

Preparation of foundations and construction of deep water piers

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ABSTRACT: The preparation of the foundations and construction of the deep water piers for the Fixed Crossing of Gibraltar Strait pose unprecedented challenges due to water depths, strong currents and sea floor slopes. The navigation intensity is very significant with an annual number of passages around 50,000. Design of the piers is dominated by the potential for collision by 350,000 ton tankers and 70,000 for submarines.

The 28 km crossing requires four deep water piers up to 305 m depth, while the alternate 14 km crossing requires three piers, up to 470 m depth. Each pier has four legs, the bases of which are about 100 m in diameter, at dredged elevations differing by up to 20 m to match the slopes. Excavation volumes average 1.3 million cu. m at each pier. Each base site will be excavated by a cutter head suction dredge, with wheel cutter designed to cut rock up to 100 MPa strength at a rate of 10,000 m³ per day. The cutterhead and power unit will be attached to a near-vertical ladder suspended from a large semi-submersible vessel. Either direct suspension or flexible connection to a sea floor tractor is envisioned. All subsea equipment will be hydraulically powered. After dredging, a 3 m thick stone bed will be placed, compacted and screeded.

Meanwhile, the base caissons will be fabricated in construction basins. A temporary staging site in 50-70 m of water will be established in Algeciras Bay or offshore the Ensenada de Ceuta in Morocco, with the four bases for each pier matching in plan and elevation those which have been prepared at the site. The four base caissons will be seated, and the lower cross arms constructed just above water. These cylindrical cross arms will provide essential buoyancy during the later construction stages as well as providing structural framing for the pier.

The four-legged assembly will then be deballasted, towed, and moored at a deep water mooring in Algeciras Bay. There the inclined shafts will be slip-formed full height, and capped with a 35 m deep upper platform.

The completed pier will then be towed to the site at a draft up to 250 m. The strong currents —up to 2.25 m/s— will require a bollard pull greater than that available with existing sea-going tugs, so tanker hulls will be shortened and converted to tugs, giving high bollard pull at low speeds. Six or more of these will tow the pier to the site where it will be moored and ballasted down onto the prepared foundation. Underbase grout and rip-rap scour protection will then be placed.

1. INTRODUCTION

Crossing the Strait of Gibraltar with a Fixed Link will require piers to be constructed at unprecedented depths. The favored 28 km crossing at the "sill" between the Mediterranean and the Atlantic requires four piers at depths up to 305 m while the alternate 14 km crossing requires three deep water

piers, the deepest being 470 m, to be founded on top of the submarine mountain, Mt. Hercules.

Environmental conditions at the sites are severe, with tidal currents projected during construction of up to 2.25 m/s, while the area is notorious for frequent storms, with accompanying swells and waves.

The sea floor at both sites is generally sloping,

with slopes up to 20°. The sea floor at the sill site is believed to consist of “flysch”, a sedimentary series of calcareous silts and sands, with relatively low strength strata interposed between stronger cemented sands and shales. Less is known about the soils under the short crossing but they are believed from geological considerations to be considerably stronger.

2. PRELIMINARY DESIGN

The preliminary design for these deep water piers calls for four-legged structures, each having a base about 100 m in diameter, spaced at 200-250 m centers. Plotting the required base footprints on the bathymetry shows that, due to the slopes, the quantities of excavation will be very large. The decision was therefore made to found each base on an individual pad, varied in elevation to best suit the topography. Even with this modification, the required quantities at each pier are over 1.0 million m³. Schedule requires that a pier site be completed each working season, which, allowing for interruptions of storms, leads to a requirement of 10,000 m³ per day. Such quantities can only be achieved by a powerful cutterhead hydraulic suction dredge.

Studies were made of present-day operations in which such dredges, equipped with a rotary wheel cutter, are achieving these production rates in rock up to 160 MPa unconfined compressive strength, although at much shallower depths.

The decision was made to employ a large semi-submersible vessel as a floating base, generating the power and providing the services and support for the underwater dredge equipment. Two alternative arrangements have been proposed for further study and selection. In both cases a near-vertical ladder is suspended from the semisubmersible. In one alternative, the wheel cutterhead is fixed to the ladder while in the other, the cutterhead is independently supported on a bottom-crawling tractor. Final decision will hinge largely on the site-specific properties of the seafloor soils.

