CHAPTER 4: ENGINEERING FOR WATER TRANSPORTATION

EARTHQUAKE DAMAGE TO SEA HARBOR WHARVES AND SHORE SLOPES

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When the Tangshan earthquake occurred the seismic intensities at the Port of Qinhuangdao and at the Port of Tianjin were rated VII and VIII respectively. The distance from these two ports to the epicenter was approximately 123 km and 82 km respectively (before this earthquake the intensities at these two ports were stipulated to be at a rating of VI). The earthquake damage at the Port of Tianjin was more serious than at the Port of Qinhuangdao. The following will recount the earthquake damage to the hydraulic structures at these two ports.

I. Docks at the Port of Qinhuangdao

1. General situation

The Port of Qinhuangdao is situated on the northwest coast of Bohai Bay. The plan of the port is shown in Fig. 1.

The Port of Qinhuangdao is based on Quaternary marine and river deposits. The lower base rock consists of a weathered granite and is overlaid with residual soil, silty clay, gravel and silt. Because of good geological conditions, in recent years the dock structures were mainly gravity caisson wharves. The water depth in front of the wharf is 6-12 m. The level of the wharf surface is +4 m. The wharf was constructed as follows: prefabricated reinforced concrete caissons were floated and settled onto rubble bedding and filled with sand and rock, then the top of the caisson and the concrete breast walls were constructed and the back of the caissons was refilled with sand and gravel. Protection from waves was provided by a mound breakwater or a concrete caisson type breakwater. Outside the breakwater concrete blocks were set irregularly to absorb wave energy and protect the breakwater slope. The data for the dock at the Port of Qinhuangdao is given in Table 1.

2. Earthquake damage

After the Tangshan earthquake damage to the No. 1-No. 9 piers, Pier A, the Crude Oil Pier and Fuel Oil Pier was investigated. It was found that the caissons of the piers dislocated and on the surface of the piers and pavement of the rock mole occurred 24 longitudinal cracks. But the damage was slight and did not influence the use of the piers.

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(1) Pier A (Fig. 2)

At the front part of the pier on the concrete surface there was a crack about 0.5-1.0 cm wide on the west side along the edge of the caisson and a crack 1-2 cm wide on the north side. There was a dislocation of about 2 cm between the wharf front of Pier A and the outer edge of the corner caisson, and a dislocation of 1 cm between the outside edge of the pier and corner caisson (Fig. 3).

(2) The first stage project of the Crude Oil Pier

This pier has nine pier shafts (8 spans) and each shaft consists of two caissons which are settled transversely. During the earthquake, due to non-uniform subsidence and inclination to the inside of the two caissons, the upper concrete pavement was pressed and buckled and the concrete pavement was damaged at the top of the No. 7 pier shaft.

The mound approach dike was built in 1974 at a total length of 746.7 m. The width of the dike top is 6 m, the bottom elevation is -5 m to -5.6 m, the elevation of the dike top is +4 m; the obliquity of both side slopes is 1:1.5 and they are protected with a slope pavement of hollow concrete blocks 1-2 tons in weight. After the earthquake, at the top of the dike at a distance of 180 m from the root of the dike two longitudinal cracks occurred about 4 cm wide and 520 meters long running south to north (Fig. 4).

(3) The Fuel Oil Pier

The inside of the pier is used to berth vessels and the outside is used as a sea wall. After the earthquake the original 1 cm expansion joint between wharf caissons widened to 4 cm.

II. Docks at the New Port of Tianjin

1. General situation

The New Port of Tianjin is located to the west of Bohai Bay and at the north bank of the Haihe River estuary. The channel and wet slips were dredged. At both sides of the channel there are the north and south breakwaters, their total length is about 15,000 m. Up until the Tangshan earthquake 24 deep sea berths had been built (Figs. 5 and 6).

(1) Circumstances of engineering geology

The New Port of Tianjin is seated on a marine sedimentary deposit (Holocene Epoch) and on an alluvial deposit of estuary delta; the thickness of these deposits is about 10 meters. There is artificial filled land distributed over the earth’s surface varied in thickness. The soil layer distribution from top to bottom is:

1) Artificial filled land.

It has a surface elevation of +4.6 to +2.0 m. The fill was mainly placed by jetting. The soil constitution is silty clay. During the jetting process the soil grains decomposed; farther away the soil grains are smaller.

2) Marine deposit.

It is distributed over an extensive range and is very thick (at the port area it is about 15 m). The natural moisture content is larger than the liquid limit. The porosity ratio of the upper soil is larger than 1.5 and the lower is larger than 1.0. It is not very compact and the sensitivity is rather high. It consists of silt and silty clay with thin sand layers.

3) Alluvial deposit of the estuary delta.

Generally, it is cohesive soil and silty sand. The cohesive soil is mainly silty clay and has the feature of horizontal stratification and cross-stratification mixed with a lens of clay. This deposit can be divided into two layers: a) yellow-brown silty clay 5 to 6 m thick with a distinct bedded structure in a normal pressure and density state, a layer of silty sand distributed between the elevation of –14 to –15 m, in a medium pressure and density state; b) brown silty sand layer with a bedded structure, the silty sand layer is mingled with the clay layer, at an elevation of –21 m there is a fine sand layer with a dense texture which is a good supporting layer for piles.

The physical properties of the above mentioned soil layers are listed in Table 2.

After the earthquake the strength, deformation and pore water pressure of the soil was observed and compared with their pre-earthquake data.

1) Change in soil strength

The change in soil strength and compactness are main factors affecting the stability of a slope. After the earthquake borings were made on berth No. 13, No. 14, No. 18, and No. 19 respectively, and vane-shear tests were made in-situ three times. In addition, at the center parts of pier No. 1 and No. 3 two borings were drilled respectively and the undisturbed soil samples were taken out of the dynamic strength test. The results of the vane-shear test are given in Table 3. It is seen from Table 3 that except for a few cases the vane-shear strength of the soil at the New Port of Tianjin before and after the earthquake did not change.

The test results of the dynamic strength of soft clay at the New Port of Tianjin are given in Table 4. It is seen from Table 4 that the values of static and dynamic strength of soft clay at the New Port of Tianjin are similar.

To sum it up, under the earthquake effect of intensity VIII, the strength of the soft clay at the New Port of Tianjin did not change significantly.

2) Deformation of soil layer

At the sand drain testing area at the No. 2 pier of the New Port of Tianjin the vertical and horizontal deformations of the soil layer before and after earthquake were surveyed. The survey results are as follows:

a) Vertical deformation-settlement. At the test site there were a set of six observation points. The observation results showed that each soil layer had settled various amounts in which the settlement of the upper layers was larger than the lower ones. The settlement values at the observation points are shown in Fig. 7. For the soil layer of poorer quality the average settlement under the action of the earthquake force was larger for example, the elevation −1.0 m of soft soil layers above the average settlements was 0.6 cm/m.

b) Horizontal deformation-lateral displacement. At the test site there were 9 clinometers set at different depths. The results of the survey show that after the earthquake each soil layer had laterally displaced (toward seaside) to various extents with the displacement value increasing with the depth of the soil layer (Fig. 8).

3) Change in pore water pressure

After the earthquake at the sand drain test area the pore water pressure was surveyed many times. The results of the survey are shown in Fig. 9.

(2) Structural pattern of wharves

According to the ground condition the docks adopted a pile foundation except for the No. 1 to No. 4 berths, which were sheet pile bulkhead wharves, and the No. 6 berth was a dolphin type wharf, the berths were all wharves of a high pile supporting platform structure. The structural type of this kind of wharf can be divided into a girderless deck structure and a beam-slab structure and according to the situation of the platform it can be divided into two parts i.e., front platform and rear platform. The front platform bears vertical loads of transport machinery and loading and unloading facilities and the horizontal load bears the mooring force of ships as well; the rear platform bears only vertical loads from stacking cargo. The total width of the platform is 33-51 m of which the front platform is 13.5 m wide. Under the platform a pile bent is set every 3.5-7.0 m along the longitudinal section and each pile bent of the front platform contains a couple of crossing piles. All the beams and slabs of the rear platform are supported on the pile cap of a vertical pile.

2. Earthquake damage

(1) General situation

Damage to the wharf structure, in general, was less than that to local buildings. For convenience of statistical analysis, according to the damage extent and degree of difficulty of repair, damage to the wharf is divided into 4 classes as follows:

Class I, seriously damaged: The wharf collapsed or the whole platform had large displacements. The main structure is seriously damaged and is difficult to repair.

Class II, heavy damage: The upper structure is damaged to various extents; the whole platform is not displaced; piles and retaining walls have more damage but can be repaired.

Class III, slightly damaged: The upper structure is basically not damaged; the whole platform is not displaced; piles and retaining walls are slightly damaged and are easy to repair.

Class IV, intact or basically intact: The upper structure is not damaged; the whole platform is basically not deformed; piles and retaining wall are slightly damaged or intact and there is little need for repair.

The total length of the wharf berth at the New Port of Tianjin is 4,907 m (including three specialized marine terminals in the New Port District). According to the above classification, the earthquake damage to wharves at the New Port of Tianjin is as follows:

Class I	0 m	amounts to	0%
Class II	1,106 m	amounts to	22.5%
Class III	1,320 m	amounts to	26.9%
Class IV	2,481 m	amounts to	50.6%

The investigation of earthquake damage to docks at the New Port of Tianjin is given in Table 5.

(2) Change in bottom slope of wharves and phenomenon of sandboils and waterspouts in the landslide area

After the earthquake the cross-section of the bottom slope under the platform of each berth was surveyed. A comparison with the pre-earthquake data shows that the bottom slopes did not slip and were basically stable but settled and moved forward slightly. The average settlement was 13 cm; the settlement at the lower part of the slope was larger and individual parts reached 120 cm. The water depth in front of the wharf did not change. After the earthquake the Tianjin Channel Bureau made a waterside survey of all harbor basins. The results of the survey show that apart from wharf frontage of about 25 m the bed level rose 10 cm on average.

After the earthquake a slope failure occurred at the corner of the No. 4 harbor basin 90 m in length when the tide level fell from +3.0 m to +0.5 m. This was the only section that had slope failure at the New Port of Tianjin during the earthquake. The wharf had not been constructed yet on this shoreline. The slope of this shore was identical to the neighboring shore but the soil strength at this location was somewhat low. According to the survey data the safety factor of stability of this shore slope is only 0.8 while the safety factors of shore slope stability under other wharves are all larger than 0.8.

After the earthquake sandboils and waterspouts occurred at nearly 100 places in the wharf area. Witnesses said that about 3-4 minutes after the earthquake water was spouting from the ground surface; the waterspouts in general were 1-2 m in height, the highest reached 3-4 m and lasted about 5 to 6 hours, some individual waterspouts lasted more than 2 days. At the same time sand boiled out from under the ground and piled up in small heaps, their height was generally 5-20 cm; some individual ones reached 40 cm. At the middle strip of the No. 1 and No. 3 piers groups of spouting holes occurred which covered a large area. The interval between spouting holes was larger but the quantity of spouting sand was less (Photo 1). At the rear landslide area at the wharf the waterspouts and sandboils basically occurred in the underlying sand layer, which existed underground about 1 to 5 meters in depth. This sand layer was loosely consolidated and the low number of the standard penetration test was smaller than the critical value.

(3) Connecting structure with shore

At the No. 14 to 18 berths sand well drains were set in the shore slope below the platform to drain off water contained in the soft soil and increase soil strength. On this soft soil a rubble-mound was piled and then the retaining wall was constructed. After the earthquake all retaining walls settled 15 to 25 cm, inclined backwards and were separated from the rear platform. This phenomenon was more serious at the end of the pier; its settlement reached 52 cm (Fig. 12).

The retaining wall at the north end of the No. 20 berth was built on a rubble-mound. After the earthquake the retaining wall settled about 42 cm and slipped forward and pressed against the rear platform resulting in a break in the retaining wall with a breach 12 cm wide and dislocation of 18 cm. Simultaneously 4 surfaces in contact with the vertical pile caps under the rear platform with the beam were opened and the opening facing the bank reached 3 cm. The vertical piles inclined backward and several cracks appeared on the pile shaft (Fig. 13).

The retaining structures of the No. 7 to No. 13 berths were sheet pile walls with inclined bearing pile type structures. The inclined bearing piles were fixed in the capping beam of the sheet pile wall. The back of the sheet pile wall had been filled with sand with a depth of about +3.5 m. During the earthquake waterspouts and sandboils occurred and the sheet pile had obvious bending deformation and the steel frame of the xenon lamp on the top of the sheet pile wall inclined also (Fig. 14).

On the shaft of inclined bearing piles original thin cracks widened and three new cracks occurred about 0.5 cm in width. At the bank side of the inclined bearing piles the concrete split, crushed and fell, the split length was about 1 m and the longest reached 2.5 m (Photo 2). According to the statistics, the damaged inclined bearing piles amounted to 95% of the total of the seven berths.

Moreover, at the No. 21 berth the inclined bearing piles were hinged with a capping beam. At the back of the sheet pile wall the depth of filling sand was +2.0 m only. The bending deformation of sheet piles was similar to the other berths but was irregular.

(4) Platforms

1) Pile footings

The crossing piles below the front platform of the wharves were vulnerable. Table 6 gives the data of the investigation. The main damage to crossing piles was that at the outer side of the inclined bankward piles open cracks occurred on the inner side (Photo 3).

In order to make clear the damage situation to the piles under the sea floor, in 1980 two inclined piles were selected for observation. A hole was drilled along each pile shaft from the wharf surface downwards then, with a submerged television camera the damage was observed. Due to deviation of the drill hole the depth of observation was only 9 m (measured from the wharf's surface). The observation results are as follows:

(a) On the two-pile shaft below the pile cap cracks were observed in the drill hole which corresponded to the cracks outside one by one.

(b) For any pile cap damaged the concrete in the drill hole cracked largely, even breaking and forming a cavity after boring.

(c) The quality of workmanship for the connection of the pile shaft with the pile cap was poor, cavities and honeycombs formed in the concrete. At the connection of plates with beams and beams with the pile cap there was the same phenomena.

For the pile caps of crossing piles, light damage was breaking of the pile cap and heavy damage was the crushing of concrete in the pile cap and exposure of reinforcement bars (Photo 4).

When a pile cap broke into two parts the bankwards inclined pile with the rear half of pile cap became an independent unit and turned downwards a little and so it separated from the beam (plate) and a gap occurred between them. As a result, all the upper loads were born by the batter pile inclined forward.

The vertical piles under the front and rear platform were seldom damaged. Damage to vertical piles below the rear platform are as follows:

(a) Pile cap split. For example, the pile cap of the vertical pile under the rear platform at berth No. 9 was split (Photo 5). This was due to an overload of sand on the top of the pile cap.

(b) If the bank slope and retaining wall moved forward the vertical pile near the bank slope under the rear platform cracked (Fig. 13).

2) Old wharves having had no maintenance

The old berths, which had long been out of repair before the earthquake, were damaged heavily by the earthquake. For example, at berth No. 14 and 15 the wharf surface plate was a Type Π plate beam structure. Before the earthquake the concrete had already cracked due to shrinkage as well as improper construction methods of the rock revetment, and in the bank slope large deformations occurred.

When these berths were completed 21 pile caps of crossing piles under the front platform had cracked and in 1975 the number of cracked pile caps had increased to 41. After the earthquake 46 pile caps, which were investigated, all had cracked. At the same time 46 batter piles inclined forward and all cracked or broke (reinforcement in the piles did not break); 4 rows of vertical piles in front of the crossing piles also cracked.

Because the concrete pile cap of the crossing pile broke (the reinforcements still connected), the batter piles inclined forward and pushed up the crossbeam, which made the two pile caps of the vertical pile in the middle of the crossbeam separate from the crossbeam. The crossbeam span increased and the crossbeam cracked at the middle of the span (Fig. 15). The investigation showed that there were 28 crossbeams that separated from pile caps and 12 crossbeams that cracked.

3) Influence of ship berthing and loading on damage to the wharf

During the earthquake 15 vessels were berthed along the wharves of the New Port of Tianjin. A cargo ship “Panalias” of 10,000 tons, in which half of its cargo was unloaded, moored at berth No. 13. Both the crossing piles under the mooring posts which were fastened by the head line and stern line of the ship cracked, but the crossing piles under the mooring posts which were not fastened by any ropes were intact. During the earthquake the portal cranes on the front platform did not overturn, but several cranes were derailed. Although the cranes were large and weighed 120 tons each (the weight of a section of the front platform is about 1,900 tons), they did not significantly influence the damage to the front platform and all the longitudinal beams under the portal crane were intact.

Bulk cargoes on the wharf surface had a direct influence on damage to the crossing piles below the front platform. Big bulk cargoes seriously damaged the structure. The load of stacked cargo on the platform increased the horizontal earthquake force, which was transmitted to the front platform and thus intensified the damage to the crossing piles. Under the rear platform there were all vertical piles and the beam and slab were simply-supported on the cap of the vertical pile. At points of overload of stacking cargo the pile caps were damaged, however the pile shafts above the seabed were intact. For pile shafts under the seabed two vertical piles had been checked with a drill hole and submerged television and no cracks were found. For example, at the 9th berth the stacked sand was 8 m in height, the average load was 6-7 t/m^2 (the largest reached 10 t/m^2); and at the 18th berth the stacked salt was about 7-8 m in height, the average load was 3 t/m^2 (the largest reached 6 t/m^2). The pile foundation under the front platform of these two berths was seriously damaged. The results of the investigation of stacked load distribution during the earthquake and damage to the pile foundation of the 9th to 11th berths are shown in Fig. 16.

4) Displacement and settlement of the wharf

After the earthquake the expansion joint between the front and rear platform changed. Some expansion joints widened about 3-5 cm and some were squeezed tightly together and the wood lath left in the joint was squeezed out. Bending deformation occurred at both the portal crane runway and railway at the expansion joint, the deflection in general was 3-6 cm and the biggest reached 7.5 cm. The concrete surface at the jetty head and jetty root was generally damaged and the jetty head was twisted.

The wharf did not move seawards apparently. No dislocation was found between sections of the berths. Comparing the data from 1973 to 1975 the wharf surface on average settled about 5.7 cm, the biggest was 7.2 cm.

(5) Sheet pile wharf

Berth Nos. 1 to 4 at the New Port of Tianjin are steel sheet pile wharves. They were constructed in the 40's. The water depth of the wharf side was originally 6.5 m. In 1951 it was increased to 8.5 m and the structure was reconstructed to a sheet pile wall with double anchor ties (Fig. 17). After the earthquake on the ground surface at the front and rear anchor wall had two longitudinal cracks which were parallel to the wharf. The crack at the top of the rear anchor wall (about 28 m from the wharf front line) was 380 m long and 6 cm wide; the crack at the top of front anchor wall (about 20 m from the wharf front line) was 250 m long and 5-8 cm wide.

(Translator: Qiu Ju)

Table 1. Data of docks at the Port of Qinhuangdao.

Name of Berth	Small Pier		Large Pier					Pier B		Pier A	Crude Oil Pier		Fuel Oil Pier
	1	2	3	4	5	6	7	8	9		First Stage Project	Second Stage Project	
Structural Type	frame type	frame type	frame type	frame type	frame type	frame type	frame and 60 m gravity wall	caisson gravity	caisson gravity	gravity wharf of caisson	pier of caisson construc-tion	pier of caisson construc-tion	gravity wharf of caisson
Length (m)	123.5	123.5	87.3	107.3	151.7	151.7	151.7	200	200	463.6	278.5		250
Width (m)	20.7	20.7	22	25	25	20	17.6	300	300	182.9	20		9.34
Water Depth (m)	6.0	6.0	6.2	7.4	9.0	9.0	8.8	10.76	10.76	12.5	11.0-14.0		
Type of Terminal	finger pier		pier, the outside of pier is slope revetment					marginal wharf		pier, the outside of pier is break-water	finger pier		pier
Year of Construc-tion	1900	1900	1901	1901	1903	1907	1954	1962	1962	1976	1973	in 1976 it was under construc-tion	1976

Table 2. Properties of the soil layers at the New Port of Tianjin.

Item	Name of Soil Layer			
	Silt	Silty Clay	Silty Clay	Silty Fine Sand
Elevation of indexes (m)	+2.0 – -2.0	-2.0 – -13.5	-13.5 – -21.0	-21.0
Natural moisture content (%)	54.6	49.0	27.4	19.2
Natural bulk unit weight (g/cm^3)	1.68	1.73	1.94	
Natural porosity ratio	1.56	1.36	0.77	0.57
Plastic index (%)	22.0	22.0	13.5	
Liquid index (%)	1.50	1.23	0.74	
Compressibility coefficient (cm^2/kg•f)	0.133	0.119	0.029	
Inner friction angle of fast shear (degree)	4	4	14	
Cohesion of fast shear (kg•f /cm^2)	0.06	0.10	0.19	
Inner friction angle of fast consolidation (degree)	18	15	26	40
Cohesion of fast consolidation (kg•f /cm^2)	0.06	0.10	0.13	

Table 3. Comparison between two values of soil vane-shear strength before and after the earthquake at the New Port of Tianjin.

Berth	Elevation (m)	Soil Layers				
		Silty Clay		Silty	Silty Clay	
		-0.5 — -5.5	— -9.5	— -14.5	above -6.0 m	below -6.0 m
23	before earthquake	0.25	0.23	0.36		
	after earthquake	0.15*	0.22	0.34		
19	before earthquake	0.25	0.22	0.33		
	after earthquake	0.26	0.23	0.34		
15-18	before earthquake				0.364	0.283
	after earthquake				0.359	0.295
13	before earthquake				0.26	0.26
	after earthquake				0.26	0.26

* - The average of two data
Unit: Kg-f /cm^2

Table 4. Comparison between the dynamic and static soil strength after the earthquake at the New Port of Tianjin.

Name of Project	Method of Test	Index of Strength		Index of Physical Property			
		φ (degree)	*C* (kg/cm^2)	*W* (%)	*r* (t/m^3)	*e*	I_P (%)
Dry-dock engineering of Xingang Shipyard	dynamic	19.4	0.17	42	1.78	1.19	19
	static	17.1	0.15	42	1.78	1.19	19
Sloping way-revetment works of Hebei Province Shipyard	dynamic	15.4	0.19	45	1.74-1.77	1.29-1.25	24-27
	static	16.0	0.21	44	1.76	1.25	22
Bank slope under the wharves of the New Port of Tianjin	dynamic	18.6	0.11	40-58	1.65-1.86	1.02-1.63	
	static	18.0	0.11	41	1.80	1.13	16

Note: The symbol of physical quantity is the same as in Table 3.
φ - inner friction angle, *C* - cohesion, *W* - natural moisture content,
r - natural bulk unit weight, *e* - liquid index, I_P - plastic index

Table 5. Damage investigation list of the harbor docks at the New Port of Tianjin.

Name of Berth			Construction Feature	Length (m)	Connecting Structure with Shore	Year of Construction	Class of Damage
No. 1 Wharf		1	sheet pile bulkhead with two anchor ties	170			IV
		2	ditto	170			IV
		3	ditto	170			IV
		4	ditto	170			IV
		5	beam and slab structure	175		1958	II
		6	/	/	/	/	/
No. 3 Wharf	No. 1	7	beam and slab structure	180	steel sheet pile with inclined bearing pile	1974	IV
		8	ditto	180		1974	IV
		9	ditto	175		1974	II
		10	ditto	175		1974	III
		11	ditto	175		1974	III
		12	ditto	270		1973	III
	No. 2	13	ditto	170		1973	III
		14	ditto	188	concrete retaining wall	1961	II
		15	ditto	188		1961	II
		16	structure of girderless deck	170		1960	III
		17	ditto	170		1960	II
		18	ditto	210		1960	II
	No. 3	19	beam and slab structure	180	rock mound	1975	III
		20	ditto	180	ditto	1975	III
		21	ditto	397	steel sheet pile with inclined bearing pile	1975	IV
		22	ditto	175	concrete retaining wall	1975	IV
		23	ditto	175	ditto	1975	IV
		24	ditto	175	ditto	1975	IV
Fuel Oil Pier			beam and slab structure	150		1974	IV
Pier of Xingang		new	ditto	220		1974	IV
Shipyard		old	ditto	149		1958	IV

Table 6. Statistics of damage to crossing piles of the wharf at the New Port of Tianjin.

Number of Berth	Category of Terminal	Investigated Number of Crossing Piles	Earthquake Damage					
			Seriously Damaged		Slightly Damaged		Basically Intact	
			Number	%	Number	%	Number	%
5	mixed cargo	50	18	36	32	64	0	0
7	mixed cargo	34						
8	mixed cargo	27						
9	mixed cargo	32	25	78	5	16	2	6
10	mixed cargo	27	2	7	25	93	0	0
11	mixed cargo	27	0	0	25	93	2	7
12	mixed cargo	36	12	33	19	53	5	14
13	mixed cargo	39	3	7	35	90	1	3
14	mixed cargo	28	18	64	10	36	0	0
15	mixed cargo	18	11	61	5	28	2	11
16	mixed cargo	54	0	0	54	100	0	0
17	mixed cargo	54	36	67	14	26	4	7
18	mixed cargo	56	30	54	25	44	1	2
19	steel material	27	3	11	16	59	8	30
20	steel material	32	8	25	13	41	11	34
21	container	59	8	13	37	63	14	24
22	mixed cargo	27	0	0	24	89	3	11
23	mixed cargo	27	1	4	20	74	6	22
24	mixed cargo	27	0		23	85	4	15

Note: "Earthquake Damage" includes damage to crossing piles and to pile caps.

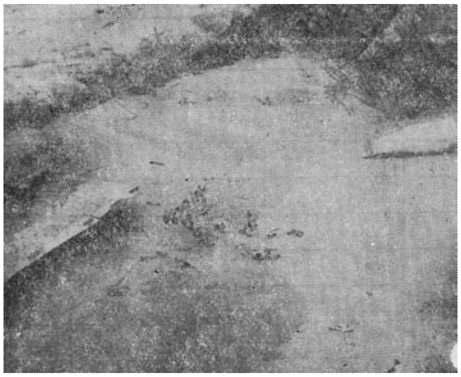


Photo 1. At the New Port of Tianjin there were holes created by waterspouts and sandboils at the rear landslide area of the wharf.

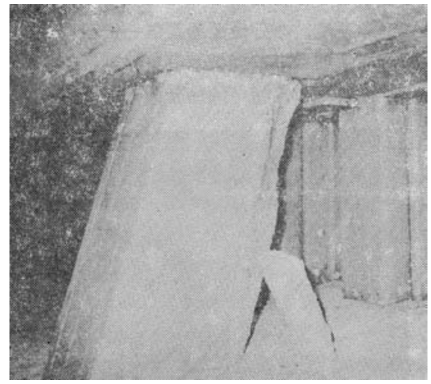


Photo 2. Earthquake damage to inclined bearing pile leaning against the sheet pile wall.

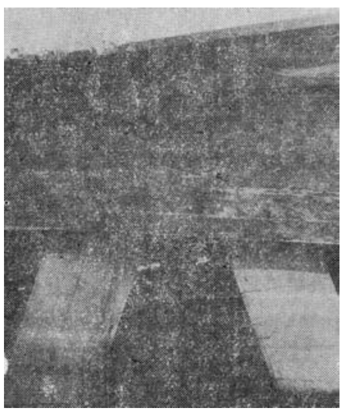


Photo 3. At the New Port of Tianjin there was damage to a crossing pile.

Photo 4. The pile cap of a crossing pile broke and there was disclosure of reinforcements.

Photo 5. The pile cap of a vertical pile under the rear platform broke at the No. 9 berth at the New Port of Tianjin.

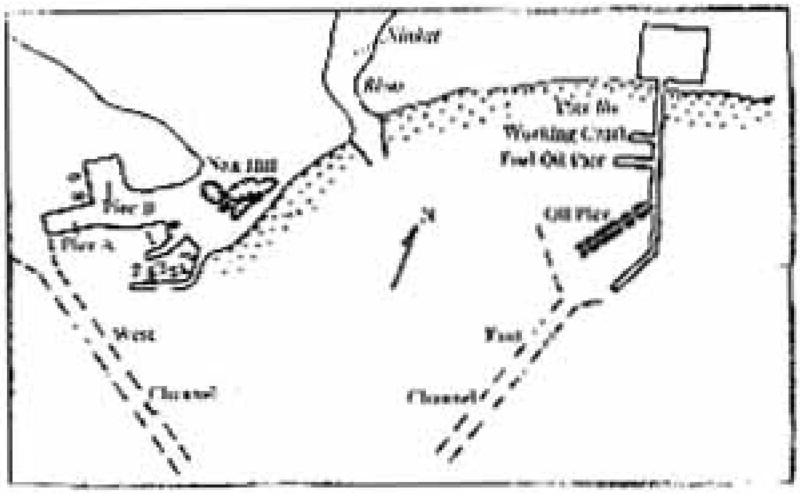


Figure 1. A sketched plan of the Port of Qinhuangdao. (number 1-9 are the code name of berth).

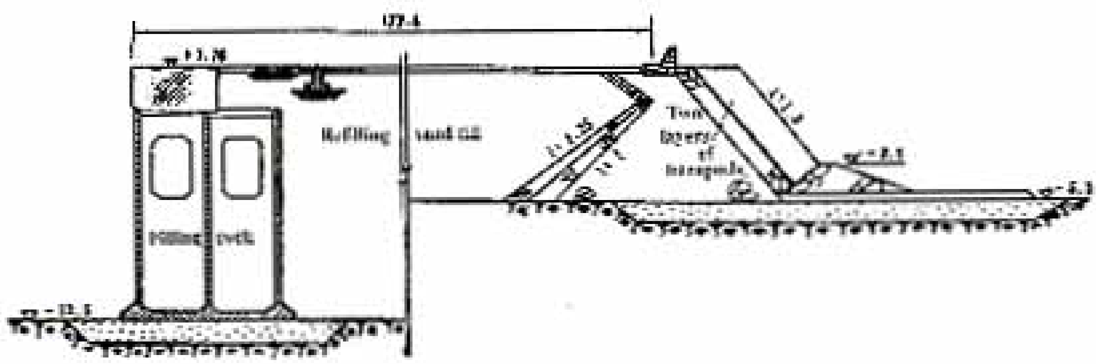


Figure 2. Cross section of pier at the Port of Qinhuangdao (in m).

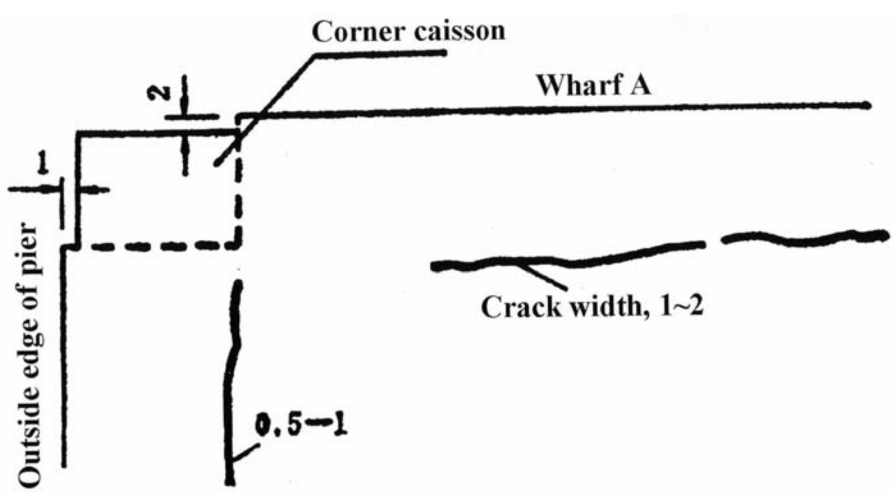


Figure 3. A sketched plan of cracks and dislocations at the corner of wharf A (in cm).

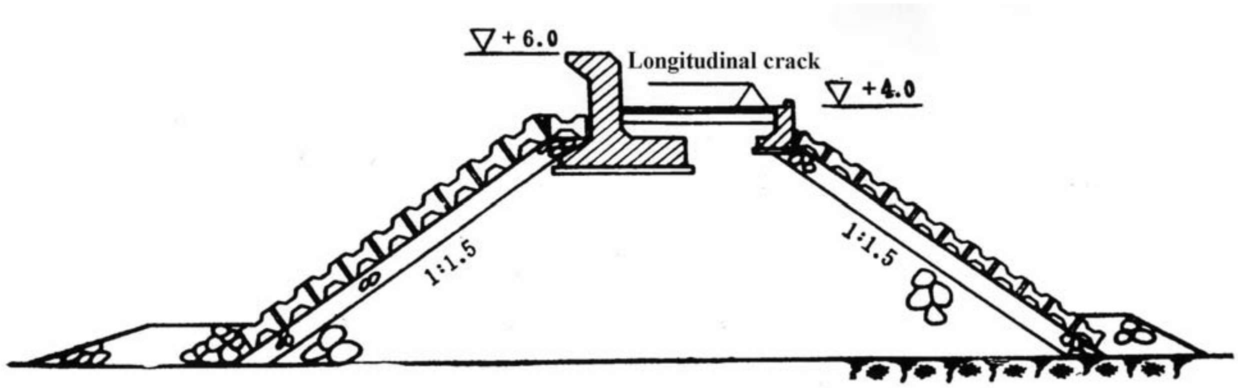


Figure 4. A sketch of the pavement structure of the mound approach dike and position of the cracks. The first stage project of the Crude Oil Pier.

