THE DESIGN AND CONSTRUCTION OF THE NEW OIL PORT IN DALIAN, C.P.R.

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Abstract

The construction of New Oil Port in Dalian,C.P.R.,was started from the end 1974 and completed in autumn 1976.In this paper a summary of the essential considerations in design and construction of this oil port,such as the planning of the pier,the determination of exciting forces (namely wave forces,forces due to earthguake, mooring line forces and berthing forces due to the impact of tanker on the fenders)on structures,the design of the large cylindrical cassion with a diameter of 9m and a height up to 19.7m and the construction of connecting bridges by two types,is presented.

General description

The New oil port is situated in Dalian,Liao-Ning,People's Republic of China,it is a terminal of the Da-Ching Oil Field.The design capacity of the export of crude oil is 15,000,000 tons per year。

Fig(1) is the general plan of the New Oil Port.The jetty is of cylinder-pier type and is located about one kilometer from the shore line。The direction of the axis of the jetty runs N150°,which gives an efficiency of 85-90% utilization of the berth every year.The depth of the water alongside the jetty is 17.85 meters at low water levet,which is sufficient for the berthing of 100,000 tonnage oil tanker。

The jetty is 421.3 meters long,consisting of an operating platform,two berthing piers and six mooring piers,as shown in fig(5).Fig(2)is its general view.

There are four spans of steel pipeline bridge between the operating platform and the piers No.6,7,8,9 and four spans of steel foot bridge between the operating platform and the piers No.4,3,2,1.The span lengths of these bridges are 24.2 meters,2-30.7meters and 51。5meters respectively.The distances between the piers are determined mainly according to the adequate angles of mooring lines and the requirement of the berthing of the tankers.In this design,the arrangement of the piers is fitting for the berthing of 30,000 tonnage up to 100,000 tonnage oil tankers。

The water depth alongside the jetty at low water level is determined mainly according to the following considerations: (1) the berthing tanker will not touch the sea bed under the wave action of the operating condition,(2) the increase of the draft of the tanker when it navigates out of the port,(3) the reserved depth for deposition and other factors.

Under the wave action,the draft of the berthing tanker will be increased due to the heave,roll and pitch motion of it .

The results of the 1:60 scale model tests are shown in table (1) for the beam sea and in table(2) for the oblique sea with an angle of 30° between the wave direction and the longitudinal axis of the tanker.

From the results shown in tab.(1),the increase of the draft under the beam sea does not exceed 0.94m.in the general case,and in the case of long period swell with the wave height less than 1.0m.,its extreme value does not exceed 2.58m.

Under the action of oblique sea,in the test the amplitude of the motion of heave and roll decreased rapidly,but a pitch motion was produced.Although the amplitude of the pitch motion was not very large,due to the fact that the length of the ship was much longer than its width,the small pitch motion still caused a significant increase in the draft of the tanker.From the results shown in tab.(2),the increase in draft ,generally did not exceed 1.17m. at high water level (HWL) and 0.57m. at low water level (LWL),and in the case of long period swell,its extreme value did not exceed 2.54m. at HWL and 1.09m. at LWL.

The elevations of all the pier tops are+10.0m, and those of the top deck and low deck of the operating platform are+12.0m and+10.0m. respectively.The determination of these elevations is mainly due to the follwing considerations:(1) no overtopping of waves will occur,(2) no strong wave action on the pipeline bridge will occur,(3)the inclination angles of the mooring lines are adeguate,(4)the operating range of the oil loading arm is sufficient for different tonnage berthing tankers.

The jetty is connected to the shore by a 111.75m.long mole consisted of rubble mounds and 9 spans of steel bridge. Each span of the bridge is 100 meters long. The bridge are supported on the cylinder piers, which are spaced 106m. apart center to center. The axis of the connecting bridge runs out in the east direction, and makes an angle of 120° with the axis of the jetty. Fig (3) is the general view of the connecting bridge.

The construction of the piers

The piers are all of gravity type using the reinforced conerete cylinder cassions as the underwater structure. The soft top layer of the sea bottom was dredged and stones weighing 15 to 100 kg. for rubble mounds were deposited in the dredged cavities up to the design level, then the cylinder cassions were rested upon these rubble mounds. The largest cylinder cassions used are 9.0m. in diameter and 19.7m. high, the bottom of the cassions is octagon in shape. The thickness of the wall of the cylinder is 30cm. and that of the bottom is 100cm. The superstructures of the piers over the cassions were three layers of solid or hollow precast reinforced concrete blocks, which were interlocked with each other by filling concrete in the concrete in the connecting holes with reinforcement in it. As an example, the construction of the operating platform is shown in fig (4).

