Seismic Response Spectrum of LNG Storage Tanks*

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Abstract: Up to now, in Mainland of China, there is no appropriate codes suitable for low temperature LNG storage tanks, though it could be referred to GB50191 - 93, GB50011 - 2001, SH3068 - 95 and etc. Both United States and Europe standards and codes can be, therefore, applied as references. As a project instance, an evaluation on seismic design requirement for Tangshan LNG project, Caofeidian Island, Bohai Bay, China is presented, showing that the definition of OBE (Operating Basis Earthquake) and SSE (Safe Shutdown Earthquake) appropriate for LNG project.

Key words: seismic assessment; LNG storage tanks; design spectrum
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1 Introduction

Nowadays typical LNG terminals have above ground storage tanks with capacities ranging from 160 000 m^3 to 180 000 m^3; capacities of 200 000 m^3 are under planning. In the case of a containment failure, the economic damage would be substantial and the danger to life, property and environment correspondingly great. Consequently, storage tanks for liquefied gases at low temperature require most advanced design and construction techniques to ensure that the potential risk involved is reduced to a minimum.

Large-scale LNG storage tanks have a fundamental natural period of about 2 to 3 Hz, depending on their shape and geometry, and are more or less within the range of maximum excitation of typical severe earthquakes. They will in fact be subjected to much stronger accelerations than the ground beneath them. In addition, the sloshing period of the liquid inside the tank depends on its actual content, and could vary in a relative large range. This increases also the complexity of the design. According to previous experience and historical accident records, earthquake is considered to be a determinant factor for the safety requirement of LNG storage tanks[1-2].

A seismic evaluation was carried out for an LNG terminal, in Caofeidian Island, Bohai Bay, China. The seismic response spectrum, as part of this study, is summarized in paper. The analysis in the paper is mostly complied with NFPA 59A, NEHRP FEMA450 and IBC 2006[3-5], and is also referred to EN1473, EUROCODE, CSA and national regulations and codes of mainland of China[6-8]. Up to now, in Mainland of China, there is no appropriate codes suitable for low temperature LNG storage tanks, though it could be referred to GB50191 - 93, GB50011 - 2001, SH3068 - 95 and etc. Both United States and Europe standards and codes can be, therefore, referred to. The difference is that in regional map for spectral parameters, the defined value of probability of exceedance, and particular design concept/method.

This analysis is major based on US codes, considering that a) there are some updates in US codes based on research after the earthquakes in Loma Prieta (1989, M7.0) and Northridge (1994, M6.7), and b) the existing attenuation relationship of spectral seismic parameters, applied in mainland of China, are derived from western and central United States Site Background[9-14].

2 Regional Tectonic

Late Quaternary deformation of continental Asia is distributed over a vast region, and includes a full spectrum of deformational styles and structural orientations.

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Much, if not all, of the deformation can be attributed to the collision and subsequent penetration of the Indian plate with respect to Eurasia. Himalayan Frontal Arc, is the consequence of such collision. The North-China block, is one the eldest continental tectonic which can be back to Archaean and early Proterozoic. Its evolvement includes three rough stages, i. e. base crystallization, covering development and crack expansion. From the Tertiary epoch, the tectonic of North-China plateau has no obvious changes; the principal compression stress is in NEE-SWW direction, almost horizontal, while the second stress is nearly vertical.

The studied LNG plant is located in the interface of Huangye concave and Chengning uplift, and this region is extension of an important active seismic fault belt (see Fig. 1).

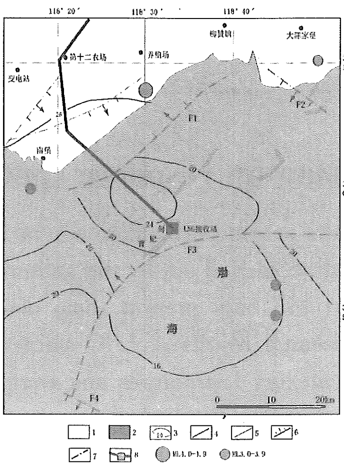

Fig. 1　Epicentre map in the proximate of Caofeidian Island
①Plain area; ②Sea area; ③Quaternary Contour (100m); ④Early Quaternary fault; ⑤Ex – Quaternary fault; ⑥Normal fault; ⑦Insidious fault; ⑧Pipeline and the LNG plant

The LNG plant is located in the edge of Bohai Bay, an area mostly belongs to shallow offshore plain and/or bottomland. There are four large scale faults exist in its proximate, all are in the orientation of NW to NE and are submerged in the seawater. They are, Laobao Fault (F1), Paogezhuang Fault (F2), Shabei Fault (F3) and Shanan Fault (F4). Among them, the Shabei fault is the closest one to the site. However, the site borehole logs show that the Quaternary stratum is basically continuous and no obvious large faults were identified, which implies that the chance of strong earthquakes particularly for this site is small.

The seismic activity in the proximity of the studied LNG plant is relatively weak in the past, as there are no historical earthquake record of MI > 4. 9. After years of 1970, there are total 39 earthquake records of MI 1. 0 ~ 4. 9, among which, 4 in a range of MI 3. 0 ~ 3. 9 and 8 in MI 4. 0 ~ 4. 9. Small earthquakes were unevenly distributed in the proximate of the site, relatively more in the north-western and south-eastern areas.

