URBAN EARTHQUAKE DISASTER MITIGATION THROUGH ARCHITECTURAL DESIGN AND URBAN PLANNING

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SUMMARY

This paper contains the architectural damages and urban disasters observed in recent China earthquakes and lessons learned from them. The paper begins with vulnerable building systems. Next follows the influence of building configuration on earthquake performance, the interaction between structural and non-structural elements. The paper concludes with the importance of mitigating urban earthquake disasters, lessons learned from 1976 Tangshan earthquake and requirements to urban planning for earthquake-prone region.

INTRODUCTION

The last few decades have witnessed that the loss of life and property mainly was caused by collapse of buildings and unrational urban planning. However, up to date, architects and urban planners mostly ignore seismic activity, and design requirements essentially deal with the structural seismic measures of a building as it affects life safety. Less attention is given to the performance of architectural components and of the whole city during an earthquake. In fact, particularly in the architectural design and the planning stages, the decisions on earthquake disaster protection made by designers, especially by architects and planners, have critical implications for life safety and disaster mitigation.

VULNERABLE BUILDING SYSTEMS

The earthquake performances among brick structures and among reinforced concrete structures based on China earthquake experiences are compared in Figures 1 and 2 respectively. In the figures the earthquake resistant performance improved gradually from 1 to 8. It may be seen that different building systems make a great difference in seismic performance. Even if same materials are used, with different building system, the seismic performance can be different. Some of building systems which are optimized in non-seismic region can be vulnerable in seismic area.

<u>Longitudinal bearing wall system for multistory brick buildings</u> There are many advantages for longitudinal bearing wall system, such as convenient operation in construction, better economic results, flexible arrangement in space, and satisfying multiple function etc. However, such system has suffered repeatedly heavy damages in past earthquakes due to insufficient transversal bearing wall. During the 1975 Haicheng Earthquake, about 40% of this type of buildings were collapsed or severely damaged in the area with intensity of VIII, and 70% with intensity of IX. A striking contrast with longitudinal bearing wall system is the longitudinal and transversal bearing wall system. During 1975 Haicheng Earthquake, the building with transversal bearing wall for each one to three bays were not collapsed in the area with intensity of VIII or IX, only 35% were severely damaged. Transversal bearing wall system has adequate

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vertical bracing elements for each bay, so that only a little damage occurred in the area with intensity of IX. The ductility and lateral load bearing capacity of the transversal bearing wall system with reinforced concrete constructive columns at intersections of the walls and with tie beams in the floor levels are greatly increased by reason of confinement of the brick walls and floor slabs. This building systems were not collapsed in the area with intensity of X during 1976 Tangshan Earthquake. It proved that the transversal bearing wall system should be adopted as much as possible for the multistory brick buildings in seismic region, and reinforced concrete constructive columns should be used for upgrading when necessary.

Brick column bearing system is a good solution for buildings with medium and small span in non-seismic areas since it is economic and convenient for construction. However, most of such buildings were damaged or collapsed in the area with intensity of VIII and above in past earthquakes. Hence, vertical reinforcements should be placed in brick columns.

Flat slab system may be a good system for the buildings which need large space and with large floor load, if we design for no earthquakes or mild earthquakes. Without girders, it's convenient in construction and the cost can be reduced by decreasing the height of the floor. However, some buildings using such kind of system were collapsed under strong motion by reason of the damages to columns. Therefore, the shear walls should be added.

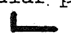
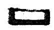
Soft first story building system can provide larger space in first story and is a good building system in non-seismic region to satisfy requirements of restaurants and shops in first story. However, it is a vulnerable system in earthquakes, although Martel suggested to adopt the soft first story to reduce the earthquake energy inputted to the building in 1929, and it was recognized the earthquake motion can be isolated by the soft first story. The damage and collapse of such a building are always caused damage of columns in first story, and it is very difficult to repair. The collapse of soft first story buildings were found in Ashkhabad, The Soviet Union, Earthquake(1948), Agadir Earthquake (1960), Skopje Earthquake(1963), Tangshan Earthquake(1976), and Romania Vranca Earthquake(1977) etc.