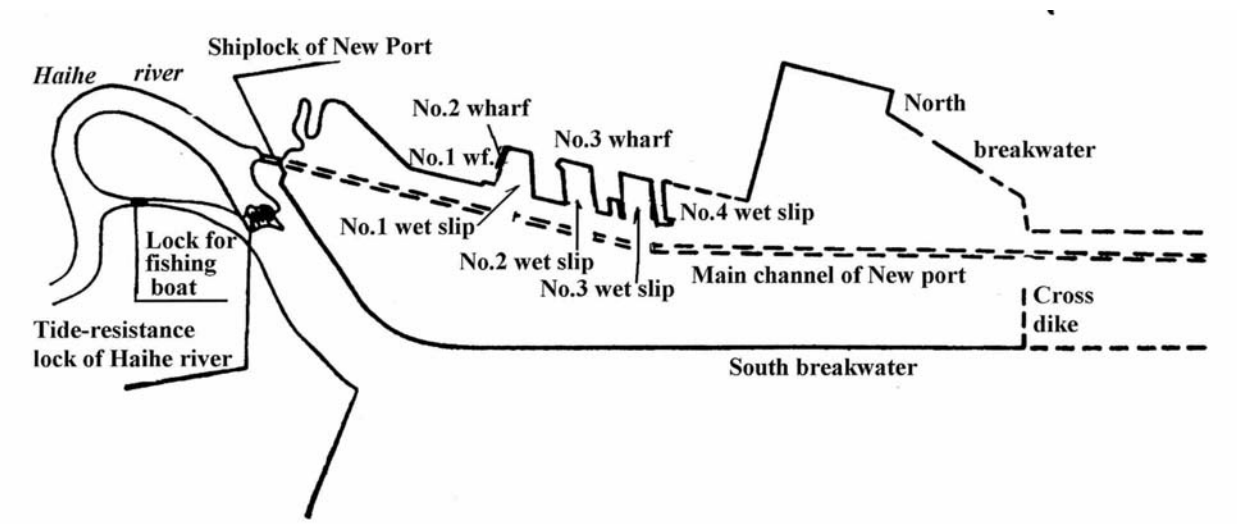


Figure 5. A sketched plan of the New Port of Tianjin.

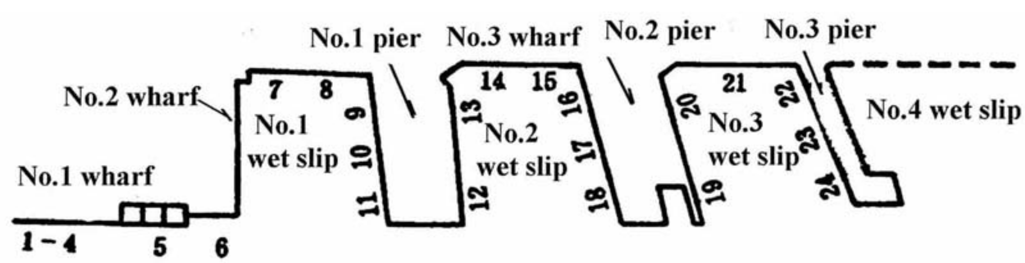
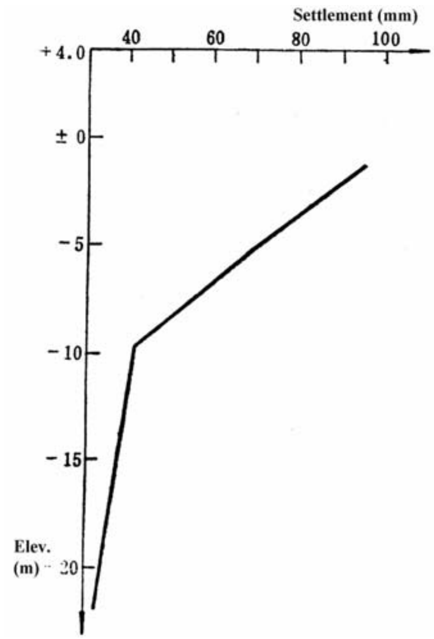


Figure 6. Arrangement plan of berths of the New Port of Tianjin.



No.of survey station	Elevation of survey station (m)	Value before earthquake (m)	Value after earthquake (m)	Settlement (m)
1	+3.5	—	—	—
2	+1.2	−1,208	−1.303	0.095
3	−5.3	−5,306	−5.368	0.062
4	−9.7	−9,705	−9.746	0.041
5	−13.5	−13,502	−13,540	0.038
6	−21.8	−21,800	−21,832	0.032

Figure 7. Curve of settlement at the sand drain test area.

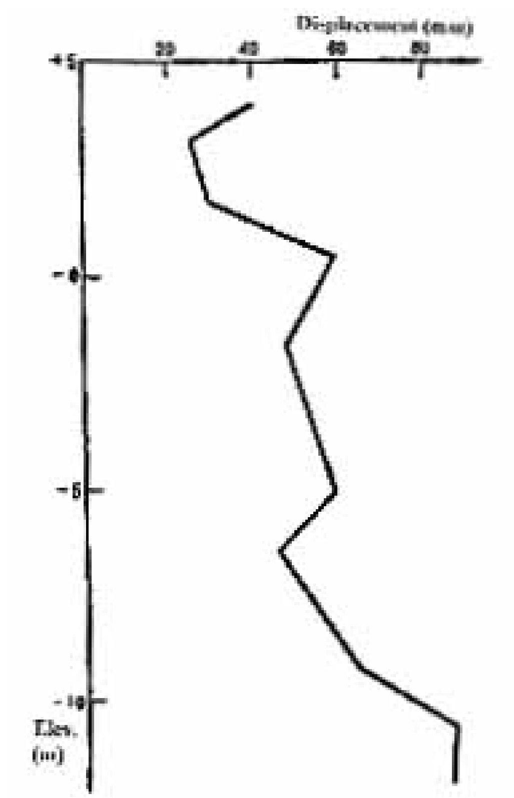


Figure 8. Curve of soil layer displacement at sand drain test area.

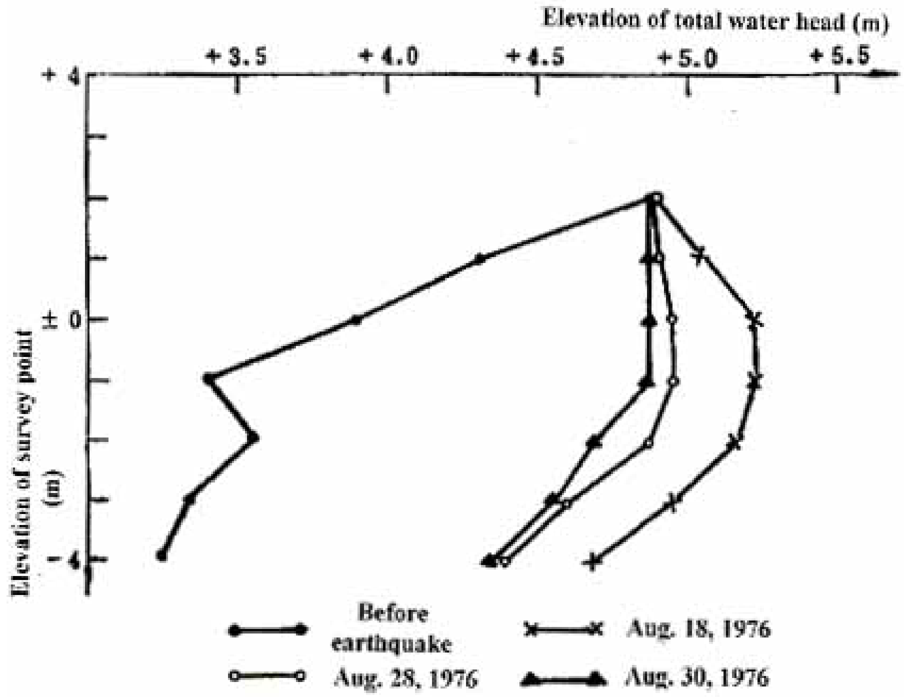


Figure 9. Surveyed results of the ground pore water pressure at the sand drain test area before and after the earthquake.

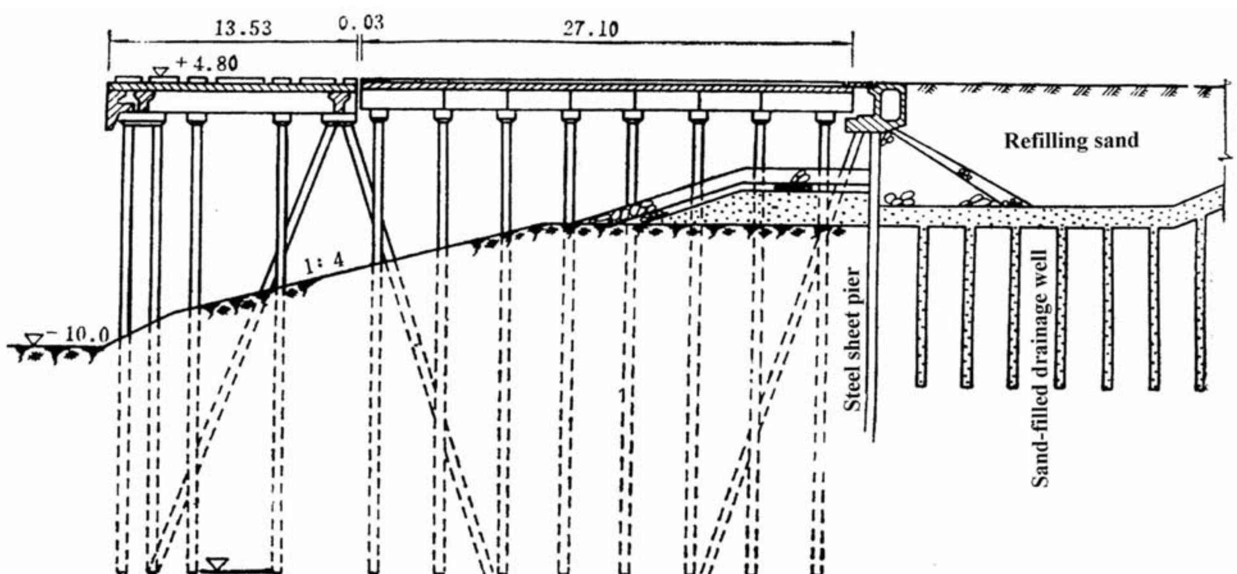


Figure 10. Cross section of No. 9-No. 13 berths at the New Port of Tianjin (in m).

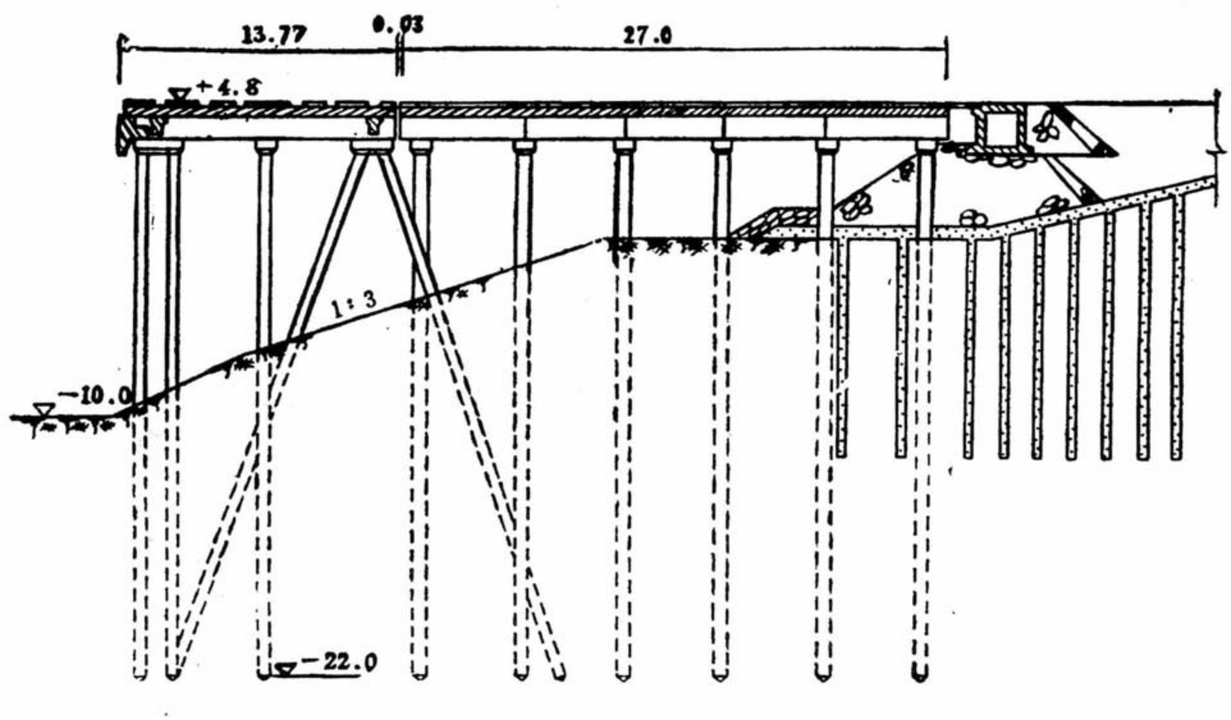


Figure 11. Cross section of No. 22-No. 24 berths at the New Port of Tianjin (in m).

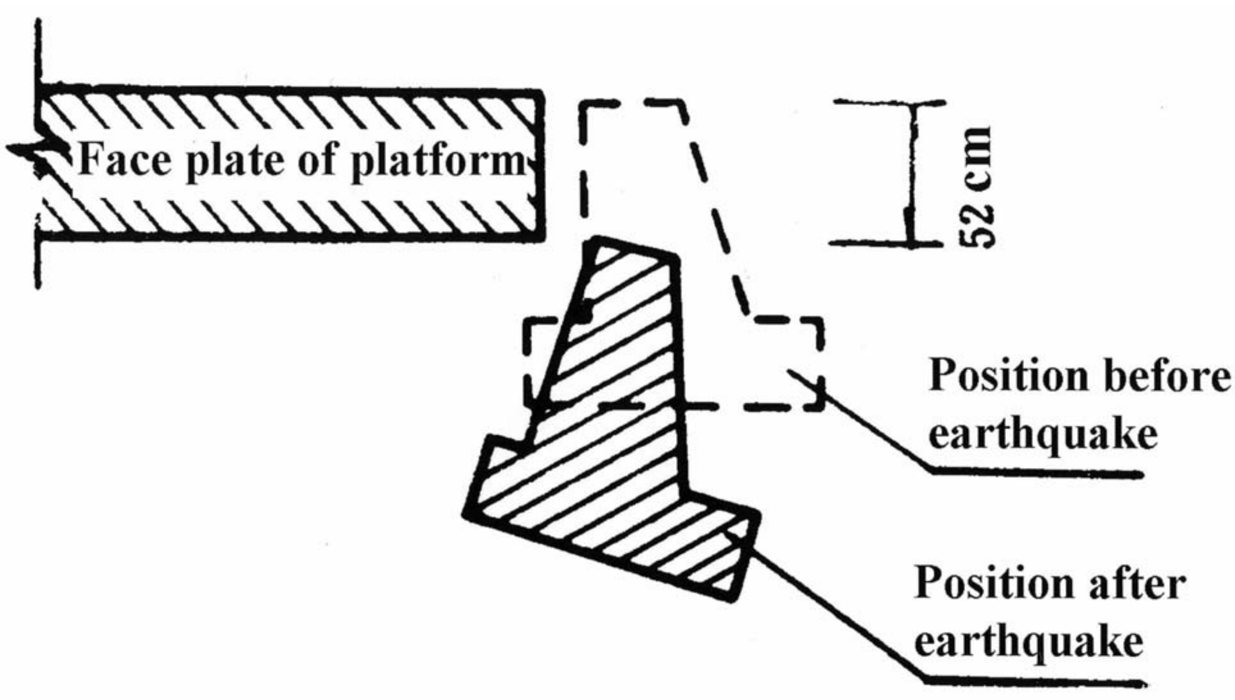


Figure 12. A sketch of a map showing the settlement of a retaining wall after the earthquake.

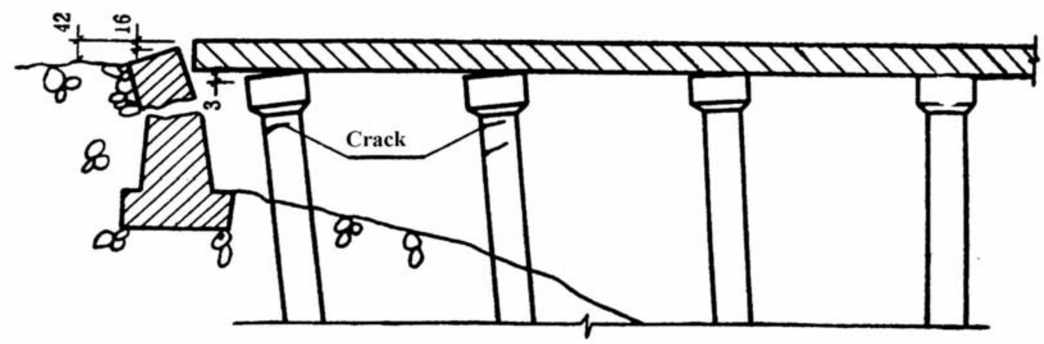


Figure 13. A sketch of a map showing damage to the retaining wall of the No. 20 berth at the New Port of Tianjin (in cm).

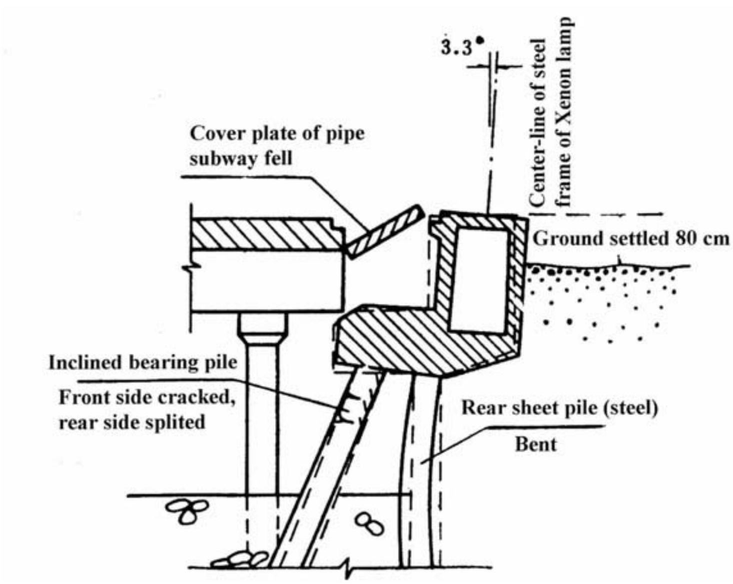


Figure 14. As sketch of a map showing damage to a retaining structure with rear sheet pile.

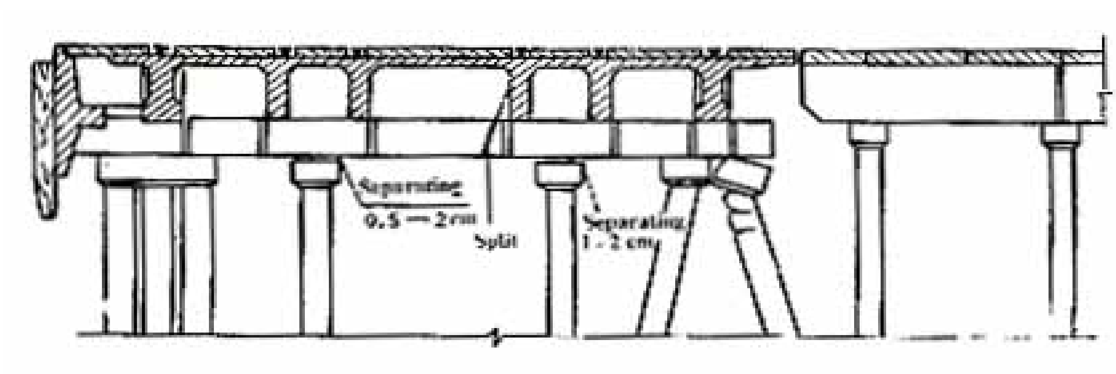


Figure 15. A sketch showing damage to a crossbeam of the No. 14 and No. 15 berths at the New Port of Tianjin.

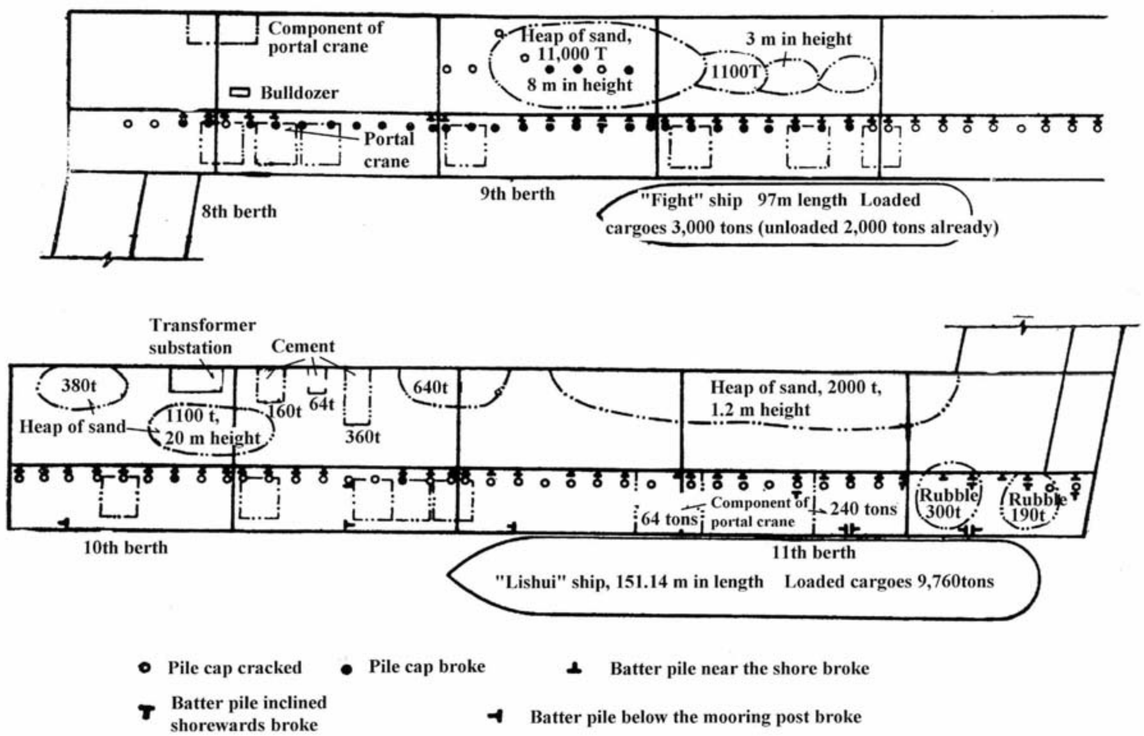


Figure 16. A sketch showing the load and damage to a pile foundation investigation for the No. 9 to No. 11 berths.

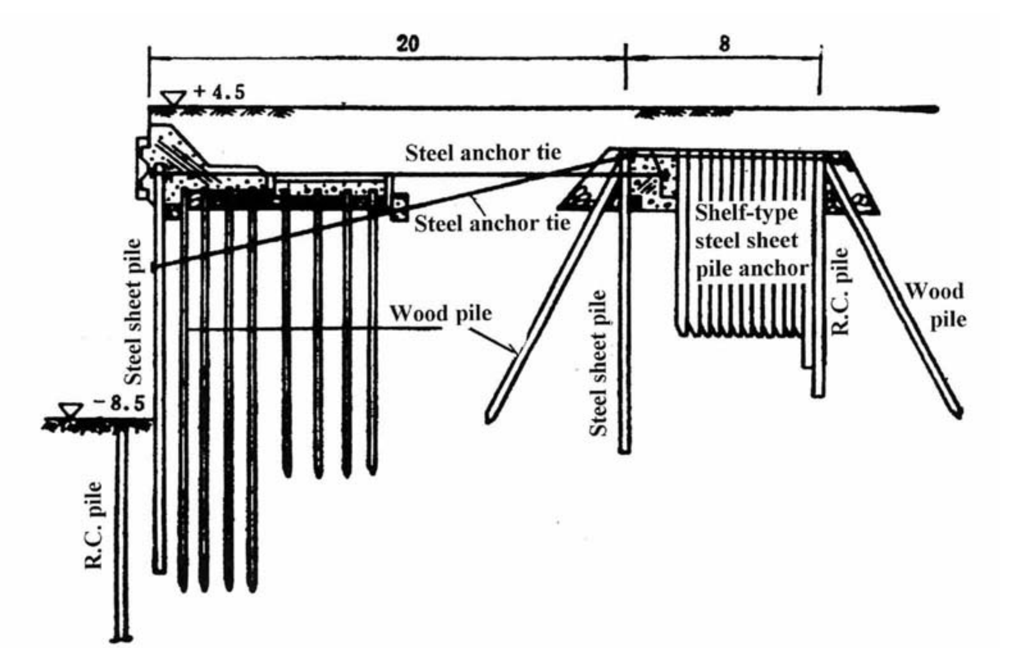


Figure 17. A sketch of the wharf structure of the No. 1 to No. 4 berths at the New Port of Tianjin (in m).

DAMAGE TO SHIP LOCKS

Lin Xiongwei*

After the Tangshan earthquake the Planning and Design Institute (PDI) along with shipping authorities of Hebei Province and Tainjin City investigated nine damaged ship locks located in the Tangshan and Tianjin areas: Beitang, Peizhuang, Yonghe, Xingang, Fish Ship Lock, Yangliuqing, Erzha, Qujiadian, and Fuxingmen. A more detailed site location of these nine ship locks is shown in Figure 1.

The ship locks are classified into four categories according to damage: seriously damaged, damaged, slightly damaged and intact. Of these nine ship locks there were two seriously damaged, three damaged, one slightly damaged, and three that were intact. The type of structure and damage are shown in Table 1 and Table 2. The damage of five ship locks is described as follows:

1. Beitang Ship Lock

(A) General features

The Beitang water conservancy project is located at the river rectification estuary of the Jiyun River. It consists of a sluice, ship lock and bridge (Fig. 2).

The sluice with in-site pile foundations consists of 10 apertures with a net width of 8 m, a designed discharge rate of 1200 m^3/s and a top sill level of −6.0 m. The sluice gate is a double leaf lifting gate with the top gate level of +3.5 m and a lifting mechanism on the working bridge. The sluice was designed according to a Class II permanent hydraulic structure and seismic intensity VIII.

The ship lock is situated on the east side of the sluice. The distance between the center lines of these two structures is 250 m. The navigation standard of the ship lock is Class V, capable of navigating a 2×300 t DWT towing unit. The ship lock chamber is 130 m long, 12.2 m in width, and the level of the top sill is −3.5 m. The lock wall was built with a guard wall on the top. On both sides there are guide walls (Fig. 3). The lock gate is a steel traversing caisson supporting a double-sided water head, which on the river side is 6.5 m and on the sea side is 5.1 m. The ship lock was designed according to a Class III permanent hydraulic structure and seismic intensity VIII.

A borehole examination at the project area was made. The physical parameters of the ship lock foundation soil are listed in Table 3. The types of structure of different parts of the ship lock are described as follows.

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The lock head is a reinforced concrete U-type structure with a bottom floor 1.5 m thick. Since the foundation stress is small (0.4-0.55 Kgf/cm^2 during operation and 0.7 Kgf/cm^2 during repair) no treatment was done to the soft soil.

The lock gate recess on the west side of lock head is a reinforced concrete integral structure and 12.8 m long. The foundation stress is 1.01 Kgf/cm^2. There are timber piles under the lock recess floor 5 m in length and 20 cm in diameter to mitigate any non-uniform settlement between the lock recess and lock head. The spacing between piles is 0.9 m and the connection between the floor of the lock head and lock recess is hinged (Fig. 4).

The lock chamber is 130 m long and divided into seven sections. The section near the down lock head is 10 m long. The chamber floor is a watertight reinforced concrete structure. Other sections are 20 m long and their lock chamber walls are masonry with concrete arches for support. The inside of the arch rings is filled with soil to an elevation of 0.0 m and the chamber floor is of leaky masonry (Fig. 5).

On both sides of the up and down stream of the ship lock there are wing walls and guiding jetties. Every guide wall is 6 spans and 36 m long. Three of them are on the wing walls and others are on pile foundations. The frame and deck are reinforced concrete and are not joined to each other by a steel bar.

The steel traversing caisson is used for the lock gate which is 12.7 m in length and 7.2 m in height. The value is set in the lower part of the gate for filling and emptying.

There is a highway bridge on the lock head; its deck is 4.5 m wide. The bridge is movable with one end supported by the track on the gate recess and the other supported by the lock floor track.

There is a 3-story operating building located on the gate recess side. The ground floor is used for a wire room and is joined with the gate recess; the second floor is equipped with the operation machines; and the third floor is the control room. The operation building was built on filled soil with a reinforced concrete raft foundation.

The slope and bottom revetment of the upper and lower approaches are made of masonry, 0.4 m in thick and 1:4 in slope.

The Beitang ship lock was completed in 1975 and had been operating normally until April 1976. However, because the lower approach was silted up the normal operation of the lock gate was affected.

(B) Damage to the lock

The Beitang ship lock was 68.5 km from the epicenter. It was within the anomalous zone of intensity VIII in the area of intensity VII. During the earthquake the water level of the upper stream and in the lock chamber was 0.72 m and the down tide level was 1.61 m. After the earthquake the lock head was slightly damaged and the lock chamber was seriously damaged.

(1) Upper lock head and upper approach

The upper lock head settled non-uniformly (see Fig. 6 and Table 4). The approach pavement on the east side of the highway settled even more, between which the bridge deck formed a 0.12 m step. The lock gate recess moved horizontally. Between the lock head and gate recess the track of the highway bridge dislocated 0.7 cm. On the repair gate recess occurred a crack 0.5 cm in width and between the top of the lock head wall and the masonry pavement there was a 0.5 cm wide crack (Fig. 7).

Both side guide walls of the upper stream tilted toward the river and the upper stream. The maximum oblique angle on the east side was 3.2° and that on the west side was 3°. All the bridge decks moved toward the upper stream and displacement was large. The deck of the first span on the east end of the bridge fell down to the river (Photo 1). On the west end of the bridge the decks between the third and fourth spans obviously arched. There were concentrated ground cracks in an area 1 km long and 500 m wide along both banks of the upper stream. The masonry pavement slope was seriously cracked and slipped towards the river and upper stream. On the east side of the ship lock there were nine ground cracks and about 12 m from the lock head the slope paving slipped 90 cm. On the west side of the ship lock there were eight ground cracks and the slope paving slipped 20 cm toward the river (Fig. 7).

(2) Lock chamber

All sections of the lock chamber wall displaced horizontally and vertically and tilted varying amounts. The width of the lock chamber decreased and the length increased. All water seals at the joints of the chamber wall broke. The guard wall on top of the chamber wall cracked and the chamber floor arched. The filled soil behind the chamber wall settled and the ground surface cracked. The settlement and displacement of the lock chamber wall was surveyed after the earthquake and the results are shown in Fig. 6 and Fig. 8.

The mortar bond rubble walls on both sides of the chamber displaced inwards (Photo 2, Fig. 8) and the top level of all the chamber walls settled with a maximum settlement of 42 cm (Fig. 6, Photo 3). Most chamber walls tilted forward slightly and some backward, with a maximum oblique angle of 1.5°-2.0°.

After the earthquake all expansion joints (2 cm in width) between wall sections of the lock chamber widened, the maximum width reached 23 cm. The filled soil behind the lock chamber wall flowed into the lock chamber.

There were many cracks or fractures in the guard wall on top of the chamber wall. A 3 cm wide and more than 100 m long crack occurred between the guard wall and filled soil. There were ground cracks near the lock chamber. The ground crack near the upper lock head passed through the lock chamber and extended outward which resulted in the expansion joint of the lock chamber widening to 17 cm.

After the magnitude 6.9 Ninghe earthquake on November 15, 1976 the lock chamber further slipped and the width of the lock chamber decreased by 1-4 cm again.

(3) Down lock head and down approach

The down lock head settled non-uniformly (Fig. 9). The ground around the lock head settled even more and a 10 cm step formed between the east highway and bridge deck. The lock gate recess displaced horizontally and as a result the track of the highway bridge dislocated 0.5 cm at the intersection between the lock head and lock gate recess. On the repair gate recess occurred a 0.5 cm wide short crack. At the joint of the lock head wall and mortar bond rubble slope revetment a 1-5 cm wide fissure was found. The down wing wall dislocated horizontally 2 cm relative to the lock head.