The cutterhead's position will be accurately controlled electronically, so that the resulting cut will be to an accuracy of +/- 0.3 m. Then screened stone will be placed through a shielded pipe to prevent segregation.

The stone bed will be 3 m minimum thickness and will be compacted to a relative density of 70% by a very powerful vibratory compactor mounted on a seafloor crawler. The final surface will be screeded, with tolerances set so as to prevent any tendency for the base to rock.

3. BASE CAISSON FABRICATION

Concurrently with pier site excavation, the four base caissons of that pier will be fabricated in construction basins, then launched and completed while floating in protected water. Construction facilities may be built in southern Spain and in Morocco, or existing facilities in Northern Europe may be used, since it is well within today's state of the art to tow base caissons of these sizes several thousand miles.

These bases will resemble those of North Sea platforms, except their wall thickness will be almost twice as great, due to the need to resist the high hydrostatic head during final deployment and installation, and the ability to withstand collision from submarines. The walls will be heavily reinforced, including through-thickness confining bars.

4. BRIDGE PIER CONSTRUCTION

While these base caissons are being fabricated, a temporary staging site will be constructed in Algeciras Bay in Spain or Ensenada de Ceuta in Morocco, resembling the final prepared installation site in deep water but located in relatively shallow water, 50-70 m deep. The individual base pads will be constructed with the same differences in elevation as the final site. Then the four base caissons are temporarily founded at the staging site.

Prefabricated steel trusses will then be floated into position on top of the base caissons to support the construction of the lower cross-arms. The cylindrical horizontal cross-arms, 30-35 m in diameter, will consist of large precast ring segments, set on the trusses and joined by cast-in-place concrete and post-tensioning. The cross-arms not only provide the necessary structural framing, but also will provide buoyancy in the later construction and installation stages, so as to maintain stability.

When the cross-arms are completed, a starter segment of each leg will be constructed. The base caissons will now be deballasted so that the assembly floats off and can be towed to a deep water mooring in Algeciras Bay.

The inclined shafts will be constructed to their full height using slip-forming techniques similar to those employed to construct the "Leaning Tower of Stavanger" in Norway. During this operation, the structure will be ballasted down to submerge the lower cross-arm.

The final construction is that for the upper platform, a 35 m deep structure tying all four legs together to serve as a base for the pylon. This will be constructed of precast concrete segments seated on steel trusses and joined with cast-in-place concrete. This results in a very heavy structure in order to resist ship collision. However, such a large mass high up creates major stability problems during tow and installation, which is the reason that the buoyancy from the lower cross-arms is essential.

5. DEPLOYMENT AND INSTALLATION

The complete pier is now ready for tow to the site. The currents, however, are very high, even during the most favorable periods of the month, reaching from 1.5 to 2.25 m/s. This requires a combined bollard pull in excess of that which can be developed with the largest tugs and icebreaker vessels currently available. Therefore it is planned to take six or more existing tankers, reduce their length by cutting out the mid-sections of the hull, and then install bow thrusters. Tankers have high bollard pull at low speeds, due to their large single propeller, substantial horsepower, and deep draft.

The pier will be towed to the site and moored to pre-set mooring buoys. The tanker-tugs will work in conjunction with winching and mooring lines to the buoys to control position as the structure is ballasted down onto the prepared bases.

Upon landing, the structure will be ballasted so as to force the short skirts into the stone bed, while maintaining the verticality of the pier's principal axis.

Then grout will be injected under the base to fill any voids, using a thixotropic, anti-bleed, low-heat mix.

To prevent scour around the bases and especially between the four legs, rock rip-rap will be carefully

placed by tremie pipe so as to avoid damage to the structure.

Survey and position control are of vital importance to the successful execution of this demanding project and will involve use of GPS (Global Positioning System), ROVs (Remote Operated Vehicles) equipped with directional and side-scan sonar, and electronic position indicators.

6. SCHEDULING

Scheduling of such an extensive endeavor has been considered in arriving at the logistical requirements and in sizing the equipment. After appropriate periods for final design, planning and mobilisation, it should be practicable to establish a one-year cycle for all construction activities. While the pier sites are being prepared with dredging and stone-bed, construction basins will be built and the base caissons fabricated. Concurrently the staging area and deep water moorings will be prepared. Construction can then proceed on a sequential pattern. Thus it appears that the four piers for the 28 Km crossing can be completed in seven years from inception.

