

EARTHQUAKE RESISTANT DESIGN OF PORT FACILITIES

by

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ABSTRACT

This paper presents the earthquake resistant design way of port facilities in Japan. Technical Standard of Port and Harbour Facilities was first established in 1973, and has been revised 3 times so far. Having experienced the 1995 Hyogoken-Nambu earthquake, significant revision has been made on the outcome of the recent research.

KEY WORDS : Earthquake Resistant Design
Port Facility
Design Code

1. HISTORY OF REVISIONS OF DESIGN CODES

Having been established in 1951, the Port and Harbour Law in Japan has been revised many times so far. The important revision in view of the design of port and harbour facilities was made in 1974, in which it was noticed that the port and harbour facilities must be constructed, maintained and rehabilitated in accordance with the Technical Standard of Port and Harbour Facilities. In 1975 the engineering requirement was established as the Ordinance of the Ministry of Transport and it was prescribed in the ordinance that the facilities in ports and harbours must be stable against the loads such as earthquake loads, dead weights, wave forces, impacts due to ships and so on.

The Technical Standard of Port and Harbour Facilities was established in 1973 as the order of the Director General of Bureau of the Ports and

Harbours, Ministry of Transport, in which the details on earthquake resistant design, such as design procedures, factor of safety and allowable stresses, were specified.

In 1979 the Technical Standard of Port and Harbour Facilities and its Commentary was compiled under the supervision of the Bureau of the Ports and Harbours, Ministry of Transport, and has been revised in every ten years after the 1979 edition.

Seismic stability of the port and harbour structures was to be examined only by the pseudo-static method in the 1979 edition and 1989 edition of the Technical Standards. The pseudo-static method is called the seismic coefficient method, and the earthquake load is obtained by the multiplication of the design seismic coefficient and the vertical load. The design seismic coefficient is obtained by the multiplication of the regional seismic coefficient, the factor for subsoil condition, and the importance factor. Those three factors were classified into three groups respectively, with the regional seismic coefficient ranging from 0.05 to 0.15, the factor for subsoil condition ranging from 0.8 to 1.2, and the importance factor ranging from 0.5 to 1.5. The resultant value, the design seismic coefficient, was rounded off to the nearest 0.05 or 0.00. As to the design of the reinforced concrete structures, allowable stress method was applied.

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Significant modification had not been made as to the earthquake resistant design procedures ever since the first edition thus far, however, the procedure of assessing the liquefaction potential was not stated in the 1973 edition, and was firstly stated in the 1979 edition.

In 1999, the order of the Director General of Bureau of the Ports and Harbours was repealed for variety of reasons, and the Ministry of Transport notified the new detailed Technical Standard. In the new Technical Standard, some significant revisions have been made based on the outcome of the recent research after the 1995 Hyogoken-Nambu earthquake. Those are summarized as follows :

(1) Principles of design

The concept of performance-based design has been introduced. The principles are:

① All the structures must be stable against the level 1 earthquake motions whose return periods are about 75 years.

② High seismic resistant facilities should keep the required performance against the level 2 earthquake motions whose return periods are over some hundred years.

(2) Seismic coefficient method

① The regional seismic coefficient and the importance factor have been modified, while the factor for subsoil condition has remained as it was. The number of regional groups for the regional seismic coefficient has come up to five, coefficient ranging

from 0.08 to 0.15. Range of the importance factor has become from 0.8 to 1.5. In addition, the resultant value has been considered down to three decimal places.

② The equation for the apparent seismic coefficient, which is the seismic coefficient used for the calculation of earth pressure below groundwater level, has been modified.

③ Consideration of the dynamic water pressures acting at the front of vertical walls has been stated.

(3) Assess of earthquake-resistant performance
Assessing way of the earthquake-resistant performance in view of level 2 earthquake motions has been introduced.

(4) Assess of liquefaction potential
Assessing way of liquefaction potential has been modified.

(5) Design method of open piled piers
Modified pseudo-static design method, which is called the modified seismic coefficient method, has been introduced for the design of open piled piers.