The mortar bond rubble slope revetment on both sides of the down approach slipped toward the river and cracked at many places, i.e. five cracks on the east side and nine on the west side with crack widths of 3-4 cm. On the right side of the expansion joint the slope revetment opened 8-12 cm. The revetment at the end of the downstream slipped and part of it arched. The mortar bond rubble revetment of the right bank, connected with the gate recess settled 10 cm relative to the recess.

The guiding wall tilted and displaced toward the river and downstream. The joint of the bridge deck opened with a maximum distance of 10 cm.

(4) Lock gate and operation building

The steel transverse caisson and highway bridge was intact and the operation building was slightly damaged. On the corner of the north side of the upper lock head operation room there was a crack. The joint between the ground floor of the down lock head operation building and gate recess opened with a crack width of 3 cm.

Other structures at the water conservancy project were seriously damaged. The filled soil around the project settled in an extensive area. The level mark on the east side of the sluice beside the highway settled 62 cm. There were sandboils, waterspouts and cracks on the ground. On the 60 m long bituminous road at the project office courtyard there were 57 cracks parallel to the river, most of them were 3-4 cm wide and the maximum was 8 cm wide. The deep well tube was damaged and the new office was seriously damaged except for the reception room. The prefabricated plate roof of a single-story brick house collapsed. The adjacent single story office house and two-story office building were pulled apart by 40 cm (Photo 5).

The sluice was seriously damaged. The abutment pier and other piers were no longer on the same axis and the relative horizontal displacement reached 6-13 cm. The operation buildings on the sluice on the two banks settled and tilted. The northeast corner of the operation building in the east settled 25 cm more than the southwest corner (Photo 6). The joint of the operation building and working bridge broke and pulled apart over 50 cm. Seven T-beam spans at the working bridge fell down and the operation machines fell down to the working bridge deck (Photo 7). The other T-beams displaced and the column supporting the T-beam cracked at the base.

After the earthquake of magnitude 6.9 on November 15, 1976, the Beitang ship lock was surveyed again and further damage was found as follows:

a. The lock chamber wall displaced further and the width of it lessened by 1-4 cm.

b. The upper spacing between the wing walls and lock significantly lessened 2 cm during the M=7.8 earthquake and the dislocation on both sides of the settlement joint enlarged after the M=6.9 shock.

c. The guiding wall was more seriously damaged. The frame tilted more and the end span tilted most seriously. The width of joints of the walking deck enlarged with the largest reaching 11 cm. On the right side of the upper stream the third span walking deck fell down into the river.

d. The concrete pavement of the upper and downstream wing wall settled more seriously and it was 6-17 cm lower than the wing wall.

e. The partition wall of the upper lock head operating room cracked.

2. Peizhuang Ship Lock

(A) General features

The Peizhuang water conservancy project is located on the Jintang Canal in Ninghe County and it consists of a sluice, ship lock and bridge. It had been completed but not put into normal operation before the earthquake. It was seriously damaged during the earthquake.

The project was built on the riverbed of the Jintang Canal with its ship lock on the south bank and its sluice on the north bank. The designed discharge of the three-span sluice is 150 m^3/s. The maximum water level of the upper stream is 2.5 m, drainage water level 2.0 m and downstream flood water level 3.81 m. The down lock head and the sluice are in the same axis line and the upper lock head is in the upper approach of the sluice. The highway bridge crosses over the down lock head and the sluice. The ship lock can be navigable by five 100 DWT barges at the same time. The lock chamber is 120 m in effective length with an 8.4 m wide lock gate and a 10 m wide bottom. The depth of the sill water is 2.0 m. The steel lift flap plate gate can support a double-sided water head with an upper water head of 2 m and down water head of 3 m. The reinforced concrete drilled piles were the foundation of the sluice and the lock head because the soil foundation is soft. There are reinforced TYPE Π concrete frames on the top of the pier with a section column of 40×40 cm and a T-beam where there are two sets of operation machines installed. The lock chamber wall on the right side is a reinforced concrete wall of a reverse T-type and the one on the left side is the slope bank with dry and mortar-bond stone pitching with a slope of 1:3. Dry stone masonry was applied to the chamber bottom for protection. The level of the chamber bottom is −3.0 m and the top level of the chamber wall is 2.0 m. There are reinforced concrete guide walls in the upper and down approach channel on the riverside, which are 20 m and 30 m in length respectively (Figs .10 and 11).

The lock soil foundation is silty clay. In the layer at level -3.0 to -7.0 m the average water content is 41%. The quick shear test showed that the average cohesion was 0.0085 kg/cm^2 and the average frictional angle was 6.6° ranging from 2.2° to 12.3°, which means that the soil is highly compressible and the bearing capacity is low. Below the level -7.0 m the soil water content is 28% and the soil foundation is better.

(B) Damage to locks

The Beitang water conservancy project is 37 km from Tangshan City and about 8 km from Ninghe County. The seismic intensity in that area is IX. The ship lock was seriously damaged in the earthquake.

(1) Lock head

The upper lock head wall is a pier type 9.7 m in height, 1.0 m in width and 9.5 m in length. On the top of the pier there are reinforced concrete type Π frames 2.5 m high. Two 9.4 m long beams are set on the top of the frames to constitute the working bridge. The pier foundation is a reinforced concrete drilled pile, 4 piles 80-100 cm in diameter and 16-19 m in length. The lock head floor is 1 m thick with a construction joint to the lock head pier. After the earthquake the type Π frame on the left pier tilted about 6° to the left side. The column base of the frame seriously cracked, steel bars were exposed and the concrete crushed. The type Π frame on the right pier tilted about 3° to the right and the column base cracked. Two T-beams fell down with the left end falling on top of the pier and the inner side wall and the right end falling on the lock gate top. All the operating machines fell into the canal. The left and right piers displaced to the outer side and the joint of the door enlarged (Photo 8, Fig. 12).

The down lock head pier is 9 m high and 12 m long. On which there is a highway bridge and type Π frame. After the earthquake the frame column tilted to the left side and the column base cracked. All T-beams of the working bridge fell down into the water more than 1 m. The vertical rubber seal was deformed by the pressure of the tilted pier.

The hinged T-beams of the down lock head highway bridge displaced 1 cm to the left and the frictional trace could be clearly recognized. Under the bridge the reinforced concrete retaining plate was damaged with a 1 cm wide crack from the top to the base (Fig. 13).

The operating house on the highway bridge collapsed. On the pier of the approach bridge there were horizontal and vertical cracks. The road at the end of the bridge settled and formed itself into a slope.

(2) Lock chamber

The chamber slope pavement on the left side slipped down to the chamber. The displacement in the middle was larger than at the two ends and formed itself into a curve. The top of the slope pavement cracked with a crack width 1-2 cm in general, and the maximum reached 10 cm. Part of the masonry pavement settled and cracked. During the earthquake the water depth in the lock chamber was about 3 m and a wave spilled over the slope bank and flowed to the land on the left.

Around the ship lock there were sandboils and waterspouts. At a distance of about 50 m from the upper lock head on the left side there was a sandboil hole 10 cm in diameter. There were many ground cracks along the bank with one crack about 20 m from the top of the bank that was 5-6 m in length and 10 cm in width.

The right lock chamber wall is a reverse T-type and 6 m in height. The base plate is 10.5 m in width. It is divided into 6 sections with a rubber seal between them, each section is 20 m long. During the earthquake the water level inside and outside of the chamber wall were the same. After the earthquake the chamber wall displaced non-uniformly with a maximum displacement of 27 cm. The expansion joints between the chamber walls widened with a maximum width of 6.5 cm. All the sealing strips were broken. On the walking bridge deck on the top of the chamber wall there were over a hundred small cracks (Fig. 14, Photo 10).

The upper and downstream guide walls tilted.

3. Yonghe Ship Lock

(A) General features

The Yonghe water conservancy project is situated on the Jinzhong River, north of Yonghe Village in the east suburbs of Tianjin City. Its downstream joins with the New Yongding River and Jiyun River then flows into the sea. The project consists of a sluice with 12 apertures and a ship lock. It was completed in 1966 but navigated only seasonally because of the insufficient water resource.

The upper and down lock head are a U-type structure with a highway bridge on the top of the upper lock head. The lock chamber is a slope type and stone masonry, which is used for protection of the chamber slope and floor. The lock gate is a steel lifting plate gate with a filling and emptying system for the lock gate opening. The upper lock gate is 7 m in width, 5 m in height, and the maximum lift opening is 7.7 m. The down lock gate is 7 m wide, 7 m high and the maximum lift opening is 9 m. A 30t hoisting winch is used to open and close the lock gate. The lock chamber bottom is 9 m in width and 100 m in length. The designed water head is 5.5 m (Fig. 15).

The geological section of the ship lock site is a clay layer above a level of -5 m, a silty clay layer from -5 m to -9 m, and silty clay, silty sand and clay interlacing layers below a level of -9 m.

(B) Damage to locks

The Yonghe conservancy project is 29 km from Ninghe County and 74.5 km from Tangshan City. The seismic intensity was VII.

(1) The lock head

At the upper lock head the top of the type Π frame of the working bridge displaced to the north about 3 cm and the column foot of the type Π frame on the right side cracked with a crack width of 3 cm. The left end of the working bridge deck cracked and concrete partly peeled off. The right wing wall pulled away 6 cm from the lock pier and it's top was 2 cm lower than the top of the lock pier. The upper lock head had non-uniform settlement with the southwest part of it higher than the northeast part. The T-beam of the highway bridge moved about 5 cm towards the south along the bridge axis and the bottom of the T-beam was crushed. At the lower lock head the tops of both the right and left columns of the type Π frame of the lock pier displaced outward about 10 cm. There were several vertical cracks 1-3 mm wide on the column of the left lock pier and vertical cracks about 4 mm wide on the upper and foot of the column of the type Π frame on the right lock pier (Fig. 11). A horizontal crack 2 m long and 3-5 cm wide occurred on the left lock pier (Fig. 12).

(2) Lock chamber

The slope protection was seriously damaged on the right side and the wing wall joint opened. Between the upper lock head and upper steps there were 3 vertical cracks. Many small cracks occurred in the middle section, the masonry joints broke, the slope pavement lifted and rose or settled in different parts. Between the down lock head and other steps there was a 3 cm wide fissure from the top of the slope into the water. The slope pavement lifted 3 cm and cracked. Outside the wing wall the pavement partly settled 3 cm along with a 2 cm wide crack on it.

On the left side there were nine cracks of which four were on the upper section, two were horizontal and on the down section, and the remaining three were vertical and were between the two steps (Fig. 16).

4. Xingang (Haihe) Ship Lock

(A) General features

The Xingang Ship Lock is located at the mouth of the Haihe River. It was built in 1939 and repaired in the early 1950's and put into operation in 1952. The lock chamber is 180 m long and 22 m wide. The designed sill water depth is 5 m and the maximum water head is 4 m. It is navigable for a 3,000t sea vessel. The lock head is a reinforced concrete U-type structure with a 2.75 m thick lock head floor and timber pile foundation. The lock chamber wall is a reinforced concrete cantilever retaining wall with a timber pile foundation and a 1.7 m thick chamber floor. The lock gate is a steel traversing caisson with a short culvert filling and emptying system.

(B) Damage to locks

The seismic intensity was VIII in the Xingang area. After the earthquake two underwater surveys were done in September and October. It was found that the chamber floor cracked and settled or lifted in many places mainly near the joint of the floor and lock wall toe, especially to the south. There was a total of seven cracks 1-4 m long, 4-20 cm wide and 5-30 cm deep. The concrete near the cracks was crushed. The chamber floor partly lifted, 3 on the south side and one on the north side. The lift height was 10-50 cm. The chamber partly settled in two places on the north side. The settlement was 5-10 cm. The damage to the chamber floor was not fully clear in the underwater survey because the chamber floor was covered by silt.

5. Fuxingmen Ship Lock

The Fuxingmen ship lock is located outside the south bank of the Haihe River in the Hexi District of Tainjin City. It was completed in 1970. The ship lock consists of two sluices with three openings and a slope type chamber. Used as a lock head the two sluices are reinforced concrete structures. The middle opening span is 6 m and the two side opening spans are 3 m. The width of the chamber bottom is 15 m and the chamber is 106 m in length. The two sides of the slope are revetted with stone masonry.

The ship lock is 105.5 km from the epicenter of the Tangshan earthquake. At the site area the seismic intensity was VIII. After the earthquake the level of the top of the down lock head pier settled 35 cm relative to the adjacent areas. There were horizontal cracks on eight columns of the down lock head working bridge and on four columns of the upper one. And the columns became oblique to the inner side. There was a ground crack about 34 cm wide and over 20 m long crossing the lock chamber.

(Translator: Lin Xiongwei)

Table 1. Lock structure.

Lock	River	Lock Dimension (m) Length×Width (gate width)×Sill Water Depth	Water Head (m)	Structure Type							Construction Year
				Upper Lock Head	Lock Chamber	Down Lock Head	Gate	Approaching Wall	Working Bridge	Highway Bridge	
Paizhuang	Jintang Canal	120×10(8.4)×2.0	2.5-3.0	pile F.R.C. wall	R.C. wall L-slope	pile F. gravity wall	lift plate	upper: frame down: gravity wall	frame	R.C.	1973
Beitang	Jiyun River	130×12.2(11.2)×2.0	5.1-6.5	R.C. U-type	gravity wall	R.C. U-type	traversing caisson	frame		steel	1973-1975
Yonghe	Jinzhong River	100×9(7)×2.0	2.8-3.5	R.C. U-type	slope	R.C. U-type	lift plate		frame	R.C.	1955-1956
Xingang	Haihe River	180×22×5.0	4	R.C. U-type	gravity wall	R.C. U-type	traversing caisson			steel	1939 (1952 repaired)
Fish ship lock	Haihe River	120×14(8.4)×2.5	4	R.C. U-type	R.C. U-type	R.C. U-type	traversing caisson			steel	1958-1959
Yangliuqing	Xihe River	210×15×4.5	7	R.C. U-type	gravity wall	R.C. U-type	mitering gate	frame		R.C.	1953
Erzha	Xinkai River	100×10(5.2)×2.5	3	mortar bond stone U-type	slope	mortar bond stone U-type	lift plate		frame	R.C.	1918
Qujiadian	Grand Canal	60×10(8)×2.0	3	R.C. U-type	slope	R.C. U-type	lift plate		steel column	R.C.	1932
Fuxingmen	Weijin River	106×15(6)×2.5	0.4	R.C. U-type	slope	R.C. U-type	lift plate		frame	R.C.	1953

Table 2. Lock damage.

Lock	Location	Epicentral Distance (km)	Seismic Intensity	Damage							Lock's State
				Upper Lock Head	Lock Chamber	Down Lock Head	Approaching Wall	Approach Channel Slope	Office Building	Working Bridge	
Paizhuang	Ninghe County	36.5	IX	1	1	1	2	2	1	1	serious damage, could not operate, need to recondition
Beitang	Tianjin City Beitang	68.5	VIII	3	1	3	2	1	1		serious damage, could not operate, need to recondition
Yonghe	Tianjin City east suburb	74.5	VII	2	2	2	3	2	3	2	damaged, can operate, need repair
Xingang	Tianjin City Tanggu	80.5	VIII	4	2	3	4	4	4		damaged, can operate, need repair
Fish ship lock	Tianjin City Tanggu	81.5	VIII	4	4	3	4	4	3		lightly damaged, before earthquake did not operate, gate needs repair
Yangliuqing	Tianjin City west suburban	116	VII	4	4	4	4	4	3		good condition
Eszha	Tianjin City Hedong Dist.	101.5	VIII	4	4	4	4	4	4	4	good condition
Qujiadian	Tianjin City north suburb	104.7	VII	4	4	4	4	4	3	4	normal
Fuxingmen	Tianjin City Hexi Dist.	101.5	VIII	2	2	2			3	2	damaged, could not operate, needs repair

Note: Damage, 1 - seriously damaged, 2 - damaged, 3 - lightly damaged, 4 -intact

Table 3. Characteristics of ship lock foundation soil.

Type of Soil	Level of Soil (m)	Water Content (%)	Void Ratio	Liquid Limit	Consistency	Compressibility Coefficient (kgf/cm^2)	Internal Friction Angle (consolidated quick)	Cohesion (kgf/cm^2)
clay with some silty clay	+0 - –4.5	32 - 56.9	1.01 - 1.62	32.3 - 50.8	0.8 - 1.3	0.12 - 0.33	14° - 19°	0.08 - 0.15
silty clay	–4.5 - –15.0	25.4 - 32.4	0.79 - 0.94	26 - 29.4	0.5 - 1.4	0.038 - 0.15	25° - 34°	0.12 - 0.18

Table 4. Settlement of the top level of the lock wall after the earthquake, Beitang Ship Lock.

Section Length (m)			Upper Lock Head (15)		1 (20)		2 (20)		3 (20)		4 (20)		5 (20)		6 (20)		7 (10)		Down Lock Head (15)	
Top Level of Lock Wall (m)	Designed		2.50	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.50
	After Earthquake	L. wall	2.27	1.67	1.70	1.70	1.70	1.67	1.65	1.68	1.69	1.68	1.69	1.71	1.70	1.72	1.97	1.87	1.79	3.24
		R. wall	2.21	1.59	1.65	1.66	1.63	1.62	1.59	1.59	1.86	1.60	1.60	1.63	1.58	1.68	1.92	1.82	1.75	3.15
	Settlement	L. wall	0.23	0.33	0.30	0.30	0.30	0.33	0.35	0.32	0.31	0.32	0.31	0.29	0.30	0.28	0.03	0.13	0.21	0.26
		R. wall	0.29	0.41	0.35	0.34	0.37	0.38	0.41	0.41	0.36	0.40	0.40	0.37	0.42	0.32	0.08	0.18	0.25	0.35

Photo 1. Damage to the upper guiding frame at the Beitang shiplock.

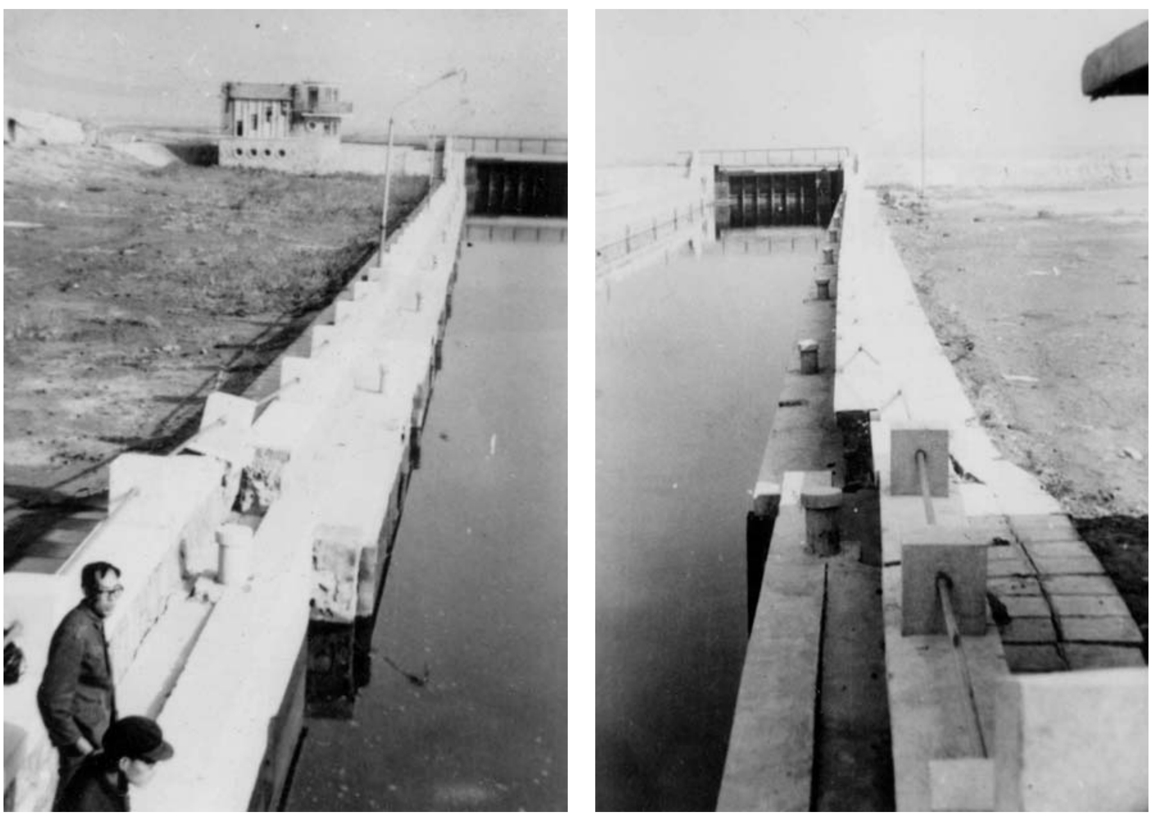

Photo 2. The chamber wall of the Beitang shiplock displaced and became oblique.

Photo 3. Two sections of the masonry retaining wall and reinforced concrete chamber, having a seam at the center of the floor, dislocated at the Beitang shiplock chamber.

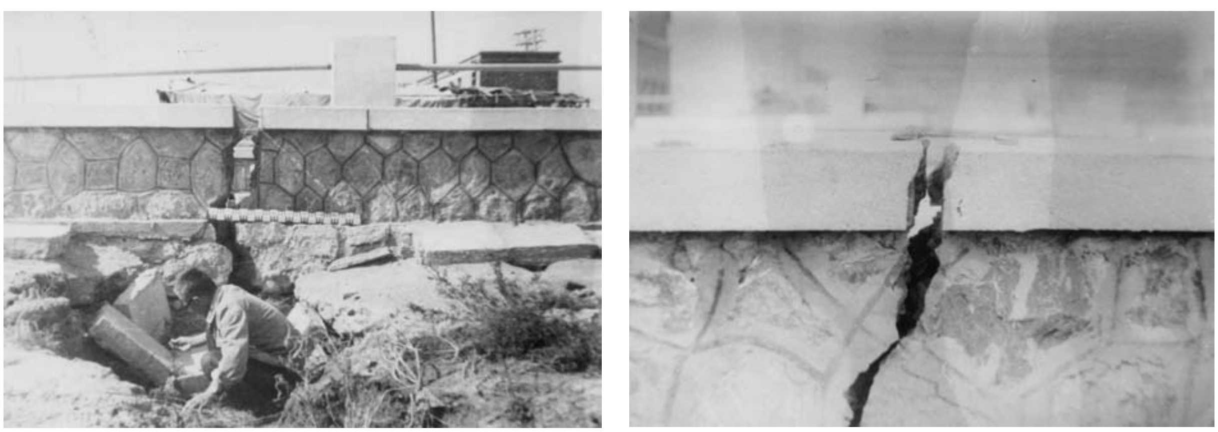

Photo 4. Damage to the guard wall of the Beitang shiplock chamber.

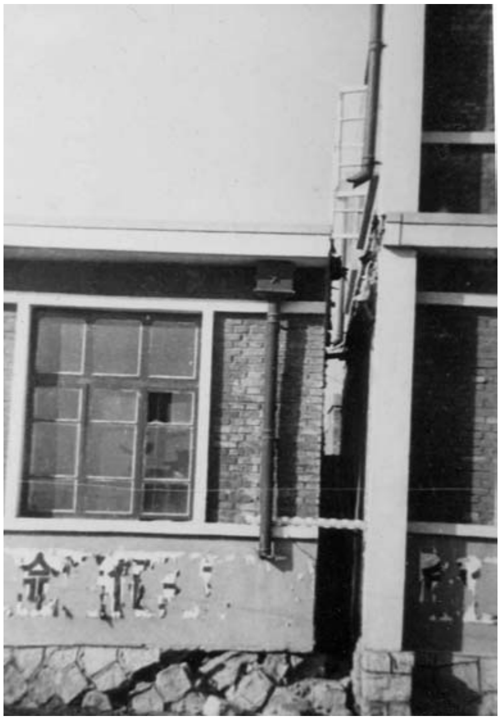

Photo 5. The Beitang shiplock office building was separated by the earthquake.

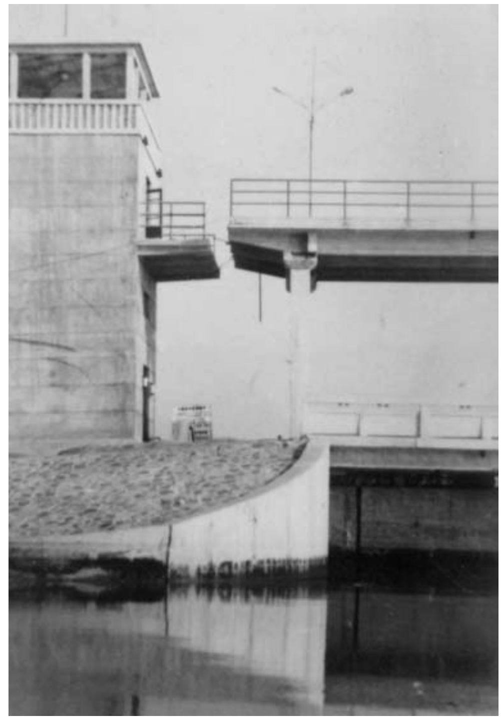

Photo 6. The sluice operating building of the Beitang project separated from the working bridge and settled.

Photo 7. The hoisting frame and equipment on the working bridge collapsed on the sluice of the Beitang project.

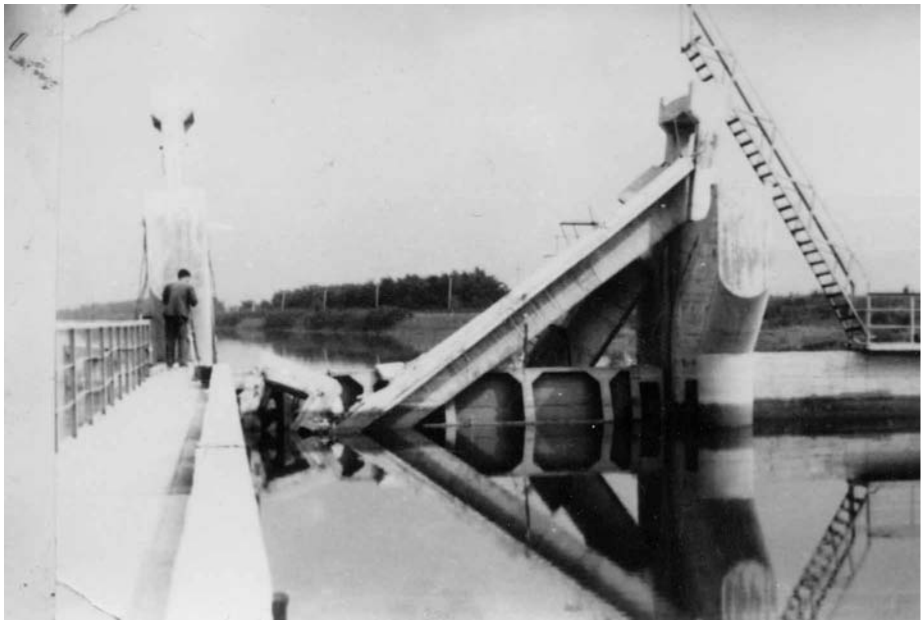

Photo 8. The upper lock head of the Peizhuang shiplock collapsed.

Photo 9. The down lock head of the Peizhuang shiplock collapsed.

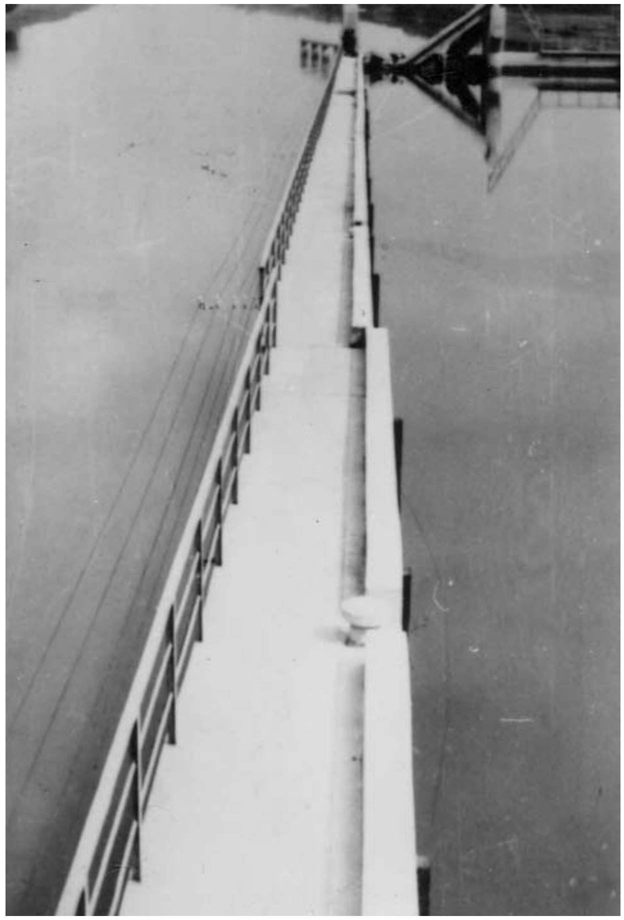

Photo 10. The left side wall of the Peizhuang shiplock displaced.

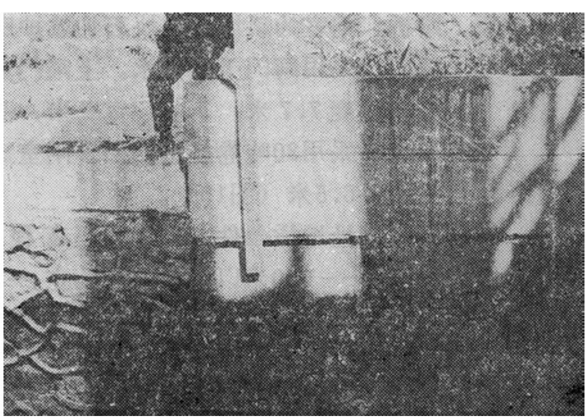

Photo 11. The Π frame column of the lock pier cracked at the Yonghe Shiplock.

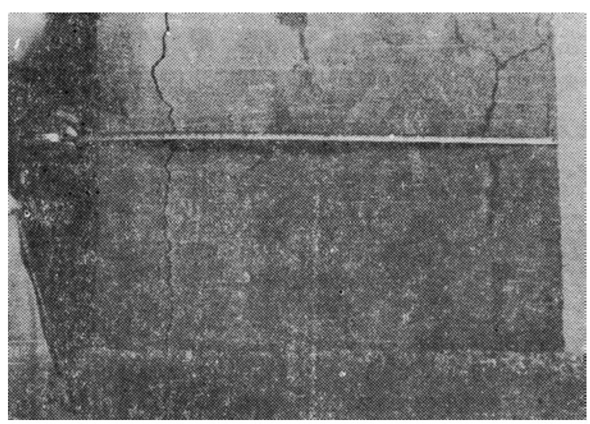

Photo 12. The left lock pier cracked at the Yonghe Shiplock.

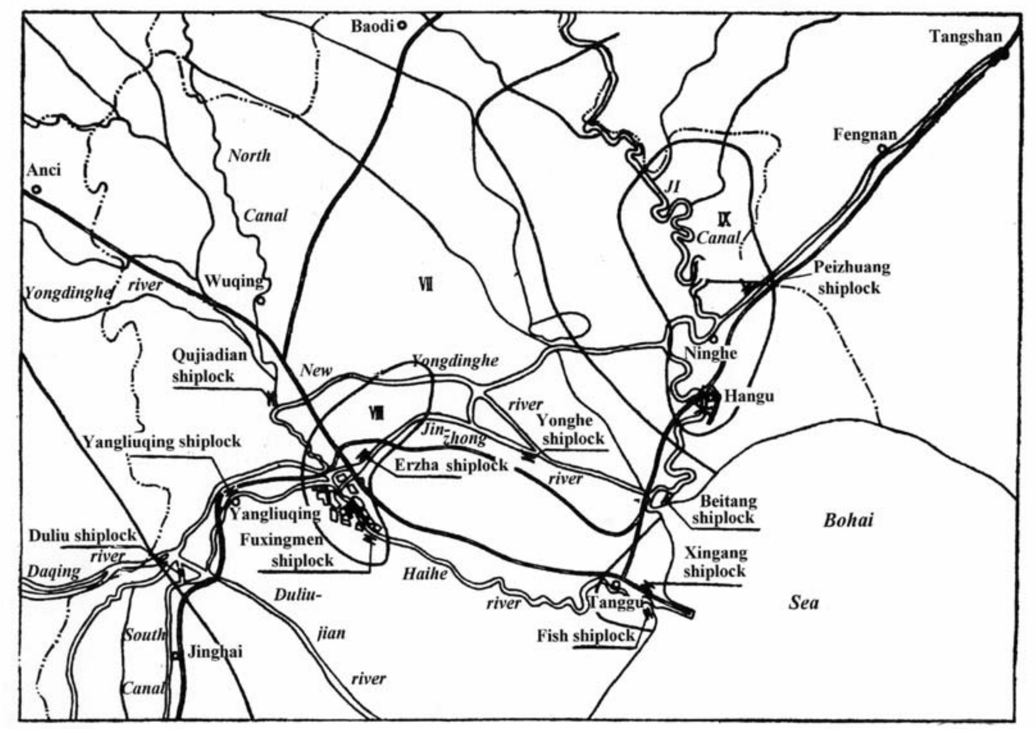

Figure 1. The lock's site in the earthquake.

