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Resistant earthquake building and city aseismic measures of Tangshan

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ABSTRACT: After Tangshan was hard hit by the violent earthquake which took place in 1976, the post-earthquake reconstruction work was set about. Since then, all the experts engaged in seismic engineering in various countries throughout the world have been showing their concern over the situation in this area. The architectural damages and urban disasters observed in Tangshan earthquake as well as the lessons learned from them, with the aseismic measures are discribed in this paper.

1. INTRODUCTION

The basic intensity in Tangshan area, in the past, was VI all along. During the Tangshan damaging earthquake occurred on July 28, 1976, a large number of buildings in the urban districts collapsed and were severely damaged, and the life and property of the people suffered a heavy loss.

The macroscopic epicentre of the Tangshan earthquake was in the southeast part of the Tangshan proper, namely in the area to the south of the Beijing-Shanhaikuan railway. Therefore, the intensity in the Lunan district and a part of Lubei district which was near the railway was XI, most of houses in the area were levelled to the ground.

The low intensity occurred respectively in the centre of Lubei district and at the roots of Phoenix Hill, Dacheng Hill and Jiajia Hill, incurring a mitigative earthquake disaster of the variou houses. Furthermore, many inflexible houses on soft soil foundations along by the Douhe River did not collapse or suffered a light damage. In addition to this, the large-sized industrial enterprises and coal mines and various houses in the other areas with intensity of X were severely damaged. We have got a rich experience and learnt a profound lesson from the Tangshan earthquake.

2. TANGSHAN EARTHQUAKE DISASTERS

2.1 Lifeline Disasters

After the earthquake, the communication in Tangshan city was entirely cut off due to the collapse of the communication buildings and damages to the communication equipment, poles and lines damaged by collapsed buildings. The emergency communication to Beijing was connected through the underground cables which were intact in the morning of July 28.

The power supply in Tangshan was completely interrupted because of the collapse of the buildings of power plants and the damage to the power equipment. Power supply was temporarily restored by means of truck power on July 28. The power was supplied to Tangshan city through Beijing-Tianjin-Tangshan power network on July 29.

The interruption of water supply in Tangshan was mainly caused by the collapse of water structures, such as water works, towers, underground pipelines and well pipes. There was no way to repair the pipelines burried under the debris at the moment. The potable water supply in Tangshan city was resumed on August 10.

While the density of buildings and population is decreased, seismic disasters will be mitigated. The lunan district of Tangshan city has a highest density of buildings, which was about 70%. About 120,000 residents lived in eight square kilometres. On the average, about 15,000 people lived in one square kilometre. The death-rate in the area was more than 45%. But in other areas of Tangshan city, the death-rate was about 21%, while in Tangshan suburds it was 14%. The death-rate of Fengnan County, with a same seismic intensity with Tangshan urban area was only 10%. Furthermore, in the region with a higher density of buildings, many people who escaped from their houses died in the narrow lanes in the earthquake. The debris in some lanes was filled higher than one metre. On this area, there was a such phenomenon that many houses were damaged by the collapsed neighbouring buildings.

The parks and green area in Tangshan city were very useful for taking the refuge and rescue. The Fenhuangshan Park and People's Park, in the densely poplulated region, were used as main sanctuaries at the moment.

The teaffic in Tangshan was blocked up after the earthquake, since some roads were filled with debris. As a result, the north-south main road in the city was blocked over ten hours, and the vehicles lined up ten kilometres on Tangfen road due to the interruption of interurban traffic and lack of qualified traffic controllers. The collapse of Shengli Bridge stopped the transport service between the urban area and East Coal Mine District of Tangshan.

The runway in the Tangshan Airport was basically intact, only some buildings were severely damaged, the normal operation was soon resumed. The Airport was used as the medical centre at the moment.

2.2 Secondary Disasters

The Douhe reservoir located at 15 km up the Douhe River which flows through the Tangshan city was damaged in earthquake, a 2,000 m long longitudinal crack with the width of 1-2 m and many transversal cracks were found on the dam. As a result, the dam leaked, but the dam stood there because of the low water and prompt repair after the earthquake.

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

The 180-metre-high R/C chimmey in the Douhe Power Plant broke at the height of 130 m during the main shock, and fell down in a largest aftershock right on the day; the nearby convey corridor was damaged by the fallen debris. Some factory buildings were also damaged or collapsed due to the fallen sections or brick pieces of the brick chimmeys.

Tangshan is a coal mine base in China, the underground tunnels of the coal mines were intact in the earthquake, but were inundated with water, which was 2 to 5 times that of the usual amount. The maximum gush in a shaft was up to 160 m³/min. It took a year to resume due to the interruption of power supply at that time.

