Comparison of seismic structure design in the world

Zedong Yang *

Civil Engineering, Zhengzhou University, Zhengzhou, China

* Corresponding Author Email: a1224403663@stu.zzu.edu.cn

Abstract. Aseismic performance is one of the important technical indexes of modern buildings, which has been written into the building codes in various countries. Aseismic structure design is to enhance the stability of the building structure, ensure the safety of the building when the earthquake disaster occurs, reduce the loss and casualties. Since ancient times, innovations have been made in the design of seismic structures worldwide, especially in areas with high earthquake incidence. It was found in the previous research that the calculation method and design of seismic structures in American and Chinese building codes are different. Based on the interest of aseismic design, this paper summarizes the traditional and new aseismic structures. This paper first introduces several commonly used aseismic structures, such as multi-storey masonry, frame and seismic wall construction. Then this paper introduces the characteristics and differences of aseismic structure design in different countries from the modern and ancient time dimensions. In the end, Finally, it is concluded that the seismic structures are different due to the differences of geography, culture and climate in various countries. We can learn from the seismic structure analysis of ancient buildings that Aseismic structure design does not have to resist earthquake, but can reduce the damage of earthquake to the building by reducing the seismic force of the building.

Keywords: Aseismic structure; seismic design; countries; tradition structure; new method

1. Introduction

Earthquake is a terrible natural disaster in the process of human reproduction and social development. Strong earthquakes often bring serious harm to social and economic development, human survival safety and social stability and social function with their unexpected abruptness and huge destructive power. According to the classification statistics of more than 130 earthquake disasters with large casualties in the world, more than 95% of the casualties are caused by the destruction and collapse of buildings and structures. Therefore, the key to avoid casualties is to carry out corresponding seismic fortification for various buildings and structures in accordance with the law, so that they are not damaged or collapsed in a destructive earthquake. Seismic reinforcement design and safety construction measures of building structures are very important in construction projects. Earthquake disaster defense is the defensive work that should be done before the earthquake. Earthquake damage defense mainly includes engineering defense measures and non-engineering defense measures, and engineering defense measures are the most important way to reduce earthquake disasters. Therefore, the seismic structure design is a very important part in the process of building design and construction, and the corresponding building code requirements are also relatively perfect.

In the design of steel structures, this paper learned about the differences in seismic codes between the United States and China, as well as the differences in seismic structure design of local buildings. Furthermore, it is found that the international seismic structure design has certain regionality and closure, and the different geographical conditions, building structures and other factors in different countries lead to different design specifications. By reviewing the relevant literature, this paper found that most professional papers focused on a seismic structure, the principle, application and improvement of certain specific aseismic structures have been elaborated by many scholars in papers and literature, in addition, aseismic design is an indispensable part in engineering practice. However, there is still a lack of horizontal comparison and longitudinal comparison on the time scale of seismic structure design in various countries. Especially for the analysis and research of the ancient seismic design, as well as the research of the difference of seismic structure design caused by regional differences.

Therefore, this paper hopes to draw some conclusions by comparing the gap of existing seismic structures in various countries, demonstrates the rationality of seismic design codes in various countries and to inspire the design and innovation of seismic structures in the future.

2. The importance of aseismic structure

Architecture not only provides people with a living environment, but also plays a very important role in improving people's living conditions. The quality of buildings is directly related to people's life safety. Only by ensuring the quality of buildings can people use them more safely and comfortably. Therefore, at present, most designers put the quality of the building in the first place, and the damage caused by earthquake to the building is very huge, and the earthquake for the current technology, was not be accurately predicted in advance. Based on this unknown situation, once an earthquake occurs, the damage to the building is very serious. Not only that, due to the development of modern economy, land resources are scarce, so in order to save land, today's buildings are mostly high-rise buildings, once the building collapse, will produce incalculable results. Therefore, aseismic design is very necessary in building structure, which not only enhances the aseismic ability of buildings, but also can further protect people's lives and property safety.

