

# DAMAGE TO PORT STRUCTURES BY THE 1978 MIYAGI-KEN-OKI EARTHQUAKE

by

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## SUMMARY

An earthquake of magnitude 7.4 occurred on 12th of June, 1978 in northern part of Honshu of Japan, and caused damage to many port facilities. As a result of field investigations and analyses, following lessons concerning to an earthquake engineering were learned.

1) 34 strong-motion accelerograms were recorded at 24 ports. The largest of the maximum horizontal component accelerations on ground was 280 Gals.

2) Port facilities as quaywalls and bulkheads were seriously damaged when a backfill liquefied. Otherwise, they suffered lightly.

3) A relationship between the seismic coefficient and the maximum ground acceleration for gravity quaywall :  $e = \frac{1}{3} \left( \frac{\alpha}{g} \right)^{1/3}$  also agreed with investigations concerning to this earthquake.

4) The above-mentioned relationship may be applicable to a stability calculation on the sheetpile quaywalls with anchor plate.

5) Current procedures for estimation of liquefaction potential could lead an appropriate judgement to actual sites.

## 1. INTRODUCTION

Ports and fishing ports in Miyagi prefecture and Fukushima prefecture were damaged by the 1978 Miyagi-ken-oki earthquake. In order to collect the engineering information and to assist the reconstruction plan of the damaged facilities, staffs of the Port and Harbour Research Institute were immediately sent to the damaged sites<sup>1)</sup>. In this paper authors present characteristics of damage on port facilities, strong-motion accelerograms in the ports, comparison of the maximum ground accelerations and the seismic coefficients by the stability analyses of the gravity quaywalls and the sheetpile quaywalls with anchor, and the case study of estimation of liquefaction for subsoils.

## 2. DAMAGE TO PORT FACILITIES

### (1) Outline of Damage

The public facilities in ports and fishing ports in Fig. 1 were damaged by the earthquake. The number of the damaged facilities and the cost of damage in these ports are shown in Table 1. Damage corresponding to 90 % of total cost happened in Ishinomaki port and 95% of the cost in this port corresponds to damage of the quaywalls. Damage in fishing ports occurred mainly at Ishinomaki and Yuriage in Miyagi prefecture. Consequently damage in ports and fishing ports converged to the above-mentioned ports, and it was not so severe in the other ports.

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Comparing the damage cost of the port facilities by this earthquake to those by the recent earthquakes, they are 22 billion Yen in the 1964 Niigata earthquake (M=7.5), 1.7 billion Yen in the 1968 Tokachi-oki earthquake (M=7.8), 0.5 billion Yen in the 1973 Nemuro-hanto-oki earthquake (M=7.4). It is judged that damage by the 1978 Miyagi-ken-oki earthquake is not always small from the viewpoint of the amount of damage.

(2) Damage to Gravity Quaywalls

A lot of gravity type quaywalls and revetments were damaged by the earthquake. The typical aspects of damage were sliding of gravity wall toward sea, tilting and settlement of the wall, and settlement, cracking and opening of the joint of the apron. These aspects occurred similarly on the gravity structures during the past earthquakes. Most of the gravity facilities did not lose its function and they were used after the earthquake without trouble. However gravity quaywalls in Yuriage fishing port were damaged seriously as shown in Fig. 2. They were useless immediately after the earthquake because the walls swelled 122 cm in maximum and the concrete pavements of the apron were mostly crashed.

(3) Damage to Steel Sheetpile Quaywalls

Five steel sheetpile quaywalls were severely damaged. Fig. 3 shows the plane of major part of Ishinomaki port which locates at the mouth of the Kitakami river. In the port both of the walls in Nakajima wharf with -10 m of water depth and Hiyori wharf (-9 m) slid toward sea by 57 cm in maximum and wall in Shiomi wharf slid by 119 cm in maximum. As shown in Fig. 4 the type of anchor of these quaywalls was steel sheetpile. At Junbi wharf (-7 m) with single vertical pile anchor in Ishinomaki fishing port the wall slid by 34 cm in maximum. At the back of these quaywalls settlement of the ground, and sand from the cracks and the joints of the pavement were observed. Therefore it was recognized that the backfilling sand liquefied. Maximum swelling of the quaywall at Yuriage fishing port in Fig. 5 was 106 cm.