7. PIER IN 470 m WATER DEPTH

The 470 m deep pier for the 14 Km crossing will be built in similar fashion except that a second set of cross-arms will be constructed while the structure is at the deep water moorings. Deployment of this structure requires up to 12 modified tanker-tugs due to the greater displacement and the higher current in the narrowed crossing.

8. SUMMARY

Although the construction of these deep water piers is of unprecedented scale, the technology is essentially that successfully employed on North Sea concrete offshore platforms. When the platform Troll is installed offshore Norway in 1995, it will be in a comparable depth of water. Steel offshore platforms in the Gulf of Mexico now reach to 500 m water depth. Thus the practicality of construction of deep water piers in the Strait of Gibraltar in the early 21st Century appears fully realistic.

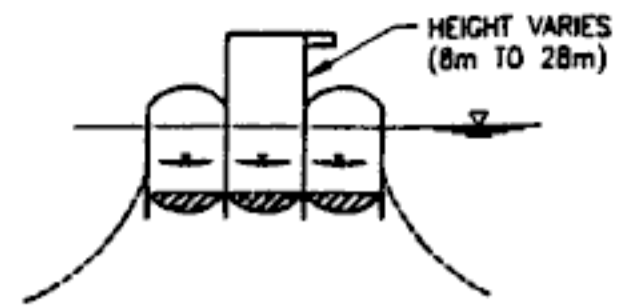


① CONSTRUCT BASE CAISSON IN CONSTRUCTION BASIN

PIER	LIFT	DRAFT
1	15m	11.4m
2	20m	15.9m
3	20m	15.6m
4	20m	14.4m

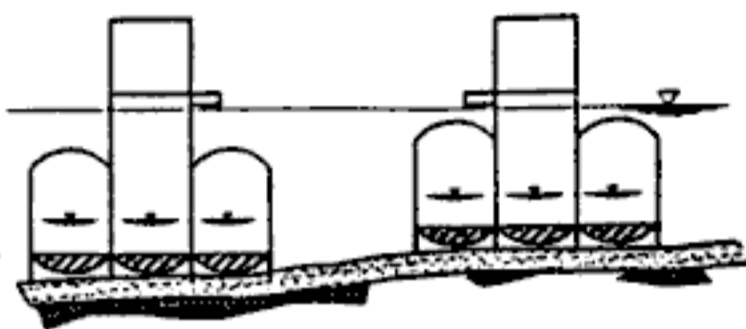


② FLOAT OUT TO MOORINGS



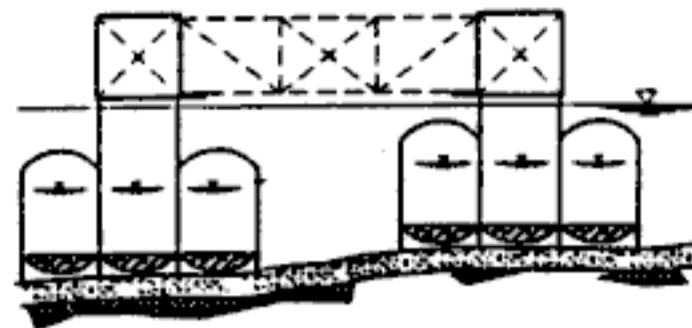
③ CONSTRUCTION AFLOAT.

PIER	DRAFT	CRITICAL GM
1	36m	21m
2	45m	21m
3	45m	21m
4	40m	18m

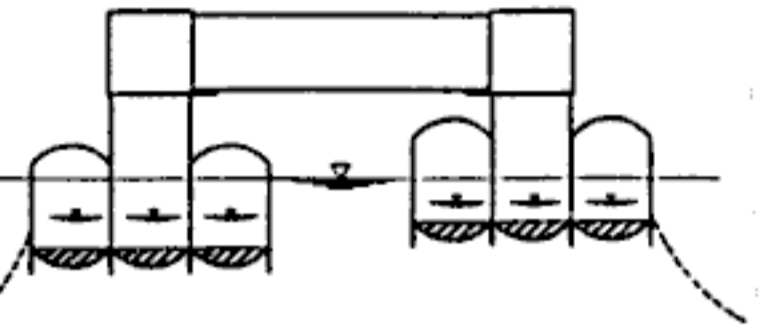


④ FOUND ALL FOUR BASE CAISSONS ON TEMPORARY STONE BED FOUNDATIONS.

