LESSONS LEARNED FROM THE 1976 TANGSHAN EARTHQUAKE

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SYNOPSIS

This paper brings up several important aspects of the 1976 Tangshan earthquake, which is a great natural disaster in the Chinese history, to the attention of the earthquake engineering community for the benefit of mitigating future earthquake hazard.

INTRODUCTION

The 1976 Tangshan earthquake in China of magnitude 7.8 occurred on the morning of July 28 at 3:42 a. m. (Beijing time) and was followed on the same day at 6:45 p. m. by a strong aftershock of magnitude 7.1 at about 70 km to the north-east of Tangshan in the county Luanxian. The epicenter of the main shock was located in the city area of Tangshan where the intensity rating was X to XI on the Chinese intensity scale. A fault breakage of about 8 km in length ran through the city with max. dislocation of 1.53 m horizontal and 0.8 m vertical. The casualties amounted to 242,000 dead and 164,000 injured; the Tangshan city was almost demolished. The whole country was shocked by this unfortunate event and tremendous work had been done in rescue, relief and recovery. On the engineering aspect, general and detailed field surveys have been made by many institutions; scientific investigations are still going on. It is only intended here to expose the most important lessons that deserve serious consideration in earthquake engineering studies.

UNDERESTIMATION OF EARTHQUAKE RISK

Tangshan is an old industrial city and has greatly expanded after the liberation of China. The old part of the city was mostly built of the traditional rubble or brick masonry constructions which are non-resistant to earthquake. The new part, although built of well-designed contemporary brick and reinforced concrete structures, had neither been given consideration for earthquake hazard. Therefore, Tangshan was practically undefended during the 1976 earthquake. It can be envisaged that if the structures had been designed for earthquake resistance, even for moderate intensity, the loss of lives and property would be very much reduced.

In China, the earthquake risk is generally designated by the "basic intensity" which is defined as the most hazardous earthquake intensity expected in a certain region. The basic intensity for Tangshan was VI in the Chinese earthquake catalog (1960) mainly on the ground that no large earthquake had occurred in that region. For basic intensity VI or lower, the Chinese design codes for buildings and structures have no requirement on earthquake resistance. This is the cause for no preparedness to earthquake hazard and the consequent disaster.

Geographically, Tangshan is on the Yanshan seismic belt where a fairly

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long record of historical earthquake is available. Figs. 1 and 2 show the spatial and temporal distribution of larger earthquakes. There were four seismically active periods in the recorded history. A number of moderate earthquakes had occurred in the surrounding of Tangshan, mostly in the county Luanxian with magnitude up to 6¼. In Tangshan, there occurred only one earthquake of magnitude 4¾ in 1935. The occurrence of the 1976 Tangshan earthquake probably indicates the culmination of energy release for the present active period of the Yanshan seismic belt. In tectonic feature, Tangshan is situated at the center of a downthrow diamond block bounded by big deep faults on four sides (Fig. 3). Inside the block, only minor faults were observed in the coal mines. Thus, before the 1976 earthquake, Tangshan was regarded as a place of low seismicity from both seismological and geological standpoints. After the event, it was revealed by geophysical prospecting that there also exists a hiding big deep fault inside the block, striking north-east ward and in alignment with the accompanying fault breakage of the event. However, even such information had been known, it is still doubtful that we could make a correct assessment of earthquake risk beforehand.

The Tangshan earthquake tells us once again that the state-of-the-art cannot preclude miscalculation of earthquake risk and such miscalculation may bring great disaster. An engineer should be aware of this and needs some conservatism in his design. One way of doing is to make the intensity map on the safe side so that risks inferred from all angles are encompassed.

COLLAPSE OF BUILDINGS

Because of the uncertainties involved in the earthquake risk analysis, it is generally conceded that structures should be designed to meet two requirements, i.e. they should be serviceable under moderate earthquake and capable of escaping from collapse during an unexpected severe event. While it seems not difficult to achieve the first requirement, no workable approach has been found to meet the second requirement as yet. The widespread collapse of buildings, especially the multi-story unreinforced brick masonry buildings, during the Tangshan earthquake renders the latter problem more acute and more urgent. Research interest should be urged toward this end.