3. Aseismic structure

3.1. Multi-storey masonry construction

Multi-storey masonry construction is one of the most common and primitive seismic structures. The masonry (divided into non-reinforced masonry or reinforced masonry) seismic wall is used as aseismic structural system, among which the structural system with transverse wall bearing is more favorable. The bearing transverse wall is also used as the transverse aseismic wall, and the longitudinal self-bearing wall is used as the longitudinal aseismic wall. When necessary, the vertical and transverse wall can be mixed bearing. The advantage of this structure are Simple structure, convenient construction and available local materials. Which make the structure became one of the most widely used structural forms in Chinese housing structure. Commonly used in residential buildings. Office buildings, hospitals, teaching buildings and other civil and public buildings. However, this structural material is brittle and has low tensile and shear strength. Therefore, the ability to resist earthquakes of this structure is relatively poor, especially the damage of multi-storey masonry buildings without seismic design is more serious in earthquake.

3.2. Frame construction

Frame structure is a structural form composed of beams, columns, nodes and foundations. Beams and columns are connected by nodes to form a load-bearing structure and transfer the load to the foundation. According to the different construction methods, it can be divided into three kinds: site pouring type (most adopt), assembly type and assembly type. According to the frame structure composition, it can be divided into beam plate and beam-less. The type of beam plate is composed of beam, plate and column and widely used in multi-storey and high-rise buildings, is a typical frame structure form. The other type is composed of plates and columns. According to the frame, it can be divided into whole frame structure and inside frame structure. Whole frame structure of the building, the roof load is all borne by the frame, the outer wall only plays the role of enclosure. In addition, its integrity and shock resistance good, belongs to the pure frame. And the inner frame structure, also known as half frame structure. The load of the building and roof is borne by the frame and the external wall. When the house has few floors and the exterior wall is thick enough, the inner frame structure can be used. However, because the stiffness of the two materials is not coordinated, its integrity and overall stiffness are relatively poor, so it is not suitable for buildings with high seismic requirements.

This structure has many advantages. Firstly, flexible layout of the building, can form a larger space (such as shopping malls, restaurants, etc.), according to the production process and the requirements of the use of the building function can be more flexible layout of column net room, deep beam size and selected height. In addition, the facades are easy to handle. Secondly, the weight of the structure is light, and the cost is low in a certain height range. Thirdly, integrity and strength are relatively good. If it is planed properly, the structure can easily achieve a good seismic effect. At the same time, it also has many disadvantages. Firstly, its flexibility is large, the lateral stiffness is small, the horizontal displacement is large under the action of wind load, and the damage of non-structural members is serious under the action of earthquake. Therefore, the partition material that is light in weight and can withstand large deformation should be used. Secondly, in the area of high seismic intensity, due to the limitation of interlayer displacement and vertex displacement, it is difficult to meet the requirements when the building is high, or although it can meet the requirements, the beam and column section size is large, with more reinforcement, which is not economic. Finally, the construction is difficult. The structure of the beam-column joint is complex, which is more prominent in the prefabricated frame structure. In addition, the construction process needs to lift bricks, more times, but also affected by the construction environment.

3.3. Seismic wall construction

Seismic wall structure is a reinforced concrete shear wall structure that resists lateral force. It is a structural system composed of vertical and horizontal seismic walls. It can be a single structure composed of seismic walls, or it can resist lateral forces together with the frame to form a frame-shear wall structure. The solid belly cylinder in the cylinder structure is also composed of shear walls. Shear walls bear most of the horizontal forces, but not only shear or shear failure. In seismic walls with height ratio greater than 2, the failure is often controlled by bending failure.

From the material point of view, the bottom of the seismic wall structure is the concrete structure, the upper is the brick masonry structure, is the upper and lower two different properties of the mixed structure. Belongs to the top-heavy light, on the soft structure. The characteristic of seismic wall is good integrity, big lateral stiffness, small lateral displacement under horizontal force action. Meanwhile, because the structure does not have beam, column to wait, room interior is decorated more convenient, drawback is cannot provide big space building. Seismic wall under the horizontal action of lateral deformation is small, bearing capacity requirements are easy to meet, but because the distance between the seismic wall was not be too large, so the plane layout is not flexible enough. Seismic wall structure in the wall and floor composition of the force system, so the disadvantage is that the seismic wall cannot be dismantled or transformed, which means the household was not be transformed on the indoor layout. In addition, the structural cost of the seismic wall is high, the construction is complex, and the steel consumption is very large. Therefore, because of the restriction of the construction unit, the seismic design of the structure had to reduce the standard because of the cost. Finally, because the ability to bear vertical force, horizontal force are relatively large characteristics, lateral stiffness, so the use of seismic wall can be built higher than the frame structure, the number of floors of the building.