(6) Design method of reinforced concrete structures
Limit state design method has been introduced, and safety factors for the design have been established.

The history of revisions of design codes is summarized in Table 1.

Table.1 Summary of history of revisions of design codes

	1973	1979	1989	1999
Earthquake design level	One level			Two levels
Seismic coefficient method	○			○ modified
Performance-based design principles	—			○
Assess of liquefaction potential	—	○		○ modified
Design of open piled piers	Seismic coefficient method			Modified seismic coefficient method
Design of reinforced concrete structure	Allowable stress method			Limit state design method

2. SUMMARY OF THE UP-TO-DATE DESIGN CODE

(1) Evaluation of Seismic Performance

(a) General

In the design of port facilities, the effect of earthquakes should be taken into account so that they possess appropriate amount of seismic resistance.

Explanation

At Kobe Port, the type of structures were quite uniform during the 1995 Hyogoken-Nanbu earthquake. This is why almost all of the structures suffered similar damage. If the type of structures had been more diverse, the amount of damage for each structure should not have been uniform because their response characteristics should have been different. Based on this experience, in the choice of the structural type of port facilities, it is recommended to adopt various type of structures as long as possible.

(b) Seismic performance requirement for port facilities.

- (1) Port facilities should sustain their structural stability and maintain their functions for a level-1 ground motion, which by definition occurs with high probability during the facility's duration.
- (2) High seismic resistant facilities, which are especially important and require high seismic resistance, are allowed to suffer only slight damage for a level-2 ground motion, which by definition occurs with relatively low probability during the facility's duration but which is very intense. In other words, high seismic resistant facilities should be prepared for rapid restoration to sustain their intended functions after a level-2 ground motion.

Explanation

In the seismic design of port structures, a level 1 ground motion, which has a return period of 75 years and a level 2 ground motion, which is a ground motion due to intra-plate earthquake with a return period of more than several hundred years or a ground motion due to a subduction zone earthquake, should be taken into account.

High seismic resistant facilities include high seismic resistant quay walls, which are specially designed for the transportation of emergency cargo or for the maintenance of economic or social activity just after the earthquake, and the revetments of the disaster prevention base, which is intended to keep the safety of the citizen just after the earthquake.

While 'to maintain their functions' means to sustain their structural stability, 'to sustain intended functions' means to suffer only a slight damage and to be prepared for a immediate restoration.

(c) Pseudo-static method

- (1) In principle, seismic load for port structures with relatively short natural period and relatively high damping factor should be designated as a design seismic coefficient for pseudo-static approach. In this case, the design seismic coefficient should be used. Seismic inertia force should be the larger of the following (a) and (b) and should be assumed to act on the gravity center of the structure.
 - (a) (Seismic force)=
(Self weight) × (Seismic coefficient)
 - (b) (Seismic force)=(Self weight + Surcharge) × (Seismic coefficient)
- (2) For structures for which pseudo-static method is not applied, seismic load should be designated in an appropriate manner, taking into account the characteristics of the structure.

Explanation

- (1) For quay walls and other similar port structures, pseudo-static method is applied as for other wide range of structures. Because natural periods of these structures are generally shorter than predominant periods of ground motions, the response of these structures during earthquake are similar to those of rigid bodies on a rigid table.
- (2) Because the seismic load is assumed to act as a static load in the pseudo-static method, it is necessary to take into account the difference between the real phenomena and the assumptions in the method. To appreciate this difference, the safety factor and the allowable stress for dynamic loads are different from those for static load.
- (3) It is preferable to examine the seismic resistance of those structures which has a longer natural period compared to predominant periods of ground motion or for which the distribution of acceleration is not uniform along the height.

(d) Earthquake response analysis

If the facility is especially important or the type of structure is rare and there is no similar conventional structure, it is recommended that it's seismic resistance should be examined by using earthquake response analysis together with conventional pseudo-static method or seismic deformation method.