General states of slight damage were the cracking of the pavement just above the anchor, and the swelling and the settlement of the ground in front of and in the rear of the anchor, respectively. In these cases the marks of the sand liquefaction were not found on the ground. When the tie rods were dug up for inspection in several damaged sites, the marks were not also found in the ground. The type of the anchors of these slightly damaged quaywalls was limited to the plate as shown in Fig. 6, or the vertical steel pipepile.

At Nakano wharf in Sendai port the steel sheetpile quaywalls with two kinds of anchors adjoined each other. These were the quaywalls with the steel sheetpile anchor as shown in Fig. 6 and that with the coupled piles anchor as shown in Fig. 7. Cracking, settlement and swelling of the pavement just above the anchor were found in the former, while nothing happened in the latter during this earthquake. This fact showed the difference of the earthquake resistance of the quaywalls caused by the anchors. Taking this fact into consideration the coupled pile anchor was accepted for the restoration works as shown in Fig. 8.

(4) Performance of Steel Pipe Piled Wharves

Steel pipe piled wharves have never been damaged by the past earthquakes, and they were also safe from this earthquake. The gravity quaywalls and the steel sheetpile quaywalls were severely damaged in Ishinomaki port and Yuriage fishing port, however steel pipe piled wharves neighboring them were safe

except the retaining wall behind the wharves. Fig. 9 shows the -3.5 m Wharf in Yuriage fishing port, which had been constructed in front of the gravity quaywall. It was supposed that the steel pipe pile resisted against the horizontal force through the access bridge during the earthquake. The same state happened at Ohte Wharf in Ishinomaki port. Judging from these facts, it was confirmed again that the steel pipe piled wharf was very tough against earthquakes.

#### (5) Performance of Composite Breakwater

A 38 meter high composite breakwater consisting of a rubblestone mound and concrete caissons in Fig. 10 was subjected to strong ground motions during the earthquake. Maximum accelerations of 350 Gals and 170 Gals were recorded at the crest and on the rock foundation, respectively. As this breakwater was made to protect the port against tsunami, 0.2 of seismic coefficient for stability of concrete caisson was applied and 0.1~0.2 for rubblestone mound in due consideration of the dynamic behavior of the structure. According to the settlement curves of the crown in Fig. 11, it was suffered 5~7 cm of very slight settlement by this earthquake but did not lose its function.

### 3. STRONG-MOTION EARTHQUAKE RECORDS IN PORTS

#### (1) Maximum Ground Acceleration in Ports

The earthquake triggered 34 strong-motion accelerographs of the network of the Port and Harbour Research Institute<sup>2)</sup>. The maximum accelerations of major records are listed up in Table 2. The largest peak ground acceleration in the port areas during this earthquake was recorded at Shiogama port as 280 Gals which is larger than 233 Gals at Hachinohe port in the 1968 Tokachi-oki earthquake. The ground condition of the observation site at Shiogama port is fill from surface to -3.4 m (N<3), tuff clay to -10.6 m, coarse sand with silt to -13.75 m (N>3), sandy tuff to -14.9 m, and tuff under -14.9 m (N>50). The maximum acceleration as 170 Gals was recorded at Ofunato port which locates in almost the same epicentral distance of Shiogama port.

#### (2) Major Wave Forms and Their Response Spectra

Figs. 12 and 13 show the main parts of acceleration records at Shiogama port and Ofunato port, respectively. Response spectra of the accelerograms (EW component) at both ports are shown as solid lines in Figs. 14 and 15. Spectra indicated by dotted lines were obtained by the records during the past earthquakes with rather small magnitude ( $M < 6.4$ ). According to Fig. 15 spectra at rocky site show similarity in shape. But spectra to this earthquake in Fig. 14 show difference in shape because the surface layer with about 15 m of thickness responds in different manner for very strong acceleration.

