CHAPTER 3: FACTORY BUILDINGS

DAMAGE TO BUILDINGS WITH REINFORCED CONCRETE MULTI-STORY FRAMES AT THE KAILUAN COAL MINE

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1. General

After the Tangshan earthquake the design institutes in the coal industry conducted an investigation of the damage to 14 buildings with cast-in-place reinforced concrete multi-story frames, which were typical buildings at the Kailuan Coal Mine, namely, the main workshop at the coal preparation plant, the refuse picking building and shaft collar rooms, etc., having a total construction area of 33,900 m². Aseismic protective measures were not considered in the original design; the damage is listed in Table 1.

Two of the 14 workshops listed in Table 1 collapsed equaling 14.2% (one of these partly collapsed); 7 had severe damage equaling 50.0%; 2 had medium damage equaling 14.3%; and 3 had slight damage equaling 21.5%. Except for one refuse picking building that completely collapsed and needed to be reconstructed, the other 13 buildings were put into operation after being reinforced.

Divided according to the types of operation, it can be seen that the damage to refuse picking buildings with a single span and multi-story frame was most severe, damage to workshops of coal preparation plants with a multi-span and multi-story frame was moderate, and damage to multi-span and multi-story shaft collar rooms was relatively slight.

2. Damage

2.1 Columns

Damage to the top part was the most common damage to columns of cast-in-place reinforced concrete frames. For slight damage cases, one or several intermittent or circular horizontal

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1 This paper was written based on the investigation reports, drawings and information which were provided by the Planning and Design Institute of the Ministry of Coal Industry; the Coal Preparation Design and Research Institute; Chongqing, Xi’an, Handan, Shenyang, Wuhan and Yanzhou Coal Mine Design and Research Institutes; the Shanxi Coal Mine Design Institute; and the Kailuan Coal Mine.

2 Shenyang Coal Mine Design and Research Institute

3 The Planning and Design Institute, Ministry of Coal Industry
cracks generally appeared at a height of approximately 600 mm below the bottom surface of the beam and the width was generally no greater than 2 mm. For severe cases horizontal broken cracks were formed, concrete on the surface of fractures was broken and partly fell off, and main bars were exposed. Vertical or diagonal cracks mainly appeared on the panel joint area of beams and columns with crack widths generally no larger than 2 mm. The damaged sections were located near the joint of beams and columns where the concrete fell off and main bars were exposed or slightly bent, etc. Severe damage was located at the joints of beams and columns and to the section below the beam where most or all of the protective concrete peeled off, part of the main bars and hoops were exposed, main bars in column corners were bent, concrete in the joint area was broken and turned into fragments; the cracks completely or partially went through the whole cross-section of columns. Then main bars and hoops in columns were partially or completely exposed and bent, and the reinforcing bars were bent in a symmetrical “lantern” shape. Photo 5 shows the damage to the top of the D-15 column on the bottom floor of the heavy medium workshop at the Zhaogezhuang coal preparation plant.

Another form of damage to tops of columns was the occurrence of diagonal cracks at an angle of 45-60°; most cracks began near the bottom surface of the beam with a width generally no larger than 2 mm. The concrete on the surface broke and fell off to form relatively tidy fractures and reinforcing bars were exposed or slightly bent and some bars were deformed into a “lantern” shape and the column was on the edge of failing. Photo 6 shows the damage to the top of the E-14 column on the bottom floor of the heavy medium workshop at the Zhaogezhuang coal preparation plant. At the same time, a relatively obvious subsidence or displacement occurred on this floor.

There were also vertical cracks in the damage on top of columns that generally started from a place under the beam or at the intersection with the column.

Damage was seldom seen in the middle part of columns but horizontal circular cracks appeared in the middle part of some columns usually appearing at the same height on most columns on the same floor (pour joints). The width of the cracks was generally no larger than 1 mm. These types of cracks could mostly be seen on relatively high columns on the top floor.

There were also diagonal shear cracks that occurred in the middle part of some columns, which were similar in shape to the diagonal cracks on the top of columns; in severe cases the cracks made the column fracture.

The investigations indicated that the damage ratio to the bottom part of columns was slightly higher than that to the middle part but was lower than to the top part. The horizontal cracks on the bottom part were generally located at a height 1 m above the floor surface, the shape and width of which were similar to those on the top of columns; in severe cases horizontal fractures formed and were generally located at a height 0.5 m above the floor surface. Severe damage occurred to the bottom part of columns where the surface concrete near the floor slab peeled off, main reinforcing bars were exposed, columns inclined and displaced, and reinforcing bars bent in a symmetrical “lantern” shape along a horizontal surface.

In addition, there were also diagonal cracks on the bottom part of columns which were crisscrossed with each other; in severe cases reinforcing bars on inclined cross-sections were
bent in the shape of a lantern. Photo 7 shows X-shaped cracks on the bottom part of columns in the heavy medium workshop at the Zhaogezhuang coal preparation plant.

Several vertical cracks that were wider on the lower part and thinner on the upper part appeared on the bottom part on one or on both sides of some columns.

The most severe damage was the breaking of columns which occurred at the top, at the bottom, or at the middle part of columns. At this time, columns lost their bearing capacity and collapsed, as shown in Photo 8.

Among the buildings investigated the damage ratio for the following four types of columns was relatively high, the details are as follows:

1) Columns on the top floor. Damage was relatively severe to columns on the top floor of most workshops and was especially severe in high-rises. For instance, at the main workshop of the Tangjiazhuang coal preparation plant there were 21 columns on the top floor; 20 were severely damaged and one was basically intact.

2) Columns of compound frames. The damage ratio for columns of compound frames was generally higher than that of ordinary frames. When the beams on two sides of a column were not on the same level but were close to each other the column segments mostly presented inclined cracks or fractures. When there was a beam on one side of the column and no beam on the other side, in slight damage cases, the concrete on the surface of this panel point area peeled off; in severe cases the concrete in the panel broke into pieces. The damage ratio was relatively high when the rigidity ratio of beam to column was comparatively high. This type of damage was common for compound frames in the washing and floatation workshops of the coal preparation plant at Tangshan Mine.

3) Short columns. The damage ratio was also high for short columns where the ratio of the clear height and the width of the column was approximately 4 or less. The damage to short columns was generally a shear failure in the bottom part (such as columns on axes 2C and 5B on the bottom floor of the main workshop of the coal preparation plant at Tangjiazhuang Mine) or on the top part (such as the columns on the 2nd and 3rd floors of the washing workshop of the coal preparation plant in Tangshan Mine). Diagonal cracks and fractures appeared and reinforcing bars were bent into a lantern shape.

4) Columns under hoppers or deep beams. The damage ratio for columns in this type of panel joint was extremely high. The damage was severe, reinforcing bars were deformed in a lantern shape and concrete broke into pieces and fell off. Some damage areas also developed above the panel joints where the hopper and column met; much of this type of damage could be seen on columns under the hopper in the main workshop of the coal preparation plant at Tangjiazhuang Mine (Photo 9).

2.2 Beams

The common damage to crossbeams of frames was diagonal cracking which generally occurred within the end third of the span, most of which were in an inverted V-shape with an angle of 45° to 60°. For slight damage cases only one or two extremely thin cracks appeared
near the ends of the beam; they were relatively short and shallow located at about 1/2 of the beam height and less than 1 mm wide. Some cracks were longer and got close to or through the whole height of the beam. The concrete near the cracks peeled off or diagonal cracks crisscrossed and the main reinforcing bars were exposed in some places. In severe cases fractures formed and reinforcing bars bent and broke, and the main bars at the support slipped, etc. The bent bars in some beams (for instance, the frame beam of a roof in the washing workshop of the Tangshan coal preparation plant) fractured.

Vertical cracks at beam ends were also common. The cracks mostly occurred in places ranging up to 500 mm from the beam end and were generally wider in the upper part and thinner in the lower part, probably due to yielding of the tension bars. In slight cases of damage a thin and fine crack occurred near the beam end with a width less than 1 mm located at about one half of the beam height. In moderate damage cases cracks extended to the top of beams and as the number of cracks increased the concrete in some places peeled off, main bars were exposed and even slightly bent. In severe damage cases the concrete near the beam ends broke into pieces, main bars were bent and slipped.

Vertical cracks on the span of beams generally occurred in the middle 1/3 of the span, probably due to yielding of the tension bars. In slight damage cases the cracks were thin and fine with a width less than 1 mm and the length was developed the bottom 1/2 of the beam. In severe damage cases the length of cracks reached the whole height of beams with a width larger than 1 mm but generally less than 2 mm and as the number of cracks increased the concrete in some places peeled off and main bars were exposed. Some vertical cracks with uniform and dense intervals appeared on some beams.

Some diagonal cracks appeared on short beams that were surveyed and these types of cracks were very long and relatively more destructive.

2.3. Slabs

Diagonal shear cracks in the corners of slabs were common forms of damage. These generally appeared near the corner columns or side columns; more cracks were concentrated near the corner columns and less around the intermediate columns. These types of cracks were more severe on the lower floors than on the upper floors and their location on the upper and lower floors usually corresponded with each other. There was this type of damage in both the heavy medium workshop of the Majiagou coal preparation plant and in the main workshop of the Tangjiazhuang coal preparation plant.

Also, cracks on slabs mostly paralleled the direction of the main reinforcing bars and a few of them were inclined cracks with an angle less than 45° from the horizontal. There were many of these types of cracks in the main workshop of the Tangjiazhuang coal preparation plant.

Cracks in the openings of orifice slabs mostly appeared around openings that were newly cut during construction for expansion and modification. Very few cracks appeared in openings that were reserved in the original design if reinforcing bars were installed around their peripheries.
3. Examples of Damage

3.1 Refuse picking building at Jinggezhuang Mine (intensity IX)

3.1.1 Layout of building structures

The site soil at Jinggezhuang Mine was composed of Quaternary alluvial and diluvial sand with a total thickness of 151 m. The upper part was a silt and fine sand layer intercalated with thin layers of clayey soil. The middle part was a thick layer of medium-fine sand formation, and in the lower part was a clay formation intercalated with pebble. There were 17 formations and groups in total reflecting the many changes of the river. The composition of soil within 15 m underground was as follows:

- **Clayey soil**: yellowish-brown, slightly wet to extremely wet, a massive structure about 2 m thick.

- **Silty sand intercalated with fine sand**: grayish-white, extremely wet to saturated, the composition was mainly feldspar, compact, about 7 m thick, the upper part was clayey soil and the lower part was generally fine sand about 2 m thick.

- **Clayey soil**: yellow, saturated, high viscosity, plastic, soapy feeling, about 1 m thick.

- **Medium-fine sand and silt**: grayish-white, the quality was pure, compact, and the composition was mainly feldspar, about 5 m thick.

Before the earthquake the ground water level was approximately 4 m below the surface.

As shown in Fig. 1, the refuse picking building had a single span of 6 m laterally; 6 column spacings of 5.6 m longitudinally; the cross-section of the columns was 500×500 mm or 450×450 mm; a double column separation joint with a width of 1.4 m was installed in the middle, the plan dimension of the building was 6.0×33.2 m. There were two floors with a brick-concrete structure above an elevation of 22.900 m and a reinforced concrete frame structure for all the other floors. A reinforced concrete receiving bin for skip was built at an elevation of 15.600-22.900 m on the 4-5 axis with a capacity of 120 m³. Two coal bins were built under floors between the axes 8-9 and 9-10 with a capacity of 50 m³ and 70 m³ respectively. The reinforcement ratio of columns below an elevation of 9.800 m on axes 4 and 5 was higher than 4%, which was reduced to less than 1% for columns above an elevation of 9.800 m. No. 200 concrete was used for both beams and columns. The two types of reinforcement used were No. 16 manganese steel and No. 3 steel.

The building was situated on fine sand formation with a bearing capacity of 2.3 kg.f/cm² and a modulus of compression of 200 kg.f/cm². There were two types of foundation, one was a reinforced concrete continuous footing between axes 4-6 with a buried depth of 2.80 m; the other was a reinforced concrete separate foundation with a buried depth of 2.80 m for axis 7 and a depth of 2.10 m for axes 8-11.

The brick filler wall for the frame was 240 mm thick. A reinforced concrete airtight wall was built from the floor to an elevation of 9.800 m on axis 4.
3.1.2 Damage

1) Axes 7-11 section: collapsed during the M7.8 earthquake.

2) Axes 4-5 section: the columns were broken below an elevation of 18.643 m during the M7.8 earthquake, the receiving bin for skip reclined on the head frame of the main shaft and smashed the sealing plate of the head frame making it concave, the columns on axes 4-5 were broken but had not yet collapsed; it completely collapsed during the M7.1 earthquake (Photos 4 and 8).

3) The damage to columns at axis 9(B) indicated that after the columns were displaced to the southeast (longitudinally) they collapsed.

4) The foundation was in good condition after the frame collapsed (Photo 10).

3.2 Main buildings of the coal preparation plant at Tangjiazhuang Mine (intensity IX)

3.2.1 Layout of building structures

As shown in Fig. 2 the original plan dimension was 14.0×27.0 and 23.0×18.0 m forming an L-shape; then a vacuum pump room with two floors was constructed. There were two types of column grid dimensions which were 7.0×9.0 and 9.0×9.0 m respectively. Additional columns were built between axes 5-6 on the bottom floor because of the installation of the bin hopper. There were four floors in most parts of the building and five floors in the part with a mezzanine. There were four types of story height i.e., 3.0, 3.5, 4.5 and 7.0 m and the stories became higher in the upper part of the building. The elevation of the eaves was 19.500 and 8.500 m respectively. The filler wall of the frame was built with No. 25 mortar and No. 75 brick on the center line of columns with a thickness of 240 mm; there was no structural joining reinforcement between the wall and the frame columns. The reinforced concrete separate foundations were buried with a depth of 2.5 m and the staircase was built on one side of axis 1(A).

The layout of equipment in the workshop was: the filter was installed on the floor at an elevation of 3.500 m; screens and washing cells were installed on the floor at an elevation of 8.000 m; and the floatation cells were installed on the floor at an elevation of 12.5000 m.

The bearing formation of the foundation was sandy clay; the allowable bearing capacity of the foundation soil was 2.0 kg.f/cm². The separate foundation was buried to a depth of 2.5 m.

The concrete used for the foundation was No. 150 and the beams and columns of the frame used No. 200. The cross-section dimensions for columns was 700×700 and 600×600 mm. The concrete used for the floor and roof slab was No. 200 and No. 3 steel was used for the reinforcement.

3.2.2 Damage

1) Damage to the filler wall. Most of the filler walls on the top floor collapsed and those on the floor with an elevation of 15.500 m partially collapsed; diagonal cracks and X-shaped cracks on the walls of the lower floors were common; walls between windows were severely damaged and some of them were broken into fragments. Cracks appeared on the walls of staircases; the
brick internal wall supporting the stair beam pulled away from the exterior filler wall. The internal partition wall on the bottom floor was basically in good condition.

2) Damage to the frame. Figure 3 shows several drawings representing cracks on the damaged frames.

The damage ratio for beams of the frame was very high. Out of a total of 152 beams 128 suffered slight or more severe damage, a damage ratio of 84.2%. The main damage was vertical and inclined cracks at beam ends, and secondary damage was vertical cracks at mid-span. Table 2 shows the statistics of distribution features for cracks on beams of the frame. It can be seen from Table 2 that 44% of the cracks were distributed within 1.0 m of the beam ends and 32% of the cracks were beyond 1.5 m from the beam end.

Approximately 20% of the damaged beams were broken into fragments or fractured and severely damaged. The severe damage mainly occurred on walls and beams at an elevation of 15.500 m; most of the damage included diagonal cracks, some of which were about 10 mm wide, and the width of some cracks was up to 30 mm. Where the beam was fractured it was possible to see completely through the beam. Vertical cracks with a uniform and dense distribution appeared on some beams and some inclined cracks appeared on the middle part.

Damage to the frame columns was severe. Almost all of the column heads on the top floor were damaged. The column heads of columns on axis 6(A) displaced outwards 60 mm and the reinforcing bars at the top of some columns were in the shape of a lantern. Damage to column heads under the refuse bin was also very severe. For instance, the concrete of columns on axes 6(A), 6(B) was broken, reinforcing bars were in a lantern shape and the lengths of the damaged areas reached up to 1.9 m and 2.2 m respectively. Some column bases were severely damaged for instance, the column on axis 5(A) displaced 300 mm at an elevation of 15.500 m. The reinforcing bars at the bases of columns on axes 5(B) and 2(C) presented damage in a lantern shape.

Table 3 shows the statistics of column damage locations and types of damage.

Table 4 shows damage to side, corner and middle columns, which indicates a damage ratio of 70.4% for the side and corner columns and 73.9% for the middle columns. The two ratios are almost identical.

3) Damage to the secondary beams and slabs. Damage to the secondary beams and slabs was generally not severe. Figure 4(a) and (b) shows the actual records of cracks on the roof slabs and floor slabs at elevations of 19.500 m and 8.000 m respectively. On the floors with openings drilled after they were built, cracks appeared around the openings after the earthquake but very few cracks appeared around the openings preserved during construction. Cracks on slabs were usually linked up with cracks on the secondary beams. For instance, four cracks got through the whole length of roof slabs at an elevation of 19.500 m. They cut off not only the slabs but also the secondary beam on the roof and the longitudinal beam of the frame.
3.3 Heavy medium workshop of the coal preparation plant at Zhaogezhuan Mine (intensity IX)

3.3.1 Layout of building structures

The heavy medium workshop was part of the main building of the coal preparation plant. The washing, floatation and heavy medium workshops were situated on axes 1-5, 6-11, and 12-16 respectively (counted from west to east). The plant building was nearly 100 m long in the longitudinal direction, from axes 1-16, and 28 m wide laterally. Expansion joints were installed between the workshops. The designed highest point of the original building was 28 m. The earthquake occurred during construction of the plant building (the washing, floatation, and heavy medium workshops had been constructed up to floors at elevations 3.500, 9.800, and 7.000 m respectively), and the building was severely damaged. When the earthquake occurred the forms on the second floor of the heavy medium workshop had not been completely removed yet and the filler wall was not installed.

The soil of each formation from the surface of the site is as follows. The surface soil was artificially filled earth mainly composed of refuse and slag with a loose structure. The second layer was clayey soil, yellowish-brown, extremely wet to saturated, plastic, and large pores were visible. The third layer was clayey soil, brown, yellowish-brown, extremely wet to saturated, and plastic. The foundation of the heavy medium workshop was situated on the latter clayey soil layer; its allowable bearing capacity was 1.8 kg.f./cm^2 with a buried depth of 3.8 m. The total thickness of the overburden was approximately 10 m i.e., there was bedrock 6 m below the bottom surface of the foundation.

The structural plan of the heavy medium workshop is shown in Fig. 5. The cross-section dimensions of columns and the amount of reinforcement on a single side are marked in the figure. The steel ratio for each column was medium. The grade of concrete was as follows: No. 200 concrete was used for beams and columns; No. 150 was used for floor plates and foundation; and No. 3 steel was used for all of the reinforcements. The foundation was a reinforced concrete separate footings.

3.3.2 Damage

When the earthquake occurred the concrete used for the frame had already reached the designed grade. Damage to the plant building was more severe from west to east; only some visible fine and thin cracks appeared on panel joints of individual beams and columns in the washing workshop. Most of the damage in the floatation workshop occurred on column heads below the floor at an elevation of 9.800 m on axes D, E, the latter with more severe damage. Damage to columns on the bottom floor of the heavy medium workshop was severe but the columns on the second floor and the beams on the first and second floors were basically intact. For the columns on the bottom floor of the heavy medium workshop, damage to the four columns on axes 14E, 15E, 14D, and 15D were most severe. The reinforcement in the column heads on axes 14E and 15E was bent into a lantern shape. The concrete was broken into pieces, the hoop reinforcement was broken, the displacement at fractures was approximately 150 mm, and the height of the damage area was approximately 1.5 m. On axes 14D an 15D reinforcement in the column heads were bent into a lantern shape, the concrete was smashed into pieces, the hoop reinforcement was broken apart, and the height of the damage area was up to 1.7 m. In
addition, for columns on axis 13D the design was modified to raise the top surface of the foundation to an elevation of -0.200 m during construction, close to the elevation of the interior floor surface. X-shaped cracks appeared on these columns at the base, the concrete at the corner of the columns peeled off, and the height of the damage area was approximately 1.5 m.

Table 5 shows the statistics of damage degrees for columns on the bottom floor of the heavy medium workshop. From this table it can be seen that the damage ratio of the middle column was higher than that of the side and corner columns. From the viewpoint of cross-section dimensions, two columns with a cross-section of 800×800 mm were all damaged; and 5 out of 7 columns with a cross-section of 700×700 mm were damaged. For these columns the ratio between the net height of the column and the width of the column was less than 5, which reflects the severity of damage to short columns. The four columns located at the intersecting points of axes 14, 15 and axes D, E, between which a rough rubble wall was built to increase rigidity, but also suffered the most severe damage to columns. Figure 6 shows the cracks on the frame of axes 14, 15.

After the earthquake a survey was made for the subsidence of the foundation. The foundation level of the column on axis 12(A) was taken as the datum mark (±0.000) because the original mark had already been damaged. The relative subsidence values for each foundation are shown in Fig. 5 (in mm).

(Translator: Zhao Yuzhen)
Table 1. Damage to buildings with reinforced concrete multi-story frames at Kailuan Coal Mine.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Building</th>
<th>Intensity</th>
<th>Construction Year</th>
<th>Building Area (m²)</th>
<th>Features of the Structure</th>
<th>Type of Site Soil</th>
<th>Damage Description</th>
<th>Damage Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Washing workshop at the coal preparation plant at Tangshan Mine</td>
<td>XI</td>
<td>1971</td>
<td>4,050</td>
<td>Plan dimension of 31.8×31 m; column intervals of 3.5, 4.3, 6.0, 6.5, 7.5, 8.0 m (6 types); maximum 6 stories; elevation of eaves 26.890 m; most of the buildings have 3 or 5 stories; thickness of brick filler wall was 240 mm; separate foundation with a buried depth of 5-6 m.</td>
<td>II</td>
<td>Nearly all of the beams and columns of the top frame were damaged; damage to the lower part was slightly less severe which for part of the beams and columns was very severe. The filler wall in the upper part partially collapsed.</td>
<td>severe damage</td>
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<tr>
<td>2</td>
<td>Floatation workshop of the coal preparation plant at Tangshan Mine</td>
<td>XI</td>
<td>1971</td>
<td>2,575</td>
<td>Plan dimension of 21×45m; column grid of 7.0×7.5 m; the main part has 3 stories partly with a mezzanine of 5 stories; elevation of eaves 22.180 m; thickness of brick filler wall was 240 mm; separate foundation with a buried depth of 5-6 m.</td>
<td>II</td>
<td>Damage to part of the columns and beams was very severe. From the viewpoint of the whole building, damage to the upper part was less severe than to the lower part. The building floor was sinking with a maximum sinking of 175 mm.</td>
<td>severe damage</td>
</tr>
<tr>
<td>3</td>
<td>Main workshop of the coal preparation plant at Tangshan Mine</td>
<td>IX</td>
<td>1966</td>
<td>4,486</td>
<td>See damage example 2).</td>
<td>II</td>
<td>See damage example 2 (Photo 1).</td>
<td>severe damage</td>
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<tr>
<td>No.</td>
<td>Name of Building</td>
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<tr>
<td>4</td>
<td>Heavy medium workshop for middling of the coal preparation plant at Majiagou Mine</td>
<td>X</td>
<td>1968</td>
<td>1,785</td>
<td>Plan dimension of 14×16 m; column grid of 7×8 m; 7 stories on the western side; 5 stories on the eastern side; floor height of 3, 3.5, 4.5 m, etc. Thickness of brick filler wall was 240 mm; separate foundation with a buried depth of 6 m.</td>
<td>II</td>
<td>Damage to side columns and the upper floor of the frame were more severe than to the central columns and lower floor respectively. Damage to columns mostly occurred to the top; 70% of the beams were damaged. Generally, damage was more severe on the upper part (Photo 2).</td>
<td>medium damage</td>
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<tr>
<td>5</td>
<td>Refuse picking building at Majiagou Mine</td>
<td>X</td>
<td>1956</td>
<td>1,550</td>
<td>Plane dimension of 6×12 m; column grid of 6×6 m; 5 stories; elevation of eaves 20 m; thickness of brick filler wall was 240 mm; separate foundation with a buried depth of 3.25 m.</td>
<td>II</td>
<td>Obvious displacements occurred on the 5th floor of the frame. Severe damage occurred to the top of columns; the concrete was broken and the reinforcement was bent and exposed; panel joints of frames generally cracked; part of the brick filler collapsed.</td>
<td>severe damage</td>
</tr>
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<td>6</td>
<td>Refuse picking building at Fangezhuang Mine</td>
<td>IX</td>
<td>1963</td>
<td>1,620</td>
<td>Plane dimension of 10×30 m; column grid of 10×6 m; 5 stories, partly 6 stories; elevation of eaves 21.00 m and 24.50 m; thickness of brick filler wall was 240 mm; reinforced concrete raft foundation with a buried depth of 2.6 m.</td>
<td>III</td>
<td>The 5th floor on top of the two spans near the head frame collapsed; beams and columns on other floors cracked and the filler wall was damaged (Photo 3).</td>
<td>partly collapsed</td>
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<tr>
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<tr>
<td>7</td>
<td>Refuse picking building at Jinggezhuang Mine</td>
<td>IX</td>
<td>1976</td>
<td>1,000</td>
<td>See damage example 1). Plane dimension of 12.6×19.6 m; column grid of 6×6 m; 6 stories; elevation of eaves 22.80 m; thickness of brick filler wall was 240 mm; reinforced concrete continuous footing.</td>
<td>II</td>
<td>See damage example 1) (Photo 4). Collapsed</td>
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<td>8</td>
<td>Crushing and screening workshop at Lujiaotuo Mine</td>
<td>IX</td>
<td>1966</td>
<td>1,021</td>
<td>Plane dimension of 12.6×19.6 m; column grid of 6×6 m; 6 stories; elevation of eaves 22.80 m; thickness of brick filler wall was 240 mm; reinforced concrete continuous footing.</td>
<td>III</td>
<td>Cracks occurred on part of the beams and columns; a few cracks occurred on brick filler walls. Slight damage</td>
<td></td>
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<tr>
<td>9</td>
<td>Refuse picking building of the No. 5 shaft at Linxi Mine</td>
<td>IX</td>
<td></td>
<td>1,931</td>
<td>Plane dimension of 14×21 m; column grid of 7×7 m; 7 stories; elevation of eaves 25.6 m; thickness of brick filler wall was 240 mm.</td>
<td>II</td>
<td>Part of the columns were severely damaged; cracks on panel joints of beams and columns were relatively common; brick filler wall partially collapsed. Severe damage</td>
<td></td>
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<td>10</td>
<td>Shaft collar room of the No. 4 shaft at Linxi Mine</td>
<td>IX</td>
<td>1947</td>
<td>1,692</td>
<td>Cracks occurred on panel joints of a few beams and columns.</td>
<td>II</td>
<td>Damage to the top of columns on the top floor was severe; cracks on panel joints of beams and columns were relatively common; the brick filler wall partially collapsed. Severe damage</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Floatation workshop of the coal preparation plant at Linxi Mine</td>
<td>IX</td>
<td>1965</td>
<td>4,350</td>
<td>Plane dimension of 32×33 m; column grid of 6×6 m; 3 stories; elevation of eaves 17.660 m; thickness of brick filler wall was 240 mm; separate foundation.</td>
<td>II</td>
<td>Damage to the top of columns on the top floor was severe; cracks on panel joints of beams and columns were relatively common; the brick filler wall partially collapsed. Severe damage</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Name of Building</td>
<td>Intensity</td>
<td>Construction Year</td>
<td>Building Area (m²)</td>
<td>Features of the Structure</td>
<td>Type of Site Soil</td>
<td>Damage Description</td>
<td>Damage Degree</td>
</tr>
<tr>
<td>-----</td>
<td>------------------</td>
<td>-----------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>---------------------------</td>
<td>------------------</td>
<td>-------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>12</td>
<td>Washing workshop of the coal preparation plant at Zhaogezhuang Mine</td>
<td>IX</td>
<td>1976</td>
<td>1,568 (Partly constructed)</td>
<td>Plane dimension of 28×28 m; column grid of 7×7 m. The floor at an elevation of 3.500 m had already been constructed when the earthquake occurred; separate foundation with a buried depth of 8 m.</td>
<td>II</td>
<td>Cracks occurred on panel joints of a few beams and columns.</td>
<td>slight damage</td>
</tr>
<tr>
<td>13</td>
<td>Floatation workshop of the coal preparation plant at Zhaogezhuang Mine</td>
<td>IX</td>
<td>1976</td>
<td>3,920 (Partly constructed)</td>
<td>Plane dimension of 28×35 m; column grid of 7×7 m. The floor at an elevation of 9.800 m had already been constructed when the earthquake occurred; separate foundation with a buried depth of 3.8 m.</td>
<td>II</td>
<td>Cracks occurred on beams and columns; damage to top part of columns on floors with an elevation below 9.800 m on D, E axes was severe.</td>
<td>medium damage</td>
</tr>
<tr>
<td>14</td>
<td>Heavy medium workshop of the coal preparation plant at Zhaoge-zhuang Mine</td>
<td>IX</td>
<td>1976</td>
<td>2,352 (Partly constructed)</td>
<td>See damage example 3.</td>
<td>II</td>
<td>See damage examples 3.</td>
<td>severe damage</td>
</tr>
</tbody>
</table>
Table 2. Statistics on the location of cracks on the frame of the main building at the Tangjiazhuang coal preparation plant.

<table>
<thead>
<tr>
<th>Direction of Beams</th>
<th>Length to Beam End</th>
<th>Crack Nos./ (%)</th>
<th>Crack Nos./ (%)</th>
<th>Crack Nos./ (%)</th>
<th>Crack Nos./ (%)</th>
<th>Crack Nos./ (%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1.0 m</td>
<td>about 1.0 m</td>
<td>1.0-1.5 m</td>
<td>&gt;1.5 m</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame on axes 1-6, main span 9 m</td>
<td>100/ (39)</td>
<td>41/ (16)</td>
<td>32/ (13)</td>
<td>83/ (32)</td>
<td>256/ (100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame on axes A-D, main span 7 m</td>
<td>133/ (48)</td>
<td>31/ (11)</td>
<td>22/ (8)</td>
<td>90/ (33)</td>
<td>276/ (100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>233/ (44)</td>
<td>72/ (14)</td>
<td>54/ (10)</td>
<td>173/ (32)</td>
<td>532/ (100)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Statistics of damage locations and damage types of frame in main buildings at the coal preparation plant at Tangjiazhuang Mine.

<table>
<thead>
<tr>
<th>Damage Location</th>
<th>Damage Type</th>
<th>Quantity</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Corner Column</td>
<td>Side Column</td>
<td>Middle Column</td>
</tr>
<tr>
<td>Column Head Section</td>
<td>horizontal cracks</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>horizontal fractures</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>cracks in panel joint area</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>reinforcing bars exposed at column corners</td>
<td>5</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>concrete in panel joint area peeled off</td>
<td>1</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>concrete in panel joint area broken into pieces</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>reinforcing bars (R.B.) presented damage in a symmetric lantern shape</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>oblique section cracks</td>
<td>1*</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R.B. at oblique cross-sections presented damage in a lantern shape</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>vertical cracks</td>
<td>0</td>
<td>2*</td>
<td>1+1*</td>
</tr>
<tr>
<td></td>
<td>Subtotal</td>
<td>19</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Middle Section of Column</td>
<td>horizontal cracks</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>inclined cracks</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Subtotal</td>
<td>0</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Column Root Section</td>
<td>horizontal cracks</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>horizontal fractures</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>R.B. exposed at column corners</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>concrete peeled off</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>oblique displacement</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R.B. presented damage in a symmetric lantern shape</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>R.B. at oblique cross-sections presented damage in a lantern shape</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Subtotal</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>23</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

Notes: * indicates that they occurred at the same location with other cracks simultaneously.
Table 4. Statistics of damage degree for side, corner and middle columns in main buildings of the coal preparation plant at the Tangjiazhuang Mine

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>Number of Members</th>
<th>Broken Into Pieces or Into Two</th>
<th>Severe Damage</th>
<th>Medium Damage</th>
<th>Slight Damage</th>
<th>Basically Intact</th>
<th>Number of Members</th>
<th>Broken Into Pieces or Into Two</th>
<th>Severe Damage</th>
<th>Medium Damage</th>
<th>Slight Damage</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.500-19.500</td>
<td>12</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12.500-15.500</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8.000-12.500</td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3.500-8.000</td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>11</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>0.000-3.500</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>12</td>
<td>3</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>54</td>
<td>13</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>16</td>
<td>46</td>
<td>12</td>
<td>13</td>
<td>8</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>24.1</td>
<td>13.0</td>
<td>14.8</td>
<td>18.5</td>
<td>29.6</td>
<td>100</td>
<td>26.1</td>
<td>28.2</td>
<td>17.4</td>
<td>2.2</td>
<td>26.1</td>
</tr>
</tbody>
</table>

Damage Ratio (%) | 70.4 | 73.9
Photo 1. The main workshop of the coal preparation plant at Tangjiazhuang Mine.

Photo 2. The heavy-medium workshop for the coal preparation plant at Majiagou Mine.
Photo 3. The refuse picking building at Fangezhuang Mine partially collapsed.

Photo 4. The refuse picking building at Jinggezhuang Mine collapsed.
Photo 5. The reinforcing bars at the column top buckled in a “lantern” shape.

Photo 6. Damage in a “lantern” form appeared on the inclined cross section at the top of columns in the heavy-medium coal preparation workshop of Zhaogezhuang plant.

Photo 7. “X” shaped cracks in the heavy-medium workshop at the Zhaogezhuang coal preparation plant.
Photo 8. The refuse picking building in Jinggezhuang Mine collapsed because the columns broke.

Photo 9. There was damage to the top of the column in the main workshop of the coal preparation plant at Tangjiazhuang Mine.

Photo 10. Posts in the refuse picking building of Jinggezhuang Mine were broken at the base, the foundation was intact.
Figure 1. Structural sketch of the refuse picking building at Jinggezhuang Mine.
(a) Profile; (b) Plan of the column grid
Figure 2. Plan of the main building of the Coal Preparation Plant at Tangshan Mine.

Figure 3 (a). Actual cracks and column failures in the frame on axis 5 in the main building of the Tangjiazhuang Coal Preparation Plant.
Figure 3 (b). Actual cracks and column failures on axis 6 in the main building of Tangjiazhuang Coal Preparation Plant.

Figure 3 (c). Actual cracks in the frame on axis C in the main building of the Tangjiazhuang Coal Preparation Plant.
Figure 4. Actual cracks in the main building of the Coal Preparation Plant at Tangjiazhuang Mine:
(a) On the roof slabs, elevation 19.500 m; (b) On the floors at the elevation of 8.000m.
Figure 5. The structural plan of the heavy medium workshop of the Coal Preparation Plant at Zhaogezhuang Mine.

Figure 6. Actual damage to frames in the heavy-medium workshop of the Coal Preparation Plant at Zhaogezhuang Mine.
(a) Column failures on axis 14; (b) Column failures on axis 15
DAMAGE TO SINGLE-STORY BRICK FACTORY BUILDINGS
AT KAILUAN COAL MINE

Zhang Lianfu2 and Jiang Chunqiou3

1. General

Single-story brick factory buildings formed a relatively large proportion of buildings belonging to the Kailuan Coal Mine. They were mostly used as hoist houses and shaft collar rooms for the hoisting system for the underground mines; also for houses of the ventilation system, substations of the power supply system and pumping rooms of water supply system. In addition, they were also used as air compressor rooms, machinery repair factories, processing rooms, mine car repairing rooms, boiler rooms, garage, grease storehouses, warehouses (sheds) for equipment, material and metals, etc. The area used by these buildings made up approximately 40% of the total building area of the industrial site of the mine.

After the Tangshan earthquake a survey was conducted on 283 single-story brick factory buildings at the Kailuan Coal Mine, a total building area of more than 0.12 million m². Most of these buildings were built in the 1950's and a portion of them were built before then. Some had a history of 50 to 60 or more years. The structural form of these buildings was different but the walls and foundations were all built with brick and stone. The brick walls were 240 and 370 mm thick and the thickness in some old buildings had dimensions of 470, 600, and 920 mm. No. 75 clay bricks were mostly used and a portion of them were Kailuan construction bricks (the grade was higher than No. 150); the mortar was mostly No. 25 cement and lime mortar. Some of the rough walls were built with rough stone but most of them were built with rubble or matched with relatively regular and tidy stones on the surface. The rough stone masonry possessed good mechanical behavior and was mostly used for the wall below windows in main plant buildings such as in hoisting houses or the wall of a basement. In this region the rough stone and rubble wall or foundation was usually built with lime-cinder. In the workshop equipped with a crane the support columns for crane beams were mostly brick columns built into the walls, and a few of them used steel members as support columns. Most of the exterior walls for higher or more spacious workshops with relatively larger spans were constructed with counterfort columns to form a brick bent system with the counterfort columns as the main load bearing structure. Bond beams were installed in some workshops mostly in the middle part of walls and were used as the window lintel. Some of the roof structures were wood trusses and tile roofs; some were cast-in-

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1 This paper was written based on the investigation reports, drawings and information that were provided by the Planning and Design Institute of Ministry of Coal Industry; the Wuhan, Chongqing, Shenyang, Yanzhou, Xi'an and Handan Coal Mine Design and Research Institutes; the Coal Preparation Design and Research Institute; the Shanxi Coal Mine Design Institute; and the Kailuan Coal Mine.

2 Yanzhou Coal Mine Design and Research Institute

3 Planning and Design Institute, Ministry of Coal Industry
place reinforced concrete beams and slabs or pre-cast reinforced concrete hollow slabs, and some were steel truss and corrugated iron and asbestos sheet roofs. A few of them used a pre-cast reinforced concrete structure. In general, flat roofs were used less than pitched roofs. The span for these workshops ranged from 6 to 20 m, most of them were approximately 14 m. The height of eaves ranged from 4 to 14 m, most of them were approximately 6 m and 10 m. The length of buildings ranged from 10 to 90 m, most of them were between 15 to 35 m. No seismic design was employed for these buildings.

The 283 single-story brick masonry workshops surveyed were all located in an intensity IX-XI area, most of them were severely damaged and only a few of them were intact or slightly damaged. Table 1 shows the statistics of damage degree.

Of the 283 single-story brick masonry workshops surveyed, damage to key buildings such as hoist houses, substations, fan houses, and shaft collar rooms are referred to in Table 2.

From Table 2 it can be seen that the collapse ratios for hoist houses and substations were very high, 42.9% and 66.7% respectively. The severe damage ratios were 95.3% and 88.9% respectively. The collapse ratio for fan houses was up to 50%. The collapse and severe damage ratio for the shaft collar room was 57.2%.

2. Features of Damage

The features of earthquake damage to single-story brick masonry workshops surveyed at the Kailuan Coal Mine can be summarized according to their structural parts as follows:

2.1 Gable wall

Most of the brick masonry workshops surveyed used a pitched roof with no roof truss for the end span, with the purlins supported on the top of the gable wall. Some of them used a flat roof with a cast-in-place or pre-cast reinforced concrete structure. As seen from the results of the survey, the damage to the gable wall was more severe than to other parts of the workshop.

Figure 1 shows slight and medium damage to a gable wall with a pitched roof. In general, vertical or diagonal cracks appeared along the eaves; at the top point of the gable wall; at corners of doors, windows and openings; and on the upper part of the connection with the exterior longitudinal wall. Horizontal cracks appeared at the height of eaves or on the top part of counterfort columns, which did not reach the roof; diagonal cracks appeared on their lower part mixed with few horizontal cracks.

Figure 2 shows severe damage to a gable wall with a pitched roof. The features of damage are as follows: cracks at each part developed and connected with each other, the surface of the wall was cut into several large sections and inclined outwards. Collapse occurred partially along the eaves or on the top part of the gable wall. For the gable wall with counterfort columns, cracks only developed on the wall between columns and did not connect with each other.

Figure 3 shows severe damage and partial collapse of a gable wall with a pitched roof. Collapse usually occurred in the upper part.
Photo 1 shows damage to the hoist house of the service shaft at Jinggezhuang Mine. The bond beams hung in the air and bent due to collapse of the gable wall.

Figure 4 shows damage to both sides of a gable wall in the same workshop. The collapsed area was larger on the side with no ring beams and collapse only occurred at the top of the gable wall on the side with bond beams.

