

# **The Great Tangshan Earthquake of 1976**

**Overview Volume**

Earthquake Engineering Laboratory  
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Pasadena, California 91125  
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# THE GREAT TANGSHAN EARTHQUAKE OF 1976

Overview Volume to the English Version

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## Report On

# THE GREAT TANGSHAN EARTHQUAKE OF 1976

Chinese Version

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## PROLOGUE

At 4:00 a.m. on July 28, 1976 the city of Tangshan, China ceased to exist. A magnitude 7.8 earthquake was generated by a fault that passed through the city and caused 85% of the buildings to collapse or to be so seriously damaged as to be unusable, and the death toll was enormous. The earthquake caused the failures of the electric power system, the water supply system, the sewer system, the telephone and telegraph systems, and radio communications; and the large coal mines and the industries dependent on coal were devastated. The railway and highway bridges collapsed so that the city was isolated from the external world. Before the earthquake Tangshan had 1,000,000 inhabitants and it has been estimated that about one half were killed. Although the building code had seismic design requirements, Tangshan was in a zone requiring no earthquake design.

An earthquake disaster requires a large earthquake efficiently close to a large city to produce destructive ground shaking and that the city has buildings not designed to resist earthquakes. The Tangshan disaster met all these requirements and the result was the greatest earthquake disaster in the history of the world. Many countries have cities whose situation is similar to that of pre-earthquake Tangshan, that is, an estimated low probability of being struck by destructive ground shaking and many buildings with low seismic resistance so this report should be of special interest to engineers, architects, and government officials in these seismic countries. The report shows what can happen when an unexpected earthquake strikes an unprepared city and it makes clear the need for earthquake preparedness even if the probability of an earthquake is assumed to be low.



# **An Introduction and Historical Summary of the Tangshan Earthquake**

## **PREFACE**

In July and August of 1978 the Earthquake Hazards Reduction Delegation from the United States visited the People's Republic of China. The visit was arranged jointly by the U. S. Committee on Scholarly Communication with the People's Republic of China--sponsored by the National Academy of Sciences, the Social Science Research Council, and the American Council of Learned Societies--and the Scientific and Technical Association of the People's Republic of China. The Earthquake Hazards Reduction Delegation, chaired by Professor George W. Housner of the California Institute of Technology, was composed primarily of earthquake engineers and had as its purpose to learn about earthquake engineering research and practice in China. During its visit the Delegation received extensive briefings about the effects of the Tangshan earthquake of July 28, 1976 from Chinese earthquake engineers and scientists. Upon return to the United States, the Delegation prepared a report on its visit, a report that included a summary of the Tangshan earthquake and its effects. This introduction and historical summary is adapted from chapters 3 and 4 of that report by Professor Paul C. Jennings of the California Institute of Technology, the editor of the Delegation's report (Jennings, 1980)\*. It provides a historical summary of the earthquake, as well as a description of various aspects of the state of the art of earthquake engineering in the People's Republic of China as seen by the Delegation in 1978.

## **THE CHINESE INTENSITY SCALE (HSIEH, 1957)**

The seismic intensity scale used in the People's Republic of China in 1978 consists of 12 deg (degrees), corresponding approximately to the Modified Mercalli intensity scale and other 12-degree scales. The zones in the Seismic Design Code for Industrial and Civil Construction are based on estimates of the maximum intensity that is likely to be experienced in each region.

The scale makes use of the following classification of buildings.

- Class I      Adobe houses, mud houses, rural structures, and houses built with stone.
- Class II     Old wood frame buildings and buildings with small wooden columns but without a well-built wooden frame.
- Class III    One story multistory modern brick buildings, well-built wooden structures, reinforced concrete buildings, and mill (industrial) buildings.

The scale describes the intensity of the earthquake in terms of observations of the effects on class I, II and III buildings, other structures, ground surface phenomena (including changes of surface and subsurface water conditions), and other phenomena.

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The brick buildings that were built in large numbers in China after 1949 are similar, at least in their general features, to those in European countries and may be used as a guide to correlating the Chinese and Western intensity scales.

## SEISMIC ZONING

In the Chinese building code in effect in 1978 design requirements including lateral forces are keyed to a “basic intensity” in the Chinese intensity scale. The responsibility for establishing this basic intensity throughout the country rests with the State Seismological Bureau (SSB) in Beijing. Locally, this basic intensity may be modified to reflect local soil conditions.

By 1978 basic intensities had already been established for many and perhaps all parts of the country. For example, the Delegation was told that the basic intensity for Beijing was VIII. Before 1976, the basic intensity for Tangshan was VI; it had since been revised to VIII. The Delegation did not see an existing zoning map for the country, but was shown at the State Seismological Bureau a proposed new map in an advanced stage of development. This map is at a scale of 1:3,000,000. The main feature that catches the eye is the detailed and rapid variation of intensity with distance, with rather small and often irregularly shaped zones. The map gives “the intensity to be expected during the next 100 years,” but the Chinese did not say just what probability was implied by this statement. The map was essentially complete at the time of the visit and was expected to be published soon for discussion and adoption. Teng Chi-tung of the State Seismological Bureau in Beijing described to us the general methods used in preparation of the map.

There had been four general steps in the development of the seismic zoning map. The first step divided the country into a number of regions and subregions, on the basis of seismic history, tectonics, and geology. The map at this step contained perhaps one to two dozen regions, some quite large and others rather small. The second step involved establishing for each region the magnitude of earthquake “expected during the next 100 years,” and the third step determined where in each region these magnitudes were expected to occur. The result at this point was a map giving the geographical variation of “expected magnitude.” The final step mapped the intensities resulting from the expected magnitudes. Most of the presentation dealt with the second and third steps.

Various methods had been used to estimate the expected magnitude, the choice apparently being dictated by the anticipated periodicity in earthquake occurrence. In northern China, four types of periodicity were recognized, having intervals of about 300, 100, 50 and 30 years. It was also recognized that in some regions there may be seismic gaps along fault zones which may have even longer intervals between major earthquakes.

Where the period is near 300 years, the Chinese used a standard time sequence of events. In the earliest stage of each cycle, earthquakes less than  $M = 6$  can occur. In the next stage there can be earthquakes around  $M = 6.8$ . The main stage may see earthquakes up to  $M = 8.5$ , or several somewhat smaller shocks near  $M = 7$ . Finally, earthquakes in the  $M = 6.5-7$  range can occur in the fourth stage. Choice of the expected magnitude then depends upon the stage deemed appropriate for the next 100 years.

When the cycle is relatively short, the Gutenberg-Richter relation,

$$\log_{10} N = a - bM$$

was used to predict for the next 100 years. In this equation,  $M$  is the magnitude,  $a$  and  $b$  are constants, and  $N$  is the number of earthquakes greater than or equal to  $M$  per year per unit area. From the census of historic earthquakes, the  $a$  and  $b$  values in this relation for various regions are analyzed to give an estimate of the average recurrence of earthquakes of various magnitudes.

In cases where a seismic gap along a fault zone is suspected, various gap-filling theories were used. As an example the Delegation saw a diagram of how certain gaps were filled by major earthquakes. A correlation was developed between length of gap  $L$  and the possible magnitude  $M$ :

$$M = 3.16 \log L - 0.31$$

( $L$  in kilometers) based upon past earthquakes that were judged to have filled gaps.

Once the time pattern for earthquake occurrence in a province has been established from historic seismicity, geologic and tectonic evidence was employed to determine the locations of the expected earthquakes. Fault activity was analyzed, the shapes of basins were considered, and ground deformation and crustal thickness provided further criteria. Several kinds of basins were considered most indicative, including grabens, asymmetric basins bordered on one side by faults, and young (Neogene) basins. Areas in which the gradient of ground deformation is steepest were considered likely sites. The margins of major crustal blocks as defined by crustal thickness were also prime targets.

To translate from expected magnitude to epicentral intensity ( $I_0$ ), a relation was developed based upon statistical analysis of 150 earthquakes:

$$M = 0.66I_0 + 0.98$$

This is essentially the relation used in the United States at that time. Various studies of attenuation of intensity with distance were mentioned during the brief visit to the SSB but were not described.

## **MICROZONATION**

The earthquake resistant design standards for the People's Republic of China in 1978 describe four classes of soil:

- Category I     Slightly or intermediately eroded rocky ground.
- Category II    Firm ground other than that falling under categories I and III.
- Category III    Sandy mud or muddy ground, deposits of silt, organic soils.
- Category IV    Soil that may liquefy.

Indices for classifying soils into these categories are available in a foundation design standard. The design lateral force specified by the building code increases (except at very small periods) in going from category I to category II to category III, and certain design requirements also become more demanding. The Delegation learned that it is the responsibility of the designer of a building to classify the soil at the site.

During the visit, several research studies were described. It was suggested that these studies might eventually be the basis for preparing microzoning maps.

## **DESIGN AND CONSTRUCTION PRACTICES IN 1978**

A special interest of the Delegation was to observe how the research and knowledge in earthquake engineering were translated into actual construction. Consequently, the team requested, and was given, the opportunity to visit various construction sites and to inquire about materials, procedures, and details. Everywhere they went in China there was much construction activity, and the Delegation was able to assure itself that the projects it examined in detail were representative.

The team had the impression that all available building materials were being used. Generally, construction was for housing, with many structures in the 5- to 12-story range. The two most common types of construction for multistory buildings were (1) a combination of precast and poured concrete for walls, frames, and floor slabs and (2) unreinforced brick walls with precast concrete floor slabs. Some projects combined precast concrete, cast in situ concrete, and unreinforced brick.

### **Beijing**

Buildings under construction in Beijing in 1978 were designed by the Beijing Institute of Architectural Design for an earthquake of intensity VIII on the Chinese scale. The State Capital Construction Commission had responsibility for construction, and this organization arranged for visits to three sites in Beijing. The first and third projects were similar 12-story apartment buildings at different stages of construction. They seemed to typify new apartment construction in Beijing at that time. An exterior view of the first building visited is shown in Figure 1. The buildings normally contain two stairways, two elevators, and a basement for machinery. The individual living units have central heat, water, gas, and electricity.



Figure 1. Exterior view of typical apartment building under construction in Beijing in 1978. The building has precast exterior walls, precast floors with topping, cast-in-place concrete shear walls, and brick partitions.

The total floor area of the first project visited was 10,000 m<sup>2</sup>, 12 floors, with 13 apartment units per floor (about 55 m<sup>2</sup> per family unit average). The exterior walls were precast concrete. Floors were 13-cm deep, hollow core precast units with a 3½-cm topping. The main interior walls were cast-in-place concrete, with one longitudinal wall running the full length of the building, and with cross-walls at alternating 5.1- and 4.5-m spacing. The cross walls were bearing walls; there were no beams or columns in the structure.

The concrete walls were 16 cm thick, with the precast floor slabs bearing on 5 cm of the wall on each side. Prestressing tenons of the floor slab project into the wall to tie the floor to the wall. The interior subdivisions of apartments are nonstructural brick walls.

The construction procedure was somewhat different from that one might expect. A floor was completed structurally on a 4-day cycle (with two 8-hour shifts). First the cross walls were poured, leaving blockouts for the longitudinal wall reinforcing. Then the reinforcing is placed for a longitudinal wall, and the steel wall forms are placed in position. The precast exterior wall units are placed in position and supported from the cross walls, as seen in Figure 2. Then the precast floor units are placed for the floor above and the longitudinal wall and the connections of the exterior wall units poured, and the cycle repeated. The topping slab and the precast balconies were added about a floor or two later and were not a part of the basic cycle. With this procedure it was taking approximately 2 months to finish the concrete construction and about 6 months for total building completion.



Figure 2. Exterior view of apartment building in Beijing in an early stage of construction in the summer of 1978. The exterior walls are precast, while interior walls are cast-in-place.

Regarding other details, the team was told that the reinforcing steel had a yield point of  $2,900 \text{ kg/cm}^2$  and that the concrete strength to the fourth floor was  $250 \text{ kg/cm}^2$  and above that,  $200 \text{ kg/cm}^2$ . The foundation under these apartments was clayey sand, and a mat foundation 50 cm thick was used.

The second project visited was quite different. The seven-story future home of the famous Beijing Duck Restaurant is shown in Figure 3. The Delegation was given a detailed and enthusiastic tour of the building by the engineer in charge of the project, who responded to all questions, including a request to examine the structural drawings. The building has a precast concrete frame, designed to take all lateral loads. The concrete details are nonductile in the U.S. sense. The building drawings showed rather complicated joints using flat bar inserts and welding. Since all lateral loads were calculated to be resisted by the frame, the walls are considered to be nonstructural. The exterior walls are brick cavity walls, with one width of brick on the exterior and a lightweight concrete block on the inside. The interior nonstructural walls are of brick of low quality. For example, Figure 4 shows the walls around the elevator enclosure. Note the “leaning soldiers” under the concrete floor beam; this detail was seen often in construction throughout China.



Figure 3. Exterior view of seven-story future home of Peking Duck Restaurant. Restaurants occupy lower five stories, with living quarters for the staff on the upper two floors.



Figure 4. Interior of elevator shaft of Beijing Duck Restaurant showing brick filler walls. Note “leaning soldier” bricks at top, a method of filling space that is not a module of brick dimensions.

## Harbin

The next building projects examined in some detail were in Harbin, where a portion of the Delegation again visited three buildings. The Harbin area was not considered to be highly seismic in comparison to other major cities such as Beijing and Tianjin.

The first building visited was a six-story brick bearing wall structure shown in Figure 5, which was slated to be an electronics factory when finished. Because of the large windows of the top story of the front (street) façade, this portion of the wall has a concrete frame. Aside from this location, there were no columns in this building except at the entry hall. Reinforcing steel in the columns was smooth with ties at about 20-25 cm, center-to-center.

The floors were precast concrete; there were apparently no ties between wall and floor construction. The roof is made of precast channel members supported on steel trusses as shown in Figure 6.

The quality of the brickwork in the building was quite poor by U.S. standards. This appeared typical of masonry construction seen in China at that time. The brick was often soft and the mortar very weak, normally, it could be broken with one's fingers. Head joints were rarely filled, and even the bed joints often have large gaps.

The second project in Harbin was a six-story apartment house shown in Figure 7. This was also a masonry bearing wall structure, but in this case the exterior walls were made of 12-in. thick lightweight concrete block that employed a fly ash aggregate. This provides added insulation for the cold winters (Harbin has the same latitude as Billings, Montana). Interior bearing walls were of brick. In some cases the walls just butted against each other without ties, while at other walls some effort was made to tie the walls together.



Figure 5. Exterior view of six-story brick walled building in Harbin. The structure was intended to house an electronics factory when completed.



Figure 6. Harbin electronics factory. The roof over the small auditorium has steel trusses supporting precast concrete channel sections.



Figure 7. Exterior view of a six-story apartment building in Harbin. Masonry blocks were cast of fly ash concrete.



The third project was an almost complete six-story apartment house shown in Figure 8. It was a part of a large complex of about a dozen similar buildings. The construction was similar to that discussed above, namely, unreinforced brick bearing walls, precast floor units, precast stairs, etc. A portion of one of the walls is shown in Figure 9, illustrating the variability of workmanship in the construction of the wall.

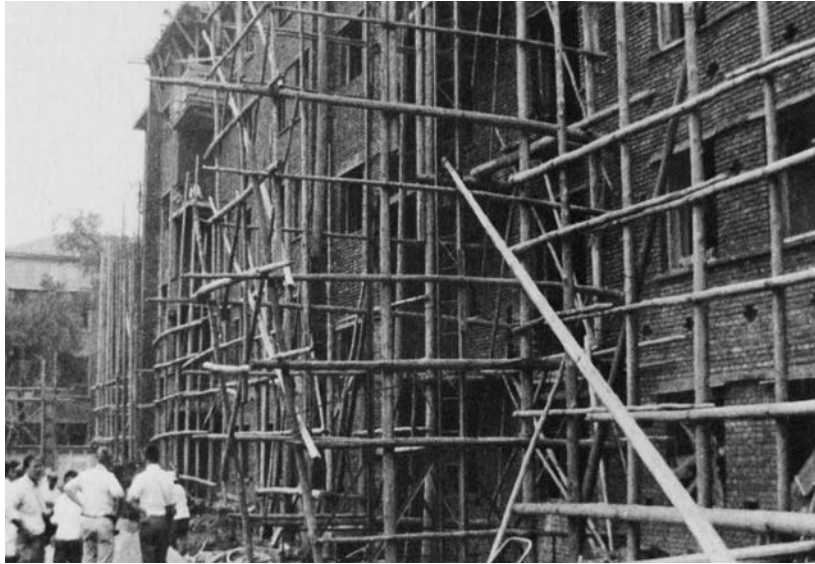


Figure 8. Exterior view, taken in 1978, of a nearly complete six-story brick apartment building in Harbin.

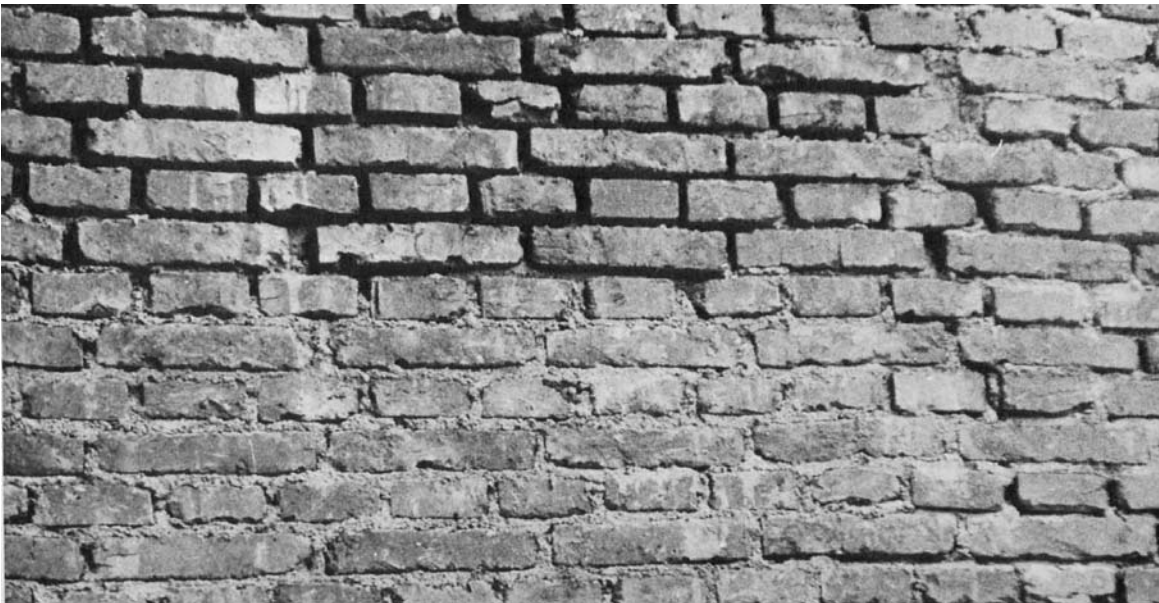


Figure 9. Apartment building shown in Figure 8. At lower left, joints are filled. In the upper portion, head joints are open, and bed joints only partially filled.

## Chengdu

The next construction examined was in Chengdu, the capital of Sichuan Province, which is a city with a population of 750 thousand people. The design intensity in 1978 was VII. The first project viewed was a completed 2-year old split-level parking garage, the only one in the province at that time. It had a cast-in-place concrete frame and floor slab, with infilled brick walls at the ends. The column spacing is 30 ft.

The second project was a nearly completed seven-story apartment house shown in Figure 10. It had brick bearing walls and un-prestressed, precast concrete slabs. Also at this location, a small building with timber trusses and brick columns was noted (Figure 11). Brick columns, such as seen here, appeared to be common in China; also, in rural areas, the Delegation saw adobe columns supporting timber roofs.



Figure 10. Nearly completed seven-story apartment building in Chengdu. The building has brick bearing walls and precast concrete floor slabs.



Figure 11. Timber truss on a small building in Chengdu near the apartment building of Figure 10. Note the unreinforced brick columns, which appeared to be used extensively in China.

The third project was a five- and six-story office and storage building. It was an L-shaped building with expansion or seismic joints at the junctions. It was a concrete frame building with three lightly reinforced brick shear walls.

Figures 12, 13 and 14 show views of the building. The concrete frame was cast in place from the third floor up, whereas the first floor columns and some second-story columns and beams were precast. Floors were precast hollow concrete planks with a topping. When the topping was placed, stirrups (Figure 15) from the cast-in-place beam would tie the slab to the beam where the slabs are parallel to the beam, but the tie to the beam that supports the slab appeared minimal.

Figure 16 shows a cast-in-place column and beam and the forms for the cast-in-place spandrel beam that will be poured next. This sequence results in construction joints through the structural joint itself. There is no provision for shear in the joint, and the detailing provides for little ductility.

The brick shear walls in this structure were made of bricks that have holes, and some light vertical wire reinforcing was inserted. In this case there were dowels to the columns but no keys. In response to a question about the amount of inspection that is customary, the Delegation was told that on this particular project they took samples of the concrete and mortar at each floor and that the job superintendent had special personnel to check the placement of the reinforcing steel. In addition, the design office had three men on the job at all times to inspect the work.

The team next looked at a multistory industrial building under construction (Figure 17), but they were unable to ascertain the function or ultimate height of the structure. The columns, girders, and the beams on the column lines were cast-in-place concrete frame construction, while the intermediate beams and intermediate girts between columns were precast and welded together. This building has a high one-story wing. The frame in this one-story portion was entirely precast, using channels for the roof and precast columns with corbels to support the precast girders (Figure 18). The girder had steel plates inset into the bottom in places, evidently to support a monorail.

## **Guangzhou**

In Guangzhou the Delegation looked at several buildings in general but only one in some detail. This was the nine-story Provincial Seismological Bureau building, which was scheduled for completion in about a month. This building is all cast in place including frame and floors. The walls are of infilled brick of above-average quality, although the mortar seemed weak. In conversations with the engineer of the building from the Provincial Construction Commission he estimated that in that region, 70 percent of the floor slabs are cast in place with the other 30 percent constructed of precast hollow slabs. Before the Tangshan earthquake, Guangzhou was in zone VI; in 1978 it was in zone VII.

