THE ARCHITECTURAL ANTI-SEISMIC DESIGN FOR URBAN RESIDENCES: THE TANGSHAN AND BEIJING(PEKING) EXPERIENCE

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SUMMARY

In the present housing construction in Tangshan and Beijin four types of building systems are commonly employed. They are comprehensively evaluated by the authors in relation to the existing conditions of China, from the viewpoints of earthquake r sistance, construction cost and period, labour and material con sumption, building industrialization, etc. Among these systems the "cast-in-situ concrete inside and brick outside" system, fu tioning as an appropriate technology, has enjoyed a rapid devel ment recently. In this paper the application of the system to multi-story housebuildings in Tangshan and Beijing is described and the important experience in house development in these two cities is summarized.

INTRODUCTION

Before the 1976 Tangshan earthquake, there were 1187 multi story brick buildings in Tangshan, 916 of which were built with brick-and-concrete structure(i.e. with brick walls and reinforc concrete components for stairs, floors and other items). 20% c the housebuildings in Tangshan were three or four story buildi constructed with such a structure(Ref.1). Little or no conside ation was given to the problem of earthquake resistance in the design and construction of all the pre-1976 structures there. The investigation made in the earthquake-stricken area showed that among the 1187 buildings the collapse ratio was 78.4%, lea ing only 0.3% with slight damage(Ref.2). However, there were still about 8% of multi-story brick buildings in the city, whic suffered serious damage, but escaped from entire destruction.

The 1976 Tangshan earthquake greatly added to the Chinese architect's knowledge of anti-seismic design and this led to various approaches for the improvement of urban residence.

SOME BACKGROUND INFORMATION FOR DEVELOPMENT IN TANGSHAN AND BEIJING

China is a country located in earthquake-prone areas. Ab 140 million people inhabit in 236 towns and cities. Half of these places are in the regions where earthquake of an intensi VII and above are likely to occur. Both Beijing and Tangshan situated in the area of intensity VIII. China is also a count with a large population. There has been a serious housing sho age in its cities. In view of this fact, it is required in th

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Sixth Five-Year Plan that 62 million square metres of apartments should be built annually in cities. The Beijing municipal government is to complete at least 4,000,000 square metres of apartments each year from now on. As a consequence, the Chinese architects are facing an arduous challenge of housing people in seismic regions, which is really a great job.

Known to all, China is also a developing country so that homes for urban dwellers have to be of low standard and low cost. It is expected that, by the end of this century, every household could have an apartment with 8 square metres of living space for each member, and this will double the present standard. Even so, we are still low at housing standard as compared with the industrialized countries.

China has long been deficient in the supply of steel, cement and wood. In 1982, the per capita possession volume of steel was less than 40kg; of cement, about 90kg. Clay brick has been the most widely used materials produced with a large amount of annual output of 150 billions, ranking first in the world. Under ordinary conditions of our country, the cost of materials for the average residential buildings constitutes about 60-70% of the total of the construction project, while the cost of labour only amounts for 20-30%. For this reason, it is more profitable for China to economize on building materials than on manpower. Considering the existing conditions of materials available in the country, we cannot but make the best of clay brick for anti-seismic housebuildings though we know very well the poor performance of brick during earthquake.

China is short of arable land, each person having 1.5mu(one hactare equals 15mu). The case is even worse in large cities' suburban areas. In Beijing, for example, the arable land for each farmer decreased to 1.2mu in 1979 from 2.5mu in 1959. In view of the severity of this fact, population control and protection of cultivated land are now considered two national policies that we should pay great attention to. So, while planning residential quarters or designing individual buildings, Chinese architects must make every effort to raise the utilization ratio of land as well as that of occupied area. Most pre-earthquake houses in Tangshan were of three stories. But according to the Tangshan rebuilding plans, new apartment buildings are chiefly of five stories with minor instances of six stories. In Beijing, the buildings in the 1960s were mostly of five story apartments. Furthermore, in recent years, six story apartment buildings have become the major ones with a few having the story number of 10 to 12 subsidiarily. Certainly, the increase in the number of stories will be unfavourable to the seismic load reduction, but it is quite helpful to thrifty use of land. For the same reason, the space between rows of buildings in north-south direction has been narrowed from 1.8 or 2.0(H refers to the height of the front building) in the 1950s to 1.6H commonly adopted nowadays in Beijing. The figure 1.6H is mainly governed by the sunlighting requirements, and at the same time, careful consideration is also given to earthquake resistance requirements, which means that a passage about five or six metres wide can be guaranteed during an intense earthquake, even when rubbles and fallen bricks lay in heaps that occupy an area as wide as two thirds of the building height.

