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LESSONS LEARNED FROM RECONSTRUCTION FOLLOWING A DISASTER: ENHANCEMENT OF REGIONAL SEISMIC SAFETY ATTAINED AFTER THE 1976 TANGSHAN, CHINA EARTHQUAKE

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Comparing an estimated death toll in the reconstructed environment of Tangshan in 1991 with the actual deaths in the 1976 earthquake, we evaluated the enhancements in seismic safety attained during the reconstruction. It was found that while the most severely affected area was remarkably improved, the less severely affected area was not rebuilt to the standards of the most severely affected area. The increased safety of the most severely affected area can be attributed to the reinforced concrete elements of the buildings. The hazardous situation in the less severely affected area is due to the collapsible nature of the unreinforced masonry construction.

Key Words : earthquake disaster, safety assessment, reconstruction, Tangshan earthquake, China

1. INTRODUCTION

Enhancements in regional safety from earthquakes often take place in the reconstruction following a devastating disaster. There were many cases where an earthquake flattened seismically vulnerable buildings and, subsequently, replaced those with sufficiently strong ones.

In spite of this general recognition, virtually no attempts to seriously examine the tendency in an organized, quantitative way have been carried out. Reconstruction of seismically affected areas was often discussed from the view point of urban and land-use planning, but was not examined in a careful manner from the view point of disaster mitigation.

In this study, we evaluated the regional seismic safety of the affected area of the 1976 Tangshan earthquake before and after the earthquake and carried out a comparison. The purpose of this case study was to elucidate the nature of the safety enhancements that were attained during the reconstruction.

We used the number of deaths, or its reciprocal, as the index to indicate the relative seismic safety of the area. We evaluated an environment having a large death toll, either actual or estimated, unsafe and that having a small toll safe.

To evaluate the seismic safety of the reconstructed area, we used a hypothetical recurrence of the 1976 earthquake as the seismic input. We compared the estimated deaths in the reconstructed environment in 1991 with the actual death toll of the 1976 earthquake. We included the change in the construction type of dwelling structures, as well as the population.

This idea can be compared to a shake table test having two different test pieces and the identical table movement. The two test pieces were the pre-event and the post-reconstruction environment of the affected area. The table movement was the ground shaking of the Tangshan earthquake. While the pre-event environment was actually shaken by the 1976 earthquake, the post-reconstruction environment had to be virtually shaken by a hypothetical earthquake having the identical ground shaking with the 1976 earthquake. As the seismic input to the post-reconstruction environment, we used an isoseismal map of the 1976 earthquake.

Actual seismicity of the case study area was not examined, since we did not try to carry out damage assessment for the "next" earthquake. We rather

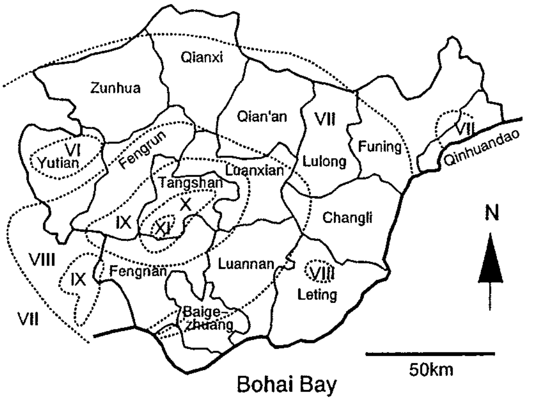


Fig. 1 Map of the case study area (Isoseismals after Yang, 1985[2]).

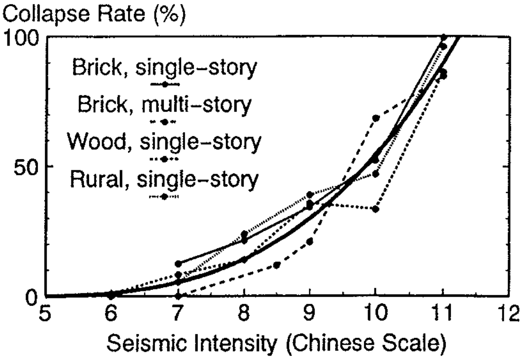


Fig. 2 Collapse rate functions of the buildings affected in the 1976 Tangshan earthquake.

focused our attention on the change in regional seismic safety in the consequences of devastation by the earthquake. Our discussion in this paper, in other words, excluded time and space related nature of disaster agent, or local earthquake activity, which is still not available, in most part of the world, as information applicable to practical decision making in disaster management.

