RELATION BETWEEN SEISMIC COEFFICIENT AND GROUND ACCELERATION FOR GRAVITY QUAYWALL

by
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SYNOPSIS

According to the present design standard for port and harbor structures, the seismic coefficients corresponding to the severity of ground motions were obtained for 129 gravity quaywalls in 49 ports damaged by 12 earthquakes. The maximum ground accelerations in the ports were estimated by calculating the ground response during the earthquake with reference to the attenuation curves of the base rock acceleration based on the accelerograms in port area.

The seismic coefficients in the past earthquakes were up to 0.25, and the upper limit of the relation between the coefficient and the maximum ground acceleration was expressed by the following equation.

$$e_A = \frac{1}{3}\left(\frac{\alpha}{g}\right)^{\frac{1}{3}}$$

where, e_A:seismic coefficient
α:maximum ground acceleration (gal)
g :acceleration of gravity (gal)

INTRODUCTION

The present earthquake resistant design for the port and harbor structures is based on the static theory, so called as the seismic coefficient method.[1)]As the seismic effect acting on the structure varies complicatedly with time, the stability of the structure depends usually on such factors as the predominant period, amplitude and duration of the earthquake motion. Therefore, the dynamic design is becoming an effective method for the port facilities with advance of the computing procedure. On the other hand, the seismic coefficient method is still often accepted to the design of the commom structures because this method is based on many experience and requires simple calculation on the stability analysis.

Authors made an attempt to improve the reliance of the seismic coefficient method. The gravity quaywalls damaged by the past earthquakes were analyzed by the present design procedure, and the seismic coefficients corresponding to the severity of the seismic effect were obtained. The maximum ground accelerations in the ports were also estimated by calculating the ground response during the earthquake. Finally the results were investigated from the aforementioned point of view.

ESTIMATION OF SEISMIC COEFFICIENTS AT DAMAGED PORTS

A list of earthquakes and the damaged ports in discussion of this paper was shown in Table 1. An example of the damaged quaywalls was shown in Fig.1. In Fig. 2 a flow chart for the estimation of the seismic coefficient (represented to e_A in this paper) was explained. As it is seen in the figure, the stability of the sliding, the overturning and the bearing capacity at the base of structure for each port facility were analyzed and the seismic coef-

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ficients in case that safety factor is equal to 1 were obtained. Judging from the characteristics of damage on quaywalls, the causes of damage were estimated and the ranges of the seismic coefficients were deduced for each facility. And finally the only one of the seismic coefficient or the range of it in the particular port was determined from these ranges[2]. Although there are various problems for this estimation procedure, the seismic coefficient e_A was estimated without contradiction in the analysis of harbor structures damaged by 1968-Tokachi-oki Earthquake and 1973-Nemuro-hanto-oki Earthquake[3]. Therefore, in this paper the estimation of the seismic coefficient was based on the procedure in Fig.2.

PREPARATION OF ATTENUATION CURVES FOR BASE ROCK ACCELERATION

The rock motion at any particular site will depend in large measure on the magnitude of the earthquke and the distance to the site from the zone of energy release. As shown in Fig.3, methods of determining the maximum accelerations in rock have been proposed by several investigators. In general the amplitudes of motions decrease with increasing the distance from the zone of energy release. Then, the distance from the zone, causative fault or the epicenter of the principal shock may be more reasonable than the epicentral distance. But it is difficult to determine these distance for the past earthquakes because the developing process of the source region for a great earthquake is very complicated. Considering these matters, Mr. Katsumata proposed the distance from the edge of source region (the effective distance) which was taken as a sphere of radius r. The following empilical formula was introduced in this paper[4].

$$\log_{10} r = 0.5M - 2.25$$

where, r : radius of source region (Km)
M : magnitude of earthquake

As Mr. Katsumata discussed for the ground acceleration of the average ground condition in Japan, in this report the relation among the base rock acceleration, the magnitude of the earthquake and the effective distance was newly proposed by using the strong motion accelerograms.

