Building and earthquake resistance

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Abstract

According to statistics, more than 40% of the world's super-tall buildings are located in China. The performance of long-period ultra-high structure under ground motion with long-period components has attracted extensive attention of scholars, and some research results have been written into the specification document. However, the comparison of these research results in application is a subject to be studied. In view of the deficiency of long period response spectrum comparison study, I choose two typical engineering structures as research objects. The time-history analysis of the long period ground motion records in hanchuan earthquake and the big earthquake in eastern Japan was carried out, and the response spectrum method was calculated by the standard response spectra of China, Japan and the United States and the suggested design spectra of the related researches. By comparing the difference of response spectrum algorithm, the stability of the algorithm and the difference of the algorithm, six structural macroscopic indexes are studied to evaluate the reliability of the long-period seismic design spectrum.

Keywords

Super tall building;Long period of ground motion;Response spectrum method.

1. Introduction

Along with the development of social economy and technology, both at home and abroad high-rise buildings emerge in endlessly, in accordance with the relevant statistics, as of December 2, 2017, the world has built more than 200 m or more tall building a total of 1407 seats, including a total of 602 in China, the proportion of 42.8070, from quantity, high-rise buildings in our country present situation and growth is very fast. At present, there are a total of 298 super high-rise buildings under construction or roof sealing (including building roof sealing and structure roof sealing) in China, typical representatives include wuhan Greenland center (636m), shenyang baoleng global financial center (568m), tianjin chow tai fou financial center (530m) and so on. It is worth mentioning that a total of 128 super-tall buildings are scheduled to be completed in 2018. It is expected that the proportion of super-tall buildings in China will further increase in the future. In terms of building height, China occupies nine of the top 20 places in the list of the world's completed super-tall buildings, and the threshold of China's completed super-tall buildings reaches more than 430 meters[1]. According to the statistical data, the height of China's built super-tall buildings in the range of $400 \leq H < 500$ accounts for 83.3% of the global data. On the one hand, it indicates that China is at the international leading level in the engineering practice of this height range.

2. The research background

2.1 The discovery of long periods of earthquakes.

China has also been rocked by earthquakes, which release huge amounts of energy and can wreak havoc. Yang gege et al. [2] sorted out the grading distribution of earthquake disasters of magnitude 5.0 and above since the founding of the People's Republic of China. Earthquake prone areas and economically underdeveloped areas are highly overlapping, and the super high-rise building is often built in areas with relatively prosperous economy, so whether away from the earthquake prone areas can be a good way to reduce the harm of the status of super high-rise buildings.

On October 28, 1981, up to a 8.4 magnitude earthquake struck Japan thick tail, to reduce the harm of human society, Japan or was established in 1982, the world's oldest earthquake research institute "disaster prevention surveys", officially opened the prelude of research on earthquake engineering, to rise to the level of science and technology of related research[3].