Tall chimneys are vulnerable system during earthquakes and the damage usually occurs in upper part of their shaft.

BUILDING CONFIGURATION

Building Plan

It is said that building shape in plan should be as simple as possible and the rectangle is the optimum. Many seismic design code, including Chinese code, specified that building with irregular shape in plan should be separated into several independent regular units by seismic joints. According to this requirement some people say that an existing building with irregular plan should be separated artificially in design for strengthening. However, the construction cost is sure to increased by the seismic joints. Moreover, for some buildings the irregular plan is needed in view of functional requirements, limit of the site and architectural considerations.

Soon after 1970 Yunnan Tonghai Earthquake, the author was sent to struck field to observe and report on the structural damage. At that time, the influence of building plan on earthquake performance came into the author's notice. Several interesting examples were found during the inspection of Osan County. The single story pigpen house with the shape of  in plan was stood well after the earthquake. This building had two rows of timber columns and a flat mud roof. It was located at Xiaojie Commune with intensity of IX. In contrast, all the nearby buildings with same structural system and same materials but with rectangular plan were collapsed. The single story candy workshop with the shape of  was slightly damaged. The building system consists of brick columns and timber truss. It was located in Yiaojie Commune with intensity of IX. While the similar Commune Hospital Building with rectangular plan near in place was levelled to the ground. The building so called "one stamp" with the shape of  was a traditional building in the countryside of Yunnan Province. It has a courtyard in centre. The height of two wings are lower than the main part. Its structural system is timber frames with Chinese traditional jointing method. In the area with same intensity, the "one stamp" buildings almost all stood well, the same buildings with rectangular plan, however, were mostly collapsed in the earthquake.

Shortly after the 1976 Tangshan Earthquake, the author was sent to the struck area to inspect the structural damage. According to the reports on 55 spacious brick buildings (21 buildings were in Tangshan city, 34 buildings were in Tianjin city), we found that the ratio of collapse for the buildings with irregular plan (with front and/or rear halls and/or with side halls) is lower than that with regular plan (without any front, rear, or side halls).

We also found that the round low structures have a good performance in an earthquake. For example, during 1970 Tonghai Earthquake, most of storage buildings with brick bearing walls in Xiaojie Commune with intensity of IX were severely damaged or collapsed, except a brick round silo for storage of grain. The same lesson was relearned from 1976 Tangshan Earthquake. Few of the round silo for grain storage in mud or brick masonry in the area of grade IX-X were damaged in the earthquake except the old ones.

The above mentioned examples indicated that the structures with round plan and less height have a good behaviour for earthquake resistance, and that the capacity for prevention collapse of a building with irregular plan, provided with meticulous design and construction, may not be lower than that with regular plan, since the different parts of the building may support each other for existance. Therefore, the author recognized that it may be beneficial to separate a building into several units of simple shape in plan by seismic joints in design for mild and moderate earthquakes, because the cost for repair can be lower. However, in design for strong earthquake, prevention of collapse became a critical problem. In this case, separating a building into several units not only needs more funds but also may be disadvantageous to hold the building in an earthquake.

Building Elevation

Earthquakes repeatedly demonstrate that the structures with simple elevation shapes have the great chance of survival and the influence of elevation shape of a building on its earthquake performance is greater than that of the plan shape.

The facade outstanding parts of buildings, either facade setbacks or penthouses, are vulnerable in an earthquake. The main reasons are as follows: (1) The analytical method for evaluation of the effects of facade outstanding parts is not given in the current normal seismic design codes. (2) About their overall seismic behaviour and structural details we know little.

INTERACTION OF STRUCTURAL AND NON-STRUCTURAL ELEMENTS

Any building always consists of two kinds of elements. The first is structural elements, which carry the dead loads, live loads, and environmental loads. The second is non-structural elements, which join or attach to the structural elements to satisfy the functional requirements. The interaction of structural and non-structural elements involves both the influence of structural system on non-structural elements and vice versa. During an earthquake, the structural system moves by ground excitation at its base. As the structural system moves, the non-structural elements move too. This accounts for their damage.

