

# Research on the Feasibility of Modular Residence Based on Post-earthquake Reconstruction

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**Abstract**—In recent years, earthquake disasters have occurred frequently. People not only lose their property, and their houses are also seriously damaged. Some natural disasters are foreseeable and can be prevented in advance, while earthquakes are basically unpredictable and have high breaking strength, so the post-earthquake reconstruction becomes the priority among priorities. China has made great achievements in post-earthquake reconstruction, but due to its particularity, there will inevitably be some problems. For example, the large-scale standardized design and construction used in post-disaster reconstruction is difficult to meet the individual needs of residents. Such problems need to be solved by people's efforts. This graduation project aims at the feasibility of modular residence after the earthquake, based on the analysis of cases of modular residences at home and abroad, it studies the design of modular residences, the impact of the earthquake on housing reconstruction, the basic needs of the people affected by the earthquake, and how to conduct modular residence design by meeting the special characteristics of post-earthquake residences. This project hopes that modular residences can be widely used in post-disaster reconstruction through the feasibility research on the post-earthquake modular residences.

**Keywords**—*earthquake disaster; reconstruction; modular*

## I. INTRODUCTION

In recent years, natural disasters occur frequently. As a common natural disaster, earthquakes are widely regarded as the most destructive one, and also one of the most active and common natural phenomena on the earth. Once it happens, it will cause serious damage to people's social life. National governments are actively looking for post-earthquake reconstruction methods that adapt to their national conditions. However, at present, international community tends to advocate the wooden structure and light steel structure building with high seismic performance. No matter where it is at home and abroad, modular buildings are more designed from the perspective of daily life. They do not have the particularity of post-earthquake buildings and are not widely used in post-earthquake reconstruction. According to the above analysis of the status quo of post-earthquake reconstruction, it is found that modular buildings of post-earthquake reconstruction is a new field that has not been deeply involved, and it cannot provide certain ideas for post-earthquake residence design.

## II. DEVELOPMENT STATUS OF REGIONAL RECONSTRUCTION AFTER THE EARTHQUAKE AND ITS IMPACT ON THE FEASIBILITY OF MODULARITY

### A. Development Status of Regional Reconstruction After the Earthquake

1) *The concept and development status of modular residences*: In the early 20th century, there was a building form of free combination of unit module, as it were the embryonic form of modular building. With the continuous development of building field, the term of modular building has gradually emerged. There are many definitions for the modular building. In the book *Building Construction* compiled by Department of Architecture of Nanjing Institute of Technology, it is called "Modular Assembled Building of Space System", which is a building form composed of modular components. Cen Weihong and Guo Ruilian from Nanjing University believed that the modular building was a kind of building type designed and constructed by using modular method under the guidance of modular thought, which reflected the application of a design and construction method. Modular buildings have obvious modular characteristics and a strong sense of order.<sup>1</sup> The modular residence in this paper refers to that the unit modules are prefabricated in the factory and transported to the site and assembled into the residence, which is fast, safe, stable, time-saving and labor-saving, and can meet different needs.

Modular buildings in foreign countries started earlier, and were more mature in development. Many architects have conducted in-depth research on the structural system and structural design of modular buildings, and have made a lot of theoretical and practical analysis and research on the connection of unit modules, so they have a lot of theoretical and practical foundation in modular buildings. Modular buildings can be predicted, mass produced, and installed quickly and conveniently, have lower cost than ordinary buildings and are popular among the public. In the United Kingdom, modular buildings have become the main construction mode, and are widely used in residences, offices, hotels and so on.

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<sup>1</sup> Journal: *The Modular Tendency in Contemporary Architecture Practice*

Modular buildings in China have been developing rapidly in recent years. Some real estate developers are also attempting to construct modular buildings by means of modular construction methods.

From an overall perspective, the modular building is a popular trend of construction industry at home and abroad and also represents a relatively advanced building type. It is widely used due to its quickness, safety and lower cost, and the public is gradually accepting this architectural form.