An earlier version of this paper[1] was presented at the Second International Conference on Continental Earthquakes, October 7-10, 1992, Beijing, China.

2. INTERPRETATION OF DAMAGE DATA OF THE TANGSHAN EARTHQUAKE

(1) Study Area

As the case study area, we selected a region consisting of the city of Tangshan and the Tangshan municipal district at the time of the disaster (**Fig. 1**). The municipal district included the city of Qinhuandao, 12 counties, and one agricultural district. In 1975, the case study area had a geographical area of 16,500 km^2 and a population of seven million, which has been increased by one million by the time of our investigation in 1991. In the 1976 earthquake, 205 thousand people were killed within this area, which corresponds approximately 85% of the total deaths in the disaster.

Among the 15 administrative units in the area, the city of Tangshan, which is the urban center of the region, was the most severely affected by the earthquake. The other 14 units, which were essentially an agricultural area encompassing the city, were less severely affected compared with the city. We estimated the number of deaths for the following two parts, respectively:

a) The most severely affected part (City of Tangshan)
b) Less severely affected part (Surrounding rural area).

(2) Building Vulnerability

We collected published data on the building damage in the 1976 event[3), 4)] to enumerate collapse rate functions for the dominant construction types (**Fig. 2**). We defined "collapse" as damage in which a building is affected "beyond repair" and gave the collapse rate function as the relationship between seismic intensity and collapse rate.

We came up with a general expression of collapse rate function as follows:

$$C(I)=\frac{100}{(I_{100}-I_0)^n}(I-I_0)^n \qquad (1)$$

where

C: Collapse rate (%)
I: Seismic intensity (Chinese scale)
I_0: Seismic intensity defined as C=0 at $I \leqq I_0$
I_{100}: Seismic intensity defined as C=100 at $I \geqq I_{100}$
n: Coefficient that accounts for the non-proportional characteristics between seismic intensity and collapse rate.

The equation has three arbitrary quantities, I_0, I_{100} and n, which we determined from the damage statistics applying the method of simplex optimization. We derived a set of coefficients: I_0=4.39, I_{100}=11.2, and n=3.1 to represent the relationships shown in **Fig. 2**. Since the difference in collapse rate among construction types was small, we derived a single relationship. Shiono[5)] described the details of this procedure in a previous paper.

Table 1 Distribution of the Death in the 1976 Tangshan Earthquake (Wang et al., 1986[7])

Area	Deaths
City of Tangshan	135,919
Surrounding Rural Area	69,065
Total	204,984

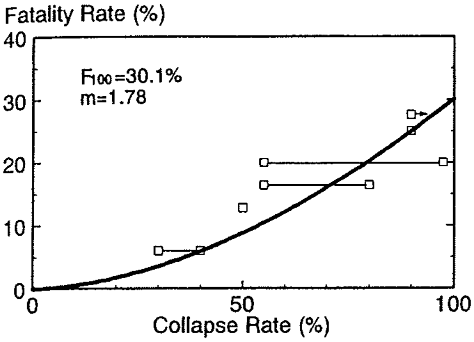


Fig. 3 Fatality rate function. Pairs of squares connected with horizontal bars show the range of collapse rate for an area in which a fatality rate was indicated.

(3) Fatality Rate Function

Referring to several casualty data collected from earthquake disasters worldwide[6], we gave a general expression of the fatality rate function as seen in Eq. (2). We defined the fatality rate as the percentage of fatalities among the total population of an area and determined the fatality rate function as the relationship between collapse and fatality rates.

$$F(C)=F_{100}C^{m} \qquad (2)$$

where

F: Fatality rate (%)

C: Collapse rate of buildings (%)

F_{100}: Fatality rate at C=100

m: Coefficient that accounts for the non-proportional characteristics between collapse and fatality rates.

