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The Latest Revision in 2014 of Technical Standards and Commentaries for Port and Harbour Facilities in Japan and Recent Progress and Development of Harbour Engineering Seismic Design

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Abstract

The disaster history of destructive earthquakes occurred in Japan and the effect and characteristics of the earthquake damage on harbor engineering structures under the destructive earthquakes was summarized. Based on understanding and recognizing for the latest revision of Technical Standards and Commentaries for Port and Harbor Facilities in Japan after the Great East Japan Earthquake 2011, and the background of One Belt And One Road, the new development and existing problems for the harbor engineering structure seismic design of our country in the future were analyzed as follows: the performance-based and life-cycle seismic design method, the maintaining and upgrading or reconstructing of the existing harbor facilities for long-time service, the seismic evaluation method of rare earthquake for pivotal port and wharf, the study of technology innovation and application for the new types of the wharf structures, the improvement and establishment of International standard system for harbor engineering seismic design. The study will provide the instructive reference for the research of the development of harbor engineering seismic code and the harbor seismic design method of our country.

Keywords

Harbor engineering; seismic design; code and standard; development and trend.

1. Introduction

In recent years, great destructive earthquakes occur frequently in China. For example, the Wenchuan earthquake in 2008 (M8.0), the Yushu earthquake in 2010 (m7.1), the Ya'an earthquake in 2013 (M7.0), the Ludian earthquake in 2014 (M6.5) and the Jinggu earthquake in the same year (m6.6) and other earthquake disasters occurred frequently and on a large scale, resulting in huge loss of life and property of the people. Although the earthquake damage in recent years has not had a destructive impact on the coastal harbor facilities and building structures, considering that the earthquake is a highly random natural disaster phenomenon, and its destructive is likely to far exceed the established seismic fortification level when the big earthquake strikes, the potential risk and harm of large-scale destructive earthquake to the harbor facilities cannot be ignored. On the other hand, under the guidance of the "one belt and one way" initiative, China's overseas harbor engineering projects are increasing in size and quantity. For example, the seaport construction in Indonesia, Malaysia and other countries in Southeast Asia is also increasing. Therefore, the anti-seismic design of the harbor wharf structure needs to be paid enough attention both at home and abroad. We should take

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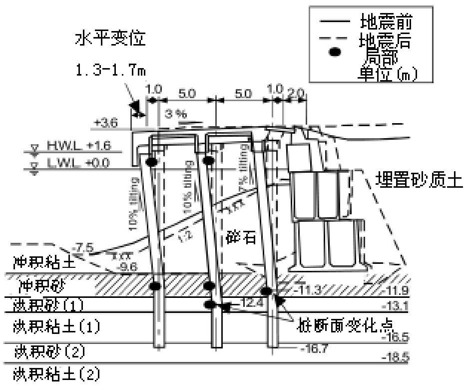
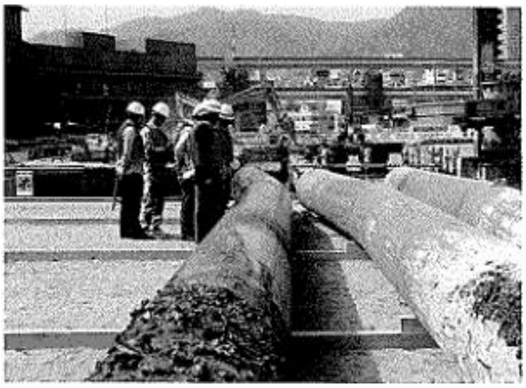
precautions against disasters, reduce the destructive impact of disasters on the wharf structure as much as possible, and have a deeper significance for the national economy and people's livelihood.