2.3 Structure Disasters

The Tangshan earthquake not only examined the capability of resisting the influemce of the high intensity of various buildings in the city but revealed the weak points of lacking rigidity, strength and ductility of most of buildings (See Table 1). According to the sequence of Table 1, we can see that the aseismic performance of masonry structures is worst, that of R/C structure better and that of light steel structure best.

Table 1. Collapse-rate of Various Buildings in the High Intensity Region

Stone Arch Bridges	Multistory Brick and Wood Buildings	One-story Houses	Chimneys
100%	97%	94%	90%

Muktistory Stone Buitdings	Multistory Brick Buildings	Onestory R/C Factory Buildings	Inner Frame Houses
86%	78%	75%	72%

Spacious Houses	Tower Type Buildings	Kilns and Furnaces	Flat Slab Buildings
61%	50%	41%	33%

Corridors	Cased Buildings	Storage Tanks	Store Houses
26%	22%	20%	18%

Bridges with R/C Beams	Buildings with R/C Frames	Factory Buildings with Light roofsteel	Propaganda Boards
17%	15%	10%	6%

Under-ground Buildings	R/C Tower Frames	Light Steel Tower Masts	Light Steel-framed Bridges
3%	1%	1%	nil

In the area with a high intensity, the large R/C frame buildings (See Fig.1) and light roofsteel industrial buildings have a better aseismic behavior. Furthermore, the multistory brick buildings with tied concrete columns

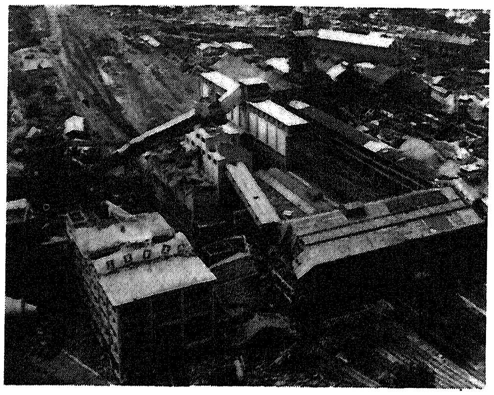

Fig.1 The large R/C frame buildings

(See Fig.2) show an outstanding vitality, and suitable for constructing low-rise masonry buildings, such as villas, apartment buildings, shops, schools, hospitals and churches, and so on.

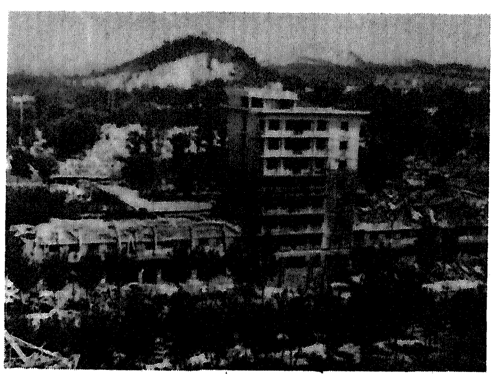

Fig.2 The inner frame building with tied concrete Columns

3. VARIOUS FACTORS OF INFLUENCING THE ARCHITECTURAL DAMAGES

3.1 Earthquake Geology and Ground Direction

1. Seismic magnitude
2. Distance of buildings from the focus
3. Geology and ground conditions
4. Foundation damping of buildings
5. Coincident functions between the seismic waves and space between the buildings

3.2 Direction of Architectural Structures

1. Structural forms
2. Stiffness, strength and ductility
3. Building configuration
4. Connecting of the structural and non-structural elements
5. Structural materials
6. Centre of gravity of a building
7. Aseismic reinforcement and non-reinforcement of a building
8. Building with aseismic precautions, and buildings without aseismic precautions
9. Workmanship of construction of buildings

4. THE RESEARCH RESULTS OF MULTISTORY BRICK BUILDINGS WITH TIED CONCRETE COLUMNS

4.1 Function of tied concrete columns

The tied concrete columns in the vertical constituted the rims with the horizontal grids, enclosing the walls, thus improved the shockproof characteriatic running in two directions. Horizontal grids and girders could slso constituted the rims surrounding the floor slabs, thus improving their integrity. The shear strength of the brick masonry and the effect of the rims were not brought into full play at the same period. During the elastic stage, the elastic force was mainly borne by the brick masonry. It was only after the elasticity of the brick masonry failed and the integrity was weakened that the rims began to play their roles. The tied concrete columns and the grids were under the effect of a combination of forces, i.e., tension, compression, shear and bend. It was noteworthy that at the juncture of tied columns and grids articulation of plastic nature were generally formed. Oblique cracks and horizontal cracks mostly concentrated at the juncture position. The walls near juncture position were subject to shear or got smashed. The larger the area of this part, the more serious were the cracks at the ends of the grids and columns. Therefore, the connections between the tied columns and the grids were of great importance.