DEFINITION OF SOURCE REGION The fault parameters of some past earthquakes were determined by the seismologists. In the case, it was assumed that the source region was equal to the fault plane. When the fault parameters were unknown, the region was taken as a sphere which was equal to the aftershock area. If the aftershock area was unknown in case of small earthquake, the region was calculated by the aforementioned equation. According to the reference (4), it was assumed that the maximum base rock acceleration at an edge of source region was independently 400 gals regardless of the magnitude of the earthquake.

USED STRONG MOTION ACCELEROGRAM The Earthquake Resitant Structures Laboratory of the Port and Harbour Research Institute has been observing strong motion earthquakes in port areas in Japan for 14 years. The observation network consists of 65 stations at 44 ports, and as the end of 1975 more than 1058 accelerograms were obtained[5]. 106 accelerograms from 21 stations were selected from the view point of that maximum acceleration was at least exceeding 20 gals and the magnitude of the earthquake is known.

CALCULATION OF BASE ROCK ACCELERATION In order to make the attenuation curves, the base rock motions were calculated from the selected accelerograms by the method based on the multiple reflection theory. The computer program SHAKE developed by Dr.Schnabel and et al. was used, in which the shear modulus and the damping of soil changed with the strain level6). The source regions were determined for the past earthquakes in which the accelerograms were obtained. For an example the fault plane and the aftershock area of 1968-Tokachi-oki Earthquake are shown in Fig.4. Fig.5 shows the proposed relation between the bed rock acceleration and the effective distance.

CALCULATION OF GROUND ACCELERATIONS AT DAMAGED PORTS

Using Fig.5, the base rock accelerations in the damaged ports were obtained. The source regions of the earthquake were determined as the same method described above. For an example the fault plane and the aftershock area in Nankai Earthquake are shown in Fig.6. As shown in the figure the fault plane was agree with the aftershock area. Additionaly, 63 Km of radius of source region for M=8.1 is given by the equation described before. The maximum ground accelerations at the damaged ports were estimated by calculating ground response during the earthquake. The frequency characteristics of the incident wave was obtained from the accelerograms at the nearest station to the port. The ground motions were calculated by the aforementioned computer program.

RESULTS AND DISCUSSION

The severity of ground motion during the past earthquakes was estimated in the form of seismic coefficient on the basis of the stability analysis on the gravity quaywalla by the current design procedure. Using the attenuation curves of the base rock acceleration, the maximum ground acceleration was also estimated by calculating the earthquake response of the subsoil layer. The results are summarized in Fig.7. The expression   indicates that the seismic coefficient exists within the range, and   or   means only the upper or lower limit of the range.

According to Fig.7, 0.25 of the seismic coefficient is the maximum in the past great earthquakes, and this fact may be very informative for the reexamination on the aseismicity of the port facilities.

As shown in the figure, the upper limit of the relation between the seismic coefficient and the maximum ground acceleration is determined to be the solid line in due consideration of the direction of the arrow. consequently it is concluded that the gravity quaywall of which the design seismic coefficient is existing over the line may have the sufficient aseismicity against the earthquake with the corresponding maximum ground acceleration.

In the figure the seismic coefficient is not proportioned to the ground acceleration. The followings discuss about the reason of the curve of the solid line. If the seismic force acting on the structure is considered to be equivalent to the product of the mass of structure and maximum ground acceleration α, the coefficient must be equal to α/g. The experimental studies on the model by the shaking table indicated that the earthpressure under the sinusoidal excitation up to 500 gals was almost same as the results from the current design procedure and the coefficient must be in proportion to the acceleration. Therefore, this fact does not explain the curve of solid line in Fig.7. Although the gravity quaywall is generally simple earth structure, its behavior during the earthquake is not elucidated. It is supposed from the results that one of the major reasons of the curve of the solid line is the dynamic response effect of the wall and the backfill, and such the seismic force as the earthpressure does not always proportionally increase with increasing the ground acceleration during the great earthquake.