2) *The concept and development status of post-earthquake reconstruction:* Post-earthquake reconstruction refers to the behavior that the state or individual spontaneously organizes people and adopts different methods for earthquake relief to restore the normal life in the disaster area after the earthquake. It must quickly address the social life and family life problems for the affected people after the earthquake. However, reconstruction is not just building houses, and what is more important is to consider the problems existing in the urban structure before the earthquake and the problems that may occur after the earthquake. In the process of reconstruction, the overall planning of the city and buildings' earthquake resistance should be improved to ensure people's normal life in disaster area and avoid the original problems. There are mainly three stages in the post-earthquake reconstruction. The first stage is rapid resettlement, which is mainly to provide temporary shelters for the affected people in the first time after the earthquake, mostly in empty places like gymnasiums. The second stage is to restore the basic livelihood of the affected people, and provide temporary shelters for them, mainly including tents. The third stage is the recovery and reconstruction. The stage of reconstruction has enabled the affected people to gradually move to permanent housings and restore their pre-earthquake lives.

In China, the legal system for post-earthquake reconstruction is not very sound, and the research on post-earthquake residential buildings still stays at a groping state. At this stage, some experience still needs to be tested by practice.<sup>2</sup> Most of the post-earthquake temporary shelters are tents. Residences built with tents cannot meet the basic needs of people in terms of functions. The design of bathroom and kitchen is not very reasonable, and the tent density is high. It cannot be a good living environment for the affected people who were physically and psychologically hurt in the earthquake, and cannot provide long-term housings for them. To solve this problem, in addition to improving the functionality of temporary shelters, it is necessary to restore and rebuild the permanent housings as soon as possible.

In foreign countries, the legal system for post-earthquake reconstruction is relatively complete. In the United States, whenever there is an earthquake, the government will promulgate a relevant legal system. Therefore, the government has accumulated rich experience on the issues of

resettlement of the affected people and the earthquake-proof design after the earthquake. Japan also has a perfect post-earthquake reconstruction system. After the earthquake, Japan will make a general plan and budget for the affected areas, lay emphasis on the site selection of reconstruction and the seismic design of housings, and restore housings of the affected people as soon as possible.

As can be seen from the above, both China and foreign countries are actively exploring and studying the theoretical system of post-earthquake reconstruction. In practice, more attention is paid to the studies of temporary shelters. Although the environment for temporary shelters has been improved, it still fails to solve the fundamental problem, that is, the affected people need a stable permanent residence both physically and mentally. In the narrow temporary housing, the affected people have to live for months or even years, so what people should do is to solve the problem of permanent housings for the affected people as soon as possible.

#### *B. The Impact of Post-earthquake Regional Reconstruction on the Feasibility of Modularity*

##### *1) The impacts of human demand*

*a) Fast installation and construction:* After the earthquake, the whole society in the earthquake-stricken area actively participates in earthquake relief work, and provides temporary shelters for the affected people at the first time. These temporary shelters mainly include tents, portable dwellings, etc., which are densely distributed. So many households often share the bathroom and kitchen, and their life is very inconvenient. Moreover, after the earthquake, there will be disasters such as aftershocks, debris flow and landslides, and some infectious diseases. Tents and portable dwellings are simple in structure, and not very strong as living space. The effect of heat insulation and moisture-proof is also not ideal. It is not feasible for these structures to be long residences. In the construction of permanent housings, it is necessary to meet the need of quickness, minimize the time of the affected people living in temporary housings, and arrange them in permanent housings as soon as possible.

*b) Assurance of seismic coefficient:* Injured by the earthquake disaster, the affected people will be more sensitive than the ordinary people, and they will attach great importance to the ruggedness of building structures and put safety in the first place on the issue of residential reconstruction. The rebuilt house is located in the area where the earthquake has occurred. Earthquakes mainly occur in fixed seismic zones, and it is more likely that natural disasters such as earthquakes will occur again. Therefore, requirements for seismic performance of residences are strict, and building structures and materials with good seismic performance should be preferred.

