Determination of Seismic Fortification Level of Offshore Platforms in China

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ABSTRACT :

The current seismic design code commonly used in the world is RP2A-WSD compiled by American Petroleum Institute, there is still no specific seismic design code for offshore platforms in China. In this paper, a brief introduction of RP2A-WSD code is given at first, and the comparison between the seismic fortification levels of RP2A-WSD and that of Chinese GB17503-1998 and GB50011-2001 suggests that the levels of Chinese Codes are overestimated. Secondly, the seismic damages and anti-seismic design requirements of offshore platforms are discussed in view of their structural characteristics. On the basis of the analysis above, summing up the factors, such as the seismic activity in the waters of China, structural characteristics of offshore platform, seismic design goal, and the seismic fortification experiences of related engineering, we recommend that the seismic fortification level of strength design take a return period of 200 years, and that of deformation design take a return period of 3000 years respectively for offshore platforms in China. Finally, the comparison with other Chinese Codes of related industries shows that the recommended fortification level is safe and rational.

KEYWORDS: Offshore Platform, Seismic Design, Seismic Fortification Level, Return Period

0 INTRODUCTION

Since the 80s of last century, the exploitation of ocean oil gained very great progress in China, Over 100 offshore oil platforms have been built in Bohai, Huanghai, East China Sea and South China sea, another 100 will be erected in the coming 5 years. The damage of offshore oil platforms may cause severe secondary disasters, and the seismicity in the seas of China is relatively high, thus, the seismic design problem of offshore platforms has attracted considerable attention (Lu Yuejun, et al, 2003).

Fixed platforms are mostly used in the exploitation of ocean oil in China, their life span is rather long, commonly is more than 15 years. During the life span the platform can not move, and must support some environmental loads, including wind, wave, current, ice, earthquake and so on. The structural damage will cause serious personnel casualty, equipment loss, oil production stop, and environmental pollution. In platform designing, earthquake load should be imposed on the platform as a separate environmental loading condition, other environmental loads should be combined in a manner consistent with the probability of their simultaneous occurrence during the loading condition being considered. And earthquake load is seriously destructive, and can not be predicted. Therefore, the seismic analysis must be taken into account in structural designing. No specific seismic design code has yet been drafted for offshore platforms in China because of insufficient knowledge on the seismic character of the sea areas. The current seismic design code commonly used in the world is RP2A-WSD compiled by American Petroleum Institute (American Petroleum Institute, 2002).

Seismic fortification is to provide resistance to earthquake for engineering structures. The following three factors should be taken into consideration in the determination of the seismic fortification of engineering structures, social economic level, seismic hazard and importance of structures. The key content of the seismic fortification is seismic level and grade (Xie Lili, et al, 1996). In this paper, a comparison between the seismic fortification levels of RP2A-WSD and that of Chinese GB17503-1998 and GB50011-2001 is carried out, and it is regard that the levels of Chinese Codes are overestimated. Summing up the factors, such as seismic activity in the seas of China, structural characteristics of offshore platforms, seismic design goal, and the seismic fortification experiences of related engineering, we recommend that the seismic fortification level takes a return period of 200 years for strength design, and 3000 years for deformation design respectively for offshore platforms in China. Finally, the comparison with other Chinese Codes of related industry shows that the recommended fortification level is safe and rational.

1. THE CURRENT SEISMIC DESIGN CODE OF OFFSHORE PLATFORM AND EXISTING PROBLEMS

1.1. The current seismic fortification code

There is no seismic design code of offshore platform in China at present. The GB17503-1998 <Specifications for Offshore Platform Engineering Geology Investigation> suggests that the levels of the strength and deformation design take 10% and 0.5% probabilities of exceedance in 50 years. The 10% and 0.5% probabilities of exceedance in 50 years correspond to a return period of 475 and 10000 years respectively. But this code does not give a corresponding interpretation of their items.