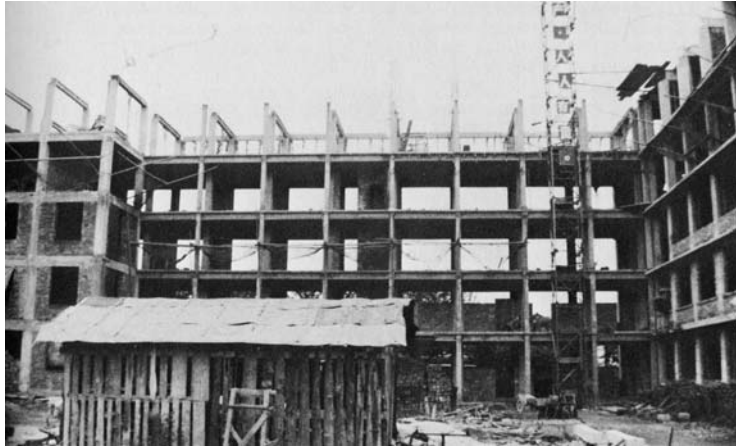


Figure 12. Six-story wing of an office and storage building under construction in Chengdu. The building is L-shaped in plan.



Figure 13. End wall of the five-story wing of the Chengdu office and storage building. The brick walls are lightly reinforced shear walls.



Figure 14. Street façade of the five-story portion of the Chengdu office and storage building.

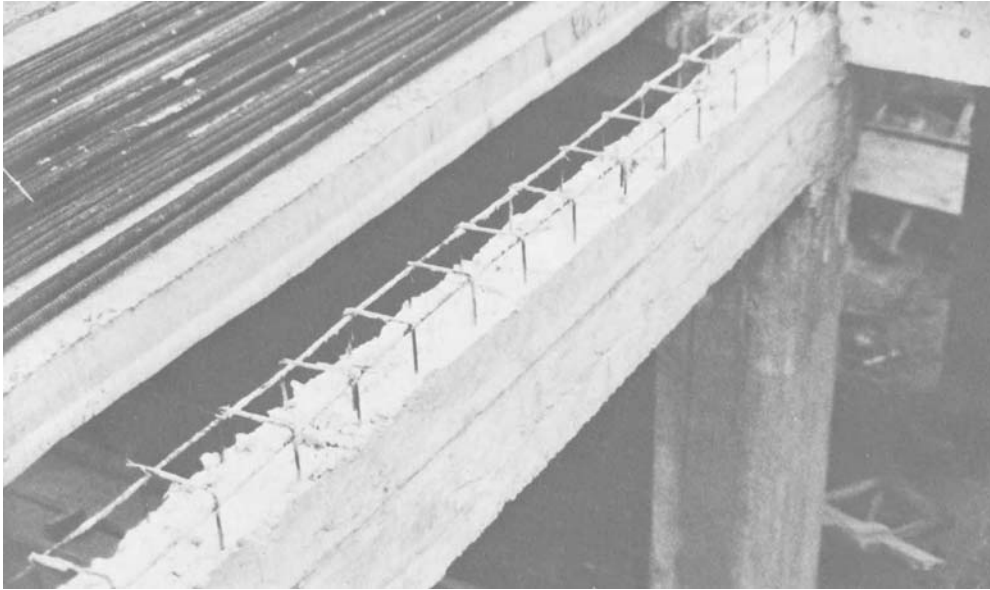


Figure 15. Chengdu office and storage building. In the upper stories, columns and beams were cast in place. Later, precast floor units were placed on the beams. Note ties from beam where beam is parallel to slabs.



Figure 16. The columns and transverse beams have been cast in place in this detail of an upper floor. Forms are in place for the cast-in-place spandrel beam. The joint is integral but a construction joint goes through the center.

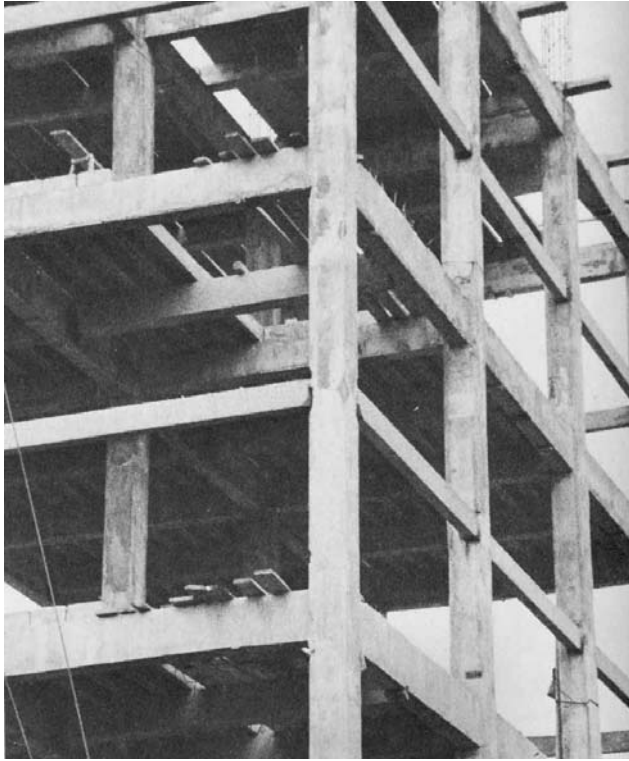


Figure 17. Multistory industrial building in Chengdu. The main frame is cast-in-place concrete, whereas intermediate girts and floor beams were precast.



Figure 18. High one-story portion of Chengdu industrial building was of precast concrete construction. The roof slab was composed of precast concrete channel sections.

## **Seminars**

Several members of the Delegation held discussion meetings with groups of engineers in Harbin, Beijing, and Guangzhou. In these meetings they learned more about their design and detailing practices, and some of their experiences. Some observations resulting from these discussions follow:

The practice of detailing concrete for ductile performance had not been adopted in China. The team saw no such evidence of detailing in the field, and discussions with engineers indicated a lack of general recognition of the need for such detailing. At the Beijing meeting, discussions on masonry and the detailing of concrete confirmed that concrete reinforcing was detailed on the basis of strength alone.

The observed quality of masonry construction lead to questions about quality control and inspection. Some engineers were aware of the problem, but there were no clearly explained measures to improve the situation. In discussing inspection with one responsible engineer the group was informed that for the 10 years under the influence of the "gang of four," manual labor was exalted and respected while intellectual concepts were demeaned. In construction practice this meant that the worker had increased authority and stature with respect to the engineer or inspector. If the inspector tried to disqualify work or refuse to accept poor materials or workmanship, the worker could criticize him. Such a situation could easily lead to a decline in standards of accepted workmanship.

At the Guangzhou meeting with the local engineers, the Delegation discussed concrete reinforcing details. They used much more cast-in-place concrete there than in other places visited in China. Unlike other places, the trim bars around openings had longer anchorage lengths, there were more stirrups, and panel zone stresses were better accommodated. The design practices resembled California practice prior to the adoption of current (as of 1978) American Concrete Institute and Structural Engineers Association recommendations.

## **CODE CHANGES RESULTING FROM TANGSHAN EARTHQUAKE**

After returning from Harbin, the Delegation attended several discussions at Tsinghua University. At the first of these, Gung Shili, Director of Building Research for the State Capital Construction Commission, described the proposed changes to the Chinese Earthquake Code. Mr. Gung was a member of the Delegation that visited the United States in 1976. It had been 3 years since the 1974 Code had been adopted, and in the intervening period, the Haicheng and Tangshan earthquakes had occurred, each causing great structural damage. As a result of those experiences, revisions of the Code seemed necessary, and engineers had been working on various proposals. In the summer of 1978 the proposed changes had been assembled and were out for review by agencies in various parts of the country, and so were tentative. Because of the tentative nature, the Delegation could not obtain a copy but did receive a copy of Mr. Gung's paper which presented the changes in general terms.

Aside from the various technical lessons that were learned from the observation of the damage, the experiences of recent earthquakes indicated that the reliance on prediction of “basic intensities” cannot be complete, so the structures must be designed for higher intensities; that “lifelines,” e.g., transportation, communications, utilities, etc., are necessary after a disaster and need more protection; that loss of industrial capability is not acceptable, so these facilities need more protection; and that the economic impact of the loss of “nonstructural” elements is too great to accept.

## SUMMARY REPORT ON THE TANGSHAN EARTHQUAKE

The Tangshan earthquake, with a magnitude of  $M_S = 7.8$ , originated under the city of Tangshan, Hebei Province, at 3:43 a.m. on July 28, 1976. The epicenter was located in the southern part of the city, and the fault slip progressed through town in a  $N40^\circ E$  direction and also extended in a  $S40^\circ W$  direction to a lesser extent. There was evidence of surface faulting within the city of Tangshan over a distance of approximately 10 km. The aftershock zone indicated, however, sub-surface faulting over a distance of approximately 140 km.

In the past there have been strong earthquakes in the general Tangshan region. As shown in Figure 19, since 1966 there have been four earthquakes of magnitude greater than 7.0: Hsingtai, March 22, 1966,  $M = 7.2$ ; Pohai, July 13, 1969,  $M = 7.4$ ; Haicheng, February 4, 1975,  $M = 7.3$ ; and Tangshan, July 28, 1976,  $M = 7.8$ . These earthquakes occurred in an area approximately equal to that of California, so the earthquake hazard is relatively high in this region.

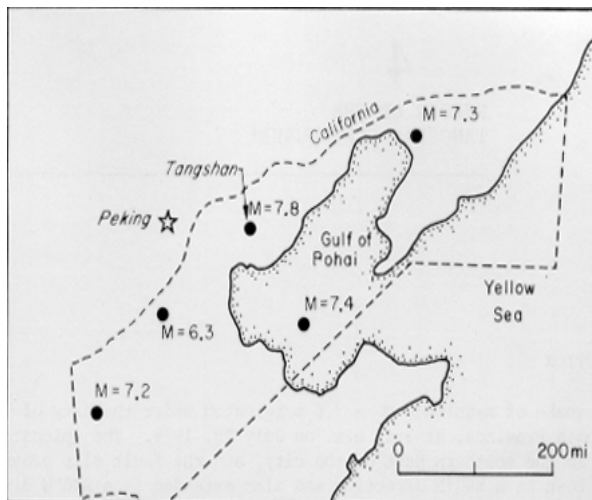


Figure 19. Epicenters of recent major earthquakes in Pohai region: Tangshan, July 28, 1976,  $M = 7.8$ ; Haicheng, February 4, 1975,  $M = 7.3$ ; Pohai, July 18, 1969,  $M = 7.4$ ; Hojian, March 27, 1967,  $M = 6.3$ ; Hsingtai, March 22, 1966,  $M = 7.2$ . The outline of the state of California is shown dotted, so it can be seen that within 15 years there were four earthquakes of magnitude greater than 7 in a region of approximately the same area as California.

The highest intensity assigned to the Tangshan earthquake was XI on the new Chinese intensity scale. As shown in Figure 20, intensity XI covers Tangshan City. The isoseismal contours of intensities greater than IX showed pronounced northeast elongation, reflecting the northeast strike of the causative fault. The areas covered by different intensities (equal to or greater than) were as follows: XI, 27 km<sup>2</sup>; X, 367 km<sup>2</sup>; IX, 1,800 km<sup>2</sup>; VIII, 7,270 km<sup>2</sup>; VII, 33,300 km<sup>2</sup>. The earthquake was perceptible to the



north as far as Harbin and to the south as far as the north bank of the Yellow River in Henan Province; the radius of perceptibility was approximately 1,100 km and the corresponding area was  $3.8 \times 10^6 \text{ km}^2$ .

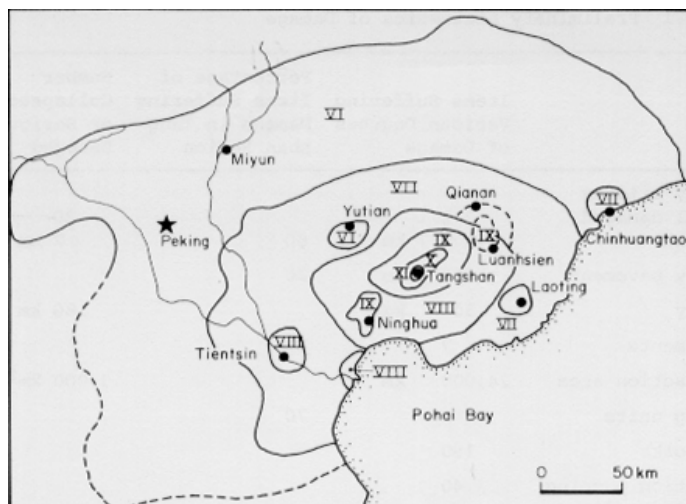


Figure 20. Intensity map of the 1976 Tangshan earthquake. The dotted lines represent a large aftershock. The Chinese intensity scale is similar to the Modified Mercalli intensity scale, but construction in China is quite different from construction in the United States, so that direct comparisons cannot be made.

Tangshan was mainly a city of unreinforced brick buildings. There were 916 multistory buildings (two to eight stories) in the city. Over 85 percent either collapsed or were severely damaged. These were mainly industrial structures and most of the population was housed in smaller, single-story buildings. Subsequent to the visit the Delegation was told by Chinese engineers that 90 percent of the residential dwellings in Tangshan either collapsed or were seriously damaged. In addition, a significant number of buildings in the major city of Tianjin collapsed or were seriously damaged. Dwellings in the cities and the countryside were mainly one-story buildings with very little earthquake resistance, and the collapse of these structures was, no doubt, the cause of the large loss of life which had been estimated as approximately 650,000.\*

Table 1 gives a summary of damage to facilities other than buildings. The extensive damage listed in this table indicates the magnitude of the disaster. Some 500 km of railway lines suffered various degrees of damage; in some cases deformation of the ground caused the rail lines to buckle as shown in Figure 21, and in other cases, settlement of the ground damaged the rail line as shown in Figure 22. Some 228 km of highways suffered various degrees of damage; in some cases the damage was severe, as shown in Figure 23, and there were numerous failures of underground pipelines; one example is shown in Figure 24.

\* The Chinese government had not made an official announcement about the number of casualties at the time of the visit. Estimates ranging from 650,000 to 800,000 had appeared in newspaper reports, but the true number was not known. Hong Kong's *South China Morning Post* in its January 5, 1977, issue stated that a "top secret" Chinese document said that 655,237 persons were killed and another 779,000 were injured. Of the injured, 79,000 were reported to have been seriously hurt. The official death toll was later given by the Chinese government as 275,000.

Public utilities suffered severe damage during the Tangshan earthquake. Approximately 70,000 water supply wells were damaged, which amounted to 64 percent of the wells in the strongly shaken area; and 70 percent of the pumping units were damaged. Soil liquefaction and sand blows were observed in an area of 24,000 km<sup>2</sup>. In the region of severe soil liquefaction (3,000 km<sup>2</sup>), so many sandblows were produced that cultivated fields were damaged by the large quantities of sand, and the harvest was adversely affected. The sand silted up irrigation canals and water wells. Forty earth dams were damaged to a greater or lesser degree. Twenty-eight trains were operating in the area of strong shaking at the time of the earthquake, and seven of these were derailed.

TABLE 1. Preliminary Statistics of Damage

Items	Items Suffering Various Degrees of Damage	Percentage of Items Suffering Damage in Tangshan Region	Number Collapsed or Seriously Damaged
Highway bridges			
Total damaged	231		20
Length	9.7 km	60	2 km
Highway pavement	228 km	20	
Railway	500 km		180 km
Derailements	7	25	
Liquefaction area	24,000 km <sup>2</sup>		3000 km <sup>2</sup>
Pumping units		70	
Waterlocks	180		
Irrigation pumping stations (discharge >10 cu m/s)	40		
Water supply wells	70,000	64	
Earth dam of reservoirs (storage capacity >1 million m <sup>3</sup> )	40		
River embankments	800 km		
Pipelines	1-3 (# of fractures/km)		



Figure 21. Buckling of rail lines due to ground deformations. The general Tangshan region had many soft soils that behaved poorly during the earthquake.



Figure 22. Failure of ground under railway line. Extensive damage was done to the rail system in the Tangshan region.



Figure 23. Damage to road near Loting Hsien. Slumping, lurching and settlement of soft soils caused extensive damage to highways in the Tangshan region.



Figure 24.  
Underground pipes  
separated by  
extensional ground  
deformation.

Damage to the main underground water supply lines was worse in soft ground than in firm ground, as shown in Table 2. These water mains and supply trunk lines were either concrete pipe or cast iron pipe, with diameters up to 300 mm. The water supply system of Tangshan was totally disrupted, and several months were required to restore service; the water supply lines of Tianjin were also disrupted, presumably because of very soft soils. A visitor to Tianjin 2 years after the earthquake reported that fire hose was still being used for water mains in some parts of the city.

TABLE 2. The Effect of Site Conditions on the Average Damage of Underground Water Supply Trunk Pipelines

District	Intensity	Soil Classification <sup>a</sup>	Average Damage (No. Of Fractures/km)
Tangshan city	X–XI	II	2
Tianjin city			
Municipal district	VII–VIII	III	0.18
Tangkyu district	VIII	III <sup>b</sup>	4.18
Hankyu district	IX	III <sup>b</sup>	10.8

<sup>a</sup>Soil classifications I, II, III represent hard, firm, and soft soils.

<sup>b</sup>Poorer than municipal district.

Some of the Kailuan coal mines in the Tangshan region were flooded as a consequence of the earthquake. The rate of inflow of water into mine galleries was increased by factors between 1.7 and 5. There were several tens of shafts in the Kailuan coal mine system, with maximum depth greater than 700 m, and 75 percent of these shafts suffered various degrees of damage, mainly ring fractures around the cylindrical walls in the upper 20 m. Because of the increased inflow of water, many of these mines and their equipment were submerged.

In Zaoge-zhuang mine branch the water level rose 280 m in the first 9 days after the earthquake. Electrical power disruption stopped the pumping, ventilation, and elevator systems in the mines.

An unusual feature of the Tangshan earthquake was the formation of craters in the countryside. An example of a crater of moderate size is shown in Figure 25. A partial view of a very large crater is shown in Figure 26. These craters were not associated with the extensive underground excavation for coal mining, but they had not yet been studied thoroughly and the reason for these ground collapses had not been established; one suggestion was that limestone karsts may have been responsible.

According to the Chinese engineers, this earthquake was such a great disaster mainly because the seismic risk in the Tangshan region had not been adequately estimated. Almost all buildings and structures had been designed without earthquake-resistant measures, except for a few of the more important structures. In addition, the poor behavior of soft soils contributed greatly to the damage. Low mortar strength in masonry, and inadequate continuity of connections between precast reinforced concrete elements also intensified the damage. Many structures suffered further damage from the aftershocks. The main shock occurred at 3:43 a.m. and was followed by a magnitude 6.5 aftershock at 7:17, and a magnitude 7.1 aftershock occurred at 18:45 on the same day. These aftershocks hit the eastern part of the epicentral area, and the cumulative damage effect of the successive aftershocks was very pronounced.

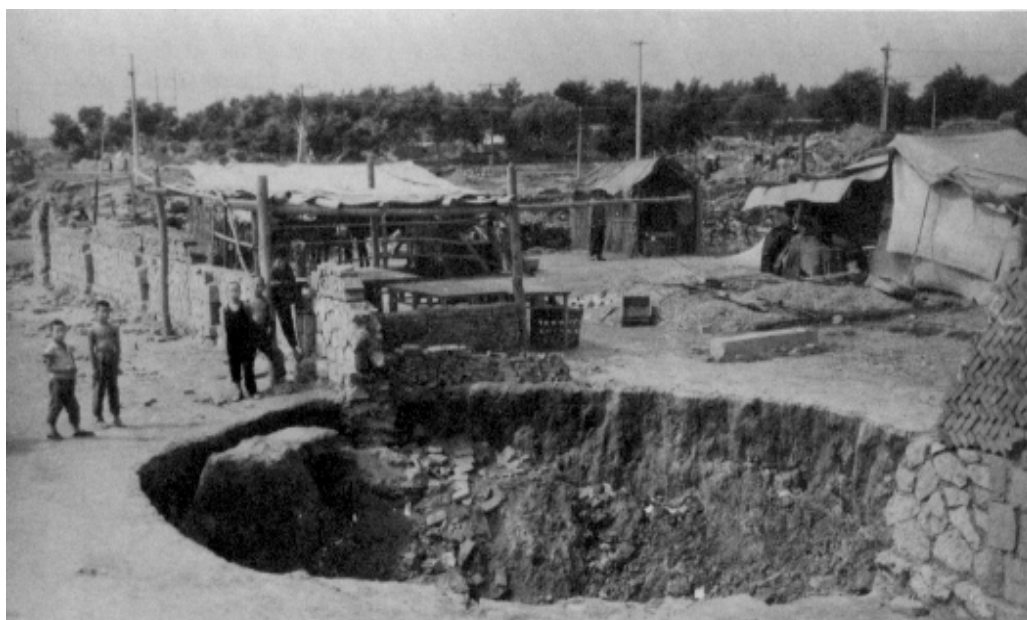


Figure 25. Ground collapse near Tachuangtuo Commune, Kuyeh Hsien. The Tangshan earthquake triggered the formation of a number of such craters. Geological investigations had not yet determined the underlying cause of these craters.

