5. DAMAGE TO PORT AND HARBOR FACILITIES

5.1 Introduction

Port of Taichung locates along the west coast of the central part of Taiwan northwest of the epicenter. Its epicentral distance is approximately 55 km. The construction work of the port was started on October 31, 1973 and completed in June 1983. Caisson type quay walls were damaged in Taichung port during the earthquake. Seaward displacements of the caisson walls were about 1.6m at maximum.

5.2 Earthquake and Ground Motions

A major earthquake(M_L=7.3) occurred near the town of Ji-Ji in Nantou, Taiwan, at 1:47 a.m., Sept. 21, 1999 local time. The estimated peak acceleration of Taichung port is 0.1g to 0.25g according to the PGA map reported by the Central Weather Bureau. The acceleration and response spectra at TCU070 are shown in Figure.5.1. The TCU070 station is located 1.6km east, 10.3km south from Taichung No4 berth.

5.3 Damaged to port and harbor facilities

5.3.1 Design conditions (No.1 to No.4A berths)

Figure 5.2 shows the plan of Taichung port. The largest damage to Taichung port occurred at the berths No.1, 2, 3, and 4 in the north terminal. The quay walls have the same type of RC caissons. The design specifications are listed in Table 5.1.

Table 5.1 Design specifications

Wharf No.	Design depth(m)	Design elevation of apron	Design residual water level	Design seismic coefficient	Ship size	Type of operation	Method of transportation
1	13	EL. +6.2m	2/3	0.15	50,000 W.T.	Grain	belt conveyor
2	13	EL. +6.2m	2/3	0.15	50,000 W.T.	Oil	under ground pipe line
3	13	EL. +6.2m	2/3	0.15	50,000 W.T.	Grain	velt conveyor
4	11	EL. +6.2m	2/3	0.15	3,000 W.T.	liquid	underground pipe line
4A	9	EL. +6.2m	2/3	0.15	10,000 D.W.T.	Cement	ground surface pipe line

These quay walls were designed by the ‘Design Manual of Harbour Structures in Japan 1967’ except No.4A. The soil condition at a silo behind the No.1 berth is shown in Figure.5.3. The ground mostly consists of silty and fine sand.

The design tidal levels are rather severe at this site. The mean high and low water levels for the design are EL.+4.5m and 0.9m, respectively. The elevation of apron is EL.+6.2m.

The quaywalls of RC caissons were constructed as follows; i)excavation of the foundation, ii)construction of rubble mound, iii)installation of the RC caissons and filling of backfill rubble. The caissons are generally supported on the stiff ground. The ground behind the quay walls was reclaimed with dredged fine sand which was carried through a pipe. Any soil Improvement has not been carried out.

Typical cross section through No.1 to No.4 is shown in Figure.5.4. Figure.5.5 shows the cross section of No.4A which is different from an ordinary caisson quaywalls in Japan, i.e. It has no backfill rubble and has a pipe which penetrates from the back wall to the front wall of the caisson. It is supposed that the function of the buried pipe is dissipation of the residual water pressure behind the walls due to the tidal level change.

5.3.2 Damage to the berths No.1 to No.4A

When the level of earthquake motion exceeds a specific limit of the earthquake resistant design, the caisson wall may displace toward the sea, causing settlement of the ground behind the wall. Typical example of the damage to the caisson quay wall(No.1) is shown in Figure.5.4. The relative seaward displacement of No.1-No.1A birth in the horizontal direction from the south west corner of No.1 birth, are shown in Figure.5.6. The maximum displacement of about 160cm occurred at No.3 birth, but the displacements of No.4 and No.4A berths are quite small. The face line of No.4A maintained straight. The settlement of quay walls is 0.1m to 1m and the angle of inclination of the caissons is 2 to 4 degree. A belt conveyor shown in Figure.5.4 was deformed due to the lateral movement of the caisson and ground surface settlement.

The ground settlements decreases with the distance from the quay wall. The sand boils due to liquefaction were observed within the area more than 40m far from the quay walls. Large ground depressions near the quay walls were observed periodically with about 26 m interval. It is supposed that the back fill sands penetrated into backfill rubble and drained away to the sea through the broken seal between caissons due to the movement of caissons and tidal water level change. The periodical ground depressions were significant at the No.3 birth.