The forces acting on the piers

The forces acting on the piers consist of the following forces: (1) wave forces, (2) forces due to earthquake, (3) mooring line forces, and (4) berthing forces due to the impact of tanker on the fenders.

The wave force exerted on single pier is calculated by Morison equation. In order to estimate the influence of the pier group,a 1:60 model test were made in the laboratory. According to the test results,a coefficient was used to modify the calulated result for single pier.For the operating platform this coefficient is 0.9-1.1, and for the berthing pier,1.0-1.4.

The mooring line force of the berthing tanker is caused mainly by the wind,current ane wave action on the tanker.For the offshore jetty,the dominant condition is the wave action.This action is very complex,because it not only depends on the scale and the direction of the wave, but also on the loading condition of the tanker,the characteristics of the mooring lines and fenders,and the arrangement of mooring lines when in berthing.Model tests of the 100,000 tonnage tanker with 1:60 scale were made for measuring mooring line forces and impact force and energy of the berthing tanker on the fenders.The mooring line arrangement in the test is shown in fig(5).The test data are tabulated in table(3).

From analysis of the test data,the following informations can be drawn:

(1) The maximum mooring forces are produced by the beam sea,if the wave direction is at an angle with the longitudinal axis of the tanker,the mooring forces will be reduced rapidly.The maximum mooring forces will occur at the ballast loading condition.For the beamsea from the outside of the berth,the mooring line forces of a tanker in full loading condition are increased as the wave height and wave period increase.As for the tanker in ballast loading condition,the mooring line forces will be maximum when the wave period coincides with the natural roll period of the tanker.For the oblique sea and head sea,the mooring line forces are also increased as the wave height and wave per-

iod increase.For the beam sea however ,the mooring line forces inside of berth will be greater than that outside of the berth due to the tendency of pushing the tanker away from the berth.

(2) When nylon breast lines are used,the mooring lines work normally for all test conditions,only for long period beam sea when the wave height reach 1.4-1.6m.,the mooring lines will be broken occasionally.When the stell breast lines are used,the mooring line will be broken in most cases during test,it can work in normal condition when wave height is less than 1.5m.and wave period less than 4 sec。for beam seas and wave height less than 2.4m. and wave period less than 5.3 sec.for oblique and head seas 。

According to the test results,the mooring line breaking force is used as the control force of the mooring line in design.This is mainly dependent upon the arrangement and the size of the mooring line selected.In design for the 100,000 tonnage tanker the 10" nylon line was selected and the arrangement of the mooring line is shown in fig (5)。

The impact force of the tankers on the berthing piers is mainly due to the following two causes:(1)the kinematic energy produced by the approaching velocity of the tanker during berthing,(2) the kinematic energy produced by the motion of the berthing tanker due to wind,current,especially the wave action。For offshore jetties in the open sea,the latter is the controlling case for determining the impact energy in design.

The model test results of the impact energy of 100,000 tonnage tanker due to wave action are shown in table 4。 From these test data we can see that the wave condition has great influence on the impact energy of the tanker.

Therefore in the design we must first determine reasonably the wave condition for safe loading operation of the berth. This is a complex problem because it depends upon many factors such as the management of the loading operation of the berth, the design criterion of the jetty, the requirement of the loading capacity of the berth per year and others. In this design, the wave condition for safe loading operation is tabulated in table (5).

From the test results and the analysis of the moored ship, we can get a semi-empirical formula for calculating the impact energy of the tanker.

$$E/H^2 = \alpha_1 \alpha_2 \alpha_3 \alpha_4 (1.4-2.7 \frac{D}{B}) \frac{LoA}{260} T^{2.5} (t\text{-}m/m^2)$$

Where: H, T—wave height (m.) and wave period (sec,) :

D, B, LoA—draft, breadth and total length of the moored tanker;

α_1 ——the coefficient due to eccentric impact of the tanker,

$\alpha_1 = \frac{1}{1+(l/r)^2}$, L is the distance between the fender and the center of gravity of the tanker on the cross section, r is the radius of gyration of the cross section of the tanker;

α_2— the coefficient due to the change of the water level, for the case of tidal range less than 4.0 m. and small reserved depth for safety for the berth, $\alpha_2 = 1.0$;

α_3— the coefficient due to the loading condition of the tanker and the influence of the elasticity of the mooring line, for the case of full loading, $\alpha_3 \equiv 1.0$, for the case of ballast loading : $\alpha_3 = 1.0$ for all nylon mooring lines, $\alpha_3 = 1.5$ for steel spring lines with nylon lines for others, and

α_3=2.2 for steel breast lines with nylon lines for others;

α_4 —— the coefficient due to different wave direction, $\alpha_4 = 0.05 + 0.95\sin^4\alpha$, α is the angle between the wave direction and the longitudinal axis of the tanker; for beam sea from inside of the berth , $\alpha_4 \leqslant 0.6$.