Based on the seismic activity and seismic risk map in the costal waters of the United States, RP2A-WSD is compiled by American Petroleum Institute (American Petroleum Institute, 2002). The code states that two levels of ground motion intensity due to moderate and rare intense earthquakes in the life span of offshore platform should be considered in strength design and deformation design respectively. The design seismic level meets the strength requirements, that is, to provide resistance to moderate earthquakes without significant structural damage, a recurrence interval of 200 years for permanent structures in Southern California is recommended. The rare intense earthquake is the input for deformation design, no life loss and significant environment pollution is allowed at this level, structural damage is likely to occur, but the provisions are intended to prevent collapse of the platform, the return period may be several hundred to a few thousand years. The first level provides the ground motion input for the elastic design of the structure, and the second level, if it is deemed necessary to analyze the structure for rare intense earthquakes, provides the ground motion input for the analysis.

1.2. Existing problems

The provisions and method of RP2A-WSD Code are used in seismic analysis of the platform, namely, strength design and deformation design are carried out respectively (Wang Zhongcang, 2005). But the seismic fortification levels are according to GB50011-2001 <Code for seismic design of buildings>(Ministry of Construction P. R. China, 2001) and GB17503-1998 <Specifications for offshore platform engineering geology investigation>. These Codes are inconsistent.

A comparison of seismicity is made between Southern California and Bohai Sea by Peng Yanju et al (2006), which shows that the earthquake number, strain energy release, and PGA in Southern California are all higher than that in Bohai and its adjacency. The oilfield PL19-3 is a joint venture project of China and the United States, and designed in light of API RP2A-WSD code. According to API RP2A-WSD and the Chinese Code GB17503-1998, Peng Yanju et al (2007) obtained the seismic design parameters at the oilfield site, the PGA at the strength design level and deformation design level is 252cm·s^{-2} and 570cm·s^{-2} respectively by the Chinese GB17503-1998, and that is 162cm·s^{-2} and 333cm·s^{-2} respectively by API RP2A-WSD code, the ratio is 1.55 and 1.71 times. Therefore, China is a developing country with limited finance and resources, there is no need to adopt a seismic fortification level of offshore platform higher than that in developed countries.

2. STRUCTURAL CHATACTERISTICS OF THE OFFSHORE PLATFORM AND ENGINEERING SEISMIC PROBLEMS

2.1. A brief introduction of the structure of offshore platform

The structural forms of fixed platform include jacket, gravity, tower, and so on. The jacket platform is the most popular structural form in the exploitation of ocean oil(gas), and consist of the following: redundant welded tubular space frame serves as the main structural element of the platform, transmitting lateral and vertical forces to the foundation, piles permanently anchor the platform to the ocean floor, and carry both lateral and vertical loads, a super structure providing deck space for supporting operational and other loads. The intrinsic period of the structure is 1 to 3s depending on its size, weight, piles deepness, and water depth.

2.2 Engineering seismological problems of the offshore platform

As for most other types of facilities, it is not warranted and not economical to design offshore platform to preclude any damage for the most severe earthquake ground shaking possible. The actual principle is intended to provide resistance to moderate earthquakes, which have a reasonable likelihood of not being exceeded during the life span of the platform. It is needed to constitute a scientific and reasonable seismic design code and determine seismic fortification level.

While designing offshore platform, earthquake forces are taken into account to ensure the structure at linear elasticity in the life. Once there are some structural members which are bended and destroyed, the structure is regarded as reaching the utmost carrying capacity and can not be used normally. According to the ponderance of the structural members in the whole structure, the destructive state of platform is divided into two ranks by Wei Wei (2004): (1) The non-importance destructive state, this is the utmost before the structure goes into plastic state, but the structure is still at linear elasticity. Hereon, the platform can still be used, or can be repaired. (2) The local collapse state, this state is at the utmost of carrying capacity, the structure or its members reach the biggest allowable carrying function. The platform cannot be used any further, some structural members or the whole structure undergo mortal deformation, but without collapsing. The study result provided a theoretical basis for the determination of seismic fortification goal.