Figure 5 shows an example of damage to a gable wall in a brick masonry workshop with a flat roof. In the case of slight damage horizontal cracks generally appeared at eaves or inclined cracks appeared on the lower part. For medium cases of damage the horizontal and inclined cracks extended and the width of the cracks expanded. For severe cases of damage cracks crisscrossed and collapse occurred locally (Photo 2) or the whole gable wall collapsed. The outwards inclination of the gable wall with a flat roof was less than that with a pitched roof, and the damage to the gable wall with a cast-in-place reinforced concrete roof was less than that to a gable wall with a pre-cast roof.

2.2 Longitudinal wall

When slight damage occurred to a longitudinal wall the cracks generally appeared at the following locations:

1. Inclined cracks appeared on the upper corners of door openings and the four corners of a window opening, see Fig. 6(a) and (b).

2. Cracks on the wall between the door and window. Horizontal cracks appeared on the upper and lower levels of openings for doors and windows and usually changed into inclined cracks at the ends of the wall [Fig. 6(c)]; inclined and X-shaped cracks appeared on walls between windows [Fig. 6(d)].

3. Horizontal cracks were below eaves.

4. Horizontal cracks near the plinth usually appeared near the juncture of the plinth, which was built with rubble, and the brick wall, see Fig. 6(e).

5. The vertical cracks at the junctures of longitudinal and lateral walls or high and low walls mostly occurred at the juncture of the longitudinal wall and the gable wall [Fig. 6(a)], or the juncture of a high-low wall [Fig. 6(e)]. The inclined cracks at corners of the wall first appeared on the upper part then developed downwards to connect with cracks at corners of windows and formed blocks in a V-shape with the inclined cracks of a gable wall, and then made the corner of the wall collapse.

6. The vertical cracks at the lintels of doors and windows varied in many different shapes as shown in Fig. 6(d).

When damage of a medium degree occurred on a longitudinal wall various types of cracks grew in length and width and often connected with each other. Cracks were distributed over most of the wall (Fig. 7); the wall inclined outwards or inwards, the maximum value of which mostly occurred on the top part but could also occur on the middle part.
Severe damage to a longitudinal wall is shown in Figs. 8-10. Collapse of longitudinal walls mostly occurred at the two ends. Figure 11 shows an example of damage to four workshops at Zhaogezhuang Mine. The hoist house of the service shaft at Fangezhuang Mine (Photo 3) is another example; both sides of the gable walls and the longitudinal wall collapsed but the roof was saved from collapse because the trapezoidal wooden truss was supported on the counterfort columns. Figure 12 shows a cylindrical shell roof with a brick wall that collapsed on one side collapse was avoided because of the action of the counterfort columns.

2.3 Counterfort columns

Some counterfort columns are projected from the outside of the wall and some are projected from the inside of the wall, or they are used concurrently as supporting columns for the crane beam. Some of them projected from both sides of the wall.

In the case of slight damage to counterfort columns, horizontal cracks mostly appeared on the upper and lower ends of the columns. In medium and severe damage cases brickwork at the lower end of the columns was broken and peeled off; the peeled height ranged from several tens of centimeters to one or two meters (for instance, the lower end of the counterfort columns in the mine car repair shop of Fangezhuang Mine was peeled off for more than one meter). The damage to counterfort columns projecting from both sides was more severe on the exterior face.

Another type of damage to counterfort columns was that horizontal cracks appeared on the middle part. Some cracks occurred near the top surface level of the crane beam, some occurred at the conjuncture of bond beams, and some at the lower part. These types of cracks made the counterfort columns form a bulge.

Vertical cracks usually occurred where the counterfort columns supported the rafter or roof truss.

2.4 Detached columns

Isolated columns were generally used as inside columns in storage shed buildings or workshops. For slight or medium damage horizontal and vertical cracks usually appeared on the upper and lower ends; for severe damage the masonry at the column heads was broken into pieces and peeled off which usually occurred on the inside columns of a reinforced concrete roof. Some column heads were sheared and displaced, see Photo 4. Some columns displaced at the lower end, see Photo 5. When low walls were installed between detached columns in some storage sheds, horizontal cracks appeared on columns near the top of low walls such as the brick column in the equipment shed at Zhaogezhuang Mine.

2.5 Foundation of houses and basement walls

Except for liquefied sites and some special cases, the foundations for single-story brick masonry workshops were basically good or only had slight damage. The damage to walls of the basement and partially-exposed basement was also generally slight.

2.6 Roofs

2.6.1 Pitched roofs
Slight cases of damage were usually shifted tiles, a few verge tiles fell off, or asbestos cement sheet roofing that shifted and broke. For medium cases of damage the members supporting panel joints were loosened; a slight visible inclination occurred on part of the roof truss or a little displacement occurred on the roofing. For severe cases of damage some purloins at end spans dropped off because the gable wall collapsed, and the roof partially collapsed. On some roofs relatively severe displacement occurred, for instance, the roof truss of the hoist house for the No. 1 shaft at Majiagou Mine inclined and the top part moved up as much as 250 mm, but the roof still remained whole. For the most severe cases of damage the walls fell down, buildings collapsed, and the roof dropped onto the ground.

### 2.6.2 Flat roofs

The damage to the cast-in-place reinforced concrete roof was generally slight. For medium cases of damage the flat roof shifted a little and the brick masonry at the beam ends peeled off. For severe cases of damage a part of the roof slab hung downward or fell due to collapse of the gable wall. For some roofs relatively large displacements occurred as shown in Fig. 8; the roof shifted 120 mm but there were no severe cracks in the roof beams and slabs. For the most severe cases of damage the wall fell down and the buildings collapsed.

### 2.6.3 Skylights

The skylight for pitched roofs were generally formed by wooden or steel roof trusses, most of which were only slightly damaged.

The reinforced concrete head type skylight supported by brick columns was mostly used for flat roofs and most of these types of skylights collapsed. Quite often a building was classified as medium damage but the skylight supported by brick columns had already collapsed. The usual damage was that the brick columns were broken at the base and collapsed, such as at the fan house of Jinggezhuang Mine.

### 2.7 Foundation for equipment

#### 2.7.1 Foundation for winders

The foundation was generally cast with No. 100 concrete, a few were built with rough stone or brick; individual ones were built with reinforced concrete. These foundations were basically in good condition after the earthquake but there were cracks in the foundation for winders that were on liquefied sites. For example, the cracks on the foundation for winders of the main shaft at Fangezhung Mine were approximately 40 mm wide. Cracks occurred on the foundation of winders for the service shaft; there were cracks on the lower part of the foundation for the band-type brake and bolts were loosened; fractures appeared on the foundation of the ground-type Koepe Winder for the main shaft at Lujiatuo Mine but all of these were relatively easy to repair.

#### 2.7.2 Foundation for other equipment

The foundation for some mechanical equipment was slightly damaged. For instance, cracks appeared at two places on the foundation for oil pumps, which were the auxiliary equipment for the winder of the No. 1 shaft at Tangjiazhuang Mine, there was one crack on the foundation for the stand-by hoisting magneto, and two cracks on the foundation for the air compressor. There
was one crack and a displacement of 5-10 mm on the foundation for oil pumps, which were the auxiliary equipment for the winder of the service shaft at Fangezhuang Mine, there was one crack with a width of 3-5 mm on the foundation for the control power generator, and one 5-10 mm crack on the foundation of magneto station. Besides, some of the anchor bolts of electrical equipment in the substation were damaged, e.g. the anchor bolts of three foundations for supports of oil switches at the Majiagou Substation were pulled out. For some of the heavy machine tools the foundations were built in sections and the long shaft of the machine tools were bent resulting from the different subsidence of sections.

2.8 Ducts

Ducts for 20 fan houses with a cross-section of generally 3.0×4.0 m were surveyed. Five of the ducts were concrete structures, 4 of which were basically in good condition and one was slightly damaged. Fifteen ducts had brick masonry walls and reinforced concrete covers, 6 of which were basically in good condition or were slightly damaged, one was severely damaged and one collapsed. The damaged parts were mostly located at the corners turning to the diffusion openings, including horizontal, vertical and inclined cracks.

2.9 Other parts

2.9.1 Lintels

Cracks were the main damage to brick lintels. When damage was severe to lintels with a flat brick arch structure built with brick-on-end in running bond with no header bricks in block and cross bond, the brickwork on the surface peeled off. For all the other types of brick lintels there were few collapses.

2.9.2 Internal walls

The damage to internal walls was generally less severe than to external gable walls; collapse of internal walls was less than exterior gable walls and the damage was mostly horizontal or inclined cracks. The damage to lateral partition walls mainly consisted of inclined cracks and vertical cracks at the connection to the external walls; several groups of crisscrossed inclined cracks broke the internal walls into several pieces which were weakened at the end with the collapse of the longitudinal walls.

Severe uneven subsidence of buildings occurred on liquefied sites, e.g. because of the uneven subsidence the entire bulldozer house at Fangezhuang Mine inclined laterally and severe cracks occurred on gable walls (see Photo 6).

3. Examples of Damage

3.1 Jinggezhuang Mine Substation (intensity IX)

3.1.1 Layout of the structure

The plan dimension was 40.00×10.00 m, Fig. 13(a); most of the building was one floor and partly two floors. The transformer room, reactance room, and capacitor room were all arranged
on one side [between axis (A)-(B)] of the bottom floor with relatively more lateral partition walls on this side. The high voltage switch cabinet room was located on the other side [between axis (B)-(C)] with no lateral partition walls on the whole length of this part. The main control room was located on the second floor. The elevation of the bottom indoor floor was 1.200 m under which was the cable trench. The foundation was on quaternary alluvial diluvium composed of fine sand, clayey soil and silt inter-bedded with each other, which was not liquefied during the earthquake. The foundation was a continuous rubble footing, the wall was built with No. 75 brick and No. 25 mortar, and the external and internal walls were 370 mm and 240 mm thick respectively. The roof and floors were made of cast-in-place reinforced concrete. There was a reinforced concrete bond beam above the window openings of the second floor that served as a lintel, Figs. 14(a) and (b).

### 3.1.2 Damage

The wall at the four corners in the main control room which was located on the partially projected second floor collapsed, the collapse at the corner on axes (1) (A) was most severe and that on axes (1) (D) was less severe. The wall between two windows on the gable of axis (1) collapsed [see Figs. 13(b) and (c) and Photos 7(a) and (b)]. There were horizontal and inclined cracks on the remaining walls between the door and window openings and under the eaves. The reinforced concrete bond beam above the window openings was broken due to the collapse of brick walls at the corners but the cast-in-place reinforced concrete roof did not collapse.

Cracks going through the circumference appeared at the eaves level on the first floor. At places where high windows were built there were cracks at the level of the top of the window openings but did not occur at the floor level. For the wall on axis (A) collapse occurred for more than 20 meters because the wall area covered by door and window openings was more than 50% of the wall area and the connection for longitudinal and lateral walls was poor. The wall on axis (D) inclined outwards. There were inclined cracks on the upper part of the gable wall on axis (3), and horizontal cracks at the eaves level and the corner of the wall partially collapsed. On the lower part of the gable wall on axis (1) inclined cracks appeared only on walls between window openings. Crisscrossed inclined cracks were formed on the internal lateral partition wall, and part of the wall was broken into triangular blocks and partly collapsed, see Fig. 14(e) and Photo 7(c).

### 3.2 Hoist house of the No. 1 shaft at Majiagou Mine (intensity X)

#### 3.2.1 Layout of the structure

The plan dimension was 26.20×17.78 m with a partially-exposed basement and the wall was 650 mm thick (the basement wall was 920 mm thick), which were all built with Kailuan construction bricks with a grade higher than No. 150. A wooden truss, plank sheathing, corrugated iron sheet roofing, a cast-in-place reinforced concrete floor and a steel door and windows were used (see Fig. 15). The construction quality was fairly good and it was built in the 1920’s. The foundation was clayey soil.

#### 3.2.2 Damage
Most of the gable wall on the south side collapsed, the north side was severely damaged with cracks appearing on both openings of the door and window and the wall space partially inclined outwards. There were two horizontal cracks along the upper and lower levels of the window openings on the longitudinal wall on axis (A), inclined cracks appeared on bays on both ends, and horizontal cracks appeared on the eaves and at the level of the plinth wall. The longitudinal wall on axis (B) presented triangular collapse partially on the upper end of axis (7), and there were inclined cracks on the side of axis (1). The square wood truss inclined to the north for about 250 mm with a displacement of the wooden purlins of about 50 mm. The steel doors and windows became warped and deformed. The floor slab was cracked and slightly displaced at the supports and some of the beams and slabs were split. There were very fine cracks on the foundation for winders and the partially-exposed basement was basically in good condition.

The hoist houses for the No. 1, 2, and 3 shafts at Tangshan Mine, and the No. 1, 3, and 4 shafts at Zhaogezhuang Mine were similar. These buildings were all built before 1949 and noted for their thick walls, high quality of materials and construction, especially the high grade of mortar so even if the brickwork was severely cracked it did not collapse so the earthquake damage was less severe.

3.3 Qibaihu fan house at Tangjiazhuang Mine (intensity IX)

3.3.1 Layout of the structure

As shown in Fig. 16, two fan houses with the same structure but with slightly different dimensions were connected to each other; the plan dimension for the main part of the north fan house was 9.00×10.90 m and the south fan house was 7.40×10.77 m, see Fig. 16(a). For both fan houses a rubble footing, rubble plinth wall, 240 mm thick brick wall and a cast-in-place reinforced concrete roof were used. The foundation was on Type II soil.

3.3.2 Damage

In the north fan house all the walls collapsed except for the wall on axis (3), and the cast-in-place reinforced concrete roof fell down, see Fig. 16(b). There were horizontal and inclined cracks on the lower and upper part of the duct respectively, with a width of 10 mm and the inclined, lateral and vertical cracks connected with each other (see Fig. 17).

The damage to the south fan house was less severe. There were horizontal cracks on the wall under the eaves on axis (B), with cracks on four corners of the window opening was classified as medium damage, see Fig. 16(b). The duct was damaged severely and partially collapsed.

3.4 Collar house of the service shaft at Jinggezhuang Mine (intensity IX)

3.4.1 Layout of the structure

The plan dimension for main the span was 10.00×25.00 m, Fig. 18(a). The foundation was on alluvial diluvium, which is composed of interbedded clayey soil and fine sand, and it did not liquefy during the earthquake. The foundation had a continuous rubble footing. The wall was built with No. 75 brick and No. 25 mortar. The roof was made of cast-in-place reinforced concrete. There were two reinforced concrete bond beams, one was also used as the lintel. Reinforced concrete frames were installed for the two vehicle exit gates.
3.4.2 Damage

The inclined cracks on the gable wall on axis (2) were crisscrossed with each other, Fig. 18(b); the wall partially broke into pieces and fell down. There were horizontal cracks on the upper end of the high window opening and inclined cracks at the corners of the window opening on the longitudinal wall. The cracks were severe on the projected part of the vehicle exits at both ends (see Fig. 19).

3.5 Air compressor room at Tangshan Mine (intensity XI)

This is an example of less severe damage that occurred in an extremely strong earthquake area.

3.5.1 Layout of the structure

The plan dimension was 16.00×10.00 m. The foundation had a continuous rubble footing with an inwards projecting counterfort column on the brick wall. A cast-in-place reinforced concrete roof was used and there was a reinforced concrete bond beam on the upper end of the window opening. The foundation was on Type II soil.

3.5.2 Damage

After the magnitude 7.8 earthquake damage fell into the category of slight damage, but damage to other buildings in the area was extremely severe. After the magnitude 6.9 earthquake the damage was increased mainly as follows: the wall above the reinforced concrete bond beam was displaced outward at the corners on axis (1) (B) with a maximum displacement of 50 mm and the wall at the corners on axis (2) (A) were displaced inwards. There were horizontal and inclined cracks on lateral walls on the both sides. There were inclined cracks at window corners on the wall on axis (A) with horizontal and vertical cracks on its upper part. The exterior appearance was still in good condition (see Fig. 20).

(Translators: Zhou Yuzhen and Li Wenrong)
Table 1. Statistics of damage to single-story brick masonry workshops at Kailuan Coal Mine.

<table>
<thead>
<tr>
<th>No.</th>
<th>Intensity</th>
<th>Number Surveyed</th>
<th>Classification of Damage</th>
<th>Collapse</th>
<th>Severe Damage</th>
<th>Medium Damage</th>
<th>Slight Damage</th>
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<td></td>
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<td>8/27.6</td>
<td>1/3.5</td>
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<td>83/100</td>
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<td>31/20.5</td>
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<td>339/1.6</td>
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<td>3</td>
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<td>47/24</td>
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<td>Total</td>
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<td>10/3.5</td>
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</table>
Table 2. Statistics of damage to hoist houses, substations, fan houses and shaft collar rooms at Kailuan Coal Mine.

<table>
<thead>
<tr>
<th>Name of Building</th>
<th>Number Surveyed</th>
<th>Collapse</th>
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<th>Medium Damage</th>
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<td></td>
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<tr>
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<tr>
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<tr>
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<td>2 33.3</td>
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<td>2 28.6</td>
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<td>0 0</td>
</tr>
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<tr>
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<tr>
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<td>1 25</td>
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Clarification of Damage
Photo 1. Collapse of the gable wall, hanging and bent ring beams of the hoist house for the service shaft at Jinggezhuang Mine.

Photo 2. Damage to the gable wall of the boiler room at Jinggezhuang Mine.

Photo 3. The counterfort columns in the hoist house of the service shaft at Fangezhuang Mine did not fall down.

Photo 4. The top part of the corner column in the material shed at Tangshan Mine was sheared and displaced.

Photo 5. The lower portion of the columns in the metal material shed at Majiagou Mine were sheared and displaced.

Photo 6. There were severe cracks on the gable wall of the bulldozer house at Fangezhuang Mine.
Photo 7a. A general picture of the substation at Jinggezhuang Mine after the earthquake.

Photo 7b. Damage to the second floor of the substation at Jinggezhuang Mine.

Photo 7c. Damage to wall on axis (A) of the substation at Jinggezhuang Mine.
Figure 1. A picture of cracks in gable walls.
(a) A workshop at Zhaogezhuang Mine; (b) Mechanical and electrical repair workshop at Zhaogezhuang Mine; (c) Refrigeration room at Fangezhuang Mine; (d) Enamel Plant at Zhaogezhuang Mine; (e) Hoist house of the No. 1 shaft at Zhaogezhuang Mine
Figure 2. A picture of cracks in gable walls.
(a) Mine car repair workshop at Fangezhuang Mine; (b) Lixin forging workshop at Zhaogezhuang Mine; (c) Warehouse at Zhaogezhuang Mine; (d, e) Boiler room at Zhaogezhuang Mine

Figure 3. A picture of cracks and collapse of gable walls.
(a) Lixin forging workshop at Zhaogezhuang Mine; (b) Turning workshop at Zhaogezhuang Mine; (c) Casting workshop at Zhaogezhuang Mine; (d) Equipment storehouse at Zhaogezhuang Mine; (e) Hoist house of the No. 1 shaft at Zhaogezhuang Mine
Figure 4. Damage to the gable wall of the riveting and supports workshop at Zhaogezhuang Mine.
(a) Gable wall on the side with no bond beams; (b) Gable wall on the side with bond beam

Figure 5. The damage to gable walls.
(a) Office of the Road Maintenance Section at Jinggezhuang Mine; (b) Garage at Zhaogezhuang Mine;
(c) Grease storehouse at Fangezhuang Mine; (d) 35kv substation at Zhaogezhuang Mine; (e) Grouting
pump room at Zhaogezhuang Mine

Figure 6. Cracks in longitudinal walls.
(a) Hoist house of the No. 1 shaft at Zhaogezhuang Mine; (b) Lamp room at Zhaogezhuang Mine; (c)
Dumper room for refuse pile at Jinggezhuang Mine; (d) Partial wall space of the refrigerator room at
Fangezhuang Mine; (e) Boiler room at Jinggezhuang Mine
Figure 7. The damage to longitudinal walls.
(a) Hoist house of the No. 3 shaft at Majiagou Mine; (b) Partial wall space of the boiler room at Zhaogezhuang Mine

Figure 8. Outward displacement occurred at many places on longitudinal walls of the bulldozer room, drill room and oil depot at Fangezhuang Mine.
Figure 9. Inward displacement at the sill level on the longitudinal wall in the mine car repair shop at Fangezhuang Mine.

Figure 10. Displacement near the end of the longitudinal wall in one workshop at Jinggezhuang Mine.

Figure 11. The damage to longitudinal walls.
(a) Riveting and supports shop; (b) 35kv substation; (c) Grouting pump room; (d) Tool storehouse
Figure 12. Damage to the material storehouse at Fangezhuang Mine.

Figure 13. Damage to the substation at Jinggezhuang Mine.
(a) Plan; (b) Wall on axis A; (c) Wall on axis D
Figure 14. Damage to the substation at Jinggezhuang Mine.
(a) Cross section for the first floor; (b) Cross section for the second floor; (c) Gable wall on axis 2, 3; (d) Gable walls on axis 1; (e) Internal lateral partition wall

Figure 15. Hoist house for the No. 1 shaft at Majiagou Mine.
(a) Plan; (b) Damage to longitudinal wall on axis A; (c) Damage to gable wall on north side; (d) Damage to gable wall on south side
Figure 16. Qibaihu fan house at Tangjiazhuang Mine.
(a) Plan; (b) Damage to wall on axis A

Figure 17. Cracks on dock wall of Qibaihu north fan house at Tangjiahzhuang Mine.
Figure 18. Collar house for service shaft at Jinggezhuang Mine.
(a) Plan; (b) Damage to gable wall on axis 2

Figure 19. Damage to collar house of the service shaft at Jinggezhuang Mine.
(a) Longitudinal walls on axis E, G; (b) Longitudinal walls on axis A, C
Figure 20. Damage to the air compressor room at Tangshan Mine.
(a) Plan; (b) Wall space on axis A; (c) Wall space on axis 1; (d) Wall space on axis 2
DAMAGE TO THE COAL PREPARATION PLANT AT THE TANGSHAN MINE IN THE KAILUAN COAL MINE AREA

Wang Dehua*

The Tangshan Coal Mine, the oldest large-scale coal mine in the Kailuan Coal Mine area, was located in the center part of Tangshan City, which was approximately 2 km away from the epicenter.

The Coal Preparation Plant of the Tangshan Mine (hereinafter referred to as the coal preparation plant) was situated in the northeastern part of the industrial site of the Tangshan Mine and was a large plant with an annual capacity of 1.8 million tons of clean coal. The large multi-story plant buildings were composed of the main washing shop, the froth floatation shop and other auxiliary structures with corridors connecting the shops.

This coal preparation plant was constructed in 1973 and no aseismic measures were considered in the original design. Therefore, in the Tangshan earthquake the main structure of the coal preparation plant was seriously damaged and the auxiliary structures such as the settling tower supported by a brick column, and corridors for conveyors belts almost collapsed. After the earthquake the main workshop was under construction for one year and then put back into use.

1. Engineering Characteristics

1.1 Site condition

After the earthquake an engineering geological exploration was performed for the site foundation of the coal preparation plant (Figs. 1 and 2). It was proved that the site area was higher in the north and lower in the south and could be divided into two parts: Part (I) and Part (II). Part (I) was a base rock area with a gentle slope and consisted of weathered rock as well as surface clayey soil. Part (II) was an alluvial plain with an even surface composed of Quaternary alluvium, clayey soil and fine sand mainly where the coal preparation plant was located.

Figure 2 is a geological section drawing across Part (I) and Part (II). The exploration showed that the soil layer in this area consisted of sandy clay, light loam, fine sand and coarse sand which were deposited along the river valley on the Permian sedimentary rock layer by a surface stream. The characteristics of the bearing layer of the foundation are shown in Table 1; it was ranked as Grade II site soil.

There was underground water between the light loam layer and the fine sand, the level of which was 5 m under the surface.
1.2 Structural layout of the main workshop

The main workshop was a framed structure with an irregular shape, multi-span and multi-story with different heights (Fig. 3) it was a poured-in-place reinforced concrete structure with a 240 mm brick enclosing wall outside. The concrete grade used for the frame was as follows: No. 150 for the foundation and No. 200 for the beams, plates and columns. After the earthquake it was indicated by a real test that the concrete grades were lower, No. 184 in average. The main structure was constructed in the winter and the axis (D) frame was given a secondary pouring to increase the strength.

The columns of the workshop were all 600×600 mm, except for the 800×800 mm-(D) columns on axis (B).

The columns of the workshop were all 600×600 mm, except for the 800×800 mm-(D) columns on axis (B).

The major loads on the frame were crushers, washers, vibrating screens, conveyor belts, cranes and tool rooms, et al installed on various floors. In addition, at the 18.500 m level of axis (B)-(C) a line of reinforced concrete buffer coal hoppers were hung; at the 4.00 m level between axis (C)-(D) and axis (2)-(3) a reinforced concrete bunker was equipped; and at the 21.80 m level on the top floor there was a reinforced concrete clean water pond on one side.

The buried depth of the foundation was –3.9 m and the allowable bearing capacity was 2 kg/cm².

1.3 Structural layout of the froth floatation shop

The floatation shop was a regular frame structure in plan and elevation with multi-spans and multi-stories From the point of view of an earthquake proof structure some unsuitable factors such as staggered layers, open spans, unbalanced loading, etc., also existed. The plane dimension of this shop was 45×21 m as shown in Fig. 4.

The poured-in-place reinforced concrete structure was adopted for this shop and a veneered brick wall 240 mm thick was used as an enclosure. The grades of concrete used were No. 150 for the foundation and No. 200 for beams, plates and columns. But after the earthquake it was indicated by a real test that the grade of concrete used was higher than No. 200 in average. The sectional dimensions of the columns were 700×700 mm for the side columns; 600×600 mm for the corner columns; 800×800 mm for the interior columns; most of the junior beams were continuous.

The major loading on the frame was from the larger floatation machines seated on the two floors with levels of 4.300 m and 11.000 m respectively. In span (A)-(B) on axis (6), (7), a pendulum hopper was hung at a level of 11.000 m. Loading tracks were laid on the bottom floor of span (A)-(B). No equipment load was arranged on the second floor, elevation of 4.300 m. Therefore, the part below the level of 11.000 m of this span was an empty frame.

The buried depth was -3.9 m and the allowable bearing capacity was 2 kg/cm².
2. Damage

The Tangshan Coal Preparation Plant was located just at the edge of the epicenter area where the intensity reached XI on the scale. A lot of buildings collapsed in the area near the plant, however, the main structure of the plant was only seriously damaged.

After the earthquake no obvious ground fissures, water eruption, sand boils and foundation subsidence was found at the site. Most foundations at the plant were laid on a clayey soil layer 5-6 m under the ground surface. For the main structure of the workshop no damage to the foundation was found due to soil failure.

The damage to the frame structure mainly occurred at the ends of beams and columns near the frame joints. The damage distribution and general damage rate are shown in Table 2. The projecting small rooms, rain canopy and outside sediment tower of the collapsed top floor and the destroyed equipment foundation are not included in Table 2.

The brick enclosing wall of the main washing shop was damaged more seriously than the veneered brick filling wall of the floatation shop; mainly crossed shear cracks appeared on the wall between windows. The veneered wall of the floatation shop was basically in good condition, larger cracks were only found on the wall of the staircase, et al. The beam supporting the brick wall of the floatation shop was damaged more seriously than the side frame beam not supporting a brick wall.

2.1 Main washing workshop

Due to the complicated shape of the main workshop, the damage distribution and damage pattern were also more complicated. Damage to the joints of the T-shaped beam was more serious than that to the joints of the crossbeam. It was found that most of the joints at the ends of the top floor columns of all frames were damaged. In general, the damage was serious in the upper part and slight in the lower part, which was shown on axis (D) and on axis (B). In addition, it was also obvious on axes (E), (F). The statistical results of damage to frame members are listed in Table 3.

Photos 2-10 indicate the bend-shaped damage to the frame of the main workshop.

2.2 Floatation shop

The earthquake damage to the floatation shop was mainly distributed in the middle part and bottom part of the frames on axes (5), (6), and (7). Damage to the frame on axis (6) was the most serious. Lantern-shape damage to reinforcing bars at the ends of the columns near the joints resulted in uneven subsidence of the floors. The statistical results of the damage to frame members are listed in Table 4. Photos 11-15 show some typical damage records.

(Translator: Li Wenying)
Table 1. Characteristics of the bearing layers of foundations.

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<th>Order</th>
<th>Number of Layer</th>
<th>Maximum Thickness (m)</th>
<th>Minimum Thickness (m)</th>
<th>Description</th>
<th>Allowable Bearing Capacity (kg/cm²)</th>
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<td>2</td>
<td>(II-5)</td>
<td>1.8</td>
<td>0.9</td>
<td>clayey soil</td>
<td>2-2.8</td>
</tr>
<tr>
<td>3</td>
<td>(II-4)</td>
<td>2.2</td>
<td>1.1</td>
<td>fine sand or light loam</td>
<td>2-3</td>
</tr>
<tr>
<td>4</td>
<td>(II-3)</td>
<td>4.2</td>
<td>1.2</td>
<td>clayey soil</td>
<td>2.5-3</td>
</tr>
<tr>
<td>5</td>
<td>(2)</td>
<td>3.1</td>
<td>0.3</td>
<td>clayey soil</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>(1)</td>
<td>--</td>
<td>--</td>
<td>weathered sandy stone shale, sandy shale</td>
<td>3</td>
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</tbody>
</table>

Table 2. Statistics of damage to frame members on every axis of the coal preparation plant.

<table>
<thead>
<tr>
<th>Main Shop</th>
<th>No. of Damaged Members</th>
<th>Total Members</th>
<th>Floatation Shop</th>
<th>No. of Damaged Members</th>
<th>Total Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis (1)</td>
<td>9</td>
<td>363</td>
<td>Axis (1)</td>
<td>19</td>
<td>271</td>
</tr>
<tr>
<td>Axis (2)</td>
<td>40</td>
<td></td>
<td>Axis (2)</td>
<td>9</td>
<td></td>
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<tr>
<td>Axis (3)</td>
<td>51</td>
<td></td>
<td>Axis (3)</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Axis (4)</td>
<td>58</td>
<td></td>
<td>Axis (4)</td>
<td>17</td>
<td></td>
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<tr>
<td>Axis (5)</td>
<td>47</td>
<td></td>
<td>Axis (5)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Axis (6)</td>
<td>48</td>
<td></td>
<td>Axis (6)</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total 253</td>
<td></td>
<td>Axis (7)</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total 253</td>
<td></td>
<td>Total 161</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Damage Rate 70%</td>
<td></td>
<td>Total Damage Rate 59%</td>
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</tr>
</tbody>
</table>

Table 3. Statistics of damage to frame members of the main shop.

<table>
<thead>
<tr>
<th>Floor Axis</th>
<th>Bottom</th>
<th>Second</th>
<th>Third</th>
<th>Fourth</th>
<th>Top</th>
<th>Total by Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
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<td>13</td>
<td>20</td>
<td>11</td>
<td>46</td>
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<td>(B)</td>
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<td>9</td>
<td>30</td>
<td>24</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>(C)</td>
<td>1</td>
<td>3</td>
<td>24</td>
<td>17</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>(D)</td>
<td>13</td>
<td>27</td>
<td>21</td>
<td>8</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>(E)</td>
<td>5</td>
<td>12</td>
<td>5</td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>(F)</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Total by Floors</td>
<td>9</td>
<td>31</td>
<td>58</td>
<td>95</td>
<td>60</td>
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</tr>
</tbody>
</table>
Table 4. Statistics of damage to frame members of the floatation shop.

<table>
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<tr>
<th>Floor Axis</th>
<th>Bottom</th>
<th>Second</th>
<th>Third</th>
<th>Fourth</th>
<th>Top</th>
<th>Total by Axes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>10</td>
<td>5</td>
<td></td>
<td>4</td>
<td>19</td>
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<td>9</td>
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<td></td>
<td>23</td>
</tr>
<tr>
<td>(4)</td>
<td>12</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>(5)</td>
<td>16</td>
<td></td>
<td></td>
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<tr>
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<td>14</td>
<td>9</td>
<td>20</td>
<td>3</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>(7)</td>
<td>10</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Total by Floors</td>
<td>85</td>
<td>45</td>
<td>20</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Photo 1. The coal preparation plant after the earthquake.

Photo 2. Damage at the upper end of the column on the bottom floor of axis (4)-(B) of the main shop.

Photo 3. Damage at the upper end of the column on the bottom floor of axis (5)-(E) of the main shop.

Photo 4. Damage at the upper end of the column on the second floor of axis (3)-(D) of the main shop.

Photo 5. Damage to the joint between the beam and column at a level of 5.00 m.

Photo 6. Damage to the eaves at a level of 18.275 m at axis (2)-(D) of the main shop.
Photo 7. Damage to the joint between the beam and column at a level of 18.500 m at axis (5)-(B) of the main shop.

Photo 8. Damage to the column base on the second floor at axis (2)-(D).

Photo 9. Damage to the column base on the 5th floor at axis (2)-(A).

Photo 10. Damage to the frame beam at a level of 16.500 m of span (A)-(B) at axis (4).

Photo 11. Collapse of a small projecting room at the level above 15.100 m at axis (6)-(7) of the floatation shop.
Photo 12. Damage to the frame beam of span (A)-(B) at a level of 11.000 m at axis (6) of the floatation shop.

Photo 13. Damage at the upper end of the column on the bottom floor at axis (4)-(B) of the floatation shop.

Photo 14. Damage at the upper end of the column on the bottom floor at axis (6)-(B) of the floatation shop.

Photo 15. Damage to the connecting joints between columns on the 3rd floor and refuse bunker at axis (6)-(B) of the floatation shop.
Figure 1. Supplemental drilling hole arrangement for engineering geological exploration.

Figure 2. A-A geological section.
Figure 3. Structural sketches of the main shop.

Figure 4. Structural sketches of the froth floatation shop (elevation: 4.300m)
I. General Description of the Structure

Tangshan and Tianjin are the cities where all the metallurgical enterprises were centralized. In Tangshan City there was a medium-sized Iron and Steel Company which was situated at the foot of Jiajiashan Hill northeast of Tangshan City. The total area of the single-story mill buildings was about 2,000,000 m². The seismic intensity at the plant site was X.

The metallurgical enterprises of Tianjin City included the steel-making plant, the rolling mill and the non-ferrous metal works, etc. most of which were situated on both banks of the Haihe River in Hedong District of Tianjin. Some workshops were in Beicang District and other districts. The total area of the single-story mill buildings was about 500,000 m². The seismic intensity in the region of the plants and works was VII.

Both the Tangshan and Tianjin metallurgical enterprises were built in the early forties and their production scale was small at that time. Their expansion was started in the early fifties, but most of the workshops were built in the sixties or later on. The majority of the main mill buildings built in the early forties and fifties had steel roof trusses (with corrugated iron roofing) and a R.C. column structure. Most of the auxiliary mill buildings were brick and wood structures (with clay tile roofing). Some had asbestos tile roofing and a light steel structure. The majority of the main buildings built in the sixties or later were reinforced concrete structures and a minority of them were steel structures or steel and R.C. combined structures; the auxiliary mill buildings were usually R.C. structures and some were R.C. and brick-wall combined structures. Some of the buildings built during this period had a heavy roof (prefabricated R.C. roof slab). The exterior walls of the main mill buildings were mostly self-bearing brick walls, a few of them had R.C. wall panels. For internal small rooms or exterior penthouses brick bearing walls were mostly used. The majority of the buildings had a longitudinal skylight (Fig. 1), but a few used a transverse skylight (Fig. 2). In the steel-making and rolling workshops, parts of the columns along some longitudinal rows were often eliminated to form large column spacings to meet the requirements of the production process. At that time, for a 18 m, or over, long lateral truss and crane girder (Fig. 3) a steel structure was usually used while for one 12 m long a steel structure or R.C. structure was used. For the workshops built mainly with a R.C. structure, some steel elements (such as a steel skylight, roof truss and lateral truss, etc.) were also adopted in the high temperature region.

1 Participants in the investigation: Ding Zukan, Zhang Xiguang, Peng Qizheng, Liu Mingjun, Zeng Xiangfu, Guan Tianxu and Wang Lanting

2 Beijing Central Engineering and Research Institute of the Iron and Steel Industry
II. General Description of Damage

No earthquake resistant measures were considered during the building of both the Tangshan and Tianjin steel companies. When the earthquake took place damage occurred in varying degrees.

(I) Tangshan Iron and Steel Company

Part of the plant area was situated on the step II terrace of the Douhe River. The subsoil was better there and the No. 3 rolling plant, the medium sized rolling plant, the metal working shop and oxygen station, etc. were built there.

Other parts of the plant area were situated on the step I terrace which had poorer subsoil, where there was a clayey soil that was close to a silt layer. In 2-4 m depth below the ground surface in some zones there was a layer of saturated loose fine and silty sand. Below 4 m was 4-5 m of thick silty clay. The liquefiable soil stratum was certified by the standard penetration test. Situated in this area was the ironworks, the No. 1 steel plant, the No. 2 steel plant, the No. 1 rolling plant and the No. 2 rolling plant.

At the Tangshan Iron and Steel Company there were 137 single-story mill buildings with an area about 80% of the total area of the industrial buildings. The earthquake damage is shown in Table 1 according to classification of the structural material. The earthquake damage to the mill buildings of various structural types is also shown in Table 1.

1. All-steel structure buildings with light roofing

In the forties and in the early fifties composite structures of light roofing and light steel sections was built. The bracing systems were complete. Buildings of this type suffered the lightest earthquake damage. Their main structure elements were in good condition or had only slight damage. The bracing systems were damaged to different degrees. But some walls collapsed because the connection of the walls to the columns was not strong enough.

2. Light roof buildings with steel trusses and R.C. columns

Most of these buildings were built in the forties and in the early fifties when the grade of concrete used for columns was lower (150 kg/cm² or lower). With the exception of cracks or moderate damage to columns, the other earthquake damage was similar to that of the all-steel structure buildings.

3. Heavy roof buildings with steel trusses and R.C. columns

These buildings were built in the late fifties to the seventies. The bracing system for the roofs of these buildings was complete (Fig. 4). The bracing between columns was with or without top column bracing, but lower column bracing was usually stronger because it had to resist the longitudinal braking force from the overhead crane. The earthquake damage to these buildings was slight. A few of the pre-cast R.C. roof panels slipped due to failure of the welded connections between the panels and the roof trusses (only few eave fascias fell); and some roof and column bracings were damaged or destroyed. A few of the columns were cracked or damaged. The brick enclosing walls were severely destroyed or collapsed. However, the pre-
cast R.C. wall panels used in some mill buildings were only slightly damaged. The extension of the No. 2 steel plant built in the seventies (Fig. 5) was this type of building. The extension area was 12,800 m². With the exception of the converter bay consisting of multistory frames, the remaining bays were single-story buildings (the platform was built in the loading bay). The roof trusses, crane girders and the top rigid frame of the converter bay were steel structures. The columns and frames of the converter bay were R.C. structures. The roof consisted of 1.5×6 m pre-cast R.C. roof panels. This building was basically intact even though it had undergone strong intensity X shaking (Photo 1).

4. R.C. structure buildings

The roof bracing system of these buildings (Fig. 6) was not as complete as that of the above-mentioned buildings. Transverse bracing was not erected for the frames of the skylight or the top chords of the roof trusses. The vertical bracing at the ends of the trapezoid truss were dominantly R.C. open web trusses. Transverse bracings were usually erected for the bottom chords of the roof trusses. Longitudinal bracing of the bottom chords of the roof trusses were erected for some buildings (when the overhead crane in the workshop was heavy duty with a large hoisting capacity or when one or two columns along some longitudinal rows were eliminated to form large column spacing). Usually, the lower column bracings were installed, but weather or not upper column bracing was installed depended on column height. The earthquake damage to these buildings was severe. Longitudinal collapse or severe longitudinal inclination of the skylight frames, and longitudinal collapse of the roof truss (or roof girders) occurred (some collapsed transversely). Severe cracking or damage occurred at the top of a column or that part of a column within the crane girder height as well as near the bottom of the lower part of the column. Collapse of the roofs and severe destruction of the main structure was sustained by 1/4 of these buildings. Most of the brick enclosing walls were severely damaged or collapsed.

5. Single-story brick buildings

These brick bearing wall buildings were used for power facilities such as the air compressor station, pump station, central step-down substation, and transformer room attached to a workshop, etc. One-half of such brick buildings with heavy roofs collapsed. As for brick buildings with light roofs, only 1/5 of them collapsed.

(II) Tianjin metallurgical enterprises

Most of the works of the Tianjin metallurgical enterprises were situated near to the old course of the Haihe River or in the location of the river cove in Hedong District. There was a flood deposit area with weak geological conditions. The spreading of the soil for the plate rolling plant was as follows:

Stratum I: The artificial soil (KC) was a yellowish-brown variegated clayey soil containing broken bricks, tiles and slag, etc. with poor homogeneity.