PIER	DRAFT	CRITICAL GM _s
1	56m	12m
2	64m	9m
3	57m	8m
4	56m	9m

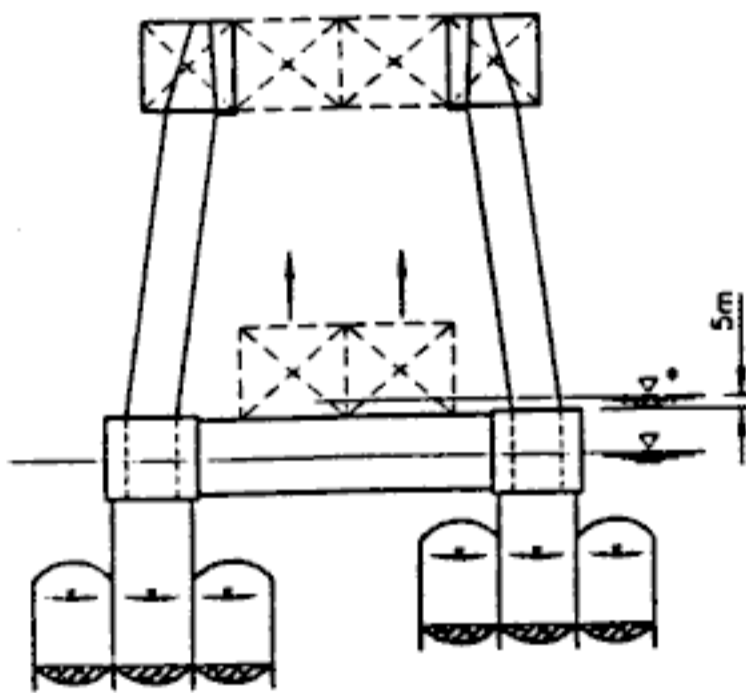


⑤ SET PREFABRICATED STEEL TRUSSES ON PROJECTING SEATS.



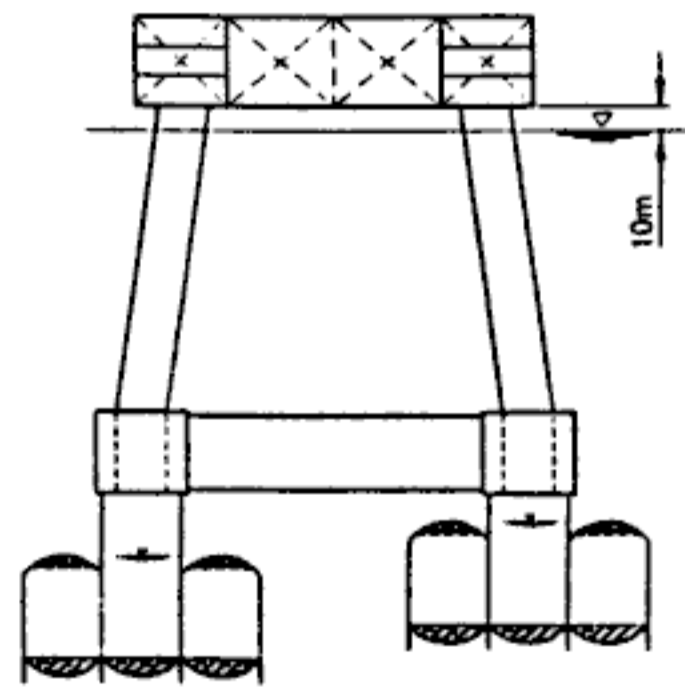
⑥ CONSTRUCT CROSS ARMS. DEBALLAST AND TOW TO DEEP WATER MOORING.

PIER	DRAFT	CRITICAL GM _s
1	36m	63m
2	46m	146m
3	46m	151m
4	41m	106m



⑦ BALLAST DOWN TO MID-HEIGHT OF CROSS-ARMS. CONSTRUCT ALL 4 SHAFTS AND CONICAL TOPS. RAISE PLATFORM FABRICATION TRUSSES AND SECURE TO SHAFT TOP CONES AND UPPER FALSEWORK (TRUSS WEIGHTS ~ 2000T)