CONCLUSIONS

Judging from the stability analysis on the gravity quaywall by the current design standard, 0.25 was the maximum value of the seismic coefficient e_A corresponding to the severity of the ground motions in the ports during the past earthquakes.

The maximum ground accelerations α in the ports were estimated by calculating the ground response during the earthquakes with reference to the attenuation curves of the base rock accelerations based on the strong motion accelerograms in port area. Then, the upper limit of the relation between e_A and α was expressed by the equation described in synopsis.

REFERENCE

1) Design Manual of Harbour Structures in Japan, The Japan Port and Harbour Association, April 1967.
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5) E. Kurata, S. Iai and H. Tsuchida; Annual Report on Strong-motion Earthquake Records in Japanese Ports (1975), Technical Note of Port and Harbour Research Institute, No.236, 1975.
6) P.B. Schnabel, J. Lysmer and H.B. Seed; SHAKE-A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report No.EERC 72-12, Col. of Eng., Univ. of Calif. Berkeley, 1972.

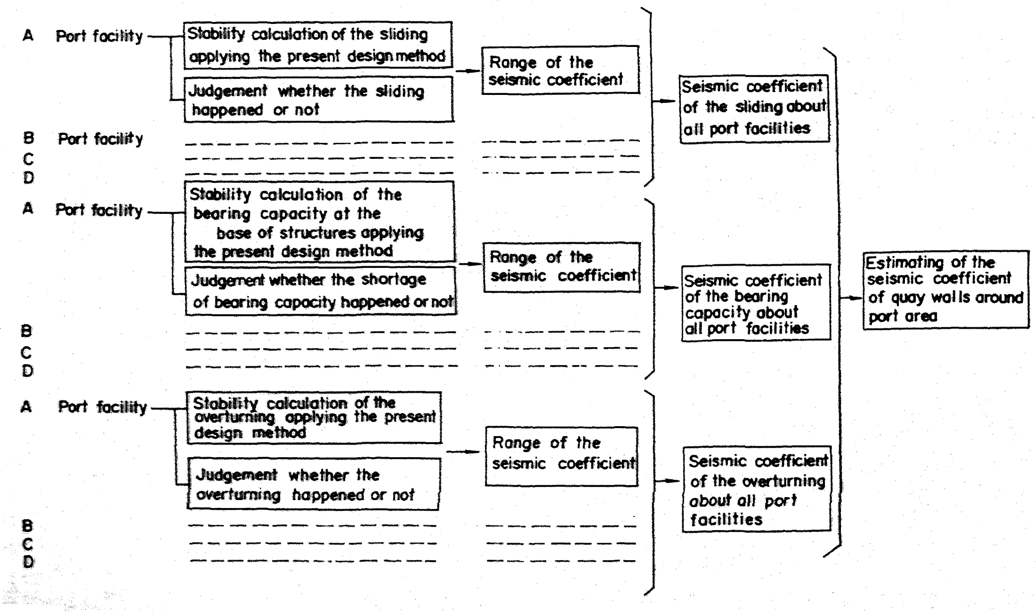

Fig.2 Flow chart for estimation of seismic coefficient

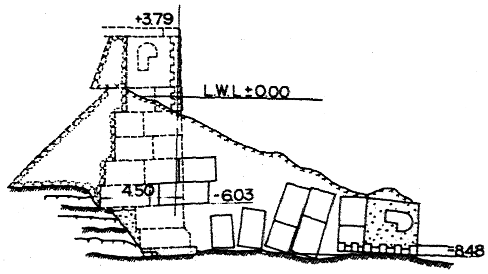

Fig.1 Damage to block quaywall at Yokohama port (Kanto earthquake)