Stratum II: New accumulation of strata (Q₄) among which clayey soil occupied the place and clay came second, it was yellowish-brown containing iron oxide, wet to very wet with high plasticity to medium plasticity.
Stratum III: Newly accumulated alluvial-lacustrine deposit stratum (Q₄) consisting of sandy silt and clayey soil, gray-brown, containing organic material, saturated with a high to very high plasticity. The sandy silt was a source of liquefaction during the earthquake.

Stratum IV: The marine deposit stratum of the Holocene series of the Quaternary system (Q₄) was a gray-brown clayey soil containing organic substances and shells; wet to very wet with a high to very high plasticity. There was no liquefaction in this layer.

Stratum V: Neopleistocene alluvial clayey soil stratum of the Quaternary system (Q₃), yellowish-brown to yellow-green containing iron oxide, wet with a medium plasticity to very low plasticity, compact and stable soil, with no liquefaction in this layer.

The severe liquefaction in this area during the earthquake caused various earthquake damage such as column inclination, wall cracking, roof collapse, etc. For example, the area of the Tianjin plate rolling plant occupied 13.1 hectares and had 3,000 or more sandboils and waterspouts, i.e. 23 sand vents per hectare. The total sandboil volume was estimated at over 200 m³. The slab storage of this plant was an open air loading bridge type and the ground was severely liquefied. The columns mostly inclined into the loading bridge (a few of them inclined outside), which reduced the gauge of the cranes on top of the column a maximum of 42 cm. Liquefaction in the area of the No. 3 steel plant was also severe and after the earthquake the columns of the main building settled and inclined to some extent. After the earthquake the ground fissure belt parallel to the old course of the Haihe River where the metallurgical repair and spare parts plants were situated passed through the south plant area. The floor and walls of the buildings of the boiler, wood model shop, dining room, etc., where the ground fissure passed through cracked severely. A portion of the wood model shop roof (single-story brick-wood structure) fell. But the geological condition in the Beicang area was rather good.

The classification statistics of damage to single-story buildings of 52 metallurgical enterprises in Tianjin are shown in Table 2.

The main buildings of the Tianjin metallurgical enterprises, which were all-steel structures with either light roofing (for example, the open hearth furnace shop of the No. 1 steel plant and the medium rolling shop of the No. 4 rolling plant) or with heavy roofing (for example, the striping shop of the No. 2 steel plant and the blooming shop of the No. 4 rolling plant) were in good condition for main structures. Usually there was only such damage as cracking of the welded seam in the joints of the roof bracing system or bending of the bracing members and slipping of a few pre-cast R.C. roof panels.

Damage caused by the earthquake to main building structures of steel and R.C. combined construction (for example, a part of sections of the main building of the No. 2 steel plant, reheating furnace shop of the plate rolling plant, and soaking pit shop of the blooming plant) was not severe. Usually the bracing system (including roof bracing and bracing between columns) was damaged to some extent; between columns suffered most damage.

R.C. structures formed a major portion of the Tianjin metallurgical enterprises (e.g. No. 3 steel plant, blooming plant, plate rolling plant, refractory material plant, metal product plant, metallurgical repair and spare parts plant, No. 2 steel plant, etc.). The spans of these buildings were usually great (21-33 m). Bracing systems were installed for their roofs. This type of
structure was also used for auxiliary buildings with spans of 15-18 m, but their roof bracing system was weak. For example, the vertical bracings at the truss ends were erected for R.C. trapezoid trusses with a span of 18 m for the mechanical repairing workshop of the No. 2 steel plant, but only the ends of the buildings and their connection with trusses were weak (only 2 φ16 bolts per connection joint). Bracing between columns was erected for these R.C. structures. The severe earthquake damage to these buildings was demonstrated mainly by cracking of some members of skylight frames; cracking, even fracturing of "null force members" for the upper chord of the trapezoid roof truss; horizontal or inclined cracking and other damage to columns; cracking or local crushing of column brackets supporting low bay roofs; slipping of the pre-cast R.C. roof panels or cracking of their longitudinal ribs; smashing of low bay roof panels from falling off high bay suspended walls; pulling out of the connection joints as well as bending of the members of the bracing system for the skylight frame, roof truss and column, etc. Roofs collapsed in some shops (e.g. mechanical repairing shop of the No. 2 steel plant, transitional bay of the main building of the No. 2 steel plant).

The majority of brick enclosing walls for the above-mentioned buildings collapsed during the earthquake because of poor connection to columns, so they damaged equipment and roofs of the adjacent penthouse and injured or killed persons. Some single-story auxiliary houses and individual production plant buildings were reinforced concrete and masonry construction (brick bearing column and brick bearing wall), of which the walls were cracked and destroyed locally without collapse.

III. Some Examples of Damage

(I) No. 2 rolling plant of the Tangshan Iron and Steel Company

1. Arrangement of the buildings

This plant was situated on the step I terrace of the Douhe River. Before construction of the plant there was a large pit resulting from excavating sand with various depth of 2-4 m where surface water was accumulated in the rainy season. Then it was back-filled with waste slag, cinders, etc. to be a flat plant site. The buried depth of the No. 2 rolling plant foundation was 2-3 m and it was situated on the pit. The geological profile is shown in Fig. 7.

The buildings at the plant were composed of two bays of the same height and the span of each bay was 18 m. On the south side a group of penthouses was built with various heights and spans (Fig. 8). Their transverse partitions were built close to external side walls of the (A) row of the mill building. Afterwards, two new buildings with spans of 21 m (axis (1)-(11)) and 24 m (axis (15)-(38)) were built on the northern side of the plant. A transitional bay was built between the old and new buildings. At the eastern end the old building was expanded from axis (32) to axis (38) with a transverse sunken-type skylight. Steel roof trusses were used for all the new buildings and in the transitional bay transverse steel beams 3.4 m long were supported on the columns of the new and old buildings. Steel crane girders were used for long column spacing of 18 m and 12 m. The rest of the main structures, both new and old buildings, were R.C. structures (of which an arched truss with top chord of R.C. and bottom chord of the steel were used for the 18 m bay in axis (1)-(32)). A shortcoming in the arrangement was that the
transverse temperature expansion joint for the new 24 m building was not aligned with that of the old building.

2. Damage

The upper parts of 15 columns were fractured or broken adjacent to the top face of the crane girders (Photo 2), mainly at places where the penthouses were in the (A) row. The lower parts of 21 columns in the (B) row cracked horizontally or were broken within 1.5 m of the ground. The concrete of the upper parts of two columns in the (B) row at the top face of the crane girders was crushed (Fig. 8(e)). The upper parts of 19 columns in the (C) row were damaged somewhat similar to those in the (A) row columns. The column capital in axis (16) was split (Fig. 8(d)). Many columns adjacent to the expansion joints on axis (32) of AB, BC bays were staggered (Photo 3). The tracks of the crane girders were sheared and staggered at axis (32). Three trusses at axes (30)-(32) of the BC bay were pulled away transversely and one end fell down to the crane girder (Photo 4, and Fig. 8(f)).

The brick chimney near (D) row of axis (11) collapsed to the southwest and smashed two trusses on axes (10), (11) and the skylight frame of axis (11) as well as the roof panels (Photo 5) were destroyed.

The walls of the main motor room in the penthouses on the southern side cracked severely and other penthouses 1-4 all collapsed (Fig. 8(a) and Photo 6). Most of the small rooms in the mill buildings collapsed or were severely damaged (Photo 7).

The connection of the steel beam of the transitional bay between the new and old buildings is shown in Fig. 8(c). They were connected with steel angles and anchor bolts to the old building. During the earthquake the bolts were broken, the angles slid, and the beam fell down. The steel beam and the roofs (10 of 23 bays) of the transitional bay on axes (15-38) fell down (Photo 8).

(II) Medium section rolling plant of the Tangshan Iron and Steel Company

1. Arrangement of the building structures

The medium section rolling plant was composed of multi-span and single-story buildings that were built in the late fifties. The plan and elevation were complex (Fig. 9(a)). The lower part of the step column had two separate legs with horizontal web members. The upper part of the column had a rectangular section. The lower column bracing was erected for each column row between the expansion joints, but the upper column bracing was not erected. The roof trusses (span 24 m) were R.C. (grade 300) trapezoid trusses. The R.C. open web trusses (C of Fig. 9(b)) were used as vertical end bracings of the roof trusses along each row of the building. They were not erected for each pair of roof trusses, but were only located at both ends and middle of each expansion zone. For the other column spaces there were erected R.C. ties. The horizontal bracings were not erected for the top chord of the roof trusses. However, transverse horizontal bracing was erected for each of the bottom chords of the roof trusses at both ends of each expansion zone; and longitudinal horizontal bracing was erected for the bottom chords of other roof trusses. The full-length steel ties were erected at the center of the bottom chords of the roof trusses and at the centers of the top chords of the skylight frames.
9 m Π type R.C. skylight frames were used. However, there was no skylight at each end of the expansion zones. The vertical steel X-bracing was erected at both end skylights in each expansion zone. The vertically placed R.C. side panels along the full length were welded with the skylight frames. The wind frame was erected 4.5 m from the skylight and R.C. posts, ties and purlins were used. The asbestos tiles were placed on the purlins for the wind plates.

The 12 m lateral trusses and 6 m and 12 m crane girders were R.C. and the 18 m lateral trusses and crane girders were steel structures.

The roofing was 1.5×6 m pre-cast R.C panels. The plant was situated on the step II terrace of the Douhe River; the site soil was grade II.

2. Damage

The damage to column rows are shown in Table 3.

The roof over 3 column spans on axes (19)-(22) in the main motor room collapsed, related columns fractured, the column capitals broke and the penthouses attached to the outside of the main motor room (distribution board room) completely collapsed (Photo 9).

The section of the lower part of the column in row (B) at axis (49) was enlarged during the construction for some reason so its rigidity was more than other columns. As a result, the top of the upper part of the column was split, the concrete at that part of the column (where the steel lateral truss was supported) peeled off in a wedge form, the stirrups broke, the longitudinal reinforcement bar bent (Photo 10), the steel lateral truss fell so its bottom chord was supported by the brake truss of the steel crane girder; therefore the roof settled 63 cm supported by the lateral truss but did not collapse. The 22 steel inserts in the skylight frames connecting to the vertical X-bracings were loose or pulled out. There were 13 horizontal cracks on the posts of the skylight frames above the side panels near (D) row.

The skylight frames and end wall plate of AB, BC bays from axes (48)-(56) inclined due to a 63 cm settlement of the roof in axis (49) of the (B) row.

There was other damage to the R.C. roof trusses such as cracks at the connection of the web to chords, breaking at the bearings, and cracking of the inclined end members. The concrete at the rib bearing of the R.C. roof panels was broken at 42 locations. The positions where these earthquake damages occurred were situated mainly in ribs of the second roof panels from the column row or just at the column row.

The tie beam in the eastern gable wall was not connected with the column so the whole gable wall fell. The longitudinal walls on two sides of the building above the column tops fell in mass. X-cracks occurred on the wall.

The new 2,016 m² buildings in axes (56)-(63) had steel trusses and well-type skylights. The buckling of members in the horizontal bracing at the bottom chord of the roof truss was observed in two locations and the buckling of the tie at the top chord occurred in one location. No earthquake damage was discovered in other positions.
(III) Tianjin No. 2 steel plant

1. Arrangement of the building structures

The area of the No. 2 steel plant was about 25,000 m² (Fig. 10(a)). The AB bay and CD bay was a R.C. high-low span bent structure that was built in 1958. The side blown converter steel-making plant buildings were single-story steel structures (Fig. 10(b), EG bay) built in 1969. The top blown converter steel-making plant buildings were multi-story steel structures (Fig. 10(c), EF bay) built in 1966 and 1975 respectively.

The distances between the new steel structure buildings and the R.C. structure buildings were 7 m and 8 m respectively. They were connected with light steel structures as a transitional bay. Trapezoid steel trusses were used for the roof of the transitional bay, one end of which was welded to the steel columns of the new building and the other end was connected to the end vertical members of the R.C. roof trusses of the old building. On the roofs of the transitional bay a 3 mm thick steel plate was supported on steel purlins and a gutter was formed at the side of the old building. Brick walls were used for the old building and pre-cast R.C. panels were used for the new building.

The No. 2 steel plant was situated on the overflow deposit zone of the old course of the Haihe River. The underground water level is usually 0.6-1.6 m below the ground surface. Within the range of the subsoil bearing layer there is a saturated loose clayey-silt (the standard penetration resistance value $N_{63.5}$ is 2-7 usually) which is a liquefyable soil stratum. The thickness and buried depth of this soil stratum varied over the plant area. Other soil strata are clayey soil, clay and silty soil respectively. According to the engineering geological drilling data, the plant site belongs to grade III soil.

2. Damage

Almost the entire roof of the transitional bay between the old and new buildings fell and broke the end vertical member of the R.C. roof truss, the pre-cast R.C. roof panel connected to the gutter was pulled down (Photo 11).

The suspended walls of the high-low bay of the old building fell and smashed the roof panels of the low bay. The wall panels at the end of the top blown converter building slipped and fell down on the crane girders of the side-blown converter building. Because some X-bracing between the columns of the top blown converter building was welded directly to the web of the I columns without stiffener later so the web of the steel column cracked there. (Photo 12).

There were horizontal cracks of varying degrees at the bottom of the column for a part of the R.C. columns in AB and CD bay and for columns of the (A) row were more severe.

(Translators: Zhou Yimin, Ding Zukan)
Table 1. Statistics of damage to single-story mill buildings of the Tangshan Iron and Steel Company.

<table>
<thead>
<tr>
<th>Type of Building</th>
<th>Structural Material</th>
<th>Building Area (ten thousand m²)</th>
<th>Damage Degree (ten thousand m²/%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column</td>
<td>Truss</td>
<td>Roofing</td>
</tr>
<tr>
<td>steel building</td>
<td>steel</td>
<td>steel, wood</td>
<td>corrugated iron, asbestos tile</td>
</tr>
<tr>
<td>R.C. buildings</td>
<td>R.C.</td>
<td>steel, wood</td>
<td>corrugated iron, asbestos tile</td>
</tr>
<tr>
<td>R.C. steel</td>
<td>R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
</tr>
<tr>
<td>R.C. R.C. R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
</tr>
<tr>
<td>R.C. open air/loading bridge</td>
<td>R.C.</td>
<td>open air/loading bridge</td>
<td>1.45</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brick buildings</td>
<td>brick</td>
<td>steel, wood</td>
<td>corrugated iron, asbestos tile, cement tile</td>
</tr>
<tr>
<td>brick steel</td>
<td>R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
</tr>
<tr>
<td>brick R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
<td>R.C.</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Statistics of damage to single-story mill buildings of the Tianjin metallurgical enterprises.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Building Area (10^4 m^2)</th>
<th>Collapse</th>
<th>Severe</th>
<th>Moderate</th>
<th>Slight</th>
<th>Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No. 1 steel plant</td>
<td>2.00</td>
<td>0.11/5.5</td>
<td>0.82/41.0</td>
<td>0.17/8.5</td>
<td>0.90/45.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>No. 2 steel plant</td>
<td>5.01</td>
<td>2.30/45.9</td>
<td>0.61/12.2</td>
<td>1.10/21.9</td>
<td>0.82/16.4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>No. 3 steel plant</td>
<td>2.00</td>
<td>0.30/30.0</td>
<td>0.31/31.0</td>
<td>0.29/29.0</td>
<td>0.10/10.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ferroalloy plant</td>
<td>1.00</td>
<td>0.25/8.9</td>
<td>0.70/25.0</td>
<td>1.10/39.3</td>
<td>0.75/26.8</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Blooming plant</td>
<td>2.80</td>
<td>1.60/69.6</td>
<td>0.16/6.9</td>
<td>0.40/17.4</td>
<td>0.14/6.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Plate rolling plant</td>
<td>2.30</td>
<td>0.29/9.4</td>
<td>1.07/34.5</td>
<td>1.34/43.2</td>
<td>0.40/12.9</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>No. 1 rolling plant</td>
<td>3.10</td>
<td>0.20/12.5</td>
<td>0.30/18.8</td>
<td>0.80/50.0</td>
<td>0.30/18.7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>No. 2 rolling plant</td>
<td>1.80</td>
<td>0.15/41.7</td>
<td>0.10/6.7</td>
<td>0.40/26.7</td>
<td>1.00/66.7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>No. 3 rolling plant</td>
<td>2.60</td>
<td>0.30/19.9</td>
<td>0.40/26.5</td>
<td>0.40/26.5</td>
<td>0.41/27.1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>No. 4 rolling plant</td>
<td>0.90</td>
<td>0.20/22.2</td>
<td>0.60/66.7</td>
<td>0.10/11.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>No. 5 rolling plant</td>
<td>0.60</td>
<td>0.20/15.2</td>
<td>0.20/30.3</td>
<td>0.36/54.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Seamless tube plant</td>
<td>1.60</td>
<td>0.15/41.7</td>
<td>0.10/27.8</td>
<td>0.11/30.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Cold strip plant</td>
<td>0.36</td>
<td>0.40/11.1</td>
<td>1.60/44.4</td>
<td>0.60/16.7</td>
<td>1.00/27.8</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>No. 1 cold drawing plant</td>
<td>0.66</td>
<td>0.30/19.9</td>
<td>0.40/26.5</td>
<td>0.40/26.5</td>
<td>0.41/27.1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>No. 2 cold drawing plant</td>
<td>0.50</td>
<td>0.20/40.0</td>
<td>0.20/40.0</td>
<td>0.10/20.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>No. 3 cold drawing plant</td>
<td>0.80</td>
<td>0.50/62.5</td>
<td>0.20/25.0</td>
<td>0.10/12.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Refractory material plant</td>
<td>3.60</td>
<td>0.40/11.1</td>
<td>1.60/44.4</td>
<td>0.60/16.7</td>
<td>1.00/27.8</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Metallurgical experiment plant</td>
<td>1.51</td>
<td>0.30/19.9</td>
<td>0.40/26.5</td>
<td>0.40/26.5</td>
<td>0.41/27.1</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Metallurgical Research Institute</td>
<td>1.50</td>
<td>0.10/6.7</td>
<td>0.40/26.7</td>
<td>1.00/66.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>No. 1 metallurgical repairing and spare parts plant</td>
<td>2.20</td>
<td>0.28/12.7</td>
<td>1.40/63.6</td>
<td>0.40/18.2</td>
<td>0.12/5.5</td>
<td>---</td>
</tr>
<tr>
<td>21</td>
<td>No. 2 metallurgical repairing and spare parts plant</td>
<td>0.90</td>
<td>0.50/55.6</td>
<td>0.20/22.2</td>
<td>0.20/22.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Machine tools repairing plant</td>
<td>0.20</td>
<td>0.10/50.0</td>
<td>0.10/50.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>12 plants of non-ferious corp.</td>
<td>4.00</td>
<td>1.00/25.0</td>
<td>1.00/25.0</td>
<td>0.40/10.0</td>
<td>1.60/40.0</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>16 plants of bar and rod corp.</td>
<td>7.50</td>
<td>1.50/20.0</td>
<td>2.00/26.7</td>
<td>0.50/6.7</td>
<td>3.50/46.6</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 49.44 | 0.46/0.98 | 9.87/19.96 | 13.43/27.17 | 11.45/23.16 | 14.23/28.78 |
Table 3. Statistics of damage to column rows.

<table>
<thead>
<tr>
<th>Position of Damage</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
<th>(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal cracking on lower part of column</td>
<td>18</td>
<td>7</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Cracking on upper part of column</td>
<td>2</td>
<td>15</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Split of column capital</td>
<td></td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Destruction of lower column bracings</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Fracture of vertical bracings of the roof truss</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breaking of end vertical member of R.C. roof truss</td>
<td>3</td>
<td>9</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>
Photo 1. A building at the No. 2 steel plant was basically intact.

Photo 2. Shearing fracture of the upper part of the column.

Photo 3. Columns on both sides of the expansion joint staggered.

Photo 4. The roof truss transversely pulled out and fell down onto the crane girder.

Photo 5. The roof was smashed by an adjacent collapsed chimney.

Photo 6. Collapse of the penthouses.
Photo 7. Damage to the small rooms in the plant building.

Photo 8. The transitional bay roof fell.

Photo 9. A broken column and collapsed roof at the medium section rolling plant of the Tangshan Iron and Steel Company.

Photo 10. The column capital of (B) (49) was split and the roof settled 63 cm at the medium section rolling plant of the Tangshan Iron and Steel Company.

Photo 11. The entire transitional bay roof collapsed at the Tianjin No. 2 steel plant.

Photo 12. Cracking of the web of the steel column at the X-bracing in the Tianjin No. 2 steel plant.
Figure 1. Sketch of the longitudinal skylight.

Figure 2. Sketch of the transverse skylight.
(a) Sunken type; (b) “Well” type
Figure 3. Sketch of the building with 18 m column spacing. 
(a) “Through type” steel lateral truss; (b) “Deck type” steel lateral truss

Figure 4. Sketch of the steel roof truss, skylight frame and their bracing of the buildings of the Tangshan Iron and Steel Company.
Figure 5. Sketch of the building structure of the No.2 Steel Plant of the Tangshan Iron and Steel Company.
(a) Plan; (b) Profile
Figure 6. Sketch of the R.C. roof truss, skylight frame and their bracings for buildings at the Tangshan Iron and Steel Company.

Figure 7. The geological data of the No. 2 Rolling Plant of the Tangshan Iron and Steel Company (N-number of blows standard penetration test).
A Row-Type S₁: upper part of columns fractured horizontally near the location of a change in section or at the top of crane girder; Type S₂: upper part of columns fractured and bent outward; Type S₃: the column capital split; Type S₄: shoulder beam split vertically; *2, 3, 35, 38 axes-lower column 800x1300 for the former (600x1300 for the later), upper column 800x500 (600x500 for the later). B Row-Type P₁: lower part of columns cracked horizontally; within 0.3 m above ground; Type P₂: lower part of columns fractured or horizontally cracked at 1.5 m (4Φ20 bars exposed, and 2Φ25 ended); Type P₃: on 12, 32 axes 2-3 diagonal cracks occurred. Concrete of upper part of columns peeled off at the wing of the crane girder but few fractured. C Row-Type 1: upper part of column peeled off at the face of the crane girder, column cracked horizontally; Type 2: concrete peeled off at the wing conduction; Type 3: the column capital was split, lower column cracked; Type 4: upper part of column broke.
Figure 8c. Scheme of the transitional bay.

Figure 8d. Damage to the column capital on 16 axis of C Row.

Figure 8e. Damage to the upper column in B Row.

Figure 8f. Damage to column capital in 31 axis of C Row.

Figure 8g. Shearing rupture of the upper part of the column caused by close bricklaying of transverse wall of the penthouse with A Row.
Figure 9a. Layout of the structure of the medium section Rolling Plant of the Tangshan Iron and Steel Company.

P: Cracking on lower part of column; S: cracking on upper part of column, the column capital broke, brake plate loosened, etc.; Q: cracking on bracket at crane girder; K: bracing between columns buckled or the joint pulled out; □: column capital on 49 axis of B row split, lateral truss fell on crane girder, related roof settled 63 cm. During repairs it was uplifted to the correct position.
Figure 9b. Damage to the roof structures of the medium section Rolling Plant of the Tangshan Iron and Steel Company.

A: bearing of the roof truss crushed; C: R.C. framed vertical supporting fractured; D: end vertical member of the roof truss broke; Y: horizontal bracing of the roof truss buckled; F: cracking occurred at the connection of web and chord in the roof truss; M: inserts loosened; T: “in skylight”; X: R.C. ties broke; B: concrete at the rib of the roof panel was crushed; R: the roof panel for the skylight was crushed; N: the post of the skylight frame cracked; V: end members of the roof truss cracked; P: concrete in the end wall panel for the skylight was crushed; Q: the end wall panel of the skylight inclined.

Figure 10a. Sketch of the structures at the Tianjin No. 2 Steel Plant.

Figure 10b. Profile of side blown converter building at the Tianjin No. 2 Steel Plant.
Figure 10c. Profile of top brown converter building at the Tianjin No. 2 Steel Plant.
**EARTHQUAKE DAMAGE TO MULTISTORY FRAME FACTORY BUILDINGS AT COKING AND REFRACTORY PLANTS**

Han Jiagu*

1. General Situation

After the Tangshan earthquake there were 39 multistory reinforced concrete (R.C.) frame factory buildings at the Tangshan coking, refractory and cement plants that were investigated. They were all situated in the Tangshan seismic zones of intensity IX and X. The frames were generally 3-5 stories, single span or multi-span, and on some stories there were bunkers. The walls of the factory building were divided into three types: fully filled wall, partly filled wall, and open type. The earthquake resistance of these buildings was not taken into consideration in the design. Of these 39 factory buildings 12 collapsed or were severely damaged, representing 31% of the total; 56% of the total number were lightly damaged or mainly intact. There were 21 factory buildings carrying brick filled walls and the walls of 10 buildings were destroyed during the earthquake. The general condition of earthquake damage is shown in Table 1.

2. Characteristics of Earthquake Damage

The characteristics of earthquake damage to the multistory frame factory buildings is summed up as follows:

(1) Beams

The earthquake damage to beams was generally 45° diagonal cracks that occurred at 1/3-1/4 points of the span. When damage was lighter there were 1 or 2 cracks that were 1 to 2 mm wide; when damage was heavier the cracks passed across the whole section and concrete of the crack edges chipped and spalled so the steel bars were exposed and some were bent. For example, the beam of the 4th story frame in the composing shop of the Maoershan Chemical Fertilizer Plant had a severe diagonal split with vertical dislocation at the 1/3 point of the span and the concrete was spalled; and main steel bars were bent. The 2nd, 3rd and top floors had diagonal cracks at the 1/3 points of the span. For heavier damage "V" or inverted "V" cracks formed, the width of the crack was about 2 mm, and the surface concrete along the edges of the crack spalled (Photo 1). The foregoing were all shear force failures.

Vertical cracks at beam ends (shear stress failure) were also a common type of earthquake damage. In cases of lighter damage cracks only appeared at joints between the beam and column; for heavier damage concrete along the cracks partially spalled. For example, the vertical cracks were wider at the beam top. The concrete on the top surface of the beam partially spalled at the beam ends of the 4th story of the transferring house at Qixin Cement Plant. The

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same happened to the frame beam ends in the dolomite shop at the Tangshan Iron and Steel Plant (Photo 2).

During the earthquake concrete broke and split at the two ends of the frame and steel bars were exposed due to pounding between buildings. For example, such damage occurred to the connection between the 3rd story frame beam of the transferring house and the silos at the Guogezhuang Bauxite Mine.

(2) Columns

Circular horizontal cracks that appeared on column heads were a common form of light earthquake damage. They generally occurred below the beam and were 1 to 2 mm wide. For heavier damage the core part of the concrete was destroyed, the width of the cracks was over 2 mm and the concrete along the crack edges chipped and spalled.

Breaking and splitting is a severe earthquake damage to columns. The broken and split areas were usually on the column head below the beam or about 1 m below and the concrete was chipped and spalled. The main steel bars were bent and deformed. For example, the frame columns in the coal washing house broke and split 1 m above the 2nd floor in the coking shop at the Maoershan Chemical Fertilizer Plant (Photo 3).

When the column head was broken the steel bars were bent into a lantern shape; the concrete was crushed. For example, such earthquake damage occurred 1 m below the beam on the top story column of the kiln head house (rotary kiln) at the Guogezhuang Bauxite Mine (Photo 4).

Other severe earthquake damage to a column was column head splitting. It was generally a diagonal split that reached directly to the core of the column, meanwhile, concrete was spalled, main steel bars in the column were bent, and the main steel bars in the frame beam were pulled out from the column head causing the frame to collapse. For example, the concrete at the column head of the top story frame in the methanol house at the Maoershan Chemical Fertilizer Plant split diagonally and the width of the crack was 1-3 cm. The main steel bars in the column were bent and the superstructure was supported by the remaining concrete (Photo 5). The column heads that were situated at (1) (A) and (1) (B) of the kiln head house (rotary kiln) at the Guogezhuang Bauxite Mine had similar damage because of splitting at a level 10.830 m (Photo 6).

There were two forms of earthquake damage at the column base. One was a horizontal circular crack whose width was about 2 mm. The concrete around the crack was chipped and spalled when the earthquake damage was severe. For example, such horizontal cracks occurred on the 3rd story frame column of the shaft kiln house at the Guye Refractory Plant and on the column base of every floor in the methanol house at the Maoershan Chemical Fertilizer Plant (Photo 7).

Diagonal cracks or splits also occurred at the column base. Concrete at the broken part was destroyed, concrete at the broken ends spalled and main steel bars were bent or broken. For example, the two "L" formed cantilevered columns which protruded from the roof and the top story columns in the industrial naphthalene shop at the Tangshan Coking Plant had a diagonal
split at the column base, the crack width was 2 to 3 mm. Another column broken at the base and the column inclined (Photo 8).

The most severe earthquake damage to columns was column breaking, which made the columns lose their bearing capacity and collapse partially or entirely. The break mostly happened 1 m above or below the joint. For example, the frame columns of the raw material selecting house and the calcined bauxite selecting house of the bauxite calcining shop at the Guogezhuang Bauxite Mine, and the dust separating house in the out transporting section of the northern lime shop at the Tangshan Iron and Steel Plant, all had such damage (Photos 9 and 10).

(3) Brick filler walls

The brick filler walls investigated were all built between columns and had steel bars to connect to the columns. The main cracks on the brick walls were horizontal cracks along the upper and lower edges of the frame beams, and along the upper and lower lines of windows; and X-shaped cracks between windows. For example, the brick filler walls between frame columns in the coal washing house at the Maoershan Chemical Fertilizer Plant had X-shaped cracks at a level of 13,500 m and horizontal cracks on the wall surface above and below the frame beam. The brickwork became loose and partially fell and the wall inclined outward (Photo 11).

Collapse of the filler walls is the most severe earthquake damage to walls. For example, the brick filler walls between frame columns all partially collapsed at the methanol house and gas producing house of the Maoershan Chemical Fertilizer Plant (Photo 12).

If the wall inside the frame does not connect with the frame the upper part of the wall will break away from the beam and displace or even collapse during an earthquake. But there were many brick filler walls that only had light earthquake damage [see example of earthquake damage (1)].

(4) Cast-in-place R.C. floor slabs

Except for one building that had little cracks on the connecting part with the steel stairs, the floor slabs of the 39 factory buildings in the investigation were mainly intact. But due to the anti-seismic separation joints between the frame structure and gantries or other buildings being too small, the structures pounded together during the earthquake and collapsed partially or entirely (Photo 13).

The above mentioned earthquake damage differed because of the differences between the structures. For frame structures (for example, the Debenzoling house at the Tangshan Coking Plant and the washing house at the Maoershan Chemical Fertilizer Plant) the plan of the structure was regular, the type was simple and without brick filler walls; generally, the earthquake damage to the upper part was severe and the lower part was light. For multistory frames (for example, the Coal Transferring Station at the Tangshan Coking Plant) the upper stories had brick filler walls but the lower story did not. The earthquake damage to the lower part was generally severe and to the upper part was light. Otherwise, the upper part was more severe than the lower part (for example, the frames of the tar-distilling house, Debenzoling house and composing house, etc., at the Maoershan Chemical Fertilizer Plant). Earthquake damage to multistory frames in which the heights were different for each span or between stories or some parts were protruding,
type of build was complex. Damage occurred where the stiffness changed suddenly. For example, the plan of the dedusting house in the out transporting section of the northern lime shop at the Tangshan Iron and Steel Plant was in an L-shape and the 2nd story frame columns broke and the building collapsed during the earthquake (Photo 14). The collapse of the kiln head house (rotary kiln) in the calcining shop of the Guogezhuang Bauxite Mine was similar.

3. Damage Examples

(1) Calcining shop of the Guogezhuang Bauxite Mine

This shop was in Guogezhuang which is situated on the southwestern edge of the Kaiping Basin in the northeast part of Tangshan; the site intensity was X. The geological condition was relatively poor; the covering soil stratum had a depth of about 40 m but the soil was not distributed uniformly on the site. The causative fault passed through the site. There were powdery fine sand and soft plastic sub-clay layers between clayey soil layers. The site soil was grade II. The underground water level was generally 12-14 m below ground. The allowable bearing capacity of the foundation soil was 2 Kg/cm².

Among the 6 multistory frame factory buildings of this shop 3 of them collapsed, 1 was suffered medium damage, and 2 were lightly damaged.

(A) Kiln head house (rotary kiln)

(a) Structural arrangement

Built and operating in 1970, the building was a rectangular R.C. cast-in-place frame structure that was an open type (without walls). Its span was 8 m and the column spacing was 7.5 m. The two-story frame roof had a cantilever partial platform and a steel platform which protruded from the roof. The columns on the 2nd story were not the same height. There was an operating room that was a brick-concrete structure on one side with a 240 mm thick wall that was laid with grade 75 brick and grade 25 cement mortar. The R.C. single foundations under the columns were 2.5 m deep. As for the plan and profile drawing of the house, see Fig. 1.

(b) Damage

The concrete of the frame columns near the beam-column joints on the 2nd floor fractured and dropped and the steel bars were bent in a lantern shape. The roof of the lower span at a level of 11.374 m fell down on the kiln body. The side column head split and steel bars were pulled out. The middle column split at the roof beam joint and the concrete fractured and the steel bars were bent. The collapsed roof turned in a counterclockwise direction. About 3/4 of the brick walls in the operating room on the 2nd floor collapsed and the R.C. roof slab warped and was supported only by the remaining brick wall. Photo 15 shows the collapsed building.

(B) Calcined bauxite selecting house

(a) Structural arrangement

The building was built and operated in 1970. The four-story building was a R.C. cast-in-place frame structure (the end part had two stories) and partially had a brick filler wall (which
was laid with grade 75 brick and grade 25 cement mortar) that was 240 mm thick. The 2nd floor was equipped with R.C. hoppers. The section size of the frame column was 400×600 mm and 400×400 mm, the beam size was 300×700 mm and 300×600 mm, and the thickness of the slab was 80 mm. The R.C. individual foundations under the columns were buried 2.1 m deep (Fig. 2). The foundation had concrete of grade 150 and the frame structure had concrete of grade 200. The steel bars were grade II and III. The plan and profile drawing of the building are shown in Fig. 2.

Design load: The live load on the roof was 75 kg/m². An overload coefficient was used at level 11.500 m where there was a vibrating screen. The hopper hanging at a level of 5.300 m had a volume of 17.22 m³. The unit weight of the high alumina bauxite stored in the hopper was 1.4 t/m³, the angle of repose for storage was 40° and the overload coefficient was 1.3.

Production was in progress during the earthquake. At that time 500 kg of material was on the screen and the volume of the material stored in the hopper weighed 1 gt.

(b) Damage

The first story columns broke at the top, the upper frame completely collapsed and reclined on the ground at an angle of 20°, but the brick filler walls were mainly intact (Photo 16).

(C) Raw material selecting house

(a) Structural arrangement

The building was a four-story R.C. frame structure which was cast-in-place and was built and operated in 1970. It had an L-shape on the plan drawing, the spans were 7 m and 5 m, the column spacing was 5 m and 4 m, thickness of the slab was 80 mm, the total height was 14 m, and there was a brick filler wall (240 mm thick). The R.C. individual foundations under the columns were buried 2.5 m deep. In the building there were R.C. storage tanks in which two ends were connected with gantries (Fig. 3).

The concrete grade for the slab and beam was 200 and for the foundation was 150. The steel bars were grade II and III. The brick filler walls were laid with grade 75 brick and grade 25 cement mortar; the wall was connected to columns with structural bars. The section of column was 400×400 mm. During the earthquake the building was in use with fully filled material bins but there was no stacking material in the building.

(b) Damage

The frame columns supporting the bunker all broke at the bottom of the bunker and in the middle part of the column. The building collapsed (Photo 17). The brick filler walls at a level of 3,000-6,000 m all collapsed. The frame at a level of 6,000-14,000 m set on the ground at an angle of 16° to the horizontal. The steel bars in the bunker wall were pulled out from the columns. The remaining brick filler walls were only partially damaged at the windows; the corner dropped or collapsed.

(D) Bauxite calcining house (square shaft kiln)
(a) Structural arrangement

The house was built and operated in 1970. It was mainly used as a feeder system for the square shaft kiln. The building was a four-story R.C. frame structure which was cast-in-place, the span was 9 m, column spacing was 6 m, and the foundation was 2.5 m underground. The building was arranged symmetrically about the center line of the gantry of the central feeding conveyor belt. The two sides of the frame stretched out separately for 3.5 m at a level of 18.55 m. The frame columns were 600×600 mm. The thickness of each floor was 80 mm. At a level of 5.400-11.400 m and above 26.200 m there were 240 mm thick brick filler walls, which were connected to the columns with steel bars. The other floors had no brick filler walls (open type). Eight steel hoppers hung at a level of 26.200 m. From the bottom to the top of the frame there were steel stairs. For the plan and profile, see Fig. 4.

The concrete grade of the slabs and beams were 200 and for the foundation 150. The steel bar grade was II and III. The quality of the construction was good.

Design load: The live load on the house roof was 75 kg/m²; the overload coefficient was 1.4; the live load on the building floors was 400 kg/m²; the overload coefficient was 1.3. The unit weight of the material stored in the bunker was 1.3 t/m³; the overload coefficient was 1.3; the angle of repose material was 40°. During the earthquake the hoppers were 80% full. There was no special loads on each floor.

(b) Damage

The frame beam of the 1st floor had light diagonal cracks near the bottom; the crack width was 1-2 mm. There were light horizontal cracks on the bunker beam-frame column joints (Photo 8).

(2) Tar-distillation house in the coking shop of the Maoershan Chemistry Fertilizer Plant

This shop was similar to a small-scale coking plant producing 40,000 tons of metallurgical coke per year.

The plant was situated in Maoershan northeast of Tangshan about 35 km from the earthquake epicenter. The site soil was grade II and III. The geological condition was bad, drilling to a depth of over 40 m did not reach bedrock. In addition, there was a filled zone (original by a canal) passing through the plant zone. During the earthquake water and sand spurted out in some places.

(a) Structural arrangement

The tar-distillation house was composed of two parts: the distillation platform and the operating room of the refining pump station. The distillation platform was a R.C. cast-in-place frame structure which was 16.2 m high and without filler walls only the ground floor had brick walls. The distillation platform was 2.75 m away from the operating room of the pump station (a 3-story brick-concrete structure). The two were connected by steel stairs. The size of the platform column screen was 3×4 m, the section size of the columns was 300×300 mm, and the R.C. single foundation under the columns was buried 1.2 m deep (Fig. 5).
Anti-seismic measures were not considered in the original design. Material: The steel bars used were grade I. The concrete grade for the foundation was 150 and 200 for the slab and beam. The field measurement shows that the quality of brickwork and the grade of concrete conformed to the design requirement.

(b) Damage

The operating room of the refining pump station collapsed and the distillation platform frame was severely destroyed (Photos 19 and 20).

Horizontal cracks generally appeared at the beam-column joints. For heavier damage, the concrete fractured and broke and steel bars were exposed after the M7.8 earthquake. The 3-story operating room of the refining pump station collapsed during the M7.1 earthquake. Its brick wall fell down on the 2nd story frame columns of the distillation platform; one column broke causing the whole frame to incline.

Table 1. Statistics of damage to multistory frames at the coking and refractory plants in the Tangshan area.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Total Number Investigated</th>
<th>Mainly Intact</th>
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<th>Medium Damage</th>
<th>Severe Damage</th>
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<td>2</td>
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<td>41.0%</td>
<td>12.8%</td>
<td>15.4%</td>
<td>15.4%</td>
</tr>
</tbody>
</table>
Photo 1. Diagonal splitting of the frame beam ends in the composing shop at the Maoershan Chemical Fertilizer Plant.

Photo 2. Vertical cracks on the frame beam ends in the domolite shop at the Tangshan Iron and Steel Plant.

Photo 3. Frame columns split at the coal washing house of the coking shop at the Maoershan Chemical fertilizer Plant.

Photo 4. Lantern-shape damage to columns of the kiln head house (rotary kiln) at Guozejhuang Bauxite Mine.
Photo 5. The head of the frame column split at the methanol house at the Maoershan Chemical Fertilizer Plant.

Photo 6. Splitting of the frame column at the rotary kiln head at the Guoigezhuang Bauxite Mine.

Photo 7. Horizontal cracks at the foot of the frame column at the methanol house at the Maoershan Chemical Fertilizer Plant.

Photo 8. The foot of the L-shaped column split at the top floor of the industrial naphthalene house at the Tangshan Coking Plant.
Photo 9. Columns broke at the dedusting house of the transporting section of the northern lime shop at the Tangshan Iron and Steel Plant.