Explanation

Recently, new type of port facilities or extremely large port facilities have been designed and constructed. On the other hand, it is sometimes required to construct port structures at a site with a poor subsoil conditions. Furthermore, it is requested to examine whether

a high seismic resistant facility will maintain their functions after a near-source ground motion such as the ground motion at Kobe Port during the 1995 Hyogoken-Nanbu earthquake. It is recommended to examine earthquake resistance of structures by conducting earthquake response analysis to understand the performance of structures during earthquake more precisely if the type of structure is new or if the structure is especially important.

(e) Seismic deformation method

Because the deformation of line structures etc. buried in the soil during earthquake is controlled by surrounding soil, it is preferable that such structures should be designed by using seismic deformation method.

(2) Earthquake Load

(a) Design Seismic coefficient

(1) For pseudo-static design of port structures, horizontal design seismic coefficient should be determined with following equation.

$$\text{Seismic coefficient} = \text{Regional seismic coefficient} \times \text{Factor for subsoil condition} \times \text{Importance factor} \quad (1)$$

Horizontal design seismic coefficient should be rounded to obtain two places of decimals. Standard values for regional seismic coefficient are:

Region A: 0.15

Nemuro, Kushiro, Tokachi and Hidaka districts of Hokkaido, Saitama, Chiba, Tokyo (Except for Hachijo and Ogasawara Islands), Kanagawa, Yamanashi, Shizuoka, Aichi, Gifu, Fukui, Shiga, Mie, Nara, Wakayama, Osaka and Hyogo.

Region B: 0.13

Pacific side of Aomori, Iwate, Miyagi, Fukushima, Ibaragi, Tochigi, Gunma, Nagano, Kyoto, Kochi and Tokushima.

Region C: 0.12

Iburi, Oshima and Hiyama districts of Hokkaido, Aomori (except for Pacific side), Akita, Yamagata, Niigata, Toyama, Ishikawa, Tottori, Hiroshima, Ehime, Oita, Miyazaki, Amami Islands of Kagoshima and Kumamoto.

Region D: 0.11

Abashiri, Goshi, Ishikari, Sorachi, Rumoi and Kamikawa districts of Hokkaido, Okayama, Tottori, Kagawa, Nagasaki (except for Goto, Iki and Tsushima Islands), Saga, Kagoshima (except for Amami Islands) and Okinawa (except for Daito Islands).

Region E: 0.08

Sorachi district of Hokkaido, Hachijo and Ogasawara Islands of Tokyo, Yamaguchi, Fukuoka, Goto, Iki and Tsushima Islands of Nagasaki and Daito Islands of Okinawa.

Factor for subsoil condition should be determined as shown in Table 2 and 3.

Table 2 Factor for subsoil condition

Classification	1 st kind	2 nd kind	3 rd kind
Factor	0.8	1.0	1.2

Table 3 Classification of subsoil

Thickness of Quaternary Deposit	Gravel	Sand or clay	Soft ground
less than 5m	1 st	1 st	2 nd
5-25m	1 st	2 nd	3 rd
more than 25m	2 nd	3 rd	3 rd

Importance factor should be determined according to Table 4.

Table 4 Importance factor

Category	Special	A	B	C
Factor	1.5	1.2	1.0	0.8

Category Special: The structure has significant characteristics described by items (1)-(4) of category A.

Category A: (1) If the structure is damaged by an earthquake, a large number of human life and property will possibly be lost. (2) If the structure is damaged by an earthquake, economic or social activity of the region will be severely suffered. (3) The structure will perform an important role in the reconstruction work of the region after the earthquake. (4) The structure handles a hazardous or a dangerous object and it is anticipated that the damage of the structure will cause a great loss of human life or property. (5) If the structure is damaged, it is supposed that the repair work is considerably difficult.

Category B: The structure does not belong to categories Special, A nor C.

Category C: The structure does not belong category Special nor A and is easy to repair or, even if the structure is damaged by an earthquake, the effect on economic or social activity is small.

(2) If vertical seismic coefficient is required in the pseudo-static design, the vertical seismic coefficient should be determined appropriately, taking into account the characteristics of structure and subsoil.