3　Seismic Design Objectives

The objective of seismic design for building structures, in mainland of China, could be described as "less damage under common earthquake, repairable under medium earthquake and sustainable under sever earthquake". In technical language, when the first level earthquake (probability exceedance is of 63% for a 50 years occurrence period) is met, the structures should remain operable. The structures could be designed in an elastic response spectral range with an elastic analysis. When the second level earthquake (probability exceedance is of 63% for a 50 years occurrence period) is met, the structures are under inelastic range. However, this inelastic deformation and/or structural damage should be controlled in a repairable level. For the third level earthquake (2% ~ 3% for 50 years), a large inelastic deformation of the structures is allowable but the structure should be still under control to avoid completely collapse.

Regarding to the design for LNG facilities, its combustible, explosive and corrosive natures and the sever consequence of its leakage should also be considered. Further to that the impacts to the surrounding population, economy, and transportation network in the event of a catastrophic event are also important factors. The above mentioned objective is, therefore, considered not be adequate for a LNG project. According to NFPA 59A[1], seismic category I components and structures should remain operable when under or after an OBE, and in fact this OBE level is approximately same to the second earthquake level of China standard. When a SSE is met, seismic category I components and structures could be designed in the inelastic range. The primary facilities could be safe shutdown during and after SSE.

4　Seismic Response Spectrum

Peak horizontal ground acceleration on bedrock on the study site is summarized in Table 1.

Tab. 1　Peak ground acceleration value based on bedrock (gal)

Probability of exceedance	50 years 10%	50 years 2%	100 years 1%
PGA	143. 6	262. 2	382. 2

The design response spectrum under OBE, for probability of exceedance of 10% , in an average 50 years occurrence period, is shown in Figure 2. The 5% damped design response spectrum under SSE (for an average 2 475 and 5 000 occurrence period), corresponding to probability of exceedance of 2% and 1% respectively, in an average 50 years occurrence period, are shown in figure 3 and 4. In Figure 5, the spectrums derived from GB50011 - 2001 are presented for comparison. One can find the major difference is in the range of long period.

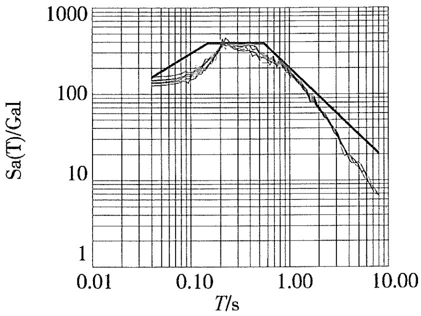

Fig. 2 Seismic response spectrum and design response spectrum, (50 years, 10%)

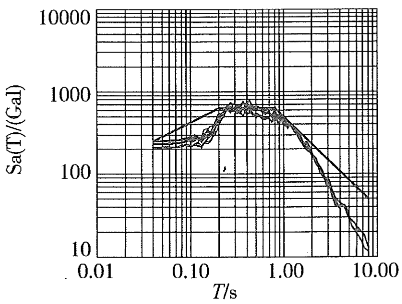

Fig. 3 Seismic response spectrum and design response spectrum, (50 years, 2%).

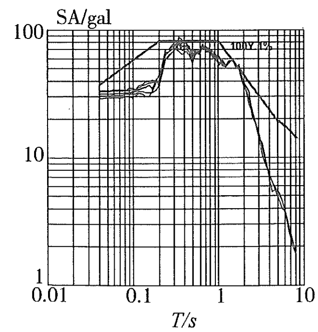

Fig. 4 Seismic response spectrum and design response spectrum, (50 years, 1%).

For easy reference, seismic spectral dynamic parameters are listed in Table 2.

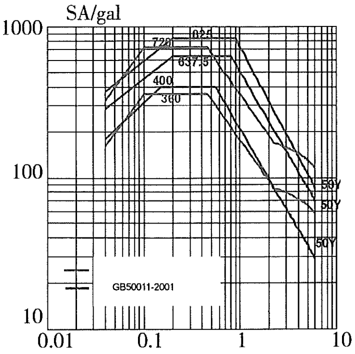

Fig. 5 Comparison of design response spectrum and ones derived from GB50011 - 2001

Tab. 2 Peak horizontal ground acceleration and parameters of design spectrum

Probability of exeedance	Amax /gal	T1 /s	T2 /s	β_m	γ
50years 10%	160	0. 15	0. 55	2. 5	1. 1
50years 2%	255	0. 2	0. 80	2. 5	1. 1
50years 1%	330	0. 2	0. 9	2. 5	1. 2

5 Discussion on response spectrum

Because the seismic evaluation works in mainland of China should be carried out by the authorized institutes, this report will only present some discussions on the updated research results of LNG storage tanks and other seismic category I structures and components.