The seismic influence on the platform structure is mostly brought by the base movement, to fulfill seismic analysis, some seismic parameters at the base site are required, including the peak values, response spectra, and time history of the ground motion. The particularity of engineering seismic problems of the offshore platform is the long period ground motion, the offshore platform is a long period structure, at the same time, the reciprocity of platform and water (appended mass) also makes the resonance period longer. Commonly, the majority of constructs and structures use the peak values of seismic acceleration as the index of seismic analysis, and the platform, which is long period structure, should use velocity or displacement, but the current seismic analysis of the platform still uses acceleration because of insufficiency of engineering seismic study. Lu Yuejun et al (2003) discussed some engineering seismic problems of platform in detail, including scenario earthquake, long period ground motion, and so on.

3. DETERMINATION OF SEISMIC FORTIFICATION LEVEL FOR LEVEL FOR OFFSHORE PLATFORM

3.1. Determination of design rule

Based on the analysis of engineering seismic problems of the offshore platform in above section, seismic fortification for platform may have an analogy with some special structure in land, such as TV transmission tower, oversize bridge, great dam and so on. Referring to the seismic fortification experiences of related engineering, the following factors should be taken into consideration in the determination of the seismic fortification of platform.

(1) To meet the Chinese and foreign current code

Presently, in order to fit to the developing trend of international anti-seismic technology, the seismic design thinking is transferring from safety factor to reliability design in China. So the seismic fortification level based on probability is needed to meet the demand of reliability design.

(2) Consideration of fortification classification and multiple-stage design

Reliability design makes the structure to meet the demand of specific ultimate state by controlling the major conditions. According to actual engineering structure design in China, the ultimate state may be divided into three states: serviceability limit, ultimate carrying capacity, and ultimate deformation. The engineering structure design is made according to carrying capacity for each state, and the seismic fortification is given based on the different ultimate carrying capacity. For example, GB50011-2001<Code for Seismic Design of Buildings> adopts three seismic fortification levels and two-stage design.

(3) Keep the consistency with the state policy of seismic fortification

The state seismic design policy restrains the fortification level. The ground motion parameters (e.g. peak acceleration and response spectrum) specified in the present codes such as GB50011-2001 <Code for Seismic Design of Buildings>, are all lower than observation values. Therefore the seismic fortification level for offshore platforms should not be too conservative, and there is no need to take a higher value than that in developed countries.

3.2 Determination of seismic fortification level for offshore platform

(1) Design reference period

Design reference period lies on the life span of facilities. Because the duration of exploitation of ocean oil(gas) is about 30 years, a suitable design reference period of offshore platform is 30 years.

(2) Seismic fortification goal

The destructive state of platform is divided into two ranks: the non-important destruction state and the local collapse state. Hereby, considering the existing design rule, the seismic fortification goal for offshore platform is determined according to two levels due to frequent and rare earthquakes during the life span. The frequent earthquake level meets the strength requirements, that is, to provide resistance to frequently encountered earthquakes without significant structural damage, the platform maintain serviceability, or can be repaired. The rare earthquake is the input for deformation design, structural damage is likely to occur, but the provisions are intended to prevent collapse of the whole structure, no life loss and significant environment pollution is allowed at this level.

(3) The frequent-earthquake level

The frequent earthquakes correspond to earthquake forces under serviceability limit design state. For common construct and structure (the class C), the design reference period is 50 years, the frequent earthquake level takes 63% probabilities of exceedance in 50 years, corresponding to a return period of 50 years. Offshore platform is an important engineering structure, consequently the seismic fortification level should be higher than that for common construct and structure. According to the recommended value for Southern California in RP2A-WSD, the strength design level for offshore platform is a return period of 200 years, corresponding to 14% probabilities of exceedance in 30 years. The intensity at frequent-earthquake level for common structures is 1/3 of medium earthquakes (return period 475 years). According to statistic of 128 results of seismic safety assessment throughout the whole country, earthquake forces at return period of 200 years is 2/3 of return period of 475 years, therefore, the frequent-earthquake level for offshore platform takes a return period of 200 years, which corresponds to 2 times the strength at the frequent-earthquake level for class C structures and is equivalent to that for class A structures.