In short, in designing houses for the people of seismic regions, we Chinese architects should pay much attention to the above factors so as to ensure that our designs should be closely related to the actual conditions of our country, and that the requirements of seismic resistance should mingle perfectly with functions, economy and aesthetics.

FOUR MAIN BUILDING SYSTEMS

After the earthquake in 1976, four main building systems for multi-story apartment buildings are adopted in Tangshan and Beijing, namely, brick-and-concrete combination structure designed earthquake resistant, "cast-in-situ concrete inside and brick outside", large prefabricated panel, and framed structure with light wall panels.

1. Brick-and-concrete Combination Structure System

As shown in all previous earthquake, unreinforced brick masonry structure is seismically vulnerable. However, we have come to the conclusion after investigation that the brick masonry structure is strong enough to resist the major shock of intensity X without collapse, as long as we can make it strong constructionally, rational in layout and good in workmanship(Ref.3,4).

Fig.1 gives a unit plan of a five story apartment that was widely used in Beijing before the Tangshan earthquake. In this kind of buildings, tie-beams were installed only at the second, fourth floor level and at roof level, but no construction column was built. They were similar in structure and layout to the buildings in Tangshan, almost all of which suffered pancake failures during the earthquake(Ref.3). Shown in Fig.2 is a unit plan that has been designed earthquake resistant structurally and architecturally on the basis of the lessons drawn from the Tangshan earthquake disaster. The improvements are as follows:

- --The layout of plan is made regular in shape; special attention is given to the enhancing of the earthquake resistant properties in longitudinal direction; inner longitudinal walls are thickened to 240mm; window and door openings are placed in proper positions; recessed balcony is no longer used, and the bearing walls are made in line.

- --Construction columns are installed inside the masonry walls and tie-beams on bearing walls at every floor(roof) level. From the Tangshan earthquake damage, it is known that the tie-beams should be placed at the floor(roof) levels(Fig.3). Tie-beams and construction columns ought to be monolithically cast together in order to tie up walls and floor(roof) structures securely.

- --A 90mm wide gap is left between precast floor(roof) slabs at the supporting positions which will be filled with concrete. This will make the hollow slabs and tie-beams connected as a whole. The ends of the slab hollows should be blocked with brocken bricks or something else, and it is proper to back them into hollows by about 40mm in order to form a series of keys, thus making the floor(roof) structures more substantial for shear(Fig.4).

- --A layer of concrete should be poured in-site at the top of the precast floor slabs, which can be used to serve as the wearing surface and also to intensify the integrity of the floor.

- --Usually, the cornices are designed of eaves projecting outward 300mm or 500mm. In order to prevent the precast eaves from falling down during earthquakes, the components should be tied up by a closure strip of site-cast concrete(Fig.3). The construction columns should extend continuously upward to the top of the parapet and be monolithic with the capping plate cast in site, only when the parapet wall higher than 500mm above roof slab surface is necessary.

- --An asphaltic dampproof coarse used very often for wall in the past should be replaced by a layer of mortar mixed with waterproof agent.

Surely, the combination system makes so much masonry and plastering work to be done by manual labour that may be considered backward in industrialization, but it is much cheaper because of its coinsiding with the level of production development of China today. Besides, its service functions are quite satisfactory and reliable in thermal and sound insulation and weather resistance. As a result, such seismically designed system has already been widely used both in Tangshan and Beijing, and in many other seismic regions.

2. Cast-in-situ Concrete Inside and Brick Outside System

This system adopted for multi-story housebuildings since 1977 in Beijing is that the inner bearing walls, 140mm, are constructed with site-cast concrete by means of the large sized steel formwork technique and the outer brick walls remain to be laid manually. Construction columns and tie-beams are constructed in the walls and perfectly combine to form a skeleton framework, greatly improving the ductility of brick masonry due to their composite behaviour.

There is another similar system called "concrete inside and panel outside", in which the outer claddings are precast panels. This system is more expensive than that of combination system. As it is the case in Beijing, the expense is raised by 30%. Consequently, this system gets less and less employed in Tangshan and Beijing, except in some high-rise housebuildings in Beijing. Fig.5 shows a floor plan of concrete inside and brick outside system built in Tangshan.