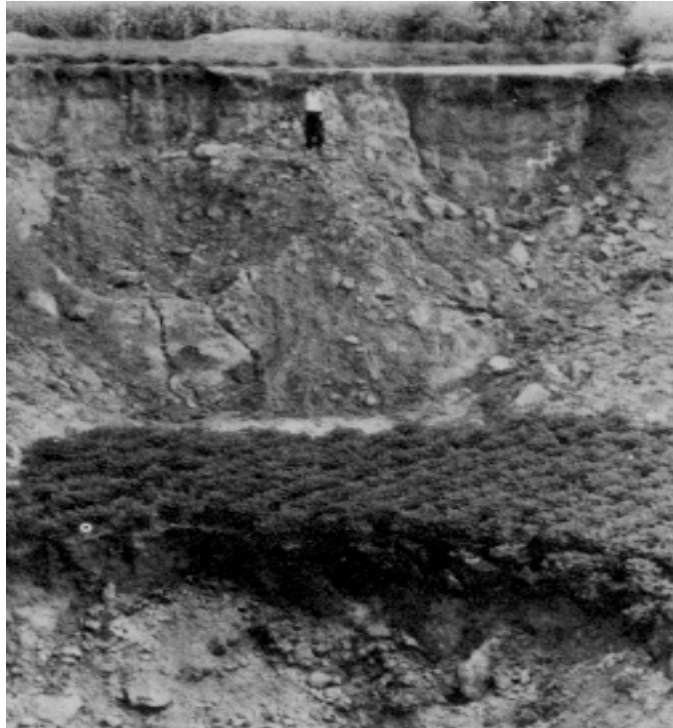


Figure 26. View of the interior of a very large crater formed near Hsiaotun, Chengchaungze Commune, north of Tangshan.

Chinese engineers outlined the valuable engineering lessons provided by the Tangshan earthquake:

1. Seismic zoning should be carefully and properly done, in particular, the “basic intensity” should be reliably assessed. (The basic intensity is defined as the maximum intensity to be expected for a certain period of years (100 years) with a certain probability.) Prior to the Tangshan earthquake, the basic intensity of the Tangshan region was rated as low as grade VI and therefore the city had little protection against earthquakes. (The building code specifies the level of earthquake-resistant design by means of intensity numbers such as VI, ..., XI, and this in turn determines the seismic coefficient; some Chinese engineers criticized this two-step procedure. Apparently, the seismic zoning was done by seismologists with no input from engineers.)

2. A correct philosophy of earthquake-resistant design should be established. Important structures should be designed so that they can withstand a probable earthquake with only slight damage and will not collapse under the action of an unexpected very large earthquake. In earthquake design, auxiliary structures should not be overlooked, because their failure may paralyze factory production and may also have a severe effect on the public.

3. Open-air facilities, when practical, have the important advantage of avoiding damage from the collapse of buildings.

4. Damage to reinforced concrete buildings was less than that to brick buildings, and damage was mainly in the structural connections. The earthquake resistance of such buildings could be much improved at small additional cost. Brick chimneys, brick water tower supports, brick columns in mill buildings, and in general, brick masonry of poor quality suffered severely during the earthquake, and such structures should not be built in highly seismic regions.

5. The functioning of the principal “lifeline” systems should be maintained following an earthquake. The Tangshan earthquake severely damaged bridges on railways and highways so that traffic was blocked and this caused great difficulties in carrying out the relief work. Interruption of water supply and electrical power also caused great difficulty in the relief work and in the restoration of production after the earthquake. For example, the interruption of the water supply and the electric power supply resulted in molten iron freezing in four blast furnaces, so that the furnaces had to be demolished by explosives. Another example is that during the Tangshan earthquake the power system of the Kailuan coal mines failed, the underground ventilation stopped functioning, and thousands of miners were put at risk.

6. Buildings with basements and underground structures such as tunnels and shelters were more earthquake resistant. In Tangshan, many buildings with basements suffered only slight damage. Mine galleries came through the earthquake almost intact.

## **TANGSHAN CITY**

Tangshan, the city at the epicenter of the earthquake of July 28, 1976, is a major industrial center strategically located on the railway line between Beijing (approximately 120 miles west of Tangshan), Tianjin (45 miles to the southwest), and the coast (Figures 27, 28, 29). The devastation of this city of over 1,000,000 inhabitants was thus a major loss to China’s national economy, quite apart from the financial costs of relief and reconstruction.

Tangshan’s industry is based on the Kailuan coal mines. The city’s development began with the opening of its first modern colliery—the first in China—in the 1870’s. This was followed in the 1880’s by extension of the railway to Beijing and Tianjin and to the seaports of Tangkyu and Chihuahua, which became outlets for the export of Tangshan coal. Other industries developed in Tangshan in the 1890’s, either in connection with mining and the railway or to take advantage of other resources in the region. The latter included a cement industry based on the limestone found north and northeast of Tangshan and a ceramics industry that made use of kaolin deposits in the area. As its population increased along with industrial development, Tangshan also became a major agricultural marketing center.

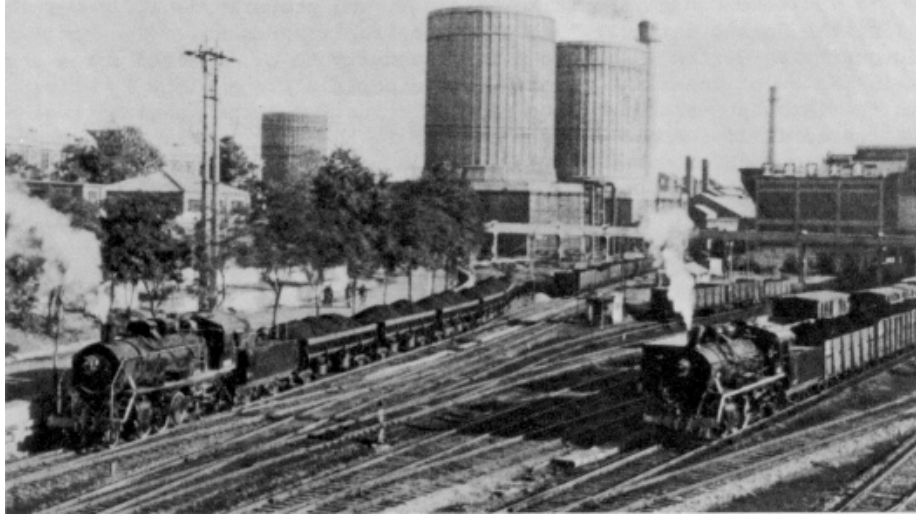


Figure 27. View of Kailuan coal mines in Tangshan before the earthquake. Coal mining was a major industry in this city of over 1,000,000 population.



Figure 28. Schematic map of Tangshan reproduced from a tourist manual.



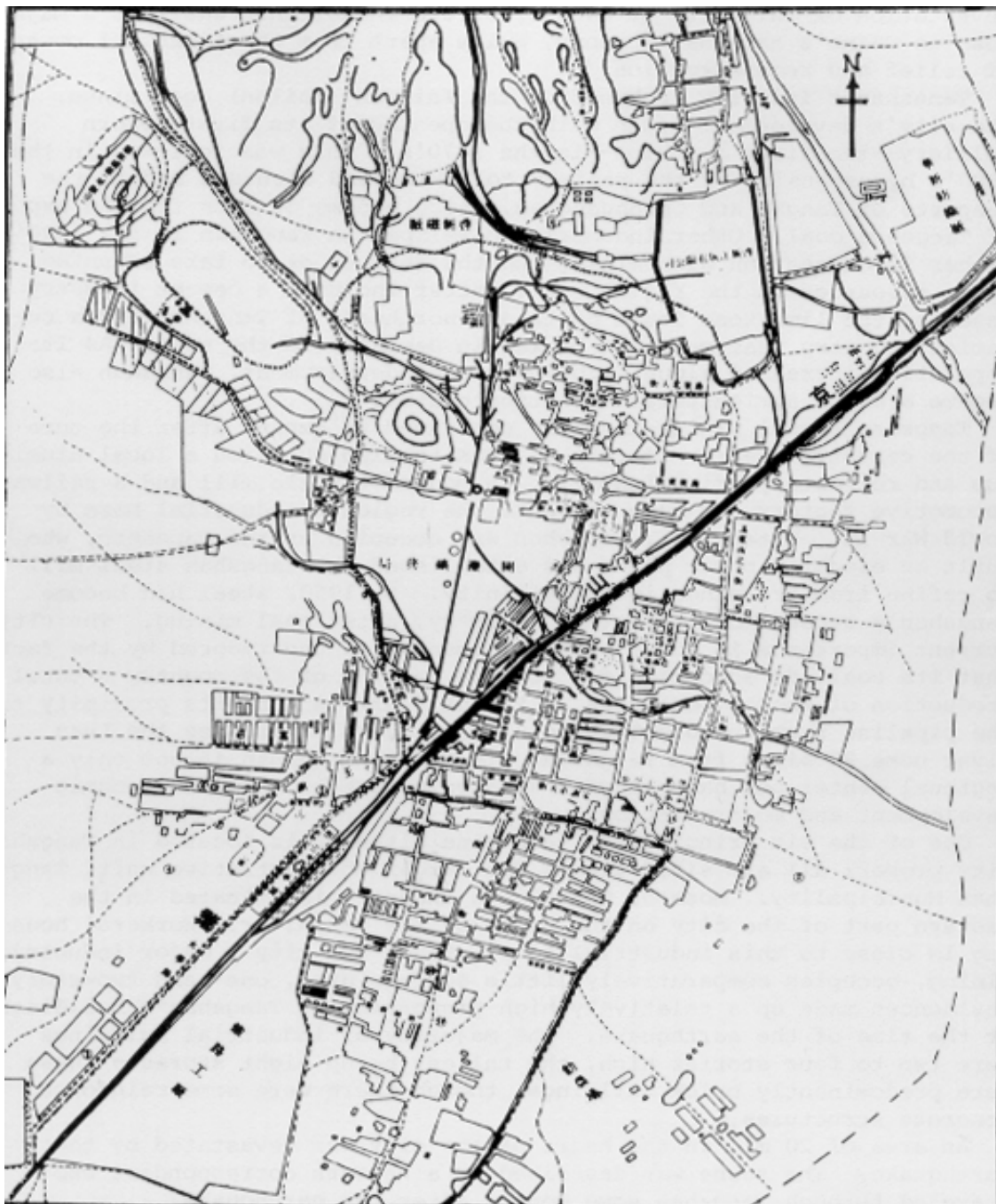


Figure 29. Map of Tangshan City, reproduced from a technical paper.

Tangshan's coal mining industry continued to expand after the turn of the century. Nearby sources of bauxite also supplied a local aluminum and refractory brick industry. A modern textile mill and a railway locomotive factory had been added to the region's industrial base by World War II. After 1935, Tangshan was occupied by the Japanese, who built an electric power plant and established the Tangshan steel mill to refine iron ore mined in the vicinity.

By 1959, steel had become Tangshan's second most important industry, after coal mining. The city's importance in China's energy economy is underscored by the fact that its coal had accounted for some 10 percent of the country's total production of energy resources in recent years prior to 1976, and by its proximity to the pipeline from the big Taching oil field, which crosses the Luan River some 30 miles from Tangshan. In short, Tangshan is not only a regional center but has played a strategic part in China's economic development and modernization.

One of the six principal Kailuan mine pitheads is located in Tangshan City proper; all are sited within the larger administrative unit, Tangshan Municipality. Most of Tangshan's industry is situated in the eastern part of the city on the banks of the Tou River. Workers' housing is close to this industrial zone. Since the city's major industry, mining, occupies comparatively little surface area, one- and two-story residences made up a relatively high proportion of Tangshan's buildings at the time of the earthquake. The majority of industrial buildings were two to four stories high, the tallest being eight stories; these were predominantly brick buildings, though there were some reinforced concrete structures.

An area of 20 mi<sup>2</sup> in the heart of the city was devastated by the earthquake. The scene was described by a Reuters correspondent who traveled through Tangshan some months after the earthquake:

One minute the train is speeding past waving fields of wheat, the next it is crawling through a desert of rubble stretching as far as the eye can see.... Factories reduced to a maze of girders twisted into fantastic shapes flank the line.... Normally level fields were shaken into mounds and craters. One can also see how surface earth caved into the Kailuan coal mines north of Tangshan. Three pit heads now appear to be working, but nearby coal trucks and twisted rails are scattered down a hillside like toys.

The Chinese government had not published official figures on the loss of life and property at Tangshan, though at the end of 1976, Chairman Hua Kuo-feng described the devastation as "rarely seen in history." The Chinese seismologists and engineers did not report casualties to us, but reports from elsewhere estimate as many as 650,000 deaths\*. Figures cited by a group of Hong Kong journalists who had visited Tangshan in 1978 reveal the implications of this loss of human life for Tangshan's economy. They reported 10,486 deaths among employees of the Tangshan locomotive plant and their families, 1,892 dead at the Tangshan iron and steel company, and 1,280 deaths at the Tangshan porcelain company.

The earthquake was not predicted; it has been stated that there were no perceptible foreshocks prior to the Tangshan earthquake and that other indicators had been ambiguous. Rather than publishing details of the city's destruction, the government-run Chinese press had written about heroic actions that saved lives and salvaged or quickly restored production facilities and services in the city. Thus it was claimed that the 10,000 miners on the night shift who were underground when the earthquake occurred were all

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\*See footnote, p.17.

rescued, most within hours, though the last were not brought to the surface until 2 weeks later.

The official accounts credit prompt action by local and provincial authorities, who organized rescue and relief operations and maintained public order and discipline, with keeping the losses from being even greater. Two years after the earthquake the Chinese press was still referring only indirectly to fatalities at Tangshan. The June 1978 issue of *China Pictorial*, for example, featured a story about a boarding school for orphans whose parents had died in the disaster without revealing the number of children involved.

Immediately after the earthquake, Hua Kuo-feng, then Premier and later Chairman of the Chinese Communist Party following Mao Tse-tung's death in September 1976, ordered the People's Liberation Army to mount a disaster relief operation. Under Hua's direction, the State Council and the Central Committee of the Chinese Communist Party coordinated assistance offered from all parts of the country for Tangshan's rehabilitation. In view of Tangshan's importance to China's economy, restoration of the city's industry was an urgent national concern. However, this program allegedly became involved in the political struggle then underway in the top ranks of the government and Party to settle the succession to Mao Tse-tung. Nonetheless, the Chinese claim that overall production at Tangshan 2 years after the earthquake had reached 90 percent of previous levels, which is very high in view of the extensive damage to industrial facilities.

Preliminary planning for rebuilding Tangshan was to be completed in 1978, and the new Tangshan was to be completely reconstructed by 1982. The national government was underwriting the cost of building materials for the city's reconstruction (one spin-off of this effort is the growth of a local building materials industry), while labor was being supplied locally. Blueprints for Tangshan's reconstruction called for several cities of 100,000–300,000 persons to be built in a wide area around Tangshan, which itself would be limited to 500,000. Each satellite town is to consist of a complex of industry, agriculture, and residential amenities. With a green belt preserved for recreation in the area south of the railway, and with a centralized system for handling industrial wastes that will minimize pollution, the new Tangshan, it was claimed, will be the product of modern techniques of city planning.

To completely plan and rebuild a city of over 1,000,000 inhabitants is a remarkable project of great interest to engineers, architects, and government officials in all countries. In view of this, our Delegation requested permission to visit Tangshan and to be briefed on the reconstruction effort. However, permission was not granted, and the Delegation was not given information about casualties, relief operations, or rebuilding.

## **GEOLOGIC SETTING OF THE TANGSHAN EARTHQUAKE**

The Tangshan earthquake occurred near the northeastern end of a seismic belt of large shallow earthquakes that extend from the Himalayas northeast across central China (figure 30). The northeastern part of this belt passes through the North China tectonic province (Figure 30) in which Tangshan is located. Extensive geological studies have been carried out in this region (Chinese Academy of Sciences, 1974); and seismotectonics, as well as seismogenic models, were discussed following the Tangshan

earthquake (Guo, et al., 1977; Qiu, et al., 1976). Wang (1974) has given a summary of the Tangshan earthquake and some precursory data.

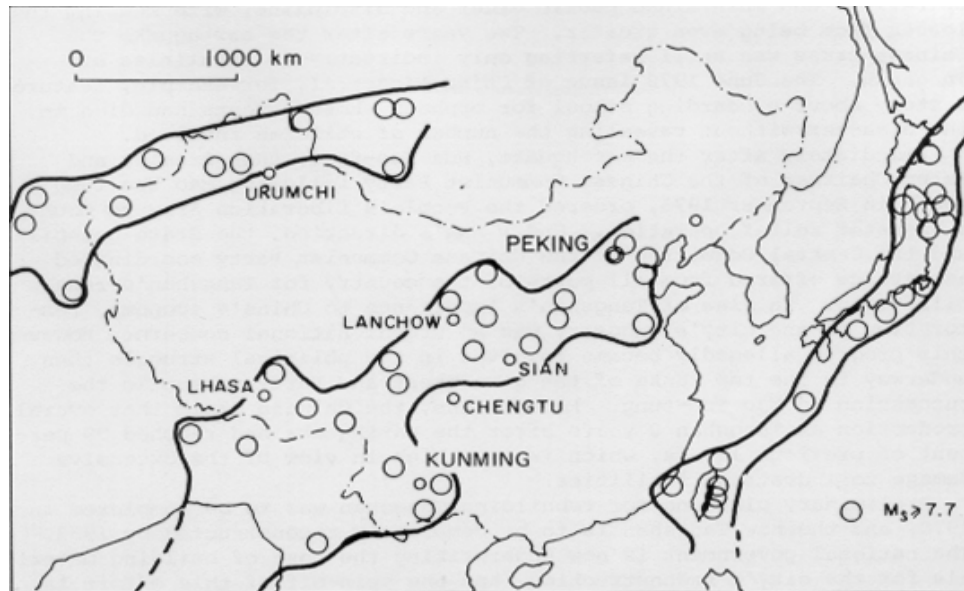


Figure 30. Three generalized seismic belts in China region.

The North China tectonic province constitutes the oldest continental crust in China, with rocks dating back to Pre-Cambrian. In the province there are two operative tectonic systems which influence seismicity. A Paleozoic system, composed of the Yenshan-Yinshan E-W tectonic belt and the Tapeishan-Chinling E-W tectonic belt, forms zones of folding and faulting along the northern and the southern borders of the province (Figure 31). The other system consists of a series of NNE-trending tectonic zones of Mesozoic-Cenozoic age (Figure 31). From east to west, they include the Tancheng-Luchiang fracture zone, a row of en echelon folds and faults called the Hebei Plain fracture zone, the Taihang Piedmont fracture zone, and the Shansi Graben fracture zone.

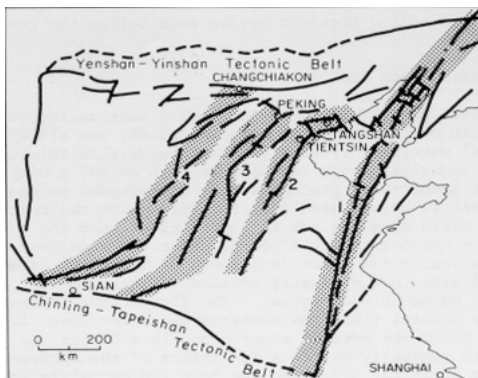


Figure 31. The north China tectonic province containing the following four fracture zones:

- (1) Tancheng-Luchiang fracture zone,
- (2) Hebei Plain fracture zone,
- (3) Taihang Piedmont fracture zone, and
- (4) Shansi Graben Fracture zone.

A system of WNW-trending faults intersects these fracture zones. Along the Tancheng-Luchiang fracture zone, an earthquake of magnitude 8.5 occurred in 1668, near Tancheng; a magnitude 7.4 event in the Pohai Gulf in 1969, and a more recent magnitude

7.3 event near Haicheng in 1975. Along the Shansi Graben fracture zone,  $M = 8$  events occurred in Huahsien (1556) and in Linfen (1303, 1695), together with at least five  $M > 7$  events. On the Hebei Plain fracture zone, notable events include the  $M = 8$  earthquakes near Beijing (1679) and an  $M = 7.2$  event in 1966 at Xingtai. The latter event inflicted heavy losses and prompted the Chinese government to launch a major effort in earthquake prediction research. The Tangshan earthquake occurred on the northern extension of the Hebei Plain fracture zone, near the location where the fracture zone intersects the Yenshan-Yinshan E-W tectonic belt (which lies a few tens of kilometers north of Tangshan). Limited by the older E-W trending Yenshan-Yinshan tectonic belt to the north, this fracture zone gradually turns to the NE and finally becomes nearly E-W in the Pohai Gulf.

The Tangshan epicenter was located at this turning juncture on a fault that had not been identified before the earthquake. The causative fault of the Tangshan earthquake is, however, part of the system of NNE-striking fractures, and the branch passing through Tangshan to Kuyeh may have marked the surface projection of the rupture that caused substantial surface breaks in the city of Tangshan.

In the Hebei Plain, Mesozoic and older rocks have been warped downward, and the basin near Tangshan is filled with sediments of Tertiary and Quaternary age ranging from 0 to 2 km thick. Downwarping or downfaulting has been uneven, so that Tangshan now is situated above a prominent northeast-trending ridge 200 km long in the surface of basement rocks. At the crest of the ridge the surface is as much as 3 km higher than it is to the northwest and southeast.

Although the causative fault had not been identified before the earthquake, many deep and large faults were known in the Tangshan area. Some of the faults at depths of 30-40 km have been revealed by seismic refraction and gravity studies. Many of the faults were active in late Tertiary time, and beds of late Tertiary age are displaced by as much as 500 m. On geologic and tectonic evidence, the area clearly was to be considered an active tectonic region even before the great earthquake.

## **SOILS AND NEAR-SURFACE GEOLOGY**

Shallow geologic profiles through the region surrounding Tangshan indicate an erratic pattern of sandy gravels, sands, and clayey soils. These alluvial materials typically have considerable thickness, with depth to the underlying rock reaching as much as 800 m within 15 km of Tangshan. At least three processes have contributed to the formation of these deposits: slope wash from the uplands to the north, the emergence of the plain from the sea in recent times, and the action of the several rivers which cross this plain. Four thousand years ago the coastline was just a few kilometers south of Tangshan, as shown in Figure 32, and since has gradually advanced seaward to its present position about 50 km south of Tangshan. The rivers have apparently changed their courses several times, as numerous old river channels have been identified.

Along the present river channels and near the coast the water table is generally within a few meters of the surface. The result of these surficial processes has been the

deposition of many weak soils (class IV) that are susceptible to failure during an earthquake.