Compared with China, neighboring Japan is located in the active circum-Pacific seismic belt, which makes the number of earthquakes in the world account for a very high proportion [1]. The occurrence of a large number of destructive earthquake disasters has also made Japanese society accumulate more rich experience in various aspects such as earthquake resistance and disaster prevention, especially in the wake of typical major earthquake disasters, such as the Hanshin temlu earthquake in 1995 and the East Japan earthquake in 2011, and in the promotion and development of seismic design and disaster prevention concept of sea port facilities and building structures, and The revision and implementation of relevant specifications of harbor engineering are the most deficient part in the seismic design of Port Engineering in China, so it has more important reference and guidance significance.

In 1995, Kobe port was severely damaged by Hanshin temlu earthquake (M7.2, maximum acceleration 818gal, direct down type). In addition to the direct economic loss of tens of billions of dollars, a large number of sand liquefaction and damage to the wharf structure caused the preparation and reconstruction of Kobe port for five years. Until 2000, the overall function of the wharf also recovered to the earthquake about 80% before the disaster, the earthquake damage caused a lot of direct and indirect losses. A new test is put forward for the seismic design concept and method, seismic performance evaluation and sand liquefaction evaluation method.



Cross section of high pile wharf damaged after earthquake



The damaged pile will be pulled out and inspected on site after the earthquake

Fig 1. The investigation of Takahama wharf in Kobe port after the Hanshin earthquake disaster

After the 2011 East Japan earthquake[4] (M9.0, maximum acceleration 2933gal, trench type), a total of 367 quays including Xiangma port, Ibaraki port and Sendai salt kettle port were investigated. The results show that only 108 quays can be temporarily used after the disaster, less than 30% of the total[5]. The wharfs of different structural forms suffered serious damage in the epicenter of the earthquake (as shown in Figure 2), and the large deformation and other damages caused by the earthquake caused the derailment of the hoisting machinery and equipment and the loss of operation capacity, as shown in Figure 3. The large destructive damage of the harbor facilities in the earthquake also shows the demand of the harbor facilities for the high-strength reinforced Wharf in the seismic structure and performance design.

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Damage and erosion of sheet pile wharf (No.1 quay of Xiangma port)

Collapse of the corner of gravity wharf (-10m) (the 4th quay of Hitachi port, Ibaraki port)

Fig 2. The failure of the different types of wharf structures in the earthquake

Fig 3. Container crane derailment caused by the bending of railway on gravity quay-wall

2. Background and Development of the Revision of the Code

The structural design of Port Engineering in Japan has experienced one partial revision (1994) and three major revisions (1989, 1999 and 2007 respectively) from the outline of port engineering design, the design basis of port building structure (1967 Edition) to the compilation of technical specifications and interpretation of port facilities (hereinafter referred to as "specifications") in 1979. Among them, in 1978, Miyagi County earthquake, the next year, "code" preparation, followed by "Building Standards Law" part of the revision.

After the Hanshin earthquake in 1995, the law on special measures for earthquake disaster prevention was promulgated, which was based on the experience of the earthquake disaster, and the code was revised in 1999. In this revision, the performance-based design concept and the two-level seismic design method are introduced for the seismic design principle, and the regional seismic coefficient and importance coefficient are modified. The assessment method of seismic performance of harbor facilities under the level 2 earthquake is proposed, and the assessment method of sand liquefaction is modified accordingly.

After the 2004 Sino Vietnam earthquake in Xinxie County, in 2005 and 2006, the "strategy for promoting disaster prevention of the East China Sea earthquake" and "strategy for earthquake disaster prevention of the capital zhixia earthquake" were successively implemented, and then the "code" was revised in 2007. Different from the revision of previous specifications, the concept of performance design system is formally introduced in this edition, and the design method with failure rate, deformation and other performance indicators is introduced, and the evaluation and setting method of ground motion is greatly modified [6]. In the design principle, follow the international standard and adopt the reliability based design method. During the design service life of the structure, the load action corresponding to three different states of

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permanent action, variable action and sudden action shall be specified on the performance of the structure through applicability, reparability and safety, and the partial coefficient method shall be taken as the basic method of performance evaluation, as shown in Figure 5. In addition, the code cancels the original calculation method of determining the design earthquake degree by regional earthquake coefficient, foundation category coefficient and importance coefficient, and uses the acceleration time history response of ground motion to design and evaluate the seismic performance of the structure.