Photo 10. Columns broke at the calcined bauxite selecting house at the Guoqezhuang Bauxite Mine.

Photo 11. Damage to the brick filler wall at the coal washing house at the Maoershan Chemical Fertilizer Plant.

Photo 12. The frame of the brick filler walls at the gas producing house at the Maoershan Chemical Fertilizer Plant partially collapsed.
Photo 13. Earthquake damage due to the pounding between the raw material selection house and the gantry at the Guogezhuang Bauxite Mine.

Photo 14. Collapse of the dedusting house of the transporting section at the northern lime shop at the Tangshan Iron and Steel Plant.

Photo 15. The frame of the kiln head house (rotary kiln) collapsed at the Bauxite calcining shop at Guogezhuang Bauxite Mine.

Photo 16. Broken and collapsed columns of the calcined bauxite selecting house at the Bauxite calcining shop at Guogezhuang Bauxite Mine.
Photo 17. The frame of the raw material selecting house collapsed at the Bauxite calcining shop at the Guogezhuang Bauxite Mine.

Photo 18. An outline of the bauxite calcining house (square shaft kiln) in the Bauxite calcining shop after the earthquake at Guogezhuang Bauxite Mine.

Photo 19. Damage to the tar-distillation platform frame of the coking shop at the Maoershan Chemical Fertilizer plant.

Photo 20. Collapse of the operating room at the refining pump station of the tar-distillation house at the Maoershan Chemical Fertilizer Plant.
Figure 1a. Ground floor plan of the kiln head house (rotary kiln) in the bauxite calcining shop at the Guogezhuang Bauxite Mine.

Figure 1b. Plan of the building floor at a level of 5.380 m.
Figure 1c. Plan of the building floor at a level of 13.980 m.

Figure 1d. Section 2-2.
Figure 1e. Section 3-3.

Figure 2. Drawing of the frame of the bauxite selecting house in the bauxite calcining shop of the Guoge Zhuang Bauxite Mine. (a) Plan at a level of 0.000m; (b) Plan at a level of 8.000m
Figure 3. Plan and section of the raw material selecting house in the bauxite selecting shop at the Guogezhuang Bauxite Mine.
Figure 4a. Foundation plan of the bauxite calcining house (square shaft kiln) in the bauxite calcining shop at the Guogezhuang Bauxite Mine.

Figure 4b. Plan at a level of 18.550 m.
Figure 4c. Plan at a level of 5.480 m.

Figure 4d. Section 1-1.
Figure 5. Plan of the tar-distillation house in the coking shop at the Maoershan Chemical Fertilizer Plant.
This article describes earthquake damage to the Douhe Power Plant and Tangshan Power Plant in separate sections.

I. Douhe Power Plant

1. General conditions

The Douhe Power Plant was one of the large thermal power plants in North China and it was also the largest power plant on the Beijing-Tianjin-Tangshan network. It was situated on the west bank of the Douhe Reservoir in the northeast suburb of Tangshan about 20 km away from the city. Its construction started in 1973 in two stages; the first stage was completed in 1975 and had two units of 0.125 million kW turbo generators imported from Japan and two sets of 400 t/h suspended boilers made by the Wuhan Boiler Plant. During the time of the shock the No. 1 unit was shutdown for inspection with No. 2 ready for testing. Two sets of 0.25 million kW turbo generators and two sets of 850 t/h suspended boilers, all imported from Japan, were to be installed in the second stage of construction which was just underway when the shock hit; 180 m R.C. chimneys were built separately in both construction stages. No seismic-proof measures were considered in the structural design.

(1) Structural design of the main building

The main building was comprised of the turbine house, the deaerator bunker room and the boiler house which had four sections separated by expansion joints. The building was 225 m in length (Fig. 1).

A frame structure was adopted for the main building with prefabricated R.C. I-section flat-web exterior columns, a 24 m span pre-stressed arch roof truss, large-size R.C. roof slabs and a 9 m span monitor frame. The plant was equipped with two sets of 75t/20t bridge cranes that ran on prefabricated R.C. T-girders. The decks, at an elevation of 5.000 m and 10.000 m, in the turbine house were built with steel frames and poured-in-place R.C. slabs.

The first stage of construction for the deaerator bunker room consisted of a single span multistory poured R.C. frame. The second stage consisted of a single and two-span multistory prefabricated R.C. frame structure.

Prefabricated R.C. frames were adopted for the structural frame of the suspended boilers (No. 1 and No. 2 boilers) in the first stage of construction; steel frames imported from Japan were adopted for the No. 3 and No. 4 boilers in the second stage.

Prefabricated R.C. frames with exterior wall cladding were adopted for the elevator shaft.

* Beijing Electric Power Design Institute
#75 brick and #25 mixed mortar were used for the interior walls and #100 brick and #25 mixed mortar were used for the exterior walls. The wall thickness was 240 mm. See Figs. 2 and 3 for sections of the main building of the 1st and 2nd stage. Photo 1 shows the outlook of the plant before the quake.

(2) Geological conditions and foundations

The site soil was quaternary alluvium; the strata were comparatively regular and about 100 m in depth. The geological profile is shown in Fig. 4.

Stepped isolated footings and foundations on prefabricated short piles were adopted for frame columns. The elevation at the base of the foundation was -4.7 m, #200 concrete and grade I and II bar were adopted, the thickness of the platform was 300 mm, and the pile cap was anchored 100 mm into the platform. 350×350 mm prefabricated square piles were poured with #300 concrete and reinforced with 8 φ16; the length of the pile was 5-6 m. Piles were driven into the yellow-brown saturated silt stratum which was about 18 m thick and the bearing capacity for the single pile was set at 60t through a static load test.

2. Damage

(1) General conditions

The Douhe Power Plant sat on an intensity IX area. The main buildings at the plant site were heavily damaged and collapsed structures caused further serious secondary damage. Photo 2 shows the outlook of the plant after the shock. See Fig. 5 for earthquake damage to the plant site.

(2) Subsoil and foundations

No sandboils, ground cracks, land tilting or cave-ins were detected in the vicinity of the plant area. Investigations conducted after the shock noted that the soil under the foundation was saturated compact silt stratum that was explored before the quake. After the quake a casing pipe driving test using a hand pulled rammer conducted at the base of the piles showed that the actual value of N was mostly over 30 blows, the same as before the quake. Table 1 shows a comparison of the exploration tests and data before and after the quake. Two inspections were made on May 31 and on August 22, 1976 at 11 settlement points in the plant area, the results of the data showed that settlement caused by the shock was comparatively slight, about 3-4 mm.

After the shock axes 1-4 of the frames of the main building collapsed. The column foundations on axis C showed cracks at axes 3 and 4 but the rest remained intact. Cracks appeared at the column base and extended 45° downward to the second step of the column foundation.

(3) Turbine house
A. Collapse of the roof structure

The roof truss of the turbine house was supported on the frame column at one end and on the frame bracket at the other end. The rooftop bracing is shown in Fig. 6. The actual roof load at the time of the quake was 370 kg/m².

The entire roof structure of the turbine house collapsed after two shocks. When the M7.8 shock hit the roof structure of the second stage construction from axes 13a to 20 collapsed; some roof slabs of the first stage construction fell off but the roof trusses held on until the M7.1 shock hit that same afternoon (Photo 3). The connecting steel plates and bolts were pulled off the frame bracket that supported the roof truss the concrete was crushed on the bracket's cantilever end (Photo 4).

B. Cracks on the frame columns

Columns along axis A were I-sectioned below the T-girder (crane girder). The concrete strength was #300; sizes of the column section are shown in Fig. 7. Walls and finishings of the 1st stage construction were already done; walls of the 2nd stage construction were not laid yet. Two sets of bridge cranes rested separately close to axis 3 and 9 when the shock hit. After the quake cracks were observed on the inner flange of the I-section columns from a level 10.000 m above to the shoulder rib. Slant and vertical cracks were observed on both the web rib and shoulder rib and concrete at the joints was crushed. The most seriously cracked part was between the elevation of 10.000 m and 12.000 m, the width of cracks was 0.03-0.01 mm, the widest being 10 mm. Five upper column brackets were broken at their roots and those not broken showed deformation. Embedded plates on column tops were pulled off, so were embedded pieces on brackets for connection of crane girder, and the concrete there was crushed (Fig. 7). Columns showed dislocation and column tops inclined 1-7 cm to the north. The column top at axis 2, which did not have a roof truss yet, had an inclination of 17.7 cm. Damage to the I-section columns is shown in Photos 5 and 6.

C. Collapse of the gable wall

An R.C. cross-beam system was used for the fixed end-wall of the turbine house. The sections of beams and columns were 300×700 mm, and concrete strength was #200. Column tops were connected to the upper chord of the roof truss to form a multi-span single frame. The 240 mm filler wall used #75 brick and #25 mixed mortar. After the quake the columns along axis B were pulled down by the collapsed frame, the brick wall above the elevation of 10.000 m collapsed as a whole, and connection welds between the columns and beams were broken.

D. Exterior wall on axis A

The 370 mm exterior wall covered the column by 120 mm, and 2 φ6 steel bars at every 8 courses of brick were extended from the column and laid into the brick joints. After the quake all of the parapet wall fell off, mostly outward, crushing the combination conductors and housing of the transformers. Diagonal cracks were observed on walls between window openings and a few bricks fell off. Walls below an elevation of 10.000 m connected to the turbine deck only had the finishing peel off and there were also many cracks (Photo 7).
E. Other locations

Welds connecting steel beams of the turbine deck to the building and deaerator bunker room were broken at an elevation of 5.000 m and 10.000 m. The poured-in-place R.C. slab at an elevation of 10.000 m were cracked at some places by the fallen roof, but the deck itself was basically undamaged.

The poured-in-place concrete pedestals of the 0.125M kW and 0.25M kW turbo generators were undamaged in the quake.

(4) Multistory frame of the deaerator bunker room

The 1st stage of construction consisted of building axes 1 to 13. The framework was divided into two parts by an expansion joint, column spacing was 7.5 m, and a 3 m bay was used at the expansion joint. The full length of this section was 93 m (Fig. 8). The belt-end transfer cabin cantilevered 3 m at an elevation of 37.000 m at axis 1 and the suspended weight was about 60 t. 24 mm filler walls were laid between the columns starting from 0.000 m along axis B and from an elevation of 10.000 m along C up to the top of the building. The poured R.C. frame used #300 concrete and grade II bar. The columns together with the longitudinal tie beam of the multistory floors formed a flexible framework.

The actual load carried by the framework at the time of the quake was lower than the design load. The actual load on the frame at axis 6 during the quake is shown in Fig. 9.

The 2nd stage of construction consisted of building axes 13a-31 where the No. 3 and No. 4 units were set. The framework was divided into two sections by an expansion joint. The column spacing was 7 m with a 3 m bay at the expansion joint. The full length of this part of the building was 132 m. The 2nd stage of construction had just progressed to the erection of structural members and equipment when the shock hit and the actual load was only about 50% of the design load. The progress of the erection of the structural members before the quake is shown in Fig. 10.

After the quake the roof of the 1st stage work at axes 1-4 fell to the ground (Photo 8). The frame at axis 5 at an elevation above 30.000 m collapsed. The frame at axes 6 and 7 from an elevation above 30.000 m tilted to the south about 23 cm, and at axis 5 the longitudinal tie beams were broken at the end (Photo 9).

In the secondary damage caused by collapse of the framework an 18 m truss of the coal conveyor corridor fell down, the 1,125 m² roof truss in the turbine house collapsed, and a set of 75t/20t bridge type cranes fell down. The gable wall at axis 1 was damaged, also seriously damaged were the turbine deck and the boiler deck at axes 1-4. The over-bridge linking the deaerator bunker room and administration building fell down, etc.

The earthquake damage to the broken frames at axes 5-7 and 7a-13 were nearly similar (Fig. 11), they only differed in degree.

S-shaped cracks were detected on columns at axis 6 and 9 (see Fig. 12 and Photo 10). The anchor length of the main bars of the beams into the columns was only 25 times the diameter
(extended beyond the column centerline by 5 cm); the bars were broken mostly on one section. Possibly, S-shaped cracks were related to the reinforcement and structure of the joint.

The main damage that developed longitudinally along the building was X-shaped cracks on brick filler walls below an elevation of 19.500 m. The cracks on the walls along axis B were worse than those along axis C (Fig. 13).

The prefabricated R.C. stair flights on axes 1-2 bay and axes 13-13a bay (3 m bays next to expansion joint) all collapsed in the quake.

Joints in the multistory fabricated frame for the No. 3 unit were not completely finished so when the quake hit the frame could not react as a whole system resulting in excessive tilting and displacement. Surveying the site revealed that the longitudinal displacement (toward the No. 4 unit) of the column top was up to 57.8 cm. At the same time, the collapse of the turbine house roof displaced the frame about 10 cm to the east. The hinged portal frame from above elevation 30.000 m all tilted to the south after the shock (Photo 11).

Diagonal and vertical cracks were observed at the ends of the transverse beams of the frame. Most groove welds of bars at beam ends were broken and failed forming a crater. For example, a vertical crack was detected at the beam end at an elevation of 16.800 m on the column along axis B at axis 18. Seven of the 8 negative bending bars were broken, the breakage measured 12 cm and more and the broken bars dislocated 10 mm horizontally. At an elevation of 10.000 m an individual beam developed camber and many cracks were detected at the beam-column connection. The width of the cracks was 1.3-2.4 mm and the beam end dislocated vertically at the crack about 7 mm.

At the No. 4 unit frame only part of the columns and longitudinal tie beams along axis B and C were erected into place before the quake; large displacements took place after the quake. The results obtained by surveying the site indicated that the maximum longitudinal inclination of columns along axis C at axis 22 was 77.5 cm with most of the others above 60 cm. The transverse inclination of columns at axis 27 (inclined to the east) was 32 cm and the rest averaged 12 cm and above. Columns along axis C were erected only to an elevation of 16.800 m so the inclination was less; longitudinal inclination (toward the north) of columns at axes 21-31 was 56 cm. Horizontal circular cracks were observed on columns at an elevation of 0.000-10.000 m due to excessive inclination. Many of the groove-welded bars at the base of columns were broken; of the 14 φ25 bars in each column at least 7 were bent and broken, the most damaged columns had 10 broken bars.

There are two kinds of column joints: column to foundation with short studs and column to column. The former was more seriously damaged (Photo 12) and the latter was basically intact.

The beams and the brackets on the columns were rigidly connected. The connections were located at the beam section where the internal stress was at its greatest. In general, the negative bending bar at the beam end had 8-14 φ32, the positive bending bar was positioned as structurally required and, generally, 2-4 bars would be extended into the column; groove welds were used for connection of bars.
The bearing load of the bracket was considered under the two following conditions: those at an elevation of 10,000 m and 30,000 m were calculated to take the total shear of the beam end and those at an elevation of 16,800 m to take only 50% with the test taken up by the 2nd grouting and the step joint.

After the quake many of the positive and negative bending bars of the beam end at the rigid connection were broken, mostly the groove weld. At axes 13a-22 40% of the transverse frame beams had their negative and positive bending bars broken with a weld crater. Transverse dislocation occurred. Local damage was observed on brackets and transverse beam ends. Damage to brackets were mostly detected on the outside of embedded steel plates and a few brackets had concrete that peeled off and bars that were exposed at the end; concrete at the beam support was crushed.

The longitudinal beam had a section of 300x650 mm. Generally, 3 φ25 were positioned on top of the beam; during construction the dead weight of the longitudinal tie beam was borne by 2 φ32 short bars extended from the frame column through welding plates to the lower bars. After a 2nd pour of concrete at the connection the total shear of the beam end would be taken up by a step joint. Damage to such connections would be less if the 2nd pour had been completed and if the walls were well laid. Otherwise, the damage would be much worse. The step supports at the joint generally cracked and most of the cracks were vertical. Tensile bars in longitudinal tie beams were generally broken at the groove weld, and a crater pulled apart 20-50 mm (Photo 13). The compression bars at the beam end were undamaged.

(5) Suspended boiler frame

Two sets of 400 t/h intermediate reheat suspended boilers were erected in the 1st stage of construction. The structure was a R.C. frame 45 m in height. The operating deck elevation was 10,000 m. Below the deck a 240 mm wall was laid with #75 brick and #25 mixed mortar to form an enclosure from elevation of 10,000 m up to the roof. The frame was topped with prefabricated R.C. roof slabs. In-between the boilers a tower-like elevator shaft was built and enclosed with R.C. claddings; the size of the shaft was 4m×4m×56.7m.

The boiler frame was a freestanding structure (Fig. 14). It was 9 m away from the bunker room and the two structures were connected by a simply supported platform at an elevation of 10,000 m; the boilers were suspended from a plate girder, the suspension rod was 5 m in length, no special sway system was adopted and the plate girder was simply supported on the frame columns. The economizer and pre-heater at the rear of the boilers were placed on top of 9 R.C. columns; the top elevation of the columns was 5.400 m and steel tie beams were used at the column tops.

The design loads for the structure consisted of equipment load, overhaul load of 800 kg/m² for the deck, and a wind load of 40 kg/m².

The frame was a fabricated structure (Fig. 15). Beams and columns were in straight sections; tenon joints for columns, rigid connection step joints for brackets on beams and columns and groove welds for connection of bars were adopted; the type of connections were the same as used in the fabrication of the framework. The concrete strength for the frame was #300, the reinforcement was grade II steel, and the 2nd pour concrete was #400.
After the quake boilers and frames and the elevator shaft appeared to be still in shape (Photo 14). The shaft frame was basically intact but there was a 25 mm displacement to the north as a whole. The steel bridges connecting the shaft to the No. 1 and No. 2 boiler house at 4 elevations (26.000 m, 29.000 m, 39.000m and 48.800m) and steel bracing connecting it to the deaerator bunker room were distorted, the embedded steel plates were pulled out and the footbridges were out of alignment.

The collapse of frames in the deaerator bunker room at axes 1-4 caused secondary collapse of prefabricated R.C. beams and slabs of connection decks at axis 1-4. Axes 6-9 connection decks had 4 pieces of prefabricated slabs fall off, at other decks staggering was observed between beams and brackets with an individual beam that tilted. Guard panels on decks around the boiler were crushed by the boiler's rigid beams.

The boiler frame as a whole tilted to the northeast, the No. 1 boiler part had a greater tilt than the No. 2 boiler part. The maximum displacement of the column top measured 114 mm and the number of column tops with displacement exceeding the allowable H/750 (H-height of structure) amounted to 27% of the total number of columns.

The 9 columns supporting the rear economizer (elevation of column top was 5.400 m) and the steel beam were in simple support connection and after the quake the anchor steels of the embedded steel plates were cut by shear; the maximum displacement of the column top was up to 160 mm; an individual column at an elevation of 10.000 m had crushed concrete at the tenon joint.

Cracks were observed on 5 beams of the No. 1 boiler frame and on 2 beams of the No. 2 boiler frame at 1/3 span (Photo 15). The cracks on beams had a maximum width of 4 mm and the rest were 1-1.5 mm.

Most of the beam-to-column connections were damaged. The 2nd pour of concrete at the beam end connection was pulled apart, the cracks generally measured 3-5 mm the widest being 15 mm; reinforcement at the beam end connection broke at groove welds. Of the 28 connections to be inspected at the site, 7 had unbroken bars (25%), 9 with bars all broke (32%) and 12 with bars partly broke (43%). Since greater displacement appeared on top of the frame, beams at a higher elevation had greater damage. Beams at an elevation of 39.300 m had the greatest damage; 54% of the beams had broken bars, 18% at an elevation of 29.600 m had broken bars, and all the breakage was detected at the groove weld. The on-site inspection also discovered that approximately 50% of the welds were not qualified. From an elevation of 21.300 m and below the displacements were much smaller and no broken bars were observed.

II. Tangshan Power Plant

1. General conditions

The Tangshan Power Plant was situated in the north suburb of Tangshan City. It sat on an intensity X area. It consisted of two plants, the old plant and the new plant. The old plant had 4 sets of generators (No. 0-No. 3) and 5 sets of boilers (No. 0-No. 4). The old plant was completed in 1942; the total power generated was 56,000 kW. The new plant was constructed in 3 stages
and it had 6 generators and 5 boilers. The No. 4 and No. 5 units of the 1st stage of construction of the new plant (capacity: 25,000 kW each) and the No. 3 unit of the old plant were put into operation in 1958. The No. 6-9 units of the 2nd stage of construction of the new plant (capacity: 50,000 kW) were completed and put into operation in 1960 and 1974. All the boilers were of an indoor type.

The plant had 3 R.C. chimneys 80 m and 100 m in height. The cooling towers used a secondary circulating water supply system. There was one induced-draft cooling tower and 3 hyperbolic cooling towers and they were arranged east and west of the main building. The chimneys and water towers were all completed after the fifties.

The plant was situated north of Dacheng Hill. The plant ground was filled earth 2 m in depth, below it was quaternary alluvium and sandy clay, at –5 m to –7 m was a sand stratum with different grain sizes about 5 m thick, and further down was the air-slaked limestone rock base. The ground water table generally was at -3 to -4 m. The elevation at the base of the foundations of the main building was -5.00 m to -7.000 m. The bearing stratum was fine sand and medium sand, and the allowable bearing capacity of the ground was 1.5-2.0 kg/cm². The foundation of the chimney was placed on sandy clay at -3.000 m and the bearing capacity was 1.8 kg/cm². The allowable bearing capacity of the ground at the cooling tower area was 1.2 kg/cm². The old plant used a pile foundation but the new plant sat on natural ground.

The No. 1 and No. 2 units of the old plant were built in the forties. Their construction included poured-in place R.C. frames, steel roof trusses, prefabricated R.C. small-sized ribbed roof slabs, and a 490 mm brick wall with small window openings. The No. 0 and No. 3 units were completed in 1956 and they were constructed in the same manner. The plant building adopted a seismic design of earthquake intensity VII degrees.

For the new plant the 1st and 2nd stage of construction used aseismic design of intensity VII. But in the 3rd stage of construction the earthquake intensity was considered at VI degrees, hence, no aseismic design was used. In the 1st stage of construction the column spacing was 5.6 m, the span of the turbine house was 23.63 m and the span of the boiler house was 24.852 m. In the 2nd stage of construction the column spacing was 5.6 m, the span of the turbine house was 24 m and the span of the boiler house was 25 m. In the 3rd stage of construction the column spacing was 7.0 m, the span of the turbine house was 24 m and the span of the boiler house was 27 m. Poured-in-place R.C. structures were used for the main frames (Fig. 16).

Roof structure of the turbine house and boiler house: 1st stage - steel truss and purlins, prefabricated small-sized roof slab with 3.1 m span; 2nd stage - steel roof truss, prefabricated large-sized roof slab; 3rd stage – pre-stressed R.C. roof truss, prefabricated R.C. large-sized roof slabs; #75 brick and #25 cement mortar were used for exterior walls.

The deaerator bunker room and coal bunker room of the three stages of construction were all poured-in-place R.C. structures. The concrete strength was 200 and the steel grade was I and II. See Fig. 17 for loads on the framework.
2. Damage

The Tangshan Power Plant was situated in an intensity X area. As a whole, the earthquake damage was not serious at the plant site. Except for heavy damage to parts of roof structures the frame structure was basically intact. Of the original 91,492 m of building area 15% collapsed or was seriously damaged, 43% was slightly damaged and 41.5% was basically undamaged. See Fig. 18 for earthquake damage to buildings and structures.

(1) Old plant

The main structures were basically intact; a number of structural elements had slight cracks and brick walls collapsed at a few locations. At the No. 0 unit the turbine house filler walls at both ends of the roof trusses collapsed and R.C. frame columns of the fixed end gable wall were cut by shear and showed apparent horizontal cracks. Apparent displacement of an equipment pedestal at the No. 1 unit was observed; it was pulled apart from the deck by 3 cm. A portion of the gable wall at the fixed end of the boiler house collapsed and had many cracks; the haunch plate girder of the bunkers had serious cracks.

(2) New plant

A. Roof structure

After the quake the roof structure of the 1st stage of construction was basically intact. 64% of the roof area of the boiler house collapsed. The roof structure of the 2nd stage of construction had less root bracing than that of the 1st stage. After the quake, at axes 14-25, the roof structure of the turbine house completely collapsed except for the bay next to the expansion joint (Photo 16); all of the brackets on the frame supporting the roof trusses were broken and the reinforcement pulled out. At the boiler house only deformation of the roof bracing was observed; a few roof slabs had local damage and the rest basically remained intact. The roof structure of the turbine house (3rd stage of construction) completely collapsed; the roof structure of the boiler house was at a greater height and larger in span than that of the previous two stages and it had a monorail crane attached to the lower chords of the roof trusses, but the roof structure was basically intact after the quake.

B. Other structures

The framework of the deaerator and bunker rooms was basically intact and only a few beams and columns showed slight cracks.

The damage to brick walls was more serious. The gable above the elevation of the lower chord of the roof truss fell off completely. The collapse of the exterior wall and parapet at the turbine house crushed the combination conductors. The gable wall at the extension end of the turbine house tilted outward and its tip displaced 1.5 m (Photo 17). Pedestals and decks of the No. 4 and No. 5 turbine units had 3-4 cm difference in settlement after the quake.

C. Framework of boilers

All boiler frames except that of No. 9 used a steel structure and no serious damage was detected in the inspection after the shock. The No. 9 boiler was a set of 200 t/h indoor
suspended boilers, it had an independent fabricated R.C. frame, the columns were tenon jointed, beam-to-column joints used rigid bracket joints and groove welds were used for steel beams at supports (Fig. 19). The top of the column was hinged where connected to the plate girder of the boiler frame and was independent of the plant frame; the foundation soil was sandy clay, the buried depth of the foundation was -3.5 m, the load bearing capacity of the ground was 20 t/m² and the rock base was 15 m below the ground.

Except for slant cracks (maximum width 3 mm) observed at beam ends on axes K1-K3 at an elevation of 17.900 m on both sides of the boilers, the rest were undamaged and the groove welds were also undamaged.

(Translators: S.Y. Zhou and Q. Li)

Table 1. Comparison of soil analysis data before and after the quake.

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<td>(surveyed in July 1974)</td>
<td>(surveyed in August 1976)</td>
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Photo 1. A view of the Douhe Power Plant before the quake.

Photo 2. The Douhe Power Plant after the quake.

Photo 3. Collapse of the turbine house roof at the Douhe Power Plant.

Photo 4. A damaged bracket of the turbine house roof truss at the Douhe Power Plant.
Photo 5. Damaged I-section column of the turbine house at the Douhe Power Plant.

Photo 6. Damage to joint of I-section column of the turbine house at the Douhe Power Plant.

Photo 7. Damage to axis A exterior wall of the main building Douhe Power Plant.

Photo 8. The axis 1-4 frame of the deaerator bunker room of the Douhe Power Plant collapsed.
Photo 9. Longitudinal tie beam of the frame at the deaerator bunker room of the 1st stage construction at the Douhe Power Plant.

Photo 10. A damaged poured-in-place frame column of the deaerator bunker room at the Douhe Power Plant.

Photo 11. The hinged portal frame of the No. 3 unit collapsed at the Douhe Power Plant.

Photo 12. A broken joint of the prefabricated frame column and short foundation stud at the Douhe Power Plant.
Photo 13. A broken groove weld on the joint of the frame of the main building at the Douhe Power Plant.

Photo 14. The boiler and elevator after the quake.

Photo 15. A crack in the middle of a boiler frame of the first stage construction at the Douhe Power Plant.

Photo 16. The roof of the turbine house collapsed in the 2nd and 3rd stage construction at the Tangshan Power Plant.
Photo 17. A tilted gable at the extension end of the turbine house at the Tangshan Power Plant.
Figure 1. Plan of the main building at the Douhe Power Plant.

Figure 2. A section of the main building of the 1st stage of construction at the Douhe Power Plant.
Figure 3. A section of the main building of the 2nd stage of construction at the Douhe Power Plant.

Figure 4. Geological section of the Douhe Power Plant are [R] = bearing capacity kg/cm².
Figure 5. Damage to various buildings at the plant site of the Douhe Power Plant.  
Figure 6. Layout of the turbine house roof bracing at the Douhe Power Plant. 
(a) Layout of bracing of the upper chord of the roof truss; (b) Layout of bracing of the lower chord of the roof truss; (c) Layout of the horizontal bracing of the monitor.
Figure 7. Typical cracks observed on columns of the turbine house at the Douhe Power Plant prepared on site (width of cracks in mm).
Figure 8. A section of the 1st stage of construction of the deaerator bunker room at the Douhe Power Plant.

Figure 9. The actual load diagram of the frame at axis 6 in the quake of the deaerator bunker room at the Douhe Power Plant. [p(t), q(t/m) (live load), g(t/m) (dead load). The bunker was filled with 30% of the coal load capacity during the quake]
Figure 10. The progress of erection of the fabricated frame of the 2nd stage construction before the quake at the Douhe Power Plant.
1. Beam located, bar welded, joint waiting for grouting; 2. Progress same as 1, beam fell off during quake; 3. Column prepared for connection; 4. Beam located, bar on top not welded, not grouted; 5. Progress same as 4, beam fell off during quake; 6. Brick wall set up

Figure 11. Cracks on axis 8-12 frame of deaerator room at the Douhe Power Plant.
Figure 12. Cracks on axis 6 frame of the deaerator bunker room at the Douhe Power Plant. (crack width in mm; no cracks were observed on columns and beams of frame from elevation 19.500 m above)
Figure 13. Cracks on filled walls along axis B frame of the deaerator bunker room at the Douhe Power Plant.

Figure 14. A section of the boiler of the 1st stage construction at the Douhe Power Plant.
Figure 15. A sketch of the boiler frame of the 1st stage construction at the Douhe Power Plant.

Figure 16. Layout of the Tangshan Power Plant.
Figure 17. Loads on the frame of the main building at the Tangshan Power Plant.
(a) Axis 29 deaerator room frame. Loads: wt. of structure, dead load of deaerator, wt. of water, dead load of crane, live load of crane, wind load, work or erection load on floors; (b) Axis 30 coal bunker room frame. Loads: wt. of structure, wt. of coal, live load of equipment, snow load, wind load, concentrated load in t, distributed load in t/m.
Figure 18. Damage to the Tangshan Power Plant.
Figure 19. No. 9 boiler frames at the Tangshan Power Plant.
(a) Boiler frame and loads; (b) Axis K1 frame; (c) Axis K2 frame; (d) Axis K3 frame; (e) Axis K1-K3 frame.
There were four power plants in Tianjin. Junliangcheng, Yangliuqing, and the Tianjin No. 1 power plants were in operation when the shock hit. The Dagang Power Plant was just completed and ready for the installation of equipment; structures of the plant were not yet in a state for undertaking the full design load. The seismic design intensity was VII degrees, hence, no apparent damage was detected after the quake. Earthquake damage to the former three power plants will be briefed in the following.

I. Tianjin No. 1 Power Plant

This plant was situated in the city in Hedong District. It sat on an intensity VII area.

The construction of the old plant started in 1937. It was designed and built by the Japanese and equipped with two sets of turbo-generators and two boilers. In the early fifties three stages of construction took place successively and were completed in 1960. Seven turbo-generators and eight boilers were equipped and the total capacity was 155,000 kW (see Fig. 1 for the plan and section of the plant).

The plant site, facing the Haihe River on the west, sat on the old riverbed of the Haihe River. It was a piece of flat land seated on quaternary alluvium and shallow sea deposit. The ground was Class II soil. The surface soil was backfill 1-3 m in depth and further down was loam or clay strata. The geological formation is shown in Fig. 2. Seismic design had not been considered for the structures of both the old and new plants.

1. Arrangement of building structures

The old plant adopted steel frames, a steel and R.C. composite floor structure, steel roof trusses and purlins with wire mesh reinforced thin concrete slabs and 490 mm self-supporting walls of both the exterior and interior were connected to the steel structures with tie rods.

All three stages of the extension buildings used poured R.C. frame structures; the 1st and 2nd stages used steel deck trusses and door-shaped steel monitors, the 3rd stage switched to R.C. inverted triangular trusses and R.C. monitors. Prefabricated large-size roof slabs were used for all three stages. Bracing for all of the roof structures, especially the monitors, was inadequate. At the boiler house, next to the expansion joint, only one set of V-shaped vertical cross-bracing was at the middle of two end bays of monitor frames; at the turbine house only one vertical cross-brace was used at each end bay in the plane of monitors. 370 mm or 240 mm exterior brick filler walls were laid between columns with 120 mm covering the column, the interior walls were 240 mm brick walls. #75 brick and #25 mixed mortar were used for all walls. No bonding or connecting measures were used for walls to columns, beams and floors. At the boiler

* Northwest Electric Power Design Institute, Ministry of Water Conservancy and Electric Power
house, steel columns and steel wind trusses were used for the gable wall on the extension end; 490 mm brick self-supporting walls were laid below the elevation 7.000 m operating deck, and 240 mm filling walls were laid above elevation 7.000 m. At the turbine house brick piers and R.C. wind frames were adopted for the gable wall at the extension end; 490 mm walls were laid below elevation 7.000 m and 370 mm walls above this elevation. The gable walls on extension ends were all laid with #75 brick and #25 mixed mortar.

The buried depth of foundations was -4.000 m. A R.C. raft foundation was used for the old plant, the bearing capacity was about 10 t/m². A pile foundation was adopted for the extension plant (prefabricated R.C. pile, 12 m in length), independent foundations were adopted for the columns, the bearing capacity of the clayey soil stratum was 20 t/m². Below the foundation base there was some local soft silt layer at a depth –5 m to –8 m with the bearing capacity under 8 t/m².

The construction quality of the old plant was quite good but the latter three stages of construction had poor quality due to the rush of construction which was carried out in winter.

During the 1966 Xingtai magnitude 7.2 quake and the 1967 magnitude 6.3 Hejian quake in Hebei Province, the plant site was greatly shaken. At the plant, part of the parapets collapsed, brick walls at the expansion joint were staggered and crushed, cracks were observed on members of monitor frames at the turbine house of the third stage construction, the gable at the extension end of the boiler house had no connection to the roof slabs and it was tilted outward 2-3 cm after the quake.

The main building was appraised after the Hejian quake and it was judged that the transverse frame structure could meet the requirement of a VII degree seismic design but for the longitudinal frame structure, no bracing or aseismic walls, nor seismic framework had been considered in the original design. It was unsatisfactory as an aseismic structure. Measures had been taken to strengthen the buildings at local parts: parapets were lowered to 300 mm, R.C. brackets supporting roof trusses of the turbine house were hooped with steel sections, upper chords and nodal points of R.C. monitor frames of the turbine house were fixed with steel parts, and section steel ties were added to connect the gable to the roof structure along the whole length of the upper chord of the roof truss at the extension end of the turbine house. Also, ties were adopted to connect the gable to the upper chord of the roof truss at the extension end of the boiler house.

2. Damage

The frame, roof structure and walls of the old plant showed no apparent earthquake damage.

The bearing structure of the extension buildings was basically intact; part of the brackets supporting roof trusses of the turbine house, though strengthened by steel hoops, still developed cracks with crushed concrete and exposed steel. The R.C. brackets supporting the elevation 12.500 m steel deck of the bunker room mostly showed fine slant cracks. The top of the expansion joint between plants, built in the 2nd and 3rd stage construction, widened about 3 cm it may have been caused by the settlement and tilting of the 3rd stage construction. No apparent damage was observed on roof trusses of extension plant buildings, but distorted steel bracing was often detected at each expansion joint and individual bolts were pulled off (Photo 1). Some
R.C. bracings were pulled off and anchor bolts of the embedded piece for anchoring the bracing were pulled out and/or broken (Photo 2). The damage was more serious at monitors where horizontal circular cracks were observed at the foot of most R.C. monitor columns of the turbine house and some of them had crushed concrete and exposed steel. Monitor frames of the boiler house of the 2nd and 3rd stage construction inclined 30 cm toward the extension end with bracing broken and twisted, and the 240 mm brick end wall of the monitor collapsed. Four temporary guy wires were installed to prevent the monitor frames from falling after the quake. Miraculously the endangered monitor frames were jolted back into position during the magnitude 6.4 Ninghe quake.

The interior walls of the plant buildings were basically undamaged but the exterior walls were much damaged. The damage generally occurred on the top part (many cracks, bricks were crushed or partially collapsed); the middle part had a lot of cracks and the lower part had slight damage or was basically intact. The most seriously damaged walls were on axis F, the wall at axis 21-22 collapsed completely from above elevation 7.000 m (Photo 3); walls in other bays showed different degrees of damage. The 240 mm parapet along axis C showed a lot of cracks and partly collapsed (Photo 4). The 3rd stage of construction where the quality of mortar was very poor, much of the parapet fell and in turn crushed more than 20 pieces of roof slabs of the turbine house. 370 mm filler walls along axis A and B were less seriously damaged except for local cracking at the joints between the old and new buildings. Expansion joints of different stages of construction originally had a designed space of 20 mm which were usually filled with debris, generally, they were compressed and broken after the quake.

The gable of the boiler house at the extension end mostly collapsed above the level of the lower chord of the roof truss (the uppermost wind truss) and many cross cracks were distributed over the surface of the wall with crushed mortar and the wall tilted outward (Photo 5). The gable wall on the extension end of the turbine house was basically intact but the gable showed slight bulging and collapsed during the magnitude 7.1 aftershock.

Due to the non-uniformity in tension of guy wires the seven chimneys, 2 m in diameter and taller than the roof of the boiler house by 22 m, tilted at different inclinations in various directions. The No. 4, 5 and 6 chimneys were the most seriously displaced; No. 5 had the greatest displacement; a single bolt was broken and the concrete crushed at the foundation of the chimney. During the inspection after the quake it was discovered that one of the guy wires of this chimney was defective before the shock hit, it had a slight crack and this wire broke during the quake and caused the chimney to tilt (Photo 6).

II. Junliangcheng Power Plant

The Junliangcheng Power Plant was situated west of Tianjin and about 20 km from the city. It sat on an intensity VII area. The two stages of construction were completed in 1966 and 1969 respectively. The capacity of the turbo-generators was 200,000 kW. It was equipped with 4 turbo-generators and 4 boilers. See Fig. 3 for the plan and section.

The ground was quite flat. The soil belonged to shallow sea deposit, the strata was comparatively regular and the ground was Class II soil; there was not much variation in thickness and buried depth of the different strata. See Fig. 4 for the geological profile.
No seismic design was considered for the 1st stage construction. After the Hejian quake of Hebei Province hit in 1967 strengthening measures were taken for structures.

1. Arrangement of building structures

First stage of construction. Poured R.C. frame structures were used for the plant buildings, prefabricated I-section R.C. columns with flat-ribbed webs were used along axis D, and large-size prefabricated rib slabs and poured longitudinal tie beams were adopted for floors at axis B and C frames. Steel roof trusses and prefabricated large-size roof slabs were used for turbine and boiler houses.

Second stage construction. A prefabricated R.C. structure was used, pre-stressed R.C. H-frame sections were adopted for the axis B-C frame, columns were tenon-jointed, and steel supported step joints were used for connecting longitudinal tie beams to columns. An exposed bracket rigid joint was adopted at the connection of the column to the longitudinal tie beam along axis A. Prefabricated large-size ribbed floor slabs were used for the floor structure, and no fixed connections were considered for beams to floor slabs. The boiler house had an open structure in the 2nd stage construction but the No. 3 and No. 4 boilers were ordinary indoor-type 230 t/h boilers. No strengthening measures were taken for the No. 3 boiler and seismic bracing was added for the No. 4 boiler proper. Pre-stressed R.C. arched roof trusses, a door-shaped R.C. monitor frame, and large-size roof slabs were adopted for the turbine house roof structure in the 2nd stage construction. A fire in 1975 injured the roof structure and the monitor. To reduce the dead load a single-sloped steel monitor frame was adopted instead and the rooftop was changed to reinforced aero-concrete slabs.

A poured R.C. frame and 240 mm filling walls were adopted for the gable wall at the fixed end of the plant building (the wall was laid with 120 mm backing the columns), the height of the wall sections all exceeded 8 m, and φ4 wall-to-column ties were spaced at 1,000 mm. R.C. I-section columns and a steel wind truss were adopted for the gable wall at the extension end of the turbine house, and filler walls were laid with aero-concrete cinder blocks. A steel frame clad with reinforced aero-concrete wall plates was adopted for the boiler house at its extension end.

Exterior walls were 240 mm brick filling walls with 120 mm covering the columns, φ4 wall-to-column ties were spaced every 1,000 mm, 200 mm reinforced aero-concrete cinder blocks were used for all interior filler walls between columns and under beams, and 240 mm brick walls were adopted for independent interior walls laid on the ground and floor. No ties were installed for connecting wall-to-column or to floor in the 1st stage construction, φ4 ties spaced every 1,000 mm for wall-to-column connection were added in the 2nd stage construction. Most interior walls were 6-7 m in height and #75 brick and #25 mixed mortar were adopted for all walls. The strength of the aero-concrete cinder blocks was a little lower than for bricks.