The formula is applicable for the condition of wave period equal to or less than 7sec..

It is necessary to determine the dynamic characteristic of the piers for calculating the earthquake reaction. For this purpose, the natural frequency and the damping ratio of the completed connecting bridge piers No.1,2,3 and the jetty pier No.8 under constrution, shown in table 6, were measured in site. The coefficient of the rigidity of foudation K calculated from the measured data was used to design the dynamic model test of the completed jetty pier No.8. The test results of the first mode of vibration of the dynamic model test were very close to the calculated values, as shown in table (7). The sketch for calculation is shown in fig(6).

Using the dynamic characteristic of the pier obtained from the test, we can calculate the deformation process of the pier during berthing and the earthquake force and its distribution along the pier.

The design of the large cassion

The construction of the reinforced concrete cassion is shown in fig. (7). The wall of the cassion is a cylindrical shell which is rigidly connected on the base plate of the cassion. In design, the following items are considered: (1) the strength and the stability of the cylinder wall against crack, under the action of the external and internal pressure, (2) the stability of the cylindrical shell under the combined action of axial force and bending moment,(3) the local strength of the shell due to the impact of the construction ships.

The cassion was built in two stages. In the first stage, the cassion was built up to a height of 12m. on land, and then slipped into sea on the slipway. In the second stage, it was built up to the full height of 19.7m. along the wharf under floating condition. Because the draft of the cassion floating vertically in state is larger than the water depth of the navigation channel, the cassion was towed by the tug at inclined position. The process of sinking down the cassion during the rising of tide and the reaction acted on the edge of the base of the cassion during sinking were checked in a 1:30 scale model test. The test results agreed closely with the calculated values.

The construction of the bridges

The all-welded Vierendeel trusses in parabolic shape are used in the construction of the connecting bridge. This is because the main loads of the bridge are uniformly distributed dead loads which occupy almost 84% of the total loads, and the moving loads are also essentially uniformly distributed.

The all-welded steel plate-girders strengthened by struts are used in the construction of the pipeline bridge along the jetty, because the total height of the bridge is limited in a small range of 4 meters. The result of using this type of structure is satisfactory in economy and service.

The span of the Vierendeel truss is 100 meters, which is divided into 12 panels. The ten intermediate panels are 9 meters in length each, and the two end panels are 5 meters in length each. The distance between the trusses is

7.6m.and the total width of the bridge is 12m.The height of truss at mid-span is 12.5m.,which gives a rise-span ration of 1/8.The joints of the truss are strengthennd,and the wedge-shape plate girders with an integral box section are used to strengthen the end panels.The sketch of the connecting bridge is shown in fig.(8).

The height of the plate-girder of the pipeline bridge is 2.0 meters.There is an elbow at each end of the girder to support the strengthening strut.Vertical members are spaced at 6.4m. apart to connect the plate girder and the strut. The distance between main girders is 5 m. center to center, and the width of the bridge is 9.0m. at the lower deck for carrying pipes and 5.0m. at the top deck.The sketch of the pipeline bridge is shown in fig.(9).

For checking the reliability of the design,several tests were made during construction.

For the Vierendeel truss,a photo-elastic model test and a 1:3 structural model test for the joint have been carried out and an overload (total load 840 t.)test for the whole bridge and a test for the non-uniform settlement of the supports were made on the assembly ground on the shore.The dynamic characteristics of the Vierendeel truss under different loading condition have also been measured,the results are shown in table (8).

Photo-elastic model tests of 1:100 scale for the whole span of the pipeline and 1:20 scale for the elbow part of the girder were made during design.The deflections of the bridge in prototype under the service loading condition were measured,the value agreed closely with the theoretical value with a deviation of about 5%.

The members of the bridges were fabricated in workshops and then assembled into a complete unit on the assembly ground, which was specially constructed for the assembly work of the bridges.After a whole span of the bridge has been assembled, the pipes,traffic deck,and all accessaries were installed on it,and then it was pulled on the shipway to the end of a mole.The assembled span was hoisted on the floating crane which was navigated by towing tugs to the bridge site and the span was finally erected on the piers.