Explanation

(1) To determine importance factor of the structure, it is necessary to consider not only the purpose, type or size of the structure but also social or economic aspects of the structure. Following factors also should be taken into account.

a) The extent of damage in the future earthquake, the difficulty of restoration work or the residual strength after the earthquake.

b) The cargo-handling capacity of the other facilities of the same port.

Therefore, it is possible to use different importance factors for the structures for the same cargo in the same port when desired.

(2) For structures other than high seismic resistant quay walls, the upper limit of design seismic coefficient should be 0.25 for several

reasons. First, in the past, the upper limit of design seismic coefficient was 0.25. Second, there has been no port structures with design seismic coefficient of 0.25 that suffered significant damage. Thirdly, high seismic resistant quay wall has been constructed in many ports.

(3) Seismic Design of High Seismic Resistant Quaywalls

(a) Evaluation of seismic performance of high seismic resistant facilities

- (1) In the design process of high seismic resistant facilities, it is requested that their seismic performance should be evaluated for a level-2 ground motion to assure that their seismic resistance is satisfactory.
- (2) Seismic performance should be evaluated by appropriately modeling the soil and the structure of the facility, with a method which is appropriate for the particular type of the structure.

Ground motion which is used for the evaluation of seismic performance should be determined with response analysis of the ground in principle.

Explanation

- (1) Evaluation of the residual deformation of high seismic resistant facilities, which is based on a earthquake response analysis, is required for the purpose of verifying that they will sustain their intended functions after a level-2 ground motion. The reason is that, for the examination of the stability of the structure or the soil for a large ground motion such as a level-2 ground motion, conventional pseudo-static method is not sufficient.
- (2) The judgement whether the high seismic resistant facilities will sustain their intended functions based on the results of earthquake response analysis should be based on the combined considerations on the stability of the structure after the earthquake, the functions and the difficulty of restoration work. Although the allowable residual deformation should be defined for this judgement, it is not easy to specify the allowable deformation at the present state of

knowledge. In the case of the 1995 Hyogoken-Nanbu earthquake, some of the caisson quaywalls with a normalized deformation (lateral residual displacement / height of the quaywall) of over 10-20% was temporary repaired and offered for immediate use just after the earthquake.

(b) Design seismic coefficient of high seismic resistance facilities

- (1) When pseudo-static design is applied to high seismic resistant quaywalls, the design seismic coefficient should be determined by a global judgement base on the seismic coefficient determined by Eq.(1) with importance factor 1.5, by following equations for which peak ground acceleration should be calculated with ground response analysis for level-2 ground motion, and by other appropriate methods.
 1. If α is smaller than or equal to 200Gal,
$$K_h = \alpha / g \quad (2)$$
 2. If α is larger than 200Gal,
$$K_h = (1/3) \times (\alpha / g)^{(1/3)} \quad (3)$$

Here, K_h is horizontal seismic coefficient, α is peak ground acceleration at free surface and g is the acceleration of gravity.

Explanations

- (1) When the design seismic coefficient can be accurately determined by investigating regional seismic activity, characteristics of ground motion, site response, etc., it is preferable to use this design seismic coefficient instead of the value designated here. For example, when the design ground motion is determined based on the information regarding regional seismic activities or based on strong ground motion observations or when seismic response analysis of the structure is conducted, design seismic coefficient can be determined based on these results.

- (2) In the design of high seismic resistant facilities, target earthquake has to be selected from earthquakes including hypothetical earthquake in the disaster prevention plan set by local government.
- (3) One way of calculating peak ground acceleration at free surface is to use multiple reflection model for the response analysis of the ground.
- (4) From the experience of significant damage at Kobe Port during the 1995 Hyogoken-Nanbu earthquake, minimum design seismic coefficient for high seismic resistant facilities should be 0.25 if the site is in a near-source region.
- (5) When it is desired, seismic resistant qua walls should be designed for level-2 ground motion with a method other than pseudo-static method such as earthquake response analysis. In this case, it is necessary to make sure that seismic resistant facilities will sustain their structural stability for level-1 ground motion.