The multi-story buildings have many shortcomings so far as earthquake resistance is concerned. Generally, they failed in brittle manner during earthquakes so that the people inside have little chance to escape. After collapsing, the survivors can hardly get out of the debris and the rescue works are extremely difficult. The casualties during the Tangshan earthquake were largely due to collapse of multi-story brick buildings. This is a painful experience that deserves special sttention. Fig. 4 shows the percentage of collapse on a map of Tangshan. It is shown that the buildings in many quarters nearly completely collapsed. There were several patterns of collapse, ranging from partial to total failure. For the most serious cases, the building formed into a pile of debris (Fig. 5) or a stack of floorslabs (Fig. 6). The mechanism of failure is difficult to imagine. Probably, it is due to the vertical compression imposed upon the cracked masonry by the gravity loads and the impact of sudden failure of some story.

Although the brick buildings are vulnerable to earthquake, their resistance can be brought up by proper design. First of all, the aseismic resistance of brick buildings is mainly dependent upon the shear strength of the walls. It has been verified by the damage data of Tangshan earthquake and some previous earthquakes, that the stronger the shear strength, the lighter the damage and by proper choice of the base shear coefficient in design, serious damage and collapse can be prevented. Loss of connection between wall elements and precast units is another cause of failure (Fig. 7). This can be remedied by strengthening the connections and by the use of reinforced concrete tie beams in the walls. Brittle failure is the fatal weakness of brick masonry structures. This can be much improved by inserting cast-in-place reinforced concrete columns in the masonry at suitable spacings, which in combination with the tie beams in the walls form a second defense line against collapse. There were some instances that part of the building, in contrast with the rest of it, has survived from the shock because of the presence of such concrete columns (Fig. 8). The effectiveness of this scheme has been also substantiated by vibration tests on reduced scale models. It is believed that if all the above measures were taken, brick buildings might be capable of escaping collapse during strong earthquakes.

The collapse of the industrial buildings was also serious. It would not be an overestimate that the collapse ratio had amounted roughly 70% in the area of intensity XI and 50% in the area of intensity X according to reports from various sources. The losses due to crashing of equipments inside the buildings were also heavy. Taking for example, in a big plant for locomotives and cars, situated in the area of intensity XI, nearly all the mill buildings built of contemporary precast reinforced concrete construction were leveled to the ground (Fig. 9). A newly constructed and carefully designed power plant of 750,000 kw located at 20 km to the north of Tangshan in the area of intensity IX was damaged to an extent that nearly 100% of the roof and 30% of the floor area had collapsed. The multi-story concrete rigid frames failed as well as the precast single-story girder-column construction (Fig. 10). In general, most collapsed industrial buildings were either failed by the collapsing of the roof system due to inadequate strength of connection between the precast units and insufficient stability of the roof trusses (Fig. 11) or by the flexural failure of the columns at the bottom (Fig. 12) or at the upper slender sections. A less serious but frequent happened case is the collapse of the curtain walls, which sometimes brought down the attached roof system.

DAMAGE DUE TO LIQUEFACTION

The shaken area of Tangshan earthquake is situated in the plain between the Yanshan mountain range on the north and the Bay of Bohai on the south. A number of rivers flow through this area to the sea and the coastal line had been subject to advancing and retreating. Under this geological background, the coastal plain, the river banks and the swamp areas are susceptible to soil liquefaction. It was reported that sandboil began at few minutes after the earthquake and lasted up to several hours. Water spouts lasted still longer, up to several days or even a couple of weeks. As revealed by the things brought up by the sandboil, the liquefaction might have gone as deep as 2/ m. It was estimated that a total area of about 3,000 sq. km have been subject to serious liquefaction and 24,000 sq. km to a lighter degree. Fig. 13 shows approximately the margins of these areas.

Liquefaction damaged many engineering works. The Douhe earth dam, situated at 20 km to the north of Tangshan was damaged by wide longitudinal cracks (up to 1.5 m wide) on both slopes, and numerous transverse cracks across the dam (Fig. 14). The silt layer under the bottom of dam might have been liquefied. It is very fortunate that the reservoir was at very low water level during the earthquake. The Baihe rock dam of the Miyun reservoir, 150 km to the north-west of the epicenter, had the sand-gravel surface course over the impervious layer on the up-stream slope slipped down into water at the reservoir level, presumably due to liquefaction of the fine aggregates. Many highway and railway bridges failed by the movement of abutments and piers due to liquefaction of the foundation soil in spite of piling. Buildings were subject to settlement and tilting (Fig. 15) and levees and road enbankments were subject to cracking, settlement and slipping in the liquefied areas. Many farmlands, irrigation channels and water wells were silted up by the materials coming up from the sandboils. Settlement and cracking of ground frequently occurred in company with sandboils. In some cases, the settlement exceeded 3 m and ponding of water formed. In short, the troubles caused by liquefaction were serious and manifold and spread as far as hundreds of km away from the epicenter.

