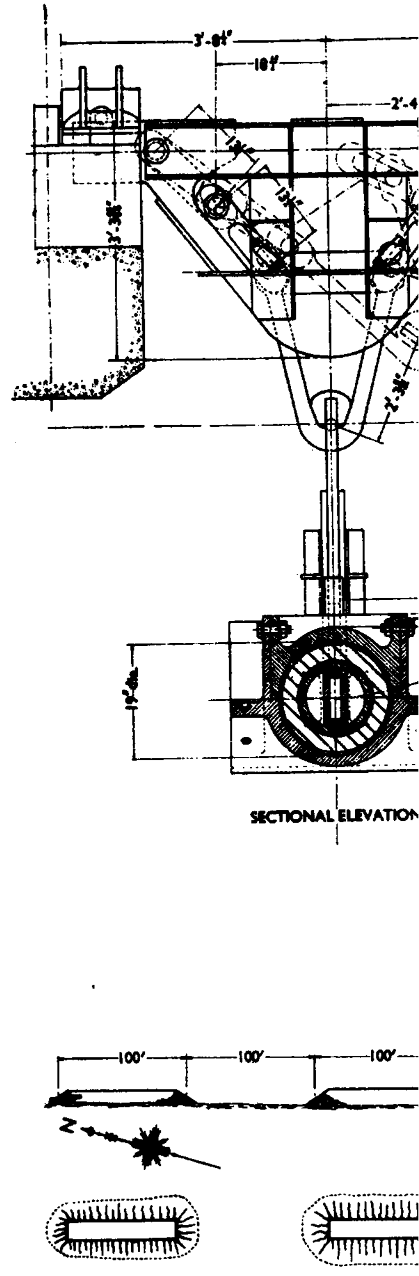


FIG. 9-BERTHING DOLPHIN



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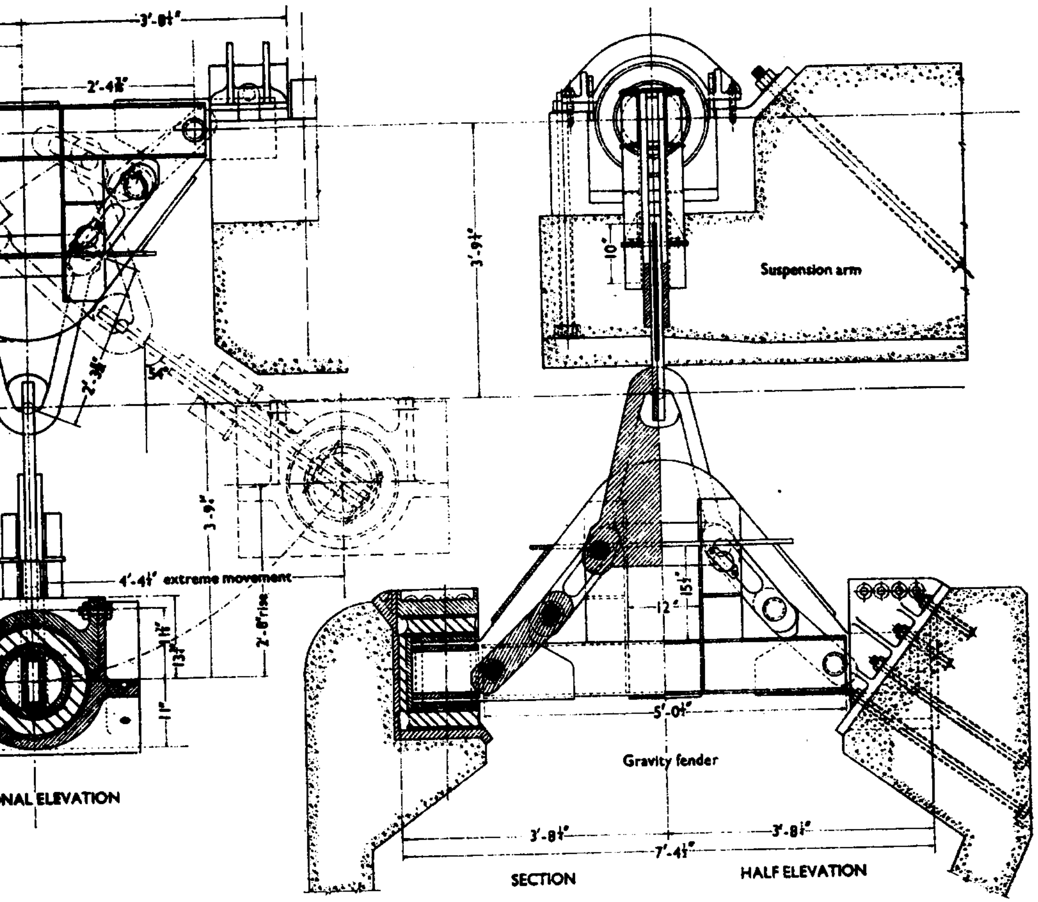

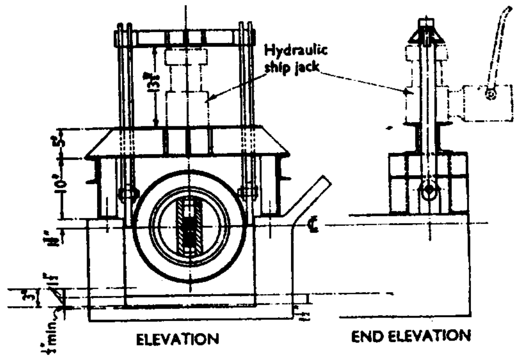

FIG. 10.—FENDER LINKAGE SYSTEM

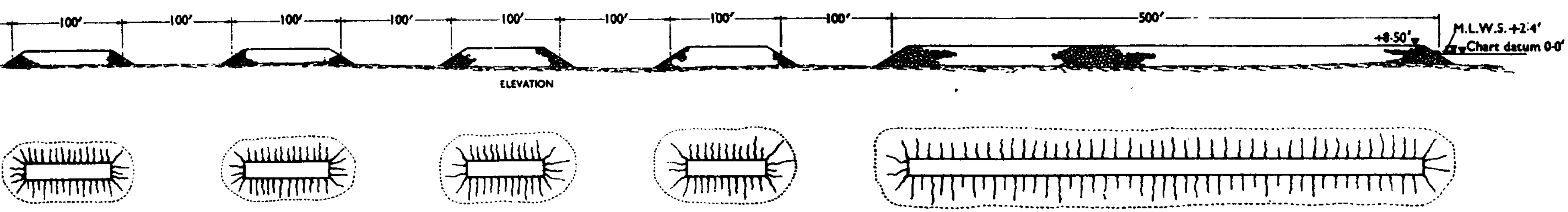

FIG. 14. HALF-TIDE BREAKWATER

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