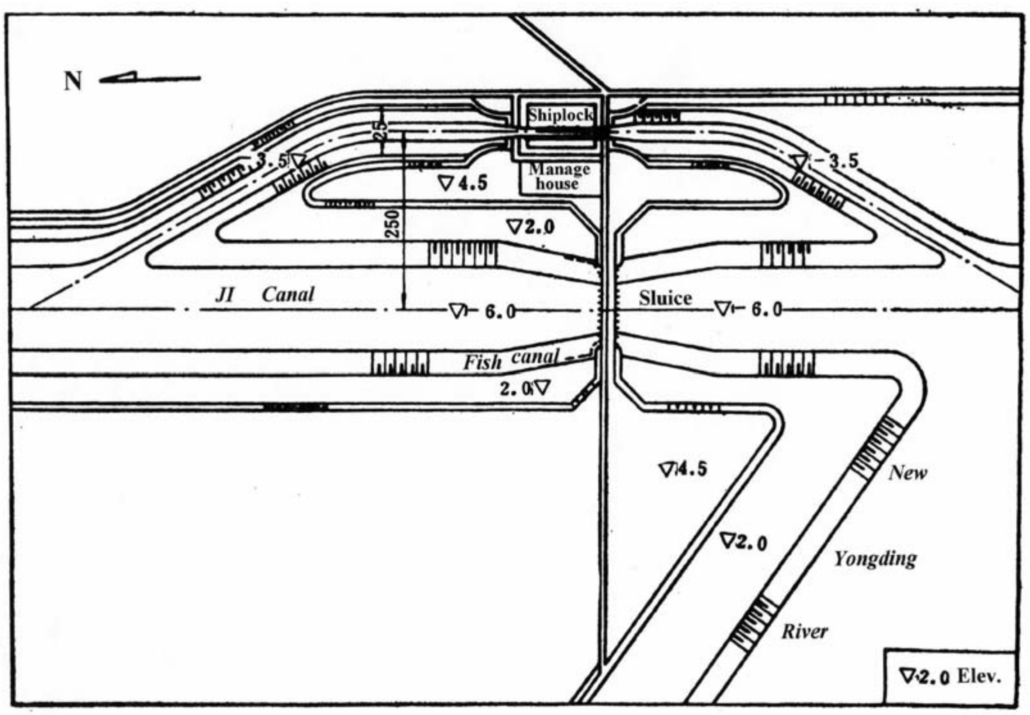

Figure 2. The Beitang water conservancy project layout plan.

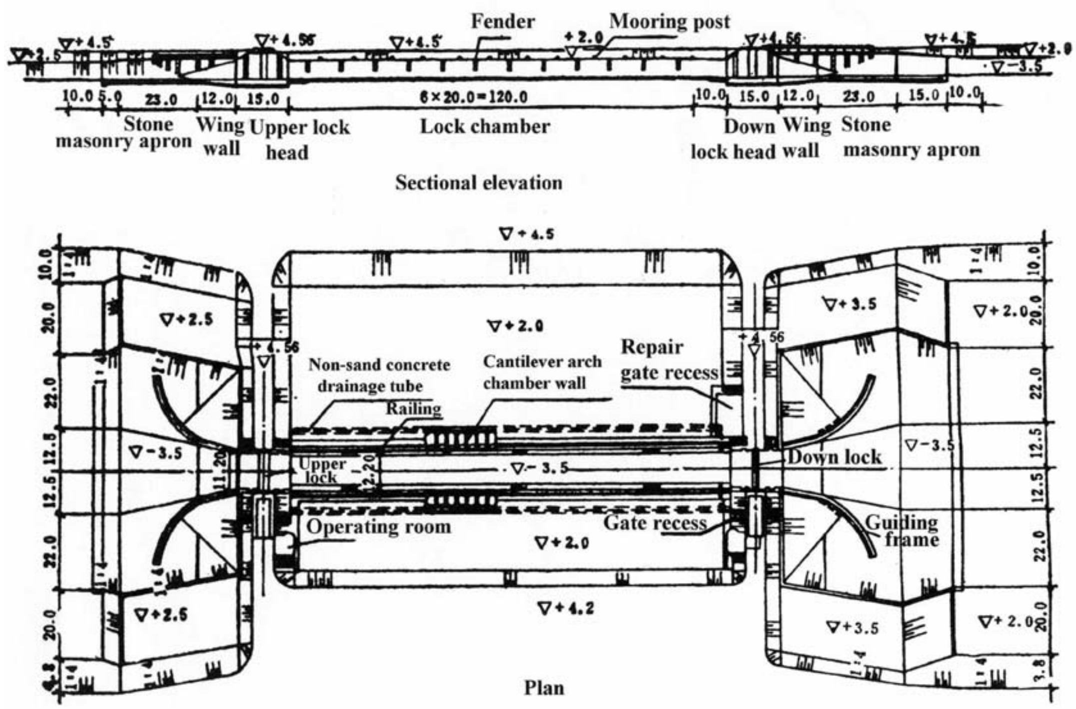

Figure 3. The Beitang ship lock layout plan (in m).

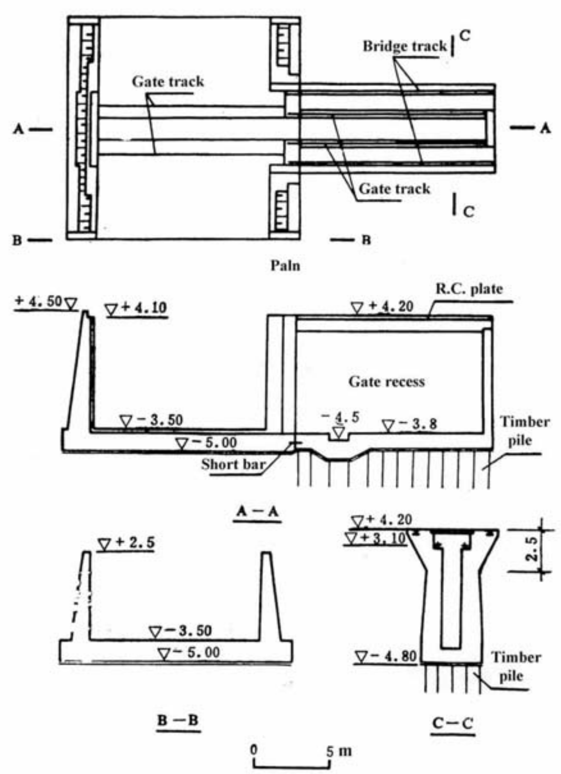

Figure 4. Lock head structure sketch of the Beitang ship lock (in m).

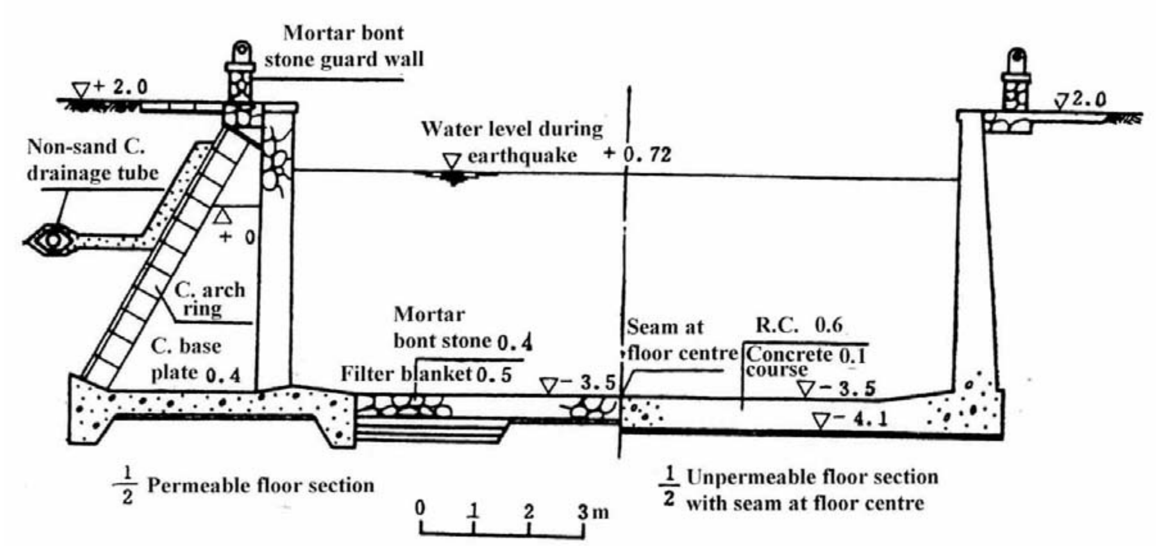

Figure 5. Lock chamber sectional drawing of the Beitang ship lock (in m).

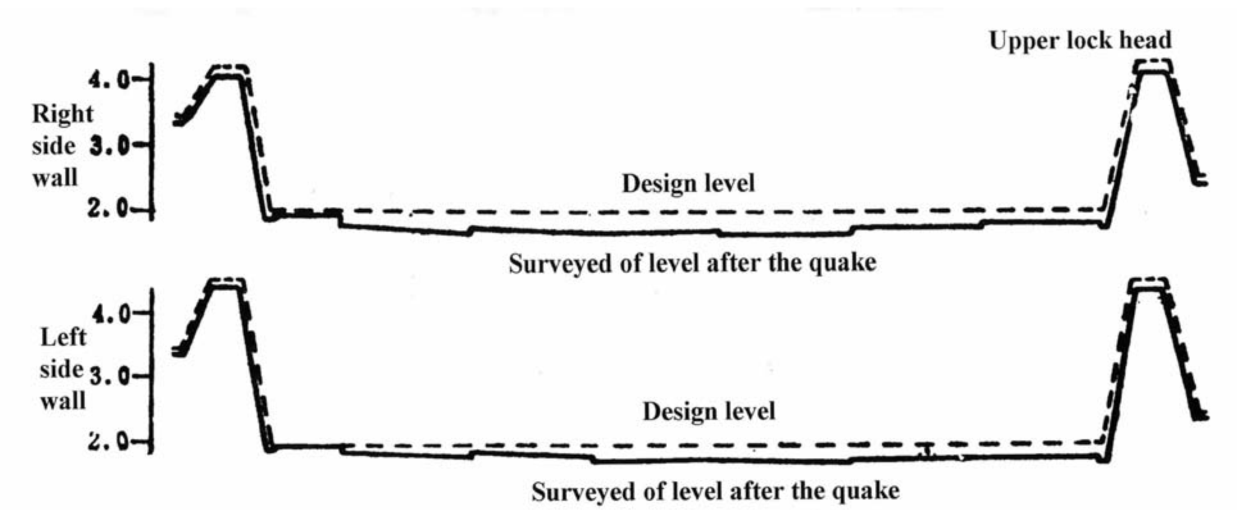

Figure 6. Settlement of the top level of the lock wall at the Beitang ship lock after the earthquake (in m). (Surveyed level after the earthquake is based on the datum horizon point that had been settled 0.62 m)

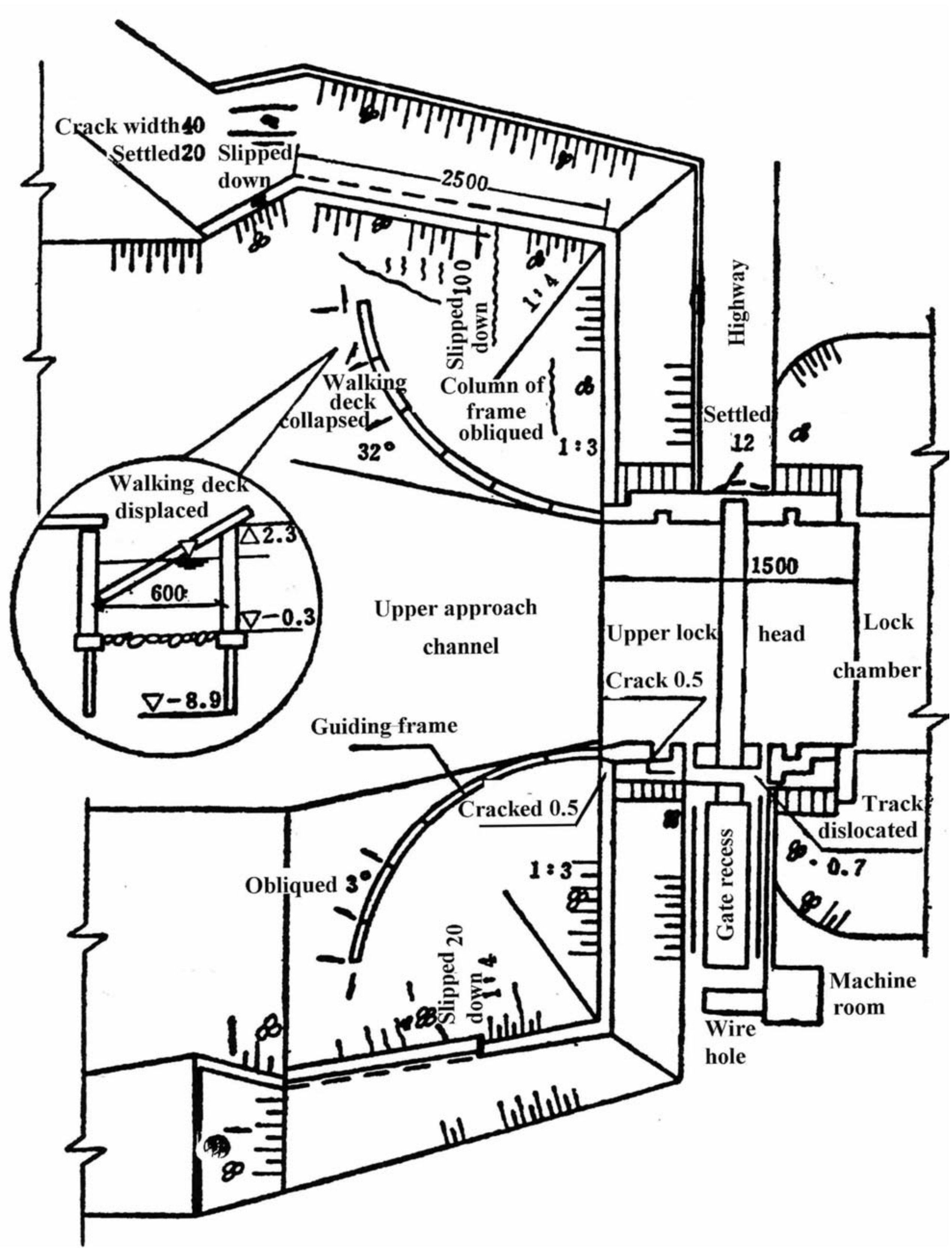

Figure 7. A sketch of the damage to the upper lock head and approach channel at the Beitang ship lock.

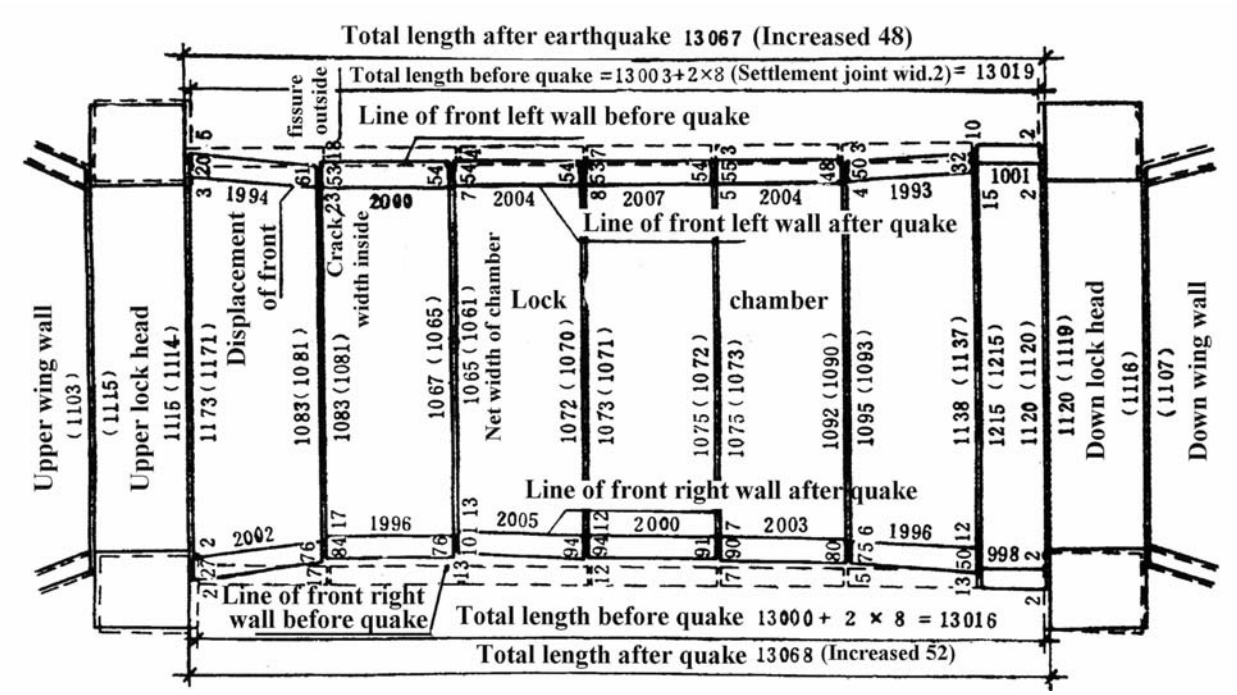

Figure 8. Horizontal displacement of the lock chamber wall at the Beitang ship lock (in cm).
(The surveyed value after the earthquake M=6.9 in parentheses)

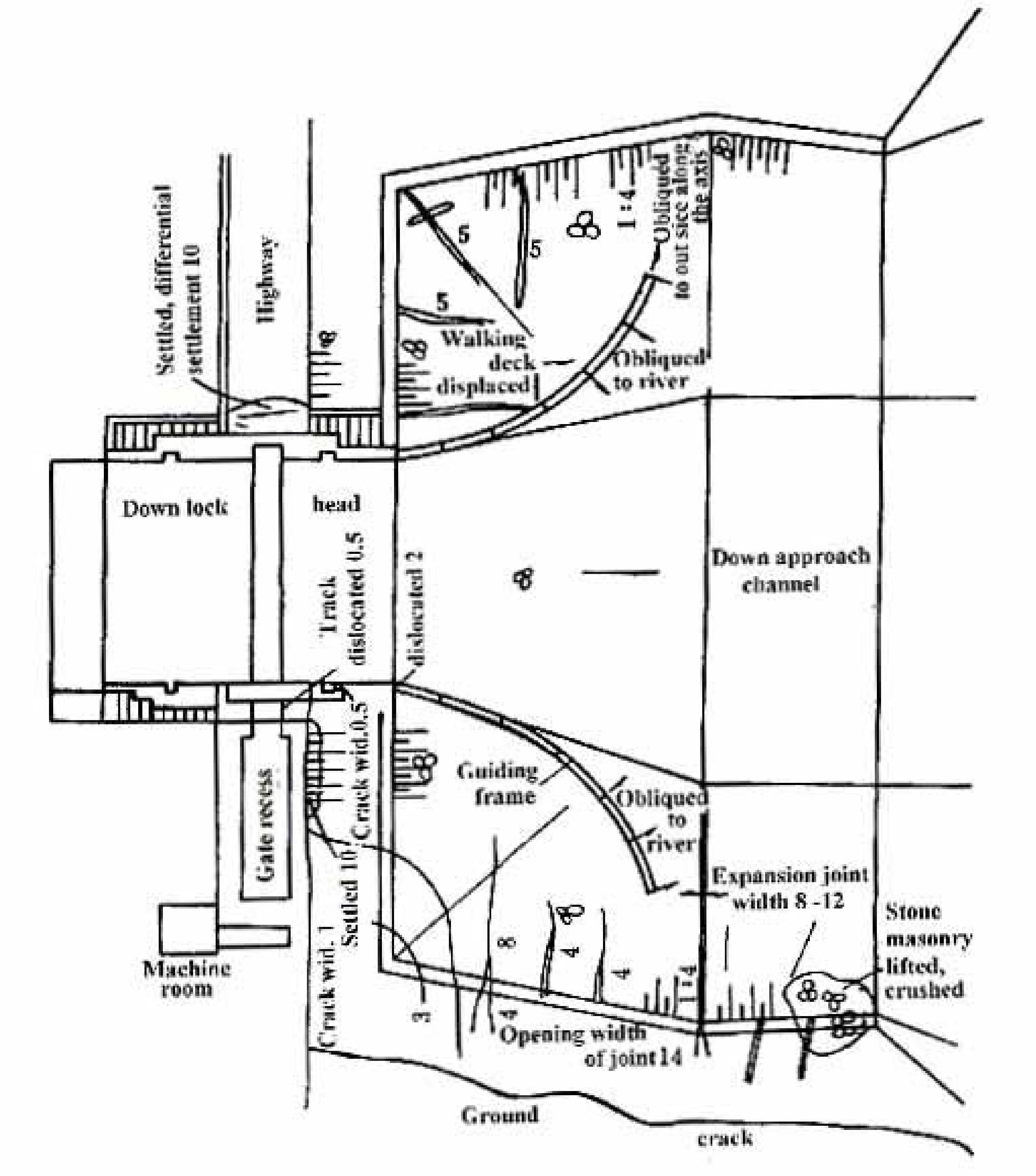

Figure 9. A sketch of the damage to the down lock head and approach channel of the Beitang ship lock (in cm).

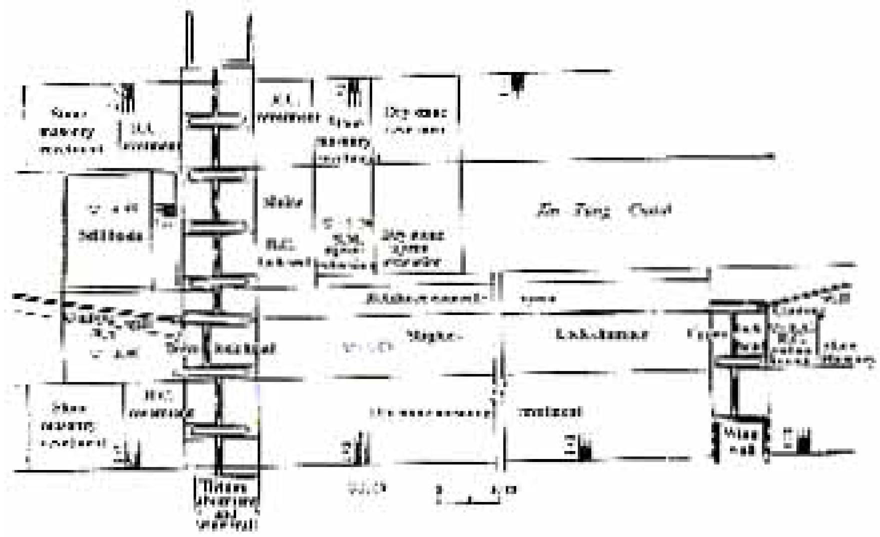

Figure 10. Peizhuang ship lock layout plan (in m).

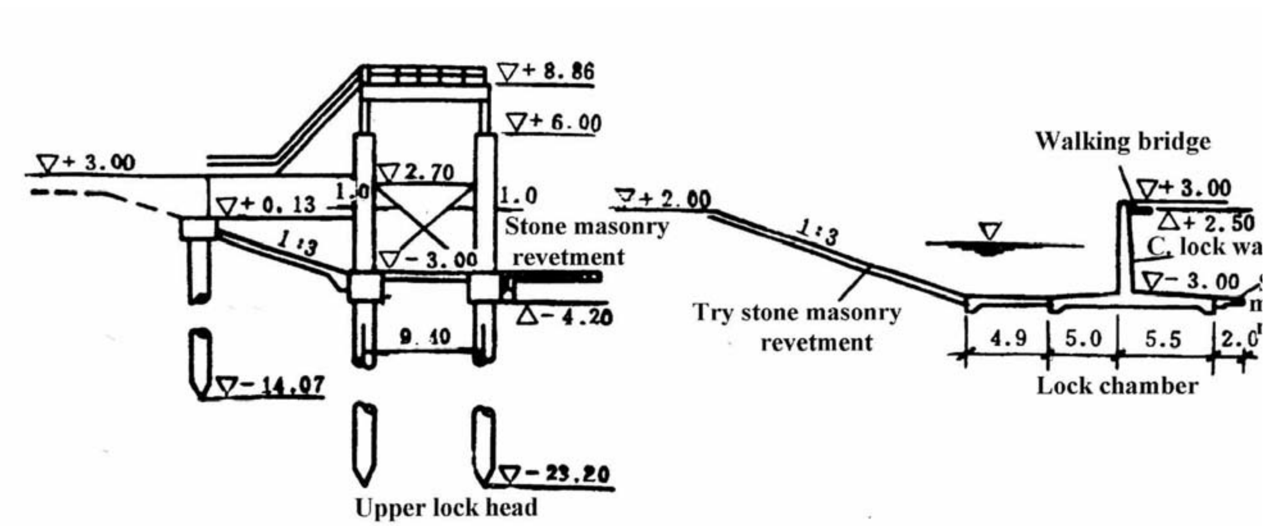

Figure 11. Sectional drawing of the Peizhuang ship lock (in m).

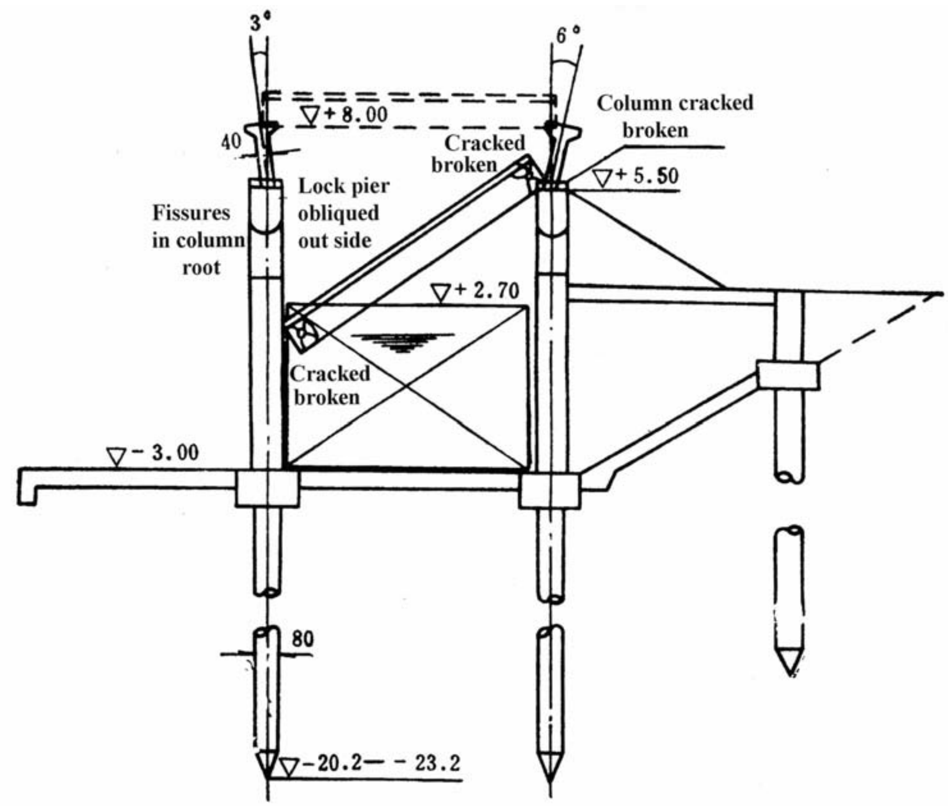

Figure 12. A sketch of the damage to the upper lock head at the Peizhuang ship lock (in cm).

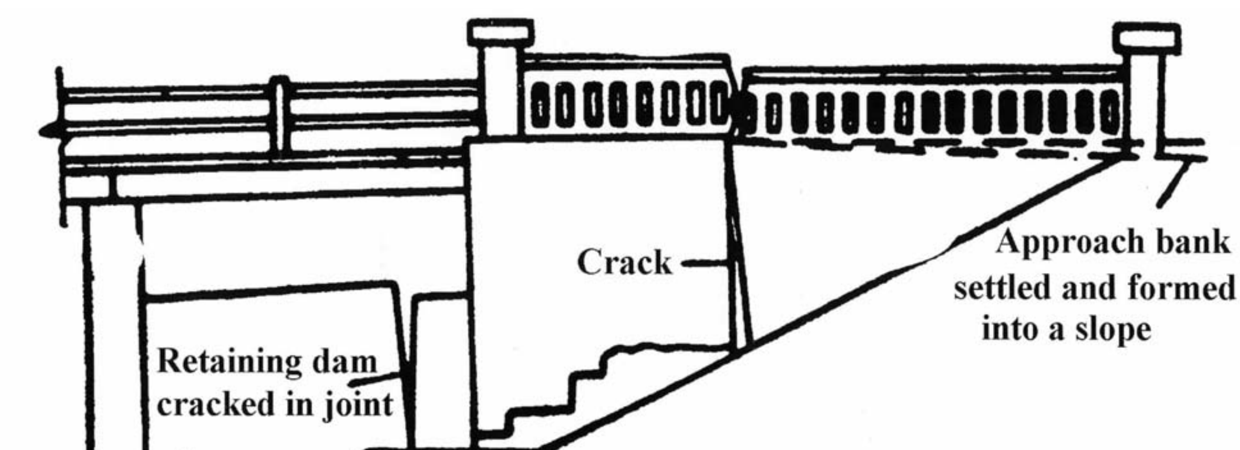

Figure 13. A sketch of the damage to the bridge abutment and retaining dam at the Peizhuang ship lock.

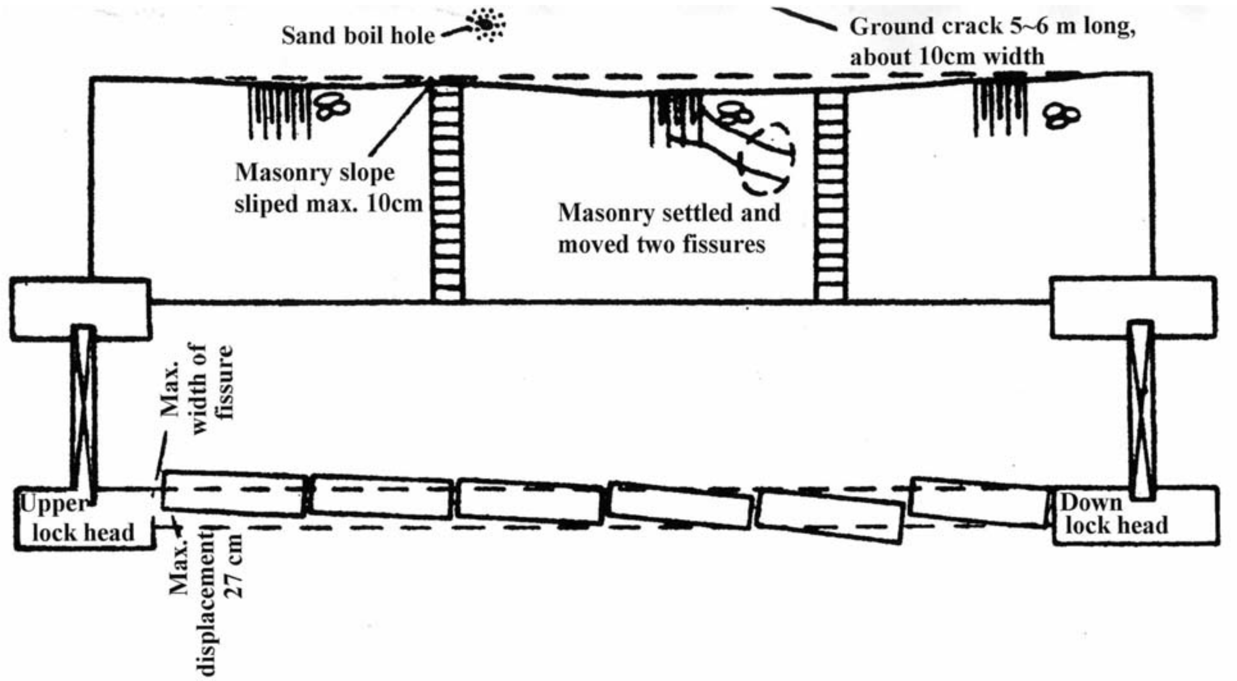

Figure 14. Layout of the damaged lock chamber at the Peizhuang ship lock.