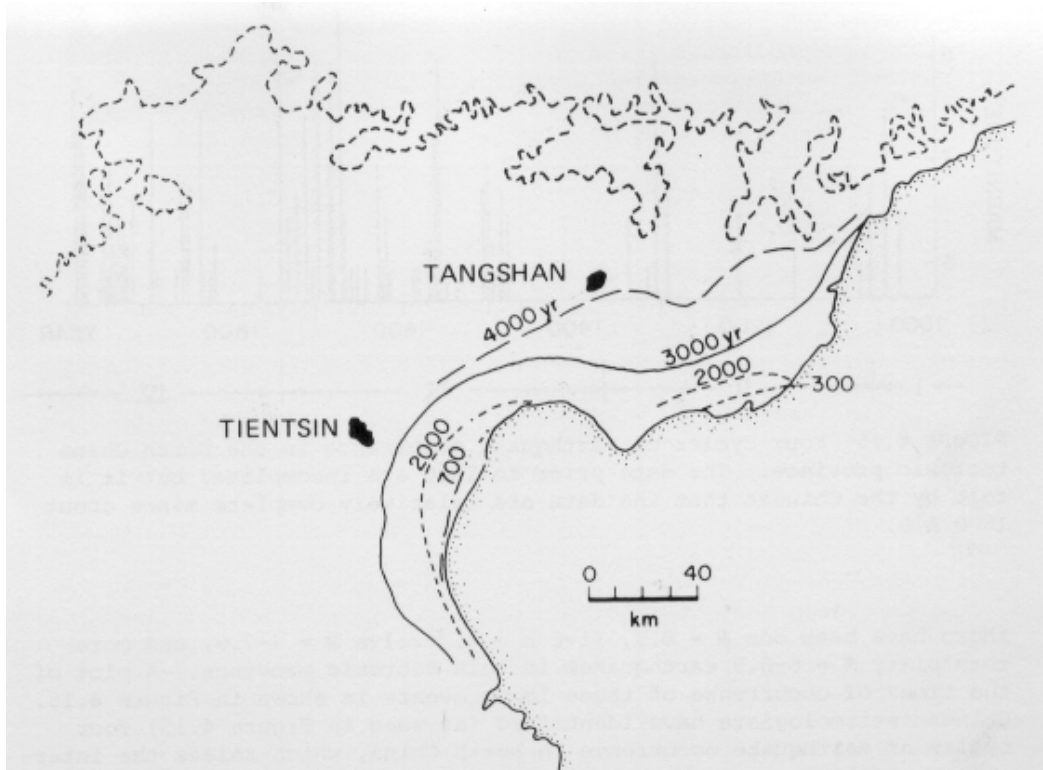


Figure 32. Map showing how the shoreline has advanced over the past 4,000 years. The shoreline 4,000 years ago passed just south of Tangshan City site; the map shows where the shoreline was 3,000 years ago, and the present location. This makes clear why there were so many soft soils south of Tangshan.

Tangshan itself is sited over a buried ridge of rock that extends from outcrop areas to the north. Low limestone hills outcrop in the northern part of the city. In parts of the city the thickness of the alluvium is only 20 m, while under the outskirts of the city, thicknesses of 100-200 m occur. Chinese engineers described the predominant surficial soil as loess-like silty clay, not necessarily of windblown origin, with lenses of gravel and sand. It was rated as a class II soil. The Delegation was shown some typical boring logs but no data concerning blow counts. Shear wave velocities had been measured by modern downhole methods, and typical values ranged from 200-300 m/s. The typical depth to the water table was 4-5 m.

Weaker soils were said to exist along the Tou River, which flows through the eastern part of the city. Here, over a limited area, there was said to be a silt layer with a shear wave velocity of only 80-90 m/s.

## HISTORICAL SEISMICITY

Seismic records in the North China tectonic province date back to 780 B.C., but early records are rather incomplete. Since 1000 A.D., however, there have been one  $M = 8.5$ , five  $M = 8$ , twelve  $M = 7-7.9$ , and more than sixty  $M = 6-6.9$  earthquakes in this tectonic province. A plot of the times of occurrence of these large events is shown in Figure 33. Chinese seismologists have identified (as seen in Figure 33) four cycles of earthquake occurrence in North China, which raises the interesting question as to whether similar cycles exist, for example, in California seismicity. Each cycle spans roughly 300 years and consists of a relatively quiet stage and a markedly active stage. The records for the first and second cycles are incomplete, but from the third cycle on, historical records are relatively complete. An enlarged plot of the third and fourth cycles together with the strain release curve is shown in Figure 34. The third cycle is considered to have begun in 1369 and ended in 1739, spanning a period of 370 years. During the first 100 years or so (1369-1476) in this cycle, possibly no  $M > 6$  event occurred, and the North China tectonic province is considered to have accumulated strain energy during this time. After 1477, seismic activity began to pick up. Between 1477 and 1667 there were one  $M = 8$ , three  $M = 7-7.5$ , and twenty-two  $M = 6-6.9$  earthquakes, with a gradual increase in the frequency of strong earthquakes. From 1662 to 1739 an outburst of great earthquakes occurred, including the  $M = 8.5$  Tancheng-Luhsien earthquake, Shantung Province, in 1668; the  $M = 8$  Sanho-Pingku earthquake, in Hebei Province, in 1679; the  $M = 8$  Linfen earthquake, in Shansi Province, in 1695; and one  $M = 8$  and two  $M = 7$  earthquakes, at Yinchuan, Ninghsia Province, in 1739 (Table 3).

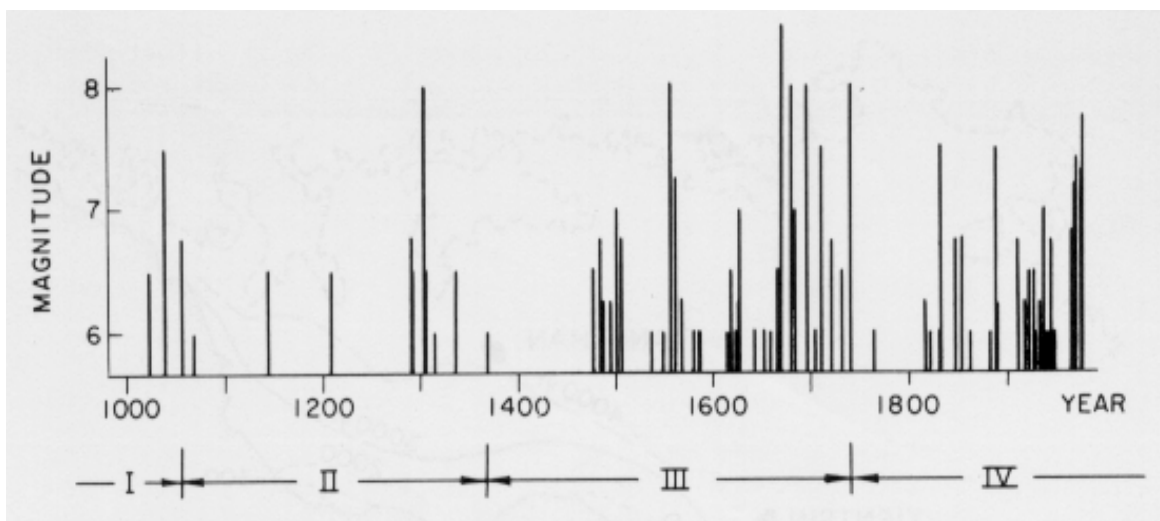


Figure 33. Four cycles of earthquake occurrence in the North China tectonic province. The data prior to 1500 are incomplete, but it is felt by the Chinese that the data are relatively complete since that time.

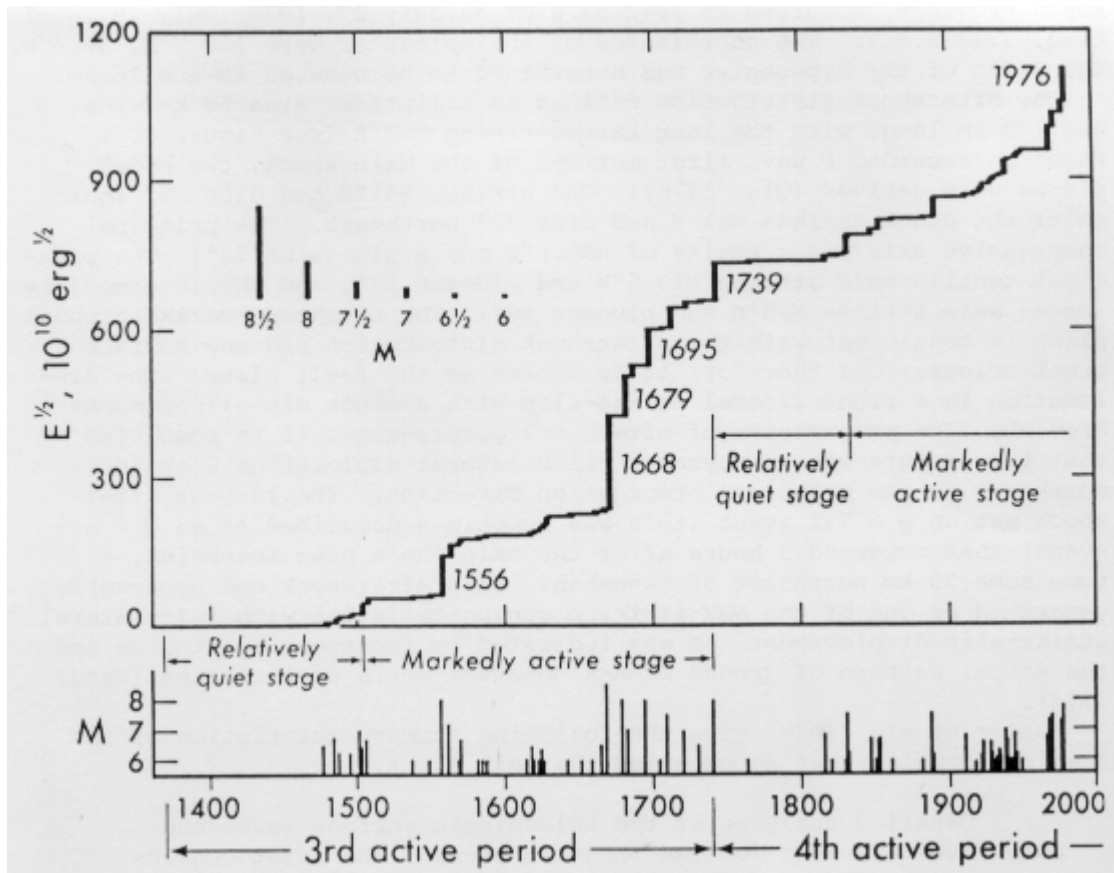


Figure 34. The third and fourth cycles of earthquake occurrence together with the accompanying strain release (from Wang 1974).

TABLE 3. Historical Large Earthquakes in the North China Tectonic Province

Activity Period	Activity Stage	Number			
		M = 8.5	M = 8	M = 7-7.9	M = 6-6.9
Third (1369-1739)	Quiescent	0	0	0	0
	Active	1	4	5	25
Fourth (1740-?)	Quiescent	0	0	0	0
	Active	(0)	(0)	(8)	(23)

The fourth cycle is considered to have begun in 1740 and lasted at least to the present (1978), for a duration of at least 236 years, hence the question mark in Table 3. A stage of low seismic activity is found between 1740 and 1814. A steady increase in magnitude and frequency of occurrence of large earthquakes is seen during the years from 1815 until the  $M = 7.8$  Tangshan event of 1976.



During the last 160 years the North China tectonic province has been the site of six  $M = 7-7.5$  and more than twenty  $M = 6-6.9$  events. Starting with the Hsingtai  $M = 7.2$  earthquake of 1966, there have been a succession of large events in North China: in 1967 ( $M = 6.7$ , Hochien of Hebei Province), in 1969 ( $M = 7.4$ , Pohai Gulf), in 1975 ( $M = 7.3$ , Haicheng of Liaoning Province), and in 1976 ( $M = 6.3$ , Inner Mongolia). The frequency of large events has been high and the losses have been heavy. One of the major questions under intensive study by the State Seismological Bureau staff in 1978 was whether the Tangshan earthquake had marked the “peak” and thus would be considered to be the conclusion of the main seismic energy release of the fourth cycle. Many Chinese scientists take a conservative view toward this question by remarking that the Tangshan event, while the largest so far during the fourth cycle, was merely an  $M = 7.8$ . If the third cycle were to provide any clue, larger seismic energy release would probably be yet to come.

### **SEISMOLOGICAL DESCRIPTION OF THE TANGSHAN EARTHQUAKE**

The earthquake of  $M_S = 7.8$  that centered under the city of Tangshan, Hebei Province, occurred at 1942:53.8 UT on July 27, 1976 (July 28 local time, 3:43 a.m.). The coordinates of the epicenter were  $118.2^\circ\text{E}$ ,  $39.4^\circ\text{N}$ . The depth of the hypocenter was determined to be between 12 and 16 km.

The aftershock distribution defines an elliptical area 50 km wide and 140 km long, with the long axis striking  $N50^\circ\text{E}$  (see Figure 20). Based on recorded P wave first motions of the main shock, two nodal planes were derived (Qiu, 1976): One strikes  $N41^\circ\text{E}$  and dips  $85^\circ$  southeast; the other strikes  $N51^\circ\text{W}$  and dips  $70^\circ$  northeast. The principal compressive axis has a strike of  $N86.5^\circ\text{E}$  and a plunge of  $18^\circ$ . The principal tensile axis strikes  $N13.5^\circ\text{W}$  and plunges  $10^\circ$ , and the intermediate stress axis strikes  $N78^\circ\text{E}$  and plunges  $60^\circ$ . The northeast-striking nodal plane is consistent with the aftershock distribution and the surface break orientation; therefore it is chosen as the fault plane. The dislocation is a right-lateral strike-slip with a minor dip-slip component. From the time progression of aftershock occurrences, it is concluded that the rupture was an asymmetrical bilateral dislocation with the northeast as the principal propagation direction. The largest aftershock was an  $M = 7.1$  event (this was sometimes described as an  $M = 6.9$  event) that occurred 3 hours after the main shock near Luanhsien, a town some 70 km northeast of Tangshan. This aftershock was apparently generated by one of the NNW-striking conjugate faults with left-lateral strike-slip displacement, as was indicated by first-motion studies and the actual pattern of ground breaks observed north of Luanhsien (Wang, 1974).

Butler, et al. (1979) give the following summary description of the complex faulting that accompanied the main event:

...Detailed analyses of the teleseismic surface waves and body waves are made for the Tangshan event. The major conclusions are: (1) The Tangshan earthquake sequence is a complex one, including strike-slip, thrust, and normal-fault events. (2) The main shock, as determined from surface waves, occurred on a near vertical right-lateral strike-slip fault, striking  $N40^\circ\text{E}$ .

(3) A seismic moment of  $1.8 \times 10^{27}$  dyne-cm is obtained. From the extent of the aftershock zone and relative location of the main shock epicenter, symmetric (1:1) bilateral faulting with a total length of 140 km may be inferred. If a fault width of 15 km is assumed, the average offset is estimated to be 2.7 meters with an average stress drop of about 30 bars. (4) The main shock was initiated by an event with a relatively slow onset and a seismic moment of  $4 \times 10^{26}$  dyne-cm. The preferred fault plane solution, determined from P-wave first motion data, indicates a strike N160°W, dip 83°, and rake +175°. (5) Two thrust events follow the strike-slip event by 11 and 19 s, respectively. They are located to the south of the initial event and have a total moment of  $8 \times 10^{25}$  dyne-cm. This sequence is followed by several more events. (6) The principal aftershock was a normal-fault double event with the fault planes unconstrained by the P-wave first motions. Surface waves provide additional constraints to the mechanism to yield an oblique slip solution with strike N120°E, dip 45°SW, and rake -30°. A total moment of  $8 \times 10^{26}$  is obtained. (7) The triggering of lesser thrust and normal faults by a large strike-slip event in the Tangshan sequence has important consequences in the assessment of earthquake hazard in other complex strike-slip systems like the San Andreas.

Surface faulting occurred within the city of Tangshan over a length of between 8 and 10 km. Maximum displacement reached 3 m in a right-lateral strike-slip sense. The northwest side was usually raised, and extension of the ground surface over a width of 300 m was as much as 0.5 m. Buildings on the faults were damaged by the slip, whereas farther out, damage was lighter. Damage also was lighter at the ends of the fault segments. The surface faulting developed in five *en echelon* segments as shown in Figure 35. The individual surface breaks had an approximate strike of N40°E, and the overall zone of surface breaks trended roughly N30°E. This zone followed essentially the southwestern section of the Tangshan-Kuyeh fault, and surface breaks were developed in the loose Quaternary sediments. Roads and rows of trees were offset (Figures 35, 36, 37, 38), and compressional ridges were seen that were consistent with the ENE compressive axis and the NNW tensional axis.

Spectral analyses of the seismic records by Chinese seismologists have been interpreted to indicate that the causative main rupture was 120 km long and that rupture was asymmetrically bilateral, beginning approximately 70 km from the northeast end. This interpretation is in general agreement with that of Butler and others of bilateral rupture beginning near the center of a 140 km break. Secondary faulting was also reported underground in coal mines. In one example where the coal bed had been displaced earlier by five pre-Pleistocene faults, all five faults were reactivated in a dip-slip sense during the earthquake, with a maximum displacement of 1 m. A rather complete cross section, about 3,000 m long, of the coal formations at a depth of 600 and 700 m was shown to the group; two of the reactivated faults were near one end of the cross section and three were near the other end.

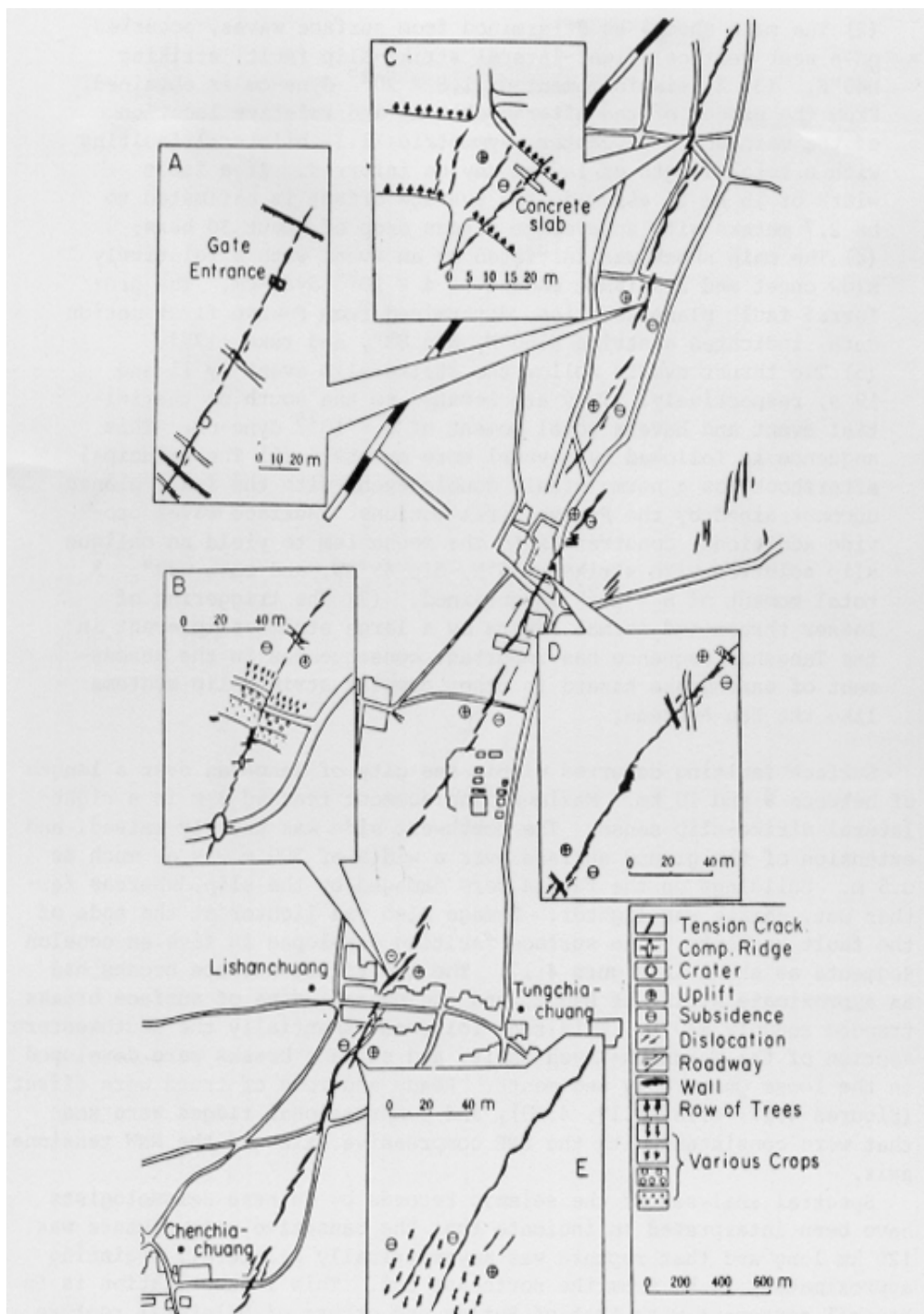


Figure 35. Surface faulting observed in the city of Tangshan.

- (A) Tangshan 10 high school;
- (B) North Lishanchuang;
- (C) Intersection of Yunhung Road and Hoping Street;
- (D) Tangshan native product warehouse;
- (E) South Lishanchuang.



Figure 36. Surface breaks and compressed pavement over drainage trench in Tangshan



Figure 37. Offset in row of young trees by surface break near Laoting Hsien (direction N40°W, maximum displacement, 0.8 m).



Figure 38. Offset in row of tree due to horizontal tectonic movement, in Tangshan.