#### (3) Predominant Direction of Ground Motion

The predominant direction did not clearly appeared from the orbit by the two horizontal components of acceleration records. However, orbits by the displacement records showed evidently the predominant direction of the ground movement. Orbits which were calculated by the simulation of the source model agreed well with those by the observed records. The predominant directions by the observed records in each port and the fault plane of the earthquake are shown in Fig. 16.

### 4. STABILITY ANALYSES OF GRAVITY QUAYWALLS AND SHEETPILE QUAYWALLS

#### (1) Facilities

Stability of facilities in the several ports was analysed by the cur-

-rent design standard<sup>3)</sup>, and the results were compared with the extent of damage and the severity of ground motion during the earthquake. The number of port facilities investigated herein are 60 quaywalls in 11 ports, that is, 36 gravity quaywalls in 10 ports and 24 steel sheetpile quaywalls in 7 ports. But, the sheetpile quaywalls damaged by the liquefaction of the backfill were not discussed in this chapter.

#### (2) Estimation of Maximum Ground Acceleration in Ports

When the procedure of earthquake resistant design is investigated by the analyses of the damaged structures, the severity of the earthquake motion acting on the structures must be very informative. Therefore, the maximum ground accelerations at the ports where accelerations were not recorded were estimated by calculating the ground responses during the earthquake. The ground motions were calculated by SHAKE program<sup>4)</sup>. As the incident wave form the acceleration records which were observed on the rockysites at Ofunato port and Kaihoku Bridge<sup>5)</sup> were used. Besides the source region and the maximum accelerations of the incident waves in each port were determined by the same way which was described in the previous paper<sup>6)</sup>. The maximum ground accelerations in each port were estimated as shown in Fig. 17.

#### (3) Stability Analyses of Gravity Quaywalls, and Relationship between Seismic Coefficient and Maximum Ground Acceleration

The stability of the gravity quaywalls and bulkheads were analysed by the current design procedure, and the seismic coefficients corresponding to the severity of the seismic effect were estimated by the way reported in the previous paper<sup>6)</sup>.

The relationship between the maximum ground accelerations and the seismic coefficients for 36 quaywalls at 10 ports were estimated as shown in Fig. 18. In the figure the curved line indicates the proposed relationship which was derived from 129 quaywalls in 12 earthquakes, and the straight line indicates the relationship for the rigid body on the firm foundation. Even though the range of the estimated values in Shiogama, Matsushima and Hagiwara ports are wide to some extent, the results of the present estimation show the similar characteristics to the proposed curve. In case of the ground acceleration smaller than 200 Gals the straight line may indicate more suitable relationship than the curved line. As arrows indicate downward in Sendai and Ishinomaki ports, the expected seismic coefficients in these ports do not always contradict with the curved line. Consequently it is concluded that the relationship between the maximum ground acceleration and the seismic coefficient for gravity type quaywalls in this earthquake is also expressed by that derived from the past earthquakes.

#### (4) Stability Analyses of Steel Sheetpile Quaywalls, and Relationship between Seismic Coefficient and Maximum Ground Acceleration

As the typical damage of the steel sheetpile quaywalls was the swelling of the wall toward sea due to the movement of the anchor, the most important item in the analyses was the stability of the anchor. The relationship between the maximum ground acceleration and the seismic coefficient which gives 1.0 of the safety factor for the anchor plate was estimated in Fig. 19. In the figure the results from the previous investigation<sup>7)</sup> were added to these at 4 ports in this earthquake. According to the figure the results at 3 ports except Yuriage port are close to the straight line. The horizontal resisting capacity of the anchor plate is expressed as the difference between the passive earthpressure in front of the anchor and the active earthpressure in the rear,

and the stability of the gravity quaywalls is also mainly influenced by this difference. Judging from these facts, the relationship between the maximum ground acceleration and the seismic coefficient for the anchor plate is possibly similar to that for the gravity quaywalls. Besides, the stability of the anchor with a vertical pipepile and a sheetpile, the embedment and the stress of the sheetpile, and the stress of the tie rod were also investigated. But the results did not agree with the actual features on structures.