During the 1995 Hyogoken-Nambu earthquake, many caisson quay walls in port of Kobe port largely moved towards the sea and seriously inclined due to the soil liquefaction. However, the damage to the quay walls of port of Taichung was not so serious since the ground was comparatively stiff and the earthquake acceleration was much less than that in port of Kobe.

5.3.3 Damage to a molasses tank

Roofs of the cylindrical tanks for the storage of molasses were broken in port of Taichung(refer 3.7). The damaged tanks located about 500m far from the No.4 birth, and had about 23m diameter and 12m height. The liquid stored in the damaged tanks was molasses. The estimated predominant period of the sloshing under an assumption that the volume of the liquid was 80% to 90% of the full capacity is around 5.0 second, which had a good agreement with the displacement response spectra of TC070 shown in Figure. 5.1. The tanks which have different heights and diameters located in the neighborhood were not damaged.

5.4 Discussion

The No.4A berth did not suffer any serious damage, while, No.1 to No.4 berths moved and inclined. The seismic coefficient is 0.15 for all the berths. The difference between No.1 to No.4 and No.4A is the existence of buried pipe for dissipation of the residual water pressure. Back analyses of seismic stability were conducted by taking the effect of the residual water pressure behind the caisson into the consideration. The astronomical tides around the time of the main shock(1:47am. Sept. 21) are shown as follows,

Sept. 20 7:42pm. EL+4.401m
Sept. 21 1:42am. EL+1.889m
Sept. 21 7:42am. EL+4.349m

The residual water level for design is EL+3.37m. The sliding safety factor for sliding of

No.1 birth reaches 1.0 at the residual water level of EL+3.6m as shown in Figure. 5.7. If the residual water level is less than EL+3.6m, no damage occurres. It can be guessed that the boundary zone between backfill rubble and backfill sands should be stuffed up by fine contents of backfill sands, and the water level behind the quay walls could not follow the astronomical tidal level. This is one of the probable causes of the displacement and inclination of walls. On the other hand, the residual water level behind the No.4A quay wall was much lower because the disipation of the residual water pressure by the buried pipe.