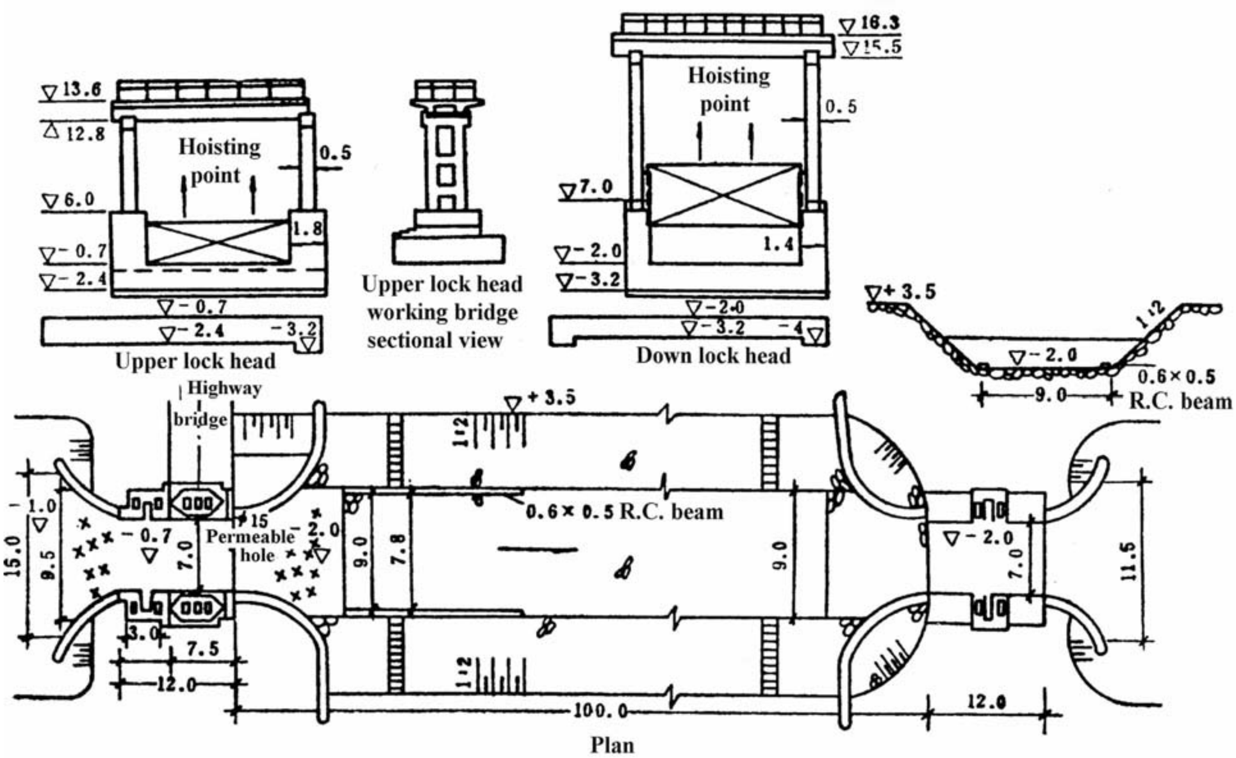

Figure 15. Yonghe ship lock structure view (in m).

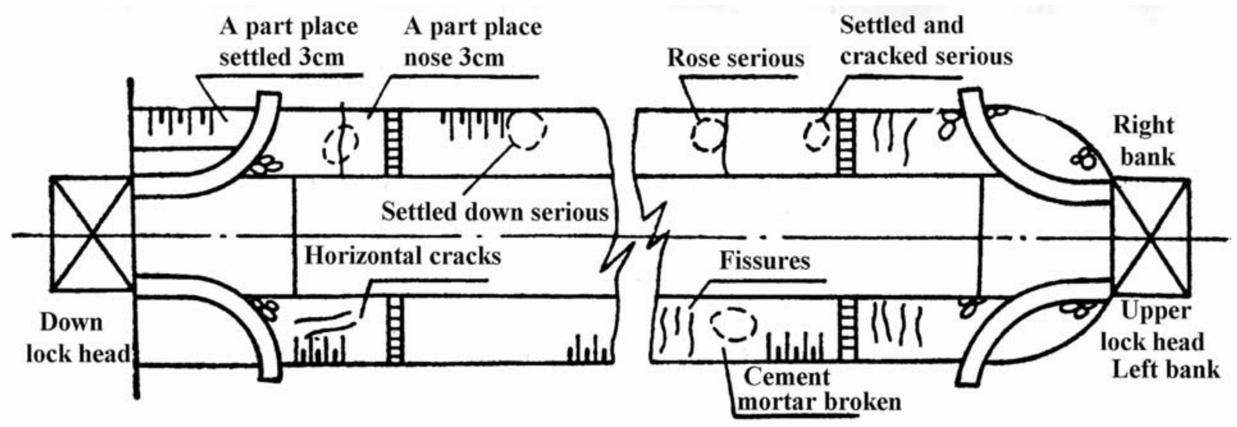

Figure 16. Damage to the Yonghe ship lock chamber.

EARTHQUAKE DAMAGE TO DOCKS ON THE BANKS OF THE HAIHE RIVER

Qiu Ju*

I. Introduction

The docks along the Haihe River are distributed mainly over Tianjin City proper and Tanggu District of the Tianjin Municipality. The docks in the urban district were constructed with sheet pile structures (steel sheet piles or reinforced concrete sheet piles). They are called sheet pile bulkhead wharves and most of them were built before 1949. Most of the docks in Tanggu District were built after 1949 and were constructed with ordinary pile structures; only a few were sheet pile type structures. The position of the docks situated in Tanggu District is shown in Fig. 1. The piled wharves in Tanggu District were constructed mainly with girderless deck structures, but some were beam-slab structures or unloading platforms supported on piles with a sheet pile wall structure and frame structure. In plan view, pillar docks have two groups: piled pier and piled wharf. The first one, a pile pier is connected to the bank by an approach bridge; and the second, a wharf surface is connected to the shore directly. The structure, which connects the pillar wharf to the shore may be a concrete retaining wall or a sheet pile wall. The structural pre-earthquake condition of most docks along the two banks of the Haihe River is given in Table 1 and Table 2.

II. Earthquake Damage to Docks

On July 28, 1976 a violent earthquake occurred in the city of Tangshan. The earthquake intensity in Tianjin City proper and Tanggu District was VIII. Damage to the docks along the Haihe River can be divided into 4 classes:

A. Undamaged - the structures are undamaged;

B. Slightly damaged - parts of the structure are slightly damaged, but easy to repair;

C. Damaged - the structures have evident deformation, parts of the structures are damaged but can be repaired;

D. Seriously damaged - the structures collapsed or have large deformations and are seriously damaged and can not be repaired.

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The damage to docks located on the Haihe River are given in Tables 3 to 4. The total length of these docks is equal to 2,933.31 meters in which:

Class A	227.92 m	make up 7.77%
Class B	912.45 m	make up 31.11%
Class C	1,163.38 m	make up 39.66%
Class D	629.56 m	make up 21.46%

The sum of Class C and Class D is 61.12%. It means that more than half of the docks, which are situated on the Haihe River, were seriously damaged during the Tangshan earthquake.

III. Examples of Earthquake Damage to Pillar Wharves

1) Xinhe External Transportation Wharf

1. General features

The Xinhe External Transportation Wharf is 130.02 m long by 18.5 m wide and was separated into two parts; the upstream part 67.5 m long, and the downstream part 62.5 m long. The expansion joint gap is 2 centimeters. On both sides of the wharf stone revetments were constructed and extended on each side approximately 65 meters. The main part of the wharf is a girderless deck structure on piles. The structure, which connected the deck with the shore, is a concrete retaining wall with a height of 1.3 m which is situated on a rock mound. The cross-section of retaining wall is shown in Fig. 2. The piles of the wharf are arranged in 27 pile bents (Fig. 3). On the even-numbered pile bents there are couples of batter piles; on even numbered bents (13 couples); while on the odd-numbered bents there are only vertical piles. At the front of the wharf there are six couples of batter piles for dolphins. All foundation piles are reinforced concrete. The cross-sectional dimension and length of piles are shown in Fig. 2. The quality of construction of the wharf was good.

2. Situation of the wharf at the time of the earthquake

Some seamen of the barges related that on the morning of July 28, 1976 there were four small cargo barges (L×B×T=39.0×7.15×2.80 m) berthed together on the upstream part of this wharf when the violent Tangshan earthquake occurred. At first, the hulls vibrated up and down then rocked left and right. The four steel mooring cables, 7/8″ in diameter, which were tied to a mooring ring snapped and the mooring ring was deformed by the pull. These barges were pushed away from the wharf about 20 m. The outermost cargo barge also snapped a steel cable 7/8″ in diameter.

3. Earthquake damage

(1) Bank slope

The foundation soil, where the wharf was constructed, is shown in Fig. 2. At the time of the Tangshan earthquake there were more 250 places, in the region of the transit shed behind the wharf structure there were sand and water eruptions. A large area of ground surface subsided. About 150 m from the wharf the two single-story reinforced concrete sheds, which were about 116 m long, 80 m wide and 7 m high, were damaged entirely. On both sides of the wharf there are retaining walls. About 20 m behind these walls more than 10 ground fissures ran parallel to the shore, the biggest width was 50 cm and largest depth was about 1.4 m. The concrete pavement, closely linked with the upstream retaining wall, also had two big ground fissures 20 cm wide by 1.2-1.5 m deep. The upstream retaining wall broke off from the brick enclosure which was situated on top of the wharf, slipped forward, moved in two parts about 1.0 m (Fig. 4), inclined, and subsided. The downstream retaining wall suffered the same, the enclosing brick wall broke off from the wall situated on top of the wharf and then slipped towards the river about 1.2 m and subsided. In front of the retaining wall the slope pavement with cement-rubble masonry had many longitudinal cracks and was squeezed in the form of random waves. The retaining wall which was closely linked with the wharf structure together with the concrete pavement mostly subsided; the amount of subsidence reached 40 cm. The piles of the wharf inclined towards the river which caused the whole wharf to slip towards the river too. The slipof the wharf structure was less than that of the bank slope but damage to the wharf was serious.

(2) Deck

The deck of this wharf is separated into two blocks by the expansion joint – the upstream deck and the downstream deck. The joint gap is about 2 cm. At the time of the earthquake the whole wharf vibrated in a north and south direction. After that the front opening of the joint was closed up and the rear opening spread about 9 cm (Fig. 4); the back side of the downstream deck had pressed into the retaining wall 36 cm yet the back side of the upstream deck was separated from the retaining wall about 15 cm. From the view of the wharf line, the upstream deck had moved forward about 55 cm. It is quite evident that the decks of the wharf had rotated clockwise.

In addition, at the middle part of the deck the tops of crossing piles were arched upwards, and had a longitudinal crack throughout the deck, the crack opening was about 2 cm. At the expansion joint the upstream deck had arched higher than the downstream about 40 cm. Because the entire structure of the wharf slid towards the bank, batter piles became steeper and the pile crown raised so that the deck was jacked up. Some cracks occurred on the surface of the decks; there were four cracks on the upstream deck and two cracks on the downstream deck; they were all located at the tops of crossing piles (Fig. 4).

(3) Foundation piles

Most of the piles had been damaged, especially the crossing piles. The damaged state of piles is as follows:

The pile of the first row: These piles are close to the shore, the greater part of the pile body was buried in the rubble-mound and ground. After the Tangshan earthquake most piles inclined towards the bank. The pile caps separated from the deck (Fig. 5). At the upstream section of the wharf from the first pile bent to the 9th pile bent the pile caps opened between the cap and the deck towards the bank; from the 10th bent to the 11th bent the pile caps kept close to the deck; at the 12th, 13th and 14th bents the pile caps opened toward midstream. But there were not many cracks on the pile body above the ground.

The piles of the second row: Most piles had their pile caps separated from the deck. The pile shaft inclined but the pile body above the sloping ground did not crack. From the 18th pile bent pile shafts displaced towards midstream for a distance, the biggest one was about 1 m. But from the 23rd pile bent the displacement of piles reduced. Since the middle part of the deck was jacked up by the inclined piles some big and small gaps between the pile cap and the bottom of the deck could be found (Table 5). At the 27th bent the opening crack of a pile cap facing the river was only 10 mm.

The piles of the third row: In this row of piles the odd numbered bents had vertical piles and the even numbered bents had crossing piles. All pile caps of the vertical piles were separated from the deck; the maximum distance between them was 380 mm. Most vertical piles inclined towards midstream, especially the pile of the 21st and 23rd bent, which inclined seriously; the maximum relative displacement between pile and deck reached 20 cm. All vertical piles except one were undamaged. The thirteen couples of crossing piles were damaged entirely. Among them, some batter piles inclined towards the river and pulled apart; one pile cap broke and fell into the water. Another batter pile that inclined towards the bank suffered a large pushing force; the obliquity of piles had become steep, the pile crown rose, and the deck was pushed up quite a lot. The concrete of the upper part of the pile body, about the range of 1 m, was pressed and broke to pieces throughout; the remaining parts of the pile body split too.

The piles of the fourth row: In this row all the piles were vertical. Most of the piles inclined towards midstream. All pile caps separated from the deck, a maximum distance of 19 mm. Of the 27 vertical piles in total, 21 pile bodies were in good condition, 5 piles had cracks, and only one pile body had a big crack; the concrete of the pile crowns was compressed and broken into pieces.

The piles of fifth row: In this row there were 21 vertical piles and 6 pairs of crossing mooring piles. Most of the vertical piles had inclined towards midstream and broke off. At the crossing piles of the mooring post the majority of the upstream side batter piles were damaged by pressure; all the downstream side batter piles were pulled apart but their pile caps were still in good condition. At the 23rd and 25th bent there were small cracks 5-10 mm wide between the pile caps and deck, and facing the river.

From the aforesaid damage situation of all piles it is evident that the wharf structures had done a clockwise torsional movement.

2) Yujiapu Foreign Trade Terminal

1. General features

The Yujiapu wharf has a total length of 102.02 m and is divided into two parts – upstream and downstream each part being 51 m long. The expansion joint between the two parts is 2 cm (Fig. 6). This wharf was constructed with a reinforced concrete girderless deck structure on long piles. The width of the wharf is 21 m. Its wharfside deck is a continuous slab; the rear two span of decks are simply supported slabs. The pile layout, the pile spacing and the construction of the wharf are shown in Fig. 6 and Fig. 7. At the frontage of the wharf 4 couples of crossing piles were set up for mooring posts. The whole wharf consists of 85 reinforced concrete piles and 18 fender piles, which are welded with steel sheet piles and placed against the wharfside deck. The geological column where this wharf is located is shown in Table 6.

2. Wharf situation at the time of the earthquake

On July 28, 1976 when the earthquake occurred there were no ships moored at the wharf. The upstream part of the wharf subsided about 60 cm. On that day in the afternoon the M 7.1 aftershock occurred; the next morning it was found that the downstream part of the wharf had already collapsed into the water. Finally, only the upstream part remained.

3. Earthquake damage

(1) Rear ground surface of the wharf

Next to the wharf structure there was a row of timber piles supporting a revetment wall. Within a range of 150 m behind the revetment wall there were about 900 sandboils and some ground fissures, which paralleled the shore. Away from the timber pile revetment wall 1.5 m, 2.4 m and 6 m there were 3 ground fissures, their width was 5 cm, 15 cm and 11 cm. About 6 m from the pile revetment wall a pole had slipped with the landslide about 90 cm. The shed structure near the wharf suffered heavy damage.

(2) Upper structure of the wharf

1. The wharf surface on the remaining upstream part of the wharf originally was leveled with the top of the concrete retaining wall, which is located behind the wharf. After the earthquake the wharf surface subsided more than the subsidence of the retaining wall. The difference in elevation between the wharf surface and the top of the retaining wall was 28 cm. The rear edge of the deck had subsided much more than the front; the original 8% forward drainage slope had become a reverse slope after the earthquake.

2. The original gap between the upstream deck and its rear retaining wall was 3 cm. After the earthquake it widened; at the 8th pile bent the width of the gap reached 10.5 cm. The retaining wall behind the downstream deck (which had already collapsed) had slipped forward, the maximum relative displacement was 30 cm and the subsidence was about 50 cm.

(3) Foundation piles

From the side view the whole upstream part of the wharf had displaced forward, and all the vertical piles inclined towards midstream (Photo 1). The fender piles against the wharf front inclined towards the midstream about 12°.

All wharf piles were seriously damaged. The total piles of the downstream part of the wharf collapsed into the water. The crossing piles of the upstream part of the wharf were damaged entirely; some inclined towards the river, batter piles were sheared and fell into the water; some were only pulled out of their pile caps (Photos 2 and 3). The forward inclined batter piles were sheared off and the wharf deck with its pile cap moved forward about 70 cm, the obliquity of piles increased from 3:1 to 6:1. The concrete pile heads were broken into pieces and the steel bar reinforcement was exposed (Photos 2 and 3).

At the upstream part of the wharf all crossing piles of the mooring post were pulled out or broken off from their pile caps. All concrete pile heads of vertical piles, which were near the wharf apron, were pressed and broken into pieces and steel bars were exposed (Photo 4). Although the bank slope of the wharf had a large displacement and subsidence, at the two rows of inshore vertical piles the pile bodies above the ground surface were damaged lightly, yet the damage to the pile bodies under the ground surface hadn't been probed with an instrument. The pile crack at the upstream part of the wharf is shown in Table 7.

After the crossing piles separated from their pile caps the crossing pile caps of the No. 6 and No. 8 bent moved toward midstream along with the wharf deck; inclined bankward batter piles had shifted to the inside of the pile caps and the inclined bankward batter pile of the No. 2 bent, after being cut off from the pile cap, had moved to the outside of the pile cap. That means the wharf deck had turned clockwise.

3) Frontier Inspection Station pier

1. General features

The Frontier Inspection Station pier had a length of 80.02 m and was divided into two parts – upstream and downstream, the former 42.5 m and the latter 37.5 m. Between these two parts there is a 2 cm expansion gap. This pier is a reinforced concrete girderless deck structure on reinforced concrete piles. The construction of the pier is shown in Figs. 8 and 9. The pier foundation piles were mainly vertical, only on both ends and central section were there a couple of crossing piles. The pier consists of 44 pre-stressed reinforced concrete piles, their sectional dimensions are 40×40 cm. Behind the approach bridges there is a bank revetment wall 131.52 m long; it is constructed with vertical piles and with horizontal retaining plates at the back.

2. Earthquake damage

This pier suffered heavy earthquake damage.

(1) Whole pier deformation

The whole pier had moved toward the midstream; the downstream part moved more than the upstream part. At the expansion joint the relative displacement of the two parts was increased to 60 cm (Fig. 10, Photo 5).

(2) Foundation piles

Among the 44 foundation piles 35 were damaged and about 21 of these piles had a crack width on the pile body that was bigger than 1 mm.

Of the 17 vertical piles in the front row on about 11 of the piles splits could be found on the bodies at the northeast corner; the length of the splits were almost 1 m and 10 cm in depth.

Among 6 pairs of crossing piles, at the northeast corner of the upstream and downstream deck, the No. 8–2 and 17–2 crossing piles were damaged most seriously (Photos 6 and 7). The caps of these two crossing piles broke in two and the backward inclined batter piles were steepened and pushed up the deck. At the southeast corner of the deck the pile caps of the No. 1-2 and No. 9-2 crossing piles also cracked but the degree of damage was not serious (Photo 8).

The whole pier had 38 pile caps of which 17 separated from the pier decking; the largest gap between the cap and deck reached 80 cm.

(3) Pier deck

The pier deck consisted of 19 prefabricated reinforced concrete plates of which 17 were damaged. The deck leaned forward and twisted. At both ends of each part of the pier the rear side of the deck was pushed up about 30 cm by crossing piles. The deck was cracked almost completely especially at both ends of each part of the pier where the deck was damaged very badly. The cracks on the surface of the deck had a width of 2-25 mm and a 45° trend. In addition, on the reverse side of the deck there were also many cracks; these made a right angle with the cracks on the upper surface. The deck, which was badly damaged, could leak water.

(4) Revetment wall

The bank revetment wall, next to the approach bridge, moved toward midstream and leaned forward; the maximum relative displacement reached 1 m more. The backfill behind the revetment wall settled.

4) No. 9 wharf

1. General features

The No. 9 wharf is a terminal of the Third Operation Company of the Tianjin Port. The wharf line runs from south to north. Previously, it was the Kailuan Company dock. In 1957 this wharf was reconstructed. The total length of the wharf line is 130.5 m. The water depth of the wharf frontage is 7 m below the design low water level. The south end of the wharf is connected to the No. 10 wharf. The No. 9 wharf is a reinforced concrete unloading platform structure supported on piles (Fig. 11). Connecting the structure with the bank is the former wharf — a reinforced concrete and sheet pile wall, the earth fill had been consolidated. The platform has a width of 9 m and is 0.5 m thick; it is a big poured-in-place reinforced concrete plate joined to all foundation piles. The foundation piles were pre-cast reinforced concrete piles. The spacing of the bents is 2 m, every bent had a pair of crossing piles to resist the horizontal forces. At the wharf frontage there were 6 mooring posts. Two rail tracks were laid on the wharf surface.

2. Wharf during the earthquake

At the time of the earthquake a cargo ship, the "Bao-Zhou" (dead weight of 10,000 tons), was berthed alongside this wharf and was loaded with cargo of about 800 tons. On the wharf surface there were no moving appliances and no stacked cargo.

3. Earthquake damage

The whole wharf had not deformed. There were no cracks found on the platform, vertical piles and inclined bankward batter piles. Otherwise, among the 65 inclined riverward batter piles 59 of them had cracks. The piles at the southern end of the wharf were damaged more seriously than those at the northern end. The cracks on piles took place mainly at the pile top or where they connected with the platform. Among these batter piles there were 10 which cracked around all four sides of the pile. Only 8 piles had cracks on the pile body and all these cracks took place on the inshore side of the piles (Table 8).

5) No. 10 wharf

1. General features

The No. 10 wharf has a total length of 355.46 m and was built in 1976. The wharf is a composite structure of beams and slabs on piles (Fig. 12). It consists of two platforms – a front platform and a rear platform. The width of the front platform is 14.0 m and the rear platform is 12.2 m. The ground level at the wharf frontage is -5.5 m. The platform consists of a deck, longitudinal girder, longitudinal crane track girder, and a cross girder. All girders are pre-stressed concrete beams. The cross-section of all girders is 120×40 cm. The thickness of the deck slab is 34 cm. On the wharf surface there are 4 portal jib cranes set up and their hoisting capacity is 10 tons. The spacing of pile bents at the front platform is 520 cm and the rear platform is 360 cm. The front platform is divided into 7 parts by an expansion joint 3 cm in width. At the point of operation this wharf is divided into 3 berths, No. 10, 11, and 12. Besides the 7th part the other parts have been equipped with two mooring posts and under each post three batter piles have been set up (Fig. 13).

2. Wharf during the earthquake

Alongside the No. 10 berth the freighter “Tie-Ling” (4,000 displacement tonnage) was lying at anchor when the earthquake occurred. There were no berthed vessels at berth No. 11 and No. 12 but at the wharf apron there were four portal cranes. On the surface of the rear platform and goods yard more than 400 tons of sand were piled up.

3. Earthquake damage

The front platform was seriously damaged and the rear platform was lightly damaged. In the case of damage to the front platform, the pile caps of crossing piles and the inclined riverward batter piles were seriously damaged, but vertical piles and inclined bankward batter piles were basically undamaged (Table 9). All cross girders, longitudinal girders, and crane track girders were in good condition. The berthing member of the wharf was intact also.

Within the 7 parts of the front platform damage to the 4th part was the least. Among the 10 pile caps of crossing piles there were only two pile caps that had several cracks. Both sides of the 4th part and all parts of the front platform had been damaged seriously, especially the 6th and 7th parts. The damage to pile caps of crossing piles is shown in Fig. 13. Damaged pile caps of crossing piles were mainly cracked; most cracks started at the joint of the crane track girders and cross girders, then progressed from cap top to bottom with a slope of 45°-60° inclined to midstream. The upper width of the cracks was larger than the lower and some cracks ran through the pile caps.

Damage to the foundation piles took place mainly on the forward inclined batter piles. The damage is shown in Fig. 14. Damage characteristics appeared as follows: the side of the pile body facing midstream cracked and the cracks extended to the left and right sides of the pile body; no cracks were found on the back side of the piles.

Generally, when a pile cap was damaged seriously then the pile body would be damaged only slightly; if the pile cap was not damaged, the pile body would be damaged seriously.

6) No. 4 pier

1. General features

The No. 4 pier consists of 4 berths (Fig. 15). At the time of the earthquake the construction of the No. 3 and No. 4 berths had just been completed and the back filling behind the retaining wall was underway. All 4 berths are landing piers with approach trestles. These piers are reinforced concrete piles with a girderless slab deck. The connecting structure next to the approach trestles had various types of retaining walls (Table 2).

2. Earthquake damage

Due to the various types of retaining walls the degree of damage to the four berths of the No. 4 pier were very different.

(1) The first berth

Next to the approach trestles there is a revetment wall – a cement-rubble masonry wall. At the time of the earthquake all masonry walls together with the front approach trestles and pier were moved forward and damaged badly.

(2) The second berth

The revetment wall of this berth is a cantilever pile with an inserted plate structure. Its capability of resistance to slope failure is strong. Although the revetment wall was seriously damaged the pier and trestles were damaged only slightly.

(3) The third and fourth berths

At these two berths a revetment wall was constructed only next to the approach trestle; the other portions of the bank have a low retaining wall. When the earthquake occurred the revetment wall behind the trestle settled and overturned backward. Only some vertical piles of the approach trestle had been damaged. The whole pier was lightly damaged.

7) Pier for overhaul works of the Tianjin Channel Engineering Bureau

1. General features

The pier for the overhaul works is a berthing jetty with a composite structure of a reinforced concrete girderless deck on piles. The entire length is 27.5 m and the width is 7.5 m. The approach trestle is 21.3 m long and 7.5 m wide. Six pile bents are provided. The pier has two wings, each wing contains two pile bents and each bent has two pair of batter piles. The pier connects with the approach trestle in the middle. Vertical piles were installed in the approach trestle (Fig. 16). All foundation piles are pre-stressed reinforced concrete piles with a cross-section of 40×40 cm. The vertical piles are 2,188 cm long and batter piles are 2,300 cm long. The pile point is founded on a stiff clay strata at -18.30 m.

The approach trestle is connected to the retaining wall which is constructed with a cement-rubble masonry. The retaining wall is 1.5 m high and 11.5 m long with a base and top width of 1.3 m and 0.6 m, respectively. It is situated on the top of a rock mound.

The pier is designed for a live load of 1.5 t/m^2 and for crane truck loading of 5 t. It can berth a tugboat and a dredger.

The condition of soil horizon for this area is shown in Table 10.

Starting from the depth of -1.84 to -5.54 m is a strata of clay loam. The penetration blow number is 1-5 so it belongs to liquefiable soil.

The construction of this pier started in the fourth quarter of 1966. The piling work was finished before the end of that year. Some of the deck slab of the approach trestle had been installed, while the deck slab on the pier had not. In order to survive through the winter, round timbers and 8# steel wire were used to bind and strengthen the piles. After the freezing period in the following year, because of the impact of floating ice, the foundation piles inclined. After inspection it was found that there existed cracks on the piles at a level from 2 m to 4 m above the subsurface of mud. Some had already broken. The methods used to save them were: straighten up the piles; for those piles that had cracks or had been broken concrete was used to repair and strengthen them; so damage already existed before the completion of the work. But the pier was used normally until the earthquake.

2. Earthquake damage

When the earthquake occurred a dredger was berthed in front of the pier but there was no load on the pier slab.

(1) Bank slope

Within a 60 meter range of the pier water and sand erupted from the ground at several places. The bank slope slid seriously. There were lots of fissures parallel to the bank. The largest one was about 100 cm wide. Many cracks crossed the wharf area to the workshop road, which caused crosswise cracks on the concrete pavement every several meters.

(2) Upper part of the structure

The whole pier had moved forward and inclined and the deformation was great. The upper structure was damaged so seriously that the slope of the deck changed from 5% to 10% incline towards the river after the earthquake. The back of the decking of the two wings bent upwards, which was higher than the deck of the approach trestle by about 30-55 cm. At the second and fifth bent the deck was broken; there were radial cracks on it, the largest one was 20 mm wide. The reinforced concrete close plates in front of the pier changed from vertical to a slope of 1:12 and inclined towards the river. There were several oblique cracks on the plate and the upstream side of the plate was seriously damaged. The widest crack was 102 mm, the reinforcement bar was broken.

(3) Piles

All the piles of the pier were damaged to various degrees. Crossing piles experienced serious damage in which the batter piles that inclined towards the river broke away from the pile cap i.e., the #6, #7 pile in the first bent, the #6 pile in the fifth bent, and the #6, #7 piles in the sixth bent (Fig. 16). All batter piles were damaged seriously except for the #6 inclined forward batter pile in the second bent, which was lightly damaged.

All the vertical piles were in the third and the fourth bents. The part of the vertical pile shafts which was above water (#1 and #3 pile) was damaged slightly but it experienced a forward sliding together from the sliding of the bank slope. But the #4 to #7 piles all inclined seriously. There were cracks on the riverside of the pile shaft of the #4 and #5 piles, and the concrete was damaged by the spalling at the back of the pile shaft. The deck had been pushed up and split at the #5 vertical pile at the joint of the approach trestle and pier.

(4) Retaining wall

The retaining wall, which connected the approach trestle, moved forward horizontally. The body of the wall was basically in good condition except there were two cracks at the top of the wall.

After the earthquake the pier was out of use for some time.

IV. Examples of Earthquake Damage to Sheet Pile Bulkheads

1) Chentangzhuang Terminal for the Ocean Fishing Company

1. General features

This bulkhead, which was completed in 1965, has an entire length of 240.9 m.

This bulkhead is an anchored pre-stressed concrete sheet pile type structure (Fig. 17). The imbedded depth of the sheet piles was 6 m and they were capped with cast-in-place reinforced concrete beams. The anchoring system consists of 50ϕ mm steel anchor rods and reinforced concrete sheet pile. The rods are placed at 2.0 m intervals. The designed normal water level is at 2.75 m and the designed lower water level at 2.0 m. The bottom elevation in front of the bulkhead is -2.5 m.

After construction it was noticed that sand was leaking through the gaps between sheet piles. In addition, the original bottom elevation in front of the bulkhead was -2.5 m but due to erosion from running water the bottom elevation fell to -4.0 m at the time of the earthquake so the depth of burying sheet piles was 4.5 m instead of 6 m.

2. Earthquake damage

(1) Sand and water erupted in many places

After the earthquake sand and water erupted around the bulkhead wharf; at the downstream end of the wharf there were 16 such places. By borehole surveying: above -6.0 m the soil is a clayey loam, which belongs to the liquefied soil. The steel pile wall and anchoring system were all constructed in this stratum.

(2) The apron moved outward and the sheet pile wall inclined forward

The whole sheet pile quay wall inclined forward and the horizontal displacement of the top of the wall was 10 cm to 20 cm. At the downstream side of the wharf there was a 20 m segment whose outward displacement was about 30 cm. It was noticed that when the earthquake occurred, in this segment at a distance 1.5 m away from the front line, there were five layers of concrete sheet piles (26×50×1130 cm), which had been left there after the construction.

(3) Cracks on the wharf surface, a concrete "dead-man" wall moved forward

Two cracks existed about 10 cm wide parallel to the riverbank; one was in front of a "dead-man" wall about 3-5 meters and the other at the back. The "dead-man" wall moved forward.

(4) The wharf surface subsided and damaged a fish shed

Subsidence of the wharf surface ranged from 20 cm to 30 cm, the largest reached 40 cm.

Due to the wharf inclining forward and the wharf surface non-uniformly subsiding, the fish shed, which was set up on the downstream side of the bulkhead wharf, was seriously damaged. The concrete ground surface at the fish shed had cracks parallel to the riverbank, the cracked slab rose and fell unevenly. Brick posts were used for the shed, which had concrete thin-webbed girders and a deck slab. After the earthquake, due to the shear force, there existed fractures at the toe of all brick posts.

Because there was no investigation the condition of the tie rod and the anchoring system is unknown.

2) Repair wharf for Xinhe Shipyard

1. General features

This dock is located in the Xinhe Shipyard. Formerly, it was a wood pile revetment wall; in 1968 it was reconstructed into a bulkhead wharf with a length of 124.4 m.

This bulkhead wharf is an anchored pre-stressed I-shaped sheet pile structure (Fig. 18). A reinforced concrete cast-in-place capping beam was provided at the top of the wall. The anchoring system consists of pre-stressed reinforced concrete piles; the spacing is about 80 cm. Steel tie rods are 50ϕ and are installed at 2.4 m center to center. The design high water level is +3.5 m and the design low water level is +1.7 m; the bottom elevation in front of the wharf is -4.5 m. The depth imbedded of the sheet piles was 7.3 m.

During construction 2 m of original bank soil was dredged out replaced with a 50 cm thick layer of sand and then backfilled with 4-6 cm of waste stone ballast at the back of the sheet pile wall.

2. Earthquake damage

After the earthquake the bulkhead wharf was basically in good condition. There was no deformation. There were no cracks or subsidence of the wharf slab.