DAMAGE TO COAL MINES

The Kailuan Coal Mines are situated in Tangshan and its vicinity. It was a rather rare occasion that a large earthquake occurred directly underneath a big coal mine. Post-earthquake survey indicates that the damage to the mining shaft is largely dependent upon the properties of the penetrated rock. Two-third of the shafts had been subject to various degrees of circumferential cracks and dislocations in vertical alignment, which generally took place in alluvium at shallow depth and in liquefied layers. None of the shaft did collapse or handicap the emergent withdraw of the workers from the mines. The damage to the underground alleys and stopes was slight except some partial failures in loose soft rock and fault area. However, the sound in the mines rolled like thundering and lasted longer than on the ground surface. The timber supports were crackling and sometimes fractured. Occasionally, the steel supports impacted each other with fire sparks. The most serious matter in the mines was the flooding caused by the sudden increase of underground water flow during the earthquake to 3-5 times of the normal and by the stop of pumping due to interruption of power supply. The underground water flow subsided slowly; it took almost a year for restoring to normal condition, and the mines were damaged by the long-time immerging in water. The increase of underground water flow might have some connection with the fissures in the Ordovician limestone in this region.

The damage rendered to the mining structures and the auxiliary buildings on the ground was much more serious than that underground. Generally, most of the mining structures, such as mining towers, coal bins, transmitting corridors etc., are built of steel and reinforced concrete. Although damaged, they can be repaired for reuse; only a few of them require rebuilding. A spectacular failure was that of a reinforced concrete mining tower which had fractured at the bottom and shifted aside to a dislocated position (Fig. 16). Most of the auxiliary buildings, such as hoisting rooms, pumping houses, power stations etc., were collapsed and the equipments inside were also smashed.

DISRUPTION OF LIFELINES

After the earthquake, railways and highways were all blockaded because of the failure of roadbed, embankments and bridges, which rendered great difficulty to the relief works. The main railway line linking Beijing and Shenyang was heavily destructed in the section Tanggu - Changli (175 km) with Tangshan at the center position. Almost 50 per cent of the bridges, including several long structures, on this section were damaged, mostly by sliding of abutments and piers toward the center of river, which induced shortening of spans, crushing of abutments and girders, shear-off of anchor bolt, bending of tracks etc. (Fig. 17). The damage to highway bridges seems more serious. Several long bridges on the main line, Tianjin - Tangshan - Changli failed by collapsing of girder spans into river (Fig. 18). For a short period after the quake, transportation was maintained by the aid of air service.

Communication,electricity and water supply were all interrupted. Right after the quake, Tangshan lost contact with the outside world until the relief personnel got into the city. The interruption of power supply brought up a series of dangers. For instance, the ventilation system of the coal mines was out of work, which led to the danger of soffocation and gas explosion. The stop of water supply renders the daily life of the people extremely difficult; water was transported by tankers from other places. It should be noted that the paralysis of the public utilities was mainly due to the collapse of the buildings housing the servicing equipments and the personnel on duty. The interruption of communication was largely due to the collapse of the telegraph and telephone offices. The cessation of power supply should be attributed to the failure of the power stations, transformer supports, switch rooms etc. The source of water supply in Tangshan is underground water. The water wells were undamaged while most of the troubles came from collapse of pumping houses and breakages of some pipelines. Such experience reminds us that the importance of a structure should be appraised from the consequence (inclusive of direct and indirect) of its failure. It is quite often that small buildings are considered as auxiliary to the main structure and designed at low standard. Such practice should not be continued.

GROUND MOTION

The main shock had been recorded at five strong-motion stations: two in Beijing, one at Miyun reservoir and two in southern Hobei. The recorded ground motions indicate long durations (more than two min.) and reasonable peak values (56-73 gals horizontal in Beijing). There were no instruments deployed in the Tangshan area so that we have no knowledge about the ground motion of the main shock in the meizoseismal area. Nevertheless, the various earthquake effects give us some impressions upon the nature of the motion.