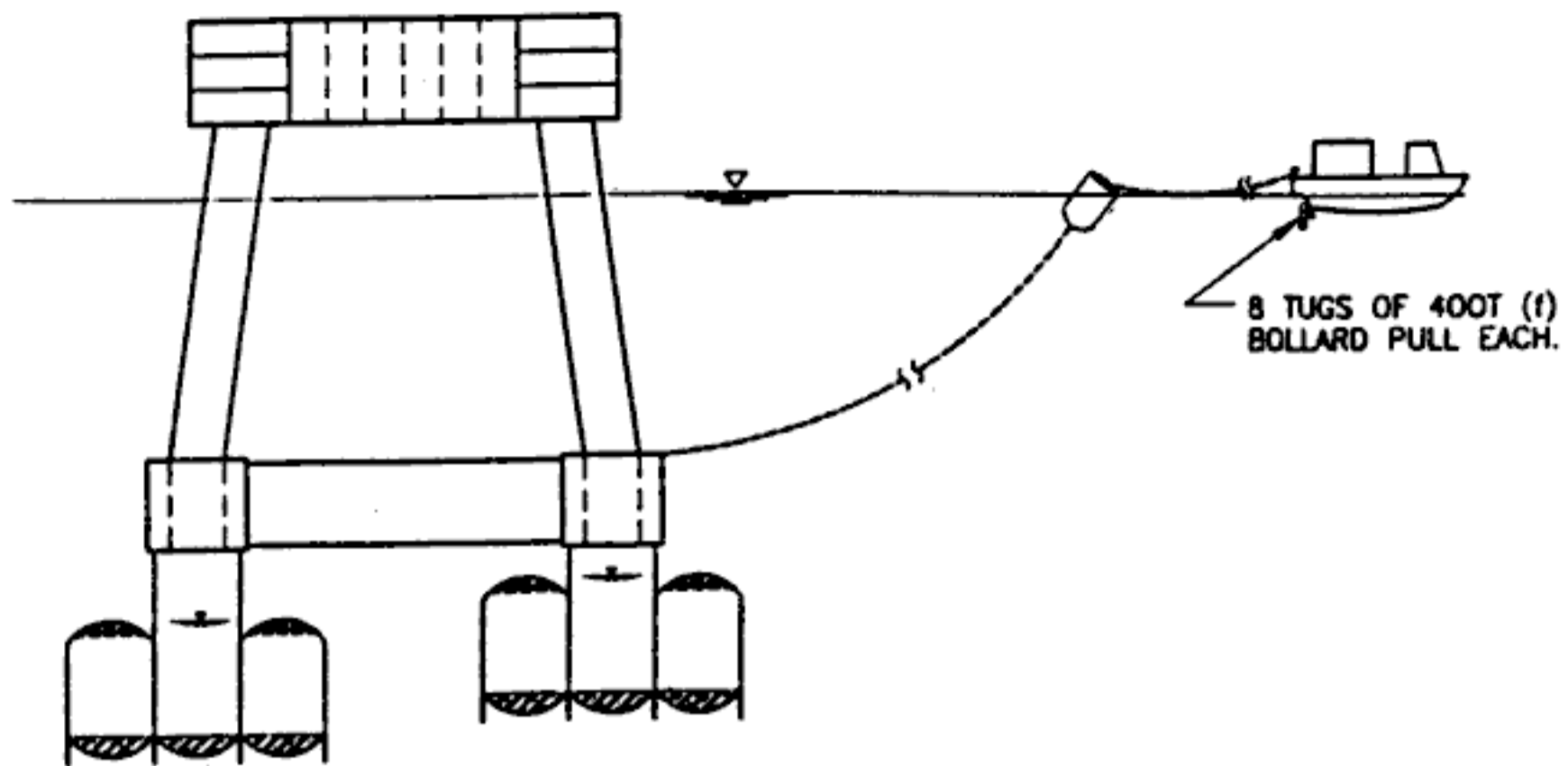
PIER	DRAFT*	CRITICAL GM _s
1	96m	22m
2	106m	34m
3	95m	36m
4	97m	27m



⑧ BALLAST DOWN TO DEEP DRAFT. COMPLETE UPPER PLATFORM. VERTICAL CROSS WALLS FORMED WITH REBAR TIED BUT NO CONCRETE PLACED.