Around this bulkhead wharf area sand and water erupted at more than 280 places during the earthquake. The workshop and lots of buildings were damaged to various degrees. A neighboring beam-slab pile structure wharf with a length of 147 m was also damaged. Its retaining wall subsided about 15 cm and most of the forward inclined batter piles had ring shaped cracks or had broken; most of the crossing pile caps had cracks.

3) Repair of wharf for the First Navigational Engineering Bureau Shipyard

1. General features

This is a marginal bulkhead wharf with an entire length of 193 m. It was constructed in 1975.

This bulkhead wharf is an anchored sheet pile structure (Fig. 19). The wharf is divided into three parts: east, middle, and west.

The east part of the wharf is 53 m long and was constructed with different types of steel sheet piles. The piles vary from 8, 10, 13 to 14 meters in length. The elevation of the pile toe is -4.8 m to -10.8 m. The designed elevation of the dredged bottom in front of the wharf of this part is -1.0 m. It became -0.4 to -1.0 m when the earthquake occurred.

The middle part of the wharf is 105 m long and was constructed with a Larssen IV type steel sheet piles with lengths ranging from 15 m to 18 m and the pile toe is at -11.8 m to -14.8 m. The design elevation of the dredged bottom in front of the wharf was -3.0 m and it became -1.0 m to -2.0 m when the earthquake occurred.

The west part of the wharf is 35 m long and was constructed with reinforced concrete sheet piles. The length of the pile is the same as that of the middle part. The bottom elevation in front of the wharf is at -3.0 m. The anchoring system consists of a 3.7 m long anchor plate and 50ϕ steel tie rods at 1.81 m center to center. A reinforced concrete capping beam provided at the top of the sheet piling.

The design HWL is at 3.5 m and the design LWL is at 1.0 m. The water level was at 2.0 m when the earthquake occurred.

When the earthquake occurred the placement of the fill had not been finished in the east part of the wharf and in some segments of the middle part. The elevation of the soil fill had already reached the bottom of the pipe chase in the capping beam.

2. Earthquake damage

This wharf was damaged quite seriously.

(1) Sand and water erupted in many places around the wharf

After the earthquake sand and water erupted at more than 200 places in the factory area. The boring log shows that at an elevation from 4.0 m to 3.0 m, from -0.5 m to -1.0 m and from -3.0 to -5.5 m there were sandy loam formations. The penetration blow number was less than 10 so it belonged to liquefied soil. These three strata are just behind the sheet pile wall and in the range of the embedded depth of the sheet pile.

(2) The apron moved outward and the sheet pile inclined forward

When the earthquake occurred a tugboat with a dead weight of 650 t was berthing in front of the bulkhead. Due to vibration the steel mooring hawser of the tugboat which was fastened onto the bollard.

After the earthquake a sheet pile wall began to incline towards the river. About three hours after the earthquake the horizontal displacement of the top of the sheet pile wall was about 10 cm. Hereafter, the middle part of the wharf continued to incline forward. On the fourteenth day after the earthquake the largest displacement of the wharf line reached 1.14 m. The previously straight wharf line became curved (Fig. 20). The displacement was larger in the middle part than at the two ends. The sheet pile wall inclined forward seriously, the inclined slope of the capping beam, which was on top of the wall, was about 6°.

(3) The wharf surface cracked, the anchor plate inclined forward

After the earthquake the sheet pile wall moved and inclined forward. There were three obvious cracks on the surface of the wharf, which paralleled the riverbank. One crack was at a distance of 1 - 2 m from the apron line of the wharf and was 10 - 20 cm wide. Another crack was near the anchor plate top with a width of 15 cm. The third one was at a distance of 20 - 30 m from the wharf apron line behind the anchor plate.

After the earthquake, in order to do the investigation, some parts of the bulkhead wharf had to be excavated. It was seen that the connection of the tie rod with the sheet pile wall and with the anchor plate was in good condition. The tie rod was in a state of tension stress; the amount of forward displacement of the sheet pile wall was larger than that of the anchor plate. The capping beam of the anchor plate became inclined. Because the forward displacement of the entire wharf was different the concrete pavement at the back of the sheet pile wall rose about 20 cm due to compression. The repair shop at the rear of the wharf was also damaged seriously.

(Translator: Qiu Ju)

Table 1. Structure of the main sheet pile bulkheads on the bank of the Haihe River.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dock Dimension		Sheet Pile Wall	Anchorage
					Length (m)	Bottom Elevation in Front		
1	Liulin Wharf of CEB	Hexi District	1969	structure is reinforced concrete sheet pile	219.52	–2.5	reinforced concrete sheet pile 26×50×1130 (cm)	reinforced concrete sheet pile 30×50×520 (cm)
2	Chentangzhuang Terminal for Ocean Fishing Company	Hexi District	1965	structure is reinforced concrete sheet pile	240.90	–2.50	reinforced concrete sheet pile 26×50×1130 (cm)	reinforced concrete sheet pile 30×50×520 (cm)
7	Repair Wharf of Xinhe Shipyard	Tanggu District	1968	pre-stressed concrete sheet pile bulkhead	124.40	–4.50	I-shaped pre-stressed concrete sheet pile 30×40×1520 (cm)	pre-stressed concrete pile 30×50 (cm)
21	Repair Wharf of the FNEB Shipyard	Tanggu District	1973	steel sheet pile bulkhead	193.00	–3.00	Larssen IV type of steel sheet-pile L=15-18 (m)	reinforced concrete anchorage sheet pile 30×60×370 (cm)

Table 2. Structure of main piled docks on the bank of the Haihe River.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
3	Xinhe Terminal for Oil Storage Office	Tanggu District	1971	pier, piled structure with reinforced concrete girderless deck	124.82	5.00	−3.60	26	44	48	40×40	15.30 24.20	2.85 4.80	concrete retaining wall; earth slope 1:3.0
4	Xinhe external transport terminal	Tanggu District	1972	wharf, piled structure with reinforced concrete girderless deck	132.02	18.50	−3.50	27	116	38	40×40	23.40 24.40	4.00	concrete retaining wall; earth slope 1:2.0
5	Equipment Wharf for Xinhe Shipyard	Tanggu District	1973	wharf, reinforced concrete beam and slab structure on piles	147.00	20.00	−4.00	27	92	57	50×50	23.70 25.50	5.00	concrete retaining wall; earth slope 1:2.5
6	Old wharf for Xinhe Shipyard	Tanggu District	around 1949	wharf, piled structure with reinforced concrete frame	49.90	12.80	−2.00							

Table 2. Continued.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
8	Frontier Station Wharf	Tanggu District	1965	pier piled structure with reinforced concrete girderless deck	80.02	6.50	−2.50	17	32	12	40×40	21.25 22.43	4.00	bank revetment constructed by vertical piles with horizontal retaining plates, 131.52 m long
9	No. 8 Wharf	Tanggu District	1965	wharf, piled structure with reinforced concrete girderless deck	229.98	22.50	−5.50	54	230	108	40×40 |40×55	25.00 26.40	4.00	Cement rubble masonry retaining wall; earth slope 1:2.3
10	Customs Wharf	Tanggu District	1971	pier, piled structure with reinforced concrete girderless deck	28.0	5.00	−2.00	6	10	8	40×40	21.00	2.70	concrete retaining wall; earth slope 1:1.5

Table 2. Continued.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
11	No. 9 Wharf	Tanggu District	1957	wharf, reinforced concrete relieving platform structure on piles	130.50	9.00	−6.40	65	130	131	40×40 45×45	19.20 24.70	3.00	reinforced concrete sheet pile retaining wall; earth slope 1:2.0
12	No. 10 Wharf	Tanggu District	1975	wharf, reinforced concrete beam and slab structure on piles	355.46	26.03	−5.50	69	331	150	50×50 45×45 40×60	23.00 26.50	front 5.25; rear 4.70	concrete retaining wall; earth slope 1:2.5
13	Fishery Wharf	Tanggu District	1964	pier, piled structure with reinforced concrete girderless deck	34.00	7.50	−2.50	8	14	12	40×40	20.70 24.09	4.50	bank revetment constructed by vertical piles with horizontal retaining plates

Table 2. Continued.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
14	Cold Storage Wharf	Tanggu District	1975	wharf, piled structure with reinforced concrete girderless deck	95.00	17.50	−4.50	20	72	30	45×45	23.30 24.90	5.00	concrete retaining wall; earth slope 1:3.0
15	Fishing Company Wharf	Tanggu District	1961	pier, piled structure with reinforced concrete girderless deck	90.50	11.50	−2.00	21	57	36	40×40 50×50	21.70 24.50	4.50	retaining wall constructed with wood piles with plug board; earth slope 1:3.0
16	Yujiapu Foreign Trade Terminal	Tanggu District	1970	wharf, piled structure with reinforced concrete girderless deck	102.02	21.00	−3.50	18	59	26	40×40 50×50	23.40 24.40	6.00	concrete retaining wall; earth slope 1:2.0

Table 2. Continued.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
17	Berth 1 of No. 4 Pier	Tanggu District	1970	pier, piled structure with reinforced concrete girderless deck	99.54	7.50	–4.00	21	55	31	40×40	23.50	4.50	cement rubble retaining wall
18	Berth 2 of No. 4 Pier	Tanggu District	1965	pier, piled structure with reinforced concrete girderless deck	101.02	7.50	–3.50	21	47	32	40×40	21.80 24.80	4.50	vertical reinforced concrete piles with horizontal plug board
19	Berth 3 of No. 4 Pier	Tanggu District	1974	pier, piled structure with reinforced concrete girderless deck	159.56	7.50	–4.20	32	62	32	50×50	21.80 24.80	5.50	next to the approach trestle there is a concrete retaining wall; earth slope 1:2.5

Table 2. Continued.

Number	Name of Dock	Position of Dock	Construction Year	Type of Dock Construction	Dimensions of Dock			Number of Pile Bent	Full Number of Vertical Pile	Full Number of Batter Pile	Cross Section of Pile (cm×cm)	Length of Pile (m)	Pile Spacing	Structure Connected with Bank
					Length (m)	Width (m)	Bottom Elevation in Front (m)							
20	Berth 4 of No. 4 Pier	Tanggu District	1975	pier, piled structure with reinforced concrete girderless deck	99.13	7.5	−3.70	20	43	22	50×50	21.80 24.80	5.50	next to the approach trestle there is a concrete retaining wall; earth slope 1:2.5
22	Wharf for Overhaul Works of the CEB	Tanggu District	1967	pier, piled structure with reinforced concrete girderless deck	27.50	7.50	−3.50	6	15	15	40×40	21.00 23.00	4.50	next to the approach trestle there is a cement-rubble masonry retaining wall, earth slope 1:3.0
23	Working Craft Terminal for the FNED	Tanggu District	1968	pier, piled structure with reinforced concrete girderless deck	69.52	5.50	−2.00	15	36	8	40×40	18.40 21.90	3.50	cement rubble masonry retaining wall

Table 3. General damage to main sheet pile bulkheads on the bank of the Haihe River.

Number	Name of Dock	Rank of Damage	Sheet Pile Wall	Anchor Structure
1	Liulin Wharf of CEB	B	upstream part of the wharf 100 m in length was undamaged; at the downstream part the sheet pile wall inclined, wharf surface subsided	there were ground fissures both in front and behind the anchor wall
2	Chentangzhuang Terminal for Ocean Fishing Company	B	the wall inclined about 10-20 cm in width, the biggest one reached 30 cm; wharf surface subsided 20-30 cm	there were ground fissures both in front and behind the anchor wall, the width of fissures was about 10 cm
7	Repair Wharf of Xinhe Shipyard	A	undamaged	undamaged
21	Repair Wharf of the FNEB Shipyard	D	sheet pile wall displaced forward, the largest displacement reached 1.14 m; sheet pile wall inclined forward, inclined slope was 10:1	anchor sheet pile moved forward one meter

Table 4. General damage to the main pile docks on the bank of the Haihe River.

Number	Name of Dock	Rank of Damage	Crossing Pile (couple)					Vertical Pile (single)					Upper Structure	Retaining Works
			Total	Undamaged	Slightly Damaged	Damaged	Seriously Damaged	Total	Undamaged	Slightly Damaged	Damaged	Seriously Damaged		
3	Terminal for Oil Storage Office	B												
4	Xinhe External Transport Terminal	D	19	0	1	10	8	116	79	9	10	18	damaged	seriously damaged
5	Equipment Wharf for Shipyard	C	27	1	0	20	6	92	91	1	0	0	damaged	seriously damaged
6	Old Wharf of Xinhe Shipyard	B												
8	Frontier Station Wharf	D	6	0	0	0	6	32	1	12	13	6	damaged	damaged
9	No. 8 Wharf	C	64	16	9	32	17	260	185	14	61	0	slightly damaged	undamaged
10	Customs Wharf	B	4	0	2	2	0	10	6	4	0	0	slightly damaged	damaged
11	No. 9 Wharf	B	65	6	39	20	0	130	130	0	0	0	undamaged	undamaged
12	No. 10 Wharf	C	69	4	17	48	0	138	138	0	0	0	undamaged	slightly damaged
13	Fishery Wharf	A	6	2	4	0	0	14	14	0	0	0	undamaged	slightly damaged
14	Cold Storage Wharf	D	15	0	1	0	14	65	37	3	14			
15	Fishing Company wharf	C	18	11	0	5	2	57	40	2	2	11	seriously damaged	seriously damaged

Table 4. Continued.

Number	Name of Dock	Rank of Damage	Crossing Pile (couple)					Vertical Pile (single)					Upper Structure	Retaining Works
			Total	Undamaged	Slightly Damaged	Damaged	Seriously Damaged	Total	Undamaged	Slightly Damaged	Damaged	Seriously Damaged		
16	Yujiapu foreign trade terminal (upstream part)	D	6	0	0	0	6	30	0	8	5	13	undamaged	damaged
17	Berth 1 of No. 4 Pier	C	16	3	1	2	10	54	14	12	8	20	damaged	damaged
18	Berth 2 of No. 4 Pier	B	16	6	2	7	1	54	34	2	6	12	undamaged	damaged
19	Berth 3 of No. 4 Pier	B	16	10	1	5	0	71	64	0	0	7	slightly damaged	damaged
20	Berth 4 of No. 4 Pier	B	11	2	1	8	0	43	32	0	1	10	undamaged	damaged
22	Wharf for Overhaul Works of the CEB	D	8	0	0	1	7	14	0	4	3	7	seriously damaged	slightly damaged
23	Working Craft Terminal for the FNED	A	undamaged					undamaged					undamaged	undamaged

Damage degree of piles: slightly damaged – width of crack <0.5 mm
damaged – width of crack 0.5 – 5 mm
seriously damaged – width of crack >5 mm

Table 5. Circumstances of gaps between the pile cap and bottom of the deck.

No. of Bent	Inclination of Pile	Maximum Gap Between Pile Cap and Deck (mm)	
		On the Bank Side	On the River Side
1-6	towards bank	310.0	1.5
7-14	towards river	2.5	195.0
15	upright	0.0	0.0
16-26	towards river	20.0	420.0

Table 6. Geological boring information of Yujiapu Foreign Trade Terminal.

Ground Soil Strata	Water Content (%)	Bulk Unit Weight (g/cm^3)	Void Ratio	Plasticity Index	Consistency	Quick Shear Test		Consolidated Quick Shear Test	
						$\overline{\varphi}$	$\overline{C}$	$\overline{\varphi}$	$\overline{C}$
+0.07 to -6.50 silty clay loam with sandwich of silty sand	41.0	1.78	1.15	13.1	1.83	20°	0.18	25°	0.08
-6.50 to -12.60 clay	46.2	1.77	1.26	20.9	1.15	7°	0.22	12°	0.19
-12.60 to -20.10 clay loam	26.9	1.98	0.74	11.4	1.00	20°	0.15	26°	0.13

Note: Below –20.1 m is the compact sand strata.

Table 7. Pile cracks at Yujiapu FTT (upstream part of the wharf).

Category of Pile		Total	Number of Damages	Number of Piles with Different Crack Widths δ (mm)		
				$\delta \leq 0.5$	$0.5 < \delta \leq 5$	$\delta > 5$
crossing pile	inclined towards river batter piles	4	4	0	0	4
	inclined towards bank batter piles	8	8	0	0	8
pile cap of crossing piles		6	6	0	1	5
vertical piles		30	29	13	3	13
pile cap of vertical piles		30	15	5	6	4

Table 8. Pile cracks at the No. 9 Wharf.

Category of Piles		Number of Piles with Different Width of Cracks (δ) (mm)				Total	Damaged Number
		$\delta = 0$	$\delta \leq 0.5$	$0.5 < \delta \leq 2$	$2 < \delta \leq 5$		%
inclined towards river batter pile	connection of the pile and platform	6	35	15	4	65	59
	on pile body		4	1	0		90.7%
inclined towards the bank batter piles		0	0	0	0	66	0
vertical piles		0	0	0	0	130	0

Note: Among the 35 piles (crack $\delta \leq 0.5$ mm) there were three piles which had cracks $\delta < 0.5$ mm on their bodies also.

Table 9. Damage statistic of the pile caps and piles at the front platform of the No. 10 Wharf.

Category of Members		Total	Number of Damage (%)	Number of Member with Different Crack Width δ (mm)			
				I $\delta = 0$	II $\delta \le 0.5$	III $0.5 < \delta \le 2$	IV $2 < \delta \le 5$
crossing piles	inclined towards river batter piles	69	$\frac{54}{78.26}$	15	31	20	3
	inclined towards bank batter piles	84	$\frac{9}{10.71}$	75	2	5	2
pile cape of crossing piles		69	$\frac{44}{63.77}$	25	8	19	17
vertical piles		138	$\frac{3}{2.17}$	135	3	0	0
pile cap of vertical piles		138	0	138	0	0	0

Table 10. The condition of the soil horizon at the pier for Overhaul Works of T. C. E. B.

Elevation (m)	Name of Soil Horizon
+5.06 to −1.84	sandy clay
−1.84 to −5.54	clayey loam with silty sand strata
−5.54 to −6.79	sandy clay
−6.79 to −12.44	clay silty sand
−12.44 to −18.94	sandy clay
−18.94 to −20.34	clay

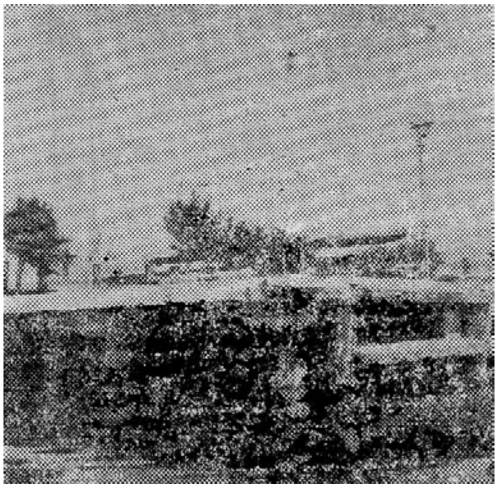

Photo 1. The upstream part of the wharf displaced forward and inclined at the Yujiapu Terminal.

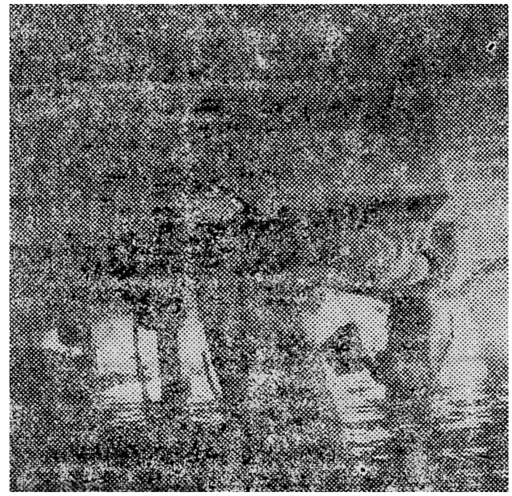

Photo 2. The No. 6 crossing piles of the upstream part of the wharf were damaged at the Yujiapu Terminal. (by Jin Guangluo)

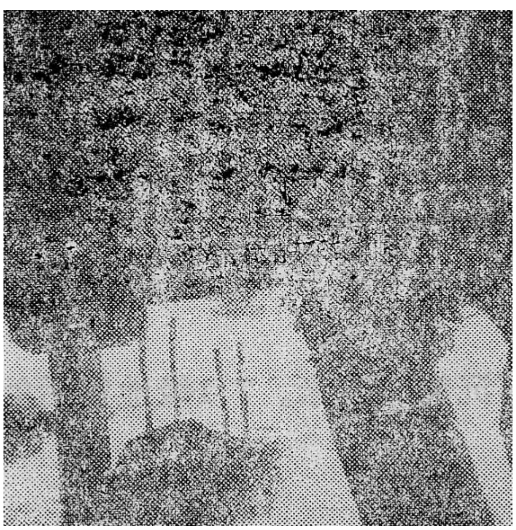

Photo 3. The No. 8 crossing piles of the upstream part of the wharf were damaged at the Yujiapu Terminal. (by Jin Guangluo)

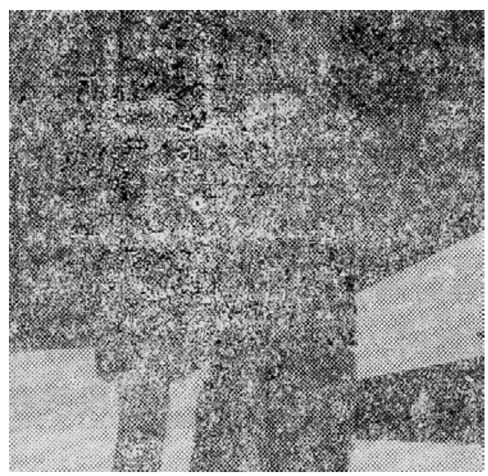

Photo 4. The first vertical pile of the No. 8 frame of the upstream part of the wharf was damaged. (by Jin Guangluo)

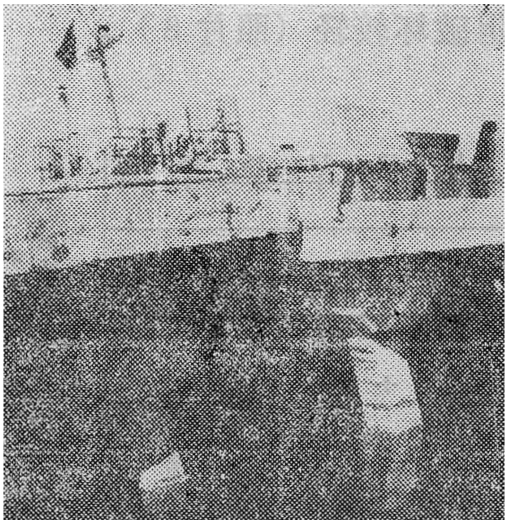

Photo 5. The horizontal staggered joint between the upstream and downstream part of the FIS pier was about 60 cm; the vertical staggered joint was about 30 cm.

Photo 6. The pile cap of the No. 8–2 crossing pile of the FIS pier broke; the inclined riverward batter pile leaned forward.

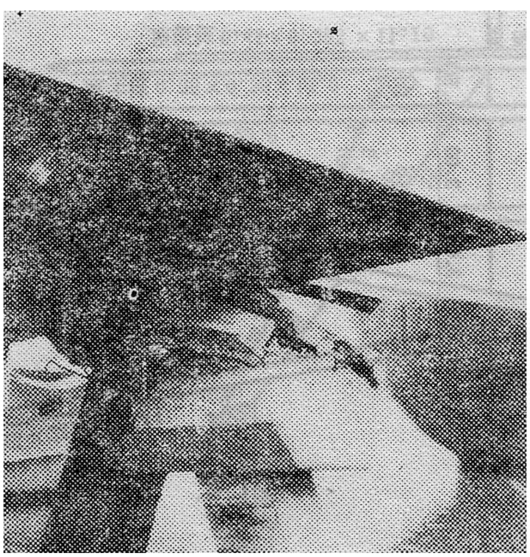

Photo 7. The pile cap of No. 17–2 inclined backward batter pile steepened. FIS pier.

Photo 8. The pile cap of the No. 8–12 crossing pile cracked at the FIS pier.

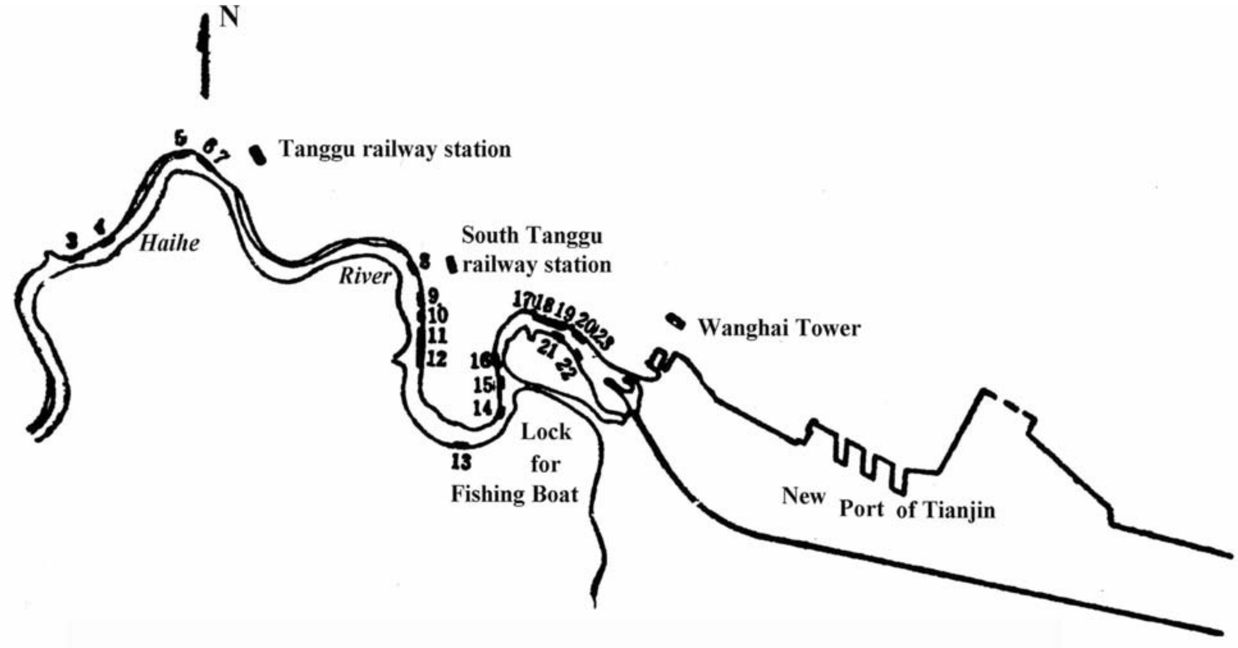

Figure 1. Position of main docks on the banks of the Haihe River, Tanggu District.

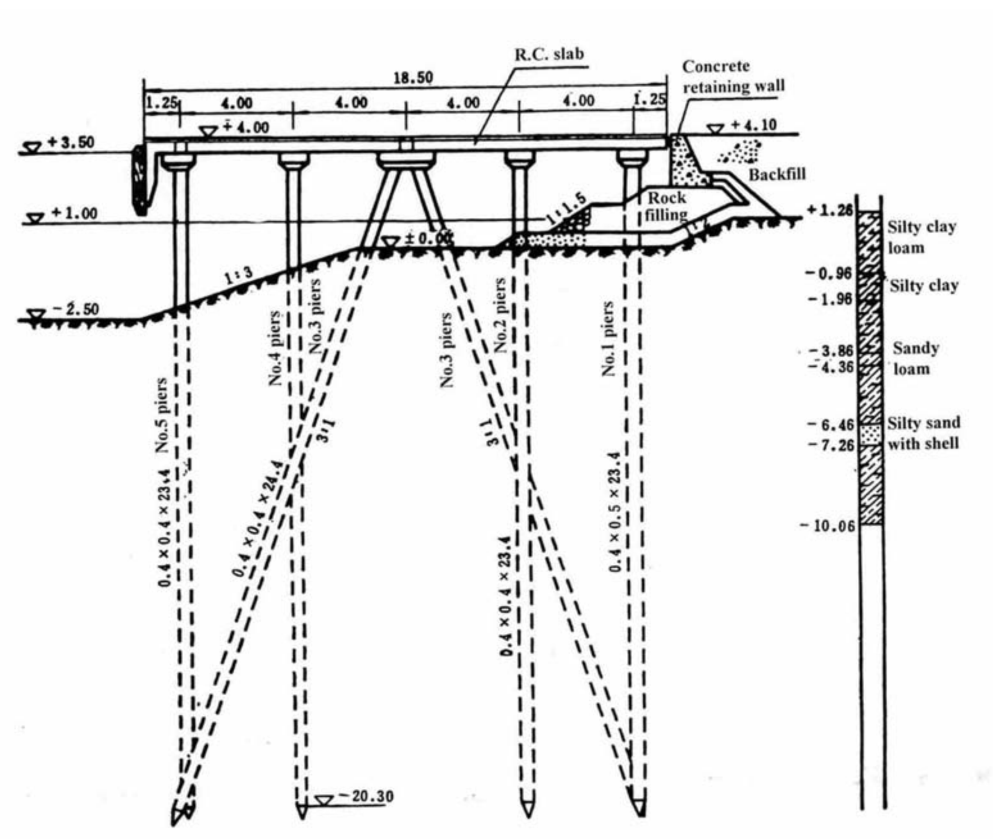

Figure 2. Cross section of the Xinhe external transport terminal (in m).

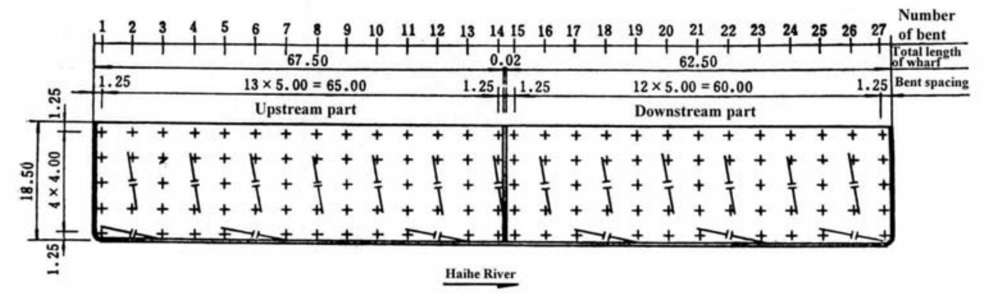

Figure 3. Pile layout of the Xinhe external transport terminal (in m).

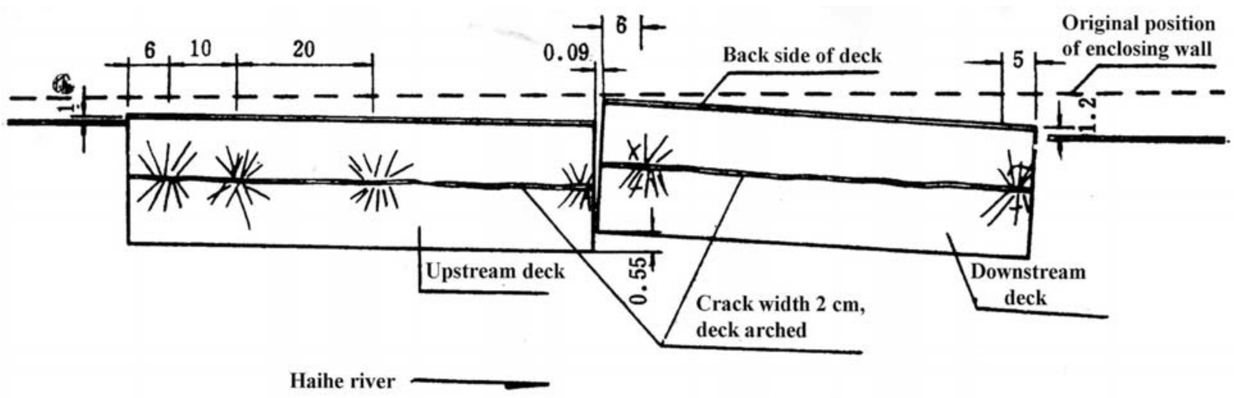

Figure 4. A sketch of damage to the Xinhe external transport terminal (in m).

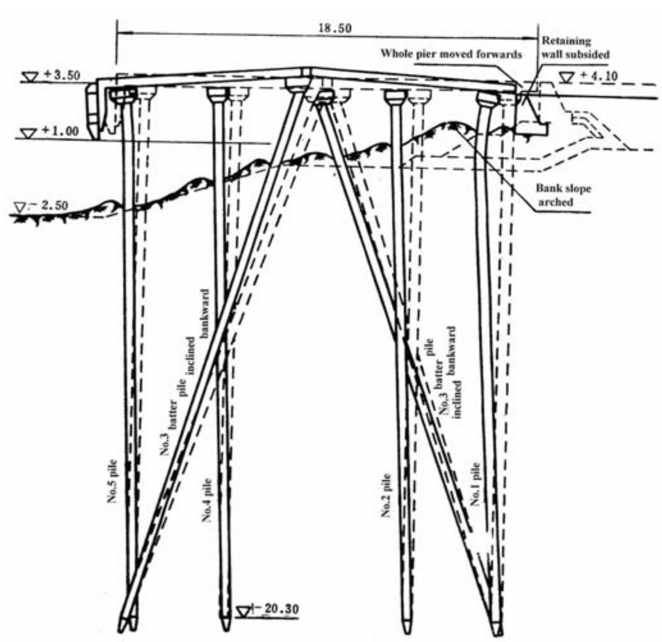

Figure 5. A sketch of damage to the Xinhe external transport terminal (in m).