It seems that the ground motion was highly complicated in spatial distribution. According to inquiries among the survivors, some people described the most violent motion as a back-and-forth movement like "sifting" while others described it as an up-and-down movement like bumping on roads. Some persons were tossed from bed to floor while some others could manage themselves to get to the door. Some families in bungalows had their things overturned and scattered around while their neighbors had everything remaining in order. It is also not uncommon that similar buildings at same

locality behaved quite differently, such that some collapsed and some remained standing (see Fig. 19). The shaking could be extremely violent, probably much more violent than we thought. As witnessed by the survivors, most buildings were not failed by long duration of shaking but by a few shocks in a few seconds and persons awaked from bed even had no time for hiding under the bed. Apparently the structures were failed by a few cycles of very high stress caused by intense impulsive ground motion. The failure patterns of structures as shown in Figs. 8, 11 and 15 may be interpreted by this type of failure. In contrast with the field experience, it is unfeasible to reproduce the same type of failure on model buildings in dynamic tests even excited to large amplitude. There is a controversy about the vertical component of ground motion. It was reported, although not well confirmed, that some persons were tossed upward. In one case, an old woman, when awaked by the earthquake, held a child in arms and sat on a heatable brick bed and when the shock was over, she found herself unharmed and sitting on the collapsed roof with the child in arms. It was wondered how it could be if she had not been tossed up above the brick bed. It was speculated that the vertical acceleration had exceeded the gravity by a great deal. Another thing is the peculiar failure pattern of brick chimneys, where a number of circumferential cracks and dislocations were formed at the upper portion of the chimney as shown in Fig. 20. This pattern of failure had occurred repeatedly in recent earthquakes and has been attributed to the multiple reflection of longitudinal stress wave in a paper by Qian Peifeng. However, eyewitnesses during the earthquake said that the chimneys were shaken like snakes and many others still believe that the failure is due to transverse vibration.

Overall, the ground motion in the meizoseismal area of a large earthquake is complicated by the effect of source mechanism, the interference of all kinds of waves at the ground surface and the inelastic properties of the medium due to large deformation and ground cracks. It is bound to be erratic, violent, nonuniform and of multi-components. Before its characteristics are clarified, there would be no sound basis for engineering designs. It is highly desirable to gain knowledge about it by all means. The most prudent approach is to carry out extensive strong-motion programs in active seismic zones. In spite of large expense and long time required to achieve the task, it remains to be the invariable way of getting conclusive results. Other approaches are by deduction from the source mechanism and the strong-motion records at remote distance and by inference from the failure of simple and typical structures. As revealed by the Tangshan earthquake, it seems justifiable to have these approaches well explored.

CONCLUDING REMARKS

The problems brought up by the Tangshan earthquake are not new; they have been repeatedly encountered in the past earthquakes. But the Tangshan earthquake was a serious case history that deserves special study. It should be noted that the serious consequences of the Tangshan earthquake are due to the coincidence of the occurrence of a large earthquake with a large city and such coincidences have been steadily increasing in recent decades. This is a natural result of the growing population and the industrial development of the world. The situation will be even more grave in future and yet the state-of-the-art is not prepared for it. It is hoped that research interests will be directed to cope with this situation and the problems raised in the paper shall receive the attention of the earthquake engineers.

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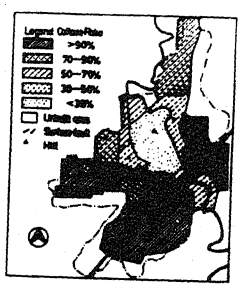


Fig.4 Distribution of collapse ratio for multistory brick buildings in Tangshan City