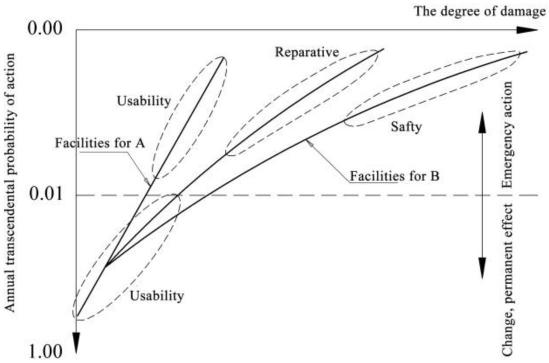

Fig 4. The concept and relationship of design condition and required performance

The current Japanese “technical specifications and interpretation of port facilities” has been revised from March 2012 to July 2014 after the 2011 East Japan earthquake. The code draws on the experience of many large-scale destructive earthquakes and the cutting-edge scientific research results of anti-seismic research of harbor facilities. On the basis of the concept of successive code revisions, combined with a series of laws and regulations, standards and specifications in the relevant fields of harbor engineering, it has been revised and modified for many times and gradually improved. In 2011, the East Japan earthquake caused a lot of functional damage to the harbor facilities and the wharf lost its operation function. However, on the other hand, the seismic reinforcement treatment has been carried out before the earthquake, as well as the newly-built harbor and wharf facilities designed according to the revised specifications, which have shown relatively superior seismic performance in the earthquake, as shown in Figure 5. The revision of the code has achieved good results in the practical test of the actual earthquake damage.

L wharf dislocation in batailang area after Hanshin earthquake in 1995

The N Wharf in the same area designed according to the revised specifications is in good condition after the 2011 East Japan earthquake

Fig 5. The comparison of the harbor structure seismic performance based on the revision of the Standard after the Hanshin earthquake disaster

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The revision of the code is mainly reflected in the improvement of the seismic design method, the rare role, the consideration method of high-strength strengthening structure and other disaster prevention and mitigation measures, as well as the evaluation of the residual bearing capacity of the structure, the introduction of regular maintenance and life cycle management and other aspects of the construction of the maintenance and management design method of the harbor facilities. This paper summarizes the background of the revision of the code, the correlation trend between the new and old codes, and the target planning.

Based on this, Japan's disaster prevention planning system, laws and regulations related to disaster countermeasures, and standards and specifications have been substantially enriched and strengthened, making its interpretation of disasters more timely, targeted and applicable. Therefore, the level by level understanding of the Japanese code and its revised contents will be helpful to promote the development of China's port engineering design code and the adaptability to the continuously expanding scale of hydraulic structures, and will also play a certain role in promoting the research of China's port seismic design methods.

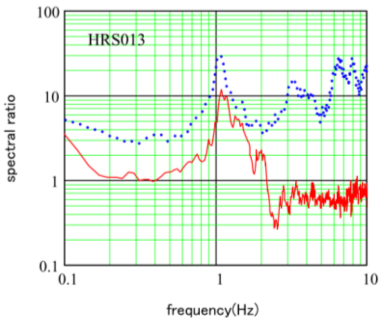
3. Main contents and Description of the Latest Revision of Technical Specifications for Port Facilities

In view of the survey results and experience summary of the 2011 East Japan earthquake, as well as the new progress and research results in the field of port engineering technology in recent years, the code was partially supplemented and revised from March 2012 to July 2014. It mainly includes:

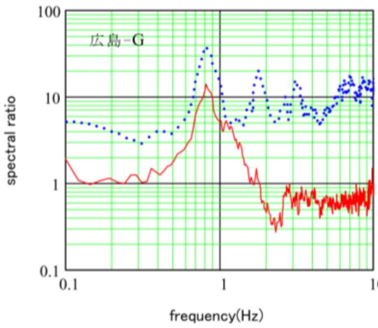
3.1. When Setting the Ground Motion, the Correction Method of Site Amplification Characteristic Is Added

The so-called correction method of the site amplification characteristics is mainly to estimate the site amplification characteristics by using the constant time (when there is no earthquake) fretting observation results [7] [8].