Tab.1

Wave height H(m)	Wave period T(s)	amp.of heavy(m)		heavy below W.L(m)		roll θ	
		mean	max.	mean	max.	mean	max.
1.5	≦8	< 0.3	< 0.6	< 0.22	< 0.42	< 55'	< 1°30'
1.0	11	< 0.6	< 1.2	< 0.55	< 1.0	< 3°40'	< 4°38'

Tab.2

depth (m)	Wave height H(m)	wave period T(s)	amp.of heavy		pitch ψ	
			mean	max.	mean	max.
H.W.L	~ 1.5	5.0 ~ 8.0		0.28		23'
		9.3 ~ 11.0	0.39	0.7	25'	48'
21.5^{m}	2.0 ~ 2.5	5.0 ~ 8.0		0.24	27'	39'
		9.3 ~ 11.0	0.51	0.84	26'	45'
L.W.L.	~ 1.5	5.0 ~ 8.0		0.15		11'
		9.3 ~ 11.0		0.2		19'
17.85^{m}	2.0 ~ 2.5	5.0 ~ 8.0		0.25		14'
		9.3 ~ 11.0		0.26	17'	22'

Tab.3

Wave height H(m)	Wave period T(s)	Condition of Loading and	Mooring	Outside beamsea breast line(t)	Outside beamsea spring line(t)	Inside beamsea breast line(t)	Inside beamsea spring line(t)	Oblique sea 30° b.l. (t)	Oblique sea 30° s.l. (t)	stern sea b.l. (t)	stern sea s.l. (t)
1.4 ~ 1.7	5.0 ~ 8.0	B.L.	ny.b.l. st.b.l.	<55 broken	<25 <27	<68 /	<45 /	≦20 may be broken	≦10 ≦8	≦10 ≦75	≦8 ≦6
		F.L.	ny.b.l. st.b.l.	<31 broken	<11 <5	/ /	/ /	≦5 /	≦6 /	≦10 /	≦10 /
1.9 ~ 2.5	5.0 ~ 8.0	B.L.	ny.b.l. st.b.l.	<67 broken	<27 <35	<145 /	<75 /	≦25 broken	≦15 ≦10	≦10 ≦135	≦6 ≦8
		F.L.	ny.b.l. st.b.l.	<59 broken	<20 20	/ /	/ /	≦10 /	≦14 /	≦10 /	≦13 /
1.1 ~ 1.15	9.3 ~ 11.0	B.L.	ny.b.l. st.b.l.	<134 /	<69 /	<80 /	<75 /	/ /	/ /	/ /	/ /
		F.L.	ny.b.l. st.b.l.	<45 broken	<25 <10	/ /	/ /	/ /	/ /	/ /	/ /
1.4 ~ 1.6	9.3 ~ 11.0	B.L.	ny.b.l. st.b.l.	broken broken	<92 <49	<96 /	<123 /	≦10 broken	≦5 ≦14	≦7 ≦105	≦15 ≦16
		F.L.	ny.b.l. st.b.l.	<88 broken	<20 <15	/ /	/ /	≦35 /	≦10 /	≦8 /	≦22 /
1.9 ~ 2.4	9.3 ~ 11.0	B.L.	ny.b.l. st.b.l.	/ /	/ /	/ /	/ /	≦27 broken	≦45 ≦20	≦20 may be broken	≦20 ≦15
		F.L.	ny.b.l. st.b.l.	/ /	/ /	/ /	/ /	≦38 /	≦18 /	≦12 /	≦20 /

B.L.:ballast loading　　ny.b.l.: nylon breast line

F.L.: full loading　　st.b.l.steel breast line

Tab.4

Wave height H(m)	Wave period T(S)	Condition of Loading and Mooring		Outside beamsea Emax (tm)	Inside beamsea Emax (tm)	Obliquesea Emax (tm)	Sternsea Emax (tm)
1.4 ~1.7	5.0 ~8.0	B.L.	ny.b.l.	< 420	< 260	< 40	< 16
			st.b.l.	< 660	—	< 55	< 13
		F.L.	ny.b.l.	< 320	—	< 30	< 20
			st.b.l.	< 370	—	—	—
1.9 ~2.5	5.0 ~8.0	B.L.	ny.b.l.	< 680	< 143	< 75	< 16
			st.b.l.	< 1950*	—	< 80	< 22
		F.L.	ny.b.l.	< 570	—	< 50	< 28
			st.b.l.	< 450	—	—	—
1.1 ~1.15	9.3 ~11.0	B.L.	ny.b.l.	< 830	< 330	—	—
			st.b.l.	—	—	—	—
		F.L	ny.b.l.	< 450	—	—	—
			st.b.l.	< 420	—	—	—