(The dotted lines show the original situation of members)

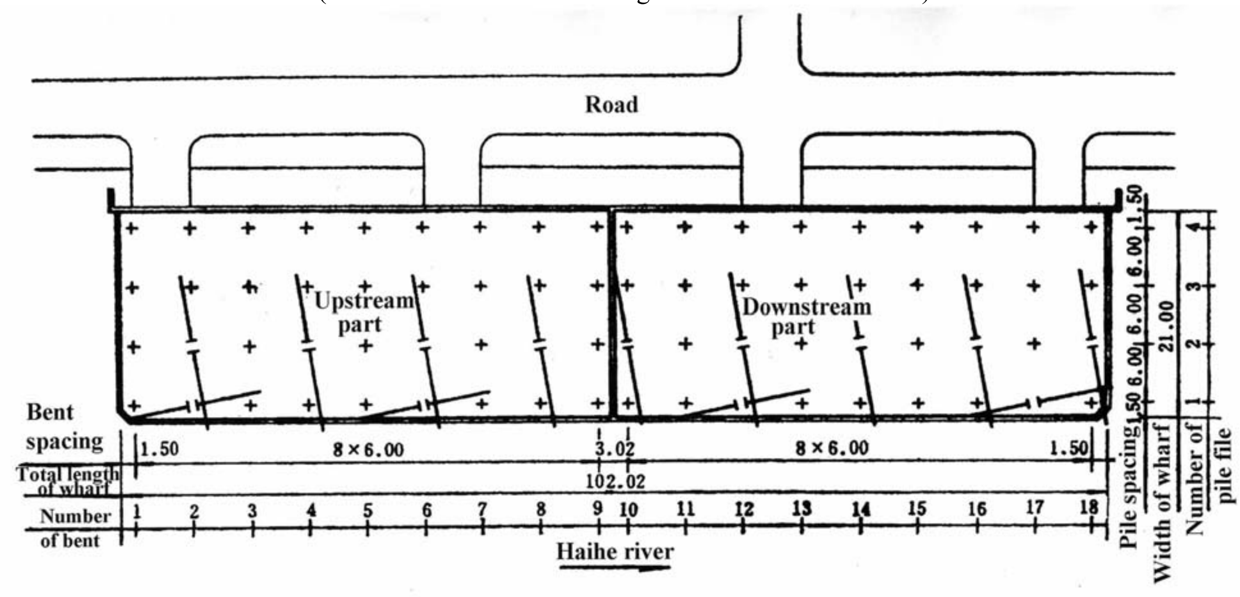

Figure 6. Plan of the Yujiapu foreign trade terminal (in m).

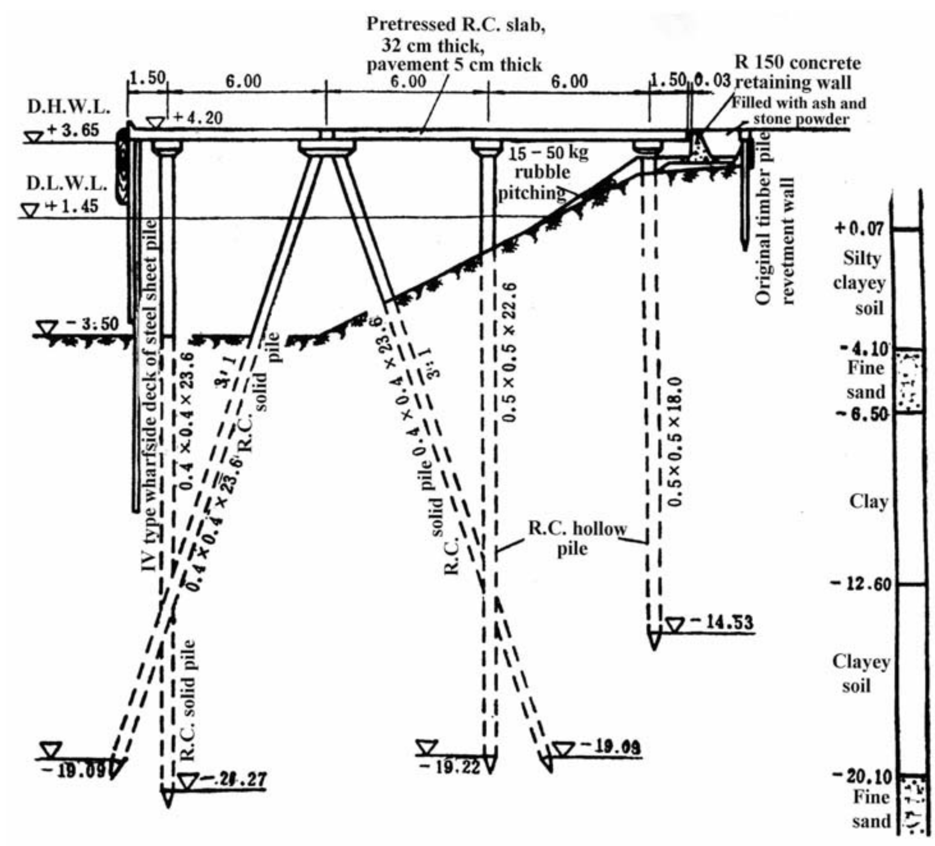

Figure 7. Cross section of the Yujiapu foreign trade terminal (in m).

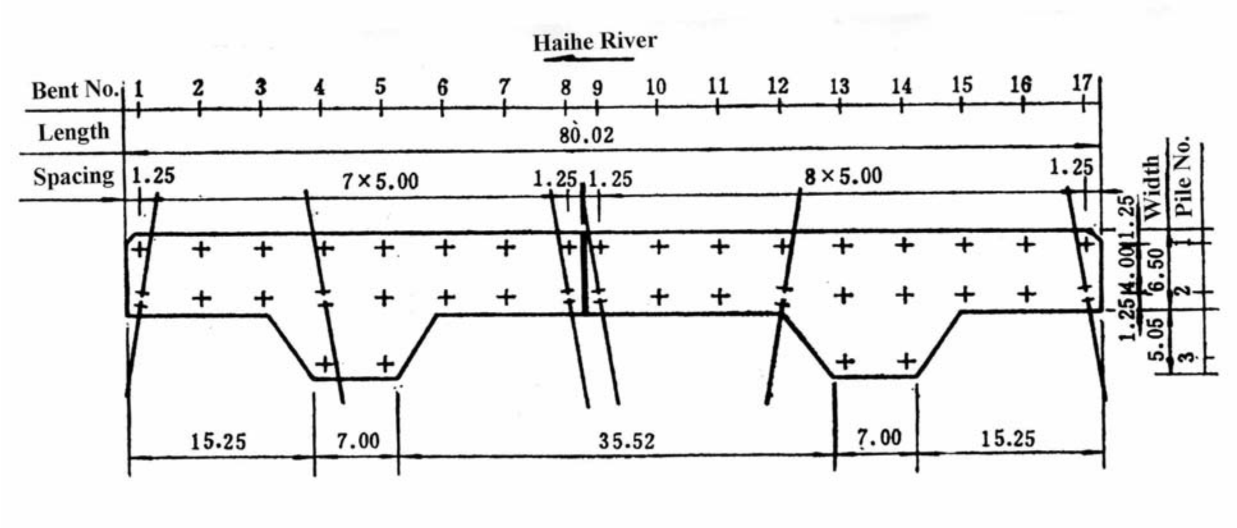

Figure 8. Plan of the Frontier Station Pier layout.

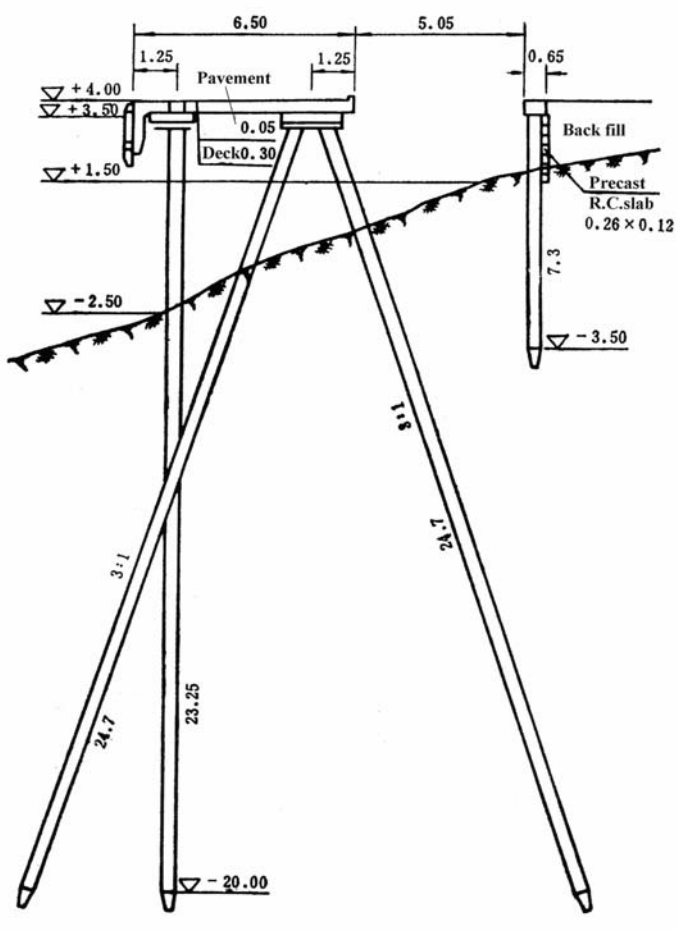

Figure 9. Cross section of the Frontier Station Pier (in m).

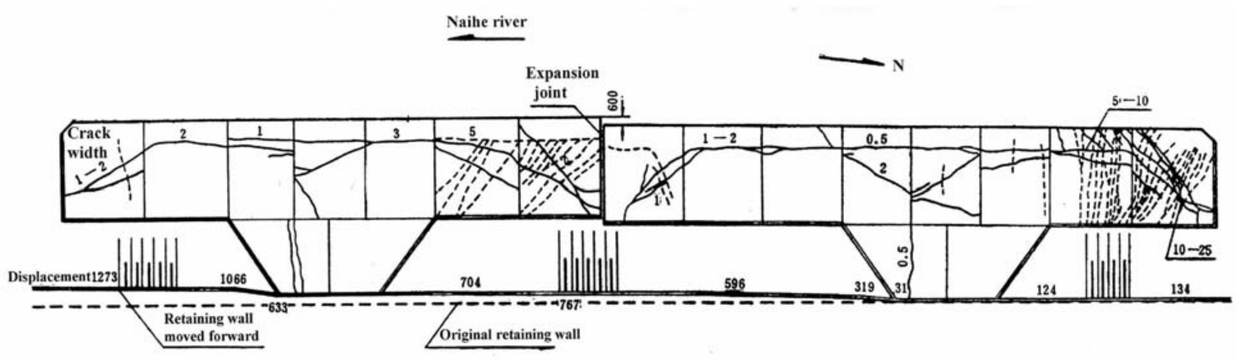

Figure 10. State of pier displacements and cracks of pier decking at the FIS pier (in mm).

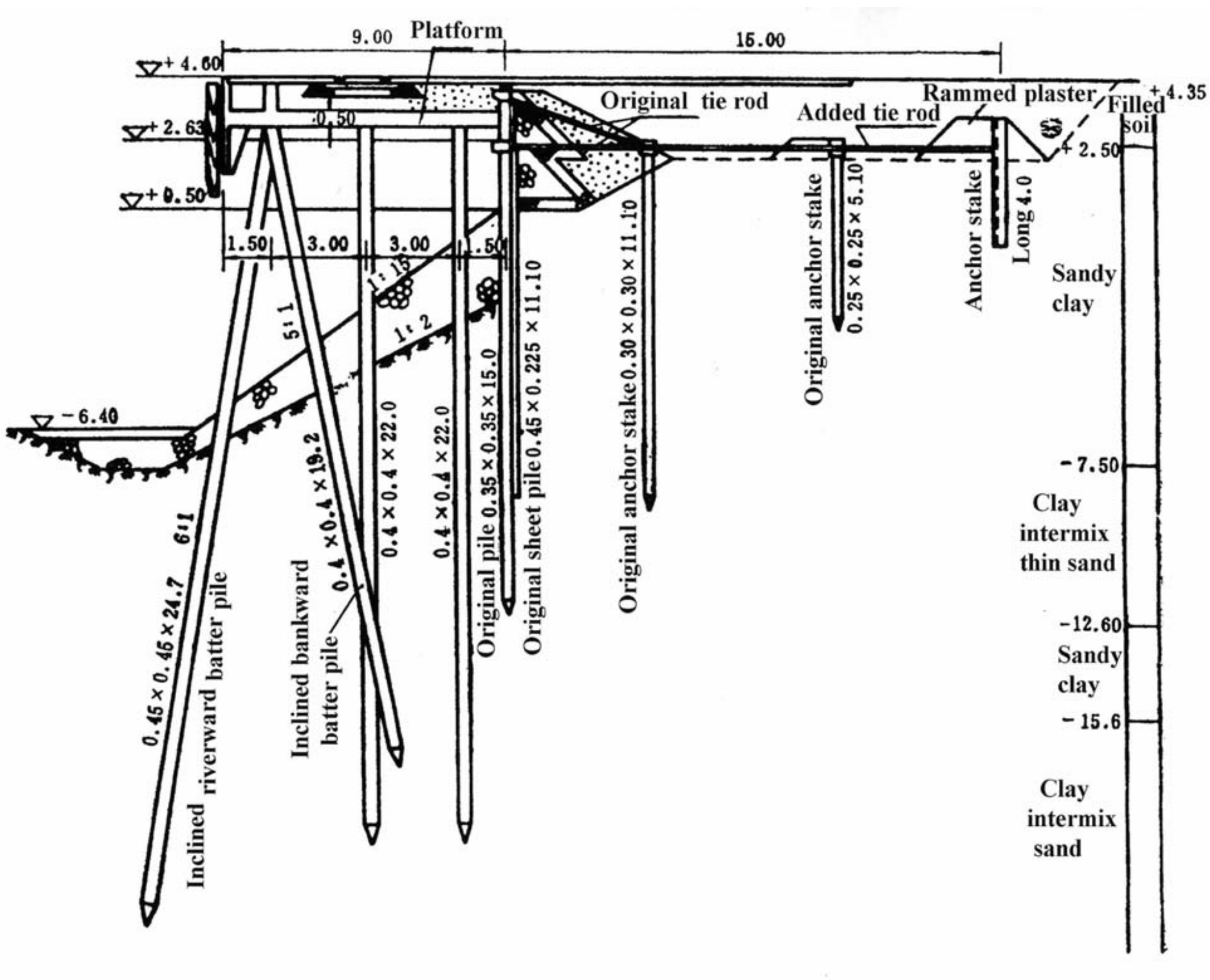

Figure 11. Cross section of the No. 9 wharf (in m).

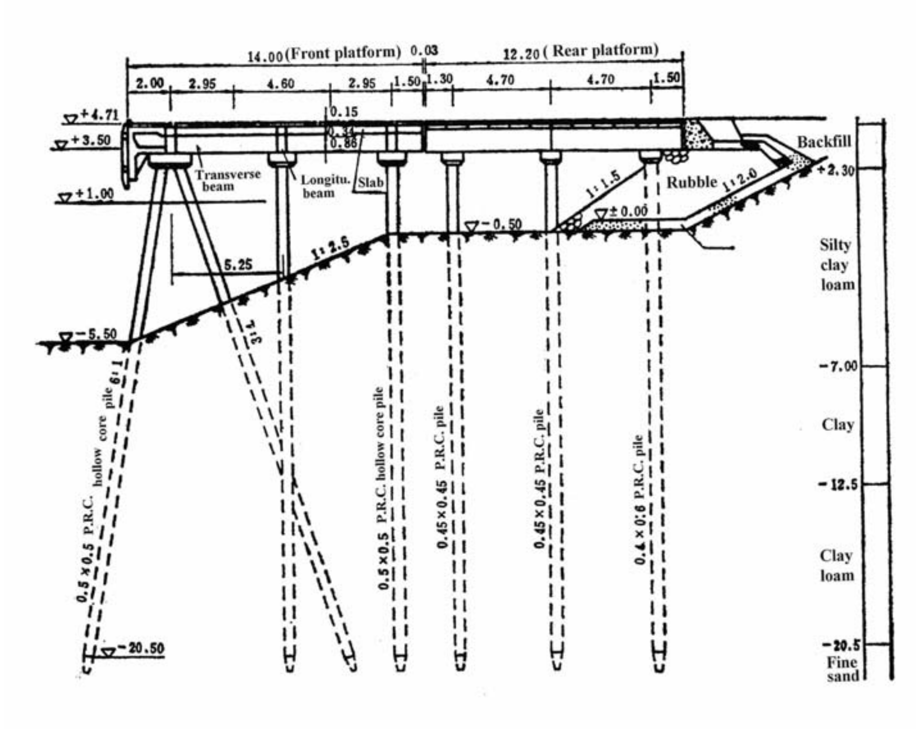

Figure 12. Cross section of the No. 10 wharf (in m).

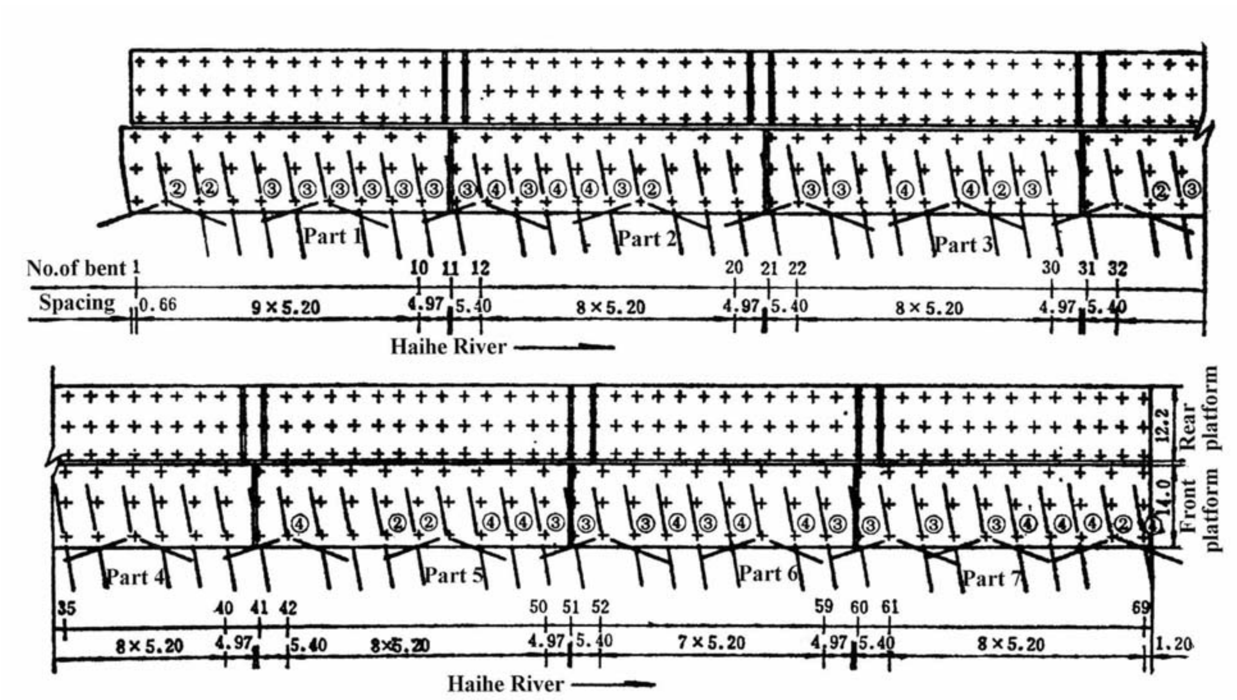

Figure 13. Cracks of pile caps of crossing pile at the front platform of the No. 10 wharf (in m)

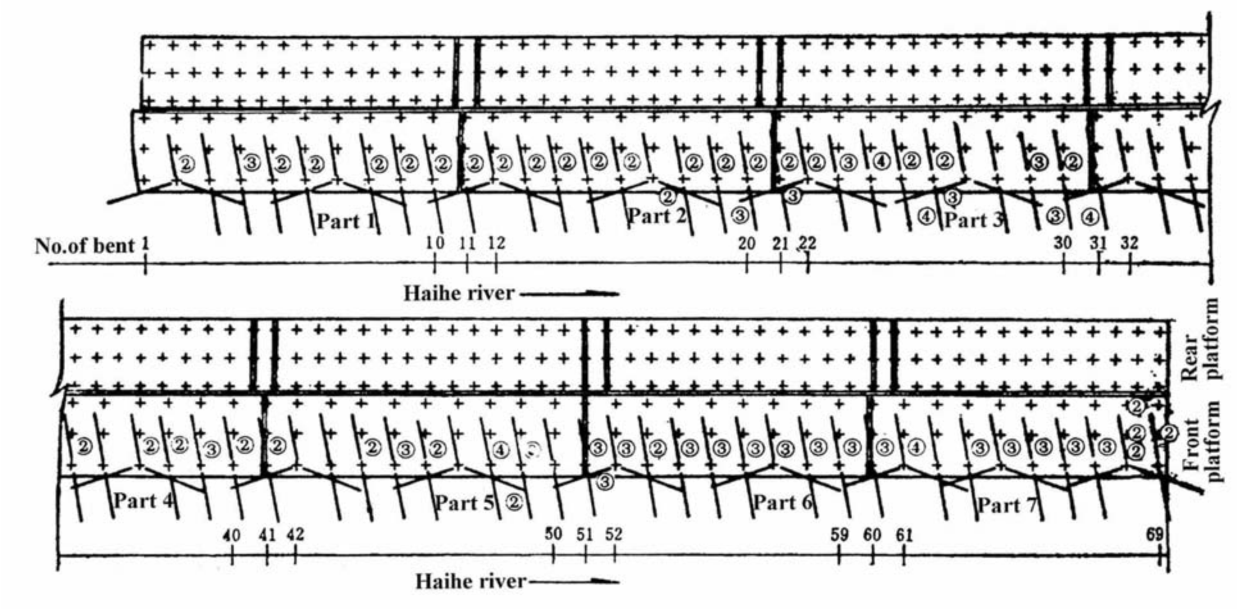

Figure 14. Crack state of pile at the front platform of the No. 10 wharf.
(Classification of crack width is the same standard with Fig. 13)

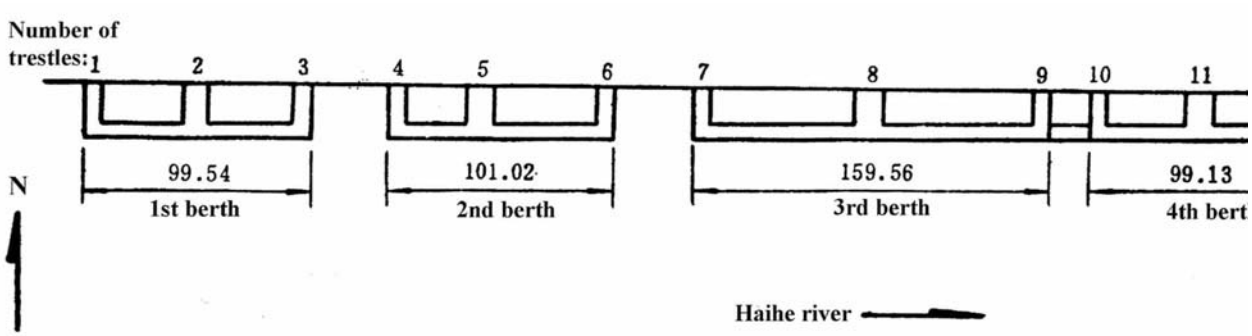

Figure 15. Plan of the No. 4 pier of the Tianjin Channel Bureau (in m).

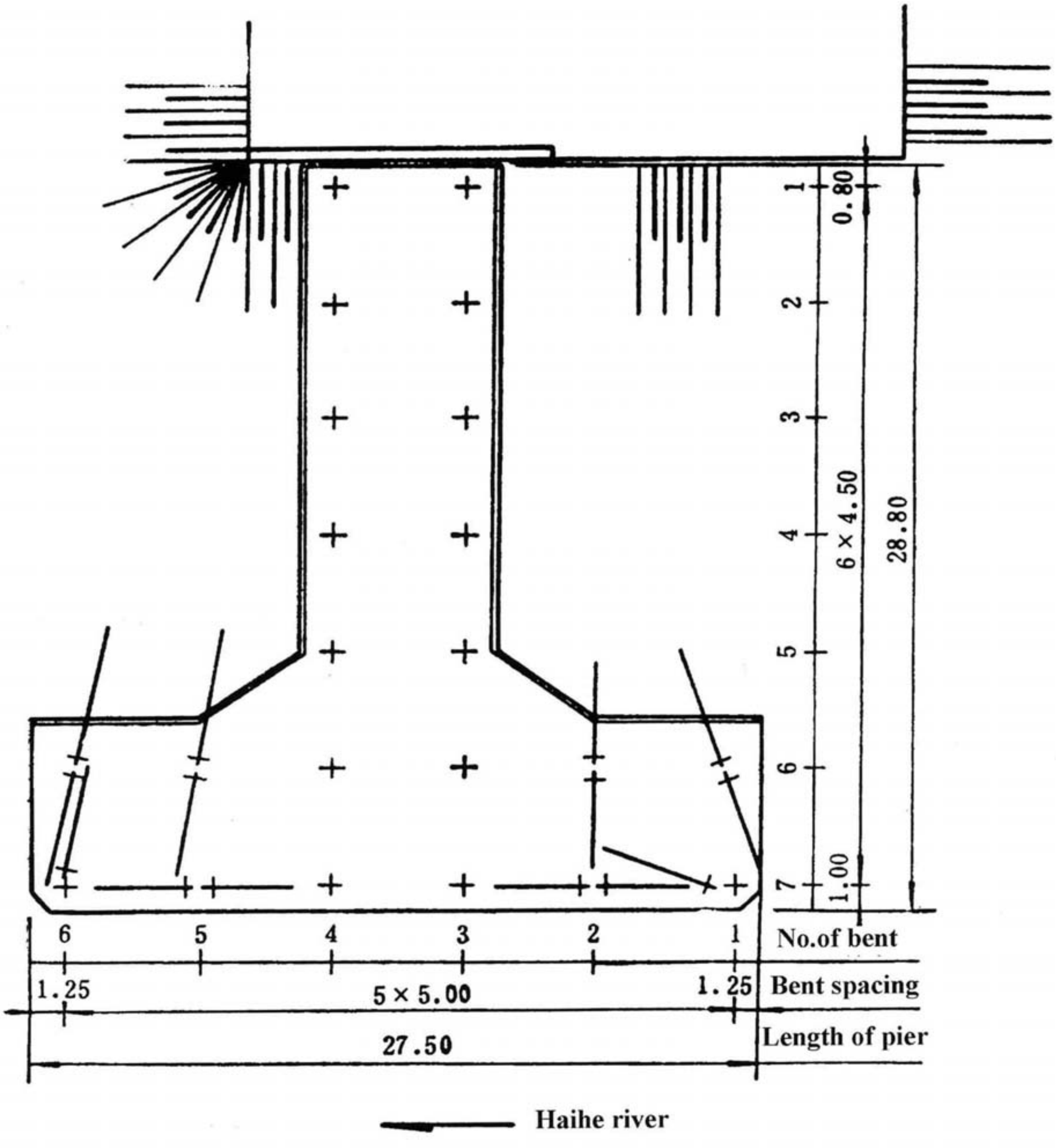

Figure 16. Plan of the pier for the Overhaul Works of TCEB and pile layout (in m).

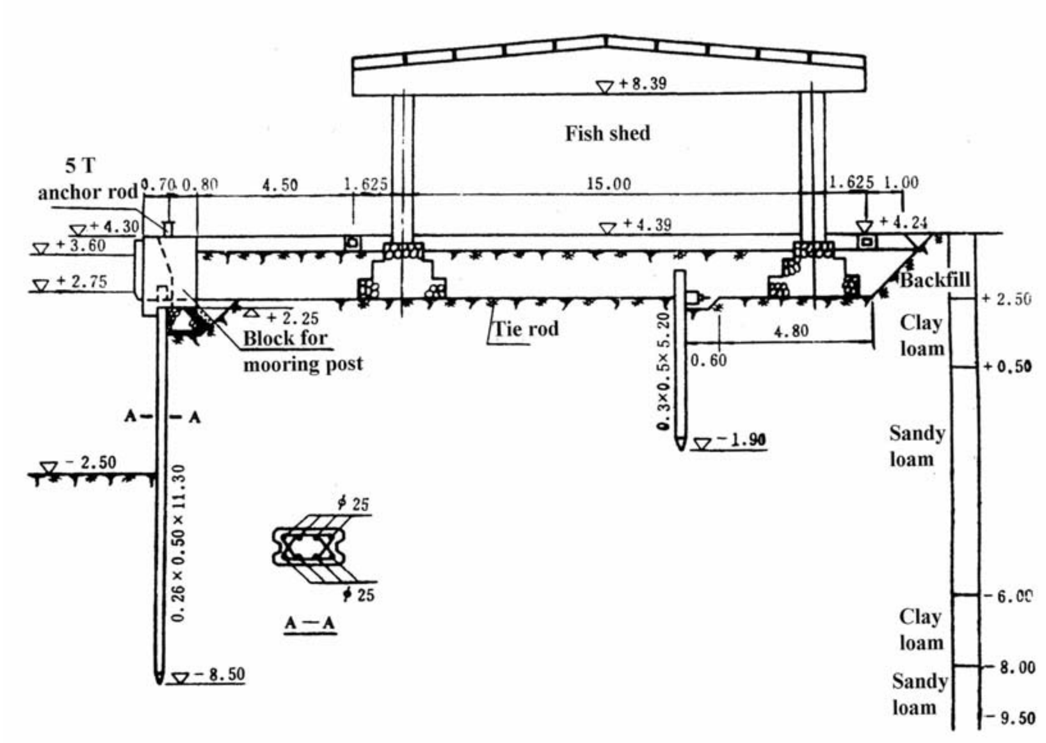

Figure 17. Cross section of the Chentangzhuang Terminal for the OFC (in m).

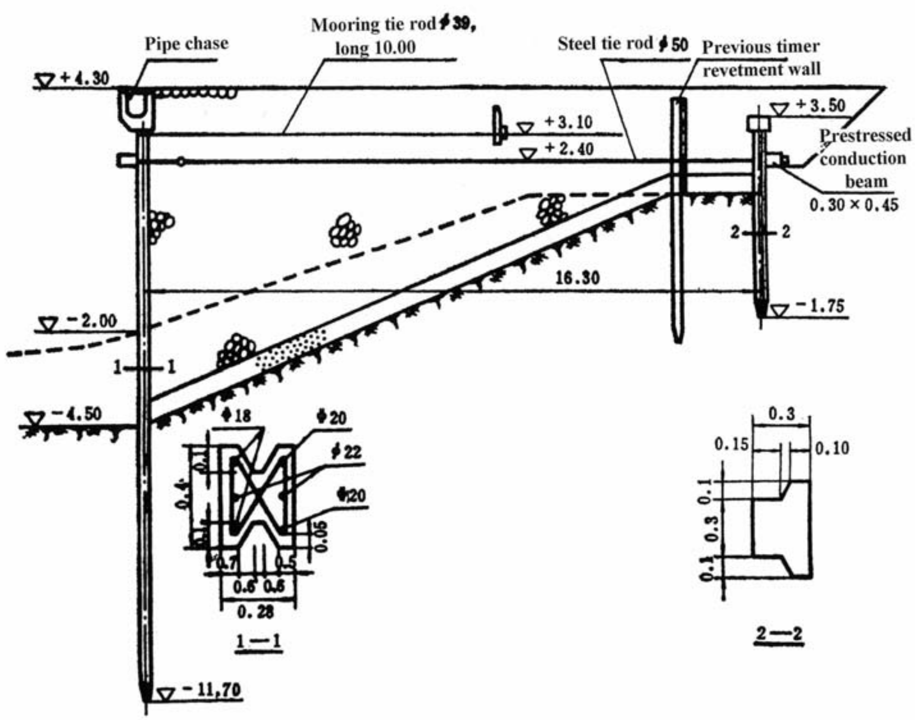

Figure 18. Cross section of the repair wharf for the Xinhe shipyard (in m).