#### 5. CASE STUDIES OF LIQUEFACTION

In the design of port facilities the possibility of liquefaction of subsoil is concisely estimated by the way based on the grain size distribution and N value<sup>3)</sup>. The relationship between the critical N value for liquefaction and the maximum ground acceleration is based on the field experiences in the past earthquakes and the laboratory tests.

In some sites of Ishinomaki port subsoil apparently liquefied, and in another sites it did not. The above-mentioned method was applied to these sites and the concise method gave the reasonable agreement with the actual evidence. Another method by the combination of the dynamic shear test and the dynamic analysis of subsoil layer was also applied and showed adequate results. This investigation is written for this conference<sup>8)</sup>.

#### 6. REFERENCES

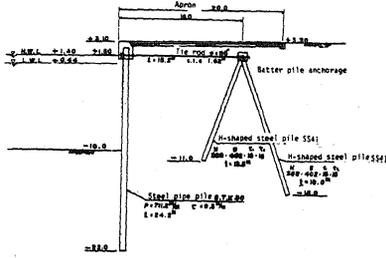
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- 2) Kurata, E., Iai, S., Yokoyama, Y., and Tsuchida, H.: Strong-Motion Earthquake Records on the 1978 Miyagi-ken-oki Earthquake in Port Areas, Tech. Note of PHRI, No.319, March 1979.
- 3) The Japan Port and Harbour Association: Engineering Requirements on Port and Harbour Facilities and Its Application, March 1978.
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- 5) Iwasaki, T., Wakabayashi, S., Kawashima, K., and Takagi, Y.: Strong-Motion Earthquake Records from Public Works (No. 2), Bull. of PWRI, Vol.33, Oct. 1978.
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Port Management Body	Number of Damaged Facility	Amount of Money (x1000 Yen)
Miyagi Prefecture	45	3,079,500
Fukushima Prefecture	4	96,500
Total	49	3,136,000

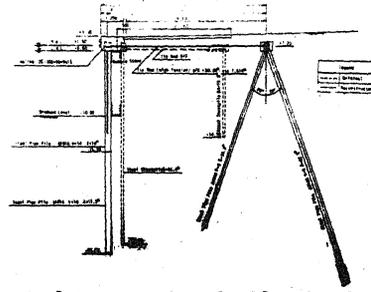
No. of Piers	Abbreviated Name	Soil Condition	Structural Distance (m)	Severe Number	Max. Acceleration (m/s <sup>2</sup> )		
					SD	SD	SD
(12)	Miyagi-ken-oki	on ground	100	0-1200	270	280	195
(1)	Miyagi-ken-oki	on ground	270	0-1200	63	61	30
(1)	Miyagi-ken-oki	on ground	166	0-1200	151	115	30
(1)	Miyagi-ken-oki	on ground	183	0-1215	143	170	60
(3)	Miyagi-ken-oki	on structure	183	0-1211	150	275	104