Rational installation of uniform continuous tied concrete columns and grids might improve the integrity and ductility of the houses in mixed structures, the loadbearing capacity and lateral resisting strength of walls. It was considered as one of the best approaches of ensuring the houses in magistoseismic area not to collapse in presence of serious cracks.

4.2 Variations of Rigidity

Taking the seismic failure mechanism of a brick building as an example, the shear-type vibration is the main cause. If tied concrete columns are added, the rigidity of the building will become stronge and never weaker.

4.3 Variations of Strength

The contrast experiments of models show clearly that loadbearing capacity can be increased by 54-58 per cent if there are tied concrete columns in the building, the initial cracking load can be raised by 20-57 per cent. But lateral resisting capacity is the most important element when the wall is in the elastic stage.

Formulas:

$$Q = \frac{R_\tau A}{\xi} + 0.07 R_h A_h + a_1 A_g R_g$$

where R_τ is shearing strength of masonry. A is section area of brick masonry. ξ is uneven coefficent of shear stress. Rh is axial compressive standard strength of concrete. Ah is section area of tied columns. ai is shearing strength influence coefficient of bars. Ag is total area of tensile and compressive bars in tied column, Rg is desigh tensile strength of hoop bars.

$$Q = \frac{R_j A}{\xi} + 0.8 f \sigma_0 A + \beta \left(\frac{2 A_g R_g b_0}{H} + \frac{0.5 R_a b b_0^2}{H} \right)$$

Where Rj is shearing strength of masonry. f is friction coefficient. 2Ag is section area of tensile reinforcement in columns, 2 for symmetric columns. bbo is width of column side and spacing of bars in tied column. H is height of wall. β is loading influence coefficent on tied columns and wall 1.4.

$$Q = 0.5 \sigma_0 A + 0.056 R_a b h_0 + 1.2 R_g \frac{A_k}{S} h_0$$

Where f is sliding friction coefficient between brick masonrys, 0.5 σ_0 is normal compressive stress. A is shearing section area of brick masonry. Ra is compressive strength of tied column concrete. b is width of tied column. ho is effective height of tied column section. Ak is total leg area of hoop bars assembled in same section in tied column end. S is spacing of hoop bars in tied column end. Rg is design tensile strength of hoop bars.

These three formulas are check formulas for the walls with tied columns. Table 2 shows the results obtained by experiments on walls with or without columns.

Table 2

Eaperimental unit	Shearing strength per cent raised
Beijing Architectural Designing Institute	10%
Dalian Engineering Institute	5-20%
Harhin Institute of Engineering Mechanics	10-13%

Table 3

Experimentat Content	$\mu = \frac{\Delta u}{\Delta y}$
Single wall without tied columns	1
Single wall with tied columns	3.24-3.84
Model without tied columns	1.81
Model with tied columns	3-4

4.4 Variations of Ductility

If tied concrete columns are placed in a brick wall, the deformation capacity of the wall will be raised (See Table 3), making the brick building get a change from a lower ductile structure to a general ductile structure with a ductility coefficient 4. Therefore the anti-collapse capacity of a building is raised.

5. PRECAUTIONS AGAINST EARTHQUAKE HAZARDS

After the Tangshan earthquake, it was very difficult to reconstruct the New Tangshan. The precautions against earthquake disasters, we have got, are as follows.

5.1 Organizing and Guidance by Governments

As soon as the Tangshan earthquake occurred, a leading group was organized by the Central Government; an earthquake relief headquarters was set up by the provincial and municipal authorities. The rescue work achieved a great success due to the unified organizing and guidance. Therefore, governments's organizing and guidance played an important role in the rebuilding of New Tangshan.

5.2 Defining Scientifically the Basic Intensity in Tangshan Area

The Central Government concentrated the Chinese experts in seismology, geology, exploring, surveying, planning and architecture on surveying and exploring in the area of 146 square kilometers of Tangshan, and on analysing scientifically the historical earthquakes. They summed up experience and lessons learned from the Tangshan earthquake. After discussed repeatedly, the experts finally confirmed that the basic intensity in Tangshan area is VIII, thus the prevention basis was provided for the rebuilding planning and design of the Tangshan city.

5.3 Rationally Revise the Urban Layout and Strictly Control the Architectural Size

After the Tangshan earthquake, the planning area of the New Tangshan is 73.22 square kilometers with a population of 760,000. The New Tangshan city is divided into three parts, such as the Original District, East Coal Mine District and New District (See Fig.3), each 25 kilometres apart from the other.