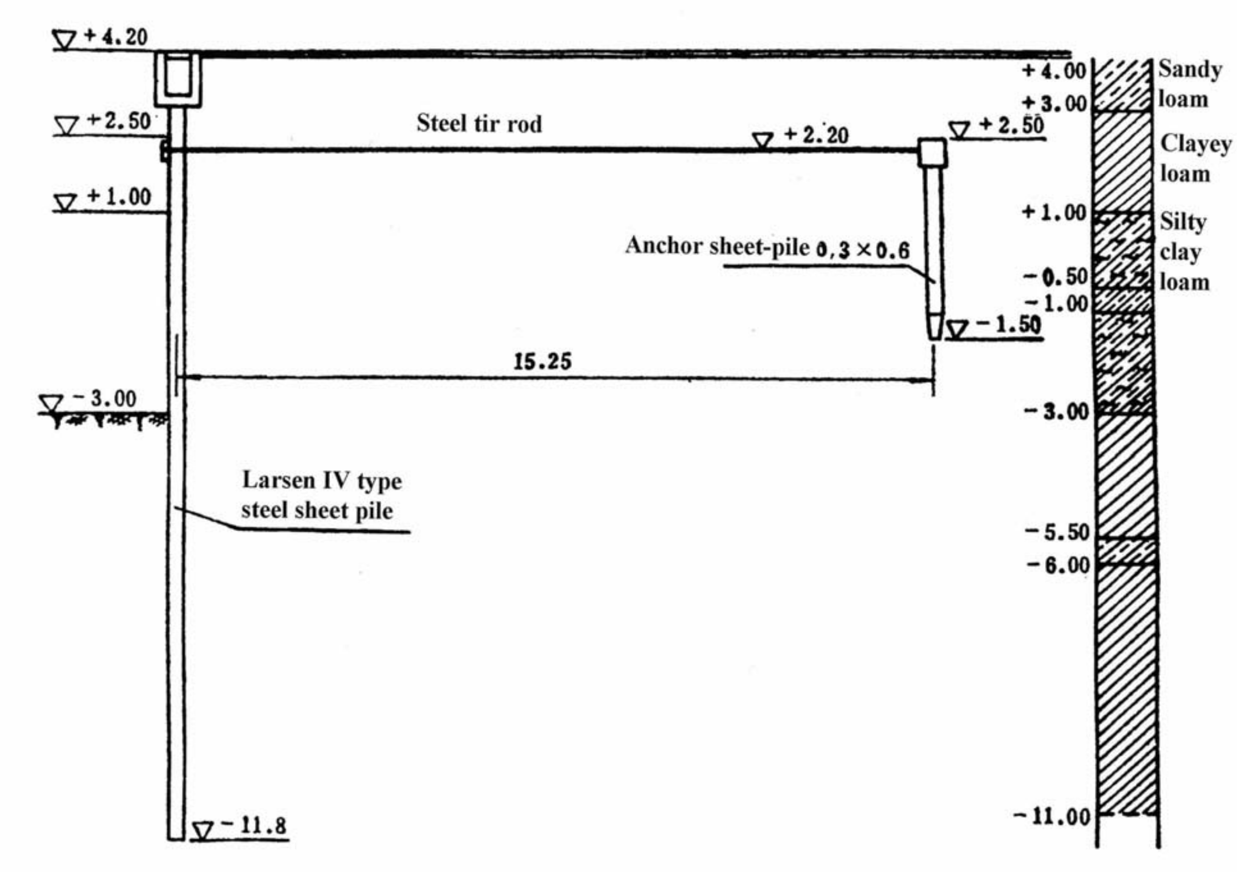

Figure 19. Cross section of the wharf for the FNEB shipyard (in m).

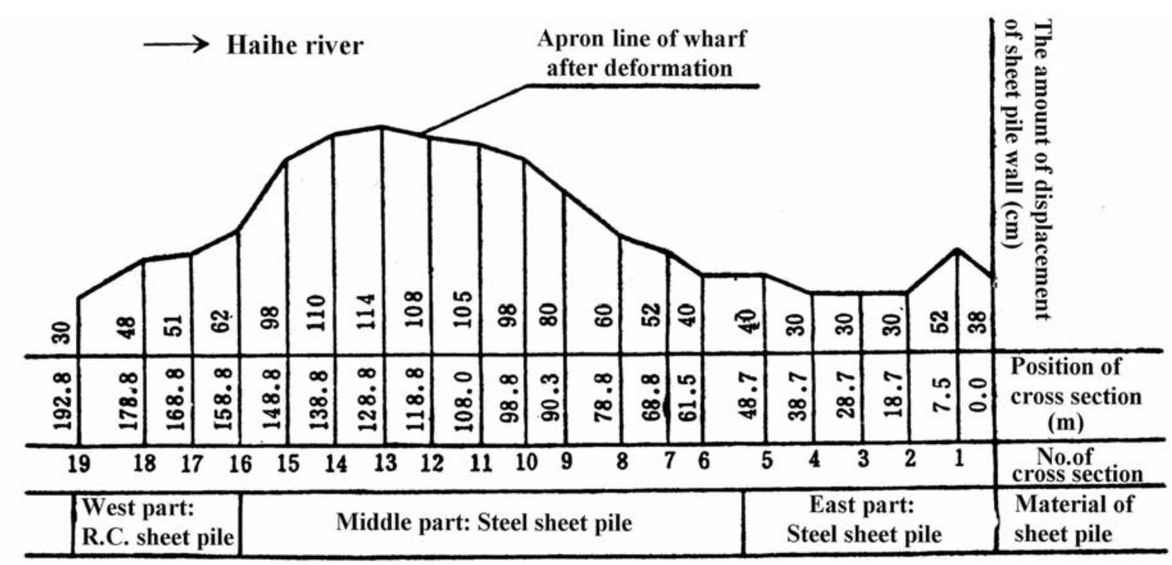

Figure 20. Displacement diagram of apron line of the wharf for the FNEB shipyard.

EARTHQUAKE DAMAGE TO BANK SLOPES AT THE MOUTH OF THE HAIHE RIVER

Pan Pinzheng, Zhang Xueyan and Yang Jinxian*

I. Background of Engineering Geology

Located in the Tanggu area about 50 km east of Tianjin City is the mouth of the Haihe River. It is characterized by deeply buried bedrock, flat and depressed topography, well developed meanders and widely distributed old channels. The sediments at the mouth are dominated by beach and alluvial deposits of an estuary delta.

From the surface of the land down to the lower soil, at the mouth of the Haihe River, it is mainly composed of silty clay, clay, silty sand, fine sand and silt, and can be generally divided into several layers as follows:

1. Artificial filled land – The dominant fill soil is silty clay and the secondary is miscellaneous soil.

2. Gray-brown silty clay – This layer covers an extensive area and is 3.5 to 7.0 m thick. It was deposited in the shallow water area of the sea facies in Holocene with a bedded structure. The intercalated sand layer, which contains smelly organic materials and shells, is in a silty state with median sensitivity.

3. Gray-brown silty clay – This layer covers an extensive area also and is 7 to 8 m thick. It was deposited in the deep-water area of the sea facies in Holocene with a bedded structure intercalating thin sand layer. The soil is of a homogeneous nature and in a plastic and soft plastic state with small water permeability belonging to clay of high sensitivity.

4. Yellow-brown silty clay – This layer is 5 to 6 m thick and is of an alluvial deposit of estuary delta in Holocene with a distinct bedded structure in a normal pressure and density state. A layer of silty sand exists at an elevation of -14.0 to -15.0 m in most of the area. The soil is plastic and of good quality.

5. Yellow-brown silty sand and silty-fine sand layer – This layer covers an extensive area with large thickness and is an alluvial delta deposit in Holocene with a distinct cross-bedded structure and intercalated clay layer lens. Its density is medium. The fine sand layer is a good bearing layer for pile footings.

The main indexes of the properties of the layers mentioned above are listed in Table 1.

In general, the natural slope gradient of both banks on the Haihe River is at a ratio of 1:3 to 1:4. The artificial slope gradient of the protection bank made with stone is at a ratio of 1:1.5 for

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a normal bank and 1:2 to 1:3 for the bank under the dock. Both the natural and artificial bank slopes were stable before the earthquake.

II. Earthquake Damage

As a small island the estuary between the right upper reaches of the Haihe gate and to the left of the diversion channel of the Yuchuan lock is situated at the mouth of the Haihe River. Soil beneath the land surface 3 to 4 m thick is mainly wind blown soil and the filled soil during construction of the Haihe and Yuchan locks. After the earthquake the bank slopes were seriously damaged, sliding towards the Haihe River and the diversion channel respectively within a distance of 30 to 40 m from the banks. There were three to ten ground cracks parallel to the banks with a maximum width of up to 80 cm and a maximum length of over 1,000 m. The surface of the land generally subsided 20 to 40 cm with waterspouts and sandboils in many places (Fig. 1).

(1) The left bank at the lower reaches of the Yuchuan lock

The diversion channel located at the lower reaches of the Yuchuan lock had just been dredged before the earthquake. The design slopes were at a ratio of 1:2 and the river bottom elevation was -3.0 m. The dredging that was conducted, in fact, was not according to the ratio of 1:2 and the dredged depth reached -3.5 m, about a half meter more than the design value. After dredging a natural collapse occurred on both banks of the channel.

Several ground cracks parallel to the bank as wide as 20 cm occurred near Yanhe Road on the left bank of the diversion channel after the July 28, 1976 earthquake. Since then, the ground cracks continued to develop and more than 20 cracks, with a maximum width of 80 cm and maximum length of over 1,000 m, developed in the area from Yanhe Road to around the Institute of Marine Petroleum Exploration Bureau until more than ten days after the earthquake. The height difference between the sides of the cracks parallel to the bank on the bituminous road along the bank was up to 40 cm. The geological research building about 40 m away from the bank slid 70 cm towards the bank, and another building about 70 m away from the bank slid 40 cm towards the bank. Both buildings subsided 30 to 40 cm but the tilting and damage to the buildings was not serious (Fig. 2). There were many waterspouts and sandboils in the vicinity of the two buildings. The small dock for the ice refinery of marine fisheries slid with the movement of the bank slope; the straight stakes under the dock tilted considerably and moved towards the center of the river and the first gangplank near the bank fell and broke.

(2) The right bank at the upper reaches of the Haihe gate

There was a protection bank laid with a ratio of 1:2 on the slope along the right bank at the upper reaches of the Haihe gate. After the earthquake the protection bank was basically intact but the slope moved. On the bituminous road along the river occurred three to five ground cracks parallel to the bank with a width of 5 to 15 cm and extended to the two adjacent docks. At the living quarters the ground cracks passed through several brick-concrete buildings of the Marine Petroleum Exploration Bureau and subsided by about more than 20 cm. Three cracks from the foundation to the top of the building, with a maximum width of up to 10 cm, were found in the middle unit of the No. 11 building. The beam of the stairs' balcony was pulled out from the wall (Fig. 3). The No. 12 and No. 13 buildings adjacent to building No. 11 were slightly damaged (there were two rows of steel stakes in front of building No. 12).

Cracks occurred at many places on the 2.7 m high enclosing wall, which was laid with stone, at the Shipbuilding Yard, Tianjin Navigation Channel Bureau and a part of the wall collapsed.

Located between the Xingang navigation lock and the Haihe gate on the mouth of the Haihe River and connected to a small island at the mouth, the Marine Petroleum Exploration Bureau Base (originally the Marine Petroleum Exploration Headquarters) is a long and narrow estuarine islet of recent sediments. Its soil belongs to softer silty clay.

Many ground cracks parallel to the bank were found at the Base along both the east and west banks. The ground surface subsided and a large number of waterspouts and sandboils occurred after the earthquake.

(1) Bank slopes

The bank slope near the Base's offices on the western bank in the center of the islet (Fig. 4) generally slid seaward by about 40 to 50 cm, and more than five ground cracks parallel to the bank with a width of 15 to 20 cm occurred. The walls in most of the buildings, expect for a few new ones, cracked where the ground crack passed through and the ground surface subsided to various extents with a settlement of 30 to 40 cm. Most of the houses tilted towards the west coast and slid to different extents.

At the dock area of the base on the east coast of the islet ground, cracks parallel to the coast occurred and most of the straight pillars under the dock's platform broke. The foundation of the back edge of the platform subsided by about 20 to 30 cm. The pile foundation of an uncompleted workshop subsided different amounts. While excavating the soil layer it was observed that most of the concrete piles broke.

(2) Enclosure wall and foundation pit at the dock

The dock at the Marine Petroleum Exploration Bureau, which was under construction, was situated on the east coast near the south tip of the islet at the mouth of the Haihe River. The dock chamber was 150 m in length, 41 m in width and 8.5 m in depth, and was available to repair 5,000 ton tankers and drilling ships. The enclosure wall outside the dock was completed in June 1973.

The enclosure wall was constructed with piled bags of soil 3.5 m high and 5 m wide at its top. The outside slope was at a ratio of 1:2 and was protected by a layer of stones. The elevation of the ground inside the enclosure wall was about +1.5 m. The foundation pit was excavated to an elevation of -6.3 m. The design slope was at a ratio of 1:4. During construction the gradient for the local segment, about 20 m long, was changed to be at a ratio of 1:3. This was a dangerous section. The enclosure wall and foundation pit plan, and the normal and dangerous sections are shown in Fig. 5.

The drill data indicates that the properties of the soil layers of the foundation pit are basically in accord with those of the Xingang area. The properties of the soil layers are listed in Table 2. The water-bearing layer was not found during excavation of the foundation pit.

The high tide level was +4.12 m during the magnitude 7.8 earthquake. The workers on duty were awakened by the shock of the pump house at the foundation pit and went out to look it over and found that ground cracks occurred on the platform at an elevation of +2.0 in the foundation pit. The slopes of the enclosure wall and foundation pit slid immediately after the workers fled from the pit. The pit filled with seawater within a few minutes.

A number of ground cracks were found on the beach outside the enclosure wall at ebb tide, and many others also occurred at the site of the engine workshop, which was under construction. The top of the foundation piles at the engine workshop all tilted and moved towards the dock chamber, the maximum displacement to the east was up to 1.3 m and about 0.5 m to the north. By excavating it was found that approximately 10 cracks occurred on the piles 2.85 m long under the bearing platform with a maximum width of 10 mm. The piles all were discarded.

(Translator: Qiu Ju)

Table 1. Main properties of the soil layers

Name			Mucky Silty Clay	Silty Clay	Silty Clay	Fine Sand
Item		Elevation (m)	+2.0 - –5.0	–5.0 - –13.5	–13.5 - –21.0	–21.0
Natural moisture content (%)			33.9 - 36.9	42.5 - 48.0	26.1 - 28.6	19.2
Natural bulk density (g/cm^3)			1.83 - 1.85	1.76 - 1.78	1.95 - 1.97	
Natural porosity ratio			0.99 - 1.02	1.20 - 1.29	0.74 - 0.78	
Plastic index			1.56 - 1.70	1.89 - 21.0	12.3 - 13.9	
Liquid index			1.06 - 1.34	1.11 - 1.28	0.77 - 0.88	
Compressibility coefficient (cm^2/kg force)			0.042 - 0.078	0.083 - 0.103	0.028 - 0.030	
fast shear intensity	fast shear	inner friction angle (degree)	11 - 13	4 - 6	12 - 18	
		cohesion (kg force/cm^2)	0.12 - 0.16	0.12 - 0.15	0.15 - 0.20	
	fast consolidation	inner friction angle (degree)	19 - 21	16 - 17	23 - 25	
		cohesion (kg force/cm^2)	0.09 - 0.14	0.11 - 0.12	0.12 - 0.11	
	cross plate	(kg force/cm^2)	—	0.20 - 0.25	—	
	lateral unlimited	(kg force/cm^2)	—	0.49		
Number of standard inertial driving			—	2	6	15 - 37

Table 2. Parameters of soil layers of the foundation pit.

Layer of Soil	Elevation (m)	Moisture Content (%)	Bulk Density ton/m^3	Porosity Ratio	Liquid Limit	Plastic Index	Liquid Index	Fast Shear		Fast Consolidation	
								Inner-Friction Angle (degree)	Cohesion (ton force/m^2)	Inner-Friction Angle (degree)	Cohesion (ton force/m^2)
mucky silty clay	+1.5 - –4.5	41.2	1.81	1.14	31.6	13.9	1.69	10.5	0.9	26	0.6
mucky clay	–4.5 - –8.4	58.3	1.66	1.61	52.6	25.6	1.23	5.5	0.9	12	1.3
clay	–8.4 - –12.4	47.4	1.74	1.31	44.7	22	1.12	3	1.2	15.6	10

Photo 1. Sliding of the enclosure wall and foundation pit of the dock at the Marine Petroleum Exploration Bureau after the earthquake.

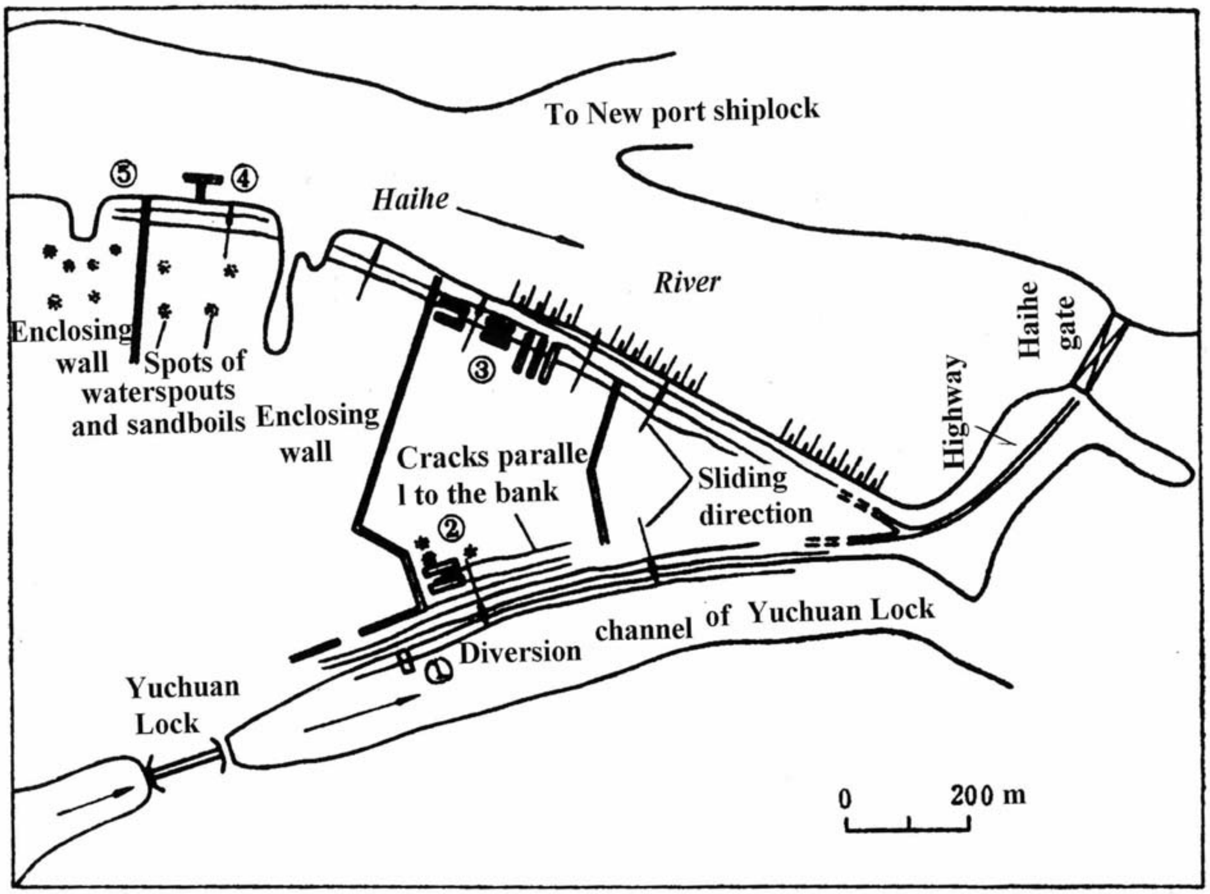

Figure 1. A sketch of a map showing sliding of bank slopes and ground cracks near the Haihe Gate and Yuchuan lock.

(1) Small dock for the ice refiner of marine fisheries; (2) Building of the Institute of Marine Petroleum Exploration Bureau; (3) Living quarters of the Marine Petroleum Bureau; (4) dock for the shipbuilding yard of the Tianjin Navigation Channel Bureau; (5) Dock for the shipbuilding yard of the First Navigation Engineering Bureau under the Ministry of Communications.

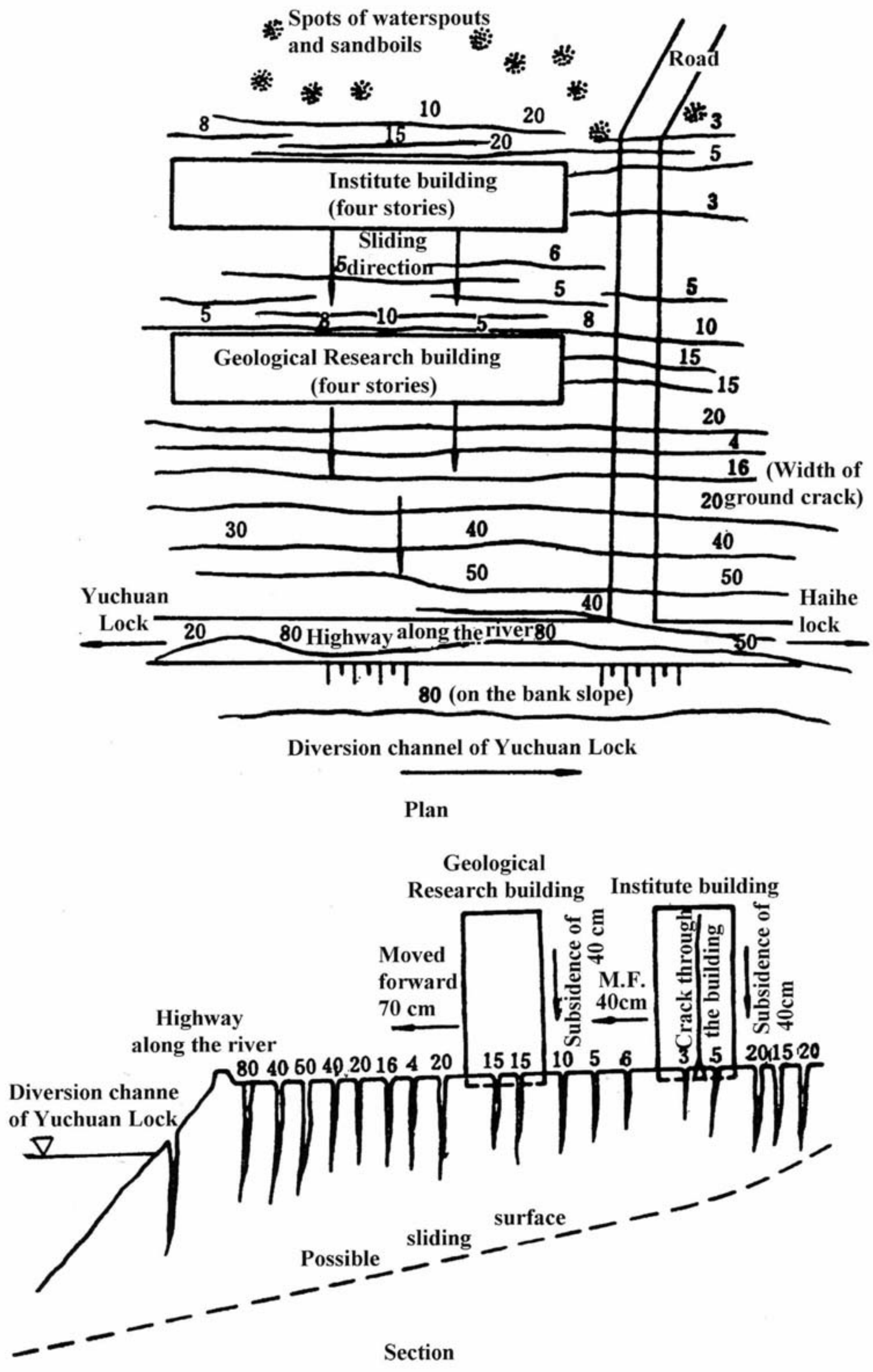

Figure 2. A sketch of a map showing ground cracks and slope sliding around the Institute of Marine Petroleum Exploration Bureau (ground crack width in cm).

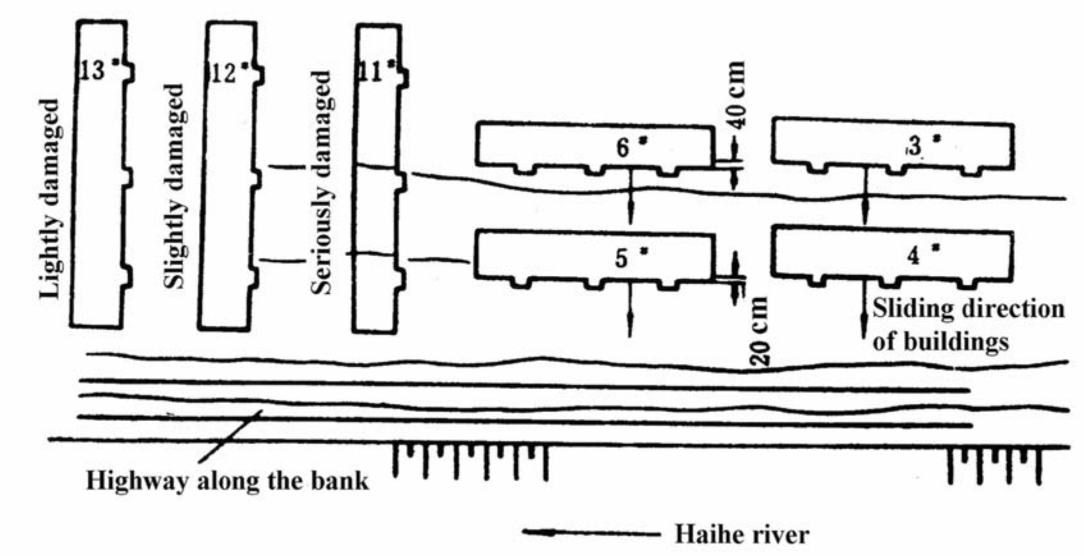

Figure 3. A sketch of a map showing ground cracks and bank slope sliding in the living quarters of the Marine Petroleum Exploration Bureau.

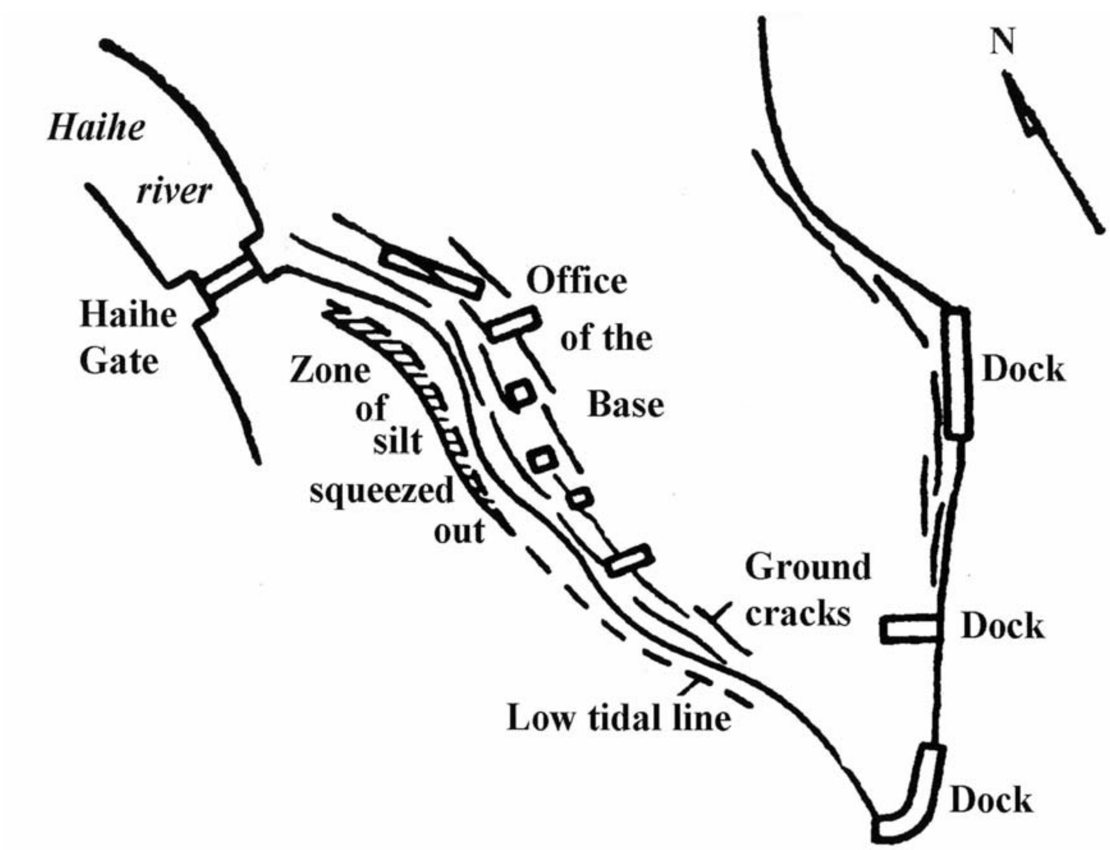

Figure 4. A sketch of a map showing earthquake damage to the bank slope of the Marine Petroleum Exploration Bureau Base.

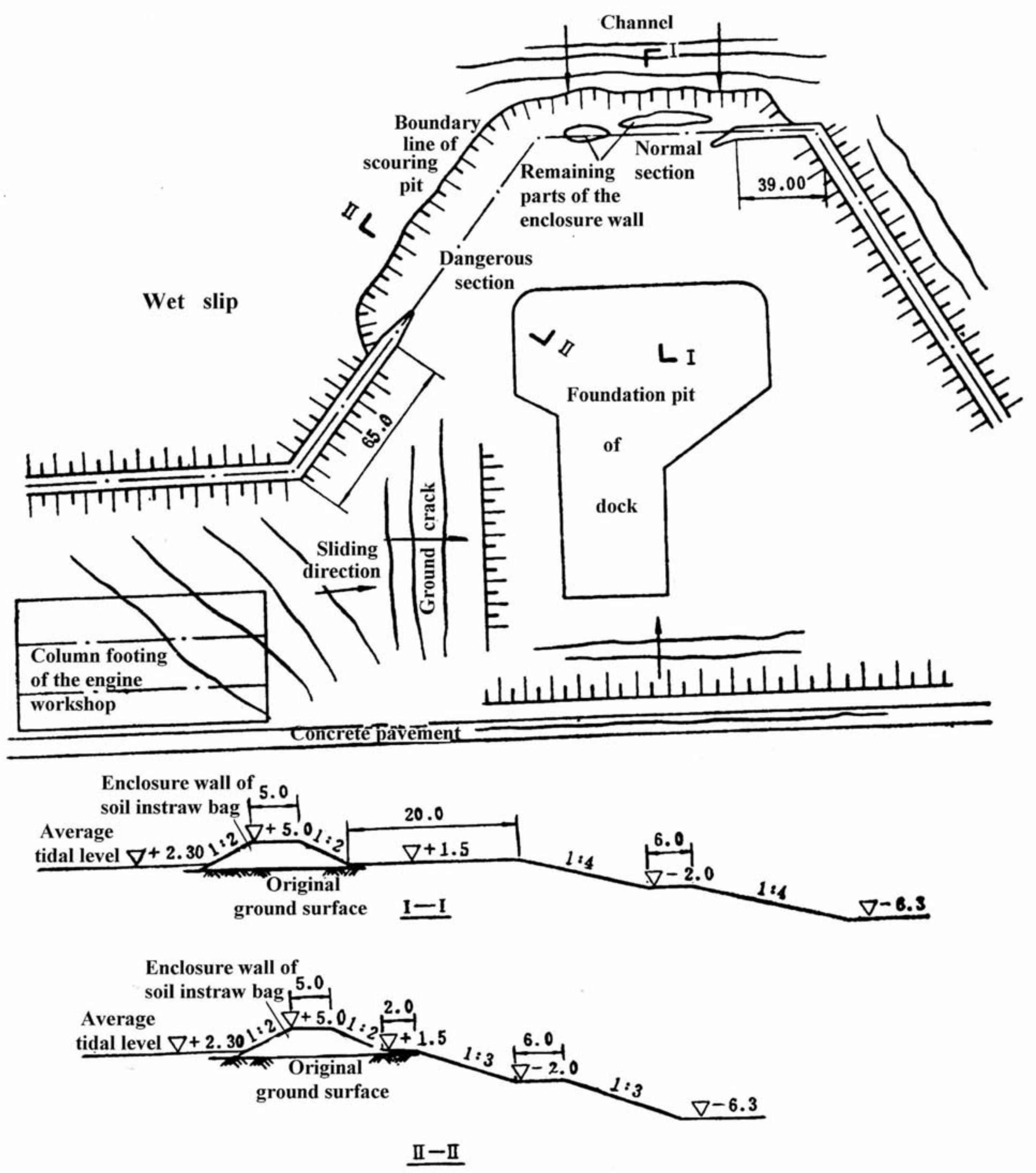

Figure 5. Plan sketch map of earthquake hazards damage to the enclosure wall and foundation pit of the dock for the Marine Petroleum Exploration Bureau.