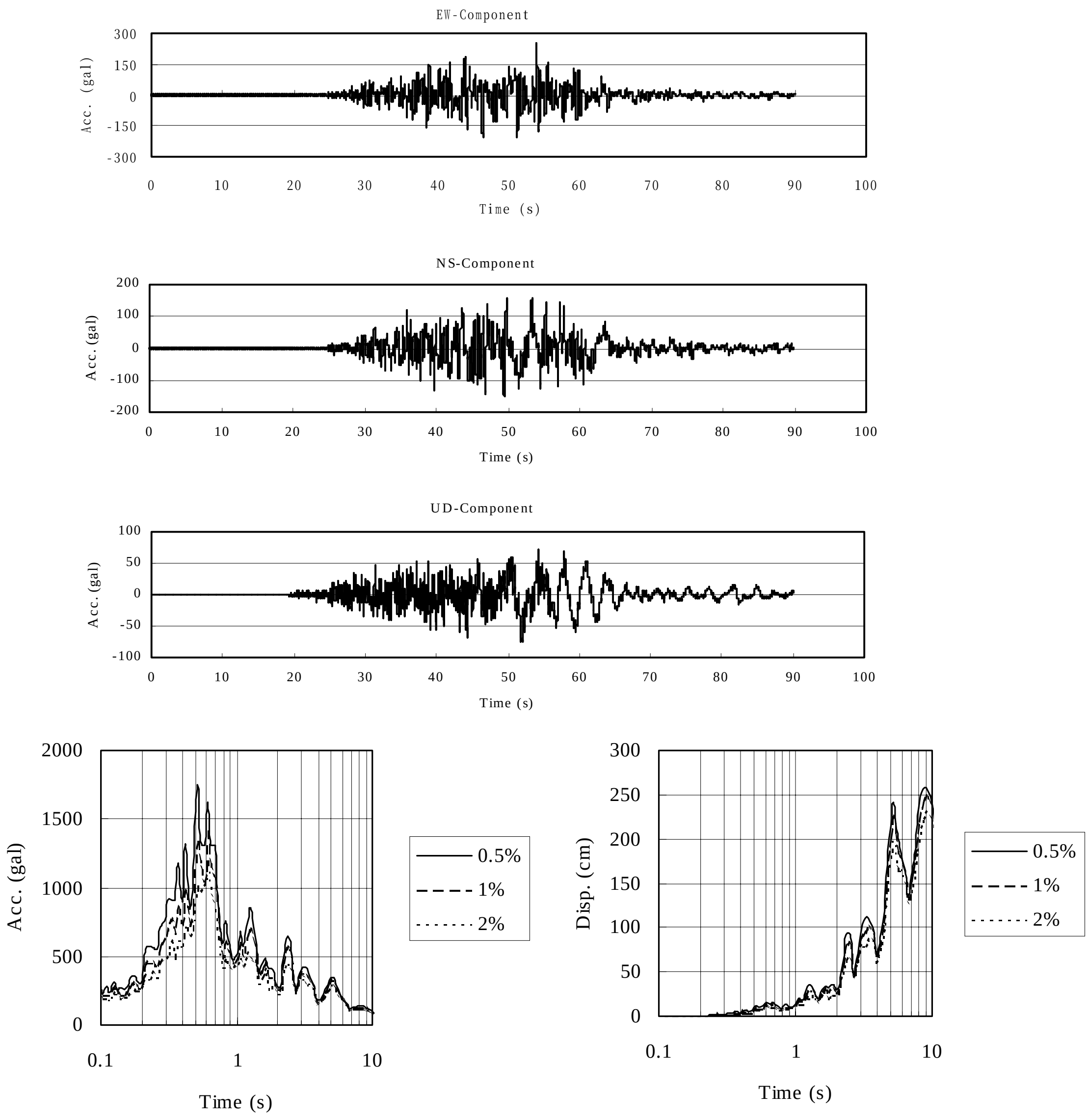

Figure.5.1 TCU070 Time histories and Response spectra

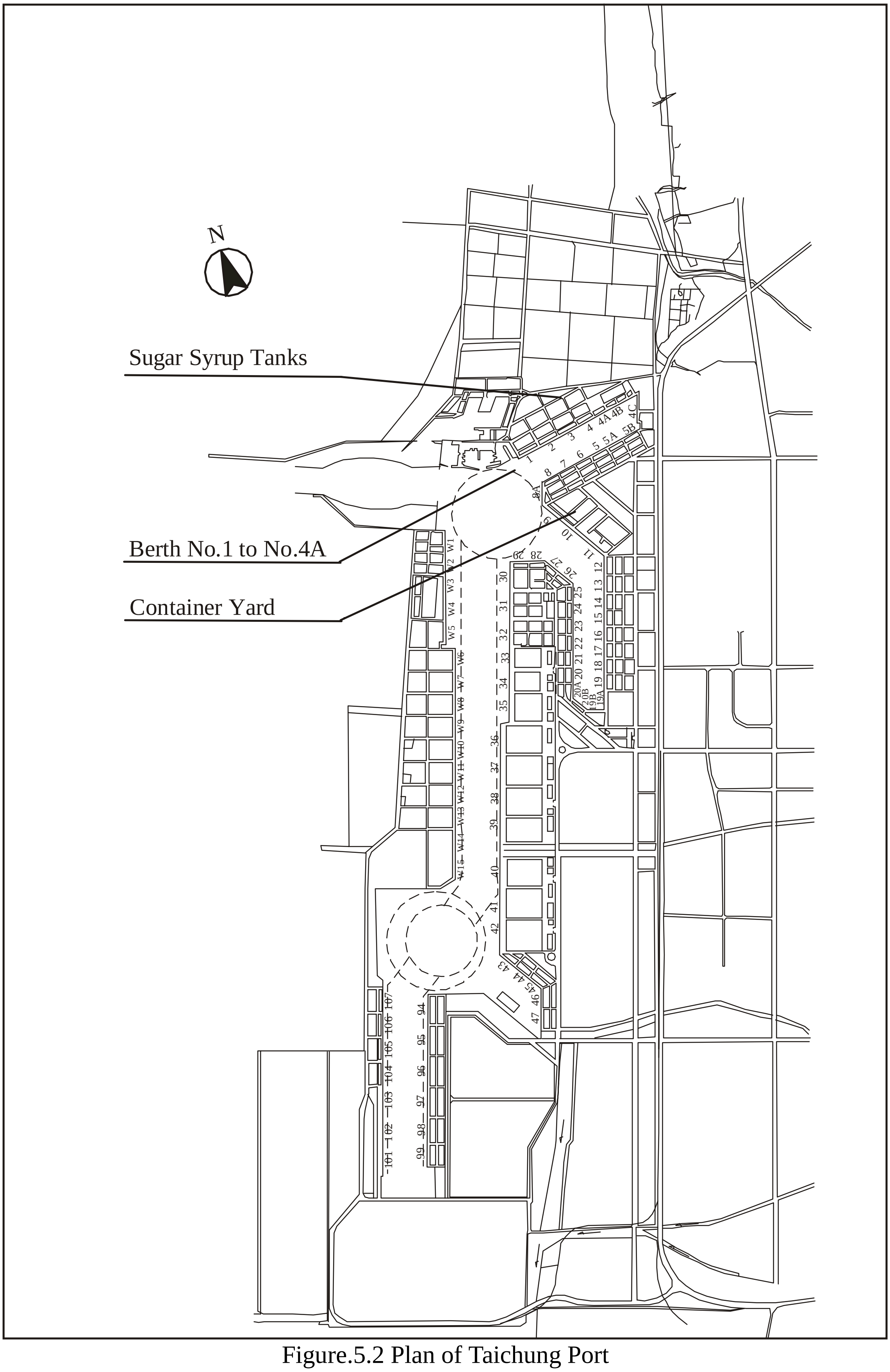