5. 1 The attenuation relationship

It is a crucial procedure for setting up the attenuation relationship for seismic spectral parameters. Usually, this relationship is quite localized and major derived from the attenuation relationship of a selected reference district. This is based on a fundamental assumption that the attenuation relationship of the intensity in different areas and all spectral parameters follows similar laws. Refer to the study of Yu Yanxiang[14], up to now, most internal site seismic hazard evaluation works are still based directly on the attenuation relationship derived by Huo Junrong, which is actually the relationship of site intensity to the spectral parametric attenuation relationship of Western United States. However, there are some two extra points should be clarified: (a) the records of sever earthquakes used by Huo Junrong were before 1996 and (b) The attenuation of accelerator spectrum data recorded by the old simulated earthquake recorder is not reliable in the long response period range (T > =3s). In fact, the recorded accelerator spectrum drops too quickly in the long response period, even faster then the one in low period, which does not consist with modern observation of strong earthquakes.

5.2 Differences of design spectrum based on different codes

As per ASCE 7, if the proposed storage tanks are not founded on Foundation Class A or B as FEMA[4], shear wave velocity distribution of corresponding soil strata should be measures through boreholes, thus the response characteristic could be evaluated. However, if the above mentioned data is absent, according to FEMA[4] or IBC 2006[5], spectral response acceleration values, corresponding to T = 0.2s and 1.0s, should be obtained from regional maximum considered earthquake (MCE) ground motion map, and then T0 and Ts could be determined. Then according to the classification of the site soil should also be considered. In addition TL can be determined from another regional spectral parameters map particular for long period.

In mainland of China, PGA and seismic natural period group can be determined from the nation published spectral parameters map. The site period will then be obtained from this natural period group and the site condition.

Seismic acceleration response curves versus period, derived from FEMA[4] and GB50011 - 2001[13], are presented in Figures 6 and 7, respectively. The difference in the long period range is obvious, although in GB 50011 - 2001[13], some improvement had been already made.

Furthermore, compared to the European codes, the width of the upper platform (0.1s ~ Tg) in China is narrower than in Europe. When the period is lager than Tg, the curve drops faster than one in Europe codes. As a consequence, for stiff structures with short period, seismic load with Chinese Codes should be relatively higher[11-13]; while for the structures with medium or long period, the seismic load with Chinese codes would be relatively smaller.

As a summarization here, in Figure 5, it is shown that the design spectrum is generally lower than the spectrum derived from GB50011 - 2001 in the range of long period[13]. The possible reasons have been discussed this section.

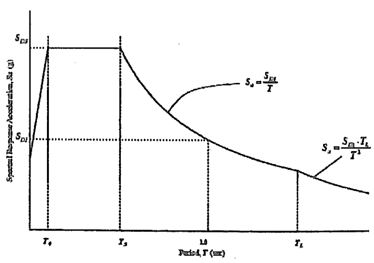

Fig. 6　Diagram of response spectrum, FEMA 450.

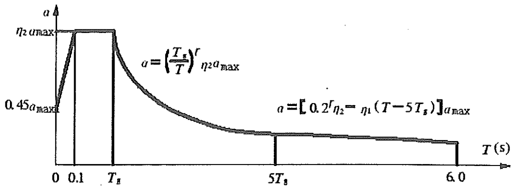

Fig. 7　Diagram of response spectrum, GB50011 - 2001

For structures of LNG storage tanks, the natural period could be relatively long due liquid sloshing, the response spectrum in the range of long to very long period is quite crucial to the design. From the view of safety, based on the existing design spectrum provided, the factor of safety in this long period should be increased. Otherwise, further study on this feature should better be implemented.

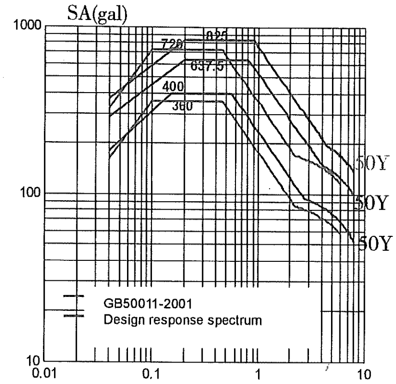

Fig. 8　Calculated design response spectrum.

6 Conclusion

Considering the characteristics of the possible structural natural period and the sloshing period of the liquid, there might be a risk in the range of long to very long period (T = 8 ~ 9s, for sloshing design), for the Code Spectrum could be lower than expected. The recommendation is that the amplificatory factor in the same range would be better increased otherwise a more detailed study should better be conducted. In Figure 8, the design response spectrum for studied LNG site, is recommended as appropriate.

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LNG储气罐的地震设计反应谱

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摘 要：对于液化天然气储罐，关注的重点往往是安全性与经济考量之间的怎样取得一个平衡，就大陆的石化工程而言，依据怎样的标准既满足社会对工程安全的期待值，又符合液化天然气储罐的结构特点和场地特征，一直是个重要的课题。重点介绍了对于液化天然气储罐这类结构的在设计中的运行基准地震水平（OBE）和安全停机地震水平（SSE）的确定。以曹妃店岛的LNG项目为例，介绍了液化天然气储罐所采用的地震设计反应谱。

关键词：地震评估；液化天然气储罐；地震设计反应谱
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