4. Traditional seismic structure

4.1. China

Bracket set refers to the transitional part between the building roof and column frame. Bracket is similar to the square pad. It has strong compression resistance. Bracket is located at the bottom of bracket. Set is a short wood with bow shape. Bracket set is placed on the bracket to support it. Bracket set is placed on the bracket to the outside and bracket set is placed on the bracket. When subjected to a large load, each component will have a small slip, and relative to concrete and other materials, wood material strength is low, especially in the transverse grain direction, wood strength is very low, under a certain load, the material will yield and appear plastic. Therefore, the whole bracket structure has the function of seismic absorption and energy consumption. The large volume and soft curves of the roof make it the most prominent image in Chinese architecture (Fig. 1). In addition to its beautiful curve and the symbolic significance of the feudal dynasty, it is also very beneficial for earthquake resistance. Compared with the internal structure of the house, the weight of the upper roof is much larger than the weight of the lower wooden frame, which can not only improve the overall stiffness of the roof, but also form a good constraint on the lower column frame, greatly improving the integrity and stability of the wooden structure, which plays a good role in earthquake resistance. Although the column frame design in ancient wooden structure is not as eye-catching as the big roof and bracket set, but their role in earthquake resistance should not be underestimated. This design can not only protect the effective protection of the column root from corrosion, but also make the column root under the action of seismic force, displacement, through this method of not passing the bending moment, can effectively consume the seismic force, protect the superstructure.

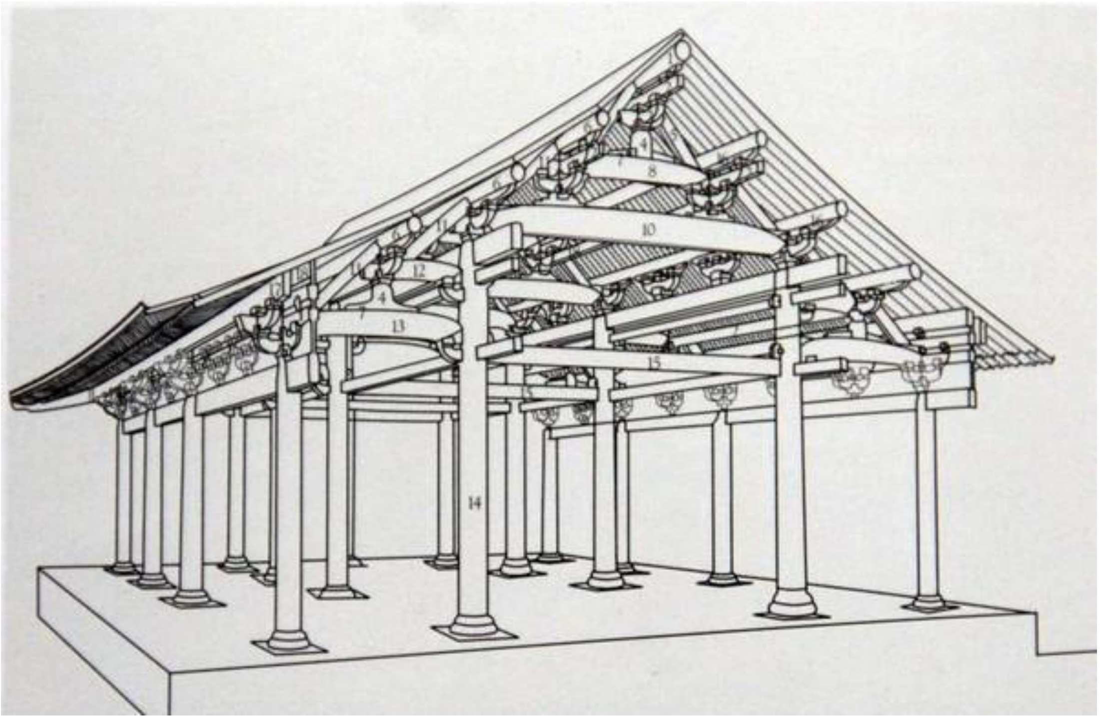

Fig 1. Structural drawings of ancient Chinese buildings.