Mine shafts at the coal mine were damaged but principally in the upper 20 m, where 75 percent of the mine shafts suffered various degrees of damage and collapse. The flow of water into the mines increased after the earthquake, markedly in some cases. The belief was expressed that the increased flow resulted from added fracturing and opening of fractures in bedrock, although some small amount may have been contributed by liquefaction of near-surface sand units. There were no reliable data about ground shaking in the mines at depth.

Surface faulting also occurred during the  $M = 7.1$  aftershock near Luanhsien (Wang, 1974), with faults having strikes of both  $N20^{\circ}W$  and  $N30^{\circ}E$ . The northeast-striking faults displayed right-lateral strike-slip and the northwest-striking faults displayed left-lateral strike-slip. The city of Luanhsien was built over perhaps one of the largest coal mines in China. Ground subsidence was widespread over areas where coal mining had removed underlying formations.

In Tianjin, Ningho, and Tangku, shallow water tables apparently contributed to greater damage through the effects of liquefaction and subsequent ground failure. Along the banks of some rivers, for example, considerable damage was apparently related to lateral spreading, although nearby building damage attributable to shaking was relatively light.

Localized damage, according to the Chinese, differed according to topographic effects. For example, at the base of a 200-m high ridge, the damage degree was only VI, whereas at the crest of the ridge, the degree was XI. In some localities, small buildings on liquefiable soil showed little damage, whereas on nearby bedrock, similar buildings were damaged. An interpretation was suggested that the soil unit susceptible to liquefaction was also effective in absorbing the strong shaking.

## DAMAGE TO BUILDINGS DURING THE TANGSHAN EARTHQUAKE

At the Institute of Engineering Mechanics (IEM) in Harbin the Delegation was given an overview summary of building damage in the Tangshan earthquake. T. Y. Chang spoke on general features of the Tangshan earthquake, Yang Yu-chen spoke on damage to multistory brick buildings during the Tangshan earthquake, and C. C. Yin spoke on damage to mill buildings. In addition, 13 technical papers dealing with the Tangshan earthquake were given to the Delegation. Five of them dealt with structural damage, and information from these is also presented here. The description of structural damage presented at IEM was mainly about brick buildings and mill buildings, although some information about lifeline systems was also presented. The technical papers contained information on damage to other types of structures. It was reported that the behavior of soft soil had an appreciable effect upon damage sustained by structures (see section below on behavior of soils); significant ground subsidence was experienced as far away as 50 km from Tangshan.

No strong-motion accelerograms were recorded in or near Tangshan during the  $M = 7.8$  earthquake (see section below on strong-motion records), and this severely hampered the engineering assessment of the damage.

Few of the buildings in the Tangshan region were designed to resist earthquakes. The Delegation was informed that the building code had zoned Tangshan for intensity VI, which did not require buildings to be designed for earthquake forces, so only a few special structures had been so designed. Most of the 916 substantial buildings in the Tangshan area were built of brick and were two to four stories in height; however, some were as tall as eight stories. They were mainly used for offices, schools, and factories. It was reported that over 75 percent of the larger brick buildings collapsed or were severely damaged by the Tangshan earthquake and its aftershocks, and only 1 percent suffered no damage. In many cases the failure pattern for these large buildings began with diagonal tension cracking in the shear panels, followed by crushing and collapse as the deformation of the structure increased. In many cases it was observed that the exterior walls failed first, followed by failure of the interior walls, and there were many evidences of failures of connections. It was reported that buildings located on thin soil, on thin layers of rock, or on thin layers of soil over rock did not exhibit the same degree of severe damage as buildings located on less firm soil. Studies of the response characteristics of buildings after the earthquake showed considerable differences in the periods of damaged buildings as compared to undamaged buildings. Dwellings were mostly one- and two-story buildings that had little earthquake resistance, and these were reported to have collapsed over large areas of the city.

Detailed studies were made of the damage in Tangshan, and the statistics are most impressive. In one study, 14 districts in Tangshan, shown in Figure 39, were selected for detailed damage compilations. The results are shown in Table 4. There were 352 multistory brick buildings in the 14 districts and of these, 117 collapsed completely, 85 suffered partial collapse, 99 suffered severe damage, 34 sustained moderate damage, 13 sustained slight damage, and 4 received no damage at all. Approximately one third of the buildings were in these 14 districts.

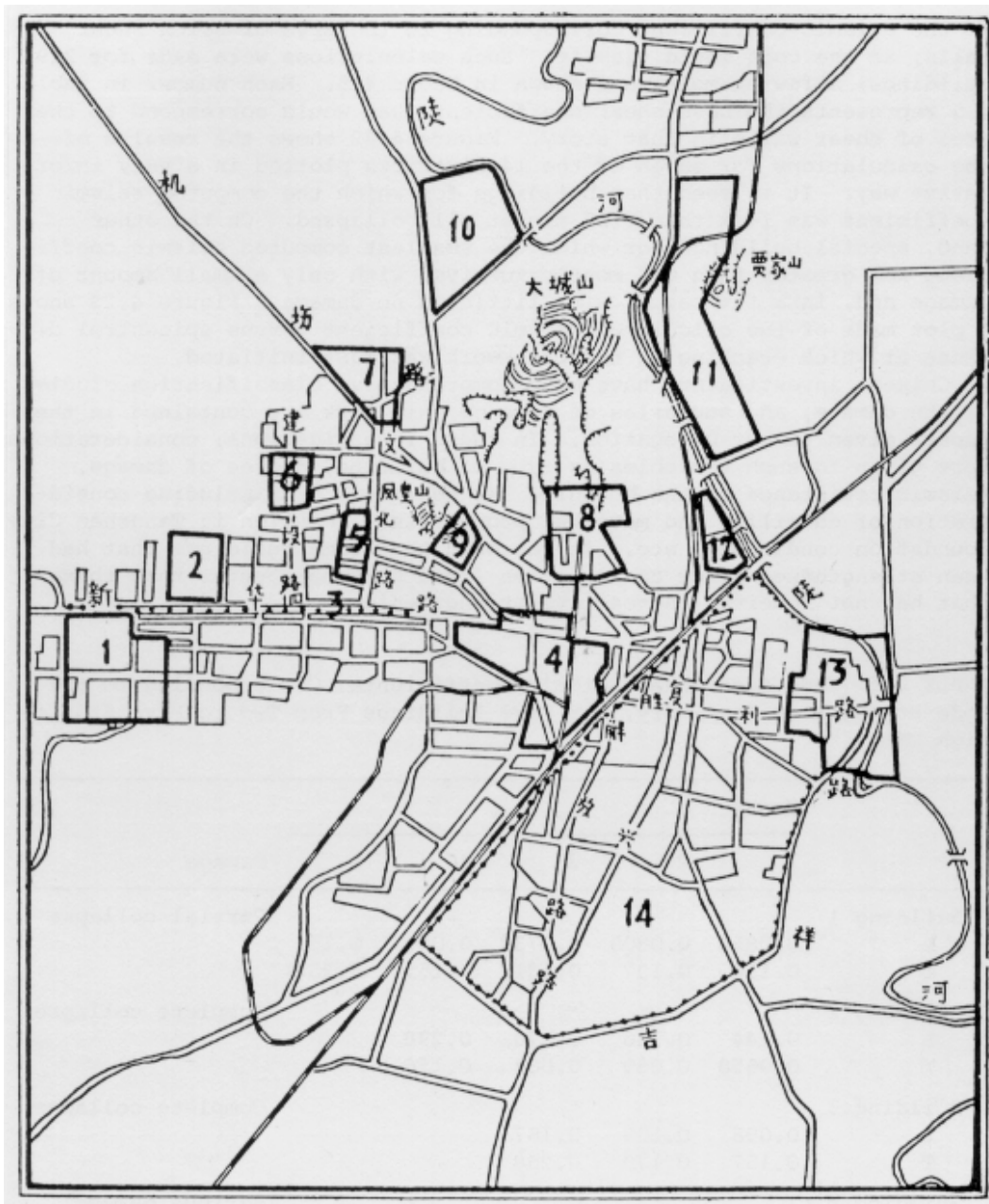


Figure 39. Plan of Tangshan City showing the 14 districts in which special damage studies were made. Three hundred and fifty two multistory buildings in these 14 districts were studied; a total of 916 multistory buildings were in Tangshan. Most of these buildings were unreinforced brick structures.

TABLE 4. Tangshan City Damage to Multistory Brick Buildings in the 14 Selected Districts Shown in Figure 39 (Institute of Engineering Mechanics, 1978)

District Number	Collapse		Damage			
	Complete	Partial	Severe	Moderate	Slight	None
1	21(70) <sup>a</sup>	6(20)	3	0	0	0
2	15(52)	9(31)	5	0	0	0
3	11(64)	3(18)	3	0	0	0
4	18(42)	15(35)	6	4	0	0
5	8(38)	5(24)	6	2	0	0
6	16(40)	10(25)	13	1	0	0
7	9(22)	14(35)	16	1	0	0
8	0	2(11)	10	2	4	0
9	0	3(43)	4	0	0	0
10	0	2(9)	11	3	5	1
11	0	8(25)	12	7	3	3
12	0	0	3	6	0	0
13	0	8(42)	3	7	1	0
14	19(79)	0	4	1	0	0
Total	117(33)	85(24)	99(28)	34(10)	34(10)	4(1)

<sup>a</sup>Numbers in parentheses are percentages.

Another interesting study involved applying the building code requirements in reverse. For each story of a building a computation was made of the seismic coefficient corresponding to the area of brick shear walls, as the code would view it. Such calculations were made for 219 buildings; a few examples are shown in Table 5. Each number in Table 5 represents the base-shear coefficient that would correspond to the area of shear walls in that story. Figure 40 shows the results of the calculations for seven of the 14 districts plotted in a very informative way. It is seen that buildings for which the computed seismic coefficient was less than 0.25 almost all collapsed. On the other hand, special buildings for which the smallest computed seismic coefficient was greater than 0.7 mostly survived with only a small amount of damage and, in a few cases, with little or no damage. Figure 41 shows a plot made of the calculated seismic coefficient versus epicentral distance at which cracking in the brickwork was just initiated.

Chinese investigators have made comprehensive classification studies of the damage, and summaries of some of this work are contained in the papers given to the Delegation. In these investigations, considerations were given to such variables as type of building, degree of damage, seismic resistance of the building (as designed, and including consideration of ductility and material properties), location in Tangshan City, foundation conditions, etc. It was said that some buildings that had been strengthened after construction fared somewhat better than those that had not received retroactive strengthening.



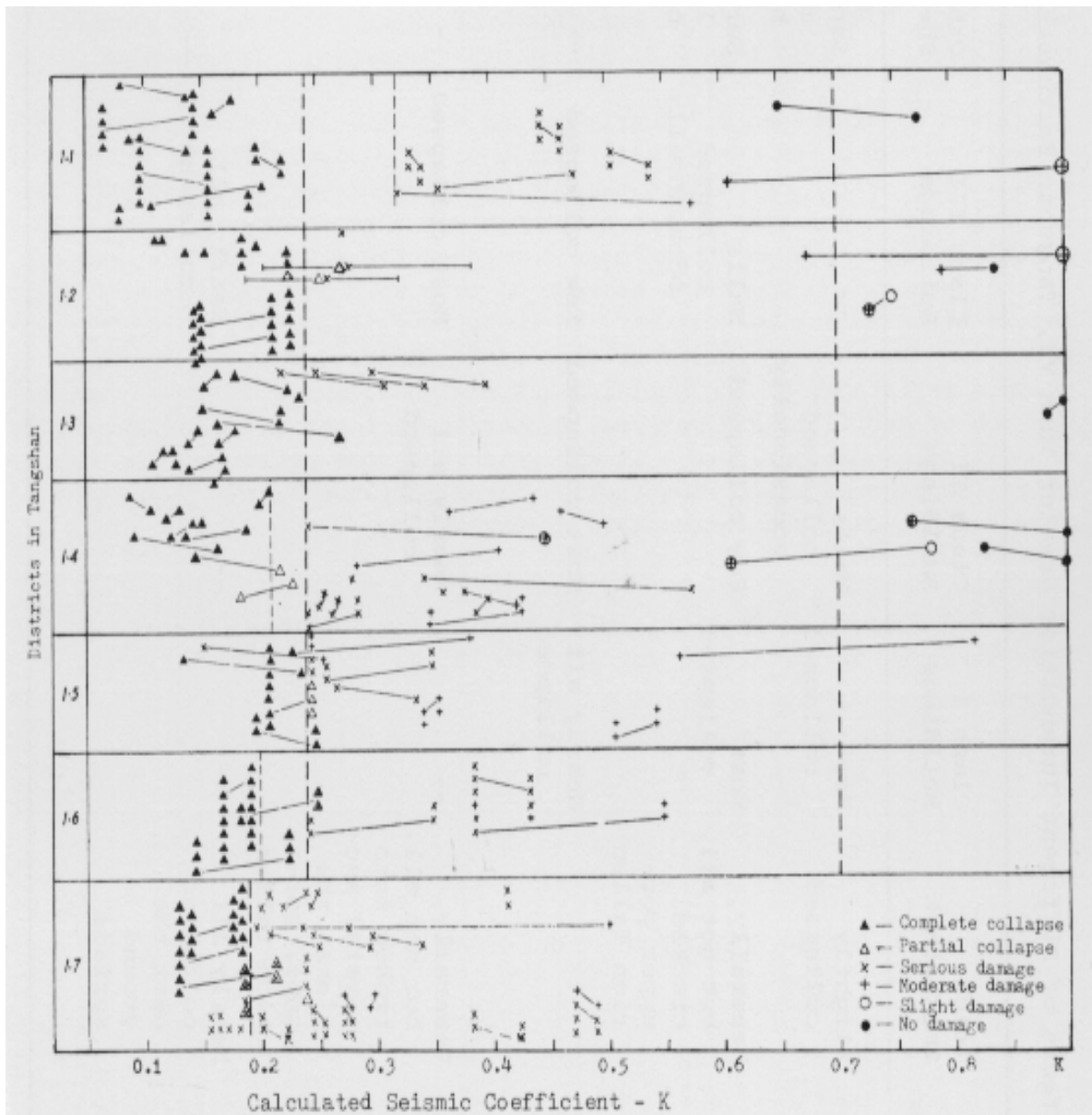


Figure 40. Plot of seismic coefficients for seven districts in Tangshan. This is a plot of calculated base-shear seismic coefficients, according to the building code, corresponding to the area of shear walls in a story. The minimum base-shear value is plotted except when only one story was damaged, and then the seismic coefficient corresponding to this story is plotted (see Table 5 and figure 39). This plot shows clearly how the nominal code strength of the building relates to the degree of damage. When the seismic coefficient was less than about 0.25, most structures collapsed; when the seismic coefficient was greater than about 0.7, the structure survived with little or damage (from Yang et al., 1978).

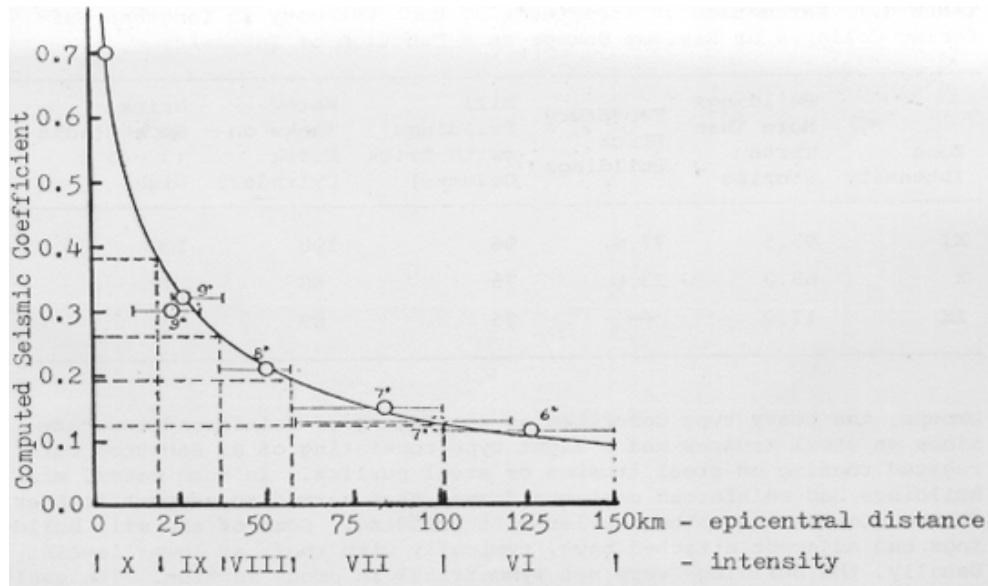


Figure 41. Plot of seismic coefficient versus intensity that produced the initial cracking, Tangshan earthquake. This is an idealized plot for the Tangshan earthquake, showing the intensity and epicentral distance at which buildings experienced initial cracking (reproduced from Yang et al., 1978).

TABLE 5. Code Base-Shear Seismic Coefficients, Corresponding to the Code Strength of the Story, for Five Buildings from Two to Five Stories High

	Story					Damage
	1	2	3	4	5	
Building 1						Partial collapse
L	0.0854	0.0805	0.0738	0.0897	0.158	
T	0.154	0.137	0.131	0.155	0.254	
Building 2						Complete collapse
L	0.144	0.146	0.170	0.298		
T	0.0658	0.069	0.084	0.156		
Building 3						Complete collapse
L	0.098	0.109	0.167			
T	0.157	0.170	0.258			
Building 4						Serious damage
L	0.332	0.506				
T	0.342	0.539				
Building 5						Serious damage
L	0.273	0.304	0.486			
T	0.199	0.226	0.375			

L, longitudinal; T, transverse. Calculated coefficients for 219 buildings are given in Yang, et al. (1978).

Buildings in China are classified into three groups ranging from mud and adobe houses to modern brick and concrete structures. A summary of damage to these three types of buildings as a function of intensity is shown in Table 6. (As noted above, the Chinese intensity scale is essentially the same as the Modified Mercalli scale.) Most class I buildings collapsed in areas where the intensity was as low as VII. There is no doubt that class I buildings, which presumably were mainly dwellings, had very low earthquake resistance and were extremely hazardous to the occupants. Table 7, which was presented by T. Y. Chang, shows the percentages of structures of various categories that suffered collapse or serious damage as a function of intensity.

TABLE 6. Lower-Bound Effects of Different Intensities Greater Than VI, Tangshan Earthquake

Intensity	Water Tower Supported on Brick Cylinder	Brick Smokestack	Class I Buildings	Class II Buildings	Class III Buildings	Other Phenomena
VI	—	Slightly collapsed	Few collapsed	Walls collapsed occasionally	—	Sand blows and mud-spouts may be observed
VII	Slightly cracked in the lower portion	Generally, but not all, cracked, upper portion fallen	Most collapsed	Few collapsed	Walls collapsed occasionally	Serious liquefaction occurred
VIII	Generally cracked with a few collapsed	—	Nearly all collapsed	Most collapsed	Few collapsed	—
IX	—	Generally, but not all, broken into several sections, the upper portion fallen	—	Nearly all collapsed	Most collapsed	—
X	Nearly all fallen down and collapsed near ground surface	Nearly all collapsed near the ground surface	—	—	Nearly all collapsed	—

TABLE 7. Percentage of Structures of Each Category in Tangshan Suffering Collapse or Serious Damage as a Function of Intensity

Zone Intensity	Buildings More than Three Stories	Two-Story Brick Buildings	Mill Buildings (with Brick Columns)	Water Tanks on Brick Cylinders	Brick Smokestacks (30-40 m High)
XI	95.5	77.6	96	100	100
X	65.0	23.6	75	88	78
IX	11.0	—	95	89	—

A summary of damage to elevated water tanks, elevated storage containers, and ground-based liquid storage tanks is given in Table 8. Many elevated water tanks were supported on brick or stone cylindrical silo-type structures, and these were severely damaged by the earthquake.

It was reported that many mill (industrial) buildings were located in zones experiencing intensity X and XI damage. Most of the mill buildings were single story, but in a few cases there were multistory rigid-frame mill buildings. The one-story mill buildings had reinforced concrete columns or brick (unreinforced) columns, though a few were reported to have had steel columns. The information in Table 7 about mill buildings refers particularly to those buildings with brick columns, which would naturally have low resistance against earthquake forces. In the evaluation of the damage the roofing systems were divided into two groups, the heavy type described as consisting of reinforced concrete slabs on steel trusses or steel purlins. In some cases, mill buildings had reinforced concrete frames that served to support lighter framed stories above the heavier mill building. Some of the mill buildings had adjacent attached bays, typically with roofs at lower levels. Usually, the buildings were not symmetrical in cross section. The gable end walls and the long unsupported side walls were described as weak elements, and many of these were lost in the earthquake.

TABLE 8. Summary of Damage to Tanks in Tangshan Earthquake  
(from Chang, FY, 1978)

Tank	Undamaged	Slightly Damaged	Moderately Damaged	Seriously Damaged	Collapsed
Elevated water tank					
Brick	0	2	7	7	5
Stone	0	1	9	2	1
Reinforced concrete	1	1	2	0	0
Elevated storage container	0	2	0	4	4
Liquid ground-based storage tank	31	25	6	29	1

<sup>a</sup>Elevated storage containers consist of reinforced concrete columns supporting containers for coal, cement, etc. Liquid ground-based storage tanks are 9-36 ft in diameter, 9-36 ft in height.

Fifty percent of the damage to mill buildings occurred in the roofing system, most of it in the heavy-type roofing systems. In such cases, the roof slabs were reported to have fallen when bracing failed between the trusses. In the case of Vierendeel trusses, a number collapsed from apparent overstress.

Some heavy cranes fell during the earthquake, but many others were reported to have stayed in place. The primary cause of crane failure was poor bracing of the beams supporting the crane rail and poor connections to the supporting columns. It was noted that the mill buildings had been designed only for low levels of wind loading and thus did not have much resistance against earthquake forces.