Damage mechanisms for non-structural elements are as follows: (1) Damage to connections between structural and non-structural elements due to earthquake inertial forces itself, (2) Change of geometrical shape of infill elements due to story drift, and (3) When the infill elements have a certain stiffness and its effect is ignored in design, the earthquake loads applied to them will be much larger than that of prediction in elastic range. In this case, the damages take place not only in infill elements but also in structural elements joined to them. As a result, the building may be collapsed by the interaction between infill elements and structural elements. The damage to non-structural elements and the measures for earthquake resistance are listed in Table 1. It is worthy of note that sometimes the cost of non-structural elements attains to almost half of the construction cost of the building. Therefore, seismic design for non-structural elements is an important project to be studied.

URBAN EARTHQUAKE DISASTER MITIGATION

Lessons learned and relearned from past earthquakes show that morden cities are more vulnerable in destructive earthquakes. In China, during the period of recent 30 years, 11 destructive earthquakes took place in main land, 9 of which occurred in countryside. The loss of life caused by 1976 Tangshan earthquake is about 90% of the total loss of life caused by earthquakes occurred in this period of time. Concern with the economic losses, they were about 70% and 15% of the total in Tangshan and Haicheng events respectively. It follows that the better part of the losses comes from the earthquakes occurred in city or near it. In the United States, the total of 1,600 people were killed by earthquakes in history. About half of the total life losses were caused by the 1906 San Francisco Earthquake. The total economic losses in history were about 2 billion dollars. Most of them, however, were caused by 1906 San Francisco Earthquake (520 million dollars), 1964 Alaska Earthquake ([illegible]00 million dollars), and 1971 San Fernando Earthquake (523 million dollars), which were occurred in nearby cities. The experts of the United States expect that if the destructive earthquake occurs in Los Angeles in the future, the loss of life would be 15,000 people and the economic losses would be 25 billion dollars. In Japan, during the Miyagiken-oki Earthquake of June 12, 1978, 28 people died and more than one thousand people injured. The property loss amounted 276 billion yen (1.1 billion dollars). It affected capital city and 7 counties. The disaster was supposed as one of the biggest earthquake disasters since the 1923 Kanto Earthquake. While 42 years ago, in the same area had a stronger earthquake occurred, the losses were less than this one.

Lessons From 1976 Tangshan Earthquake

The Tangshan Earthquake of July 28, 1976 brought great disasters to Tangshan city with a urban population of about six hundred thousand and many disasters to Tianjin and Beijing. It took the lives of 242,000 people, caused 164,000 injuries. The macroepicenter was in Tangshan down town area. A lot of useful lessons for urban earthquake disaster mitigation can be draw from this earthquake.

Rational building density While the density of buildings and population decreased, the disaster will be mitigate. The Lunan District of Tangshan city has a highest density of buildings, which was about 70%. The death-rate in this district was more than 45%. In other area of Tangshan city, the death-rate was about 21.3%, while in Tangshan suburbs, it was 14%. In rural area, the death-rate was only 10%. Moreover, in the region with higher density of buildings, many people who escaped from the houses died in narrow lanes in the earthquake. The debris filled in some lanes higher than one meter. Many structures were damaged or collapsed by the debris fallen from the nearby collapsed buildings.

Correct Evaluation of Basic Intensity The concept of basic intensity of a region has been defined as the maximum possible seismic intensity caused by earthquake that may be occurred in that region during a future period of one hundred years under ordinary site condition. The Tangshan Earthquake shows that the main cause which led to great disasters is that the basic intensity of Tangshan region had been assessed too low. In fact, before the Tangshan shock, the basic intensity in Tangshan city was of only VI. It means that the structures were not required to be designed to resist earthquakes. Actually, the intensity in Tangshan city attained to XI during the Tangshan Earthquake. The same situations were found in Xiantai Earthquake (1966), Tonghai Earthquake (1970), and Haicheng Earthquake (1975) etc.

Prevention of secondary disasters Tangshan is a coal mine base in China. After the earthquake, the underground passageways were intact, but were inundated with water, which was 1.7 to 5 times that of the usual amount. The maximum gush in a well was up to 160 m^3/min. It took a year to resume due to interruption of power supply at that time. Hence, secondary power supply and emergency drainage facilities must be available for rapid recovery.