5.4 Change the Originally Inresonable Layout of Functional Divisions by Means of Land Use and Planning

In line with being advantageous to the production, convenincing the daily life, protecting the environment and aseismic principle, the industrial area, residential quarters and storehouse area were rationally arranged in the new urban planning.

1. Original District
Taking the Douhe River as a boundary, the steel and porcelain industries are in its east; the residential quarters are in its west. The Dacheng Hill is a natural greening screen. The residential quarters shops, sports centres and administrative centres, which can concentratively mirror the new look of the Tangshan city (See Fig.4).

2. East Coal Mine District
The main part includes five coal mines of Kailuan Coal Mines. The district is divided into five residential quarters, linked up with highways between them. The Shahe River

Fig.3 The New Tangshan City is divided into three Parts

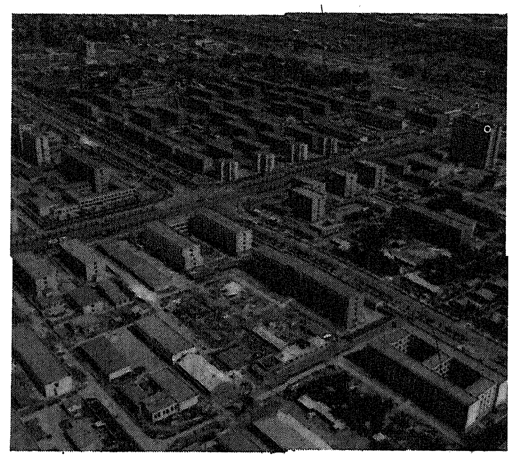

Fig.4 The new look of the Tangshan city

flowe through the district, from north to south.

3. New District
With the Huanxiang River in the north, the New District faces the Beijing-Qinhuangdao railway. There is a north-east fault zone with in the area. According to the planning, an 80-metre-wide isolated greening belt was created, the Living quarters in its west, the industrial region and storehouses in its east.

5.5 A Good Traffic Planning and More Exits Opened Up

The measures have been taken in the new planning to widen roads, straighten roads, open up new trunk roads, break through the T-shaped roads and increase exits. Now, a good transport and communication network has been formed in Tangshan.

By reason that the Beijing-Shanhaiguan railway with much coal sterilized below it, runs through the city, therefore, it is decided to change its route to the western part of the Old District to avoid traffic jam problems.

5.6 Precautions Against Earthquake Disasters to the Lifeline System

1. Watersupply: Measures have been taken to form a ringlike water supply system with several water soueces, the soft connectors were used for pipes as many as possible.
2. Power supply: A ringlike power supply system with several power sources have been adopted, connecting Beijing-Tianjin with high-tension lines.
3. Communication: A wireless communication system in combination with a wired system is used, and can be standby for each other. The operating centers are located at different places. The cables are burried underground and linked up in a roundabout way.
4. Gas: Both the gas of new-built Coal Coking Gas Works and the gush of coal mines are used according to the unified planning.
5. Centralized heating: The urban centre uses the heating systems of the thermal power plants, but the border districts of the city adopt heating systems of heating boilers.
6. Water draining: Rain water and sewerage are seperately treated; rain water is drained to the Douhe River or other natural cisterns. Sewerage is drained into two new sewage treatment plants, after treated, treated sewerage will be used to irrigate farm lands.

5.7 Selection of the Aseismic Structures

The aseismic structures for the New Tangshan are: (1) R/C frame structure, (2) R/C precast panel structure, (3) brick structure with tied concrete columns, (4) light roofsteel structure. The space between the buildings were widened on purpose to have enough day lighting, disperse the population and do rescue work.

5.8 Precautions Against the Secondary Disasters

To avoid the occurrence of the Secondary Disasters the combustibles, explosives and deadly poisions have moved out of the urban districts. The dam of the Douhe Reservoir was reinforced, the river course was widened and straightened and river mud was also cleared out.

5.9 Disperse the Population in Combination with Making the city Green

Before teh Tangshan earthquake, Tangshan had only two parks. The new planning includes nine parks and three scenic spots. In addition, to plant trees and grass in the resistential quarters, circular safety islands and the two sides of the roads can not only raise the covering rate of planting trees in and around the city but also can help disperse population in earthquakes.

5.10 Make a Good Job of the Seismic Monitoring

Fifty seismic monitoring stations have been set up in Tangshan area. From microcosmic angle and macroscopic angle, we carry out various seismic monitoring work. Through holding regular conferences, we furnish the departments concerned with informations about seismic monitoring, earthquake prediction and earthquake disaster prevention.

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