Generally, the construction of buildings will avoid the adverse geological conditions, such as seismic zones and faults, especially for super-tall buildings. However, the large rupture scale of large earthquake source leads to abundant low-frequency components of seismic waves, and the propagation attenuation of low-frequency seismic waves is much lower than that of high-frequency components. If the foundation of super-high-rise buildings is covered with soft soil layer or thick soil layer, the amplification effect may even be formed [4]. In 1952, an earthquake occurred in kern county, California, USA. The damage of the earthquake to the buildings of Los Angeles city, 150km away, was limited to buildings over 20m [3]. In 1954, two earthquakes of magnitude 7.1 and 6.8 occurred in Dixie valley and fairview valley in the United States in a short time, during which the underground pool of Sacramento city was damaged 300km away [3]. In 1957, a 7.5-magnitude earthquake occurred in Mexico City, 360km away from the epicenter. Due to the thick alluvial phase formed by volcanic ash accumulation, more than 1,000 houses were damaged[3]. In 1964, an earthquake occurred in shinkai city, Japan. The oil storage tanks in the city had a long period of oil storage, which was close to the frequency of the long-period components in the earthquake. [3] in the same year, an 8.4-magnitude earthquake occurred in prince William strait, Alaska, USA, which caused severe damage to some 30m to 50m houses in anchorage city 120km away [5]. In 1976, a 7.8-magnitude earthquake occurred in tangshan, China. In tianjin, 100km away, the damage of long-period industrial plants and chimneys was significantly higher than that of general low-rise civilian houses[3]. In 1977, buildings in Sofia were severely damaged by the 7.2-magnitude earthquake in Romania 45Okm away[6]. In 1983, a 7.7-magnitude earthquake occurred in the central sea of Japan, causing oil overflow in the oil tank in akita city and causing fire[5]. In 1985, an 8.1-magnitude earthquake occurred in Mexico City, 400km away from Mexico City, due to the magnification of seismic effect caused by the soft soil layer underneath, causing serious damage to some high-rise buildings [3,7]. In 1989, a magnitude 7 earthquake occurred in loma prieta, USA, which caused the east bridge of Oakland bay bridge to fall off and closed the bridge for about a month [8]. In 1994, a 7.3-magnitude earthquake occurred in the Taiwan strait, making residents living above 10 floors in Shanghai feel visibly shaken and unable to stand [9]. In 1995, a 7.2-magnitude earthquake occurred in kobe, Japan, causing the bolts of the dongkobe bridge to fall off[10]. In 1996, a 6.1-magnitude earthquake occurred in the yellow sea, causing five lightning detectors on the Oriental pearl tower in Shanghai to fall off [9]. In 2003, a magnitude-8 earthquake occurred in shishengchong, Japan, which caused oil storage tanks to overflow in the refinery located at tomabecechu, resulting in a fire[10]. In 2005, a magnitude 7 earthquake occurred in kyushu, Japan. In Shanghai, 930km away, some residents living above 15 floors felt the earthquake obviously[11]. In the 8.0 magnitude earthquake in hanchuan, sichuan province in 2008, the buildings of baoji city, 520km away from the epicenter, and xi 'an city, 700km away from the epicenter, were felt violently and showed large horizontal displacement, especially in high-rise buildings, and the filling walls of many high-rise buildings were damaged[12,13]. East Japan 9.0 earthquake in 2011, is 770 km from the epicentre of the Osaka city high-rise office building was acute, and 100 kilometers from the epicenter of high-rise structure seismic response is the same as the sendai, high-rise buildings shake the structures of intense and long lasting, cause serious damage, such as: condole top, accessory equipment damage, etc., and even parts of high-rise buildings shook as long as 10 minutes, making some residents have serious fear[14,15].

2.2 Research on long period structure design

With the rapid development of social economy and technology, global ultra-high buildings emerge in endlessly, in accordance with the relevant statistics, as of December 2, 2017, the world has built more than 200 m or more tall building a total of 1407 seats, including a total of 602 in China, the proportion of 42.8070, from quantity, high-rise buildings in our country present situation and growth is very fast. In the past decade, Chinese scholars have studied the response of super-tall structures to earthquakes rich in long-period components. This paper mainly discusses the difference between the influence of long period ground motion and ordinary ground motion on the structure from the source characteristics, the acquisition of ground motion data in site conditions, the response index of super high-rise structure, the characteristics of response spectrum, the requirements of engineering design.

In 2007, Yang dixiong[16]analyzed the influence of the direction of rupture, pulse effect and hanging wall effect of near-fault ground vibration on long-period buildings. The results show that the pulse effect is positively correlated with the initial period of the structure, especially in the long period structure. The directionality of near-fault ground motion rupture mainly affects seismic isolation buildings and large-span cable-stayed Bridges. In addition, the long period structure is very sensitive to the hanging wall effect.

In 2008, Cauzzi[17]and others using the broadband and digital earthquake from digital earthquake data and reliable long period ground motion records, found that based on displacement acceleration digital record of zero line correction and high-pass filtering process can lead to a conservative estimate, which is a kind of new to the long period ground motion prediction formula and used in the probabilistic seismic hazard analysis.

In 2009, Zhang Zhenxuan[18]ordinary seismic waves and three long-period seismic waves were analyzed the difference between the time and frequency characteristics, and by using the ANSYS software to study the seismic response of a high-rise building, draw the conclusion: high-rise buildings in long period ground motion under the action of a significant increase in displacement and internal force, displacement index difference is particularly prominent.

In 2009, Yang weilin[19]studied the vibration differences between deep and weak sites and bedrock sites based on the seismic records provided by the southeast strong earthquake center. It is pointed out in the literature that the existing design response spectrum cannot cover the response spectrum applicable to long-period structures on the deep soft soil site, so the displacement, velocity and acceleration of structures should be taken into consideration in the design of long-period structures.