In Kaiping Chemical Plant, liquid chloride flew out due to damage of the valves. It took the lives of two people. Fortunately, it was diluted by rain water, which avoided another disaster.

Explosions and fires happened in some institutions because of damage to chemical containers. Severe disaster, however, did not take place due to prompt rescue.

The Douhe river flows through the Tangshan city. The Douhe resevoir is situated at 15 km up the river. It was damaged in the earthquake. A 1700m long longitudinal cracks with width of 1 to 1.5m and many transversal cracks were found in the dam. As a result, the dam leaked after the earthquake. Fortunately, the dam was stood because of low water and prompt repair.

The reinforced concrete chimney of 180m high in Douhe Power Station broke at the height of 132m during the main shock, and fell down in the largest aftershock right on the day. The nearby conveying cooridor was collapsed by the fallen debris. Some factory buildings were damaged or collapsed due to fallen sections or brick pieces of the brick chimneys. Therefore, the buildings should be constructed at a certain distance away from tall chimneys.

Safegurding security of lifeline After the earthquake, the power supply in Tangshan were completely interrupted due to collapse of buildings and damage of equipments. Power supply was temporarily restored by means of truck power on July 28. The power was supplied to Tangshan through the network on July 29. The Tangshan power plant was completely recovered by the end of 1976.

Interruption of water supply in Tangshan was mainly caused by collapse of water structures, such as water works, towers, buried pipelines and well pipes. A lot of pipelines buried under debris were difficult to repair. The potable water supply in Tangshan city was resumed on August 10, and the water supply was recovered in late September. While in Tianjin city, it was restored at the end of August.

After the earthquake, the communication in Tangshan city was entirely cut off due to the collapse of buildings and damage to equipments, lines and poles. The emergency communication to Beijing was connected through underground cables, which were intact in the morning of July 28. It was entirely restored on September 1.

The traffic was blocked up both in Tangshan and Tianjin cities after the event, since the debris filled on some roads. For example, there was no trasport service on 80% of roads in Heping District, Tianjin city. After the earthquake, traffic was interrupted over 10 hours in the north-south main road in Tangshan city. Vehicles lined up 10km on the Tangfeng road because of the interruption of interurban traffic and lack of qualified traffic controllers. The collapse of Shengli bridge cut the transport service between the down town area and east mine district of Tangshan city. The failure of the Ji Canal bridge led to the periodical traffic interruption between Tangshan and Tianjin cities. All this had a severe effect on rescue work.

Both the natural gas and the contained liquefied gas were slightly damaged, and gas supply was resumed basically in late August. The contained liquefied gas not only satisfied the previous customer's needs but also provided the gas for hundred rescue medical teams.

Tangshan airport suffered damages of only some buildings, normal operation was soon resumed.

Underground construction and open space In the area with intensity of X to XI, underground constructions were slightly damaged, while nearly all the buildings on the ground surface were levelled to the ground. Moreover, the buildings with basements had slighter damages than those without basements.

After the earthquake, the parks and green area were very usefull for taking refuge and rescue. The green open space in Tangshan airport was used as the medical centre. The main parks in Beijing and Tianjin cities provided refuge places for 300,000 people.

Requirements of Urban Planning

The earthquake resistant requirements should be considered in making urban planning for seismic regions in order to maximum reduce earthquake disasters. The principal requirements can be listed as follows.

- Getting size and population of a city under control, and constructing more small cities and towns.

- Getting density of buildings under control, and the distance between two buildings should be larger than the sum of their height.

- Adopting the underground structures if it is possible. Critical facilities for urban communication, water supply and power supply should be installed in underground structures as much as possible. The underground structures should not be constructed in soft soil, and their entrances and exits should be situated in free fields to prevent clogging.

- The circular networks and multiple entrances and exits as well as standby facilities for power supply, communication, water supply and traffic systems shall be adopted.

- The requirements of refuge, evacuation and rescue should be considered in road planning. Each road shall have adequate width and multiple entrances and exits to prevent interruption of transport service.

- Rational land use planning should be made based on the seismic risk analysis. Riskful areas should be used as the parks or green open space.