4.2. Ancient Greek

Take the Parthenon as an example, this ancient temple has been survived for more than 2000 years. On the one hand, the Parthenon's location is excellent. It was built on limestone, which is more stiff and more rigid. It appears that the Parthenon’s foundations, built directly on solid rock, have helped it survive. However, this along does not explain how these temples have stood firm against earthquakes. The walls of the Parthenon are made of huge stone blocks with grooves on the sides, and the grooves of the adjacent blocks on the left and right are connected by iron blocks. The gaps are filled with lead to prevent the iron from rusting. The iron kept the stones in order and fixed the wall during the earthquake. In addition, the middle of the stone column is slotted, and the upper and lower adjacent stones are linked with wooden components. The wooden components act as the pillars' cartilage and hold the stones in place during an earthquake, keeping the pillars from collapsing.

5. New seismic structure

5.1. Seismic isolation technique

The concept of seismic isolation was first proposed in 1881 by Japan's Hehoe Zao. In the modern sense, the isolation technology began in the 1960s and 1970s. Generally, it is composed of isolation devices, dampers, ground micro vibration and wind response control devices, and complete insurance structures when necessary. Compared with the early isolation system, the performance is more reliable and the function is more perfect. The application of the rubber bearing isolation technology is earlier, has been widely used in Bridges in Europe in the 1950 s the epicenter, application in the construction began in the 1960 s, with laminated rubber pad, following the lead laminated rubber vibration isolation cushion, high damping rubber vibration isolation cushion, and various damper is developed, rubber bearing isolation has gradually become the mainstream of the isolation technology (Fig. 2). In this respect, Japan, the United States, Canada, France, New Zealand and other economically developed countries are in the leading position, and have built a large number of seismically isolated buildings. Some of these buildings have been tested by earthquakes and have shown good isolation effect. At present, seismic isolation technology is more and more accepted by engineers and society.

Fig 2. Shockproof rubber elastic pad.

5.2. Modern light timber construction

Light timber structure is the main structural form used in low - and multi-storey houses in North America, New Zealand and Japan. This type of structure is mainly based on reinforced concrete or masonry, and the superstructure is made of gauge timber and wood-based structural panels and other engineered wood products, with characteristics similar to box structures. The superstructure is connected to the foundation by anchor bolts. The roof and shear wall form the main lateral force resistance system of the structure. During the earthquake, the horizontal seismic force is transmitted to each shear wall through the transverse horizontal components, namely the floor and the roof, and the shear wall of each layer adds the seismic force to the bottom shear wall and transmits it to the foundation. To ensure the safety and reliability of this force transmission route, all components must have reliable stiffness and strength.

5.3. Application of new seismic structures

5.3.1. Britain

Britain is building a 'self-healing' house on a hillside in Greece. The Nano-Manufacturing Association in Leeds, UK, will spearhead the EU-funded project to develop special walls using nano polymeric particles. The idea is that when pressed by pressure during an earthquake, nano polymeric particles will flow into the cracks and harden, forming a solid material. In addition, the walls will be made of a unique load-bearing steel frame. The house is also equipped with wireless, battery-free sensors and radio frequency tags, which ensure it collects timely information about pressure, vibration, temperature and humidity. So that if something happens outside, the smart sensor network will immediately alert residents, giving them enough time to escape.

5.3.2. America

The United States has built a kind of earthquake-proof "ball building". The principle of this design is to install stainless steel ball bearings under each column or wall of the building. The ball bearings support the whole building, and the criss-cross steel beams can firmly fix the building with the foundation. When an earthquake occurs, the elastic steel beams stretch and stretch themselves, so that the building slides slightly back and forth on ball bearings, greatly reducing the force of the quake. The “floating foundation” of the Utah State Capitol is also an example of "shock-free design" in the United States. The "floating foundation" concept is to separate the surface building from the foundation and place the building on a network of 280 isolators made of laminated rubber to form its own foundation isolation system. In the event of an earthquake, these isolator bearings appear vertical rather than horizontal and allow the building to be gently shaken back and forth without moving the foundation of the building.