1.4 ~1.6	9.3 ~11.0	B.L.	ny.b.l.	≦1520*	≦ 360	≦80	≦17
			st.b.l.	≦1930*	—	≦95	≦22
		F.L.	ny.b.l.	≦1370*	—	≦95	≦27
			st.b.l.	≦1010*	—	—	—
1.9 ~2.4	9.3 ~11.0	B.L.	ny.b.l.	—	—	≦140	≦21
			st.b.l.	—	—	≦320	≦37
		F.L.	ny.b.l.	—	—	≦180	≦29
			st.b.l.	—	—	—	—

*When Emax⇒1000 t.m., the data is usually not true, because Eexp.⇒ (Efen.) crit.

Tab.5

direction of waves	wave height H(m)	mean Period T (s)
E,ENE,NE	≦ 1.0	< 6
other direction of waves	≦ 1.5	< 7~8

Tab.6

No of cylinder piers	direction of vibration	nat.freq, f	ratio of damping ζ
No 1 pier of connecting bridge	per. to axis	1.98	0.06
	par. to axis	2.16	
No 2 pier of connecting bridge	per. to axis	2.36	
	par. to axis	2.44	
No 3 pier of con.bri.	per. to axis	2.34	0.044
	par. to axis	2.49	
No 8 pier of jetty (before constructed)	per. to axis	2.06	0.060
	par. to axis		

per.: perpendicular   par.: parallel.

Tab.7

η		1.208	1.0	0.8	0.6	0.4	0.2
first mode of vib.	Y (η) meas.by acc. meter type SHQ-8A	1	0.740	0.622	0.445	0.334	0.289
	Y (η) meas.by acc. meter type DS-1	1	0.800	0,609	0.376	0.184	/
	Y (η) (cal.)	1	0.813	0.626	0.448	0.279	0.125
Second mode of vib.	Y(η) (cal)	-1	0.281	1.500	2.130	1.980	1.140

Tab.8

loading condition	mode of. vib.	curve of vib. mode	nat. freq. f (s^{-1})	exp. ratio of damping δ	duration of damping(s)
whole bridge 316 t.	1st mode	antisym.	1.58	0.122	11.9
	2nd mode	sym.	2.33	0.134	7.7
whole bridge 388 t. (with 5 pipelines)	1st mode	antisym.	1.48		
	2nd mode	sym.	2.18		
whole bridge 460 t. (with 10 pipelines)	1st mode	antisym.	2.14	0.205	5.4
	2nd mode	sym			

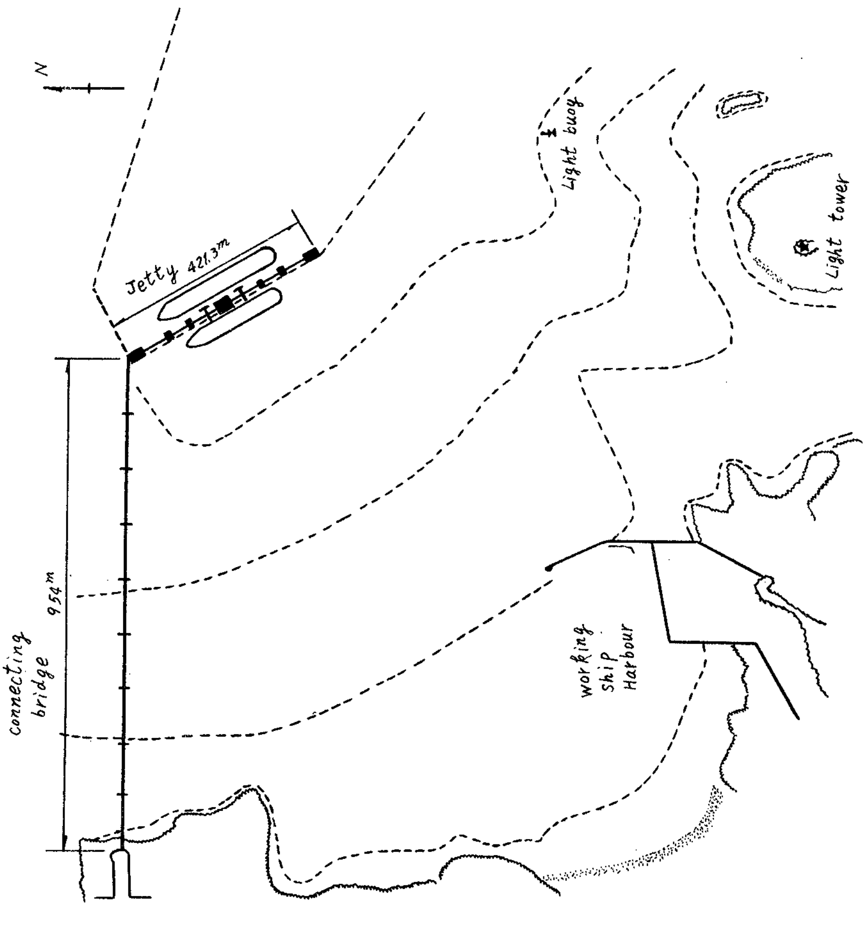
N
Jetty 421.3m
Light buoy
Light tower
connecting bridge
954m
working ship Harbour