The so-called constant time fretting refers to the small foundation vibration which cannot be sensed in the state of no earthquake. The inherent characteristics of constant fretting are mostly in the form of surface waves, so by using the characteristics of surface waves, we can obtain effective information about the peak value of site amplification characteristics[9]. Figures 6-8 show the comparison between the observation results of the constant time fretting response spectrum and the site amplification characteristics. It can be seen from the figure that the two have the same frequency value at the peak of the response spectrum. By using this correlation, it is possible to estimate the amplification characteristics of the site through constant time fretting observation.



——Constant fretting H / V response spectrum-
Site amplification characteristics



——Constant fretting H / V response spectrum-
Site amplification characteristics

Fig 6. The comparison of the site amplification factors and microtremor H/V spectrum

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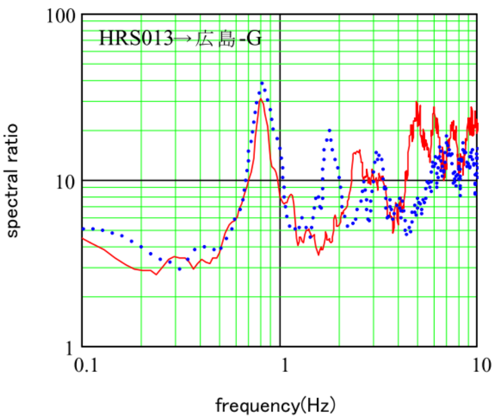
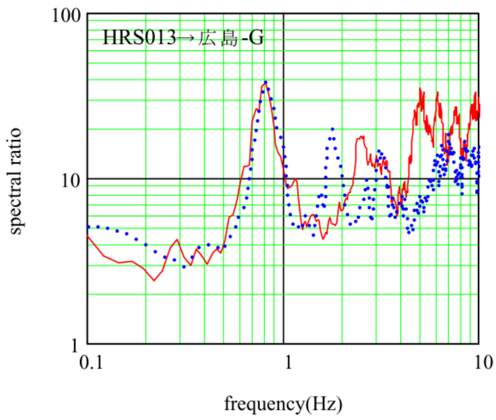


——Constant fretting H / V response spectrum-
Site amplification characteristics

Fig 7. Estimating the site amplification factors by using the microtremor H/V spectrum (no modification)



——Constant fretting H / V response spectrum-
Site amplification characteristics

Fig 8. Estimating the site amplification factors by using the microtremor H/V spectrum (modified)

In addition, the empirical method can be used, that is, the response spectrum of the site amplification characteristics of the strong earthquake observation points in the harbor and its surrounding areas can be modified, and the statistical analysis results can be used to estimate the site amplification characteristics of the harbor.

3.2. Modification of Calculation Method for Horizontal Seismic Coefficient of Different Wharf Structures

The calculation methods of design horizontal seismic coefficients for vertical sheet pile wharf, double sheet pile wharf and inserted large cylinder wharf are modified. This paper mainly supplements the calculation formulas of filter function, low reduction rate and characteristic value of design horizontal seismic coefficient considering frequency characteristics. Three different types of wharfs are similar in the formula structure. Taking the calculation of vertical sheet pile wharf as an example, the parameters can be calculated according to formula (1) - (5).

$$a(f) = \begin{cases} b & f \leq 1.5Hz \\ \frac{b}{1-\{g(f)\}^2+4.5g(f)i} & f > 1.5Hz \end{cases} \quad (1)$$

$$g(f) = 0.34(f - 1.5) \quad (2)$$

Value range of B value： $0.35H - 0.47 \leq b \leq 0.35H + 0.59$

Where, F: frequency (Hz); I: imaginary unit; H: wall height (m)

$$p = 0.39ln\left(S/\alpha_f\right) - 0.42 \quad (3)$$

$$\alpha_c = p \cdot \alpha_f \quad (4)$$

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Where, P: low reduction rate; s: the square root of the sum of the squares of the acceleration after filtering (cm/s^2); α_f: the maximum acceleration after filtering (cm/s^2); α_c:the maximum corrected acceleration (cm/s^2)