(4) The rare intense earthquake level

The rare intense earthquakes correspond to earthquake forces in utmost deformation design. In the design reference period of platform, the structure suffers from such earthquake forces by accident, the structure is likely to incur the biggest deformation, but can keep overall stability without collapse. The level of rare intense earthquake takes 2～3% probability of exceedance in 50 years for class C structures, corresponding to a return period of 1500 to 2500 years, that for class A structures takes 2～3% in 100 years, corresponding to a return period of 3000 to 5000 years. Usually the design reference period of offshore platforms is 30 years, because the damage of platforms may cause great economic loss and environment pollution, it is appropriate that the deformation design level takes 1% in 30 years, corresponding to a return period of 3000, which is already higher than that for class A structures and approximates to the upper limit in RP2A-WSD.

According to the analysis above, and taking RP2A-WSD as a reference, it is safe and rational to take the earthquakes with a return period of 200 years and 3000 years for offshore platforms in China as the strength and deformation design level respectively.

4. A COMPARISON WITH RELATED CODES

4.1. A comparison to the codes of oil/gas and other chemical structures

Oil/gas and other chemical structures are large and complex engineering systems, including comprehensive station, pipeline, oil storage, chemical structure, and so on. In case of earthquake demolishment, the structural damage will cause serious economical loss and environmental pollution, so the seismic problems are taken seriously. Based on the structural characteristics and importance, oil/gas and other chemical structures are divided into three classes: A, B, and C; the offshore platform is affirmed as class A of the utmost importance. We recommend that the seismic fortification level of strength design takes a return period of 200 years, and that of deformation design takes a return period of 3000 years respectively, the return period is the longest in oil/gas and chemical industry. We may regard that the seismic fortification measures for offshore platforms are stricter, its seismic risk is smaller.

Table 1 The seismic fortification level for oil and gas structures

Class	Structure	Reference period(a)	Return period for frequent earthquakes (a)	Return period for rare intense earthquakes (a)
A	Offshore Platform	30	200	3000
B	Large comprehensive station, important section of oil &gas pipeline, large oil structure and important chemical structure	50	100	3000
		30	50	2500
C	Oil gas and other chemical structures besides Class A&B	50	50	2500
		30	30	1500

4.2. Comparison with seismic fortification levels of relevant industries

Because the seismic design idea varies in different industrial fields, it is obviously difficult to comprehensively compare the difference between their seismic levels. Therefore, only those industrial departments, which have the same seismic design idea and similar seismic fortification goal, are selected to compare; here we emphasize a comparison of the return period of rare earthquake between different structures. In order to rationally reflect the difference of seismic fortification for structures with different reference period and return period, we convert return period to probability of exceedance (P_T) in reference period, then (P_T) can indicate the relative seismic risk in the reference period.

Table 2 is the deformation design level of different structures. The data shows that the reference period of offshore platforms is relatively short, the probability of exceedance of rare earthquake takes 0.01 in the reference period. Its seismic level is just lower than that for nuclear power station, and matches up to that for the Three Gorge Dam. Therefore a return period of 3000 years of rare earthquake for offshore platform is safe.

Table 2 The deformation design level of different structures

Structure	Reference period(a)	Rare earthquake	
		Return period(a)	P_T
Offshore platform	30	3000	0.01
Nuclear plant	40	10000	0.004
Three Gorge Dam	100	10000	0.01
Hydraulic structures of Class A reserving water	100	5000	0.02
Buildings and Structures of Class A	100	3000～5000	0.02～0.03
Large-scale Bridge	100	3300	0.03

Television Tower of Class A	100	2000	0.05
Buildings and Structures of Class B	50	2500	0.02
Buildings and Structures of Class C	50	～2000	0.02～0.03
Hydraulic Structure of Class A without water	50	1000	0.05

5. SUMMARY

On the basis of seismic activity in the sea areas of China, structural characteristics of offshore platform, seismic design goal, and the seismic fortification experiences of related engineering, we recommend that the seismic fortification level of strength design takes a return period of 200 years, and that of deformation design takes a return period of 3000 years for offshore platforms in China.

The return periods recommend in this paper are only used in the comparison between Chinese related Codes, has not been applied in structural analysis of offshore platform, also the reliability analysis of the design has not been done for difference platform structures. There is still a long way to go before the constitution of seismic code for offshore platforms, and many researches should be done in future.

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