Fig 1

Fig 2

Fig 3

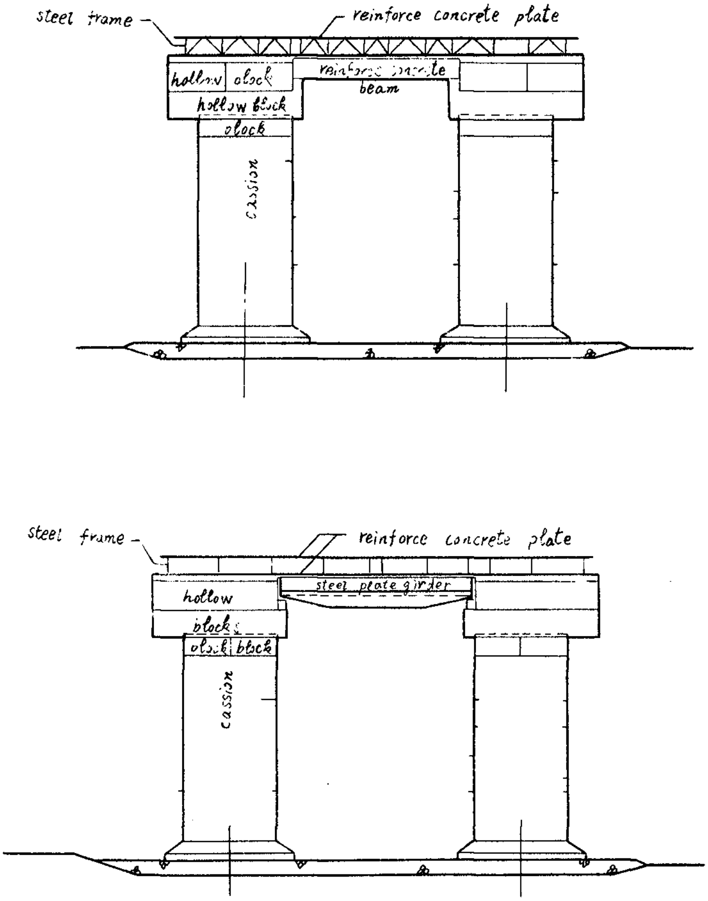
steel frame
reinforce concrete plate
hollow block
reinforce concrete beam
hollow block
block
cassion
steel frame
reinforce concrete plate
steel plate girder
hollow
blocks
block block
cassion