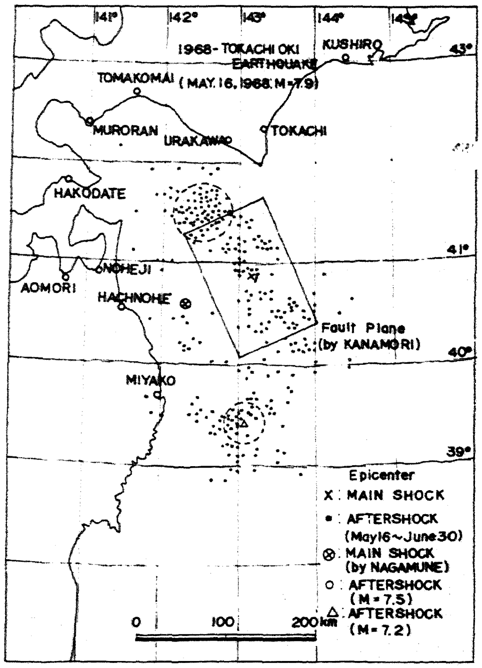

Fig.4 Distribution of epicenters of aftershocks (1968 Tokachioki earthquake)

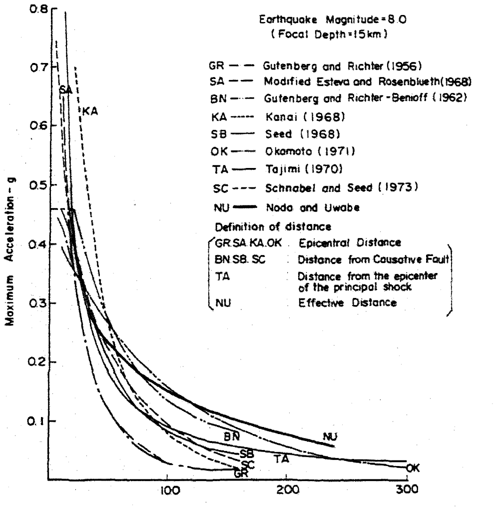

Fig.3 Comparison of maximum accelerations at bed rock

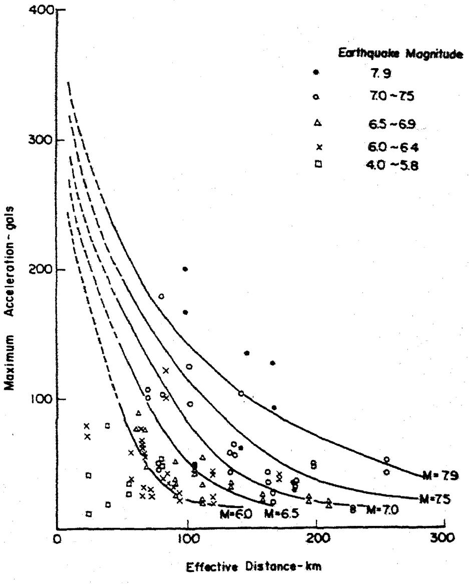

Fig.5 Proposed attenuation curves of bed rock acceleration

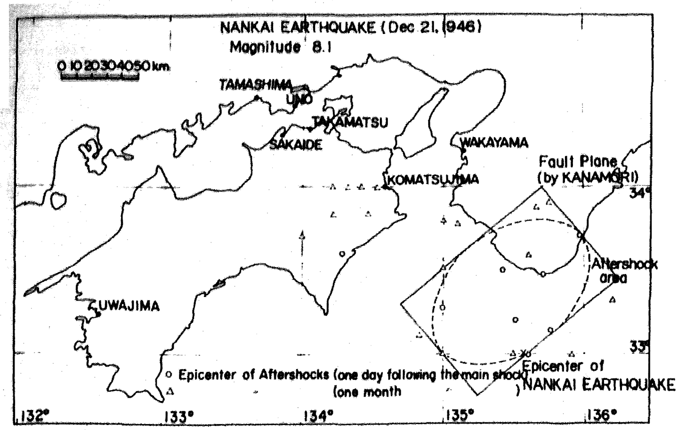

Fig.6 Distribution of epicenters of aftershocks (Nankai earthquake)