In 2011, ya-yong wang about new specification for the adjustment of the design response spectrum to explain: due to the acceleration response spectrum in the long weeks period of decay rapidly, and the limitations of the strong earthquake meter band, lead to seismic response of long period structure is too small, can't afford to control function, thus improve the speed of response spectrum control and displacement control section[20]. In 2013, wang yayong elaborated on the minimum shear coefficient and discussed its relationship with other structural parameters. The design of high-rise structures under different circumstances is listed, and the response of the structures to wind load and earthquake is shown to be different. This paper analyzes the relationships among various parameters of a super high-rise building, and proves the necessity of the regulation of shear weight ratio in the code[21]. In 2017, wang yayong made a detailed explanation of the input ground vibration criteria stipulated in the seismic code, discussed the output results of time-history analysis, and evaluated the reliability of the output results based on actual projects. At the same time, two concepts, namely GPA of peak ground acceleration and EPA of effective peak acceleration, are discussed. It is proposed that seismic wave acceleration should be adjusted on the basis of effective peak acceleration, so that the results of time-history analysis and mode decomposition response spectrum method can be effectively compared[22].

In 2012, luo chiyu[23]used five seismic waves (including two long-period waves) to analyze the time history of poly business center. The results showed that, compared with short-period waves, long-period waves caused greater damage to the structure, especially to the shear wall and the bottom strengthening zone of the beam. In this paper, at least 3 natural waves are selected to simulate and design the envelop of super-tall structures.

In 2012, li[24]with a 32 layer shear wall structure as an example, the overall stiffness softening model is established and the bottom of the weak layer model, probes into the structure of the different period of nearly earthquake fault slip effect sensitivity, the conclusion slide flush effect amplifies the long-period deformation index of the structure, the characteristics in the yield strength of the structure of small and into a larger nonlinear deformation stage.

In 2013, wang[25]to study the long cycle of the structure of the kind of resonance and the transient effect phenomenon, through the comparative analysis excellent time frequency and energy distribution coefficient, it is concluded that the long period of time and frequency of seismic energy distribution characteristics, show that on the energy distribution, in the long period ground motion near the fault type pulse frequency is higher than remote terrestrial vibrations, but overall is still low frequency; The literature also proposed the concept of transient effect, that is, it is the inherent property of high frequency components of the ground motion, but the transient displacement caused by its action on the structure is not enough to damage the structure.

In 2014, zhang junwen[26]took a 68-story frame core tube as an example to analyze its response under the action of 7 normative response spectrum seismic waves and 7 long-period seismic waves. The results show that the maximum inter-layer displacement Angle of the structure is far different under the action of the two kinds of waves, and the average maximum inter-layer displacement Angle under the action of the 7 long period ground motions is 2.57 times that of the short period. Some stressed members are damaged under the action of long period ground motion, while the structure remains intact under the action of short period. The literature points out that it is difficult to evaluate the seismic performance of high-rise buildings if only the selected ground motions are provided according to the codes.

In 2014, jian-ping han[27]block in high-rise building for example, USES the wenchuan earthquake and the northeast earthquake ground motion records, abundant long cycle by using the elastic and elastic-plastic time history analysis, respectively, and the analysis results and the EICentro wave results comparison, the results show that structural maximum interlayer displacement Angle and maximum horizontal displacement index is sensitive to long period ground motion, thus put forward in the design of high-rise structure, pay attention to the adverse effect of long period ground motion for structure.

In 2015, based on an 80-storey building in shenzhen, xiao xiong[28]studied many factors affecting the seismic shear coefficient, and found that the base shear of the structure was negatively correlated with the periodic reduction coefficient, and the increase of damping ratio would slightly reduce the base shear. The literature also points out that different sites have a great impact on the base shear and displacement response of the structure, among which the base shear and displacement response of the type I site are only about half of that of the type IV site.

In 2015, liu bin[29]on the first three minimum seismic shear coefficient to make analysis and put forward the corresponding control method, and then by comparing the three structure models of seismic and collapse resistance, draws the following conclusions: restricted by the existing regulations adopted by the minimum shear coefficient, the structure design, the material consumption is larger, the bearing capacity of the component to reasonable use; The literature also compares the layout schemes of two kinds of internal support of shear wall, and the results indicate that the arrangement of internal support on the middle and upper shear wall of the structure can improve the collapse resistance of the structure.