Fig 4

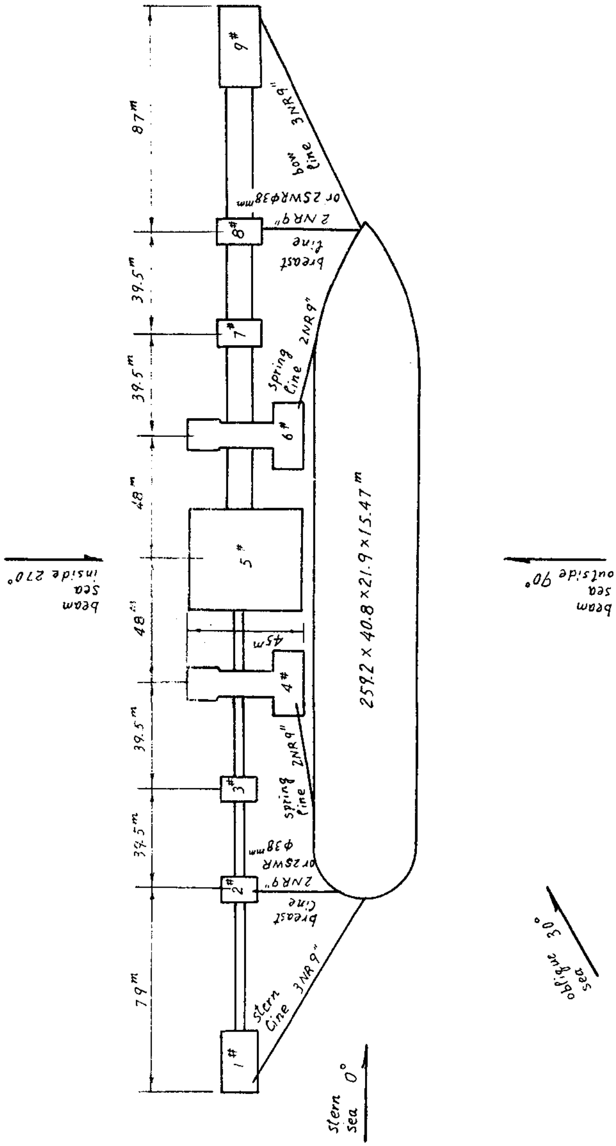
9#
8#
7#
6#
5#
4#
3#
2#
1#
87m
39.5m
39.5m
48m
48m
45m
39.5m
37.5m
79m
bow line 3NR9"
2NR9" or 2SWRφ38mm
breast line
spring line 2NR9"
259.2 × 40.8 × 21.9 × 15.47m
spring line 2NR9"
2NR9" or 2SWR φ38mm
breast line
stern line 3NR9"
beam sea inside 270°
beam sea outside 90°
oblique sea 30°
stern sea 0°

Fig 5

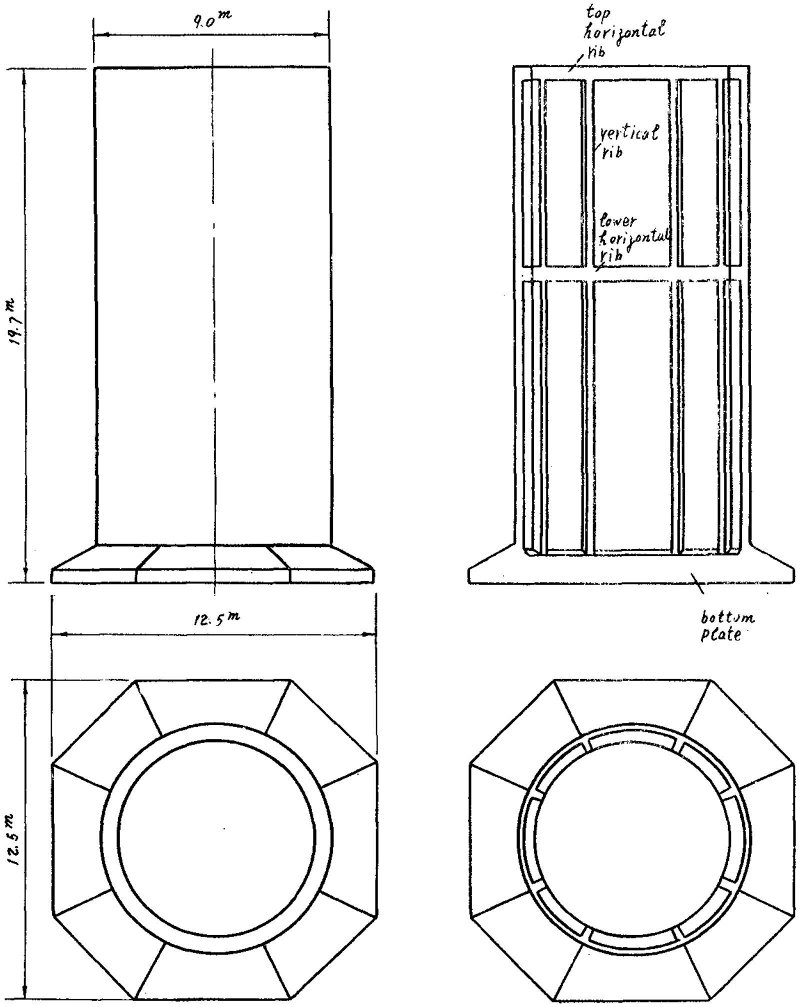
9.0 m
19.7 m
12.5 m
12.5 m
top horizontal rib
vertical rib
lower horizontal rib
bottom plate