・Design horizontal seismic coefficient

$$k_h = 1.40(D_a/D_r)^{-0.86} \cdot \alpha_c/g + 0.06 \tag{5}$$

Where, k_h: design horizontal seismic coefficient; D_a:allowable deformation $(= 20cm)$; D_r: reference deformation $(= 10cm)$; g:Acceleration of gravity

3.3. Revision of Liquefaction Prediction and Determination Method

For the prediction and determination method of sand liquefaction [10-12], the influence of seismic waveform is considered, and the calculation formula of equivalent acceleration is modified. By using the response time history of the maximum shear stress of the foundation under the action of earthquake, the calculation and judgment of each soil layer are carried out. All parameters can be calculated according to formula (6) - (9).

$$\alpha_{eq} = 0.7 \cdot \tau_{max}/\sigma_v{}' \cdot g \cdot 1/c_\alpha \tag{6}$$

$$c_\alpha = 5^{-d_1} \cdot {n_{ef}}^{d_1} \tag{7}$$

$$d_1 = \begin{cases} 0.2 - 0.7D_r (D_r \geq 0.2/0.7) \\ 0 \qquad (D_r < 0.2/0.7) \end{cases} \tag{8}$$

$$D_r = 0.16[170N/(70 + \sigma_v{}')]^{1/2} \tag{9}$$

Where, α_{eq}: Equivalent acceleration (Gal); τ_{max}: Maximum shear stress (kN/m^2), g: Acceleration of gravity; c_α: Waveform correction factor; n_{ef}: Effective wave number. As shown in Figure 12, the maximum shear stress response time history is taken as 60% of the number of wave heads; N: Value of N; D_r: relative density $(D_r \leq 1.0)$; $\sigma_v{}'$: Effective upper load (kN/m^2)

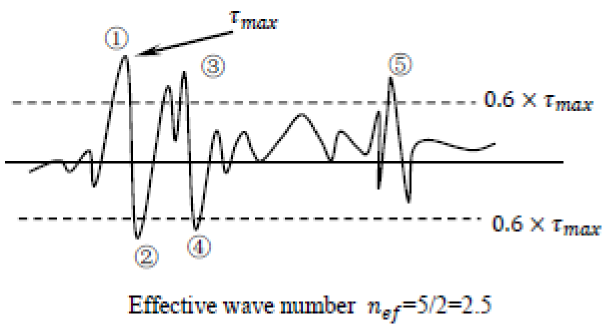

Fig 9. Definition of the effective waves number nef

3.4. Increase of Evaluation Method for Design Ground Motion of Trench Type Earthquake

In view of the investigation results, experience summary and relevant research results of the 2011 East Japan earthquake, the source characteristics and source parameter settings have been revised corresponding to the trench type earthquake [13] [14].

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For the trench type strong earthquake, the large-scale regional slip produced on the fault plane is different from that produced by the general strong ground motion, and there are certain differences in its seismic porter. Moreover, in the actual seismic wave observation of the East Japan earthquake, a large number of pulse waves with a period of 1-s are collected near the source. Therefore, in order to better reproduce the wave characteristics of the trench type earthquake, the SPGA (strong motion pulse generation area) focal model of strong earthquake artery impulse generation area is selected in the specification.

In addition to the above revisions, the parameters of the super large container ship and its corresponding container terminal, the required performance of the tsunami fortification and facilities, and the anti-impact design of the wave bank have been modified accordingly.