*c) Lower costs:* As a result of the earthquake, people's property suffered extremely serious losses. In particular, residents in remote areas have a lower income,

<sup>2</sup> Paper: Research on Restorative Reconstruction of Residential Buildings after Earthquake.

coupled with losses caused by the earthquake, and a large part of the affected people could not afford the housing reconstruction. For example, during the post-disaster reconstruction of Fangbei Village in An County, Sichuan Province, household surveys revealed that villagers were still generally short of funds after government subsidies, loans and self-financing. Finally, a group of professors inspected Fangbei Village, and came up with the form of "one helping another". The government lent money to Fangbei villagers without interest to repair their houses. The loan amounts ranged from 10,000 yuan to 20,000 yuan and were paid off in equal amounts in five years. The loan agreement was signed on a door-to-door basis, which enabled the reconstruction of Fangbei Village to be continued.

*d) Catering to different needs:* The reconstruction of permanent residences can't be the same as the construction of temporary shelters. People need to ensure the basic functions of housings, such as heat preservation, sound insulation, moisture-proof, and also makes sure that housings are equipped with living room, bedroom, kitchen, toilet and other basic living units, to meet residents' living needs. In addition to basic living needs, the affected people also have other special needs. For example, the residents who have lost relatives in the earthquake should notice to communicate with the outside world, and people who have been physically injured and disabled in earthquakes need the barrier-free design and also consider whether the area has its own unique lifestyle. Therefore, the residence reconstruction after the earthquake should not only meet the basic living needs of the affected people, but also should be adjusted to achieve the personalized needs of permanent housing.

## 2) *The impact of natural environment*

*a) Damage to roads delays the relief work:* The earthquake itself and secondary disasters including debris flow and landslide caused by the earthquake have seriously damaged the traffic network. For example, the strong Wenchuan earthquake fractured roads and bridges. Buildings in the severely afflicted area were almost completely destroyed, and the road system was also affected by the rubble and other factors. In addition, the traffic system became extremely congested or even paralyzed due to the interference of pedestrians. What's worse, pedestrian interference made the traffic system extremely congested and even paralyzed. The paralysis of traffic network directly led to the failure of timely access of relief materials to disaster areas.

*b) Aftershocks have a certain impact on the transportation and construction of building materials:* After the earthquake, there will be many aftershocks. The study shows that aftershocks usually last for a few days, sometimes for a month or even years. Aftershocks will aggravate the damage to buildings, roads, natural environment and so on. Therefore, in the process of post-earthquake reconstruction, it is necessary to prevent

aftershocks from damaging both the transportation of building materials and later construction.

*c) Geological changes make the design of buildings adjusted accordingly:* In the course of post-earthquake reconstruction, geological changes should be taken into account in the design and construction of buildings. The earthquake will distort the underground structure, and change the density of stratum as well as the pressure of underground buildings. If there are problems in the design of waterproofing and drainage, it will have an impact on buildings, thereby reducing their service life.

*d) Damage to the natural environment reduces the available living space:* After the earthquake, buildings are damaged, and ground may also subside and crack. In China, earthquakes mainly damaged some remote urban and rural housings. This is because the buildings in these areas are not aseismic, but they are generally built in mountainous areas, so the damage to mountains aggravates the damage degree of these housings. And even the secondary disasters including debris flow and landslide enabled the buildings more to be damaged. There is less land suitable for living in mountainous areas. Moreover, damage to the mountain and collapse and fissure of the land also reduce the area of residential land after the earthquake.

*e) The site selection for post-earthquake reconstruction should be scientifically and rigorously analyzed:* The occurrence of an earthquake will cause destruction to the geology, so reconstruction should avoid earthquake fault zones. A second disaster may happen in the area where an earthquake has occurred, so there is a certain risk to conduct reconstruction work on the original site. However, it took a long time to form the original mode of social life before the earthquake, so moving rashly to another place is also inadvisable. Whether rebuilding on the original site or moving to a more suitable place to rebuild requires a scientific and rigorous analysis.