In 2016, Chen lidong[30]studied the influence of Mw9.0 earthquake in eastern Japan on the long period characteristics of the distant site, and found that the duration of ground shaking increased with the increase of propagation distance. By comparing the seismic response of a frame-core tube structure model under long period ground motion and ordinary period ground motion, it is found that the inter-layer displacement Angle, base shear force, horizontal displacement and overturning moment of the structure under the action of the former are larger. By analyzing the relationship between the formations and the base shear force, the literature found that the influence of different formations on the base shear force could be reflected by the product of the response spectrum amplitude and the mass participation coefficient a of the formations.

In 2016, Liang Zhihao[31]a long-period seismic simulation shaking table test and finite element numerical simulation software, and the standard spectrum and the fitting spectrum and numerical simulation were analyzed, the results showed that: with general structure, the seismic dynamic response of the structure for a long period of time under the influence of structural natural vibration period is smaller; With the increase of the natural vibration period, the dynamic amplification coefficient of the first-order array decreases rapidly. It is considered that the value of dynamic amplification coefficient for long period period is too large.

In 2017, zhou jing[32]compared and analyzed two types of acceleration spectra, namely, absolute acceleration spectrum based on seismic inertial force and quasi-acceleration spectrum based on hysteretic restoring force. The results show that the results of using the absolute acceleration spectrum based on inertia force to analyze buildings with large damping ratio and long period are relatively conservative. The attenuation laws of the two kinds of acceleration spectra are different in the long period. The site conditions have obvious influence on the dynamic amplification coefficient of long period seismic spectrum, and different coefficients should be selected for different sites. When determining the damping correction coefficient, if the absolute acceleration spectrum is adopted, the result will be more conservative, in contrast, it is more appropriate to use displacement response spectrum or quasi acceleration spectrum.

In 2017, han jianping[33]took lanzhou honglou times square as an example to analyze its response under different ground motions, and obtained the conclusion that the structure meets the current code requirements under the ordinary earthquake. Compared with the ordinary ground motion excitation, the structure has a larger vertex displacement, and the inter-layer displacement Angle is much larger than the ordinary ground motion excitation, and exceeds the specification requirements. In this paper, it is proposed that the adverse response of long period earthquake to structure should be fully considered when designing and calculating the long period structure in the site with thick soil layer, if the surrounding geological structure may produce earthquake with large magnitude.

As the above scholars study, the main general rule is that the structural response under the action of long period earthquake is larger than the ordinary earthquake, and the structural response will also be affected by site conditions, structural characteristics and so on.

2.3 Seismic response spectra of different codes are compared

In 2005, Hu Xing etc.[34]the Chinese specification (GB50011-2001) and the European standard (EU8) comparison, found that Chinese specification in the frame beam shear resistance and cycle of earthquake action value be higher than 3 s, and for different shear span ratio of frame column shear resistance values are each are not identical, beam-column steel minimum reinforcement ratio values depending on the seismic grade and column type with high and low.

In 2006, li jie et al. [35]compared the seismic isolation ideas, design response spectra and design methods of China, Japan and the United States, and put forward Suggestions on the revision of the long period section of China's acceleration response spectrum through the vibration table test of a five-story steel structure isolation structure and time-history analysis.

In 2006, fan li et al.[36]made a comparison between the European code (eu8-2003) and the Chinese code (gb_50011-2001) and found that the overall level of designed earthquake effects in the two countries was similar, but the Chinese code was more strict in the goal of prevention. Since EC8 USES different performance coefficients and China's specification USES constant value coefficients, it is unreasonable that the reliability of ductile structure in China's specification is higher than that of brittle structure.

In 2008, yu zhan et al.[37]compared the values of platform segment, characteristic period and attenuation index in seismic design spectra of China, the United States and Europe, and the results showed that the values of acceleration response spectra of China (gb50011-2001) gradually approached and exceeded those of the United States (NEHRP2003) and Europe (eu8-2003 draft) as the period grew longer.