Figure.5.2 Plan of Taichung Port

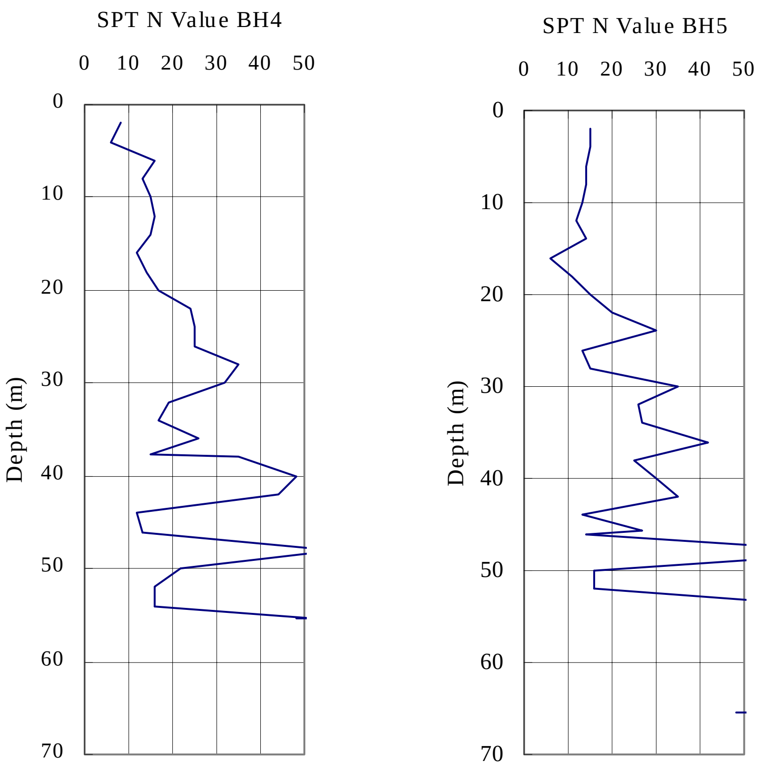

Figure.5.3 STP-N value log

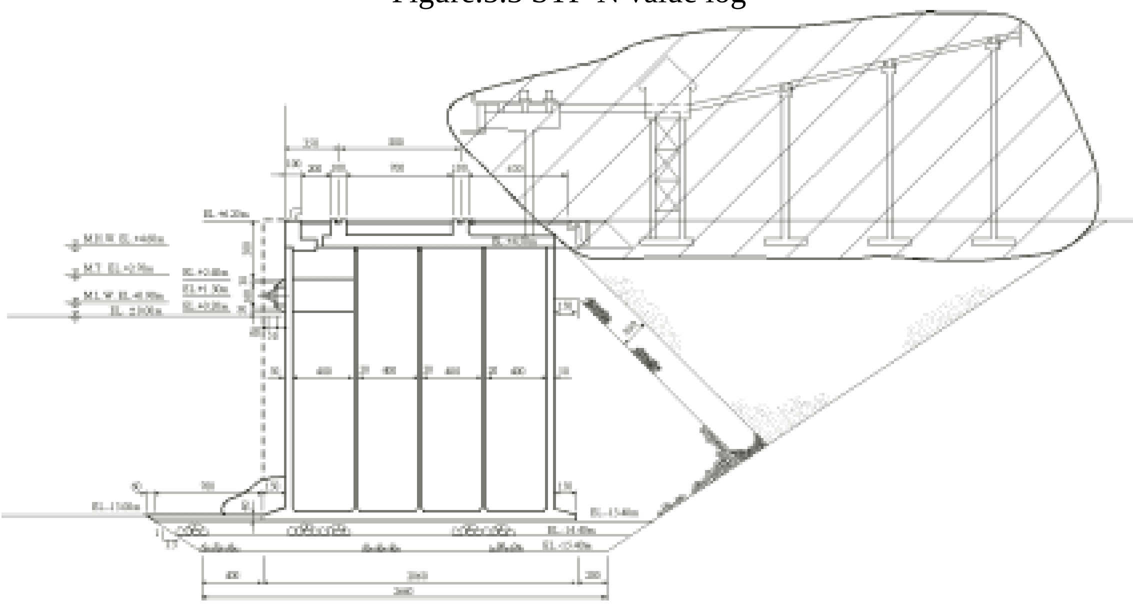

Figure.5.4 Cross section of No.1-4 berth