## III. STUDY ON THE FEASIBILITY OF MODULAR RESIDENCES FOR POST-EARTHQUAKE RECONSTRUCTION

### A. *Design Features of Modular Residential Quarters*

*1) Diversified functions:* In the process of residence reconstruction after the earthquake, designers should take into account the basic living needs and some special needs of the affected people, so the functions of residence must be diversified. Modular residences are composed of individual modules, which create diversified space to meet different needs of residents through rich combinations between individual modules. At the same time, residents can add or delete modules according to their own needs. It is difficult to make some spatial modifications to a traditional building after it has been designed and constructed by the designer. Because the traditional building is not very flexible in function, the designer will adopt mass design due to the

time limit in the design process, which is difficult to meet some special needs of residents. The living needs of the people affected by the earthquake will be very different from those of ordinary people, so modular residences with diversified space are more suitable for post-earthquake reconstruction.

2) *Low cost is more suitable:* People's property suffered great losses after the earthquake. The common housing forms in daily life are often too expensive for the affected people to afford. In terms of cost, the modular residence itself is mass produced, which directly reduces the production cost. In the production process of modules, the size, distance and other design dimensions of modules can be precisely controlled by computer machinery, which reduces unnecessary waste of materials and costs. Moreover, the modular residence has a relatively simple structure, and its construction and installation do not require professional workers, so that the affected people can directly participate in the process of residence reconstruction, which lowers labor costs and residence costs. Therefore, compared with traditional buildings, modular residences have more advantages in cost and are more suitable for post-earthquake reconstruction.

3) *Higher land use rate:* Due to the destruction of natural environment after the earthquake, people's habitable land area will be greatly reduced. Modular residences are more flexible in space, so there is less unnecessary waste in the interior space. Designing the required space according to the needs of different residents also reduces the waste of habitable land.

#### *B. Construction Characteristics of Modular Residential Quarters*

1) *Short construction period:* After the earthquake, the environment will be greatly affected, such as aftershocks and secondary disasters, road damage, ruins caused by collapsed buildings and so on. Common residences can only be constructed after all the unfavorable factors have been eliminated. During the period of ruins and roads cleaning, reconstruction cannot be carried out in time. However, for modular residences, people can use this time to prefabricate the required unit modules in the factory in advance, and transport them to the site for construction and assembly. All unit modules transported to the site are prefabricated, and workers only need to assemble them according to the drawings, which greatly shortens the construction period. The outdoor operation time of modular residential construction is reduced, so it is less affected by the weather, which also speeds up the construction progress to a certain extent.

2) *More precise construction:* The unit modules required for modular residences are more precise in design size due to the control of the machinery, greatly reducing

construction errors. Compared with the traditional construction technology, modular construction significantly enhances the construction quality of the building.

3) *Reduced amount of labor:* As far as modular residences are concerned, most of the work has been done in the factory, so there is not much need for workers in the field construction. The study shows that the total amount of labor used in modular residences can be reduced by 10-15% compared with large slab buildings, by 30-50% compared with brick buildings. The amount of labor used at the construction site is decreased, generally by more than half of that of large slab buildings<sup>3</sup>. However, a large number of buildings need to be rebuilt after the earthquake, so modular buildings with less amount of labor are more suitable for post-earthquake reconstruction compared with traditional buildings.

#### IV. CONCLUSION

Modular buildings have more advantages than ordinary buildings. As a building form, it has gradually appeared in people's daily life, but its function has limitations. In recent years, modular buildings have gradually been applied to post-earthquake reconstruction in the form of portable dwellings and container housings, and some problems in post-earthquake reconstruction have been solved. However, they are temporary buildings in functions, and cannot provide long-term shelter for the affected people. The modular residence studied in this paper is permanent residence, which can provide the affected people with the housing they need more quickly on the existing basis. Based on the analysis of the post-earthquake environmental conditions and human needs, this paper summarizes the problems that need to be addressed in post-earthquake reconstruction, and studies the characteristics of modular residences, so as to prove the feasibility of modular residences for post-earthquake reconstruction. This paper hopes that when facing the same situation in the future, more reasonable solutions can be put forward, so that modular residences can be more widely used in post-disaster reconstruction to solve some problems existing in post-earthquake residence reconstruction in China.

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