The distribution of the deaths in the 1976 earthquake shown in **Table 1** came from a report by Wang et al.[7]

Using the method of simplex optimization, we determined the arbitrary quantities in Eq. (2) with a condition that the equation derives the best approximation to the above distribution. Shiono[5] described the details of this procedure in one of his previous papers. We determined the optimum coefficients as follows:

F_{100}=30.1

m=1.78.

In **Fig. 3**, in addition to the fatality rate function, we, using pairs of squares connected with horizontal bars, showed fragmental data of the relationship between seismic intensity and fatality rate. We collected those data from publications on the 1976 earthquake. The data are consistent with the fatality rate function that we derived on the basis of the spatial distribution of the deaths.

3. ESTIMATION OF FATALITIES IN THE RECONSTRUCTED ENVIRONMENT

(1) Method

To estimate a death toll, we used an equation as follows:

$$D=\int_0^{2\pi}\int_0^{\infty}[\Sigma(S_c\rho d_c(f_c(I))]drd\theta \qquad (3)$$

where

D: Total deaths

S: Rate of population dwelling in each construction type

ρ: Population density (ρ=ρ(r, θ))

d: Fatality rate (Deaths/Population)

f: Collapse rate of buildings

c: Suffix to indicate construction type

I: Seismic intensity (I=I(r, θ))

r: Distance

θ: Azimuth.

We gave regional characteristics in terms of the distribution of population and the construction types of local buildings. Referring construction type, we gave collapse and fatality rates, which eventually affect a death toll. We have already confirmed the accuracy of this procedure[9), 10)].

(2) Building Vulnerability

a) The Most Severely Affected Area (City of Tangshan)

One of the most significant aspects during the reconstruction after the earthquake was the change in the dwelling type in the most severely affected area. Single-story houses, which were mainly of unreinforced masonry and wood frame construction having masonry infill walls, were largely replaced with four- to six-story apartment buildings.

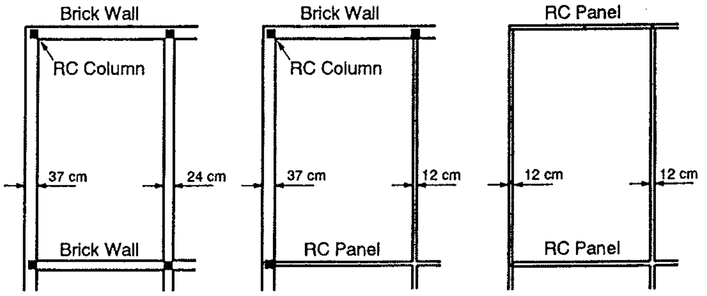
Construction types of the multi-story residential buildings can be seen in **Table 2**, and their wall configurations are shown in **Fig. 4**. Confined masonry construction has earthquake resistant elements of reinforced concrete beams and columns in brick walls. Its seismic capacity obviously

Table 2 Construction Types of Apartment Buildings Built during the Reconstruction of Tangshan

Construction Type	Relative Number of Buildings
Confined Masonry Load-bearing brick walls are reinforced with RC columns and lintels.	25%
Composite Outer walls are composed of brick walls, and inner walls are composed of RC panels. Both outer and inner walls are load-bearing components.	50%
RC Panel Both outer and inner walls are composed of RC panels and are load-bearing components.	25%

Table 3 Comparison of Building Types

Existing in Tangshan	Classification in an SSB publication
Confined Masonry	Intermediate between Brick Masonry and Multi-Story RC Buildings without Seismic Design
Composite	Multi-Story RC Buildings without Seismic Design
RC Panel	Multi-Story RC Buildings with Seismic Design



Confined Masonry Composite Panel

Fig. 4 Wall configurations of the apartment buildings employed in the reconstruction from the Tangshan earthquake.

exceeds that of unreinforced masonry construction, but falls below that of composite construction. The composite construction, which has interior walls of reinforced concrete panel, seems to perform better than the confined masonry against ground shaking. However, while reinforced concrete panel buildings can be regarded as an earthquake proofed system, the composite buildings were not built to the standards of the panel system.

We gave a collapse rate function for each of the three construction types, referring to the assessment done by State Seismological Bureau of China[8]. The functions are shown in **Fig. 5** with the SSB evaluation. Since the assessment of damage rate by SSB was given only in the range of seismic intensity between six and nine, we extrapolated the assessment using the general expression of the collapse rate function given in Eq. (1).