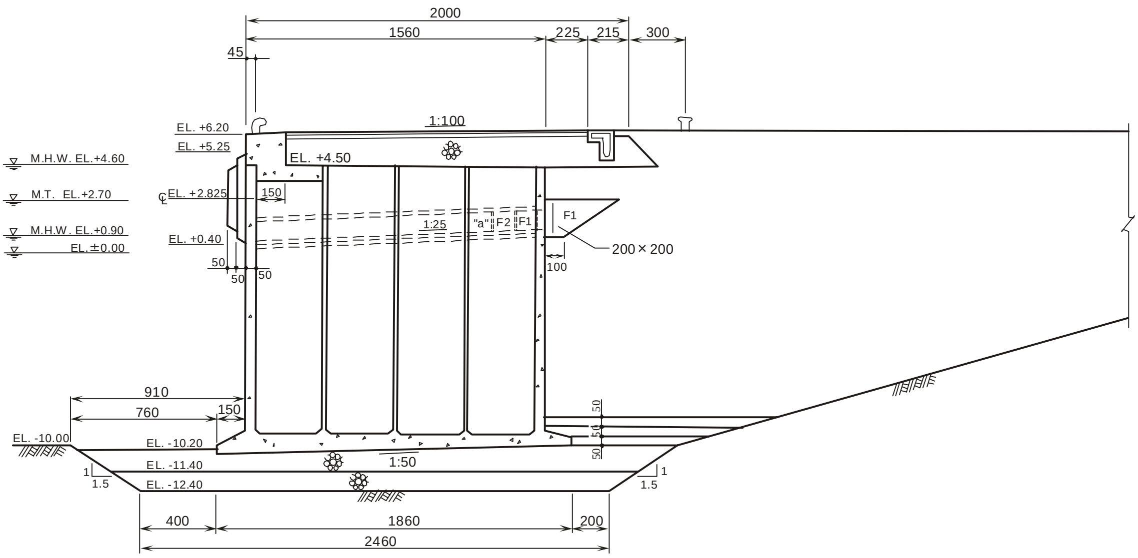

Figure.5.5 Cross section of No.4A berth

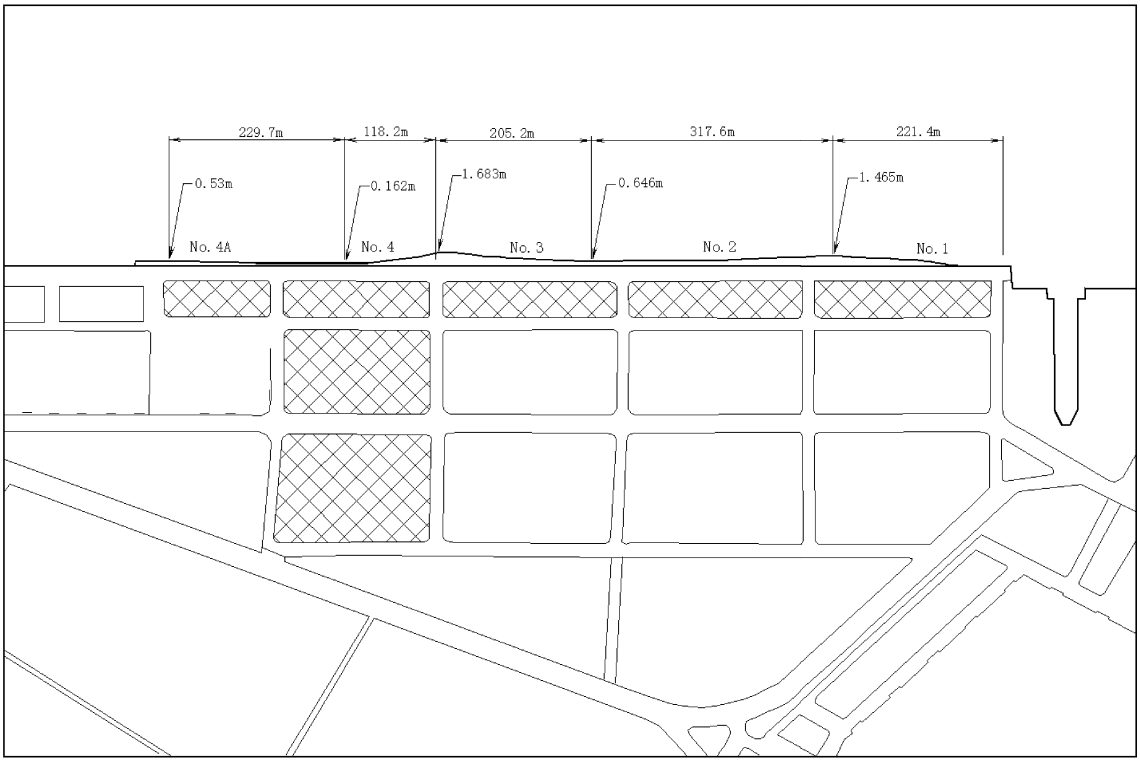

Figure.5.6 Horizontal displacement of quay walls

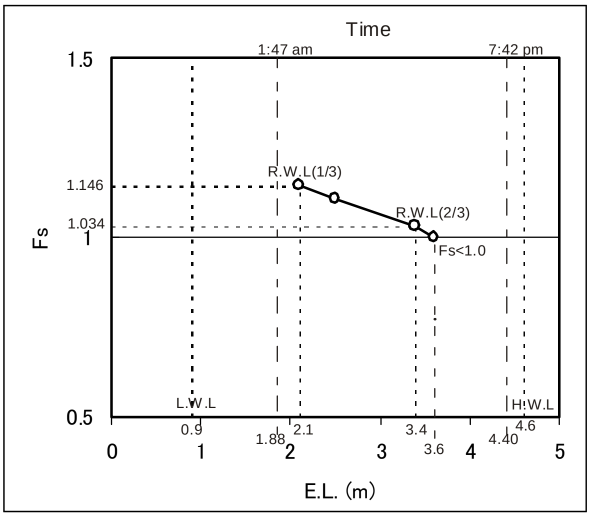

Figure.5.7 Relationship between safety factor and residual water level