A number of columns were reported to have failed because of poor lateral support. In cases where folded-plate roofs were used (often these were prestressed concrete slabs with reinforced concrete connections), failure of the connections and loss of the panels led to column overstress. Frames with infilled walls between the columns seemed to fare better than those without infilled walls. It was noted that frequently changes in stiffness (for example, points of attachment of X-bracing, or short columns supporting heavy roofs) were points of overstress susceptible to damage. Flexible stories were also susceptible to damage. It was concluded that much damage was caused by injudicious practices that induced force concentrations and stress concentrations.

According to Table 7, approximately 90 percent of the mill buildings in Tangshan either collapsed or were seriously damaged. This damage would strongly affect industrial production so that the loss to society would greatly exceed the cost of repairing or rebuilding the mill buildings.

Photographs of earthquake damage in Tangshan were given to the Delegation. A selection of the more interesting photographs is shown in Figures 42-71. Although most buildings were severely damaged, it is significant that some well-designed structures survived with little damage, as shown in Figures 69-71.



Figure 42. Collapsed out-patient service building of the Kailuan coal mine general hospital, Tangshan.



Figure 43. Collapsed top story of the three-story Kailuan coal mine dormitory, Tangshan.



Figure 44. Collapsed four-story Tangshan Mine-Metal Institute residence building.



Figure 45. Collapsed five-story physics-chemistry building of the Tangshan Mine-Metal Institute.



Figure 46. Collapse of Kailuan coal mine reception building, Tangshan.



Figure 47. Collapsed five-story office building, Tangshan. The lower three stories had concrete columns, and the upper two stories were unreinforced brick without concrete columns.



Figure 48. Collapse of six-story building at the Kailuan coal mine hospital, Tangshan.



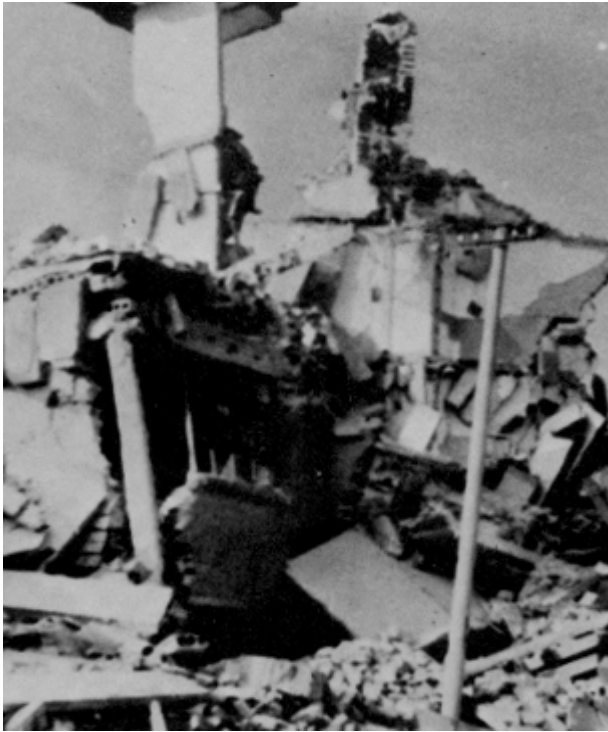


Figure 49. Collapsed building, Tangshan.



Figure 50. Eight-story Hsinhua Hotel in Tangshan was badly damaged at the fifth-story level but remained standing. In the foreground is a collapsed six-story building.



Figure 51. Collapsed workers' cafeteria building of the Chinkechuang coal mine.

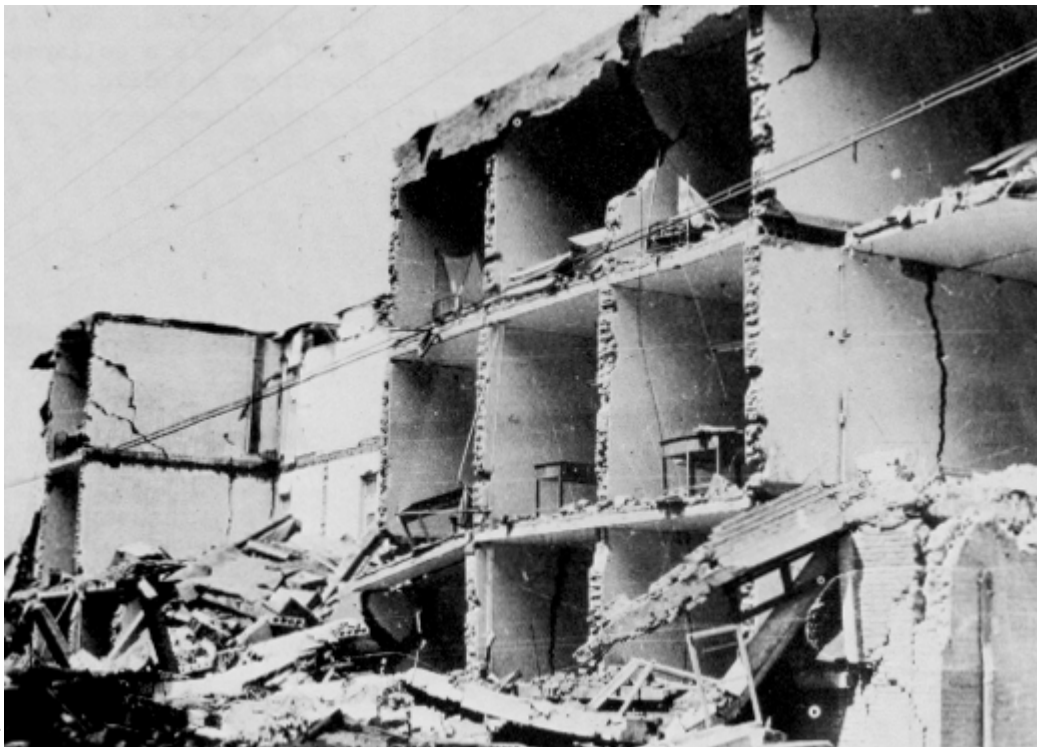


Figure 52. Partly collapsed residence building showing the type of construction: unreinforced brick bearing walls and precast concrete floor beams.



Figure 53. Collapsed building showing the type of construction: precast concrete floor slabs made of four-hole beams, simply supported on bearing walls.



Figure 54. Badly distorted brick building on the verge of collapse. The second floor appears to be of precast concrete slabs supported on precast concrete beams, which, in turn, are supported on unreinforced brick piers.



Figure 55. Collapsed brick cylindrical storage bin at the Fankechuang mine.

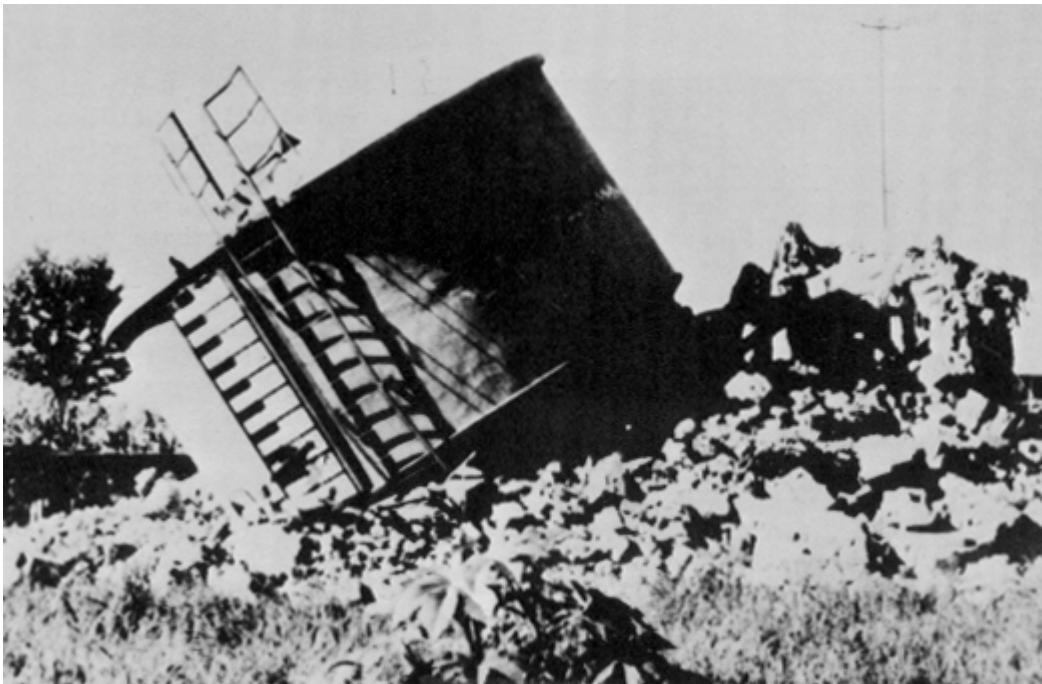


Figure 56. Collapsed elevated storage tank that had been supported on a brick cylindrical tower, Tangshan scale factory.

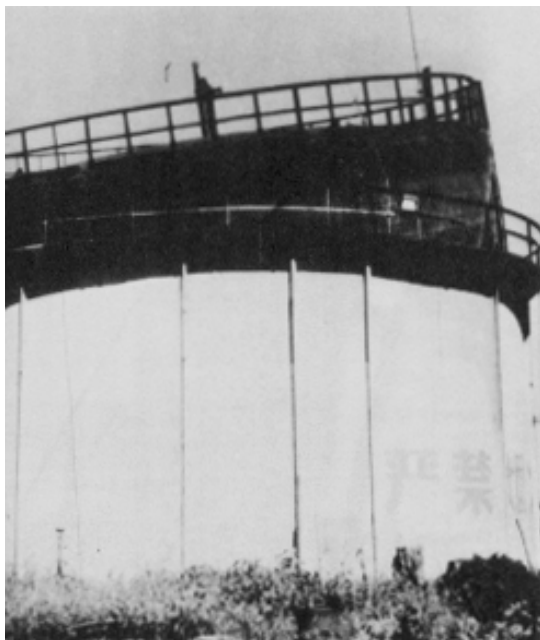


Figure 57. Damaged gas holder at Tangshan fertilizer factory.

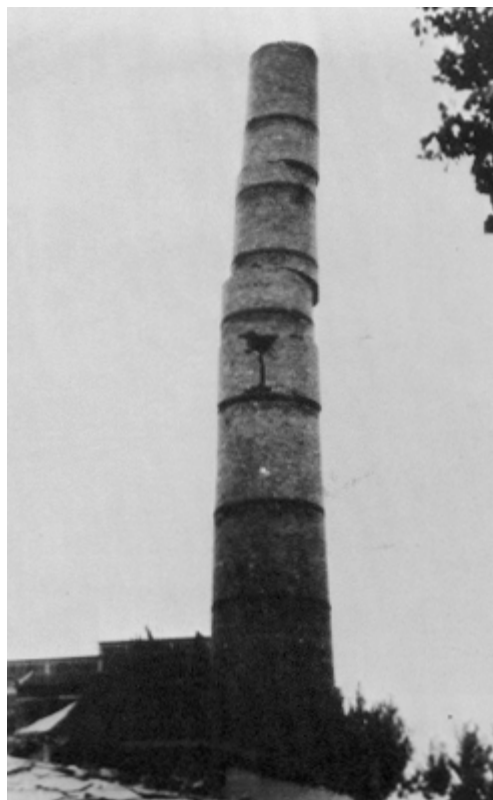


Figure 58. Damaged brick chimney at Chaokenchuang mine. The top of the chimney fell off, and four horizontal cracks appeared in the remaining portion.



Figure 59. Damaged brick chimney.



Figure 60. Tilted ventilation tower at Tangshan coal mine.

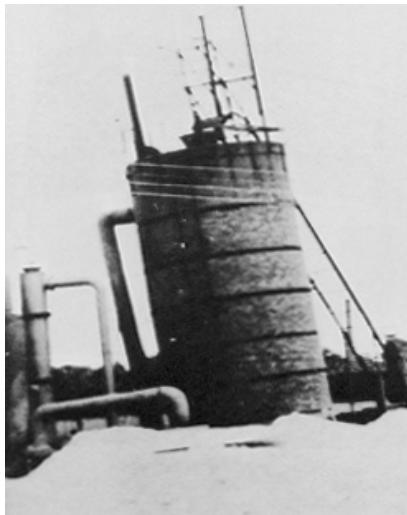


Figure 61. Tilting of a lime firing tower.

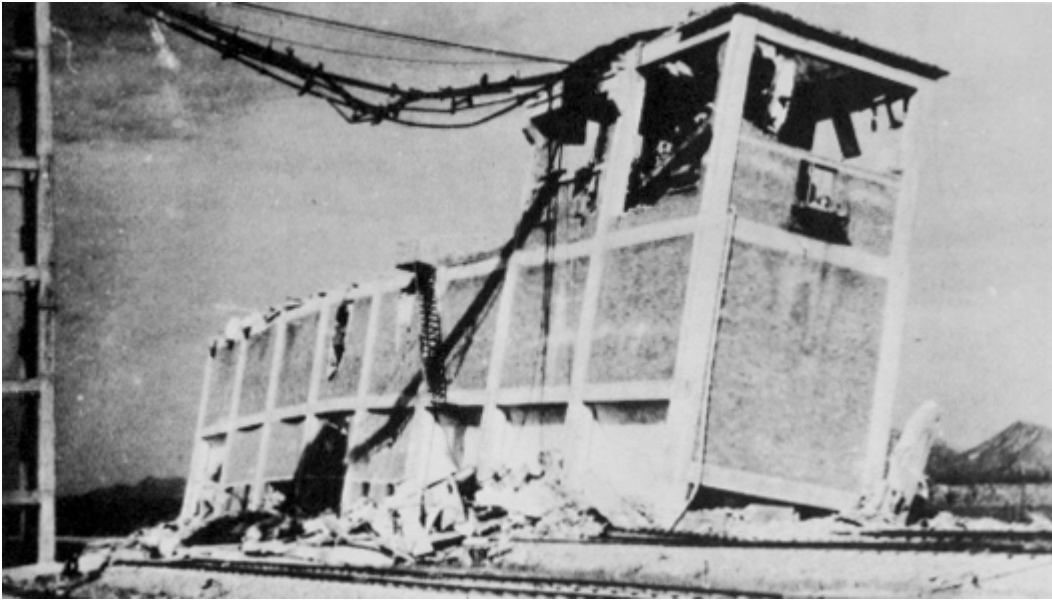


Figure 62. Collapsed coal storage structure at Chinkechuang.



Figure 63. Tilting of brick cylindrical storage bin.



Figure 64. Partly collapsed five-story building at Coal Mine Design Institute in Tangshan.



Figure 65. Uneven settlement of office building, Fankenchuang Commune, Luan-nan hsien.





Figure 66. Damaged building at Kailuan coal mine general hospital in Tangshan.



Figure 67. Damaged reception building in Tangshan.



Figure 68. Damaged Tangshan second reception building. Although damaged, this two-story brick building remained standing.



Figure 69. Damaged car factory dormitory building in Tangshan. The first story was most severely damaged but the building remained standing.



Figure 70. Tangshan light-machine plant official building. This structure, which was located in district 13 of Figure 39, was only slightly damaged. The remains of a collapsed building can be seen in the foreground.



Figure 71. Cement factory worker apartment building 422. This structure was located on bedrock north of Tangshan and received only slight damage.

## DAMAGE TO BRIDGES

The Tangshan earthquake caused extensive damage to the highway and railway systems in the general vicinity of Tangshan. Highway pavements and railroad lines were extensively damaged by soil settlement, soil spreading, and soil deformation. Twenty highway bridges collapsed or were seriously damaged, and an additional 211 were damaged to a lesser degree. In addition, railway bridges were also damaged. Most of the damage to bridges was caused by poor behavior of the soils: soil spreading caused inward movement of bridge abutments and subsequent failure or collapse of the deck. Similar damage to bridges was caused by the great 1964 Alaska earthquake and, in fact, is commonly found in regions where very soft soils are stressed by strong ground shaking. The general soil conditions in the Tangshan region of heavy damage were quite poor; the soils consisted mainly of weak materials such as marine deposits and thick layers of silty sand. During the earthquake, upward water flow that caused sand venting was a common occurrence, thus indicating that liquefaction had occurred at depth. Two types of soil failure were responsible for most of the damage to bridges. In one type a circular failure surface developed under the abutment, and in the other type, high earth pressures behind the abutment caused it to slide toward the center of the bridge (Ho and Kao, 1978). In both types of failure, large settlements occurred behind the abutments and large transverse cracks developed. There was evidence that liquefaction of the loose backfill materials contributed to many of the soil-abutment failures.

The inward movement of bridge abutments caused an inward shifting of the deck spans which progressively closed the joints separating them, thus transferring abutment backfill loads to supporting columns and piers, causing them to fail in many cases. This compressive action also caused some failures to deck spans and, in the case of railroad bridges, caused buckling of the steel rails.

### Some Representative Cases of Bridge Damage

To illustrate the type of bridge damage that occurred during the Tangshan earthquake, four cases will be described briefly: the Yenchuang and the Janshan highway bridges and two railway bridges located on the Tangshan-Kenhua and Beijing-Shanhaikuan lines.

#### Yenchuang Bridge

This bridge crossed the Tangshan River at a location where the earthquake intensity equaled IX on the Chinese scale. The deck was supported by simple span-reinforced concrete girders, which in turn, were supported on double-column piers. A large slide occurred at the east bank, shown in Figure 72, which forced the abutment to move inward and many of the piers to tilt eastward, thus allowing the first 14 spans from the east abutment to fall into the river, as shown in Figure 73.

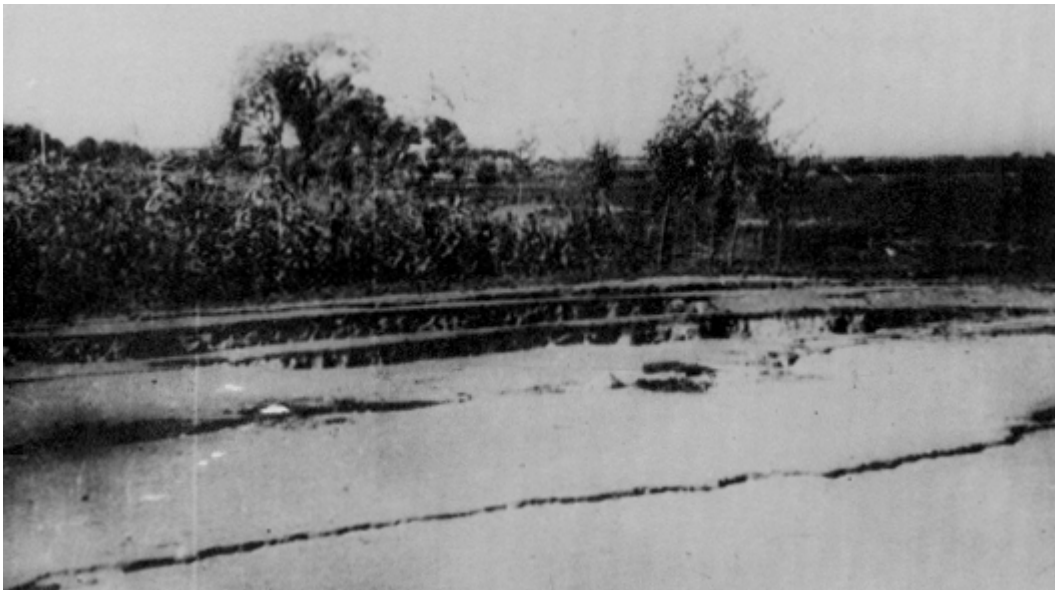


Figure 72. Large landslide at east bank of Tanshan River, which caused damage to the Yen Chuang Bridge.

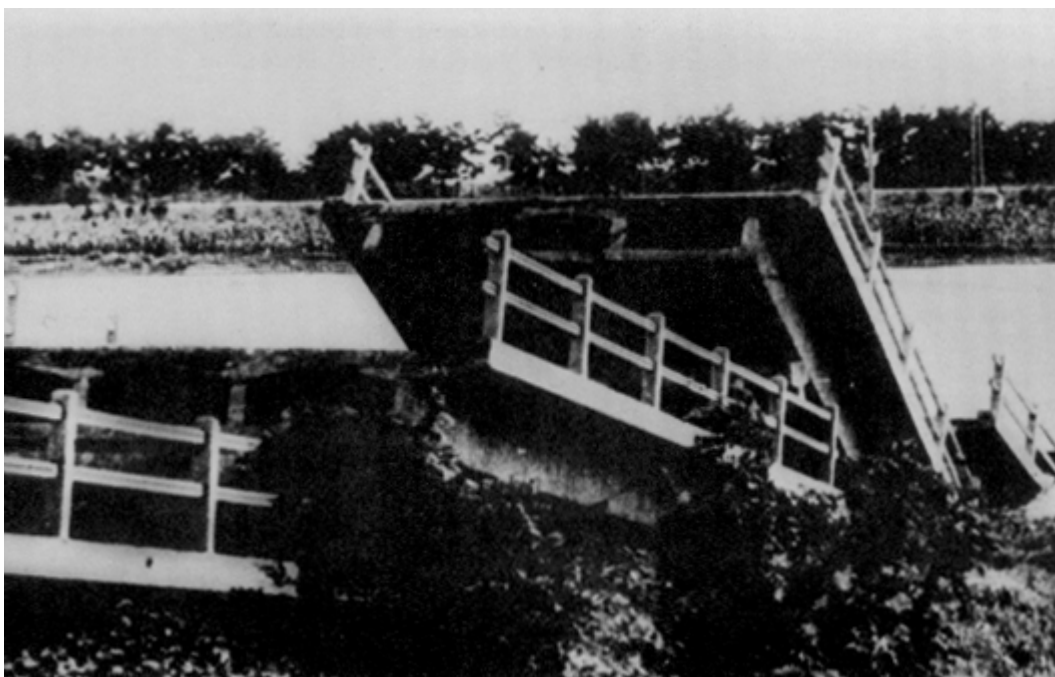


Figure 73. Deck spans of Yen Chuang Bridge were pushed off their supports by the landslide.