5.3.3. Japan

In an earthquake, slender tall buildings are more likely to be destroyed by an earthquake. The flexibility and height of high-rise buildings determine that their natural vibration frequency is low. If the natural vibration frequency is close to the vibration frequency of seismic waves, it is easy to lead to dangerous resonance. To avoid resonance, it is necessary to change the natural vibration frequency of the building at the right time. To this end, Japan developed active mass damping (TMD) and tuned mass damper (AMD) and other seismic technologies. The basic principle of TMD is to set a heavy hammer in the building which is about 1% of the total mass of the building. When the building is vibrated by earthquake or wind, the vibration energy will make the heavy hammer vibrate in the opposite direction, to reduce the vibration amplitude of the building. On the basis of TMD, AMD adds sensors and hydraulic actuator/servo motor motors to reduce the vibration amplitude of buildings and offset the deformation of buildings by using active mass damping. What’s more, the breakthrough of Japanese modern architecture in earthquake resistance is mainly reflected in the application of new materials. Some modern anti-seismic buildings use nickel-titanium memory alloys that can recover shape within a certain deformation range, and some use steel-fiber concrete that is more resistant to fatigue and impact than reinforced concrete. The "marriage" of fiber polyvinyl alcohol and cement gives birth to the high fiber cement composite material, which is both strong and ductile. And light steel materials made from hot-galvanized steel strips by cold-rolling technology, not only lighter, but can carry the same load more economically with the help of sophisticated computer stress analysis algorithms. The benefits of lightweight building materials go beyond that: lightweight, high-strength carbon fibers and carbon nanotubes can greatly increase the strength of buildings without adding much mass. Not only does the aerated concrete reduce the weight of the building, but the tiny air bubbles that fill the material also serve as heat and insulation. These new materials with light weight and high strength are widely used in the field of construction, which greatly reduces the total weight of buildings. Besides, lightweight not only helps make buildings more earthquake-resistant, but also reduces damage to people if materials fall.

6. Conclusion

With the progress and development of construction technology, as well as the depth of research on seismic structures, many new seismic structures have been invented and applied to engineering practice. It is worth mentioning that what has changed is not only the building materials and construction methods, but also the new ideas of building design combined with the seismic requirements. Through the horizontal comparison of seismic structures in different countries and the longitudinal comparison between ancient and modern, some conclusions are drawn in this paper. First, due to the geographical location, climate conditions, living habits and other factors, the design requirements of seismic structures and specific implementation methods are different in different countries. Which can be reflected in the differences of seismic design codes in different countries. In addition, the design ideas of ancient buildings may not be backward. Due to the lack of materials and equipment, ancient people had to use ingenious ways to improve the seismic performance of buildings, which will bring us a lot of inspiration. Nowadays, the seismic structure design no longer focuses on the study of higher strength materials, but from the structure, the pursuit of resolving and dispersing the seismic force to reduce the damage of the earthquake to the building. Therefore, in the future design of seismic structures, we can use more "force elimination structure", such as using the displacement within a reasonable range to reduce the seismic force and other measures, with more economic, higher strength as the goal, to design more practical seismic structures.

References

[1] Bai Jitao, Building aseismic technology and its development trend. Shanxi building, 2021, 47(05): 52-55.

[2] Duan Jingyi. Seismic technology of modern buildings in Japan. Nature Exploration, 2018(08):30-31.

[3] Luo Fuqiang Brief analysis of the importance of architectural design in building seismic design. Jiangxi building materials, 2021, (04): 65-69.

[4] Zhu Hailan. Analysis of the importance of seismic conceptual design in building structure design. Theoretical research on urban construction, 2018, (16):56.

[5] Guan Xiaodi. Analysis of seismic design of ancient buildings in China. Management and Technology of Small and Medium-sized Enterprises (Mid-day Issue), 2016, (05): 99-100.

[6] Liu Liangbin. Aseismic structure design in building structure design. Residential Facilities in China, 2022, (02):22-24.

[7] Wang Guoxin, Liang Shuxia, Giuliano F. Panza. Earthquake Inputs for Structural Aseismic Design in Cities. ASCE 12th Biennial International Conference on Engineering, Construction, and Operations in Challenging Environments.

[8] J. N. Yang, A. Danielians, S. C. Liu. Aseismic Hybrid Control Systems for Building Structures. Journal of Engineering Mechanics, 1991, issue 4.

[9] A.B.M. Saiful Islam; Mohammed Jameel; Md. Alhaz Uddin; Mohd Zamin Jumaat. Competent Building Elevation for Incorporating Base Isolation in Aseismic Structure. Procedia Engineering, Volumn50, 2012.

[10] Wang Guangyuan, Wang Wenquan. Fuzzy optimum design of aseismic structures. Earthquake Engineering and Structural Dynamics, 1985, issue 6:827-837.