4. Development Trend and Existing Problems Analysis of Seismic Design of Port Engineering Structure in the Future

At present, China's port facilities design has initially formed a professional wharf construction technology with international leading or advanced level and relatively comprehensive system, and has been applied in many ports engineering construction at home and abroad. Under the guidance of China's "one belt and one way" initiative, the expansion of overseas markets has accelerated the integration of China's economy and the world economy, and the port engineering construction area has been expanding in the world. For the port engineering structure located in the strong earthquake distribution zone, the research of its aseismic design and the integration of the world's aseismic design standards have gradually become the focus and difficulty of the port engineering design. Moreover, with the rapid development of the world economy, the large-scale transportation of ships and the large-scale growth of port throughput, the construction of harbor engineering has been increasingly oriented to the deep water area and large-scale development [15]. Therefore, further research work is needed in performance design, earthquake prevention and mitigation, and structural analysis methods. At present, the aseismic design of Port Engineering in China is mainly based on the code for aseismic design of water transport engineering (JTS 146-2012) [16]. In view of the increasing number of overseas port projects in China, the above technical aspects are reflected in the standards and specifications of port engineering, which should be more targeted, practical and general. Therefore, the understanding of the standards and specifications of countries with rich experience in harbor engineering design, such as Japan, is of far-reaching significance for the development of seismic design of port engineering structures in the future, as well as to improve the competitiveness of port construction in China based on the world.

Based on the revision of technical specifications for port facilities in Japan and the current situation of port engineering construction in China, the development trend of seismic design for port engineering structures in the future is summarized as follows:

4.1. Seismic Design Method Based on Performance and Life Cycle

The life cycle of port engineering structure can be divided into four stages: planning and design, construction, operation and decommissioning [17]. The design method requires that the structural performance and cost of the whole life cycle should be considered from the planning and design stage, and the performance degradation of the structure in the service process should be considered. Through reasonable structural design and maintenance design, the whole life cycle cost of the engineering structure should be optimized, the serviceability of the structure should be improved, and the service cycle should be extended. From the perspective of the design method of the whole port engineering, the life cycle design method is another breakthrough in the design concept after the safety factor method and the limit state design method (bearing capacity limit state and normal use limit state) [18-20]. Based on the concept

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of performance design system, corresponding to the degree of allowable damage, Japanese code classifies the required performance into three aspects: usability, reparability and safety. As mentioned above, the function of the main wharf, i.e. the facilities to ensure the conveyor function of the emergency rescue materials after a major earthquake, should be set relatively small for the damage degree of the occasional disaster to ensure its usability; while for the facilities to ensure the minimum function is available for the occasional disaster, the allowable value of the damage degree can be set to a large value to ensure that it is not subject to fatal injury Security. Between the two facilities, that is, to ensure its restorability. Therefore, the required performance of terminal facilities can be integrated into the life cycle design method, so that they can learn from each other and complement each other in the performance design method.

The research on the life cycle design method of port engineering structure in China started from the project of "theoretical analysis and Research on the life cycle design method of Port Engineering" in 2008. At present, it is still in the stage of theoretical research. In some specific design methods, it needs to be further strengthened.

4.2. The Evaluation Method of the Rare Strong Earthquake of the Main Hub Port

There is no doubt that the main hub port plays an important role in the whole transportation network. In view of the occurrence of the 2011 East Japan earthquake and the massive paralysis of important port facilities, the prediction of the rare strong earthquake recurrence is reflected in part of the revision of the code. For the trench type earthquake, the strong ground motion pulse generation region source model (SPGA) can be selected as the source model corresponding to the waveform data and ground motion information [21-22]. This method needs to analyze and screen a large number of SPGA configurations based on a certain scale of historical seismic database. For example, if there is a huge earthquake in the South China Sea trough of Japan, in many analysis cases, it can be considered to integrate the ground motion distribution assumed by the Japanese cabinet office with all the ground motions, or to compare and select the ground motion distribution obtained by SPGA model with that assumed by the cabinet office, etc. This method can be used to evaluate the ground motion of the object area, but it needs the support of large-scale historical ground motion database [23]. Compared with Japan, there are still some deficiencies in the collection and arrangement of historical ground motion data and the statistical analysis and sharing of data in China, and the future research space needs to be further expanded.