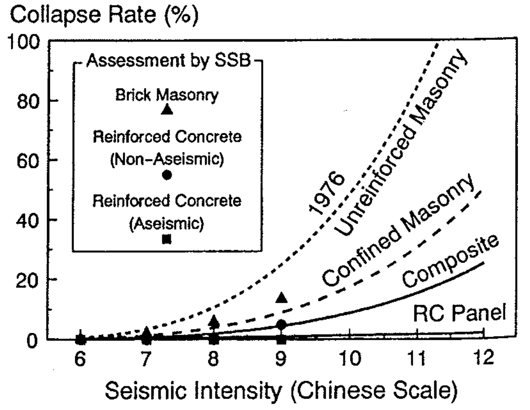


Fig. 5 Collapse rate functions for the apartment buildings in the reconstructed city of Tangshan.

Table 4 Estimated Deaths and Their Comparison with the Data of the 1976 Tangshan Earthquake

	Deaths (Fatality Rate)	
	Data (1976)	Estimate (After Reconstruction)
City of Tangshan	136,000 (11.4%)	8,000 (0.5%)
Surrounding Rural Area	69,000 (1.1%)	21,000 (0.3%)
Total	205,000 (2.8%)	29,000 (0.4%)

Table 3 shows a comparison between the existing construction types in Tangshan and those employed in the SSB publication for a general classification.

To estimate the relative number of apartment buildings by construction type, we carried out a small field investigation in July 1991[11]. We visited 21 residential quarters to inspect the wall material, both the exterior and interior, distinguishing brick from reinforced concrete. The results are shown in the right column of **Table 2**. We estimated the population in each construction type, which we needed in the calculation of deaths, assuming it proportional to the relative number of buildings by construction type (see Eq. (3)). In the investigation, we also confirmed that the size of residential buildings, or the number of living units in a building, is essentially the same with no distinction of construction type. This observation was a good evidence to support the above assumption.

b) Less Severely Affected Area (Surrounding Rural Area)

In the surrounding rural area, unreinforced brick masonry was employed even during the reconstruction. In addition, in the usual renewal of residential buildings these days, unreinforced masonry construction is still being used. According to the SSB assessment[8], the present brick buildings are considerably stronger than those existing at the time of the disaster. Two collapse rate functions for pre- and post-1976 brick buildings are shown in **Fig. 6**.

A plausible collapse rate function that assesses the vulnerability of the existing buildings in the reconstructed environment should be given between these two functions. To simplify our discussion in this paper, however, we used the lower assessment proposed by SSB, which accordingly implies a low estimate of fatality.

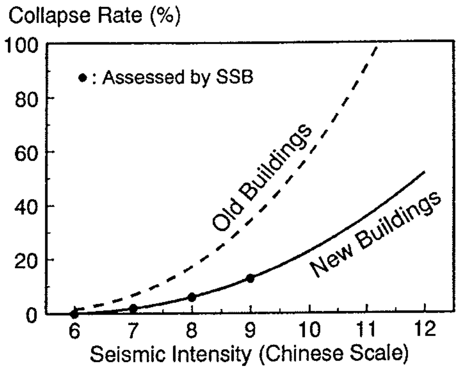


Fig. 6 Collapse rate functions of brick houses in the surrounding rural area.

(3) Estimated Fatalities

Applying our assessment model, of which simplified expression is shown as Eq. (3), we estimated the fatalities in a hypothetical recurrence of the 1976 earthquake (**Table 4**). The collapse rate functions shown in **Figs. 4** and **5** were used in this estimation. Coefficients to determine those collapse rate functions were: $I_0=4.3$, $I_{100}=11.2$, and $n=3.1$ for unreinforced masonry, $I_0=4.1$, $I_{100}=13.7$, and $n=3.6$ for confined masonry, $I_0=4.1$, $I_{100}=15.7$, and $n=3.6$ for composite, and $I_0=4.1$, $I_{100}=34.6$, and $n=3.6$ for reinforced concrete panel. Seismic intensities higher than 12, such as 13.7, 15.7, and 34.6 are notional, which we employed for the sake of convenience in calculation. We also used the fatality rate function, Eq. (2) with $F_{100}=30.1$ and $m=1.78$, that was derived from the fatality data of the 1976 earthquake.