After the 1967 Hejian quake in Hebei Province strengthening measures were taken for the 2nd stage construction such as, lowering the height of the parapet and strengthening bracing to the roof structure, and a full height R.C. quake-resistant wall was erected along axis B from axes 11-12. Also strengthened was the parapet along axis A of the 1st stage construction. According to the seismic computation, the transverse frame of the 1st and 2nd stage construction could meet
the requirements of seismic design of intensity VII but the longitudinal frames were far from satisfactory to stand such an earthquake intensity.

In the 1st stage construction an R.C. strip foundation was adopted for columns along axis A and D, and an R.C. raft foundation and prefabricated R.C. piles were used for frames on axis B and C. In the 2nd stage construction an independent foundation and pre-stressed R.C. prefabricated piles (length: 16 m) were used. The buried depth of the foundation was -5.5 m; soil at the base of the piles was hard yellow clay and the allowable bearing capacity of the ground base was 16 t/m².

Before the quake the No. 3 and No. 4 boilers had already switched to crude oil. When the quake hit the bunkers for the No. 3 and No. 4 boilers had no stored coal (coal storage capacity was 560t for each boiler).

2. Damage

The main load bearing structures of the plant buildings were basically intact. Slant cracks were detected at beam ends and 1/4 points of the beam span on longitudinal tie beams along axis B at elevation 12.500 m and 18.500 m (the beams were independent of the deck). Cracks on poured-in-place tie beams of the 1st stage construction were more serious, concrete at the bottom of the beam end was crushed and steel was exposed, a crack width of about 0.5 mm encircled the whole beam section. Damage to the tie beam of the 2nd stage construction was comparatively slighter, only fine cracks were observed at the secondary pouring of the step joint where the old and new concrete was joined. Similar cracks were observed at the poured-in-place simply supported beams at elevation 12.500 m and 18.500 m from axes 1-2 along axis C. Brackets supporting the roof truss of the turbine house on the column at axis B-8 developed a slant crack along the setscrew of the roof truss and concrete around the crack was crushed and steel was exposed. A small steel structure compartment with corrugated iron roof sheets was built on top of the No. 3 boiler between steel columns of the boiler frame and column at axis C. Walls were finished with mortar on wire mesh. The I-steel section joists of its floor were supported on elevation 25.300 m R.C. tie beams which connected the boiler's steel columns and columns on axis C. After the quake an embedded steel plate in the tie beam for welding the I-steels arched up and part of the welds broke which caused vertical cracks encircling the beam under the I-steel joists; the width of cracks was about 1 mm. At the same time, embedded steel plates used to fix steel studs onto the floor were pulled up, the steel studs were used to fix the wire mesh and were about 2 m in height. Concrete on the floor around the studs were broken into holes.

The roof structure was basically intact. Partial bracing deformation, with a connection bolt pulled off, was observed in both stages of construction but no damage was detected on the R.C. vertical bracing and horizontal tie rods of the 2nd stage construction. The asphalt built-up roofing at axis 1-2 of the turbine house was badly cracked. No measures were taken to connect the gable of the fixed end of the boiler house to the roof structure at axis 1 (roof truss and small-size roof slabs). After the quake the small roof slabs were displaced outward, the largest displacement measured 5-6 cm at the corner close to axis D. The roofing was seriously damaged and the gable tilted outward and cracks were observed on it.

Damage to exterior walls was comparatively slight. Tilting and cracking of the gable were also observed in the turbine house since there were no connections between the gable wall and
columns at axis A and B on the extension end of the turbine house. Walls on both sides of the 2 cm expansion joint, of the 1st and 2nd stage construction were crushed from pounding, and the top part of the wall at axis A collapsed. The 120 mm of brick covering the R.C. columns mostly cracked and locally collapsed along axis B from above the roof of the turbine house (Photos 7 and 8). The parapet along axis C and D tilted outward.

Damage to the interior walls was comparatively heavier. The finishing on the aero-concrete cinder block filler walls between columns peeled off and the walls cracked along the mortar joints. Interior partition walls on the floors at elevation 18.500 m on the axis B-C mostly collapsed. Column spacing walls at elevation 28.000 m on axis C mostly cracked and the wall between axes 5-8 mostly collapsed. The other walls, transverse or longitudinal, on the ground or at upper floor levels showed cracks and tilted outward. It was estimated that 90% of the interior walls were more or less damaged. The aero-concrete cinder block walls were more seriously damaged than the brick walls.

No gap had been provided for the floor finishing at the expansion joints in the 1st and 2nd stage construction. All floor finishing on both sides of the expansion joint was broken after the quake.

III. Yangliuqing Power Plant

The plant was situated 13 km west of Tianjin City. It was in an intensity VII area. The two stages of construction were completed separately in 1972 and 1974. It was equipped with 4 turbo-generators and 4 boilers, the total capacity was 375,000 kW. See Fig. 5 for the layout of the plant building.

The ground was quite flat. The soil was mainly composed of river alluvium and sea deposits. The soil strata were quite regular and were classified as Class II soil. See Fig. 6 for the geological profile. Seismic design of intensity VII was adopted.

1. Arrangement of building structures

The 1st and 2nd stages adopted fabricated structures. I-section columns with flat ribbed webs were used along axis A of the turbine house, the deaerator bunker room at axis B-C used H-frame sections. Tenon-joints for columns were used and steel supported step joints for connecting longitudinal tie beams to frame columns. The floors were built with prefabricated double-T channel slabs welded onto girders and the slabs were also welded to each other. The floor was finished with cement mortar.

Pre-stressed R.C. arched roof trusses, through-type R.C. monitor frames and prefabricated large-size roof slabs were used for the roof structure of the turbine house.

The boiler house was an open structure. It had suspended boilers on a prefabricated R.C. boiler frame. The beams and columns were in rectangular sections, tenon-joints were adopted for columns, exposed brackets and rigid joints were used for beam-to-column connections; part of the tie beams employed steel brackets. The boiler frames were independent of the building frames. The operating deck between axis B and C and the local top deck were simply supported.
Both end walls of the turbine house were R.C. structures. The exterior walls were 240 mm brick filler walls with 120 mm covering the columns. The height of the parapet was 1 m. The interior walls were 240 mm brick and aero-concrete cinder block walls and #75 brick and #25 mixed mortar were used for the walls. The 200 mm aero-concrete cinder block wall had lower strength.

Independent foundations and prefabricated R.C. piles were used for the plant building and boiler frames. The length of the piles was 14 m and 15 m, the buried depth of the foundations was -5.00 m, and the bearing capacity at the base of the piles was about 20 t/m².

2. Damage

The damage to the plant building was comparatively slight and no anomalies were observed. The roof structure was basically intact; a few broken welds at the connection plate of an individual lower chord of the roof truss was observed and some crushed concrete with steel exposed at the connection end of a R.C. vertical bracing to the roof truss was also observed.

The column tops at axis K₁ and K₂ of the No. 2 R.C. boiler frame had been given a second pour concrete because of defective work; horizontal circular cracks were observed at this pour joint. Horizontal cracks were observed on top of the concrete of the tie beams at the joints where the beams were connected to the steel plates of the steel brackets on columns of the No. 2, 3 and 4 boiler frames, and the width and length of the cracks increased with the height of the beam elevation. The steel plate connecting the No. 2 boiler frame column to the tie beam support at elevation 22.500 m had a broken weld, the concrete was crushed and steel bars were exposed at the beam end (Photo 9). The R.C. beam supporting the ventilation fixtures rested on elevation 18.00 m brackets on the No. 2 and 3 boiler frame columns; the connecting welds of the beam next to the No. 2 boiler frame column and the beam end next to the No. 3 boiler frame column were pulled apart with crushed concrete and exposed steel at the bottom of the beams. The steel deck between the No. 3 boiler frame and column on axis C was pulled off and sagged about 5 cm at the column on axis C.

The exterior walls were basically intact, only through cracks were observed at the lower part of the walls (370 mm in width) between the windows. These walls were at elevation 18.00 m and along axis B. No abnormal conditions were observed on walls along axis A though the construction was the same. Cracks were observed on parapets along axis C.

Cracks were greater in number on the interior walls than on the exterior ones but no collapse occurred. The more seriously damaged interior walls were those of the two-storied small compartment at elevation 23.100 m between axis K and C columns where the No. 4 boiler was stationed. Wide X-cracks were observed on the filler walls 6 m in height on the east and west sides; damage was heavier on the west wall and on the lower story. The walls on the north and south were undamaged; one of the brackets on the axis C column supporting the small compartment had the concrete cover crushed and steel exposed. Besides, multitudinous cracks were observed on the aero-concrete cinder block walls of the centralized control room of the No. 1 and 2 boilers and the relay room at elevation 8.00 m, axis B-C, with part of the walls bulging outward and damage was even more serious at the east and west sides and at the corners. At the plant, nearly all the walls built with aero-concrete cinder blocks had their finish peel off.
A small ventilator room 5m(w) x 3.5m(h) of brick-concrete construction was built on the roof of the B-C frame, axes 17-19. After the quake slant cracks developed on the east and west exterior walls and interior partition walls and those on the west wall were more serious; the cracks cut through the wall thickness and the width of the cracks was 2-3 cm.

There was a settlement joint between the elevation 8.000 m cantilever platform at axis A column and the turbo-generator pedestal, but the floor finish was not provided with a joint as required. After the quake the floor finishing was crushed and broken along the joint.

(Translators: S.Y. Zhou and Q. Li)
Photo 1. Bent steel bracing of extension building, at the Tianjin No. 1 Power Plant.

Photo 2. R.C. bracing of turbine house, Tianjin No. 1 Power Plant.

Photo 3. Damage to the wall at axis F of the plant building at the Tianjin No. 1 Power Plant.

Photo 4. The parapet at axis C of the plant building cracked and collapsed at the Tianjin No. 1 Power Plant.
Photo 5. The gable wall at extension end of the boiler house partially collapsed at the Tianjin No. 1 Power Plant.

Photo 6. The steel chimney inclined at the Tianjin No. 1 Power Plant.

Photo 7. The wall on axis B cracked at the Junliangcheng Power Plant.

Photo 8. Local collapse of the wall on axis B at the Junliangcheng Power Plant.
Photo 9. A damaged beam connection of the No. 2 boiler frame at the Yangliouqing Power Plant.
Figure 1. Plan and section of the Tianjin No. 1 Power Plant.

Figure 2. Geological profile of the Tianjin Power Plant site. R – allowable bearing capacity (kg/cm²); E – elasticity modulus (kg/cm²)
Figure 3. Plan and section of the Junliangcheng Power Plant.

Figure 4. Geological profile of the Junliangcheng Power Plant site. Allowable bearing capacity (kg/cm²); \(a\) – compression factor (cm³/kg).
Figure 5. Plan and section of the Yangliuqing Power Plant.

Figure 6. Geological profile of the Yangliuqing Power Plant site.

1. Clayey soil, allowable bearing capacity $R=1.5\text{kg/cm}^2$, elastic modulus $E=90\text{kg/cm}^2$; 2. Clay, $R=2.0\text{kg/cm}^2$, $E=50\text{kg/cm}^2$; 3. Clayey soil, $R=1.1\text{kg/cm}^2$, $E=70\text{kg/cm}^2$; 4. Clayey soil, $R=1.8\text{kg/cm}^2$, $E=70\text{kg/cm}^2$; 5. Clay, $R=2.2\text{kg/cm}^2$, $E=100\text{kg/cm}^2$; 6. Clayey soil, $R=2.2\text{kg/cm}^2$, $E=140\text{kg/cm}^2$
DAMAGE TO SUBSTATIONS IN THE TANGSHAN AREA AND THE CITY OF TIANJIN

Fang Hao

I. General Features

There were eighty-six 35 kV and above substations in the Tangshan area and in the city of Tianjin including fifty 35 kV substations, twenty-nine 110 kV substations, and seven 220 kV substations. After the quake, according to the degree of damage, an estimation was made as follows: 25 substations were basically intact (29.1%); 9 were slightly damaged (10.5%); 31 suffered medium damage (36%); 16 were seriously damaged (18.6%); and 5 collapsed or were destroyed (5.8%).

The substations in the Tangshan area were mostly concrete-brick structures and the earthquake damage was quite heavy. Of the 38 substations under the Municipal Electricity Supply Bureau of Tangshan (6 substations in the Chengde area not included) 33 were heavily damaged and 5 were slightly damaged and their enclosure walls mostly collapsed. Of the 33 that were heavily damaged, 5 had complete collapse of the roof and walls, 8 had local collapse of the roof and walls, and 20 had cracks on walls and local collapse of walls but the roof still stayed on.

Another statistic made according to location of substations in the Tangshan area in different earthquake intensity areas was as follows: all 4 substations in the intensity XI area collapsed; of the 9 in the intensity X area 2 collapsed, 5 had locally collapsed roofs and 2 had cracked walls but the roofs held on; of the 5 in the intensity IX area 2 had locally collapsed roofs and 3 had cracked walls but the roofs stayed on; of the 7 in the intensity VIII area 1 collapsed and the rest had cracks on the walls but the walls remained standing; of the 6 in the intensity VII area the damage was the same as in the intensity VIII area; of the 2 in the intensity VI area 1 had cracks on one wall corner and the other was not damaged at all.

Different degrees of damage were observed at the 48 substations in Tianjin; those in Hangu District (about 29 km away from the epicenter) and in Ninghe County had the heaviest damage. It was estimated that 26 were basically intact, 14 had medium damage and 8 were heavily damaged (Huangsoo, Louzhuang, Hangu, Dongnanjiao, Tiangang, Xianshuigu, Zhangguizhuang, and Dasuzhuang substations).

Damage to 30 main substations in the Tangshan area and the city of Tianjin could be listed according to their location intensities.

1 This paper was written based on the information provided by the Tangshan Power Supply Bureau, the Tianjin Electric Bureau, the Tianjin Power Transport and Transformation Company, the Beijing Electric Power Design Institute and the Tianjin High-Voltage Power Supply Substation.

2 Northwest Electric Power Design Institute, Ministry of Water Conservancy and Electric Power
The investigation indicated that all collapses took place in the intensity VIII to intensity XI areas. Photo 1 shows the collapsed roof of the control room at the Lujiatuo Substation; at some substations the wall collapsed and the roof cantilevered out. Photo 2 shows the switch room at the Xibeijsiao Substation with a collapsed gable wall, but the roof cantilevered.

In spite of damage to buildings the outdoor switchgear framework, supports and foundations of equipment were basically intact and mostly not damaged, only slight tilting of an individual framework caused by deformation of the ground was observed. They were put into operation again after minor repairs.

Listed according to topographical and geological features, the substations such as Junken, Buogezhuang, Bijiaqu and Tandi were located along the seaside with intercrossing rivers and channels. The ground cracked and fissured after the quake and large displacement occurred. Though the earthquake intensities registered were VII and VIII, the buildings had more cracks and greater inclinations than those located in the intensity IX area. For example, Leting Substation which was situated in the intensity VII area sat next to a large pond; the largest ground fissure measured 2 m, the ground developed a massive cave-in and slid toward the pond and raised the bottom level of the pond up from -5 m to -2 m; buildings in the vicinity of the pond were heavily cracked and the main structure tilted up to 10° (Photo 3, Fig. 1).

II. Examples of Damage

1. Lujiatuo Substation

Lujiatuo Substation was situated northeast of the city of Tangshan, south of Guyezhen and in the neighborhood of Yingezhuang. It was in an intensity IX area.

The ground was quite flat. From the ground level downward to a depth of 50 m the soil was basically fine sand strata with alternate strata of quaternary fluvial outwash and sea deposit. It was Class II soil.

This was a 220 kV key substation in the northeast Tangshan area. It was equipped with one set of 220/121/38.5 kV and 120,000 kVa transformer; sets of 110/38.5/11 kV and 50,000 kVa and 31,500 kVa transformer each, and also with a set of 50,000 kVa compensators. It mainly supplied electric power to Linxi Mine, Lujiatuo Mine, etc. of the Kailuan Mine.

The three stages of construction for this substation were completed and put into operation in 1960, 1971 and 1975 respectively.

(1) Arrangement of building structures

The original control room, 10 kV distribution room and equipment room had brick bearing walls, poured-in-place R.C. floors and roof slabs. The new control room was close to the east end of the original main control room. Seismic design of intensity VII was considered. Composite reinforced brick piers were adopted in combination with bearing walls (100 brick and 50 mortar). Steel roof trusses and prefabricated R.C. channel slabs welded to steel trusses at 3 points were used for the roof structure; there were tie rods between roof slabs and their connection to the walls. An R.C. bond beam was on top of the walls and under the roof structure, and horizontal bracing was installed on both the upper and lower chords of roof
trusses. The building had a good monolithic quality (Fig. 2). A plain concrete strip foundation was set at -2.70 m.

(2) Damage

Walls on three sides (south, west and north) of the original main control room collapsed (Photo 4), the fallen girder of the poured-in-place R.C. roof struck two large holes through the cable mezzanine and the entire roof structure fell on the control panels, but the cable mezzanine floor stood with only minor cracks. The end wall of the new control room developed serious 45° cracks; the composite brick piers were basically intact. The building still remained as a whole, only the fallen roof of the original control room crashed on the new control room and damaged its suspended ceiling (Photo 5). The roof of the 10 kV distribution room partially collapsed because of broken bearing walls. The side walls of the compensator room tilted outward and cracks were observed on the gable walls (Photo 6).

2. Jiaanzi Substation

This substation was situated in the north suburb of Tangshan on the west side of Jiaanzi Village. It was the 110 kV key substation in the Tangshan area and also the liaison substation of the Tangshan-Beijing-Chengde district network. It was equipped with a set of 15,000 kVa and a set of 31,500 kV transformers. It mainly supplied electric power to industries and coal mines in the north suburb of Tangshan. The site was in an intensity IX area.

(1) Arrangement of building structures

The control room was in a one and a half story composite structure. It had brick bearing walls, R.C. thin-webbed T-girders and large-size roof slabs. The distribution room and attached rooms were a two-story composite structure with brick bearing walls and poured R.C. roof and floor slabs. The wall construction consisted of a 370 mm exterior wall and a 240 mm interior wall of #75 brick and #25 mixed mortar. Brick and stone strip foundations were set at an elevation of -1.40 m. The ground was of Class II soil (Fig. 3).

(2) Damage

Both side walls of the main control room collapsed outward from above the elevation of the poured cable mezzanine floor; two of the thin-webbed T-girders fell and crushed the poured floor slab at one end. Tie beams of the floor slab were also broken. The other end of the T-girders thrust outward and sat on the broken wall, the tie beams of the side walls also fell and broke. The gable wall and roof of the equipment room collapsed (Photo 7).

The gable wall of the 6 kV distribution room collapsed completely from above an elevation of 4,000 m and its lower part was heavily cracked. The brick wall on the ground floor and the poured R.C. floor slab were basically intact. All of the 120 mm enclosure walls with pilasters collapsed.
3. Bijiadian Substation

The 110 kV Bijiadian Substation was situated north of Guye in the Tangshan area. It was a terminal substation. The ground was quite flat and in an intensity IX area. The substation was equipped with a set of 31,500 kVA transformers.

(1) Arrangement of building structures

The main building was a single-story composite structure with 370 mm brick bearing walls and a poured R.C. roof slab. Brick and stone strip foundations were set at -1.250 m. The ground was Class II soil (Fig. 4).

(2) Damage

The upper part of the 10 kV distribution room mostly collapsed, and part of the roof fell and broke (Photo 8). Serious cracks were observed on the gable wall and side walls of the control room (Photo 9). 45° cross-cracks were observed on the gable wall at axis 1 and 2 and horizontal cracks on the top and bottom of window openings on the side walls along axis A and D of the 110 kV main control room that was newly built in 1973.

4. Ganyao Substation

This substation was situated in Ganyao Commune of Lubei District northeast of the Tangshan Power Plant. It was in an intensity X area. Two sets of 7,500-15,600 kVA transformers were at the substation which was built in 1971.

(1) Arrangement of building structures

The main building was a 3-story composite structure with brick bearing walls and poured R.C. beams and slabs. The transformer room was on the 1st floor, the switch room on the 2nd floor and the main control room on the 3rd floor. In one wing was the 110 kV main control room with brick bearing walls and a prefabricated R.C. roof slab on R.C. roof girders; in the other wing was the 10 kV distribution room with brick bearing walls and a poured R.C. beam-slab roof. The ground was Class II soil.

(2) Damage

The brick walls in the control room and distribution room (Photo 10) in the two wings and those on the upper stories (Photo 11) collapsed. The walls in the other buildings of the substation, such as the office, dormitory, store room and enclosure walls all collapsed.

5. Dongnanjiao Substation of Tianjin

This 110 kV substation built in 1954 was situated in the southeast suburb of Tianjin. It was in an intensity IX area.

The ground was quite flat and on an old riverbed with a high ground water table. The ground was Class III soil (clayey soil and clayey silt strata).

(1) Arrangement of building structures
The main control room and switch room was a single-story composite structure with brick bearing walls and a poured R.C. roof. The 490-620 mm walls were laid with #150 brick and #75-100 mixed mortar. See Fig. 5 for the plan and section.

(2) Damage

Full length cracks up to 100 mm in width were observed on walls along axis 5 between axes B to C at an elevation of 4.500 m to 5.300 m (Fig. 6a). Vertical cracks ran upward on walls between axes 1-3 along axes B, C and E with a maximum width up to 120 mm (Figs. 6b, 6c and 6d). Many horizontal and slanted cracks were observed on the axis 1 wall between axes B and C (Fig. 6e). Walls on axes C and E between axes 1 and 2 mainly developed vertical cracks with widths up to 40 mm (Figs. 6f and 6g). Many cracks were observed on walls on axes 2, 3, 4 and 5 between axes B, C and D with a maximum width up to 50 mm (Fig. 6h).

The floor of the control room cracked near axis 2. The side next to the restroom settled 18 cm. Rooms between axes 3-5 tilted to the left. Also detected were several cracked walls in the rest of the rooms. The entire building was devastated.

Translators: S.Y. Zhou and Q. Li

<table>
<thead>
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<th>Classification of Damage</th>
<th>Roof Structure</th>
<th>Masonry Wall</th>
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<tr>
<td></td>
<td>Poured Structure</td>
<td>Prefabricated Structure</td>
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<tr>
<td>Basically intact</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Slight damage</td>
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<td>3</td>
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<tr>
<td>Total</td>
<td>14</td>
<td>16</td>
</tr>
</tbody>
</table>
Photo 1. The control room collapsed at the Lujiatuo substation.

Photo 2. The gable wall of the switch room collapsed at the Xibeijiao substation.

Photo 3. Tilting at the Leting substation was caused by deformation of the ground.

Photo 4. The rear wall of the control room collapsed at the Lujiatuo substation.

Photo 5. The ceiling of the new control room collapsed at the Lujiatuo substation.

Photo 6. The side wall tilted and cracked the gable wall at the compensator room at the Lujiatuo substation.
Photo 7. The control room collapsed at the Jiaanzi substation.

Photo 8. The 10 kv distribution room collapsed at the Bijiadian substation.

Photo 9. The side wall of the control room was heavily cracked at the Bijiadian substation.

Photo 10. The main control room collapsed at the Ganyao substation.

Photo 11. The main building of the Ganyao substation collapsed above the 2nd floor.
Figure 1. Topographical deformation of the ground at the Leting substation after the quake.
Figure 2. Plan and section of the main control room at the Lujiatuo substation.
(a) Plan (elev. ±0.00 m)

Figure 3. Plan and section of the Jiaanzi substation.
Figure 4. Plan and section of the Beijiadian substation.

Figure 5. Plan and section of the Tianjin Dongnanjiao substation.
Figure 6. Damage to the Dongnanjiao substation of Tianjin (width of crack in mm).
1. General

After the Tangshan earthquake an investigation was made of the damage to single-story buildings of the machinery industry in Tangshan, Tianjin and Beijing. The number of buildings investigated is shown in Table 1.

(1) Structural characteristics of buildings

The structural type of plants in the machinery industry can be divided into mainly three categories: 1) framed structures with pre-cast R.C. columns, frequently used in large and medium size plants with bridge cranes; 2) framed structures with brick columns (walls), frequently used in small size plants, medium and small size power stations and warehouses; and 3) composite frame structures with R.C. columns (a few with steel columns) in the middle rows and middle span, and brick buttresses in the side spans (or load-bearing walls) or with R.C. columns in the main span and brick columns in other spans. Plant buildings with an all steel structure were seldom seen.

The plan of these buildings was relatively simple in shape, generally rectangular. When the plan was of a Π-shape or L-shape expansion joints were usually installed to separate different sections of the building, but the width of the joint was relatively small. Plant buildings were also classified as single-span plants, multi-span plants of equal height and multi-span plants with unequal heights. Most plants with R.C. columns had a roof system without purlins while those with brick columns had a roof system with purlins. Large-size roof slabs were mostly used on roofs without purlins; hollow slabs were used at a few plants. Light roofs of air-entrained concrete slabs were only used at a few plants. Asbestos tiles, corrugated steel, and clay tiles were generally used in roof systems with purlins and R.C. single-channel tiles were used in a few systems.

Reinforced concrete skylight frames Π-shaped were used in most of the plant buildings investigated; steel skylight frames were used in a few plants, some semi-buried skylights and plain skylights were also used. One of the cross-sections of the R.C. Π-shaped skylight frame projecting on the roof was T-shaped (Type J107 and JT2101 skylight frame), another was rectangular shaped (Type 6410) and all were made of concrete 200 kg/cm² in strength. Mostly the skylight roof was the same as the roof of the whole plant. The lower beam of the skylight frame was made of pre-cast R.C. beams welded together with the struts of the frame. Vertical bracing of the skylight frames was usually installed at the two ends of the skylight unit. Single angles (L60x5) were used for the cross bracing of Type J107 and JT2101 skylight frames welded with the struts of the frame. M-shaped bracing was used in Type 6410 frames and was connected with bolts to the struts of the frame. For a load-bearing roof an arch truss and thin-walled beams were mostly used. R.C. sawtrusses and composite trusses were also used. Steel sawtrusses were also used in some of the plants. R.C. trusses were often used in plant buildings

* Earthquake Engineering Research Division, Ministry of Machinery Industry
with a span \( \geq 18 \text{ m} \); and composite trusses and roof beams were mostly used in plant buildings with a span \( \leq 15 \text{ m} \). Most of the R.C roof trusses and roof beams were monolithic, only a few were pre-cast. Wood (or wood-steel) roof trusses, triangular steel roof trusses or thin-walled R.C. beams were generally used in plants with brick columns (walls). Usually, a roof truss, or beam, was welded to the columns. At the connection of a large-size roof slab and truss or beam three-point welding was required, but this was not always done.

In the plant buildings investigated, the cross-section of R.C. columns in a bent varied with the height. When the height was \( \leq 800 \text{ mm} \) the columns were usually of a rectangular section; when \( \leq 1,600 \text{ mm} \) an I-section was often used; when \( >1,200 \text{ mm} \) most were double-columns. When the height was smaller I-section columns were of a solid type; when it was greater pre-cast columns with openings in the web were often used. Thin-walled I-section columns were used in a few plant buildings. Double-columns were mostly connected by horizontal web members; a few had oblique web members. Pre-cast web members were usually used in large double columns. The upper part of the columns in R.C. plant buildings were mostly rectangular sections, a few were I-sections, or I-sections with a thin web. Composite columns (steel column in the upper and R.C. column in the lower) were used in some plant buildings, especially high and large plants (e.g. the 6,000 ton hydraulic machine workshop at the Tianjin Heavy Machinery Plant). R.C hollow columns were only used in a few buildings. Most of the load-bearing brick columns were not reinforced. The brick buttress columns were of three types: those projecting outside the buttress wall; those projecting inside the buttress wall; and those projecting both inside and outside. Brick columns were all of a rectangular section.

Brick walls were used for these plant buildings, generally 240 mm or 370 mm thick, but at a few plants large R.C. panels or asbestos panels were used. Reinforced bond beams were usually incorporated in the brick walls and reinforcing bars were also used to connect the brick wall with R.C. columns, but sometimes poor connections were found. Most of the brick gable walls at the plants with R.C. columns were not load bearing, but at small plants load-bearing walls were also used instead of a load bearing bent. Gables at plants with brick columns were all bearing walls, some of the wind-resistant columns were erected up to the top of the plant but some were not. The wind-resistant columns in the gable of R.C. plants were mostly R.C. columns and those in the medium and small size plants were brick columns. There was usually no reliable connection between the roof members and the bearing gable wall and the wind-resistant brick columns.

In general, the roof bracing members were made of steel sections except for the vertical struts at both ends of a trapezoidal R.C. truss and the upper and lower struts in some plants. Round steel bars were used for the horizontal roof bracing in a few small plants. Bracing between columns was generally made of steel sections, R.C. bracing was used in a few plants.

The plant buildings investigated were mostly pre-cast assembled structures, therefore, they were poor in integrity and a majority were not designed for earthquake resistance. But, the safety factor of some plants (such as plants with larger cranes) was large but some were small (such as plants with cranes of a small capacity or those without cranes). In addition, there was a great difference in the quality of the connections and workmanship in these plants.

Most of the plants investigated were located on Type II and III site soil and part of the plants were on Type I site soil.
(2) Earthquake damage statistics

Statistics on damage to 467 plants investigated are listed in Tables 2-5.

2. Description of Damage

(1) Damage to skylight frames

a. Damage to R.C. skylight frames was mainly in the longitudinal direction

i) Fracture or failure of struts in the skylight frame

The damage pattern happened first in the area of intensity VIII (on Type III site soil). The fractures were all located at the bottom of the strut where the T-section connected with the rectangular section. The bottom of the fractured strut remained on the upper chord of the roof truss. In the intensity areas above X, collapse of the skylight frames and the roof system occurred but the struts fractured in the longitudinal direction.

ii) Longitudinal cracks occurred at the connection of the strut and the side plate or the middle angle

A wide range of such cracks generally occurred in the skylight formed by a large-size R.C. side plate welded to the strut. In Tianjin, an area of intensity VIII, such a damage pattern occurred generally, as shown in Photo 1; in Beijing, an area of intensity VI-VII, some such damage also occurred. The width of cracks ranged from 0.2 mm to several millimeters. In some cases the concrete in the skylight was loosened and fell off and the reinforcement was exposed. There were 122 skylight frames in the repair workshop of the Tianjin Tractor Plant, all of which were T-sections. After the quake the struts in 83 frames cracked badly at the connection with the side plate.

iii) Buckling failure of the vertical bracing on both sides of the skylight

Such damage patterns were first seen in areas of intensity VI. In areas of intensity VII and above a lot of such damage occurred. Based on the statistics of 6 machinery plants in Tianjin, in the area of intensity VIII, there were 72.4% vertical bracings in 504 skylight frames that suffered buckling failure (Photo 2).

iv) Damage to the connection joint between the strut and the vertical bracing

Such damage patterns mostly occurred on the J107-type T-section skylight frame. It happened in the area of intensity VI and more generally in the areas of intensity VII and VIII. Joint failure always accompanied the buckling failure of the bracing. Figure 1 shows several types of such failure.

The ratio of damage to the bolted connection joint between the vertical bracing and the Type 6410 skylight frame was relatively low.
b. No obvious damage to the settled-type skylight was found

Figure 2 is a sketch of the settled-type skylight and Table 6 shows a comparison of damage to the two types of skylight at the Tianjin Large-Size Machinery Plant indicating that damage to the settled-type skylights was slighter.

c. Damage to the steel skylight frame was slight

Damage to steel skylight frames was much less than to the R.C. skylight frames. A lot of steel skylight frames were basically intact after the quake, but in some cases the steel frames inclined longitudinally and some even collapsed with the roof. For example, in the impact extrusion workshop at the Tianjin Tractor Plant the steel skylight frame inclined seriously after the quake due to the large spacing of the vertical W-shaped bracing (66 m). Some ten days after the quake, the above-mentioned skylight frame suddenly collapsed with the roof.

(2) Damage to the roof system

a. Damage to roofs with purlins was slighter than to those without purlins

The roof of the No. 4 metal processing workshop at the Tangshan Metallurgical and Mining Machinery Plant was composed of R.C. slabs with channeled tiles on it. The workshop was basically intact after the quake except that the parapet wall fell down. The damage to the roof with purlins was mainly sliding of the tiles. In individual cases, purlins with channeled tiles fell down due to the poor connection between the roof truss and the purlins.

The two damage patterns of roof systems without purlins were damage to the whole system and damage to the members of the system. No cases showing overall inclination or collapse of the roof existed in the area of intensity VII. Only a few roofs in the area of intensity VIII collapsed and the main damage was due to the M7.1 aftershock. For example, there were 133,898 m² of roofs (827 trusses) at 24 workshops at the Tianjin Large-Size Machinery Plant, and roofs on 11 trusses of 6 workshops (total area: 1872 m²) collapsed amounting to 1.33% of the trusses and 1.4% of the total area. Of the 11 collapsed trusses 8 were induced by the aftershock amounting to 73% of those that collapsed. The damage in the intensity IX area was similar to that which occurred in the intensity VIII area, but the damage occurred more generally and seriously. About half of the roof systems in the intensity X area collapsed and suffered serious damage. Using the Tangshan Metallurgical and Mining Machinery Plant as an example, there were 47,304 m² of roof in 12 workshops, and 16,472 m² of the roof (35%) collapsed and 7,488 m² of the roof was seriously damaged. Based on the statistics of damage to roof trusses there were 126 (30%) out of 415 trusses that collapsed and 49 trusses (12%) were seriously damaged. Except for those that collapsed, some of the R.C. trapezoidal trusses inclined longitudinally, as shown in Photo 3. Only the Tangshan Toothed Wheel Plant was surveyed in the area of intensity XI. There were 5 workshops with a heavy roof system at the plant. After the quake 4 workshops completely collapsed in a lateral direction, half of the roof of one of the workshops collapsed longitudinally and the other half that also inclined was damaged quite seriously.
b. Damage to roof slabs occurred more generally

Among the damage patterns of the members of the roof system, damage to roof slabs generally occurred. Cracking and loosening happened mainly at the support of ribs of the slab and at the end of the truss (Photo 4). Also, offset of roof slabs occurred due to connection failure at the truss and beam and even a few slabs fell off the support of the skylight frame or the truss. At expansion joints the adjacent slabs were sometimes crushed due to pounding. When the upper wall or roof slab in the higher span fell down due to earthquake vibration it led to collision with the roof slab in the lower span (Photo 5). The roof beam damage pattern that was frequently observed was cracking of concrete at the end of the beam and exposure of the reinforcement. More serious was the damage to the connection between the beam and top of the column, or that the beam shifted on the column top (Photo 6), or that the beam fell down, induced by the collapse of the skylight frame or fracturing of the upper column (Photo 7). The damage that was frequently observed to the arch truss was cracking at the arch end and cracking of the struts supporting the roof slabs (Photo 8). Serious damage that was seldom seen was cracking and crushing of concrete under the rib of the first roof slab on the upper chord panel or at the end panel and buckling of bars (Photo 9). The upper chord of arch trusses at individual plants fractured under the vertical bracing of the skylight frame. The damage that was frequently observed to trapezoidal trusses was the failure of the vertical member at the end and the first panel of the upper chord (Photos 10 and 11). The damage pattern of the roof bracing was mainly buckling of members and failure of joints. Damage to the bracing of trapezoidal trusses was serious and generally occurred at the R.C. vertical member at both ends of the truss and longitudinal bracing members. Some joints were pulled apart and vertical members were overturned also, some braces were bent and fell down (Photo 12). In some cases such damage to trapezoidal trusses was made worse due to the failure of the bracing.

In summary, there were several characteristics of damage to the roof system in the single-story machinery plants.

(i) Damage to the lightweight roof system was less than to the heavyweight roof system. Photo 13 shows a comparison of damage to two adjacent plants, one with a light roof (intact) and the other with a heavy roof (collapsed).

(ii) Damage to the roof with bracing rationally arranged was slight. For example, in a workshop at the Tangshan Xijia Power Plant the north part of the bracing system was built in 1957. The steel roof trusses were covered with small ribbed slabs and the bracing system was strong enough. The roof of this part was intact after the quake. The middle part was built in 1960 and the steel roof trusses were covered with large-size slabs but no bracing system was installed. The roof of this part collapsed completely in the quake. The south part was built in 1972 and the pre-stressed R.C. trusses were covered with large-size slabs and the bracing system was not perfect. The roofs collapsed completely except for those having lateral bracing.

(iii) Damage to plants with a low center of gravity roof was less than to those with a high center of gravity. Generally speaking, damage to roofs with thin-walled beams was less than to roofs with trusses, and damage to roofs with arch trusses was less than to those with trapezoidal trusses. Damage to plants without skylights was less than to those with skylights; damage to plants with shaft skylights and those with settled-type skylights were relatively slight also. For
example, in the rivet welding workshop of the Tangshan Cement Manufacturing Machine Plants there were two bents of trusses in the workshop of equal height. One was an R.C. arch truss 18 m in span and the other was a composite R.C. trapezoidal truss 24 m in span, and the roof bracings of these two bents were not consistent with earthquake resistance requirements (lateral bracing and vertical bracing were installed in the lower chord in the second panel at two ends). After the quake, the large-size roof slabs in the first panel at both ends in the 18 m span fell down. Most of the roof in the 24 m span collapsed and the few remaining trusses inclined longitudinally; the damage to the roof was much worse than to that of the 18 m span (Photo 14).

(3) Damage to R.C. columns

a. Column tops

Damage to the column occurred at several tens of centimeters below the top and often occurred to columns with bracing, partition walls, and at the connection with a working platform or living rooms or at the corner of the building. At plants of different heights a little damage to the column top also occurred. When the damage was slight the welded seam cracked and cracks occurred in the concrete surface. When the damage was serious the welded seam failed, buried members were pulled out, concrete was crushed, and even the whole column head fractured. The slight damage mostly occurred in areas of intensity VII-VIII and the heavy damage in areas of intensity IX-X (Photo 15). Fracturing of the column top frequently led to falling down of the roof truss (Photo 16), and this appeared in the area of intensity VIII or greater. However, in some cases, although the column top was crushed for a height of tens of centimeters with the main reinforcing bars buckled the roof truss still remained on the column (Photo 17).

b. Upper columns

Damage that was frequently observed was horizontal cracking that appeared at the bottom or on the top surface of the crane beam (Photo 18). At the Tianjin Large-Size Machinery Plant in the area of intensity VIII there were 27 single-story workshops with R.C. columns. Except for 5 workshops the spacing of the transverse partition walls was less than 60 m, of the remaining 22 workshops there were 11 in which such cracks occurred. The more serious damage was wider cracks, crushing, peeling off of concrete in the compression zone and exposure and even buckling of reinforcement. Such damage also occurred in the areas of intensity VIII-X (Photo 19).

The rupture at the bottom of the upper column was extremely serious and mostly occurred in the area of intensity X e.g., at the processing workshop (Photo 20), the assembling workshop and the cast workshop at the Tangshan Cement Manufacturing Machine Plant. Such damage was also observed in the areas of intensity VIII and IX.

c. Plants with high and low bents

The characteristic damage to columns at plants with both high and low bents was that horizontal cracks occurred in the upper and lower part of the roof support in the lower bent. Such damage was generally found in the area of intensity VIII. For example, of the 8 plant buildings with high and low bents at the Tianjin Large-Size Machinery Plant, horizontal cracks occurred in 6 buildings. Most seriously, concrete in the compression zone was crushed and the
longitudinal reinforcement buckled. In addition, the bracket supporting the roof in the lower bent often cracked in tension and the embedded parts were demolished.

d. Beam shoulders

Splitting failure often occurred in the beam shoulder. Such damage occurred mainly in areas above intensity VIII. For example, a whole row of columns in the rivet welding workshop at the Tianjin Power Generating Equipment Plant suffered such damage except for several columns near the gable wall at the end (Photo 21).

e. Lower columns

Damage to the bottom part of lower columns occurred in areas above intensity VIII. Horizontal cracks occurred in the tension zone when the column was only slightly damaged; crushing of concrete in the compression zone and exposure and buckling of reinforcement occurred when the column was seriously damaged (Photo 22). Some of the columns completely fractured at the bottom leading to collapse of the plant buildings. This occurred mainly in the area of intensity X-XI. For example, in the area of intensity XI the columns in 6 workshops out of 10 at the Tangshan Toothed Wheel Plant fractured at the bottom part leading to collapse of the building. At plant buildings with a large array of columns, but with no column bracings installed, diagonal cracks, exposure and buckling of reinforcement sometimes occurred at the bottom of the column.

f. Double-columns

Damage to double-columns occurred in areas of intensity VIII to X. Photo 23 shows crushing of a double-column under a crane beam in the steel casting workshop at the Tangshan Metallurgical and Mining Machinery Plant in the area of intensity X.

g. Web of columns

Cracking of webs with openings or webs with horizontal elements occurred in areas of intensity VIII-X. Diagonal cracks (Photo 24) or vertical cracks (Photo 25) occurred between openings of the web as well as cracking at both ends of a horizontal web member (Photo 26). Such cracks generally appeared on the columns at the Tianjin Large-Size Machinery Plant located in the area of intensity VIII.

h. Bracing of columns

Damage to bracing between columns started in the area of intensity VIII i.e., mainly buckling and fracturing of bracing members and joint failure. Buckling of the bracing member was always accompanied by pulling out of another member (Photo 27). Some members were fractured in tension (Photo 28). The damage pattern of joints was a pulling apart or shearing of the welded seam on the gusset plate (Photo 29), pulling out or shearing of the anchored bars, etc.