- The water area, either rivers or lakes, should be preserved.

- The factories and storages for production of storage of materials and goods, which are vulnerable to fire and/or explosion and/or violently poisonous, should be built far away from the city. The nearby reservoir should be situated at a certain distance down the river.

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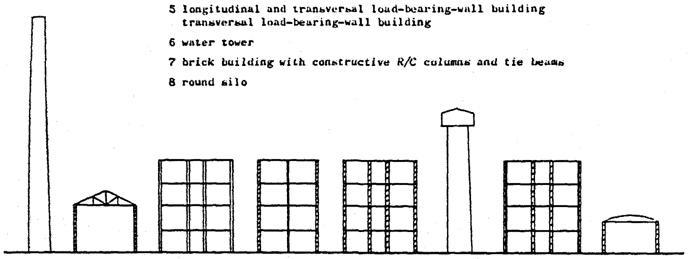
TABLE 1 DAMAGE TO NON-STRUCTURAL ELEMENTS AND ASEISMIC MEASURES

type	example	damage	effect	causes of damage	aseismic measures
vertical outstanding	- brick parapet - brick stovepipe	- crack - collapse	- death and injury of people - ruined nearby structures	- amplified lateral load - weakness in brick masonry	- decreasing its height - reinforcing brick masonry
attached	- ornament - finish - face brick	- crack - fall down	- injury and death of people	- weakness in connection - drift of structure - collapse of structural element joined	- strengthening of connections - limit to drift
horizontal outstanding	- balcony - canopy	- fall down	- death and injury of people - ruined nearby structures	- collapse of supporting structure	- control collapse of supporting structure
vertical	- partition - cladding	- crack - collapse	- death and injury of people - ruined nearby structure and contents of rooms	- weakness in connection with structure - lower strength and ductility	- strengthening of connections - increasing lateral load bearing capacity
infill	- brick wall - panel - window -door	- crack - collapse - glass breakage - deformation	- death and injury of people - ruined nearby contents of rooms - changing response of structure - clogging door	- no account its effect in design - weakness in connection - storey drift	- considering its effect - strengthening of connections - limit to drift - separating from structure
suspended	- ceiling - hanging wall plate - hanging lamp, lantern	- fall down	- death and injury of people - ruined nearby structure and contents of the rooms	- weakness in connection	- strengthening of connections

1 chimney
2 single story building with brick columns
3 longitudinal load-bearing-wall building
4 inner frame building
5 longitudinal and transversal load-bearing-wall building
transversal load-bearing-wall building
6 water tower
7 brick building with constructive R/C columns and tie beams
8 round silo

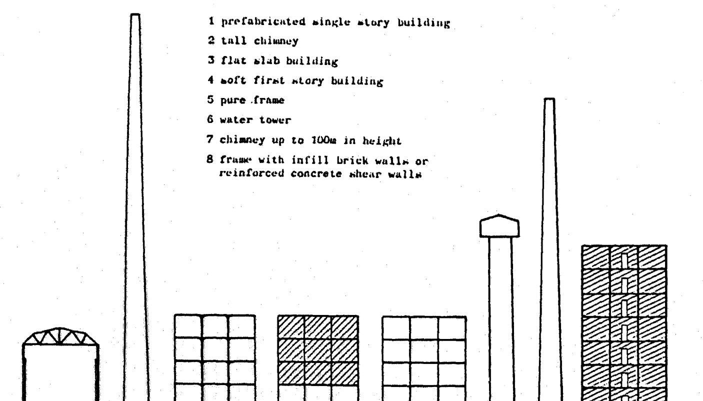


1 2 3 4 5 6 7 8

(The earthquake performance improved gradually from 1 to 8)

Fig. 1 The Earthquake Performance of Brick Masonry Structures

1 prefabricated single story building
2 tall chimney
3 flat slab building
4 soft first story building
5 pure frame
6 water tower
7 chimney up to 100m in height
8 frame with infill brick walls or
reinforced concrete shear walls



1 2 3 4 5 6 7 8

(The earthquake performance improved gradually from 1 to 8)

Fig. 2 The Earthquake Performance of Reinforced Concrete Structures