We used a fatality rate function that we derived from the data of fatalities attributed to the collapse of buildings having masonry walls. Therefore, our assessment for the city of Tangshan may have resulted in an over-estimate. Buildings in the present city of Tangshan have large structural elements, including reinforced concrete columns, beams, and panels. This means a longer survival time for those trapped in the collapsed buildings and, consequently, a better chance of live recovery[12].

4. DISCUSSION

Regional seismic safety of the city of Tangshan, which the 1976 Tangshan earthquake affected most

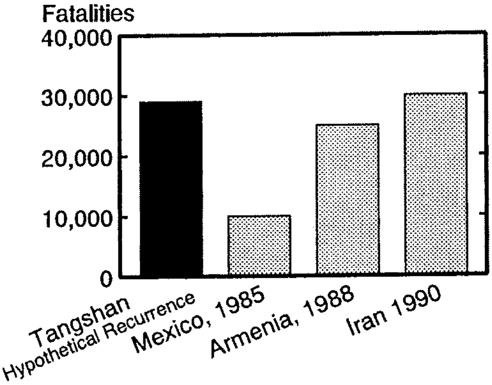


Fig. 7 Comparison of death tolls among recent "first-class" earthquake disasters worldwide.

severely, was remarkably improved during the reconstruction. The death toll estimated in the reconstructed environment for a hypothetical recurrence of the 1976 earthquake was almost 1/20 as small as the actual human loss in the 1976 disaster. Since we used a fatality rate function that was expected to provide a higher estimate, the estimate can be reduced even further.

In the surrounding rural area, in contrast, improvements in regional safety were carried out to a sizable extent, but did not reach the level of the city of Tangshan. Deaths in the reconstructed environment were estimated to be twenty thousand, while the actual death toll of the corresponding area in the 1976 earthquake was seventy thousand. Since we used a collapse rate function that conceivably gave a lower estimate, the estimate can be considerably increased.

The total number of estimated deaths in the entire case study area was still in the order of several tens of thousands, although the toll was expected to decrease to less than one-seventh. The estimated death toll was comparable with those of the recent major disasters including the 1985 Michoacan, Mexico earthquake, the 1988 Armenia earthquake, and the 1990 Manjil, Iran earthquake, where death tolls of ten thousand, twenty-five thousand, and thirty-five thousand were reported, respectively (**Fig. 7**). The affected area of the 1976 earthquake could suffer a "first-class" disaster, despite the regional safety enhancements that actually took place.

From the viewpoint of regional planning for safety development, enhancements in the seismic safety in Tangshan is characterized as a case achieved at a "point" rather than an "area." Only the earthquake safety in the most severely affected area, or at a point, was remarkably upgraded during the reconstruction, while that in the less affected area, which was located very close to the point, was less than sufficient. The remarkable enhancement in seismic safety successfully attained at the point did not spread over the area around the point.

From a building quality point of view, seismic vulnerability of unreinforced masonry construction, as well as its lethal nature, is a significant issue warranting a discussion. We pointed out that the hazardous environment still existing in the area is attributed to buildings of such a type. Structural quality of unreinforced masonry buildings has been considerably improved these days, but is still and essentially inferior to that of buildings constructed with attention given to earthquake safety, including confined masonry and reinforced concrete buildings.

5. CONCLUSIONS

By assessing the improvements in earthquake safety attained in the reconstruction following the 1976 Tangshan earthquake, we discussed the nature of the safety enhancements for the city of Tangshan and its vicinity. We compared the estimated death toll in the reconstructed environment with the actual deaths in the 1976 disaster. We calculated the deaths using a hypothetical recurrence of the 1976 earthquake as the seismic input.

It was found that the city of Tangshan, which was damaged the most in the affected area, was remarkably improved regarding safety against earthquakes, but the surrounding rural area, which was less severely damaged, was not rebuilt to the standards of the city. The increased safety of the city can be attributed to the seismic-resistant elements of the apartment buildings including reinforced concrete columns, beams and wall-panels. The hazardous environment still existing in the surrounding area is due to the unreinforced masonry construction, of which earthquake capacity was gradually upgraded after the disaster, but is essentially inferior to that of the buildings constructed within the city.

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