The concrete inside and brick outside system well integrates the traditional masonry technique, the cast-in-situ technique and prefabrication technique into one. This brings into full play the advantages of respective systems in different parts of the building. It can offer the following marked superiority over similar combination structure:

--Much better in earthquake resistance.

--The occupied space would be 3-5% increase because the inner concrete walls are much thinner than the brick ones, i.e. thinning from 270mm to 140mm.

--Masonry work would be reduced by 50-60%, so the mechanization degree can be raised to 50-60% from 30-40% when combination system is employed. Another advantage is that there is no need for plastering on the concrete walls. As a result of all above factors, the whole construction period can be shortened by 29%.

--The construction cost was becoming lower and lower. It is, now, as low as that of combination system. In Beijing, it is even 3-4% cheaper than that of combination system, if calculated on the basis of occupied area. However, the consumption of cement is higher than that of combination system by 1/3; the consumption of steel is a little increase.

3. Large Prefabricated Panel System

This building system has developed since 1959 in Beijing. It can shorten the construction period by about 30% in comparison with the combination system. In Beijing, the outer claddings are 280mm thick compound panels, composed of reinforced concrete and aerated concrete, while the inner bearing walls are merely 140mm thick solid R.C. panels. Fig.6 gives a unit plan of Beijing's multi-story large panel apartment houses. Since the Tangshan earthquake, much more consideration has been paid to the seismic properties of the system. Architects have tried to improve their design by laying the walls in line and adding right amount of steel bars to the joints between panels, thus ensuring the integrity of the building as a whole.

The panel system consumes more steel and cement of about 76% and 59% respectively higher than the combination system. In addition, a large sum of initial investment is needed to set up a permanent panel-precasting plant, and also the transport charge is much higher. All of these makes the cost of panel system become higher, saying about 32% higher than the combination system. Therefore, the panel system has been developed at a low speed. And it has been refused in reconstruction of Tangshan, also because much time is needed for construction of the plant itself.

4. A System of Framed Strucrure with Lightweight Wall Panels

This is a new industrialized building system first experimented in 1975 in Beijing. Both outer claddings and inner walls are made of light materials, that are mounted on the R.C. frames. Fig.7 shows a plan of the pilot building designed by the Architectural Department of Tsinghua University. The stair wells were engineered to resist horizontal quake forces and placed on both sides(north and south) so as to prevent torsion failure.

The chief feature of the system is lightness in building weight, about 500-800kg per square metre(of floor area), which is very helpful to reducing earthquake load. But, the steel consumption is about 80% higher than that of combination system, while the construction cost is 46% higher. As for insulation against noise, it is quite unsatisfactory. With all these problems, the system is still on experimental stage in Beijing, and it is rarely used in Tangshan.

Summarily, the advantages and disadvantages are listed in the following Chart 1, in which "I" denotes "best"; "IV", "worst". The functional qualities refer to the performances of the insulation from cold, heat and sound, and performance of watertightness, according to the evaluation from dwellers.

Chart 1

Systems	Total cost	Construction period	Steel	Consumption above ground level			Functional qualities
				Cement	Brick	Labour in site	
1 Brick combination	I	IV	I	I	IV	III	I
2 Conc. in. & brick out.	I	II	II	II	III	II	II
3 Large panel	III	I	III	IV	I	I	III
4 Framed str. with panels	IV	III	IV	III	I	IV	IV

Chart 2

Year	1977	1978	1979	1980	1981
Completed floor area (Kilometre^2)	38	96	378	567	693

It can be seen from Chart 1 that the comprehensive effects of concrete inside and brick outside system are quite good in economy and function. So, this system has been under a rapid development recently in Beijing. From Chart 2 it is known that the system is suitable to China's present situation and is considered an appropriate technology which confirms with the production level of Beijing's building industry. Accordingly, this system was awarded the prize of the Class I for outstanding results in scientific research by the State Building Construction Administration in 1981.

CONCLUSION

1 Architects should share responsibility with engineers for seismic resistance in housing construction. Without their cooperation, it would be impossible to meet the needs of the people for architectural functions, low level cost, aesthetics as well as structural earthquake resistance.