The investigation showed that damage to bracing of lower columns was more serious than to the bracing of upper columns; damage to the bracing of middle row columns was more serious than to the bracing of exterior row columns; damage to the bracing of columns independent of the exterior longitudinal wall was more serious than to the bracing of columns connected to the
and damage to column bracing with a large slenderness ratio was more serious than to that with a small slenderness ratio.

Longitudinal cracks usually occurred at the connection between the bracing and the column and also at the top of the low embedded wall or working platform. Such damage occurred in all areas of intensity VIII to X. The concrete cracked when slightly damaged, and concrete was crushed and reinforcement buckled when seriously damaged (Photo 30). The lower joint of the lower column bracing was easily damaged. Damage to the column was serious when the connection of the column and its bracing was above the ground level of the workshop. Damage to the column top where the connection of the upper column bracing was located, always led to the collapse of the roof. On the Type III soil in areas of intensity VIII or above horizontal cracks often occurred on column shafts and especially at the column bottom when no bracing was installed between columns. In this case, some columns would incline longitudinally or fracture and even collapse.

i) Wind resistant columns

Damage to wind resistant columns was accompanied with damage to the gable wall. The damage patterns were failure of the connection between the column and the roof truss and cracking of the section at the various locations or cracking at the lower column bottom (Photo 31).

In addition, in the area of intensity VIII, due to the large displacement induced by the roller support on the transverse expansion joint, the column in the higher bent was cracked by pounding (Photo 32).

(4) Damage to walls

a. Bearing walls

In areas of intensity above VIII horizontal cracks occurred at the window ledges or the plinths of the longitudinal wall in single-story plants with brick columns, and when severely damaged the wall would be dislocated, crushed, or even collapsed. In some cases vertical cracks appeared at the connection between a longitudinal wall and a gable wall or a transverse wall. Oblique cracks or X-cracks mostly occurred on longitudinal walls with large openings and on gable walls or transverse walls. Bearing gables or the triangular tops were often damaged causing the collapse of the roof in the first panel (Photo 33). Gable walls with brick wind resistant columns mostly inclined outward or even collapsed.

b. Enclosing walls

No damage was found to exterior walls made with R.C panels but brick walls suffered damage to different extents. In areas of intensity VI-VII cracks occurred on the wall and the top of the wall inclined outward; the top of the gable wall at individual plants fell down. In areas of intensity VIII-IX the main damage to walls was that many gable walls (top portion) and parapet walls collapsed. In the case when a spandrel beam was not connected firmly to a column, a large area of wall would collapse with the spandrel beam. Collapse of filler walls between the high and low bents would break the roof on the lower bent and equipment in the plant. Based on
statistics made by the Tianjin Machinery Industry organizations, there were 137 plant buildings out of 148 that had walls that collapsed amounting to 92.6% of the total. Based on the damage survey in the area of intensity VIII, out of 65 plant buildings with high and low bents there were 34 buildings with roofs on the lower bent that broke due to falling of a filler wall. In areas of intensity X-XI walls were mainly damaged by shear and large areas of the walls collapsed.

There are two types of exterior walls. One is placed outside the exterior columns and the other fills the space between the columns. The damage pattern of the former was vertical cracks at the corners of walls and collapse of the wall corner. The cracks were generally wide in the upper section and narrow in the lower section (Photo 34); diagonal cracks and inclined cracks occurred on gable walls; gable walls that did not have a spandrel beam always inclined outward or bulged or even collapsed (Photo 35). Damage to parapets on longitudinal walls first started in areas of intensity VI. Inclined cracks or diagonal cracks often occurred and when seriously damaged the walls were dislocated, crushed and peeled off. In addition, horizontal cracks also occurred at the eave line, at spandrel beams on the top story or at the elevation of the window ledge.

Damage patterns of the inserted wall between the higher and lower bent were mainly outward inclination and collapse (Photo 36).

A spandrel beam enclosed in the wall had a significant effect on enhancing the earthquake resistance. However, if the spandrel beam was not enclosed or not connected firmly with the column it made the damage to the wall more serious. When the cross-section of the spandrel beam was small and its reinforcement was not sufficient shear cracks often occurred at the corners.

Damage to exterior walls in which the columns were embedded was less than to walls installed outside the exterior columns (Photo 37). Damage to a plant with embedded walls was generally more serious. For example, one of the workshops at the New Harbor Ship Building Plant was a building with three spans (higher bent in the middle and lower bents on both sides). Walls were embedded between the columns in the exterior row and no bracing was installed between the columns except for the middle row of columns. The roofs on both side-spans collapsed and column tops in the exterior row were seriously damaged, but the embedded columns and walls were only slightly damaged; bracing members between columns in the middle row and the joints were seriously damaged; columns were fractured horizontally at the bottom and some of them inclined seriously in the longitudinal direction (inclination of columns in the exterior rows was smaller) and the roof in the middle span survived.

(5) Conclusions

If the plan and elevation of a building were irregular the damage to the building was more serious. When a small building was attached to a larger building the damage to both was heavier. A working platform connected to the columns of a plant always made the damage more serious. For example, in one of the workshops at the Tianjin No. 1 Machine Tool Plant the top of a column connected to a R.C. platform for the mixing machine was damaged (the surface of the platform approached the column top) making an arch roof truss fall down and the roofs on both sides fell also but the columns were intact (Photo 38).
Partition walls installed between the columns, whether they were up to the column top or not, would increase the damage to a plant building with R.C. columns. While in a building with brick columns a partition wall which was built up to the column top would generally lessen the damage, but walls which were not built up to the column top would make the damage more serious.

When the center of rigidity of the plant did not coincide with the center of gravity the damage to the plant would be more serious. For example, in a warehouse at the Tangshan Cement Manufacturing Machinery Plant the opening at one end was connected to an outdoor store building. During the quake the columns at the opening fractured, the roof beam fell down and the wall at the other end was seriously damaged (Photo 39).

When one end of the plant was exposed (without a wall) and attached to a small house the damage to the plan would be more serious. For example, in the cleaning workshop at the Tianjin Tractor Plant pounding of the R.C. column near the expansion joint against the transverse wall and the roof of the attached building caused the column adjacent to the attached building to fracture and become off-set.

At plants with an irregular plan the damage at the expansion joints between sections was caused by pounding.

Damage to plant buildings with multi-spans of various spacing was more serious also.

The following are the factors that affected earthquake damage based on the statistical information:

a. **Effect of the site and foundation**

The investigation showed that damage to similar buildings would be quite different when located on different sites on different foundations in the same area of intensity. For example, damage to the Metallurgical Circular Saw Plant, Standard Parts Plant, Diesel Engine Auxiliaries Plant, Tangshan Building Ceramics Plant, and the Tangshan Cement Posts Plant which were all located at the bottom of Dacheng Hill in Tangshan City was very slight because the bedrock on which these plants were built was on shallow soil was relatively firm. However, in the same area of intensity the damage to the Tangshan Metallurgical and Mining Machinery Plant was much more serious than to that of the Metallurgical Circular Saw Plant which were only a few hundred meters apart although the structures in both plants were similar. Comparison of damage to these two plants can be seen in Table 7.

b. **Effect of the section of the plant building**

The statistics showed that damage to plant buildings with multi-spans of equal height was more serious than to single-span buildings; damage to plant buildings with unequal height spans was more serious than to buildings with equal height spans even when the structures of both buildings were similar. Table 8 shows a comparison of damage to buildings of different profiles at the Tangshan Metallurgical and Mining Machinery Plant.

c. **Effect of a crane truss**
A crane truss lessened the damage to a plant building. For example, at the maintenance garage of the Fengren Railway Station (Fig. 3) the upper columns in rows (B) and (C) fractured in the quake, the bracing members of the lower columns cracked, and the roof in the middle span collapsed, but in the portion where the crane trusses parked and in the side span where transverse partition walls existed (5 panels total) no upper columns fractured and no roof collapsed.

d. Effect of strengthening prior the quake

Generally, damage to plant buildings that had been strengthened prior to the quake was greatly lessened. Before the Tangshan earthquake the walls, roof bracing and welding between the large-size roof slabs and the truss of the main production buildings at the Tianjin Power Generating Equipment Plant had been strengthened. No collapse of walls and roofs were found after the quake, greatly reducing the percentages of buildings that were seriously damaged and moderately damaged and increasing the percentage of those that were basically intact (Photo 40). Production was soon restarted at the plant. Table 9 is a comparison of damage to several plants showing that the effect of strengthening was significant.

3. Case Examples

(1) No. 4 metal processing workshop and metallic structure workshop at the Tangshan Metallurgical and Mining Machinery Plant

a. Details of the building structure

Foundation: Type II soil, sandy clay; cup foundation for columns, buried depth, -2.0 m.

Structure: No. 4 metal processing workshop - steel triangular roof trusses in spans (A)-(B) and (B)-(C), R.C. corrugated roof slabs; R.C. columns (lower columns, I-section; upper columns, rectangular section) with crane beams. See Fig. 4 for bracing arrangement. 240 mm brick exterior wall; three R.C. spandrel beams were installed at elevations of +6.0, +10.0 and +14.2 m respectively. No spandrel beam was installed in the gable wall.

Metallic structure workshop: pre-stressed arch roof truss in spans (D)-(E) and (E)-(F), R.C. triangular skylight frames, pre-stressed large-size slabs on the roof. R.C. columns with crane beams (lower column, I-section; upper column, rectangular section). See Fig. 4 for bracing arrangement. 240 mm exterior wall, three R.C. spandrel beams were installed at elevations of +6.0, +10.9 and +14.9 m respectively. No spandrel beam was installed in the gable wall.

b. Damage

The roof in span (D)-(E) fell down completely and the trusses fell in span (E)-(F) (Photo 41). In span (C)-(D) the partition wall was crushed, and part of the roof cracked. The roof over the living room collapsed. The parapet wall and the gable top above the spandrel beam on the side wall in both workshops all collapsed. Both ends of the longitudinal wall in the No. 4 metal processing workshop cracked slightly. X-cracks were frequently found on the wall between
windows in the middle at the metallic structure workshop, and vertical cracks often occurred on the wall between windows. The cracked wall between the windows sometimes bulged outward for a maximum of 50-60 mm. The upper spandrel beam fractured at the corner.

The bracing of columns in the two workshops mostly buckled. The bracing in the middle row of columns was seriously damaged while those in the exterior rows were slightly damaged. Bracing between the upper columns buckled; horizontal bracing of roof trusses also buckled.

Concrete in the column top on axis (D) was crushed and the bracket of the column supporting the roof in the lower bent on axis (E) was cracked in tension.

(2) No. 2 metal processing workshop at the Tianjin Large-Size Machinery Plant

a. Details of the building structure

Foundation: Sandy clay, Type II soil; cup foundation for columns, buried depth -2.5 m.

Structure: Type G211 pre-stressed arch roof truss, Type G103 R.C. large-size roof slabs, R.C. skylight frames of T-section in span (C)-(D) (Fig. 5). R.C. columns, the upper columns of which were rectangular in section, and the lower columns were I-section. See Fig. 5 for the arrangement of bracing of the roof. The gable wall was 370 mm; the side wall was 240 mm; and the grade of mortar was #25. Walls in axis (B) were infilled between the columns and others were placed outside the columns. Three R.C. spandrel beams were installed on the wall (two at the elevation of +3.6, +7.2 m and the other one was enclosed); spandrel beams on top (in the higher span at 12.7 m, in the lower span at 10.05 m) were not enclosed. The parapet wall on the gable wall and the side wall was 1.65-1.70 m high.

Construction at the end of the pre-stressed arch roof truss was weak. The steel plate supporting the roof slab was buried in plain concrete. There was one φ32 U-shaped bolt in the slab at the column top connecting to the roof truss and no anchor bars were installed. During the quake the cranes in the three bents were all parked between the columns in axes (16)-(17).

b. Damage

About 7-8 m height of the gable wall collapsed. Three panels of the roof over the living rooms were destroyed by the fall of the gable wall. The whole eave wall in axis (E) collapsed destroying the transformer room. The bracket of columns supporting the roof system in the lower bent in axis (C) was crushed and cracked. Concrete at the end of the arch truss was crushed and cracked. In span (D)-(E) the column tops and beams in rows (16) and (17) were damaged; stirrups straightened, main bars bent and concrete was crushed and fell down. Two roof trusses fell down, the end of one fell on the crane beam and the other end still remained on the column top, destroying the crane beam and bringing down 36 roof slabs between rows (15)-(18) and one roof slab between rows (14)-(15).

In axis (C) cracks occurred on the brackets of 17 columns out of 21 at the connection of the higher and lower bents.

In span (B)-(C) circular cracks occurred on the wind resistant columns in row (1), and the wind resistant columns opposite the living room wall were split at various sections. A lot of roof
slab ribs were damaged. The skylight bracing was pulled out from the joints. Tie members on the column tops of rows (16)-(17) and (17)-(18) in axis (C) were buckled. The column shoulder in row (16) connected to the bracing cracked, the width of which was 30-50 mm and the length was 1.65 m. In axis (E) the concrete of the column tops connected to the bracing in rows (15) and (16) was crushed and became loose (Photo 42). Column bracing buckled out-of-plane.

(3) Chassis workshop at the Tianjin Tractor Plant

a. Details of the building structure

Foundation: Type III soil, cup foundation.

Structure: The structure is outlined in Fig. 6. Steel roof trusses and large-size roof slabs in span (A)-(B); steel roof trusses, steel skylight frames and large-size roof slabs in span (B)-(C). Pre-stressed trusses, pre-stressed thin-web I-beams, R.C. skylight frames (Type 6410) and large-size roof slabs in spans (C)-(W). Pre-stressed I-beams with thin webs, R.C. skylight frames (Type 6410) and large-size roof slabs in rows (1)-(8).

Spacing of columns in spans (A)-(B), (B)-(C), (1)-(5), and (5)-(8): 6 m.; upper columns, rectangular in section; lower columns, I-section. Spacing of columns in spans (C)-(W): 12 m; R.C. columns, rectangular in section. No cranes were installed in span (4)-(B), but step-wise columns were still used in axis (A).

Expansion joints, 20 cm in width, were installed between the longitudinal spans and transversal spans respectively. Two and three expansion joints, 30 mm in width, were installed in the higher bent and the lower bent respectively along the longitudinal direction.

At the intersection of span (A)-(B) and rows (27)-(29) there was a corridor upon which cantilever beams were put and no expansion joint was installed.

The offices in the workshop were in a two-story brick R.C. structure. Cantilever beams were installed on the floor and roof in order to separate them from the longitudinal wall in the workshop. The width of the isolation joint was 20 mm.

Horizontal bracing was installed between the upper chord and the lower chord in the second panel from the end of spans (A)-(B) and (B)-(C). Vertical bracing was placed at the two ends and in the middle of the trusses. A through tie rod was put between the upper chords and the lower chords respectively. A bracing member was installed on the upper chord in the first panel at both ends of the workshop to connect with the top of the wind resistant column. In the remaining spans no roof bracing was put on the pre-stressed roof beam. For the steel and R.C. skylight frames horizontal bracing of the upper chord and vertical bracing at the two sides were installed at both ends of the expansion section in the workshop. Cross bracing was used for steel skylights and W-shaped bracings were used for R.C. skylights.

In spans (A)-(B), (B)-(C), (1)-(5), and (5)-(8) bracing between the upper columns and lower columns was installed in the middle of the expansion section and no bracing was installed between the upper columns at both ends of the section. In the 12x12 m column array no bracings were installed between the columns.
The exterior wall was a 240 mm brick wall supported by a foundation beam. The bearing wall and exterior wall of the office area were 240 mm brick walls also, built on a strip foundation. In spans (A)-(B) and (B)-(C) three R.C. spandrel beams were installed at elevation +4.8, +8.4 and +10.88 m respectively; in spans (1)-(5) and (5)-(8) two R.C. spandrel beams were installed at +4.8 and +8.4 m respectively.

b. Damage

The strut of the R.C. skylight frame, 2.4 m high, was crushed and cracked at the lower jamb. The strut of the R.C. skylight frame, 1.2 m high, also cracked at the lower jamb. The vertical bracing of the R.C. skylight frames and steel skylight frames were deformed or pulled apart.

The block wall between the higher bent and the lower bent on axis (C) collapsed destroying 50 roof slabs on the lower bent (15)-(40). Further, in the M6.9 aftershock 9 roof slabs in rows (11)-(15) were crushed. Those in row (A) pounded against the corridor destroying 4 roof slabs.

On axis (A) the columns in rows (27)-(29) pounded against the corridor, the upper columns fractured inclining inward with a maximum displacement of the column top of 10 cm. The connections between the steel roof trusses and columns in rows (27)-(29) were damaged, concrete on the column top was crushed, the support was offset, the bolt buried in the column top was bent, the plate supporting the roof truss shifted outward and the lower chord was bent and deformed (Photo 43). Tie bars at both ends of the truss in rows (29)-(30) fell down. In the M7.8 Tangshan earthquake column brackets in rows (18)-(31) were split; in the M6.9 earthquake the splitting extended to rows (12)-(35) and the length of some cracks started from the bottom of the upper column to the middle of the lower column. Two columns located in the corridor in rows (27) and (29) were seriously cracked.

In the 12x12 m column array 18 concrete columns in rows (19)-(31) on axes (E)-(J) were cracked diagonally at the bottom, about 10 cm from the ground surface; the reinforcement was exposed and bent and the damage ratio of columns was up to 50%. The same damage pattern occurred to 7 columns in rows (34)-(41) amounting 23% of the total; and to 3 columns in rows (9)-(19) amounting to 10% of the total. One to six horizontal cracks occurred on the column at a distance 10-100 cm above the ground surface and some of the cracks passed through the whole section. Damage was found to be serious in the middle region of the workshop, but slight in the east and west region. Damage to the middle columns was serious and those on the sides and at the expansion joint was slight. No diagonal cracks were found on the columns on axes (C) and (W) except for horizontal cracks along the column. In the M6.9 earthquake the opposite side of the above columns was crushed but most of the reinforcement was not exposed, and at the same time, the damaged side of the columns was made heavier. There were 27 columns in rows (19)-(31) amounting to 77% of the total, and 8 in rows (31)-(41) amounting to 27%, and 18 in rows (9)-(19) amounting to 60%, suffering diagonal damage at the bottom induced by these two earthquakes. After the M6.9 earthquake horizontal cracks on the column also increased and more columns at the expansion joint suffered damage also.

In axis (C) horizontal cracks appeared at the roller support at the bottom of the upper column in rows (16)-(33) due to pounding of the end of the roof beam.
Horizontal cracks also occurred along the height of most columns on axis (W) (26 columns amounting to 74% of the total).

Serious horizontal cracks occurred on part of the roof slabs on axis (W) due to pounding against the office panels. At the expansion joint roof slabs collided with each other leading to cracking of concrete. Nearby, one of the upper jambs of the skylights fell down.

Almost all parapet walls on axis (A) collapsed. On axis (B) column bracing in rows (25)-(26) buckled. Most of the parapet walls on axis (W) collapsed internally crushing the roof slabs of the workshop. Damage to the panels in rows (19)-(31) was serious. At the transverse wall the end of the roof beam cracked or the bracket crushed in tension.

(4) No. 2 Metal processing workshop at the Tangshan Metallurgical and Mining Machinery Plant

a. Details of the building structure

The workshop was a building with composite bents, the structure of which is outlined in Fig. 7. Wood roof trusses were installed on the central span of the building and cross bracings were put between the trusses. On the roof there were wood sheathing, tar felts and asbestos tiles. In the side spans there were cast-in-situ R.C. girders with hollow brick tiles with ribs closely arranged on the roof. No reliable connections were installed between the tiles and rafters as well as the gable wall.

In the central span there were cast-in-situ rectangular R.C. columns and crane beams. No bracings were designed for the columns. The longitudinal wall in the side span was 240 mm thick. The girders were supported by brick buttresses. Crane beams were made of steel sections. At both ends of the workshop there were bearing gable walls without wind-resistant columns. There was one R.C. spandrel beam at the elevation of the crane beam.

b. Damage

The column bracket at the connection of the higher bent and lower bent was damaged and the buried members in the roof of the lower bent were pulled apart causing the whole roof system on both side spans to collapse (Photo 44). Most of the columns in the two rows on axes (B) and (C) fractured at the bottom.

The gable wall at both ends collapsed completely. The roof in the first panel at both ends of the main span collapsed. The spandrel beam on the west gable wall was hanging at the end of the R.C. crane beam.

(5) Processing workshop at the Tianjin Gong-nong Electric Machinery Plant in Hangu

a. Details of the building structure

Foundation: Weak foundation soil; bearing stratum was silty soil; allowable capacity was 8 ton-force/m²; underlying layer, black sandy soil; allowable capacity was 12 ton-force/m² belonging to Type III soil.
Structure: The workshop was a building with composite bents (Fig. 8), a 370 mm exterior wall and bearing reinforced brick columns in the wall. Large-size roof slabs were placed directly on the 370 mm gable wall and no beam was laid on the wall top and no connection was made between the slabs and the wall. Two R.C. spandrel beams were placed at elevations of +4.0 and +6.5 m. The window was 1.5 m wide.

The central columns were 400x600 mm R.C. columns. Bracings were installed between columns in the second panel from the ends and only for lower columns, Type L100. R.C. crane beams were of T-section.

b. Damage

The roof system in the central span (B)-(C) collapsed completely. Columns on axis (B) inclined to the north while those on axis (C) inclined to the south. Roof slabs near the east gable in both side spans fell down.

Horizontal cracks generally occurred on the brick columns on axes (A) and (D) (Photo 45). Longitudinal walls inclined to the north and south; the maximum inclination was 22°. Brick columns in rows (4) and (9) on axis (D) fractured at a distance of about 1 m from the ground surface with cracks 50 mm in width. Cracks of different extents were found on other brick columns.

The sloping thin-web girder was pulled out from the support at about 200 mm and splitting was found at the ends. The pull-out distance from the support decreased gradually from the center of the workshop to the gable wall at both ends.

Horizontal cracks were found at the bottom of the central columns. Concrete at the bottom of the columns in row (9) on axis (B) was crushed and loosened and steel bars were bent. Through parallel cracks occurred on the gable wall in span (C)-(D) about 200 mm wide below the roof slab. The east gable wall inclined to the east and part of the roof slabs fell down.

(Translator: Lu Rongjian)
Table 1. Number of plants investigated.

<table>
<thead>
<tr>
<th>Intensity Area</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>Kailuan Mining District</th>
<th>Tangshan</th>
<th>Tangshan</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>4</td>
<td>7</td>
<td>32</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>13</td>
<td>3</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>No. of plants</td>
<td>43</td>
<td>19</td>
<td>187</td>
<td>20</td>
<td>22</td>
<td>19</td>
<td>100</td>
<td>57</td>
<td>467</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Statistics on damage to plant buildings in areas of different intensities.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Number Investigated</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>43 (100%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>7 (16.3%)</td>
<td>36 (83.7%)</td>
</tr>
<tr>
<td>VII</td>
<td>19 (100%)</td>
<td>—</td>
<td>3 (15.8%)</td>
<td>5 (6.3%)</td>
<td>7 (56.8%)</td>
<td>4 (21.1%)</td>
</tr>
<tr>
<td>VIII</td>
<td>207 (100%)</td>
<td>8 (3.9%)</td>
<td>55 (26.5%)</td>
<td>74 (35.8%)</td>
<td>36 (17.4%)</td>
<td>34 (16.4%)</td>
</tr>
<tr>
<td>IX</td>
<td>41 (100%)</td>
<td>10 (24.4%)</td>
<td>19 (26.4%)</td>
<td>6 (12.6%)</td>
<td>1 (2.4%)</td>
<td>5 (12.2%)</td>
</tr>
<tr>
<td>X</td>
<td>100 (100%)</td>
<td>42 (42.0%)</td>
<td>28 (28.0%)</td>
<td>18 (1.8%)</td>
<td>10 (1.0%)</td>
<td>2 (2.0%)</td>
</tr>
<tr>
<td>XI</td>
<td>57 (%100)</td>
<td>42 (73.7%)</td>
<td>7 (12.3%)</td>
<td>4 (7.0%)</td>
<td>2 (3.5%)</td>
<td>2 (3.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>467 (100%)</td>
<td>102 (21.8%)</td>
<td>112 (24.0%)</td>
<td>107 (2.9%)</td>
<td>63 (13.5%)</td>
<td>83 (17.8%)</td>
</tr>
</tbody>
</table>
Table 3. Statistics on damage to single-story plant buildings with R.C. columns.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Number Investigated</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>36 (100%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>7 (19.4%)</td>
<td>29 (80.6%)</td>
</tr>
<tr>
<td>VII</td>
<td>7 (100%)</td>
<td>—</td>
<td>1 (14.3%)</td>
<td>1 (14.3%)</td>
<td>5 (19.4%)</td>
<td>—</td>
</tr>
<tr>
<td>VIII</td>
<td>141 (100%)</td>
<td>7 (5.0%)</td>
<td>36 (25.5%)</td>
<td>54 (28.3%)</td>
<td>27 (19.1%)</td>
<td>17 (12.1%)</td>
</tr>
<tr>
<td>IX</td>
<td>10 (100%)</td>
<td>—</td>
<td>7 (70.0%)</td>
<td>2 (20.0%)</td>
<td>1 (10.0%)</td>
<td>—</td>
</tr>
<tr>
<td>X</td>
<td>45 (100%)</td>
<td>16 (35.6%)</td>
<td>11 (24.4%)</td>
<td>15 (33.3%)</td>
<td>3 (6.7%)</td>
<td>—</td>
</tr>
<tr>
<td>XI</td>
<td>32 (100%)</td>
<td>21 (65.6%)</td>
<td>5 (15.6%)</td>
<td>8 (9.4%)</td>
<td>1 (3.1%)</td>
<td>2 (6.3%)</td>
</tr>
<tr>
<td>Total</td>
<td>271 (100%)</td>
<td>44 (16.2%)</td>
<td>60 (22.1%)</td>
<td>75 (27.7%)</td>
<td>44 (16.2%)</td>
<td>48 (17.7%)</td>
</tr>
</tbody>
</table>

Table 4. Statistics on damage to single-story plant buildings with brick columns.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Number Investigated</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>3 (100%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3 (100%)</td>
</tr>
<tr>
<td>VII</td>
<td>11 (100%)</td>
<td>—</td>
<td>2 (18.2%)</td>
<td>4 (36.4%)</td>
<td>1 (9.1%)</td>
<td>4 (36.4%)</td>
</tr>
<tr>
<td>VIII</td>
<td>35 (100%)</td>
<td>1 (2.9%)</td>
<td>9 (25.7%)</td>
<td>11 (31.4%)</td>
<td>3 (8.6%)</td>
<td>11 (31.4%)</td>
</tr>
<tr>
<td>IX</td>
<td>23 (100%)</td>
<td>9 (39.1%)</td>
<td>6 (26.1%)</td>
<td>3 (13.1%)</td>
<td>—</td>
<td>5 (21.7%)</td>
</tr>
<tr>
<td>X</td>
<td>44 (100%)</td>
<td>21 (47.7%)</td>
<td>14 (31.8%)</td>
<td>3 (6.8%)</td>
<td>6 (13.7%)</td>
<td>—</td>
</tr>
<tr>
<td>XI</td>
<td>14 (100%)</td>
<td>12 (85.8%)</td>
<td>1 (7.1%)</td>
<td>—</td>
<td>1 (7.1%)</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>130 (100%)</td>
<td>43 (30.1%)</td>
<td>32 (24.6%)</td>
<td>21 (16%)</td>
<td>11 (8.5%)</td>
<td>23 (17.8%)</td>
</tr>
</tbody>
</table>
Table 5. Statistics on damage to single-story plant buildings with mixed bent columns.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Number Investigated</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>4 (100%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4 (100%)</td>
</tr>
<tr>
<td>VII</td>
<td>1 (100%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1 (100%)</td>
<td>—</td>
</tr>
<tr>
<td>VIII</td>
<td>31 (100%)</td>
<td>10 (32.2%)</td>
<td>9 (29.0%)</td>
<td>6 (19.4%)</td>
<td>6 (19.4%)</td>
<td>—</td>
</tr>
<tr>
<td>IX</td>
<td>8 (100%)</td>
<td>6 (75.0%)</td>
<td>1 (12.5%)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>X</td>
<td>11 (100%)</td>
<td>5 (45.4%)</td>
<td>3 (27.3%)</td>
<td>—</td>
<td>1 (9.1%)</td>
<td>2 (18.2%)</td>
</tr>
<tr>
<td>XI</td>
<td>11 (100%)</td>
<td>9 (81.8%)</td>
<td>1 (9.1%)</td>
<td>1 (9.1%)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>66 (100%)</td>
<td>55 (22.7%)</td>
<td>20 (30.3%)</td>
<td>11 (16.7%)</td>
<td>8 (21.1%)</td>
<td>12 (18.2%)</td>
</tr>
</tbody>
</table>

Table 6. Comparison of damage to the Π-shaped skylight and the settled-type skylight at the Tianjin Large-Size Machinery Plant.

<table>
<thead>
<tr>
<th>Type of Skylight</th>
<th>No. of Plant Buildings</th>
<th>Description of Damage</th>
<th>Damage Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Π-shape R.C.</td>
<td>4</td>
<td>struts cracked; joints pulled apart; bracings buckled</td>
<td>100%</td>
</tr>
<tr>
<td>settled-type</td>
<td>6</td>
<td>intact</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7. Comparison of damage to plant buildings with light roof and brick columns at the Tangshan Metallurgical Circular Saw Plant and Tangshan Metallurgical and Mining Machinery Plant.

<table>
<thead>
<tr>
<th>Name of Plant</th>
<th>Total</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallurgical Circular Saw Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Buildings</td>
<td>5 (100%)</td>
<td>0</td>
<td>0</td>
<td>1 (20%)</td>
<td>3 (60%)</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>3,540 (100%)</td>
<td>0</td>
<td>0</td>
<td>460 (13%)</td>
<td>1,980 (56%)</td>
<td>1,100 (31%)</td>
</tr>
<tr>
<td>Metallurgical and Mining Machinery Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Buildings</td>
<td>19 (100%)</td>
<td>8 (42.1%)</td>
<td>8 (42.1%)</td>
<td>0</td>
<td>3 (15.8%)</td>
<td>0</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>15,002 (100%)</td>
<td>7,312 (48.7%)</td>
<td>5,680 (37.2%)</td>
<td>0</td>
<td>2,010 (14.1%)</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 8. Damage to plant buildings with R.C. columns and different profiles at the Tangshan Metallurgical and Mining Machinery Plant.

<table>
<thead>
<tr>
<th>Section of Plant Building</th>
<th>Total</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
</tr>
</thead>
<tbody>
<tr>
<td>single-span</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of buildings investigated</td>
<td>6 (100%)</td>
<td>0</td>
<td>1 (16.7%)</td>
<td>4 (66.6%)</td>
<td>1 (16.7%)</td>
<td>0</td>
</tr>
<tr>
<td>area (m²)</td>
<td>10,061 (100%)</td>
<td>0</td>
<td>2,160 (21.5%)</td>
<td>7,460 (74.1%)</td>
<td>441 (4.4%)</td>
<td>0</td>
</tr>
<tr>
<td>multi-span of equal height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of buildings investigated</td>
<td>4 (100%)</td>
<td>1 (25%)</td>
<td>1 (25%)</td>
<td>0</td>
<td>2 (50%)</td>
<td>0</td>
</tr>
<tr>
<td>area (m²)</td>
<td>18,816 (100%)</td>
<td>5,892 (31.3%)</td>
<td>6,912 (36.7%)</td>
<td>0</td>
<td>6,012 (32%)</td>
<td>0</td>
</tr>
<tr>
<td>multi-span of unequal height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Buildings investigated</td>
<td>4 (100%)</td>
<td>1 (25%)</td>
<td>3 (75%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>area (m²)</td>
<td>19,982 (100%)</td>
<td>4,032 (20.2%)</td>
<td>15,950 (79.8%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9. Statistics on damage to strengthened and non-strengthened plant buildings.

<table>
<thead>
<tr>
<th>Name of Plant</th>
<th>Total</th>
<th>Collapsed</th>
<th>Seriously Damaged</th>
<th>Moderately Damaged</th>
<th>Slightly Damaged</th>
<th>Basically Intact</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianjin Tractor Plant</td>
<td>21 (100%)</td>
<td>1 (4.8%)</td>
<td>16 (76.2%)</td>
<td>4 (19%)</td>
<td>0</td>
<td>0</td>
<td>not strengthened prior to the quake</td>
</tr>
<tr>
<td>area (m²)</td>
<td>111,136 (100%)</td>
<td>6,084 (5.5%)</td>
<td>83,740 (75.3%)</td>
<td>21,312 (19.2%)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tianjin Large-Size Machinery Plant</td>
<td>18 (100%)</td>
<td>0</td>
<td>11 (61%)</td>
<td>5 (27.8%)</td>
<td>2 (11.1%)</td>
<td>0</td>
<td>not strengthened prior to the quake</td>
</tr>
<tr>
<td>area (m²)</td>
<td>131,593 (100%)</td>
<td>0</td>
<td>71,509 (54.4%)</td>
<td>39,985 (30.4%)</td>
<td>20,099 (15.2%)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tianjin Power Generating Equipment Plant</td>
<td>14 (100%)</td>
<td>0</td>
<td>1 (7.1%)</td>
<td>2 (14.3%)</td>
<td>3 (21.4%)</td>
<td>8 (57.2%)</td>
<td>strengthened prior to the quake</td>
</tr>
<tr>
<td>area (m²)</td>
<td>46,313 (100%)</td>
<td>0</td>
<td>3,024 (6.5%)</td>
<td>15,770 (34.1%)</td>
<td>17,014 (36.7%)</td>
<td>10,505 (22.7%)</td>
<td></td>
</tr>
</tbody>
</table>
Photo 1. The middle strut (T-section) of the skylight frame in a workshop at the Tianjin Boiler plant fractured.

Photo 2. The M-shaped vertical bracing of the skylight buckled in the impact extrusion workshop of the Tianjin Tractor Plant.

Photo 3. The roof truss at the cast steel workshop of the Tangshan Metallurgical and Mining Machinery Plant inclined to the west.

Photo 4. The rib of the roof slab near the gable wall cracked at the model workshop of Tianjin Large-size Machinery Plant.

Photo 5. The collapse of the roof slab in the higher span induced the bending of the steel roof truss in the lower span (Tanggu Xinhe Shipbuilding Plant).

Photo 6. Sliding of the roof beam at the top of the column in the lower span (Tanggu Xinhe Shipbuilding Plant).
Photo 7. Collapse of the skylight frame led to the collapse of the roof beam (Tianjin Engineering Machinery Plant).

Photo 8. Cracking of the strut supporting the roof slab at the end of the arch truss (Tianjin No. 3 Casting Plant).

Photo 9. Damage to the end joint of the arch truss (Tianjin Tractor Plant).

Photo 10. The vertical member at the end of the trapezoidal roof truss ruptured near the spandrel beam (Tianjin Power Generating Equipment Plant).

Photo 11. The upper chord of the trapezoidal truss fractured (Tangshan Metallurgical and Mining Machinery Plant).

Photo 12. The continuous horizontal bracing and the vertical bracing at the end bent fell down (Tangshan Metallurgical and Mining Machinery Plant).
Photo 13. Damage to the old workshop with a light roof was slight and the adjacent new workshop with a heavy roof collapsed completely.

Photo 14. Damage to the rivet welding workshop of the Tangshan Cement Manufacturing Machine Plant.  
(a) The 24spm-span trapezoidal roof truss collapsed.  
(b) The 18spm-span arch trusses were intact.

Photo 15. Damage to the column top at the welding workshop (Tangshan Metallurgical and Mining Machinery Plant).

Photo 16. Damage to the top of the central column at the iron casting workshop (Tangshan Metallurgical and Mining Machinery Plant).

Photo 17. Pounding failure at the column top at the repair workshop (Tianjin Engineering Machinery Plant).

Photo 18. Cracking of the upper column on the top surface of the crane beam at the repair workshop (Tangshan Metallurgical and Mining Machinery Plant).
Photo 19. Crushing of concrete and bending of reinforcing bars of the upper column on top of the crane beam in the higher span of the tool workshop (Tianjin Tractor Plant)

Photo 20. Fracturing of the upper column at the processing workshop (Tangshan Cement Manufacturing Machine Plant).

Photo 21. The beam shoulder supporting the roof truss in the lower bent at the Tianjin Power Generating Equipment Plant cracked.

Photo 22. The lower column in the middle row was crushed and reinforcing bars were bent in a workshop at the New Harbour Shipbuilding Plant, Tanggu.

Photo 23. A vertical member of the double-column at the steel casting workshop was crushed (Tangshan Metallurgical and Mining Machinery Plant)

Photo 25. Column braces in the middle row were bent and vertical cracks occurred between openings of the web (New Harbour Ship-building Plant, Tanggu).

Photo 26. A horizontal web member of the double-column at the hydraulic workshop cracked (Tianjin Engineering Machinery Plant).

Photo 27. Bending of column bracing in the steel casting workshop (Tangshan Metallurgical and Mining Machinery Plant).

Photo 28. Fracturing of column bracing by tension in the extrusion workshop (Tianjin Tractor Plant).

Photo 29. Pulling off of the upper column bracing (Tangshan Metallurgical and Mining Machinery Plant).

Photo 30. Peeling of concrete at the lower column bracing in the middle row of the welding workshop (Tianjin Engineering Machinery Plant).
Photo 31. Outward inclination of the gable wall and fracturing of the wind resistant column (Tianjin Boiler Plant).

Photo 32. Damage to the column in the upper bent due to pounding of the roller support in the assembling workshop (Tianjin Tractor Plant).

Photo 33. Collapse of the load bearing gable wall caused the roof of the No. 2 workshop to collapse (Tangshan Metallurgical and Mining Machinery Plant).

Photo 34. The corner of a wall in the welding workshop collapsed (Tangshan Metallurgical and Mining Machinery Plant).

Photo 35. Collapse and bulging of the gable wall in the welding workshop (Tangshan Metallurgical and Mining Machinery Plant).

Photo 36. The roof of the lower bent collapsed caused by the falling of the filler wall of the higher bent (Tianjin Tractor plant).
Photo 37. Embedded walls were basically intact at the workshop (Tangshan Cement Manufacturing Machinery Plant).

Photo 38. The top of the column connected to the platform in the casting workshop was damaged in the quake and the roof truss fell down (Tianjin No. 1 Machine Tool Plant).

Photo 39. One end of the warehouse was exposed. The columns at the end fractured and the roof collapsed (Tangshan cement Manufacturing Machine Plant).

Photo 40. The strengthened gable walls of the assembling workshop of the Tianjin Power Generating Equipment Plant were basically intact after the quake.

Photo 43. The upper column fractured, the column top displaced inward, the lower chord of the steel truss buckled, and the anchorage parts at the top of the column were destroyed due to pounding of the corridor on the workshop (Tianjin Tractor Plant).
Photo 44. The bracket supporting the roof was damaged; the roof of both side spans collapsed completely (Tangshan Metallurgical and Mining Machinery Plant).

Photo 45. Damage to the reinforced brick column of the north exterior wall at the processing workshop (Gong-Nong Electric Machinery Plant).
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Figure 3. Maintenance garage at the Fengrun Railway Station.
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(a) Plan; (b) Profile
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Figure 7. Sketch showing the structure of the No. 2 metal processing workshop at the Tangshan Metallurgical and Mining Machinery Plant.
Figure 8. Sketch showing the structure of the processing workshop at the Tianjin Gong-Nong Electric Machinery Plant.
(a) Plan; (b) Profile
DAMAGE TO MULTI-STORY PLANT BUILDINGS
OF THE CHEMICAL INDUSTRY

Ni Jimiao

1. General Features

Multi-story frame R.C. structures were mostly used for plant buildings of the chemical industry in the Tangshan area and Tianjin City. After the quake 46 of these buildings had been surveyed mainly by the Damage Survey Group of the Ministry of the Chemical Industry (Table 1). These buildings can be divided into the following approximate categories: (1) framed buildings with filler walls; (2) framed buildings without exterior walls; (3) framed buildings without floor slabs; (4) framed buildings with a composite (brick-concrete) structure on the top story; (5) framed buildings with an abrupt vertical change in stiffness; and (6) framed buildings with a higher center of gravity.