In 2011, sun yuping[38]compared the mechanical energy of Chinese and Japanese codes from the five aspects of seismic impact coefficient, horizontal seismic standard action, floor shear distribution, designed internal force and structural measures, and found that the structural period increased to a certain extent, and the seismic level set by Japanese codes would exceed that of Chinese codes.

In 2011, li hui, etc.[39]according to Chinese standard specification (GB_50011-2010) and Japan (BSL1981), the seismic code (IBC2009), European standards (EC8) of seismic action were compared with calculated value, and based on the bottom shear method of calculation of a reinforced concrete frame model, found at the bottom of the shear calculation result of The Three Kingdoms in the us and Europe, results similar to the four floor seismic force distribution, though Japan specification of interlayer, maximum displacement values, but its corresponding strictness is highest in the four countries.

It can be found that the existing standard comparative study is aimed at the system comparison, including seismic isolation measures, calculation values, structural reinforcement, index limits, etc., but for the long period, especially the basic period of the structure after 6s is a little less research, so it is necessary to use the actual example to make in-depth discussion.

3. Research objective and content

3.1 Research purpose

Many research literatures at home and abroad have involved the research on the influence of different types of long-period seismic waves on different structures and different indexes. These studies can be summarized as follows: the maximum structural response under the action of long-period seismic waves is larger than that under the action of ordinary seismic waves, and the structural response is also affected by site conditions and structural characteristics. Super-tall structures based on seismic response of different seismic design spectrum comparison research necessity can be summarized as: (1) the current domestic and foreign in view of the structure under the long-period seismic response characteristics of study more, and different response spectrum calculation also have certain research, the results of the evaluation indexes for long period structure, relatively few comparative study on the applicability of different algorithms; (2) there are few researches on the stability comparison of different algorithms for long-period structures under long-period ground motions. (3) in practical projects, due to different countries' inconsistent specifications, the theoretical models proposed by scholars are also not the same, the horizontal comparison of structural indicators based on different algorithms can provide reference samples for the revision of China's specifications.

Previous studies on the performance of long-period structures with different damping ratios under long-period ground motions have achieved certain results and accumulated relevant experience. On this basis, comparative studies are conducted based on different normative spectra and theoretical algorithms of scholars to achieve the following objectives:

(1) compare and analyze the calculated results of long-period structure indexes with different response spectra, discuss their applicability and sensitivity from both qualitative and quantitative aspects, focus on the comparison of the variation rules of results of various algorithms and the stability of their algorithms, and provide necessary data support for the theoretical research and engineering practice of this kind of structure design.

(2) the research[40]shows that the application and effect of energy dissipation and shock absorption device of super high-rise buildings are very good. In view of the promotion of energy dissipation and shock absorption measures at the present stage, this paper adds the comparison of algorithms with high damping ratio to discuss the application and engineering practice of different algorithms and provide reference opinions.

3.2 The research content

In order to study the difference and stability of response simulation of long-period structures under long-period ground motions under different algorithms, the following aspects are mainly completed:

(1) theoretical comparison: including reaction spectrum method, time history analysis method and other control methods, to introduce and compare, and study the theoretical basis, design concept and failure mechanism of different algorithms.

(2) establishment of finite element model: based on the statistical analysis of the structure height, two models at the typical height dividing line are selected. The research standard algorithm and scholar algorithm are converted into parameters to establish a unified premise for comparison. Collect and sort out the time history data of the great east Japan earthquake and hanchuan earthquake.

(3) comparison of results of various algorithms: mainly studied six indexes, changed input mode, damping ratio value and other parameters, calculated the model in this paper by using theories and time-history analysis methods proposed by various countries' norms and scholars, studied the applicability and stability of different algorithms and proposed engineering design Suggestions.

4. The summary of this chapter

The conclusion shows that super-tall buildings are developing rapidly in the world, and more than 40% of the buildings in the world are located in China. This is a big background of this research, which promotes the continuous innovation of China's structure in this field. With the structure of the long period in the long-period seismic performance under caused the related scholars both at home and abroad to discuss and put forward the related theory, some achievements in the normative documents, to choose the standard response spectrum to calculate the long period structure under the effect of long period ground motion response, and the structure of macro indicators contrast study is less, proved the necessity of the subject. By selecting typical practical projects as research objects and establishing a unified premise, the feasibility of comparing the performance of long-period structures under long-period ground motions is realized.

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