4.3. Technical Innovation and Application Research of New Type Harbor Wharf Structure

With the large-scale transportation ships and the development of port engineering construction to the depth of the ocean, and for the functional Wharf under the sudden action of rare earthquake, tsunami and other natural disasters, its safety, usability, reparability and other functions are ensured, the traditional pile wharf, Gravity Caisson Wharf and other structural forms have gradually failed to meet the needs of future port engineering structures in service operation, performance design, disaster prevention and mitigation and other aspects of the demand. In addition to meeting the basic design and construction requirements, the new wharf structure also needs to introduce a new design concept in the aspects of improving the overall performance of the structure, reducing the construction difficulty and enhancing the bearing capacity of the structure, so as to inspire a new way of thinking in the design and construction, so that the new wharf structure can be better applied and promoted in the actual project. Therefore, the innovation and R & D of high-performance, diversified, scientific and practical new port structure and its composite structure will be the inevitable trend of future port engineering development and construction.

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4.4. Maintenance and Upgrading of Existing Harbor Facilities in Service for A Long Time

With the passage of time, the existing harbor facilities that have been in service for a long time have been unable to meet the rapid development of the whole port industry in terms of their functions of use and safety. Especially for the main wharf, it should not only meet the regular use function, but also bear the function of its transportation hub in case of disaster. Therefore, based on the concept of life cycle, the existing Wharfs in service for a long time or damaged wharfs should be maintained and nursed in a timely and active manner; for the existing harbor facilities that do not meet the performance requirements or the design requirements according to the current standards and specifications, necessary and reasonable renovation and upgrading should be carried out to ensure that they should be equipped with Required performance. Therefore, for the future development of port engineering, the maintenance and upgrading of existing harbor facilities that have been in service for a long time, especially in the aspect of earthquake resistance and disaster reduction, the design method and design concept are still a part that needs to be studied in depth.

4.5. Promotion and Construction of International Standard System for Seismic Design of Harbor Engineering and Breakthrough and R & D of Technical Bottleneck

With the acceleration of the integration of China's economy and the world's economy, the design and construction of China's harbor projects have stepped abroad, actively participating in the international market competition and seeking development with the world. Under the background of "one belt and one road", with the continuous expansion of overseas markets such as Southeast Asia, the port engineering construction area has been expanding in the world. For the engineering projects located in the strong earthquake distribution zone, the seismic design standards and codes of the United States, Europe and other countries or regions where the project is located are often involved. By referring to various standards and codes, combined with the local hydrogeological conditions, construction requirements and earthquake damage history, the complex engineering structure design and seismic analysis are carried out, and the reference in the seismic analysis is also required The number, model selection, load combination, etc. have strict review mechanism. Seismic design research has gradually become the focus and difficulty of port engineering design level, and also the main bottleneck of overseas project technology promotion. Therefore, it will be the key content of port engineering design and construction work in the future to know and define the important standards and specifications of all countries in the world, to build and promote the international standard system of anti-seismic design specifications of Port Engineering in China, to connect with the international technically, to break through the technical bottlenecks in overseas engineering projects, and to realize the improvement of transnational operation capacity.

5. Conclusion

The harbor construction of our country is in a period of rapid development. The understanding of the national standards, codes and the revised contents with advanced experience overseas has certain guiding significance for the development of the port engineering design codes of our country and the research of the port seismic design methods. In the future, the port construction will tend to be multi-functional and integrated. The research work in the whole life cycle of seismic design method, the maintenance and upgrading of existing port facilities, the evaluation method of rare strong earthquake ground motion of main wharf, the technical innovation and application of new wharf structure form, and the promotion and construction of international standard system of seismic design still need to be done In order to meet the

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needs of China and the world for high-quality and multi-functional ports and wharves, realize the diversified transportation network with ports and wharves as the hub, and comprehensively enhance China's comprehensive shipping strength based on the world.

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