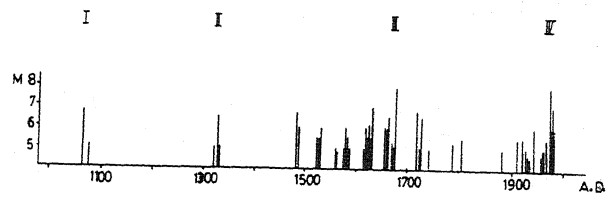


Fig 1 Temporal distribution of historical earthquakes

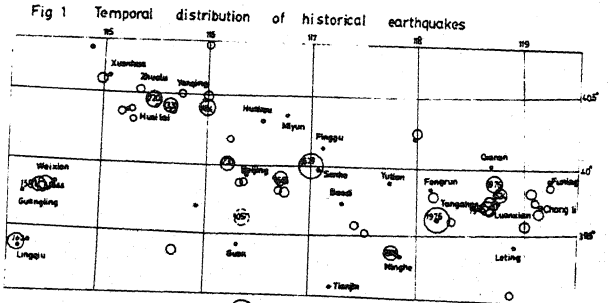


Fig 2 Epicenter Map of Yanshan Seismic Belt

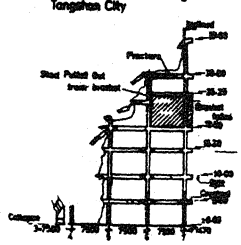


Fig.10 Collapse of R.C. right frame (Qushe power plant)

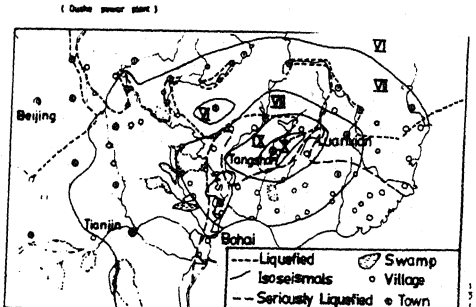
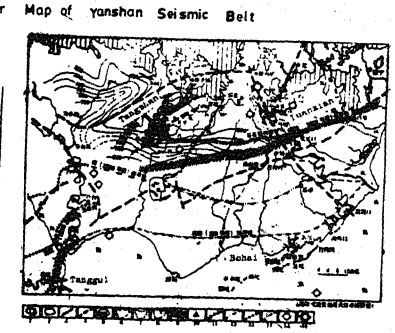


Fig13 Liquefied Area



1 - mountainous area
3 - active fault
4 - inferred active fault
5 - isopach, Quaternary deposit
12 - coast line, [illegible] yrs. ago
14 - coast line, [illegible] yrs. ago
15 - epicenter, M = 6-7
16 - epicenter, M ≥ 7

Fig. 3 Tectonic features of Tangshan district (After Guo Shunmin, reproduced from Scientia Geologica Sinica, p.310, 1977)

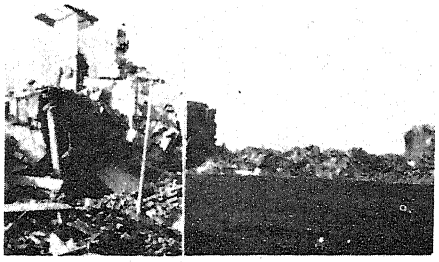


Fig. 5

Fig. 6

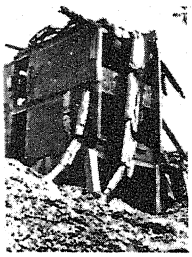


Fig. 8

Fig. 7

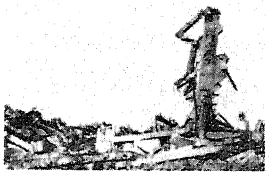


Fig. 9

Fig. 11

Fig. 12

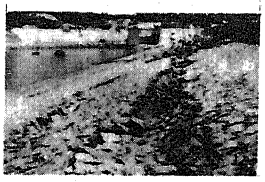


Fig. 14

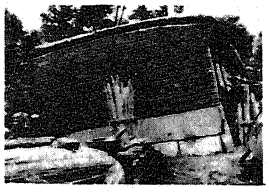


Fig. 15

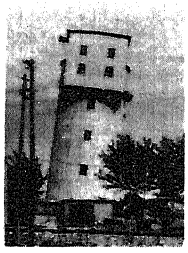


Fig. 16

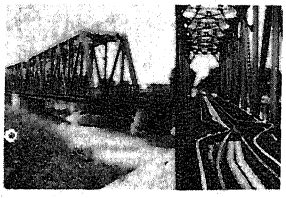


Fig. 17

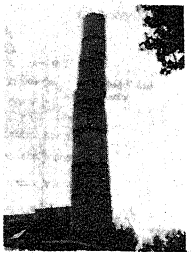


Fig. 20

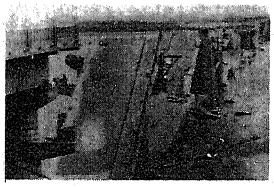


Fig. 18

Fig. 19