Fig 7

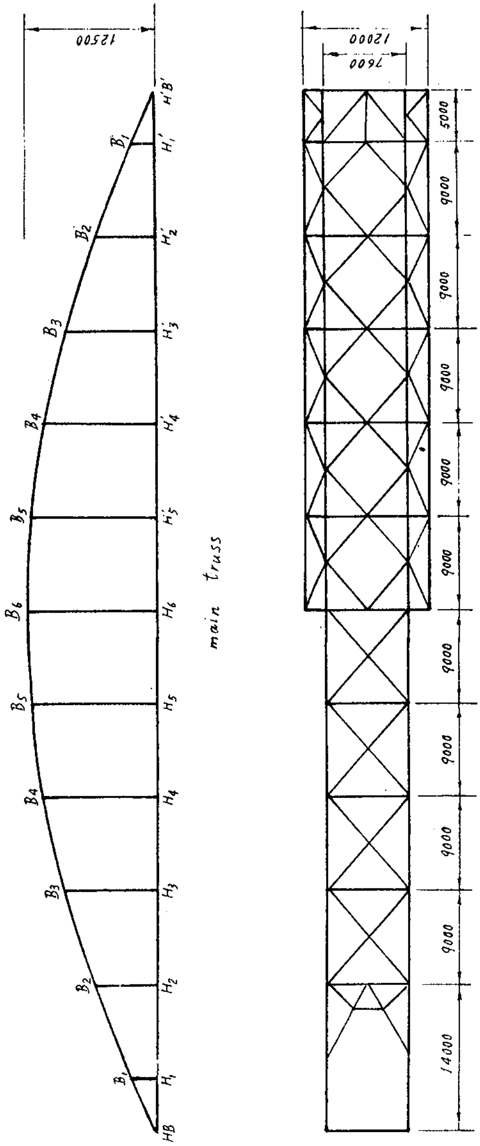

Fig 8

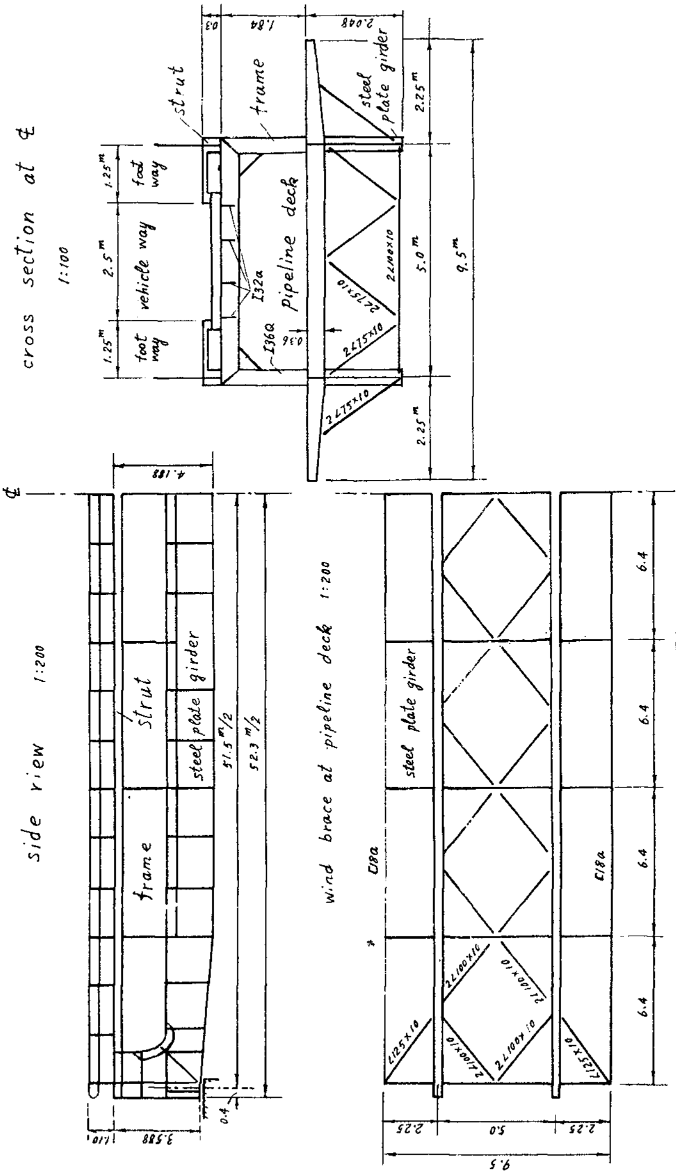
cross section at ℄
1:100
strut
frame
foot way
vehicle way
pipeline deck
steel plate girder
I32a
I36a
1.25m
2.5m
5.0m
9.5m
2.25m
side view 1:200
strut
steel plate girder
frame
51.5m/2
52.3m/2
wind brace at pipeline deck 1:200
steel plate girder
[18a
6.4
2.25
5.0
9.5

Fig 9