2 While designing houses for city people in the seismic regions, architects have to take into consideration the factors in the following aspects: architecture, structure, function and economy. Under China's present situation the standard and cost of most residences can only be kept at quite a low level.

3 China is a country rich in manpower, but poor in economy and technology. For such a country, it is of great significance to stress developing appropriate technology. When determing what kind of technology is suitable, we must do it in accordence with our own conditions so as to carve out a Chinese way of house production. That is, it is essential that we must not copy blindly the experience from the developed countries, in other words, not put undue stress on overall mechanization in building construction. Certainly, we value sophisticated technology provided it goes well with China's special conditions at present or in future. This kind of technology is the one we appreciate most.

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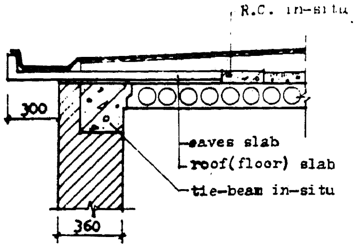

Fig.3

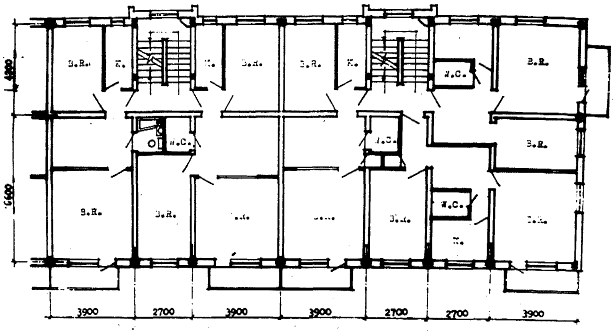

Fig.2 Brick-and-concrete combination apartment. Beijing, 1980

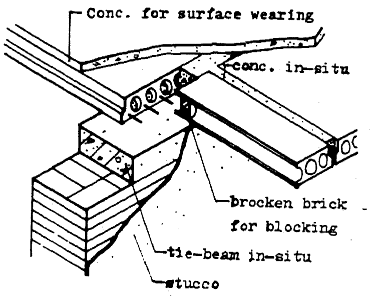

Fig.4

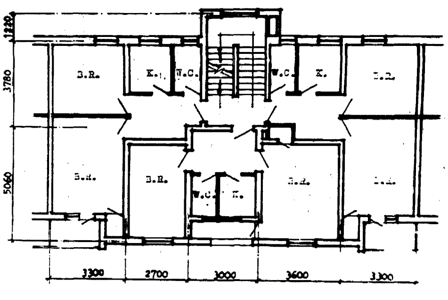

Fig.1 Brick-and-concrete combination apartment. Beijing, 1973

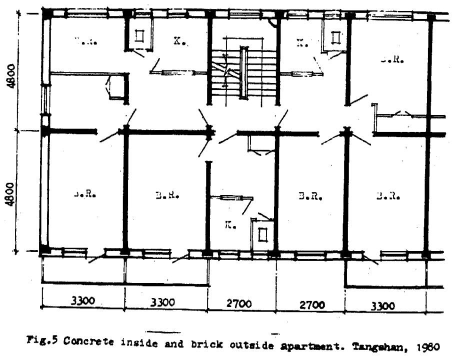

Fig.5 Concrete inside and brick outside apartment. Tangshan, 1980

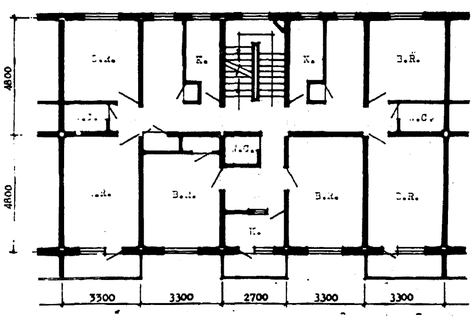

Fig.6 Large panel apartment. Beijing, 1977

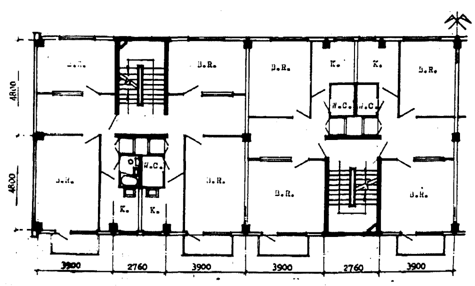

Fig.7 Framed structure with light panel apartment. Beijing, 1980