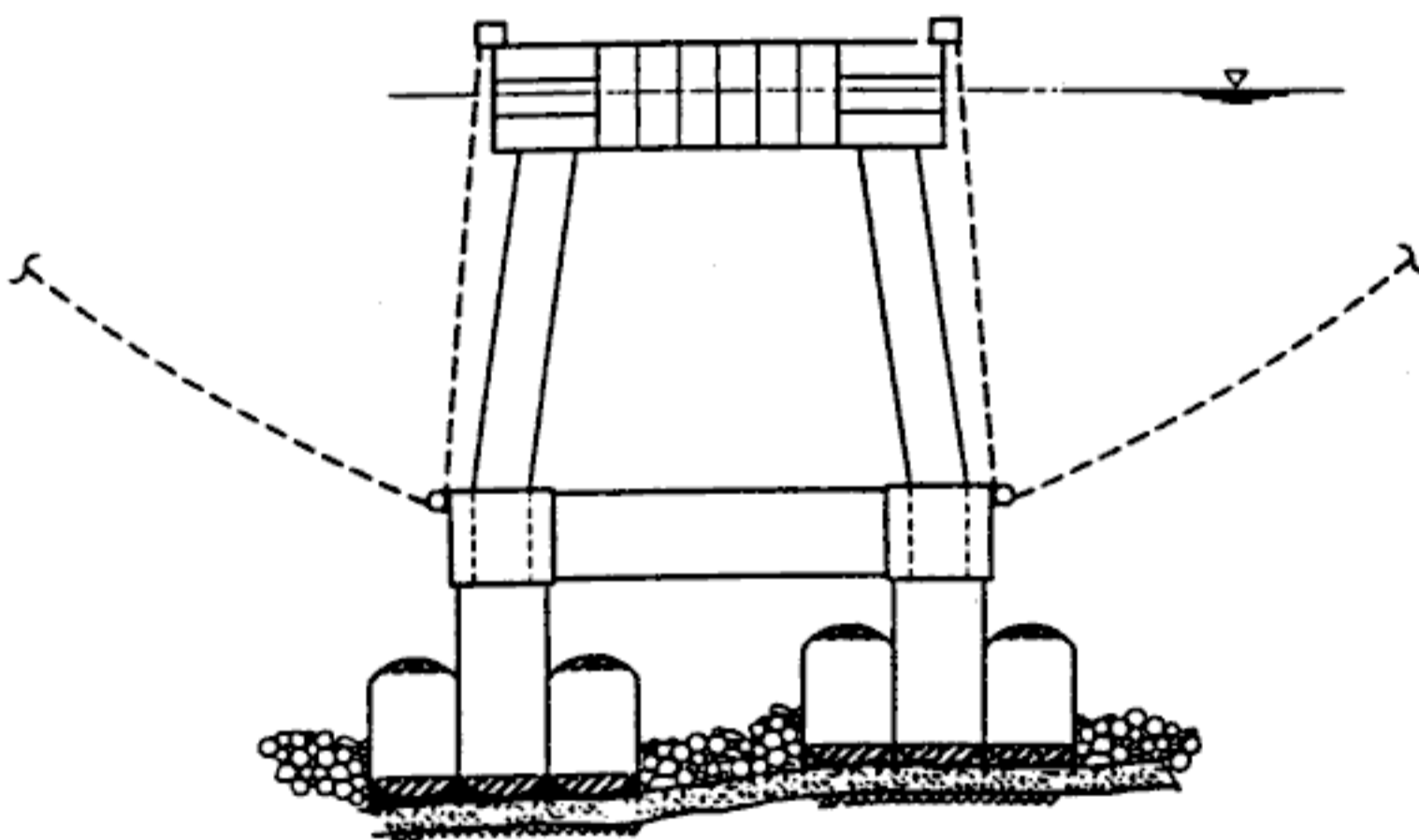
PIER	DRAFT*	CRITICAL GM _s
1	103m	5m
2	281m	21m
3	246m	16m
4	196m	6m

Fig. 6a



⑨ DEBALLAST TO OPTIMUM DRAFT AND TOW TO SITE.

PIER	MIN. DRAFT	GMs
1	90.8m	3.1m
2	216.0m	2.2m
3	191.0m	2.3m
4	186.0m	3.0m



- ⑩ MOOR TO PRE-SET MOORING BUOYS, BALLAST DOWN TO FOUND ON PREPARED STONE BED FOUNDATION.
- ⑪ GROUT UNDER BASE.
- ⑫ INSTALL SCOUR PROTECTION AS NECESSARY.
- ⑬ PLACE CONCRETE IN PLATFORM CROSS WALLS.

Fig. 6b