In the Tangshan earthquake the multi-story plant buildings of the chemical industry mostly suffered different degrees of damage in the areas of intensity VII and above. The damage to plant buildings in areas of different intensities was as follows:

Area of intensity VII: Buildings were basically intact, only small cracks occurred on a few filler brick walls in the frame. The composite structure on the top story of the framed plant building suffered slight to moderate damage.

Area of intensity VIII: Most of the buildings were basically intact (Photo 1); part of the buildings were slightly to moderately damaged and some individual buildings collapsed (Photo 2). Most of the filler walls were slightly to moderately damaged; part of the building collapsed. The composite structure on the top story of the plant was moderately damaged or partly collapsed.

Area of intensity IX: A few buildings were slightly to moderately damaged; most buildings were seriously damaged (Photo 3) or even collapsed. Some seismically designed plant buildings remained intact. Filler walls were mostly damaged and some collapsed. Most of the composite structures on the top story of the buildings collapsed or partly collapsed.

Area of intensity X: The frame with filler walls and a composite structure on the top story generally suffered serious damage and a few collapsed (Photo 4).

The characteristics of damage to different types of plant building are as follows:

1 Most of the information in this paper was provided by the No. 6 Design Institute, Ministry of the Chemical Industry; related information about the Tianjin Alkali Plant and Tianjin Chemical Plant was provided by these plants.

2 Chemical Engineering Design Corporation, Ministry of the Chemical Industry
(1) **Framed buildings with filler walls**

In the area of intensity VII the frame remained intact, and only a few fissures occurred on the filler walls. In the area of intensity VIII the frame was basically intact also, but in some cases vertical cracks occurred at the beam-ends and horizontal or inclined cracks occurred at the column end while larger cracks were on the filler wall. An individual frame collapsed (Photo 2). In the areas of intensity IX and X buildings mostly suffered serious damage or collapse. The damage was mostly crushing of concrete at the end of a column or in the beam-column joint, bending of reinforcing bars, relatively large offset occurred at the column ends and in some stories fracturing of the column and collapse of the building (Photo 4). A few plant buildings only suffered slight damage in the area of intensity IX and individual frames designed for intensity VII survived the quake.

(2) **Framed buildings without exterior walls**

In the area of intensity IX the damage to all the buildings with cast-in-situ R.C. floor slabs was failure of the column top or the beam-column joint, but the beam itself was intact (Photos 5 and 6). There was only one exception where damage to the beam occurred induced by cracking at the connection of the floor slab and the beam. No such damage patterns were found in the areas of intensity VII and VIII.

(3) **Framed buildings without floor slabs**

In areas of intensity VIII and above the damage patterns of framed buildings without floor slabs included damage to the beam end and damage to the beam body when the beam had shoulders, however, the columns were basically intact (Photos 7 and 8). With the increase in intensity of shaking the number of cracks on the beam would increase and widen and concrete would peel off and reinforcement would be exposed.

(4) **Framed buildings with a composite structure (brick-R.C.) on the top story**

Figure 1 is a sketch of this type of plant building. In the area of intensity VII more serious damage to the composite structure on top had occurred e.g., cross-cracks or inclined cracks occurred on the wall between windows or on the corner wall next to the window. In the area of intensity VIII certain cases of collapse happened but the frame basically remained intact. In areas of higher intensities the composite structure generally collapsed or partly collapsed while most of the frames only suffered slight damage (Photos 9 and 10).

(5) **Framed buildings with an abruptly varied vertical stiffness**

These were two buildings at the Kaiping Synthesized Chemical Plant located in the area of intensity X. One was a 4-story frame building 22.11 m high. At elevation 11.00 m the frame hanged from 3 to 2 spans. The column of the 2-span section of the frame fractured at the bottom, leading this frame structure to fall on top of the 3-span section (Photo 4). The other building was the acid workshop, a 3-story frame building with a high central portion of 2 spans and lower side spans 7 m high. The elevation of the central part was 14 m higher than the side spans (Fig. 2). In the quake the portion of the structure that was higher than 7 m collapsed to the north completely.
The ACET station of the Tianjin Chemical Plant, located in the area of intensity IX, was a 3-story frame building 18 m high. The first story had exterior walls while the second story (elevation 5.0 m) and the third story (elevation 7.3 m) did not. In the quake the third story collapsed and the second story inclined (Photo 11).

(6) Frame buildings with a higher center of gravity

This type of building was heavy in the upper stories and light in the lower stories (Fig. 3) because the upper stories were usually loaded with heavy equipment or used for storing materials. After the quake the columns of the frame in the first story were fractured and the equipment and materials on the upper stories had fallen down and the frame was overturned.

The main building of the ACET workshop at the Tianjin Chemical Plant was a 4-story frame building (Fig. 3) with a grid foundation under which was a sand layer 2 m thick beneath which the foundation soil was soft clay. The cross-section of the middle columns was 500x700 mm and that of the exterior columns was 500x500 mm. Reinforcing bars in the longitudinal direction were in continuous beams. Seven silos, three 35-ton hoists and three groups of large electrodes were installed on the fourth story. In the quake the whole building collapsed to the south along the longitudinal axis (Photo 12).

In area of intensity VIII a coke silo at the Tianjin Alkali Plant collapsed due to shear failure of columns (Photo 13) while in the area of intensity IX a limestone silo at the Tianjin Chemical Plant overturned and the R.C. support of the silo fractured (Photo 14).

2. Damage Cases

(1) The new vapor absorption workshop at the Tianjin Alkali Plant

a. Arrangement of the structure

The Tianjin Alkali Plant was located in Tanggu District in Tianjin City in the area of intensity VIII. The new vapor absorption workshop was a 13-story R.C. frame building 52 m high rigidly connected in both directions. Along axis A a 2-story corridor for the pipeline was built and attached to the workshop. The workshop was completed in 1959 and was not seismically designed (Fig. 4).

The workshop was built on a natural foundation soil of soft clay. A raft foundation, 2 m in depth, was used. The profile of the foundation soil is shown in Fig. 5. The calculated total load on the foundation base, the area of which was 20x29 m, was 7,593 tons.

In the middle of the workshop four cast iron tanks 47 m high and each 327-435 tons in weight were installed from the ground through the openings in the floors. Around the tank on each story there were wood floor slabs, but in both side spans of the workshop there were R.C. floor slabs. On the 2nd story of the side span to the west there were two tanks each 85 tons in weight containing raw materials. The concrete used for the frame was 200 Kg./cm² in strength and the reinforcement was Grade I steel. The field wall was laid with hollow bricks 250 mm thick and cement mortar 50 Kg/cm² in strength.
Since the completion of the workshop the concrete of the building had bulged and reinforcement corroded due to the corrosive alkaline atmosphere suffered by the building for a long time. A relatively large differential settlement had occurred in the foundation before the quake and until 1965 the building had an inclination of 1.5% to the south; after that iron blocks, more than 1,000 tons in weight, were placed to the north of the building in order to compensate the settlement in the south. As a result, about 40% of the inclination was restored. After the Tangshan earthquake the survey found that the foundation settled again by 14 cm in average.

By measurements taken in 1966, the natural period of the workshop was 1.2 sec. and the predominant period of the foundation soil was 0.45 sec.

b. Damage

The stories above the 8th floor collapsed completely between axes (2)-(4) of the main part of the building; the upper two stories between axes (1)-(2) collapsed; the staircase shaft in the upper nine stories and the three stories of the workshop between axes (4)-(5) collapsed and most of the broken beams and columns fell to the ground scattered near the building (Photo 2) or piled up on the floor (Fig. 6). The exterior columns and beams that had not yet collapsed on the upper stories inclined inward. Columns in the upper stories were mostly fractured at the bottom while the members in the lower stories were damaged more seriously.

It was found in the post-quake investigation that the strength of the concrete used for the building was slightly lower than 200 Kg/cm² and that the spacing of stirrups in the column was relatively large, usually φ6-φ8 @ 200-350 mm. No stirrups were in the beam-column joint area.

(2) The chloral workshop at the Tianjin Chemical Plant

The Tianjin Chemical Plant was located in Hangu District in Tianjin in the area of intensity IX.

a. Arrangement of the structure

The chloral workshop was a 5-story frame cast-in-situ R.C. building that was completed in 1960 and not designed for earthquake resistance. The spacing of columns was 3.5x3.5 m, but in the side span (1)-(2) the spacing was 3 m. The cross-section of columns was 400x400 mm in the 1st to 4th stories, and 300x300 mm in the 5th and 6th stories. The cross-section of the longitudinal beams was 300x400 mm; the transversal beams were generally 300x500 mm and 200x400 mm in axis (5). A sketch showing the structure of the building is shown in Fig. 7.

The brick filler walls were laid with 1:2.5 lime mortar. The thickness of the walls was 240 mm in the 1st and 5th story and 300 mm in the 2nd to 4th stories.

An R.C. raft foundation was used. The buried depth of the foundation was 3.1 m, the area of the foundation bottom was 26.4x14.1 m with a 30 cm thick layer of rocks and mortar under the foundation. The foundation was laid on soft clay belonging to Type III soil. The profile of the foundation soil is shown in Fig. 8.
The main equipment was installed on the 2nd floor (8 distillation tanks and 2 chlorinator tanks about 50 tons each); on the third floor there were several coolers that were not so heavy; the loads on the 4th and 5th floors were small. Corrosion of the frame was relatively serious.

b. Damage

After the quake the ground deformation at the plant was large. Settlement of buildings at the plant was generally great; the workshop settled uniformly 30 cm. Soil in the vicinity of the plant heaved somewhat.

Filler walls in the frame were generally damaged in the 2nd story and 1st story (Photo 15), and damage to the walls in the 2nd story and on the staircase was most serious. A lot of cross-cracks occurred on these walls and part of them collapsed. Damage to walls on the 3rd story was slight and walls on the 4th and 5th stories were basically intact.

Damage to columns in the 2nd story was most serious. Both ends of a column were generally sheared and offset and reinforcement in the column was bent. When both ends of the corner column fractured the column axis dislocated up to 12-15 cm. Beams of the frame were basically intact.

(3) The fatty alcohol workshop at the Kaiping Synthesized Chemical Plant

The Kaiping Synthesized Chemical Plant was located in Kaiping, a small town in the suburb of Tangshan City in an area of intensity X. The fatty alcohol workshop was not designed for earthquake resistance. It was completed in 1976 with all equipment installed. At the time of the Tangshan earthquake it was not yet in operation.

a. Arrangement of the structure

The workshop was a multi-story framed cast-in-situ R.C. structure built on Type II foundation soil. The column array was 6x6 m. The east span was 4 stories and the other spans were 2 stories. Next to the east span there was a staircase, the plan area of which was 3.2x6 m (Fig. 9).

The cross-section of all columns was 400x400 mm; transverse beams in the frame were 300x600 mm; and longitudinal beams were 250x250 mm. The strength of the concrete used was 200 Kg/cm² for columns and 150 Kg/cm² for beams.

The 240 mm thick exterior walls were built into the frame. In the middle of the exterior wall on each story an enclosed spandrel beam 240x240 mm in cross-section was installed. A pre-cast beam was put in the foundation supporting the wall. Column footings were used. The elevation of the foundation base was -2.3 m.

b. Damage

The workshop was seriously damaged in the quake. The part of the building that was 4 stories collapsed completely with the staircase (5 stories), Photo 16. Damage to the beam-column joints and both ends of columns were relatively serious. On the west side two corner
columns suffered serious damage at the joint on the 2nd floor. A relatively large offset occurred between the upper and lower stories leading to obvious inclination of the 2nd story (Photo 17).

Filler walls were seriously damaged and some of them collapsed. On the east side the walls collapsed together with the frame; on the west side oblique or cross-cracks occurred at the window or door opening of most of the filler walls, especially for walls on the first story. On the south side most of the walls on the first story collapsed leaving some triangular remains next to the column; oblique or cross-cracks occurred on all walls between the windows on the second story. On the north side damage to the walls on the first story was more serious than to those on the 2nd story. The lower part of the walls between the windows on the first story were all thrown down, and the walls on the two sides of the door opening were seriously crushed and collapsed; in the upper part serious cross-cracks and cracks around the wall occurred. On the second story a portion of the walls had oblique cracks. Partition walls were generally damaged or collapsed.

A portion of the frame having four stories and the staircase (between axes (1/1) and (2)) collapsed completely to the east with the top story falling to the ground 14 m away from axis (2). The floor slabs on different stories fell in turn (Fig. 10) and both ends of the columns failed in shear, and concrete in the joint region was crushed as well. In the part having two stories (axes (2) to (5)) the exterior columns were still intact; concrete of the middle columns bulged at about 80 cm from the bottom and fell down; reinforcing bars buckled. Damage to the top of corner columns was most serious and two corner columns in axis (5) were fractured in shear at the end and shifted about 12 cm to the east. The damage to exterior columns in row A was more serious than to those in row C. Exterior columns generally fractured horizontally. Concrete of the column top in the middle row, except for those in axis (2), peeled off to different extents, reinforcement was exposed, and horizontal cracks also occurred on the columns. In the 2nd story the columns cracked around the top, concrete peeled off, and reinforcing was exposed. Damage to the columns in row C was more serious than to those in row A. Damage to the beam-column joints in the 2nd story was heavier; concrete in the joint region of two corner columns was crushed with bent reinforcement. For columns in the exterior row damage to the joint region in row A was heavier and concrete was generally broken and reinforcement was exposed. The columns in the middle row were better. No damage to the joint region was found in the top story.

(Translator: Lu Rongjian)
Table 1. Statistics on damage to multi-story plant buildings of the chemical industry.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Name of Plant</th>
<th>No. of Buildings</th>
<th>Damage Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basically Intact</td>
</tr>
<tr>
<td>VII</td>
<td>Qian'an Fertilizer Plant</td>
<td>4</td>
<td>4 (100%)</td>
</tr>
<tr>
<td></td>
<td>Dagu Chemical Plant</td>
<td>4</td>
<td>3 (75%)</td>
</tr>
<tr>
<td>VIII</td>
<td>Tianjin Alkali Plant</td>
<td>12</td>
<td>6 (50%)</td>
</tr>
<tr>
<td></td>
<td>Plants in Tianjin urban area</td>
<td>4</td>
<td>3 (75%)</td>
</tr>
<tr>
<td>IX</td>
<td>Guye Fertilizer Plant</td>
<td>7</td>
<td>2 (28%)</td>
</tr>
<tr>
<td></td>
<td>Tianjin Chemical Plant</td>
<td>8</td>
<td>1 (12%)¹</td>
</tr>
<tr>
<td>X</td>
<td>Kaiping Chemical Plant</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kaiping Synthesized Chemical Plant</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Remarks: 1) The newly built boiler house, 20 ton/hr capacity, at the Tianjin Chemical Plant was designed for intensity VII; pile foundation.

2) The 13-story framed building at the Tianjin Alkali Plant in the area of intensity VIII collapsed, an unexpected case.
Photo 1. The frame of the new south building was basically intact and filler walls cracked at the Tianjin Alkali Plant.

Photo 2. The 13-story frame of the new north building of the Tianjin Alkali Plant collapsed.

Photo 3. A beam-column joint of the frame was damaged and a filler wall cracked at the Gas workshop, (Guye Fertilizer plant).

Photo 4. The broken column in the 4th story of the mirabilite workshop fell on the 2nd floor (Kaiping Synthesized Chemical Plants).

Photo 5. Damage to the joint of the frame at the tar workshop (Guye Fertilizer Plant).

Photo 6. Shear failure at the column top of the frame at the methyl alcohol workshop (Guye Fertilizer Plant).
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Photo 7. Cracking of the frame beam with spalling of concrete at the synthesis workshop (Guye Fertilizer Plant).

Photo 8. Shear cracks on the frame beam at the synthesis workshop (Tianjin Alkali Plant).

Photo 9. Part of the composite structure of the top story of the repair workshop (Tianjin Chemicals Plant).

Photo 10. The R.C. composite structure on the frame of the chlorination workshop collapsed completely (Tianjin Chemicals Plant).

Photo 11. The top story of the ACET station collapsed; the second story inclined (Tianjin Chemicals Plant).

Photo 12. Collapse of the ACET workshop (Tianjin Chemicals Plant).
Photo 13. Columns supporting the coke silo fractured at the Tianjin Alkali Plant.

Photo 14. The support of the limestone silo fractured and the silo overturned (Tianjin Chemicals Plant).

Photo 15. The beam-column joint of the frame of the chloral workshop was damaged seriously; the filler wall bulged (Tianjin Chemicals Plant).

Photo 16. Serious damage to the fatty alcohol workshop and collapse of the staircase (Kaiping Synthesis Chemicals Plant).

Photo 17. A column at the northwest corner of the fatty alcohol workshop was damaged.
Figure 1. Sketch showing the frame building with a composite (brick R.C.) structure on the top story.

Figure 2. Sketch showing the frame structure of the acid workshop at the Kaiping Synthesized Chemical Plant. 
(a) Elevation; (b) Plan
Figure 3. Sketch showing the structure of the ACET workshop at the Tianjin Chemical Plant.  
(a) Elevation; (b) Plant
Figure 4. Sketch showing the structure of the new vapor absorption workshop at the Tianjin Alkali Plant. 
(a) Elevation; (b) Plan
Figure 5. Log diagram of the foundation soil.

Figure 6. Sketch showing collapse and pile-up of the damaged beams, columns, etc. (A axis).
Figure 7. Sketch showing the structure of the chloral workshop.
(a) Elevation; (b) Plan

Figure 8. Profile of the site soil at the Tianjin Chemical Plant (in the north-south direction).
Figure 9. Sketch showing the structure of the fatty alcohol workshop (Kaiping Synthesized Chemical Plant).
(a) Elevation; (b) Plan

Figure 10. Part of the frame between axis 1, 1-2 collapsed.
I. General Situation

All together there were thirteen mill buildings and fifteen workshops. The main bearing of this type of mill building were commonly assembled bents composed of bracket columns (T-shaped columns, L-shaped columns), double-beams (i.e. bracket beam and concurrently wind beam), triangular roof trusses in a saw tooth shape and prefabricated roofing. The gable walls were sometimes used as bearing walls and the adjacent frames were omitted; some were only used as exterior walls and the adjacent roof truss was still acting as a load bearing structure. There were also two types of eave walls in the front and at the back; one was used to support the roof trusses and the other was used only as the bearing wall of the neighboring auxiliary building. Besides, reinforced concrete columns were set up to support the superstructures, such as wind beams, roof trusses etc., and most columns were on reinforced concrete independent bases. Besides single-story mill buildings for textile work there were also rigid frames with roof trusses of two hinged arches. This paper emphasizes the earthquake damage to such mill buildings.

During the Tangshan earthquake this kind of mill building suffered different degrees of damage. According to the damage degree the features of earthquake damage can be illustrated as follows:

1. Seriously damaged mill building

The ground surface cracked, uplifted or subsided. Bracket columns settled unevenly and the column shaft tilted and broke. The gable wall on both sides cracked and tilted outwards, the top of the gable wall collapsed, and roofing of the side span dropped down. Wind beams broke and were pulled out at the support, dropped down, and caused part of the roofing to drop down. The internal walls of the neighboring auxiliary building were seriously cracked and partially collapsed. The workshop for picking wool and carbonization of the Tianjin Wool Strip Mill suffered this type of earthquake damage.

2. Moderately damaged mill building

This kind of mill building made up the major portion. The earthquake damage features of the mill structure were as follows:

(1) Bracket column

Usually horizontal cracks occurred at the base of the column roughly within 30 cm of the ground, some concrete at the four corners were broken and peeled off, reinforcing bars bulged
out and bending deformation of the main reinforcement occurred. The number of columns which suffered this kind of cracking was large. In some workshops it was more than 80%.

Horizontal cracks also occurred often in the column beneath the bracket; concrete at the top end of some brackets cracked or peeled off.

(2) **Double wind beams**

Earthquake damage mainly occurred at the support of the beam end. At the supports of double beams the majority had diagonal cracks.

(3) **Roof truss in a saw-toothed shape**

Damage was mainly found at the supports at the ends of the trusses; a few cracks occurred at the lower side of the top or ring cracks occurred at the elevation of the window ledge of the skylight.

(4) **Gable wall**

When the gable walls, in a saw-toothed shape, at both ends were not load bearing walls the majority tilted outward, cracked, and even the peak of the gable wall collapsed. While for bearing walls, the majority tilted outwards or collapsed resulting in roof slabs and wind beams pulling out and falling.

(5) **Front and back eave walls**

When the roof truss was supported on top of the front and back eave walls (not on a bond beam) earthquake damage was mainly eave walls tilted outwards or the truss was pulled off of the wall and dropped.

When a roof beam in a saw-tooth shape was supported on a column top, or on a simple beam linking the factory building with an auxiliary building the simple beam tilted outward, vertical cracks occurred at the column cap, concrete peeled off, reinforcing bars were exposed and horizontal cracks occurred at the joint with the eave wall.

When an inclined beam (saw-tooth shape) was supported on double beams which spanned from column to column they were moderately damaged but there were still horizontal cracks through the neighboring eave wall.

3. **Slightly damaged mill building**

No sandboils and waterspouts were found on the ground. The main bearing structure was intact. The peak section of the gable wall at both ends cracked and partially collapsed, for example at the Printing Workshop in Tianjin. The Second Printing and Dyeing Mill used a scheme of inclined beams; the inclined beams pulled out and the eave walls tilted outwards.
II. Examples of Damage

1. Tianjin Woolen Strip Mill

The Tianjin Woolen Strip Mill was located in Hedong District north of Jintang Highway on the east bank of the Yueya River and west of the old channel of the Haihe River. The general layout of the mill is shown in Fig. 1. The engineering geology of the mill region is listed in Table 1, according to the 1958 exploration report.

During the earthquake ground fissures occurred in the eastern part of the mill region and passed through in a north-south direction. The maximum width of each fissure reached up to 50 cm (Photo 1), the narrowest one was several centimeters. There were more than 1,000 sandboils and waterspouts in the entire mill region and at the Woolen Strip Workshop there were 92 (during the 1967 Hejian earthquake there were also sandboils and waterspouts in the northern part of the mill region).

The buildings that were located on the band of ground fissures from south to north were the Workers University (two-story brick structure), the workshop for picking wool and carbonization (single-story reinforced concrete mill building with a saw tooth roof), the newly built duster room (half underground foundation, slab of reinforced concrete with a bearing structure of brick walls), the storehouse for clean wool (single-story mill building jointly supported by reinforced concrete columns and brick walls), etc. and all were damaged. Among them the damage situation of the workshop for picking wool and carbonization was as follows:

The workshop for picking wool and carbonization consisted of reinforced concrete roof trusses in a saw-tooth shape, inverted T-shape roof slabs, double beams, bracket columns with independent footings. The size of the column array was 12x10.5 m and the column section was 0.8x0.8 m (the plan figure is shown in Fig. 2). The auxiliary building was wall bearing, the roof had small beams and small plates of an inverted T-shape. The roof had two layers of asphalt felt and three layers of asphalt on 100 mm of thick asphalt hull.

During the earthquake the ground fissures passed through the workshop from south to north. The width of the ground fissure outside the auxiliary building south of the workshop reached up to 50 cm (Photo 1). The concrete ground in the workshop cracked and the widest crack reached up to 30 cm (Photo 2). There were several hundred locations of sandboils and waterspouts on the workshop grounds; the diameters of the sandboils were 1-6 m (Photo 3). The ground uplifted, columns mostly subsided and tilted, in some cases torsion occurred, the east gable wall tilted outwards up to 300 mm, a row of columns on the eastern side tilted outwards and seriously subsided, and at the level of the inner ground the column footings cracked. The original level ground of the whole workshop was like a wave after the shock.

Vertical cracking and concrete crushing occurred at the (inclined) edge of the main beam support. A pair of double beams was destroyed due to concrete crushing at the (inclined) edge and the roof cover of two column arrays fell. But the steel plate of the main beam support was still on the column bracket; the anchor bars of the steel plates were pulled out from the main beam concrete (Photos 4 and 5).
Ground fissures passed through the southern auxiliary building. The width of the cracks on the wall reached up to 50 cm, the maximum subsidence of the wall was 30 cm, and the external wall tilted outwards and partially collapsed (Photo 6). The roof of the auxiliary building at that location (reinforced concrete small beams, inverted T-plates) dropped down. The partition wall between the southern auxiliary building and the workshop was also seriously cracked and was on the verge of collapsing (Photo 7). The eastern and western gable walls were all cracked and the majority of the tops of the gable walls collapsed; the portion that most frequently collapsed was the top triangular portion (see Photo 8).

2. Tianjin No. 4 Cotton Textile Mill

The mill was located on the south-west bank of the Haihe River in Hexi District, the general layout of the mill is shown in Fig. 3. The geological situation of the soil layers in the mill region is shown in Table 2, according to the soil penetration report in 1978.

During the earthquake ground fissures, sandboils and waterspouts occurred in the mill region.

The Second Spinning Workshop had timber trusses in a saw-tooth shape. The elevation of the lower chord of the roof truss was 4.0 m, and the roof system consisted of wood boarding, thermal insulating layer and asbestos tiles. The upper portion of the gable wall was not saw-toothed but was flat topped. The size of the column array was 5.4 m (NS)x4.3 m (EW) and the area of the workshop was 102.6x68.8 m. It was built in the 1940’s.

After the earthquake eight lines of ground fissures from east to west passed through the workshop; and the eastern and western gable walls, the middle bearing gable wall, and the floor slab cracked. The widths of the gable wall fissures resulting from ground fissures had a maximum of 20-30 mm. At the joint of the western gable wall and roof of the western auxiliary building there were horizontal fissures; the upper portion of the gable wall tilted outwards roughly 10 mm but did not drop down. There were sandboils and waterspouts under a column slightly subsided.

The Second Cloth Workshop consisted of reinforced concrete bents in a saw-tooth shape with double lines of wind beams and a 370 mm thick exterior bearing brick wall. The roof cover consisted of a thin slab, a foam concrete thermal insulating layer and an asphalt felt layer. The western end was a bearing gable wall. The size of the column array was 7.5x8.6 m, the section of column was 400x300 mm, and the area of the workshop was 120x60 m, built in 1964.

During the earthquake sandboils and waterspouts occurred at the workshop. Different degrees of horizontal cracking occurred on 80% of the middle column footings at the workshop and among them the concrete at four corners peeled off on a few column footings; on many of the column footings the concrete peeled off at corners and the reinforcement bars were exposed. The western gable wall tilted outwards and collapsed, and at seven locations double beams dropped down and the roof cover was destroyed (Photo 9).

Simple beams had been put on a row of columns on the southern side, the simple beams inclined, column caps inclined and cracked, the concrete of individual column caps cracked and peeled off and reinforcing bars were exposed. The southern wall tilted outwards. There were
horizontal cracks that passed through the southern wall at the roof of the auxiliary building (before the earthquake it was found that the simple beam inclined due to the thrust of the tripod so horizontal tension bars were added, see Photo 10). Simple beams on the top of a row of columns on the northern side tilted northwards and the northern wall tilted outwards. There were vertical fissures at the joints of oblique beams and pillars on the top of a few tripods. The tripod displaced in a longitudinal direction up to a maximum of 80 mm; the tail portion was pulled out from the beam surface. There were many oblique fissures that passed through the surface of the oblique beam at the tripod of the western gable wall.

(Translators: Zhong Nanping and Chen Dasheng)
Table 1. Exploration data of engineering geology at the Tianjin Woolen Strip Mill. Underground (static) water table: 1.10-2.15 m.

<table>
<thead>
<tr>
<th>No. of Layer</th>
<th>Type of Soil</th>
<th>Thickness of Layer (m)</th>
<th>Depth of Bottom Layer (m)</th>
<th>Soil Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water Content (%)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit Weight (g/cm³)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Specific Gravity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Porosity Ratio</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Plasticity Limit (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Plasticity Index (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Liquidity Index (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compressibility Factor (cm²/kg.f)</td>
</tr>
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<td>1</td>
<td>sandy silt</td>
<td>0.9-1.8</td>
<td>2.51-3.27</td>
<td>25-33.9</td>
</tr>
<tr>
<td></td>
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<td>2.68-2.75</td>
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<td>.771-1.038</td>
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<td>14.7-20.9</td>
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<td>9.6-16.3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>.006-.048</td>
</tr>
<tr>
<td>2</td>
<td>clay</td>
<td>.15-1.5</td>
<td>1.51 to -2.70</td>
<td>41.8-42.2</td>
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<td>1.742-1.772</td>
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<td>2.74-2.77</td>
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<td></td>
<td>1.2-1.255</td>
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<td></td>
<td>20.8-26.6</td>
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<td>18.3-22.1</td>
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<td>0.69-1.17</td>
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<td></td>
<td></td>
<td>0.055-0.076</td>
</tr>
<tr>
<td>3</td>
<td>sandy silt</td>
<td>0.26-2.56</td>
<td>-2.17 to -3.49*</td>
<td>24.8-27.9</td>
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<td>17.0-20.7</td>
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<td>9.42-13.5</td>
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<td>0.5-0.71</td>
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<td></td>
<td></td>
<td>0.072-0.018</td>
</tr>
<tr>
<td>4</td>
<td>sandy silt</td>
<td>0.5-4.50</td>
<td>-11.23*</td>
<td>23.4-33.8</td>
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<td>1.856-2.03</td>
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<td>15.4-22.8</td>
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<td>0.56-1.17</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>0.026-0.044</td>
</tr>
</tbody>
</table>

* Not passed through
### Table 2. Geological situation of soil layers at the Tianjin No. 4 Cotton Textile Mill.

<table>
<thead>
<tr>
<th>Thickness of Layer (m)</th>
<th>Depth of Bottom Layer (m)</th>
<th>Type of Soil</th>
<th>Description of Soil</th>
<th>Water Content (%)</th>
<th>Unit Weight (g/cm³)</th>
<th>Porosity Ratio</th>
<th>Plasticity Index (%)</th>
<th>Inner Friction Angle (degree)</th>
<th>Cohesion (kg force/cm²)</th>
<th>Compressibility Factor (cm³/kg force)</th>
<th>Compressibility Modulus (kg force/cm²)</th>
<th>Sampling Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>misc. fill</td>
<td>yellowish-brown, wet, soft, mainly clayey soil, a lot of brick slag</td>
<td>1.0</td>
<td>yellowish-brown, wet, soft, mainly clayey soil, a lot of brick slag</td>
<td>34.9</td>
<td>1.82</td>
<td>1.02</td>
<td>15.5</td>
<td>19</td>
<td>0.17</td>
<td>.053</td>
</tr>
<tr>
<td>0.3</td>
<td>1.3</td>
<td>clayey soil</td>
<td>yellowish-brown, saturated, no stratification, contained ferric oxide</td>
<td>1.4</td>
<td>yellowish-brown, saturated, no stratification, contained ferric oxide</td>
<td>29.5</td>
<td>1.79</td>
<td>0.98</td>
<td>25.8</td>
<td>15</td>
<td>0.31</td>
<td>.049</td>
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<tr>
<td>1.8</td>
<td>4.5</td>
<td>clayey soil</td>
<td>yellow, saturated soft plastic, no stratification, contained mica, ferric oxide, partially sandy, easy to liquify</td>
<td>1.8</td>
<td>yellow, saturated soft plastic, no stratification, contained mica, ferric oxide, partially sandy, easy to liquify</td>
<td>29.5</td>
<td>31.2</td>
<td>1.89</td>
<td>0.86</td>
<td>13.5</td>
<td>22</td>
<td>0.18</td>
</tr>
<tr>
<td>0.5</td>
<td>5.0</td>
<td>clayey soil</td>
<td>brownish-gray, saturated, soft plasticity, contained many silts, highly sandy</td>
<td>0.5</td>
<td>brownish-gray, saturated, soft plasticity, contained many silts, highly sandy</td>
<td>29.5</td>
<td>31.2</td>
<td>1.89</td>
<td>0.86</td>
<td>13.5</td>
<td>22</td>
<td>0.18</td>
</tr>
<tr>
<td>Thickness of Layer (m)</td>
<td>Depth of Bottom Layer (m)</td>
<td>Type of Soil</td>
<td>Description of Soil</td>
<td>Water Content (%)</td>
<td>Unit Weight (g/cm³)</td>
<td>Porosity Ratio</td>
<td>Plasticity Index (%)</td>
<td>Inner Friction Angle (degree)</td>
<td>Cohesion (kg force/cm²)</td>
<td>Compressibility Factor (cm³/kg force)</td>
<td>Compressibility Modulus (kg force/cm²)</td>
<td>Sampling Depth (m)</td>
</tr>
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</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>sandy loam</td>
<td>brownish-gray, saturated, plastic, contained many silts, no stratification, liquefiable</td>
<td>29.8</td>
<td>1.91</td>
<td>0.83</td>
<td>8.0</td>
<td>24</td>
<td>0.12</td>
<td>0.023</td>
<td>77</td>
<td>5.0-5.4</td>
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<tr>
<td>3.0</td>
<td>9.0</td>
<td>clayey soil</td>
<td>brownish-gray, saturated, bad plasticity, no stratification, contained mica, a few organic matter, highly sandy</td>
<td>32.7</td>
<td>3.14</td>
<td>0.93</td>
<td>13.7</td>
<td>29</td>
<td>0.07</td>
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</tr>
<tr>
<td>0.5</td>
<td>9.5</td>
<td>sandy loam</td>
<td>brownish-gray, saturated, bad plasticity, contained mica, a few rotten plants</td>
<td>36.5</td>
<td>1.79</td>
<td>1.08</td>
<td>16.8</td>
<td>17</td>
<td>0.18</td>
<td>.102</td>
<td>21</td>
<td>9.5-9.8</td>
</tr>
<tr>
<td>1.5</td>
<td>11.0</td>
<td>silty loam</td>
<td>brownish-gray to gray, saturated, flow plasticity, slight stratification, contained mica, a few organic matter</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of Layer (m)</td>
<td>Depth of Bottom Layer (m)</td>
<td>Type of Soil</td>
<td>Description of Soil</td>
<td>Water Content (%)</td>
<td>Unit Weight (g/cm³)</td>
<td>Porosity Ratio</td>
<td>Plasticity Index (%)</td>
<td>Inner Friction Angle (degree)</td>
<td>Cohesion (kg force/cm²)</td>
<td>Compressibility Factor (cm²/kg force)</td>
<td>Compressibility Modulus (kg force/cm²)</td>
<td>Sampling Depth (m)</td>
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</tr>
<tr>
<td>2.2</td>
<td>13.2</td>
<td>clayey soil</td>
<td>brownish-gray to gray, saturated, soft plasticity, slight stratification, part sandy loam intercalation, contained mica, a few shells</td>
<td>32.7</td>
<td>1.89</td>
<td>0.91</td>
<td>12.6</td>
<td>23</td>
<td>0.13</td>
<td>.055</td>
<td>0.025</td>
<td>11.0-11.3</td>
</tr>
<tr>
<td>0.3</td>
<td>13.5</td>
<td>silty sand</td>
<td>gray, saturated, relative dense, no stratification, contained a few shells</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>34</td>
</tr>
<tr>
<td>0.25</td>
<td>13.75</td>
<td>clayey soil</td>
<td>gray, saturated and plasticity, clear stratification, clay intercalation, a few organic matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.0-13.3</td>
</tr>
</tbody>
</table>
Photo 1. Ground fissures were near the workshop for picking wool and carbonization at the Wool Strip Mill.

Photo 2. Level ground cracked and dislocated at the workshop for picking wool and carbonization at the Wool Strip Mill.

Photo 3. Sandboils and waterspouts at the workshop for picking wool and carbonization at the Wool Strip Mill.

Photo 4. Double beams dropped in the workshop for picking wool and carbonization at the Wool Strip Mill.

Photo 5. Similar to Photo 4 (near sight of the bracket).

Photo 6. An external wall tilted outwards, cracked, and partially collapsed at the southern auxiliary building of the workshop for picking wool and carbonization at the Woolen Strip Mill.
Photo 7. The southern wall of the workshop for picking wool and carbonization at the Wool Strip Mill was seriously damaged.

Photo 8. The gable wall of the workshop for picking wool and carbonization at the Woolen Strip Mill was damaged.

Photo 9. Double beams on the western gable wall dropped down the Second Cloth Workshop of the No. 4 Cotton Textile Mill.

Photo 10. On the southern side of the Second Cloth Workshop a row of column caps and a simple beam were damaged.
Figure 1. Layout of the Tianjin Woolen Strip Mill.

Figure 2. Plan of the workshop for picking wool and carbonization.
Figure 3. Layout of the Tianjin No. 4 Cotton Textile Mill.
A. Introduction

Before the Tangshan earthquake there were 6 buildings with flat slab floors; one was built in 1935 and the others were built after 1949 (listed in Table 1). Three of these buildings were 2 stories high, two were 4 stories high and the other one was to have 7 stories but only 5 stories had been built. They were used mainly as warehouses but some were used as offices or workshops. The plans were rectangular. There were two structural types, one was a composite structure with two rows of interior columns and exterior load bearing walls, and the others were structures with multiple rows of columns, interior and exterior, and self-supporting exterior curtain walls. In some buildings a flat slab was used for the second floor and an ordinary frame structure with same column layout as in the bottom story were used in the upper stories. In a great majority of these structures the rooms were spacious and only in a few were there small amounts of masonry inner partition walls or large areas of window openings on exterior walls. Reinforced concrete bond beams were generally used on curtain walls and sometimes reinforced concrete columns were used. The site conditions of these buildings ranged from a soft foundation to bedrock. Masonry strip foundations were used for exterior walls and inner partition walls while masonry or reinforced concrete independent footings were used for reinforced concrete columns. The embedded depth of a footing was generally 1.15 m under natural ground level. Reinforced raft foundations were used in some cases.

Three flat slab floor buildings collapsed during the earthquake while the other three buildings were moderately damaged. The damage conditions of 4 buildings are listed in Table 1 and the other two buildings are described in the damage examples in this paper and in the paper “Damage of cold storage warehouses in Tangshan and Tianjin” of this chapter.

From Table 1 it can be seen that there were the following characteristics of damage to flat slab floor structures in Tangshan City.

1. Brick walls

Buildings with a large ratio of length to width had diagonal cracks in the transverse walls. Transverse end walls had the main damage. Horizontal cracks appeared often on interior transverse. On longitudinal walls the horizontal cracks at the upper and lower edges of window openings were the main damage. In flat slab floor structures with a small ratio of length to width (nearly square) the horizontal and diagonal cracks on longitudinal and transverse walls were essentially the same. In addition, horizontal cracks often appeared along the lower edge of reinforced concrete bond beams. Attached self-supporting exterior walls were easily overturned.

* Urban Construction Bureau of Tangshan
2. Reinforced concrete columns

On damaged columns horizontal cracks appeared below the column caps or above the column footings, or concrete broke away and reinforcement was exposed. Some columns were intact or nearly intact.

3. Flat slab floors

There was only minor damage to the flat slabs except that some floors broke or collapsed due to the collapse of the supporting columns. The lesser damaged sections of floor were mainly located between the supports and cracks developed along the longitudinal direction of a slab. In addition, the collapse of the upper structure often damaged the lower flat slab floors.

4. Gird and constructional columns

Reinforcing bond beams and columns in brick walls as well as horizontal and vertical cracks often existed and adjacent brick walls also often cracked diagonally and partially collapsed.

5. Foundations

The foundations suffered little damage but when there was unequal settlement or when ground fissures occurred the masonry strip foundations often settled and cracked and vertical cracks appeared on the walls.

B. Damage Example: Library at the Tangshan Mining and Metallurgy Technical College

The library consisted of reading rooms and book storage. It was situated at the east end of the college and on the south side of the east gate. During the Tangshan earthquake the causative fault passed through the campus and the college was situated in an area of intensity XI and most buildings at this college collapsed. The west and middle parts of the reading rooms collapsed overall while at the east end the pre-cast frame structure was seriously damaged and was on the verge of collapsing (Photo 12).

All site soils above the bedrock in the Tangshan urban district consisted of quaternary deposit or diluvium layers 0-300 m thick. There was a sharp change of thickness near the fault, which was obviously controlled by fossil landform. The college was situated near the sudden change in thickness of layers (Fig. 5) where interfaces of bedrock were higher in the east and lower in the west and in the eastern part of the campus escarpment formed.