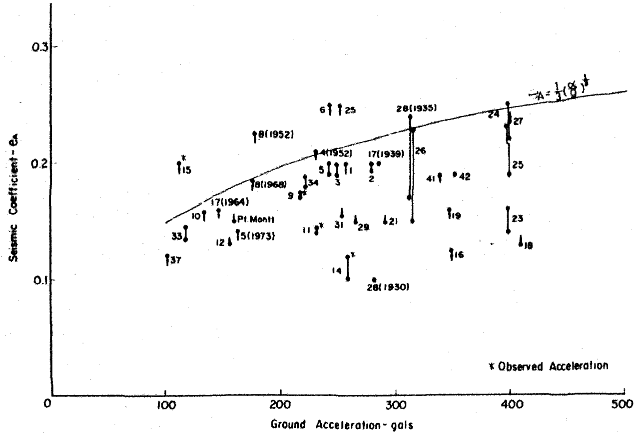

Fig.7 Relation between seismic coefficient and ground acceleration

Name of Earthquakes	Location of Epicenter	Damaged Harbours
Kanto Sep.1, 1923 M = 8.16	WESTERN KANTO (35.4°, 139.20°) DEPTH 0~20km	TOKYO YOKOHAMA YOKOSUKA KAMAKURA
Kitaizu Nov. 26, 1930 M = 7.0	E.SHIZUOKA PREF. (35.1°, 139.0°) DEPTH 0~5km	SHIMIZU
SHIZUOKA Jul.11, 1935 M = 6.3	MIDDLE OF SHIZUOKA PREF (35.0°, 138.4°) DEPTH 10 km	SHIMIZU
OGAHANTO Apr. 1, 1939 M = 7.0	W.AKITA PREF. (39.95°, 139.8°) DEPTH 0	AKITA FUNAKAWA
NANKAI Dec.21, 1946 M = 8.1	OFF NANKAIDO (33.0°, 135.6°) DEPTH 30km	UNO SAKAIDE KOMATSUJIMA TAMASHIMA TAKAMATSU WAKAYAMA UWAJIMA KOCHI
1952-TOKACHIOKI Mar. 4, 1952 M = 8.1	OFF TOKACHI (42.20°, 148.9°) DEPTH 45km	AKKESHI KUSHIRO TOKACHI HOROIZUMI URAKAWA MURORAN
HYUGANADA Feb. 27, 1961 M = 7.0	OFF MIYAZAKI PREF (31.6°, 131.85°) DEPTH 40 km	HOSOJIMA MIYAZAKI AOSHIMA UCHIUMI ABURATSU TONOURA
NIIGATA Jun. 16, 1964 M = 7.5	SW.AWASHIMA (38.35°, 139.18°) DEPTH 40km	NIIGATA IWAFUNE SAKATA AKITA
1968-TOKACHIOKI May 16, 1968 M = 7.9	OFF TOKACHI (40.58°, 142.33°) DEPTH 20km	URAKAWA MURORAN HAKODATE AOMORI NOHEJI KAWAUCHI HACHINOHE MIYAKO
1973-NEMUROHANTOOKI Jun. 17, 1973 M = 7.4	OFF NEMURO PEN. (42.97°, 145.95°) DEPTH 40 km	HANASAKI KIRITAPPU NEMURO AKKESHI KUSHIRO
1974-IZUHANTOOKI May.9, 1974 M = 6.9	OFF IZU PEN. (34.57°, 138.8°) DEPTH 10km	SHIMODA INATORI MERA
CHIRE May.23, 1960 M = 8.5	OFF CHIRE (37.5°, 73.5°) (39.5°, 74.5°)	Pt. Montt Talcahuano

Table-1 Earthquakes and harbors