### Janshan Bridge

This bridge crossed the Jan River at a location where the earthquake intensity equaled IX. The deck consisted of 35 simple spans supported on built-up block piers approximately 15 m high. Each simple span had a hinge support at one end with a roller support at the other. The roller support was positioned 0.5 m in from the edge of the pier. The earthquake caused the piers to tilt sufficiently to allow many spans to fall into the river, as shown in Figure 74.

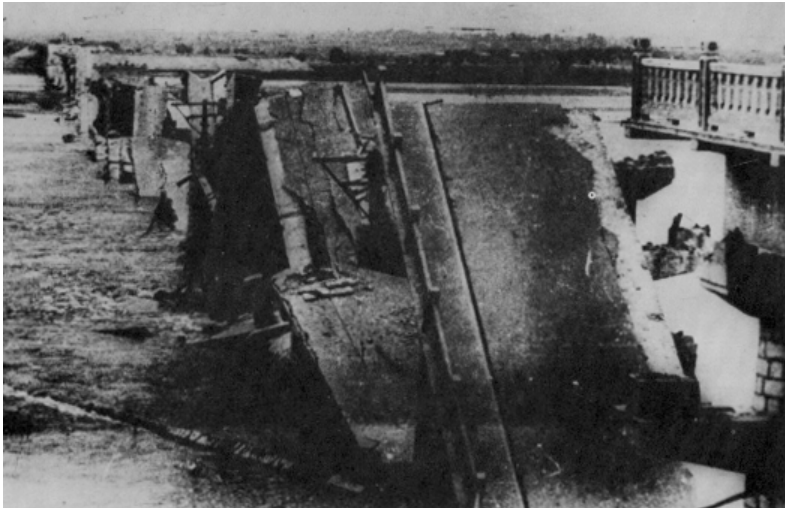


Figure 74. Fallen spans of the Janshan Bridge.

### Railway Bridge on Tangshan-Kenhua Line

This bridge crossed the Tou River at a location where the earthquake intensity was X. Soil fracture at the right abutment, shown in Figure 75, forced it to move inward, causing the deck to move to the left and to tilt two piers and break the left abutment at midheight. The steel rails on the deck buckled into an “S” shape.



Figure 75. Tilted piers and broken abutment of the railway bridge on Tangshan-Kenhua Line.

### Railway Bridge 55 on Beijing-Shanhaikuan Line

This bridge crossed the Chi Canal at a location where the earthquake intensity was IX. During the earthquake both abutments moved inward and shortened the distance between them by 2.1 m. This compressive movement caused buckling of the steel rails (Figure 76) and fracturing of a supporting pier (Figure 77).



Figure 76. Buckled steel rails on railway bridge on Peking-Shanhaikuan line.

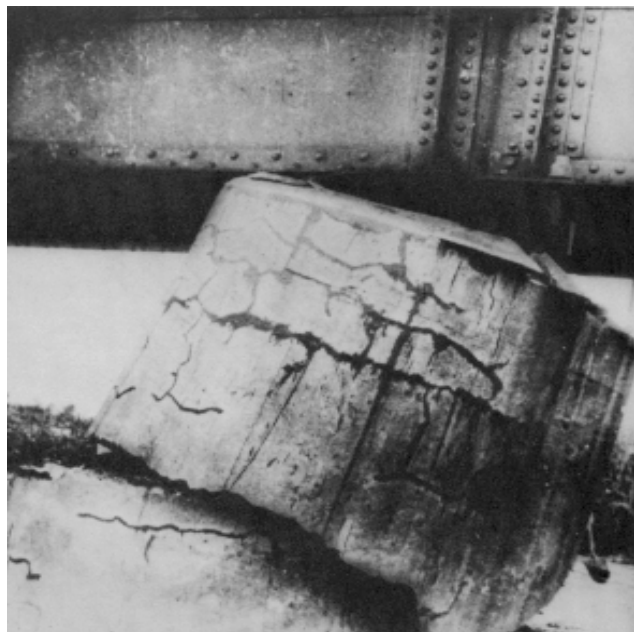


Figure 77. Broken pier of railway bridge 55 on the Peking-Shanhaikuan line.

## BEHAVIOR OF SOILS

All the usual manifestations of soil liquefaction were observed during the Tangshan earthquake. Sand boils, lateral spreading and subsidence, slumping of embankments and of the banks of rivers and canals, and sand entering water wells all occurred during the earthquake (Figures 78-82). Adverse soil behavior affected buildings with differential settlements, bridge supports settled and collapsed, and irrigation systems were affected. It was reported that in one village near the coast, the ground surface settled 3 m with resulting permanent flooding. Some instances of liquefaction also occurred during the magnitude 7.1 aftershock on November 15, 1976. As shown on the map (Figure 78), the effects of liquefaction were especially severe between Tangshan and the coast, and along the old courses of rivers, such as the Luan River, which flowed southward from the Yin Shan Uplift Province to Pohai Gulf. Along the banks of the Hai River there was considerable damage to buildings, apparently related to lateral spreading and subsidence, but there was little evidence of building damage from ground shaking. This apparently was the explanation for the zone of intensity IX embedded within a zone of intensity VIII on the intensity map.

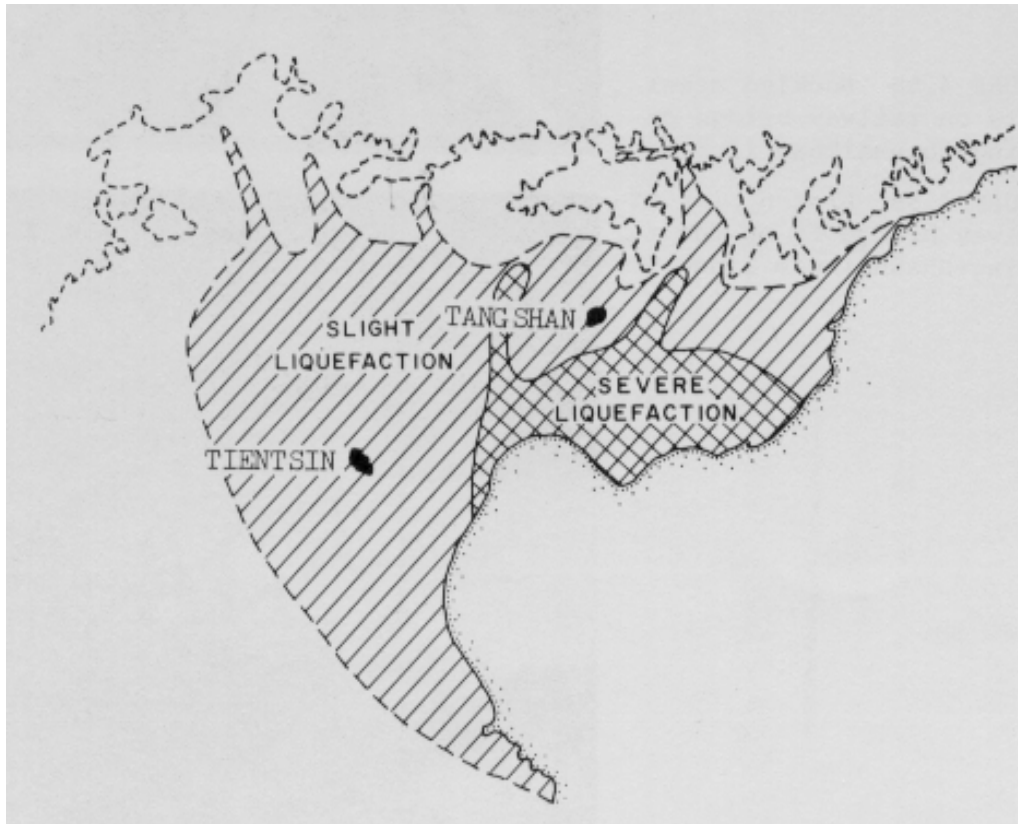


Figure 78. Map of Tangshan-Tientsin region showing areas of liquefaction.



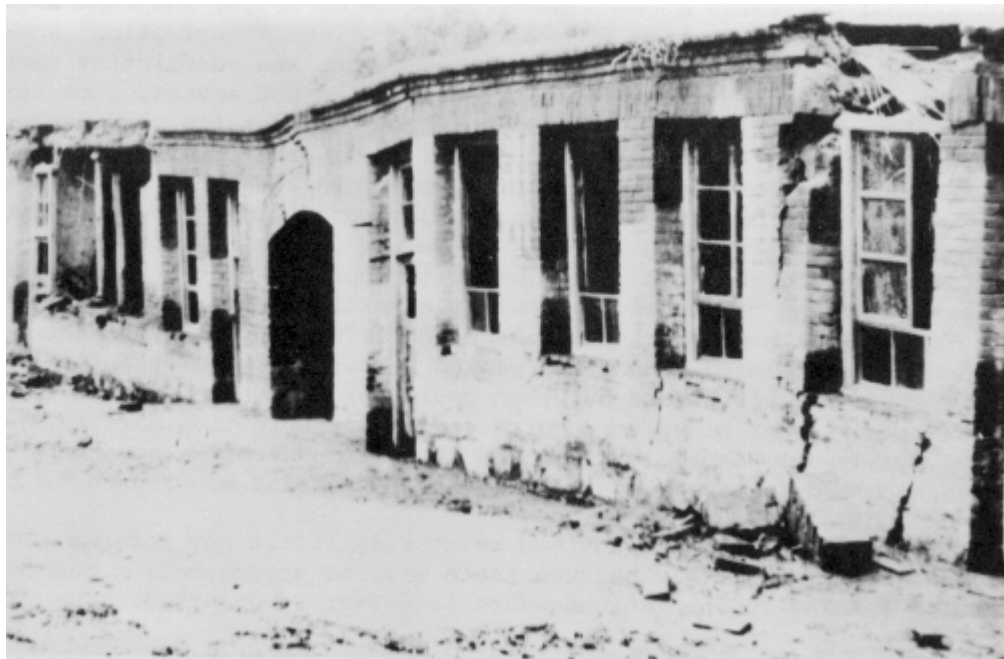


Figure 79. Structure damaged by unequal ground settlement.

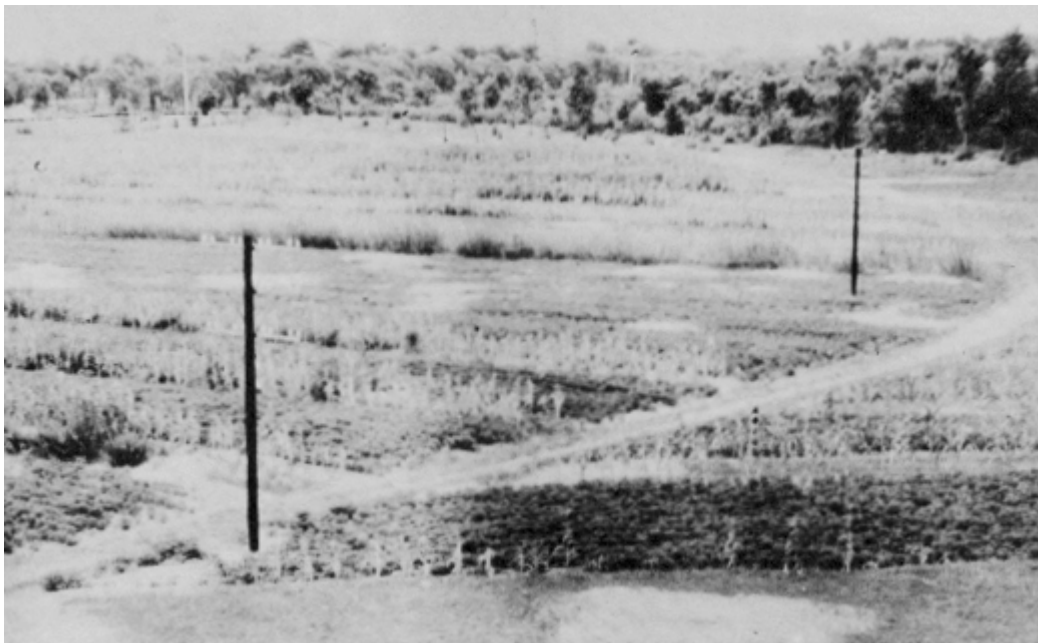


Figure 80. View of sandblows in a field.



Figure 81. Damage to a road caused by soil failure.



Figure 82. Damage to railway line caused by loss of support.

Occasional instances of sand boils, filling of wells, and bank slumping occurred within the much larger area of “slight liquefaction” shown in Figure 78. In Tangshan City, although there was conflicting testimony, the effects of liquefaction apparently were not severe. One report mentioned that the upper portions of some mine shafts were damaged because they passed through liquefied sands, but other engineers said that the sand had not liquefied. A few buildings along the river apparently were damaged by slide failures. Underground pipes received some damage (Table 2).

It was reported that sand boils began to appear a minute or so after the earthquake and continued to flow for several minutes and in some cases for several hours. (A story from the 1970 Tonghai earthquake in Yunnan Province related that a man walked across the river bed immediately after the earthquake but then could not return because of the liquefaction.) Sand blows were quite common in irrigation ditches and caused considerable damage to farmland irrigation systems. One sand blow is reported to have had a height between 2 and 3 m. Figure 80 shows sand blows in a field.

The Tangshan earthquake provided relatively little new information about liquefaction, mainly because there were no strong-motion records of ground shaking in the regions where liquefaction occurred. The Chinese engineers thought that the relation between threshold intensity and blow count was confirmed by experience during the Tangshan earthquake; however, the report on this subject had not been completed at the time of the visit. A previously published relation between magnitude and greatest distance to liquefaction ( $D_{\max} = 0.87M - 4.5$ ) was also felt to have been confirmed. The Tangshan earthquake clearly spurred interest in basic research on liquefaction, and it was expected that there will be many publications on this subject in the future.

Some of the Chinese engineers cited instances of damage that they attributed to the influence of soils, local geology, or local topography. Some of these were (1) in northern Tangshan, brick buildings founded upon limestone outcrops were little damaged, whereas similar buildings built upon class II soil elsewhere in the city collapsed; (2) at a hill 200 m high and some distance from Tangshan, buildings at the foot of the hill were undamaged, whereas a temple on top of the hill collapsed; (3) in Tianjin, multistory buildings built over filled ground were much more heavily damaged than buildings elsewhere in the city; (4) also in Tianjin the damage to underground water supply trunk lines varied with the soil conditions, from 0.2 breaks/km within the best soil, to 4.2 and 10 breaks/km in parts of the city with poorer soils. On the other hand, the coal seams beneath a portion of Tangshan had been left unmined so as to reduce the likelihood of subsidence damage to the railroad, and damage to buildings was observed to be the same over the mined and the unmined areas.

Following the Haicheng earthquake, Chinese engineers reported evidence that buildings founded over soils with a soft layer had been screened from damaging ground motions. They described several similar observations in connection with the Tangshan earthquake: (1) In Tangshan itself, some buildings founded over the soft stratum of silt near the river appeared to be less damaged than similar buildings over soil without a soft stratum; (2) in Tianjin, damage to multistory buildings was least in an area where there was a soft layer within the soil profile. However, in neither of these cases was there instrumental data to support the hypothesis.

The Tangshan earthquake yielded very little direct information concerning the effects of local soil and geological conditions upon strong ground motions. For the main shock the only data comparing motions on soil and rock came from stations at a distance of 400 km from the epicenter; in this case the peak acceleration on soil was somewhat more than twice that on rock. Two records were obtained in or near Tangshan City during the aftershock of November 15, which was located some 50 miles away. The recording stations were 6 km apart, one on limestone and the other sited on 111 m of alluvium (20 m of coarse sandy clay and 80 m of sandy gravel) overlying rock. The peak acceleration on the surface of the soil was about 2.5 times that on the rock. Several normalized spectra from the main shock and aftershocks showed amplification in the long-period region for records on soil as compared to those on rock.

### BEHAVIOR OF EARTH DAMS

It was reported that 40 earth dams were damaged by the Tangshan earthquake. There was a partial failure of the Paiho main dam at Miyun reservoir. This dam is on the upper reach of the Chao and Pai rivers, 90 km northeast of Beijing and about 150 km from the epicenter of the earthquake. The dam was built between 1958 and 1960 and had a maximum height of 66 m and a total crest length of 960 m. It had a thin upstream-sloping clay core with a blanket of sandy gravel 3-5 m thick. A schematic cross section is shown in Figure 83. At the end of the earthquake the water level was 21.6 m below the crest. The sand-gravel facing over the clay core failed over almost the entire length of the dam. The upper scarp was close to the water line, ranging as much as 2-5 m above or below the water line. The total volume of slide material was 150,000 m<sup>3</sup>. The sliding surface was essentially within the sand-gravel layer; the clay core was exposed and scraped only at a few spots. The slope of the clay core beneath the failed facing was 2.8 on 1 while that of the upstream slope was 3 on 1 and then 3.25 on 1. The slide material came to rest on the bottom of the reservoir within 40 m of the heel of the dam. According to witnesses, the failure occurred during the earthquake. Earthquake-induced settlements of the crest reached a maximum of 59 mm, and permanent horizontal displacement had a maximum of 28 mm. This failure is of special interest because strong-motion recordings were made at the dam. According to reports furnished to the Delegation, on the ground surface below the downstream toe the peak horizontal accelerations were 0.097 and 0.058g and the peak vertical accelerations were 0.065g. The corresponding peak horizontal accelerations on the crest were 0.128 and 0.16g. The accelerograms recorded on the crest showed apparent periods of about 0.6 s.

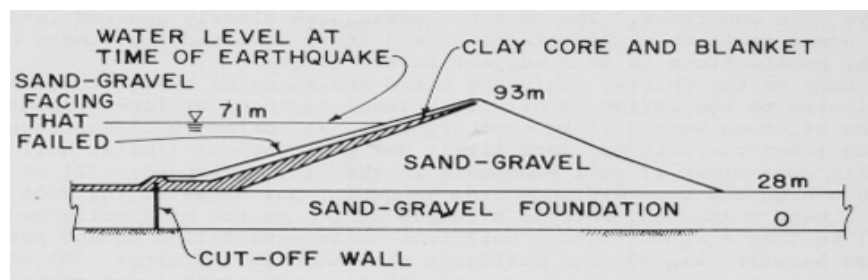


Figure 83. Cross section of Paiho main dam at Miyun Reservoir. During the earthquake the sand-gravel facing on the upstream face of the dam slumped down.

A number of studies had been made at IEM on the failure of the Paiho Dam using a finite element model and a shear beam model to analyze the dynamic response characteristics of the dam. The pseudo-dynamic safety factor for the gravel facing, using the peak observed horizontal accelerations, was 1.1-1.3. Most attention was focused on behavior of the facing material under the action of repeated loading.

This material was gap-graded pebbles and fine sand, with pebbles constituting about 60 percent of the weight. Tests on a shaking table indicated that pore pressures would build up in such a soil when the pebbles made up less than 70 percent of the total weight; in such a case, the pebbles are unable to form a skeleton and the overall behavior was controlled by the fine sand. The fine sand itself had an average particle size ( $D_{50}$ ) of 0.35 mm, a measured permeability of  $10^{-3}$  to  $10^{-4}$  cm/s, and a relative density of about 30 percent. Repeated load tests were made to determine the resistance of this sand to liquefaction using various ratios of principal stresses during consolidation and various criteria for failure. The overall conclusion was that the soil should have failed by liquefaction during the shaking, which was estimated to have had a duration of perhaps 60 cycles of motion.

The Paiho Dam was repaired by removing the remaining upstream facing, then thickening the clay core to resist cracking, and constructing a new facing using broken rocks with a transition layer of crushed stone between the rocks and the core.

A potentially more serious failure occurred at Touho reservoir about 20 km north of Tangshan. This earth dam consisted of a uniform cross section of rolled fill. It was built in 1956, and had a height of 22 m and an overall length of 1700 m. The earthquake produced cracks on both the upstream and downstream faces (Figure 84), and the crest settled as much as 1 m. Sand boils appeared at the downstream toe and also appeared in adjacent fields. Fortunately, at the time of the earthquake the depth of water in the reservoir was only 10 m. Chinese engineers believe that this failure was the result of liquefaction in the foundation, which consisted of 8 m of cohesive soil overlying 10-12 m of fine sand. Dynamic finite element analyses were made, which, together with test results, indicated that liquefaction should have been expected.

The severity of the damage sustained by the other 38 dams was not described.

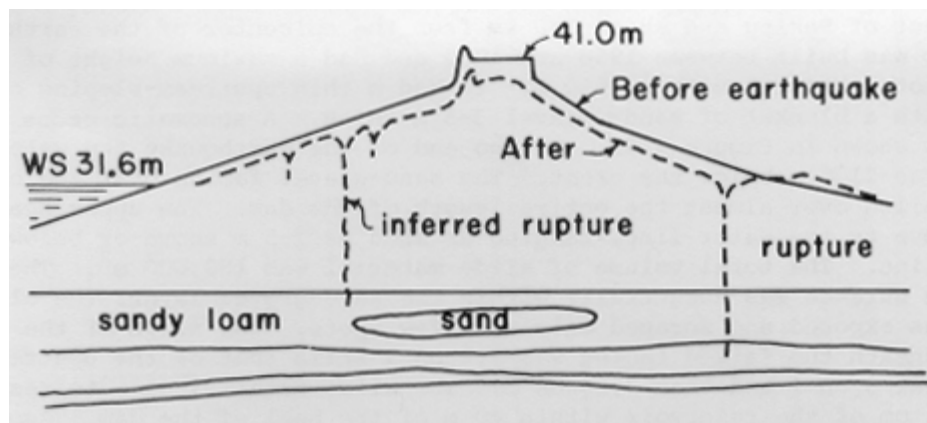


Figure 84. Sketch showing settlement of the earth dam at Touho reservoir.

## STRONG-MOTION RECORDS OF THE TANGSHAN EARTHQUAKE

The standard strong-motion accelerograph (RDZ-1-12-66) in use in China at the time of the earthquake consists of a central recording unit to which 12 pickups can be attached. Approximately 18 such recorders, with pickups, were installed in northeast China in 1976, but there were no strong-motion instruments in place in or near Tangshan. Strong-motion records were obtained at 10 permanently installed stations during the main shock of the Tangshan earthquake; of the 10 stations, six produced good records and four produced poor records. Four mobile recorders were brought into the epicentral area to record aftershocks.