T-1 Damage of Public Port Facilities | T-2 Maximum accelerations in Ports

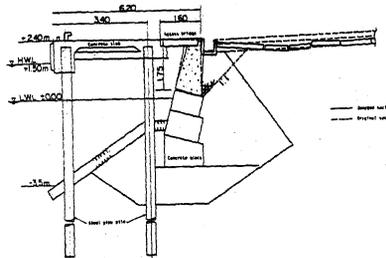




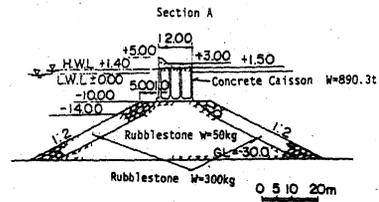
F-7 Nakano -10m Wharf



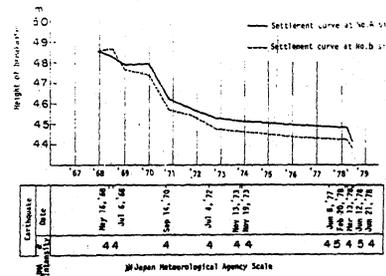
F-8 Reconstructed -10m Wharf



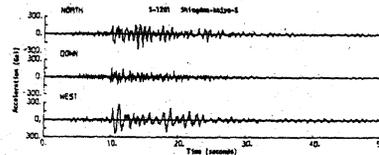
F-9 Yuriage -3.5m Wharf



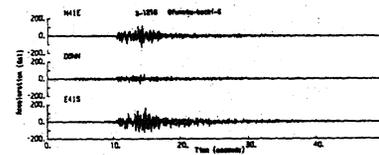
F-10 Composite Tsunami Breakwater



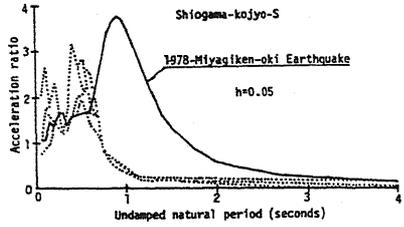
F-11 Settlement Curves of Breakwater



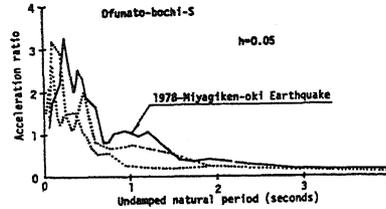
F-12 Accelerograms at Shiogama Port



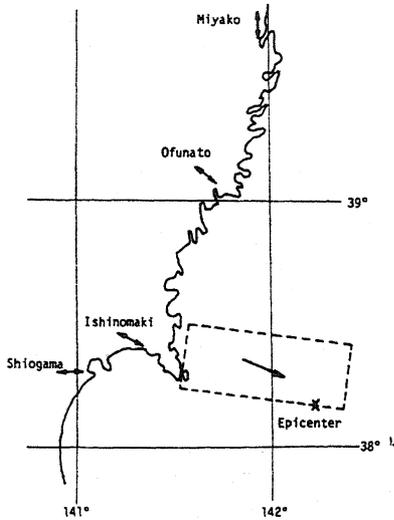
F-13 Accelerograms at Ofunato Port



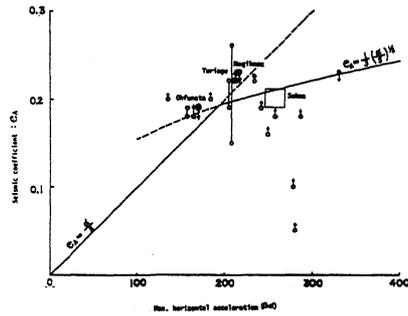
F-14 Response Spectra of Shiogama-site



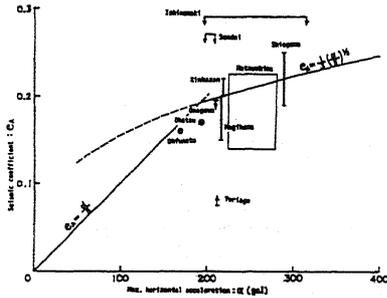
F-15 Response Spectra of Ofunato-site



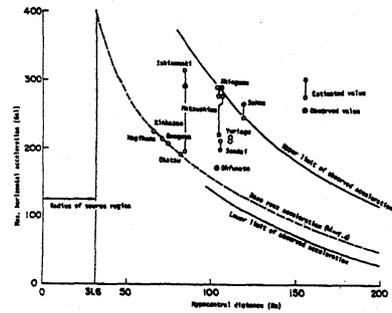
F-16 Predominant Direction of Ground Motion



F-17 Maximum Ground Acceleration in Ports



F-18 Seismic Coefficient and Maximum Ground Acceleration (Gravity Structure)



F-19 Seismic Coefficient for Anchor Plate and Maximum Ground Acceleration