The locations of these stations are shown in Figure 85. The station at Tianjin Hospital, approximately 80 km southwest of Tangshan, was the closest permanent station to the epicenter, but only a portion of the ground motion was recorded, as the range of the instrument was set for a maximum of 0.10g. The maximum ground acceleration completely recorded during the main shock was 0.097g at Miyun dam, which is located 153 km from the epicenter. The 17-story Beijing Hotel, located 147 km from the epicenter, had two RDZ-1-12-66 recorders with 19 transducers distributed throughout the building. The maximum accelerations recorded at the Beijing Hotel during the main shock were 0.040g in the basement (8 m below grade), 0.073g at grade level, and 0.200g at the roof level.

The data traces from the ground stations that produced good records during the main shock have been digitized by the Institute of Engineering Mechanics and the records obtained from 14 aftershocks with magnitude greater than 4.0 also have been digitized. This entire data set is summarized in Table 9 and is available for further analysis (Institute of Engineering Mechanics, 1978). The computed acceleration, velocity, and displacement and corresponding response spectra from a record obtained by a mobile station during the first of the two listed aftershocks on August 31 are shown in Figures 86-91.

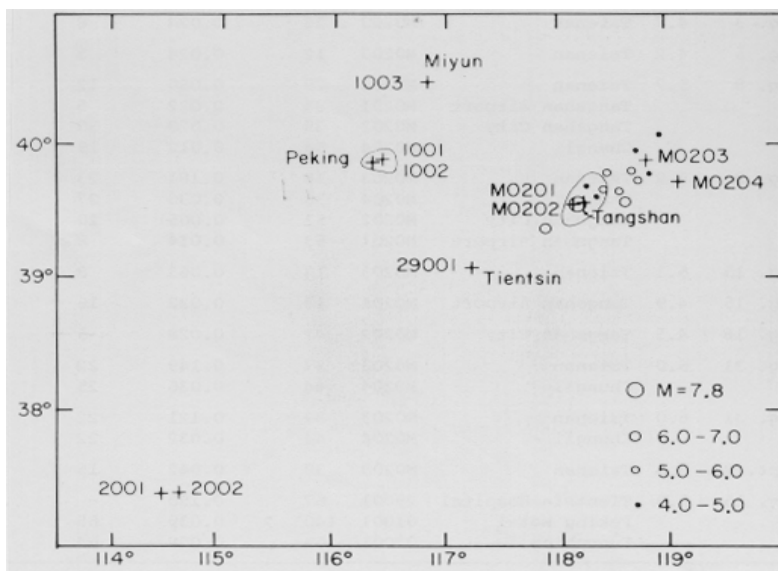


Figure 85. Locations of strong-motion instruments and locations of main shock and principal aftershocks. Instruments labeled M0201, etc., are mobile instruments installed following the main shock.

TABLE.9. Summary of Digitized Strong-Motion Data, Tangshan Earthquake of July 28, 1976, and Aftershocks

Date	M	Station	No.	Distance (km)	Acceleration (g)	Duration (s)
July 28	7.8	Miyun Dam	01003	153	0.097	114
		Hujailau	01002	153	0.056	135
		Beijing Hotel	01001	157	0.073	150
		Hungshan	02002	391	0.007	250
		Fungchien	02001	405	0.017	138
July 31	5.6	Tangshan Airport	M0201	31	0.034	38
Aug. 2	4.7	Tsienan	M0203	12	0.022	5
Aug. 3	4.2	Tsienan	M0203	10	0.059	5
Aug. 3	4.7	Tsienan	M0203	23	0.024	8
Aug. 5	4.2	Tsienan	M0203	12	0.024	5
Aug. 8	5.7	Tsienan	M0203	29	0.056	12
		Tangshan Airport	M0201	34	0.022	5
		Tangshan City	M0202	35	0.020	30
		Chungli	M0204	54	0.012	19
Aug. 9	5.9	Tsienan	M0203	18	0.181	23
		Chungli	M0204	30	0.036	27
		Tangshan City	M0202	51	0.005	20
		Tangshan Airport	M0201	53	0.014	8
Aug. 15	5.1	Tsienan	M0203	13	0.063	8
Aug. 15	4.9	Tangshan Airport	M0201	14	0.022	16
Aug. 18	4.5	Tangshan City	M0202	7	0.028	5
Aug. 31	6.0	Tsienan	M0203	37	0.149	22
		Chungli	M0204	44	0.036	25
Aug. 31	6.0	Tsienan	M0203	37	0.121	22
		Chungli	M0204	44	0.032	22
Sept. 25	5.6	Tsienan	M0203	38	0.042	15
Nov. 15	6.9	Tianjin Hospital	29001	67	0.150	—
		Beijing Hospital	01001	140	0.039	65
		Fungchien	02001	369	0.008	64

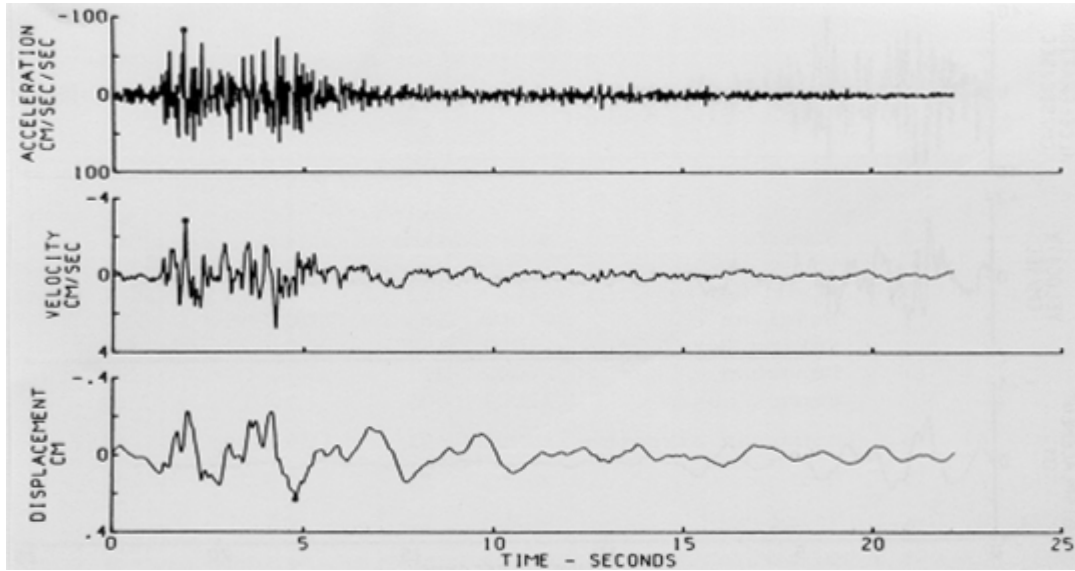


Figure 86. Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, 1976. Tsien-An station M0203, E-W component. Peak values are acceleration,  $-84.0 \text{ cm/s}^2$ ; velocity,  $-2.83 \text{ cm/s}$ ; velocity,  $-2.83 \text{ cm/s}$ ; and displacement,  $0.23 \text{ cm}$ .

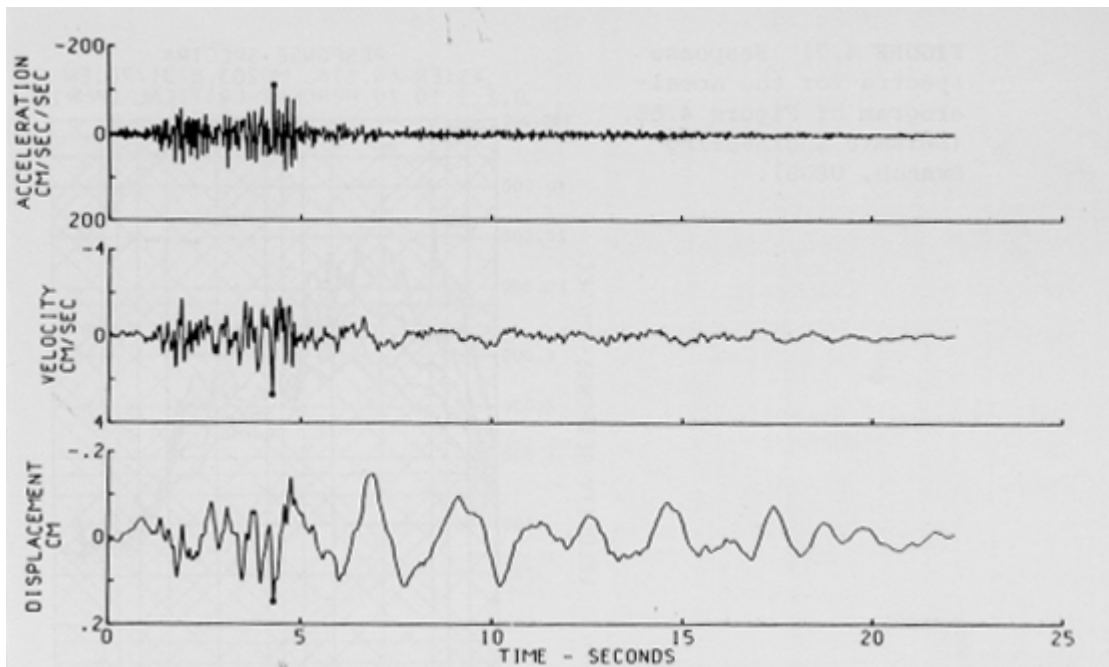


Figure 87. Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, 1976, N-SXZ component. Peak values are acceleration,  $-113.4 \text{ cm/s}^2$ ; velocity,  $2.71 \text{ cm/s}$ ; and displacement,  $0.15 \text{ cm}$ .



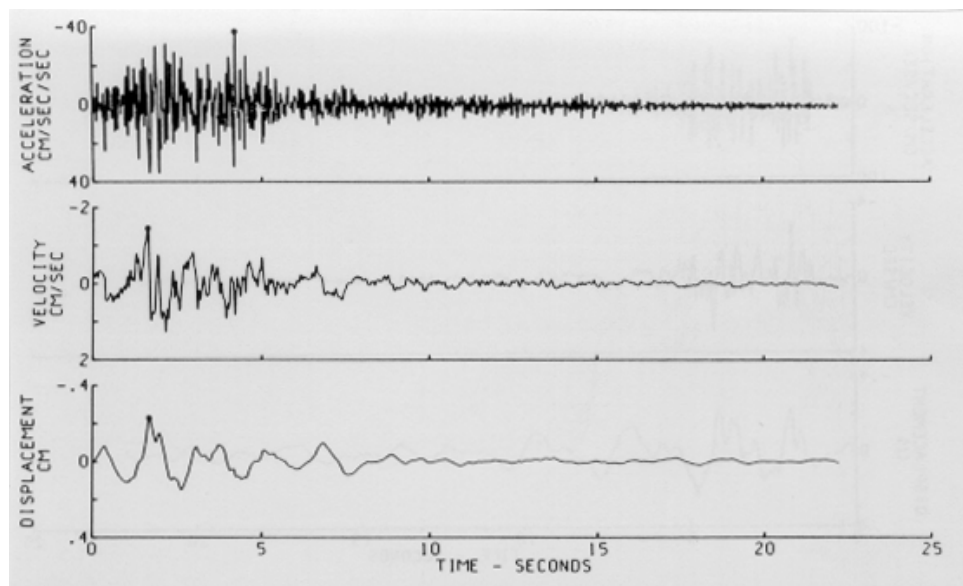


Figure 88. Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, vertical component. Peak values are acceleration,  $-38.0 \text{ cm/s}^2$ ; velocity,  $-1.45 \text{ cm/s}$ ; and displacement,  $-0.23 \text{ cm}$ .

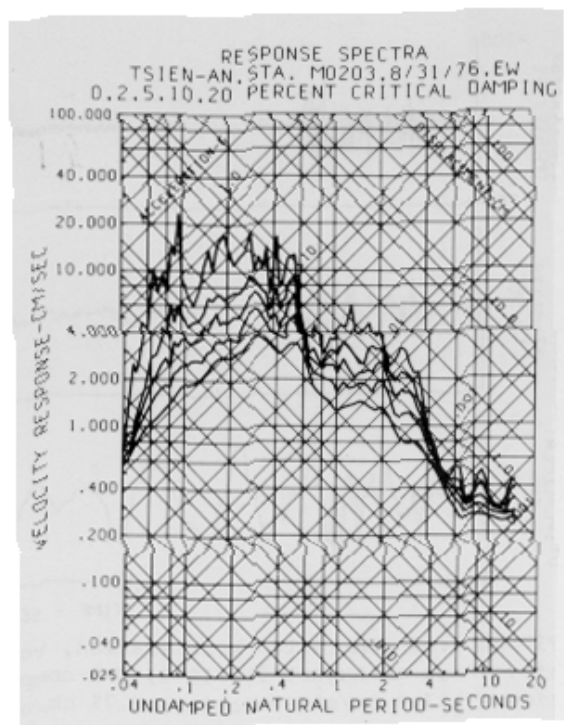


Figure 89. Response spectra for the accelerogram of Figure 86. (Seismic Engineering Branch, USGS).

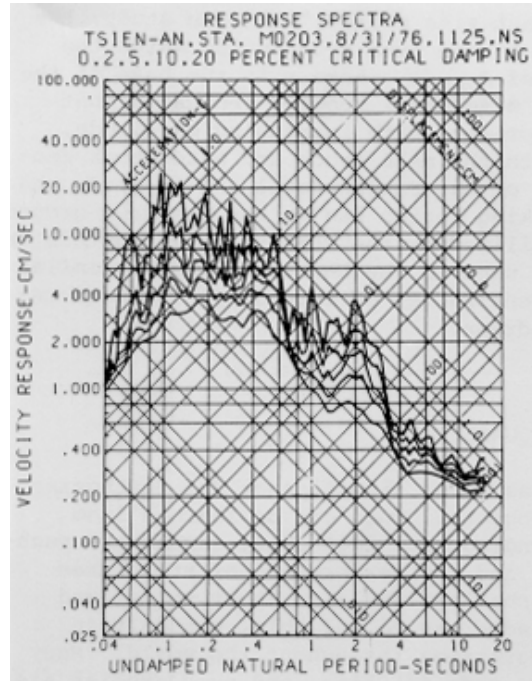


Figure 90. Response spectra for the accelerogram of Figure 87 (Seismic Engineering Branch, USGS).

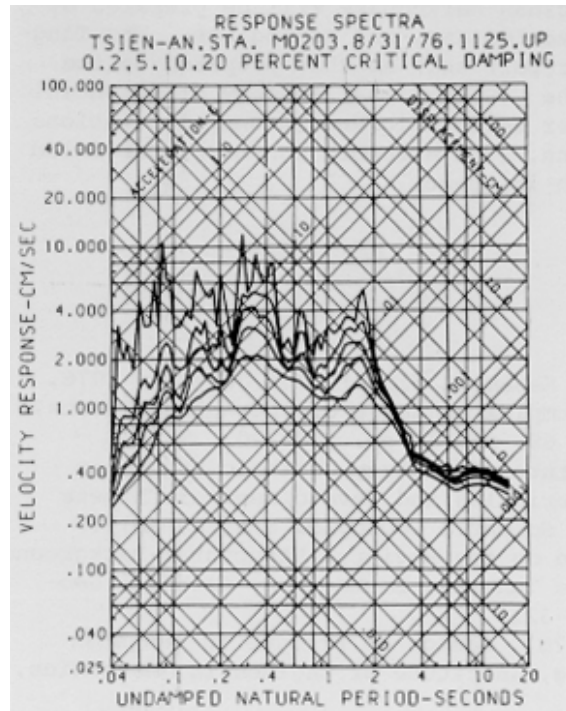


Figure 91. Response spectra for the accelerogram shown in Figure 88. (Seismic Engineering Branch, USGS).

Several preliminary studies of the strong-motion data from the Tangshan earthquake and its aftershocks have been conducted by IEM. Plots of peak acceleration versus distance exhibit a considerable scatter, and a difference in the records obtained from instruments on soil and on rock was noted. Studies of Fourier spectra from these records indicate that both soil type and propagation path have a significant influence on the spectra and the "dominant site period." In one study, the duration of the record was defined as the time span during which the acceleration peaks exceed a value of  $A_{\max} / e$ , where  $e$  is the base of the natural logarithms; and studies of aftershock records indicated that duration defined in this manner increases with increasing magnitude. Analyses are being performed on both the main shock and aftershock records to study the dynamic response of the Beijing Hotel and to study the influence that the soils in the Beijing region had on the measured ground response. The procedures being utilized by the Chinese investigators in these studies are similar to those used in the United States in similar studies. Further analysis of the entire set of records is required before any final conclusions can be drawn.

### **SIGNIFICANCE OF THE TANGSHAN EARTHQUAKE**

Clearly, the Tangshan earthquake has great significance for earthquake engineers, seismologists, and geologists. Much can be learned from this earthquake in the way of extending knowledge about earthquake mechanisms, earthquake ground motions, and the performance of structures under the action of strong ground shaking, and also about relief and rebuilding operations. This knowledge can be valuable, not only in China, but also in other seismic countries throughout the world.

The Delegation noted that many studies of the earthquake have been made in China, and such studies were continuing so that much information was being amassed. The Delegation expressed the hope that a comprehensive report on the Tangshan earthquake would be prepared by Chinese earthquake engineers, seismologists, and geologists. In their view the Tangshan earthquake warranted a major report such as that prepared on the great 1964 Alaska earthquake by the U.S. National Academy of Sciences. In their report, the Delegation expressed the prescient desire that such a report would be prepared and a version published in the English Language.

## REFERENCES

American Seismology Delegation (1975), Earthquake Research in China, *EOS*, Vol. 56, No. 11, pp.838-881.

*Beijing Review* (1976), Conference of Representatives of Advanced Units and Individuals in Anti-Quake and Relief Work, No. 37, September 8, pp. 6-11.

*Beijing Review* (1976), The 'Gang of Four' Sabotages Anti-Earthquake and Relief Work, No. 48, November 26, pp. 17-19.

Butler, R., G. S. Stewart, and H. Kanamori (1979), The July 27, 1976, Tangshan, China Earthquake—A Complex Sequence of Intraplate Events, *Bull. Seism. Soc. Amer.*, Vol. 69, No. 1, pp. 207-220.

Chen, P. S., et al. (1978), The Stress Field of the Beijing-Tianjin-Tangshan-Chanchiakou Area Before and After the Tangshan Earthquake of July 28, 1976, *Acta Geophysica Sinica*, Vol. 21, pp. 34-58.

Chinese Academy of Science, Institute of Geology Tectonic Map Group (1974), The Fundamental Characteristics and Development of Chinese Tectonics—A Preliminary Study, *Scientia Geologica Sinica*, No. 1.

Chinese Academy of Sciences, Institute of Geology (1979), Chinese Seismology.

Foreign Languages Press (1976), *After the Tangshan Earthquake; How the Chinese People Overcame a Major Natural Disaster*, Beijing.

Guo, S., et al. (1977), Discussion on the Regional Structural Background and the Seismogenic Model of the Tangshan Earthquake, *Scientia Geologica Sinica*, Vol. 20, pp. 305-321.

Haicheng Earthquake Study Delegation (1977), Prediction of the Haicheng Earthquake, *Eos*, Vol. 58, No. 11, pp. 236-272.

Hsieh Yu-show (1957), A New Scale of Seismic Intensity Adapted to the Conditions in Chinese Territories, Institute of Geophysics and Meteorology, Academia Sinica.

Ho Tu-hsin, and Kao Chin-ying (1978), Damage to Bridges in Tangshan Earthquake from Abutment Sliding, Institute of Engineering Mechanics, Academia Sinica, No. 78-029.

Institute of Engineering Mechanics (1978), Uncorrected Acceleration, Digitized Records of Tangshan Earthquake, Vols. 1 and 2, Academia Sinica.

Jennings, Paul C., Ed.(1980), Earthquake Engineering and Hazard Reduction in China, CSPRC Report No. 8, National Academy of Sciences, Washington, D. C.

Lewis, John Wilson (1971), Commerce, Education and Political Development in Tangshan, 1956-69, in John W. Lewis, ed., *The City in Communist China*, Stanford: Stanford University Press, pp. 153-179.

Malcolm, Andrew H. (1977), Chinese Disclose that 1976 Quake was Deadliest in Four Centuries, *New York Times*, June 2, pp. 1, 16.

*New York Times* (1977), Quake-Struck Chinese City is a Vast Plain of Rubble, June 11, pp. 1, 4.

Qiu, Q. (1976), On the Background and Seismicity of the  $M = 7.8$  Tangshan Earthquake, Hopei Province of July 28, 1976, *Acta Geophysica Sinica*, Vol. 19, pp. 259-269. (English translation, *Chinese Geophysics*, Vol. 1, No. 1, pp. 67-78.)

Rosenblueth, Emilio (1978), *Earthquake Prediction and Engineering in China*, Mexican Society of Seismic Engineering, December 1976 (translated by William H. Smith, edited by Alvaro L. Collin, p.27, October 1978 (unpublished)).

*Ta Kung Pao* (Hong Kong) (1978), A New City on Drawing Board, August 10, pp. 1, 3.

Wang, C. Y. (1974), Some Aspects of the Tangshan (China) Earthquake of 1976, *Chinese Geophysics*, Vol. 1, No. 1, pp. 157-172.

Wei Hsin-chen, and Chu Yun-ch'eng (1961), *Economic Geography of Tangshan*, Beijing: Commercial Press, 1959. (Translated in *JPRS* 10937, November 9).

Wong Siu-kuan (1978), Tangshan: Two Years After Quake, *Ta Kung Pao*, August 24, pp. 1, 8.

Yang Yu-chen, et al. (1978), Summary of Damage to Multi-Story Brick Buildings in the Tangshan Earthquake and Engineering Analysis, Institute of Engineering Mechanics, Academia Sinica, No. 78-05.