1. Layout of structures

The library was built in October 1975. It was a 1,146 m² cast-in-situ flat slab floor structure with columns arranged in two rows with load bearing exterior walls in which the dimensions of the column layout was 4x3.75 m and the height of the story was 2.25 m (Fig. 6). The designed live load of the floor was 400 kg/m² with a load factor of 1.3. The areas of the window openings on the east, west and north sides were rather large (dimensions of openings were 1,400x750 mm). The width of the settlement joint between the reading room and the book storage was 30 mm.
The steel bars of the reinforced concrete columns are shown in Fig. 6. Slabs 120 mm thick and rectangular column caps were poured as a whole with grade 150 concrete. At the exterior walls on every floor 370x350 mm bond beams were poured with the slabs. The exterior walls were built with #75 bricks and #25 mortar, vertical and horizontal beams, 250x250 mm cross-section were poured bond beams and extended into the parapet walls.

The building was situated on an area of Class II site soil with permissible bearing capacity of 18t f/m². The foundations of the columns were independent footings poured with #100 crushed stone concrete and that of the walls were strip footings of rubble stone built with #50 mortar 1,730 mm wide at the bottom. Reinforced concrete independent footings were also used for the vertical beams in the walls (Fig. 7). At the time of the earthquake there were no live loads on various floors.

Before construction of the library steel samples had been tested and the strength was somewhat low. Also, the quality of construction of the brick walls and bond beams was very bad.

2. Damage

The bottom story collapsed; all the columns were broken by shear force; exterior walls were also broken by shear force. The 2nd floor fell onto the first floor (Photo 13, dotted lines in Fig. 6). The upper structure that fell displaced and twisted as a whole.

There were severe horizontal cracks at the levels of the upper and lower edges of window openings on the 2nd story exterior walls. Diagonal cracks were on walls between windows. Horizontal cracks appeared along the lower edge of the bond beams on the south eave wall and some diagonal cracks also appeared. The damage to the 3rd and 4th stories was similar to that of the 2nd story but lighter (Photos 16 and 17). Many cracks with a maximum width of 10 mm could be found at joints between column caps and floors. Besides horizontal cracks on the south eave wall of the 4th story many serious diagonal cracks were also found but they were controlled by the R.C. beams in the walls (Photo 18).

There was no obvious damage to footings and the central heating ducts were smooth and intact.

(Translator: Jin Guoliang)
Table 1. Damage to flat slab floor structures in Tanghan.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Name of Engineering</th>
<th>Year Built</th>
<th>Building Area (m²)</th>
<th>Class of Site Soil</th>
<th>Type of Foundation and Depth (m)</th>
<th>Condition of Structures</th>
<th>Condition of Damage</th>
<th>Classification of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>XI</td>
<td>Tool Workshop at the Locomotive and Vehicle Factory (2 stories high)</td>
<td>1935</td>
<td>1,432</td>
<td>II</td>
<td>Stone strip foundation and independent footings. Level of bottom of footings was -2.08 m entirely.</td>
<td>East part was a grinding machine workshop with tall cast-in-site R.C. beam and slab roof (540×400 mm haunched girders) and load bearing brick walls. West part was two row columns and load bearing exterior walls, reinforced concrete flat slab floor structure, 2 stories high. Bottom story was a machine repair workshop and the 2nd story was an office and fitter's workshop (Fig. 1). Exterior walls, 482 mm thick were built with #50 bricks and #50 cement-lime mortar, and there were 127×600 mm brick buttress piers between windows and at corners of the building. At axis 2 the inner partition wall was 508 mm thick. Two row circular columns 356 mm in diameter in the 1st and 2nd stories with main reinforcements 8 Φ30+4Φ16, and 4Φ17 with stirrups Φ12@75, Φ12@304 mm. Longitudinal reinforcements in the columns were entirely discontinued at 1 m above the floor with a lap length of 600 mm. The roof was covered with a slag insulating layer 90 mm thick.</td>
<td>At the grinding machine workshop load bearing exterior walls collapsed and the roof fell down (Photo 1). In part of the flat slab floor structure exterior walls cracked and collapsed along the level of sills, floors and roof slabs broke off along a longitudinal direction (at these sections in slabs reinforcements, part of which reached the plastic limit remain to connect). Slabs were supported on the ground and column just like an umbrella and they circled the column on the bottom story from east, south, and north directions (Photos 2 and 3). Columns on the bottom story entirely inclined toward the inside of the building but column caps inclined entirely toward the outside of the building. At the roots the columns broke off so that concrete seriously broke apart and reinforcements were exposed and yield. On footings of columns the concrete also broke off and reinforcements were exposed (Photo 4). The columns on the 2nd story broke off 1 m above the floor and fell over toward the north with roof slabs entirely. At broken joints of columns ends vertical reinforcements in the lower part spread all around while vertical reinforcements in the upper part were in a tensile plastic stage (Photos 5 and 6).</td>
<td>collapsed</td>
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Table 1. Continued.

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<th>Intensity</th>
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<th>Building Area (m²)</th>
<th>Class of Site Soil</th>
<th>Type of Foundation and Depth (m)</th>
<th>Condition of Structures</th>
<th>Condition of Damage</th>
<th>Classification of Damage</th>
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<tr>
<td>X</td>
<td>End Product Warehouse of the Northwest Well Grain Depot (2 stories)</td>
<td>1965</td>
<td>1,167</td>
<td>I</td>
<td>Strip footings were used under exterior walls while R.C. independent foundations, the level of which was -1.15 m, were used for inner columns. In cast-in-situ R.C. a 2 story flat slab floor warehouse with two rows of columns and load bearing exterior walls was used on the bottom story and an inner frame structure was used on the upper story (Fig. 2). Door and window openings on exterior walls (with 2 reinforced concrete girds) were rather much, cantilever staircases were set up on gable walls. The better part of the building was situated on bedrock of Dacheng Hill but the part at the northwest corner was situated on the edge of ditch (filled with deep waste rock and soil), at which the foundation was R.C. footing with a &quot;L&quot; form connecting ground beam, 8-16 m deep. During the earthquake 210t and 200t grain were stored and the building was fully loaded on the 1st and 2nd stories respectively.</td>
<td>Diagonal cracks appeared on gable walls while cracks stretching upward to the corner of the building and connecting to the diagonal cracks on gable walls along the upper and lower edges of window openings also appeared. At corners the walls inclined or fell off; large diagonal cracks were found. R.C. structures were intact except that concrete broke down, reinforcements were exposed or vertical hair cracks appeared (Photo 7). At the northwest corner the ground outside the building settled about 50 cm while inside the building the ground settled in varying degrees, and at the settlement position on part of the exterior walls vertical cracks appeared. Damage to the whole warehouse was obvious i.e., upper was light damage and lower was serious.</td>
<td>moderately damaged</td>
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Table 1. Continued.

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<th>Intensity</th>
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<th>Condition of Damage</th>
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<tr>
<td>X</td>
<td>Main building of the office of the Cement Design Institute (7 stories high)</td>
<td>1976</td>
<td>840</td>
<td>II</td>
<td>R.C. floating foundation poured with cross-beams. The level of footing was -2.00 m.</td>
<td>The bottom story of this building had a reinforced concrete flat slab floor and the other stories had an inner frame structure with cross beams floors; 7 stories high. 370 mm thick load bearing walls (built with #75 bricks and #50 mortar) with 16 R.C. constructional columns, in which there were 2 φ6 steels extending into the walls up to 500 mm along the height of the column average 480 mm were used. On every floor there was grid poured with the floor and contraction joints were arranged between the main building and west and north halls (Fig. 3). Cross-sections of parts of the columns on the 1st story of the entrance hall were octagon while on other stories they were rectangular. Marks of concrete in all elements were #200. Above the 2nd story at axis E a 240 mm thick inner partition wall was set up. Before the earthquake construction was carrying on, the walls on the 6th story were built to 1 m high (dotted line in the cut away view of Fig. 3) and the reinforcements in the constructional columns were binded.</td>
<td>The main building as a whole was complete, i.e. entrance hall columns, column saps and slabs were fundamentally intact (Photos 8 and 9). The 2nd story columns and slabs were also fundamentally intact but the 1st and 2nd story walls were seriously damaged and on other stories the damage was light. On the 6th story east and west cave walls, 1 m high, breaking and overturning of the canopy at the northwest corner of the 1st story, break down at roots and inclined towards west. On the 1st story exterior walls were seriously damaged, i.e. a large part of the north wall and part of the east wall collapsed, many diagonal cracks appeared on south and west walls, in the former bricks broke into pieces and fell off and walls and constructional columns cracked or cracked circularly along bottoms of girds. The constructional columns at the northeast corner broke down and a column 1 m away from the top protruded 6 cm toward the east and a horizontal crack was 1 cm wide. At joints between other corner columns and girds concrete fell off, reinforcements were exposed, or seams between the columns and post built brick walls appeared, etc. On the 2nd story parts of the east spandrel walls collapsed and part of the west walls that collided with the bulging buttress of the west side hall sank and partially cracked. Many horizontal and diagonal cracks appeared on inner partition walls.</td>
<td>moderately damaged</td>
</tr>
<tr>
<td>Intensity</td>
<td>Name of Engineering</td>
<td>Year Built</td>
<td>Area (m²)</td>
<td>Class of Site Soil</td>
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<td>XI</td>
<td>Old warehouse at the Huaxin Textile Mill (2 stories high)</td>
<td>1950</td>
<td>1,630</td>
<td>III</td>
<td>The wall foundation was strip, but R.C. independent footings were used under the columns. The level of the bottom of the foundation was -2.98 m.</td>
<td>This building was a flat slab floor 2-story structure with columns arranged in two rows with load bearing exterior walls situated on the east coast of the Douhe River. Load bearing exterior walls (built with #50 bricks and #25 lime-cement mortar) in which reinforced concrete constructed columns (1st story 559×508, 2nd story 559×457 and corner column 559×559 mm) were set up along axes of columns, were poured with girds in 2 stories as a whole. At axes 4 and 7 254 mm thick inner partition walls were built (Fig. 4). R.C. circular columns, the diameter of which were 559 and 457 mm respectively on the 1st and 2nd stories, were poured with column caps and floors as a whole. There were R.C. exterior staircases at the southwest corner and R.C. corridors and canopies at the west side. All concrete elements in the warehouse were poured with #150 concrete.</td>
<td>All columns, flat slab floors and girds, etc. were intact (Photo 10). Exterior corridors and canopies were intact except for parts of concrete that broke away at corners. Damage to walls were obviously serious at the bottom and light at the top and serious in the south and light in the north. On the bottom story exterior walls generally cracked vertically from the ground to windowsills 10 cm from the constructional column sides. The average width of seams reached 1 cm. A few diagonal cracks were found on walls between two windows. The exterior walls on the 2nd story were fundamentally intact but on constructional columns of exterior walls X-cracks appeared in the range of window openings especially on the column of the south end gable wall and corner column (Photo 11). The north gable wall and constructional columns cracked horizontally along upper and lower levels of window openings on the 2nd story and part of the concrete broke away. Many horizontal and diagonal cracks appeared on inner partition walls, which separated from columns an average of 10 cm, and part of bricks fell away. The foundation at axis D in the east part produced unequal settlement, i.e. the settlement at the southeast corner reached 10 cm and a 2 cm wide penetrating crack on the inner ground along axis C appeared.</td>
<td>moderately damaged</td>
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Photo 1. The roof of the grinding machine room at the tools workshop of the locomotives and vehicles factory collapsed.

Photo 2. Slabs broke in the east and north side buildings of the machine repair room at the tools workshop of the locomotives and vehicles factory.
Photo 3. Damage to south of the tools workshop of the locomotives and vehicles factory.

Photo 4. Concrete broke on a column footing on the 1st story of the machine repair room at the tools workshop of the locomotives and vehicles factory.
Photo 5. In machine repair room of the tools workshop of locomotives and vehicles factory the columns in the 2nd story broke off and roof slabs fell and piled up on each other.

Photo 6. Columns in the 1st and 2nd stories of the machine repair room at the tools workshop of locomotives and vehicles factory broke off.
Photo 7. A side view of the west end of the product warehouse of the Northwest grain depot after the earthquake.

Photo 8. The Southern portion of the main building and the west side hall of the Cement Design Institute are intact after the earthquake.

Photo 9. Columns in the entrance hall, column caps and floors on the 1st story of the main building of the Cement Design Institute are fundamentally intact.
Photo 10. Columns, column caps and floors on the 1st story of the old warehouse of Huaxin Textile Mill are intact after the earthquake.

Photo 11. The south gable wall of the old warehouse of the Huaxin Textile Mill partially broke.

Photo 12. A west side view of the reading rooms at the Tangshan Mining and Metallurgy Technical College after the earthquake.
Photo 13. The library building above the 2nd story at the Mining and Metallurgy Technical College entirely fell off on the ground.

Photo 14. The northwest wall of the library at the Mining and Metallurgy Technical College displaced northward.
Photo 15. The 1st story column of the library of the Mining and Metallurgy Technical College displaced toward the northeast.

Photo 16. A column base on the floor of the library at the Mining and Metallurgy Technical College cracked.
Photo 17. The column caps in the 4th story of the library at the Mining and Metallurgy Technical College cracked.

Photo 18. Diagonal cracks on the south eave wall in the 4th story of the library at the Mining and Metallurgy Technical College.
Figure 1. Plan of the 1st story and structural sketch of the tools workshop of the Locomotive and Vehicle Factory.

Figure 2. Plan of the bottom story of the end product warehouse of the Northwest Grain Depot.
Figure 3. Plan of the 1st story (raft foundation was used in the dotted line area) and structural sketch of the main office building of the Cement Design Institute.

Figure 4. Plan of the 2nd story and structural sketch of the old warehouse of the Huaxin Textile Mine.
Figure 5. Changing depths of bedrock.

Figure 6. Plan of the 2nd story and structural sketch of the library of the Tangshan Mining and Metallurgy Technical College. (dark dotted line in the figure is the position after the earthquake.)
Figure 7. Sketch of the foundation structure.
DAMAGE TO THE TANGSHAN 1ST FLOUR MILL

Zhou Qijing¹ and Zhu Yaoling²

A. General Condition

The Tangshan 1st Flour Mill was situated in an area of intensity X about 200 m northwest of Fenghuang Hill in Lubei District in Tangshan City. It had a flour manufacturing shop (main workshop), a wheat moisture storehouse, a primitive wheat storehouse and an end product warehouse (auxiliary buildings); the general layout is shown in Fig. 1.

This mill was built in 1964 and was put into production in 1965. Before the earthquake the daily output was 11,000 bags, which was more than the 5,000 bags per day from the original design. The foundation material was limestone so the damage to the buildings was light, except that on the bottom story of the masonry wheat moisture storehouse the brick columns broke off causing the storehouse to fall to the ground (Photo 1). Although the other buildings were damaged, production was recovered shortly after repairs and strengthening. This paper emphasized the damage conditions of the flour manufacturing shop (Photo 2).

1. Layout of the building structure

The flour manufacturing shop was a cast-in-situ reinforced concrete frame structure, 5-stories high with a design intensity of VIII.

The plan, elevation and section view of the mill are shown in Fig. 2. Brick filler walls 240 mm thick were used with R.C. bond beams at the upper and lower edges of the windows.

The columns of the mill building had reinforced concrete independent conical footings which sat on limestone. On the tops of the footings there were joining beams with a cross-section of 250x500 mm and 2 φ16 reinforcements at the top and bottom of the beams connecting all of the footings. They were also used as ground beams under filler walls.

The cross-section dimensions of the columns are shown in Fig. 2 in which 7.5-8.3 cm² vertical steel bars and φ8 @ 300 mm stirrups on the 1st story and φ6 @ 300 mm on other stories were used. There was no stirrup at the core of the column joint but at the ends of transverse beam (φ6 @ 250 mm) stirrups were used at ends of longitudinal beams (φ6 @ 300 mm stirrups) and at individual positions (φ6 @ 350 mm) stirrups were used.

At the beam-column joints (longitudinal and transverse directions) only two bottom bars, the areas of which were 1/3-1/4 the area of negative steel bars extended into the joints. The bond length of these steel bars was only 15-20d (‘d’ is the diameter of the steel bar).

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² Research and Design Institute, Ministry of Grain
2. Material and load

#200 concrete, #3 steel bars, #75 bricks and #25 mortar were used. On the 2nd story of the flour manufacturing shop there were 6 double roll flour milling machines each weighing approximately 2.5t; on the other stories the equipment was lighter. The load on the structure of the mill building was mainly self weight and the total load on each floor was 212.7t for the 5th floor, 438.5t for the 4th floor, 405.9t for the 3rd floor, 453.7t for the 2nd floor, and 514t for the 1st floor.

B. Damage

Cracks mainly appeared on columns but no cracks were found on beams and at joints between beams and columns. The tops of central columns on the bottom story cracked horizontally at the level of lower edges of beams and on column footings 100 mm from the ground; on the 2nd story the cracks on the tops of columns were only found at the lower edges of hunches of beams, but they were lighter than on the 1st story. On the 3rd story the position of cracks were the same as on the 2nd story but the cracks were thinner; on other stories there was no obvious damage. The cracks on columns in the exterior walls appeared at the upper and lower edges of windows. They were serious on the bottom story while they decreased in the upper stories. At axes 4 and 6 these columns were seriously damaged as vertical steel bars bent and concrete broke; the cracks are shown in Fig. 2, Photo 3 and Photo 4. The damage to longitudinal brick filler walls mainly appeared between windows on the 1st and 2nd stories, and regular cross-cracks also formed. On transverse filler walls cross-cracks partly formed (Fig. 3), some of which became peripheral cracks along the frames, but the walls above the 3rd story were intact.

The landing beam L1 of the staircase on the 1st story cracked and fell off because during construction a timber block was mixed into concrete, then, the upper and lower part of the stairs, landing beam L2 and walls on the intermediate landing were seriously damaged (Fig. 4).

In summary, the flour manufacturing shop was lightly damaged and manufacturing was resumed after strengthening. In June 1977 after the strengthening of the mill building the measured fundamental periods of the building were 0.25 sec (transverse) and 0.21 sec (longitudinal).

(Translator: Jin Guoliang)
Photo 1. Brick columns on the bottom floor of the wheat moisture storehouse broke off, and the whole building fell to the ground.

Photo 2. After the earthquake the flour manufacturing shop was essentially intact.

Photo 3. Damage to walls and columns in the 1st and 2nd stories.

Photo 4. Damage to side columns in bottom story.
Figure 1. General layout of the Tangshan Flour Mill.

Figure 2. Structural sketch of the flour manufacturing shop. (a) Plans of foundation and bottom story; (b) East elevation
Figure 3. Cracks on filled wall.

Figure 4. Damage to the staircase on the bottom floor.
1. General Description

After the Tangshan earthquake fourteen cold storage buildings in the areas of Tangshan and Tianjin were investigated; nine were multi-story buildings and five were single-story buildings. They were used for refrigerating meat. In the original designs of these buildings no consideration had been given to earthquake resistance.

Among the nine multi-story cold storage buildings only the 4,000-ton cold storage building of the Tianjin First Refrigeration Plant was a steel frame structure with reinforced concrete floor slabs. The eight others had cast-in-place R.C. flat slabs with brick exterior walls and brick or lightweight concrete partitions. All the adjacent but structurally independent stairs, elevator and transit hall buildings were constructed either with reinforced concrete or brick bearing walls with R.C. beams and floors.

Of the five single-story cold storage buildings two were cast-in-place R.C. flat slab structures, two were pre-cast R.C. frames and one was a brick and reinforced concrete structure (brick bearing walls, R.C. columns and floors).

Of the fourteen cold storage buildings investigated the 4,500-ton cold storage at the Tangshan Refrigeration Plant (seismic intensity XI), completely collapsed from the second floor up. The roof of the Tangshan Export Cold Storage (seismic intensity X) partly collapsed. Horizontal cracks were found below the capitals of some of the flat slab columns on the 5th floor of the 10,000-ton cold storage at the Tianjin Second Refrigeration Plant in the region of intensity VIII.

The other eleven cold storage buildings that were inspected in regions with a seismic intensity of VII, VIII and X either suffered minor damage or remained intact after the earthquake.

The non-bearing exterior brick walls of the multi-story cold storage buildings, which had been provided with R.C. bond beams at every floor and tied to the floor slabs met with damage of various degrees. Since no appropriate measure was adopted to tie the exterior wall to the roof structure it caused the upper part of the 1,000-ton cold storage of the Tangshan Export Refrigeration Plant to suffer more severe damage and partly collapse (Photos 1 and 2). Before the earthquake vertical cracks were found along the corners and horizontal cracks were under the eave of the exterior walls at the 6,000-ton cold storage and 4,500-ton cold storage buildings at the Tianjin First Refrigeration Plant, and at the 10,000-ton cold storage building at the Tianjin Tanggu Export Refrigeration Installation; these cracks were all widened after the earthquake.

* Design Institute, Ministry of Commerce
But no cracks were detected on the exterior walls of the single-story buildings in the regions of intensity VII and VIII.

At the time of the earthquake no live load was acting on any of the stairs, elevator and transit hall buildings in the multi-story cold storage buildings investigated. Most of the buildings were basically intact except for some cracks at the ends of columns or on the walls.

In several cold storage buildings that were situated in regions higher than intensity VII there were leaks in the ammonia circulating pipe system at welds, at joints of pipe segments of different diameters and at rigid supports under walls.

2. Case Study

(1) 4,500-ton cold storage at the Tangshan Refrigeration Plant

A. Architectural and structural layout

This building was built in 1959 and was situated west of Shengli Bridge on the Douhe River. The local observed seismic intensity was XI.

The building site was originally a low and depressed land that was filled with earth during construction of the cold storage building. The soil was designated as Type III according to the current Chinese Aseismic Design Code, which meant rather weak soils such as high water content, loose sands, soft clay or silt, etc. Independent footings for the columns and strip foundations for the exterior walls rested on the filled ground and both were provided with 90 cm thick compacted 3:7 lime-clay footings. After the earthquake ground cracks appeared at the site in directions approximately parallel to that of the Douhe River indicating that the ground moved towards the river (Photo 3 and Fig. 1).

This cold storage, like most of the multi-story cold storages in China nowadays, consisted of a main storage building, stairs, elevator and transit hall, ammonia compressor room, ice plant, transformer and switchboard station, truck loading platform and a slaughter house. The main storage was a 6-story building that had an attic and a basement. The total height above the ground surface was 21.3 m. The lower five floors were cast-in-situ R.C. flat slabs with equal story heights of 4.2 m. The 2.4 m high attic was added on top of the main storage at a later date with cast-in-place columns and a pre-cast ribbed slab roof. The columns of the attic were connected to those of the flat slab floor by welding together their main reinforcements. The framing plan of the main flat slab was 6m x 6m and the cross-section of the columns was 700mm x 700mm. There were six spans in the east-west direction and five spans in the north-south direction. The stairs, elevator and transit hall were located in the southeastern corner (Figs. 2a and 2b).

The grades of structural concrete were: cellar and first floor columns, 300; second floor columns, 200; third and upper floor columns, 150; and floor slabs, 150. The thickness of the floor slab was 150-250 mm.

The design live loads were: floor slab of the ice plant, 2.5 tons per square meter; floor slab of the cold storage room and freezing room, 2 tons per square meter; and the top slab of the
freezing room, 2.35 tons per square meter. The thickness of the exterior brick walls was 240 mm or 370 mm and it was self-supporting and separated structurally from the floor system, it was stuffed with rice husks as thermal insulators. On every floor R.C. bond beams were constructed and connected the exterior wall to the floor slab. The spacing of tie beams on the first floor was 3 m and was 6 m on the other floors. Tie beam reinforcements were extended 220 mm into the ring beams.

The stairs, elevator and transit hall were a brick and reinforced concrete mixed structure with brick bearing walls and reinforced concrete floors. The total height of this building was 5 stories and was 19.6 m above the ground surface. The elevator machine room was 2.4 m higher. The design load for the floor was 1 ton per square meter and 0.4 tons per square meter for the stairs.

The ice plant was an independent single-story cast-in-situ R.C. frame structure. The ammonia compressor room and transferor and switchboard station were single-story brick and reinforced concrete mixed structures.

At the time of the earthquake the third and fourth floors of the main storage building were fully loaded with commodities, about 1.6 tons per square meter and half of the storage rooms on the second floor were also similarly loaded. The freezing rooms on the first floor and the zero degree (centigrade) storage in the cellar were nearly empty. The rice husks in the attic were roughly about one meter thick, equivalent to 120 kg per square meters of floor area. It was evident that when the earthquake occurred all the loads were practically concentrated in the upper part of the main storage building. There was no applied load in the stairs, elevator and transit hall.

B. Damage

The main building of this cold storage completely collapsed above the second floor and (Photo 4). All columns of the second story were broken either under their capitals or at the foot along horizontal or inclined planes, and most of them were cracked along the construction joints near the floor and fell down in a northeast direction. On the second floor some 20 square meters of the floor slab was crushed by fallen structural elements that collapsed on the upper floors while the unaffected portion was seriously cracked in the middle strip of the southern span. The first floor slab failed by punching shear along the perimeter of the basement column capitals. All of the columns on the first floor did not collapse; those in the central portion remained in fairly good condition but some of the columns at the edges in the western portion were badly cracked at sections just under the column capitals.

The first floor slab, columns and exterior wall of the basement had little or no damage. Capitals of the collapsed columns still retained their original shape but the attached floor slab had been punched through.

The stairs, elevator and transit hall building went through the disaster without complete collapse but the bearing walls were severely damaged (Photo 4); numerous large vertical or inclined cracks had developed.

The single-story ammonia compressor room, ice plant and transformer switch board station all collapsed.
(2) 10,000-ton cold storage at the Tianjin Second Refrigeration Plant

A. Architectural and structural layout

This storage building was located on Hongqi Road in Nankai District of Tianjin. Construction began in 1974 and was completed just before the earthquake but was not put into operation. The local seismic intensity was VIII.

The soil conditions below the ground were as follows: 1.3-2.5 m backfill; 2.5-8.3 m clayey soil and silty clayey soil being deposits of the recent Epoch, Quaternary Period; 8.3-27.3 m clayey soil, sandy loam, powdered fine sand etc., alluvial deposits of the Pleistocene Epoch, Quaternary Period.

The site soil was designated as Type II according to the current Chinese Seismic Design Code, which meant soils of medium strength and moderate compressibility. Pre-cast reinforced concrete piles 14.5 m in length were driven under the main cold storage and the stairs, elevator and transit hall buildings.

This installation was comprised of one main cold storage building, two stairs, elevator and transit halls, railway and truck loading platforms. The structural plan and section of the installation are shown in Fig. 3.

The main cold storage was a 6-story structure. The lower 5 stories were of a cast-in-place R.C. construction with equal story heights of 4.8 m each. There was an attic with cast-in-place R.C. columns and pre-cast R.C. beams and a slab roof. The frame of the main cold storage was 6m x 6m, and the cross-section of the columns was 700mm x 700mm. The edge panel of the flat slab was a cantilever strip 3 m in width. The grade of concrete of columns on the three lower floors was 300; floors 4-6 was 200. The thickness of the slab was 22 cm with the exception of the attic which was 16 cm thick. The grade of concrete of the floor slab was 200.

The exterior walls of the main storage building were brick and were structurally independent of the main building frame; 550 mm thickness of rice husks was stuffed in-between the exterior wall and inner R.C. wall slab for insulation. Bond beams were provided at every floor in the exterior wall and were tied to the floor system by triangular section R.C. beams spaced at 6 m.

The structure of the 7-story stair, elevator and transit hall building on the southern side was a cast-in-place R.C. frame with non-bearing walls. The columns and walls of the northern transit hall building were cast-in-place in slip forms. The columns were reinforced and the walls were plain concrete. The construction of beams on various floors followed the completion of the construction of the columns and walls. The layout and floor heights of both the north and south transit hall buildings were the same, and they were both connected to the exterior walls of the main storage building. The floor slabs of the transit halls were pre-cast elements. The outer columns were in alignment with the axis of the exterior wall of the main storage building.

There were no commodities stored in this building when the earthquake occurred.

B. Damage
The flat slabs in the main storage building survived the quake without severe damage but horizontal cracks developed under the capitals or near the floor of four columns along axis (13) and three columns along axis (21) on the 5th floor. In the attic a number of welds were omitted due to negligence during the construction process which caused some parts of the beam and slab to fall down (Plate 5); some of the columns were forced to incline 1-5 cm out of alignment on the top.

Several vertical cracks were found on the exterior walls of the main storage building. In the design and construction of this building no aseismic joint was provided between the exterior wall of the main storage and transit halls so the exterior wall of the main storage cracked vertically at the junction. A portion of the eave collapsed and fell down. Cracks were also observed on the exterior wall under the eave.

Partitions in the cold storage were built with brick walls 120 mm thick lightweight concrete blocks 200 mm thick. No provision was made to join the exterior wall with the floor or column in the design. After the earthquake the interior walls of the third to fifth floors were partially collapsed or severely damaged and cracks were found on the interior walls of the first and second floors.

In the southern transit hall building there were cracks on the beams of the third floor frame and at the ends of the supporting beam of the stairs on the second floor. The nonbearing enclosure wall suffered minor architectural damage; the plaster cracked and fell down in some places and the wall cracked and separated from the columns in the frame.

In the north transit hall building the walls built with plain concrete were seriously cracked between the windows as shown in Photo 6. Plaster on the wall also cracked and partly fell off.

(Translator: Hu Zongyi)
Photo 1. Collapsed roof trusses and roof slabs at the Tangshan Export Cold Storage.

Photo 2. Collapsed roof slabs and a crumpled wall on the upper portion of the Tangshan Export Cold Storage.

Photo 3. Ground fissures on the building site of the Tangshan Refrigeration Plant.

Photo 4. The main cold storage building collapsed and the transit hall building was severely damaged at the Tangshan Refrigeration Plant.
Photo 5. A beam and slab of the roof fell onto the top floor, 10,000-ton cold storage at the Tianjin 2nd Refrigeration Plant.

Photo 6. Heavy cracks on the wall between windows at the Northern transit hall, 10,000-ton cold storage, Tianjin 2nd Refrigeration Plant.
Figure 1. Sketch showing ground fissures at the building site of the Tangshan Refrigeration Plant.

Figure 2a. 1st floor plan of the 4,500 ton cold storage at the Tangshan Refrigeration Plant.
Figure 2b. 1-1 section of the 4,500 ton at the Tangshan Refrigeration Plant.

Figure 3a. 1st floor plan of the 10,000 ton cold storage at the Tianjin 2nd Refrigeration Plant.
Figure 3b. I-I section of the 10,000 ton cold storage at the Tianjin 2nd Refrigeration Plant.
A. General Condition

Multistory reinforced concrete rigid frame mill buildings were widely used in Tianjin. They were mainly used at manufacturing plants of electronics, instruments and meters, lights, prints, oceanic chemicals, petrochemicals and other industries and were also used for warehouses of international trade and commerce departments.

In Tianjin most of the multistory mill buildings were rigid frame and inner rigid frame structures, and a few of them were brick-reinforced concrete and lift slab structures. Most of the multistory rigid frame mill buildings were three stories or less (about 70%), a few of them were four or five stories and one was up to 13 stories (total height 54 m).

About 70% of the multistory rigid frame mill buildings in Tianjin were full pre-cast structures which were composed of cast-on-site pre-cast columns and pre-cast in factory beams and slabs. The joints of the beams and columns were rigid; i.e. the upper reinforcing bars in the beams were welded for continuity and the reinforcing bars in the columns were also welded for continuity and then the concrete was poured in the joint. In 70% of these mill buildings rigid joints were used in longitudinal and transverse directions.

Partly pre-cast rigid frame structures were always constructed with cast-on-site beams and columns; and 28% of slabs were pre-cast at the factory. The joints of beams and columns were poured after assembly. Approximately 2% were fully cast-in-place rigid frame structures.

Solid clay brick walls 240 mm thick were generally used as curtain walls and inner partition walls. There were some short bars between the walls and frame columns connecting them together. In most of the mill buildings there were few with no inner partition walls. The windows on the walls were generally placed just below the frame beams.

For multistory rigid frame mill buildings in Tianjin a complete static design had always been done but after 1974 most were designed according to earthquake resistant requirements of intensity VII. Some that were built in the 1950’s and early 1960’s were designed as continuous beams and columns and were deficient in hoop reinforcing now required by the current design code.

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1 This paper was written according to the materials provided by the Tianjin Municipal Institute of Architectural Design and Chinese Academy of Building Research.

2 Tianjin Municipal Institute of Architecture Design

3 Chinese Academy of Building Research
B. Outline of Earthquake Damage

(A) General condition

In Tianjin after the Tangshan earthquake and aftershock the damage to more than 40 multistory rigid frame mill buildings was investigated. These totaled an area of about 70% of that built after the 1950’s. Most of these mill buildings were located in urban Tianjin (earthquake intensity VII to VIII). The statistics of degree of damage are shown in Table 1. A comparison of data of similar mill buildings in a similar intensity region for the February 4, 1975 Haicheng earthquake of magnitude 7.3 are also shown in this table.

From Table 1 it can be seen that damage was moderate or more to about 38% of the multistory rigid frame mill buildings in Tianjin while damage to only 10% of those in a region of similar intensity during the Haicheng earthquake was moderate and more. Besides, at the Tianjin Chemical Works located in Hangu District (intensity IX) a lot of multistory rigid frame mill buildings were seriously damaged; the calcium carbide workshop, the acetylene station and the synthetic workshop collapsed. At the Tianjin Alkaline Factory located in Tanggu District (intensity VIII) a new evaporating and absorbing building (13 story rigid frame) also collapsed. These buildings are not listed in Table 1.

The main characteristics of damage to multistory rigid frame mill buildings in Tianjin were as follows:

(1) The damage to buildings with brick filler walls was light in the upper stories and serious in the lower stories. Of the 15 with moderate or more damage 5 with few filler walls, five stories high had damage concentrated at the second story, or second and third stories, and in 10 rigid frames with 3-stories the damage was concentrated in the first story or first and second stories. The damage to the filler walls was severe in the lower stories and was light in the upper stories.

(2) The destruction of columns was the main damage to moderately and above damaged multistory rigid frame mill buildings. Damage to beams was light and that to columns was severe. The damage at the top of columns was more severe than at the bottom and damage to exterior columns was most severe.

(3) The damage was closely dependent upon the configuration of the structures (main rigid frames, staircases, and elevator shafts). For example, the plans of the structures of the No. 11 workshop at the Tianjin 754 factory and the assembly workshop of the Bohai Radio Factory in Tianjin were the same. But the Bohai Factory had an expansion joint between it and the masonry-reinforced concrete structures at the ends of the workshops (the staircases, the elevator shafts and living rooms) while the Tianjin Factory did not. After the earthquake the frame columns and masonry-reinforced concrete walls of the latter were seriously damaged (Photo 1), while the former was basically undamaged; only light pounding broke the thin concrete cover plates over the 8 cm joint (Photo 2).
(B) Columns of frames

1. X-shaped cracks occurred on columns

For example, serious x-shaped cracks and diagonal cracks occurred on the columns in the two central rows on the second story of the No. 11 workshop at the No. 754 Factory in Tianjin (Photo 3). Concrete broke (coarse aggregates were river gravel), the main reinforcement of columns buckled, and necking and breakage of hoop reinforcement occurred.

2. Concrete at tops and bottoms of columns fractured

For example, concrete at the tops and bottoms of rigid frame columns on the second story of the middle south building of the Tianjin Second Woolen Mill fractured and a similar phenomena happened at the tops of some columns of the third story and to a few columns of the first story (Photo 4). In general, the damage at the top of a column was more serious than at the bottom.

3. Diagonal cracks and x-shaped cracks at the top of columns

For example, this phenomenon happened to most of the exterior columns in the printing and bindery workshop of the Tianjin People's Printing Factory (Photo 5). These types of cracks also happened to the rigid frame columns in the first story of the gable wall in the ceramic warehouse at the Beicang warehouse of the Tianjin Light Industry and Arts Import and Export Company (Photo 6).

4. Horizontal cracks occurred on exterior columns at the sill level

For example, horizontal cracks occurred on almost all the exterior columns on the second to fourth stories at the sill level in the five-story printing and bindery workshop at the Tianjin People's Printing Factory.

5. Damage to beams and column joints

In general, there were two types of damage. In the first type the concrete of the column at the bottom of a beam cracked through the joint. For example, at the printing and bindery workshop of the Tianjin People's Printing Factory there was such damage at almost all the corner columns (Photo 7). In the second type many minute diagonal cracks appeared on the joint, for example at the joint of the first story corner column in the gable wall of the ceramic warehouse of the Beicang warehouse at the Tianjin Light Industry and Arts Import and Export Company.

6. Typical damage to brackets of exterior columns of pre-cast structures of mill buildings

One type of damage was a fracture of the anchor reinforcement to the built-in plate on the top face of a bracket and a crack in the concrete of the bracket. Another type was a diagonal crack in a bracket. There was such damage to the bracket of the exterior columns in the multistory building of the Chenglinzhuang warehouse at the Tianjin Textile Fabric Company and in the Beicang ceramic warehouse.
7. The damage of built-in fitting connecting longitudinal beams to columns of pre-cast rigid frame mill building

This type of damage is shown in Photo 8.

(C) Beams of rigid frames

In general, the damage to beams in rigid frames was light even in seriously damaged buildings. The damage to beams of rigid frames only occurred in a few structures such as in the three span six-story building of the Tianjin Textile Fabric Company. Inclined cracks occurred in the bottom of beams of the transverse rigid frames in the middle span of the first story, and they were small at the upper part and large at the lower part and some extended above mid-height of the beam. The inclined cracks on beams of rigid frames formed an inverted V-shape. As another example, vertical cracks at the ends of beams of rigid frames appeared and concrete at the ends of beams cracked seriously due to inadequate anchor length of the bottom bars in the four-story refinement workshop of the Tianjin Synthetic Chemical Factory.

(D) Brick filler wall

Damage to brick filler walls, especially curtain walls, occurred to many buildings. The number of seriously damaged and moderately damaged buildings equaled 37.5% of the total number investigated, while the number of those that were lightly damaged equaled 27.5% and the total damage ratio reached about 65%.

In buildings the damage to filler walls was in accordance with the distribution law "serious in the upper part and light in the lower part" but when damage to columns of rigid frames in any story was serious the damage to brick filler walls of that part was generally serious also. For example, the damage to columns and filler walls on the third story of the printing and bindery workshop of the Tianjin People's Printing Factory. For any single filler wall the damage had the following characteristics:

1. When the damage to a filler wall without an opening was light the contact between the filler wall and joint of the beam and column was compressive but there was no diagonal crack on the wall, such as there was on the filler walls of the two end gable walls of the No. 1 warehouse of the No. 09 unit in Tianjin. When the damage was more serious cracks occurred between the perimeter of the wall and the beams and columns and x-shaped cracks appeared on the wall. When the ratio of width to height of the wall was larger a segment of a horizontal crack appeared in the central part of the wall, and then diverged to the four corners. This type of damage was found in the lower stories of mill buildings.

2. The damage to a filler wall with an opening was determined by the dimension and position of the opening. When the opening was not large and was situated at the central part of the wall the damage was similar to that of a wall without an opening. When there was a flat and wide opening close below the beam, approximately horizontal cracks appeared on both sides of the opening (Photo 6) but X-shaped cracks appeared on part of the wall under the opening. When the height of the opening was large not only did horizontal cracks appear on the top of the wall on both sides of the opening but diagonal cracks also occurred on the wall.
(E) Staircase and elevator shaft

Most of the staircases and elevator shafts were masonry structures. When they were connected to a rigid frame structure damage to the masonry included x-shaped and diagonal cracks on the wall (along the stair direction). Diagonal cracks on the wall at the level of top of doors and windows was comparatively serious.

If the damage to the wall of the elevator shaft was light then horizontal cracks or diagonal cracks appeared on the lower part of the wall (Photo 9). If the damage was serious then the wall collapsed and the roof of the elevator shaft fell down.

C. Examples of Damage

(A) Central south building of the Tianjin Second Wool Mill

During the Tangshan earthquake the central south building of the Tianjin Second Wool Mill was seriously damaged. After partial strengthening it was reused but during the magnitude 6.9 earthquake on November 15, 1976 it collapsed.

1. General geological features

The Tianjin Second Wool Mill was situated in Heping District in Tianjin. Before construction in 1931 the site of the factory was a water pool 2.8-5.1 m deep. Around 1933 the pool was filled with earth to its present level. Bore hole data within 24.5 m depth are shown in Table 2.

Prospecting showed an orderly arrangement of the foundation soils. The bottom of the layers was flat and the soils were uniform. The foundation soil was Type II-III of the design code.

At the factory the original ground level was about 4 m below the present ground surface, and the static ground water level was 1.1 m below ground surface.

The footings of the reinforced concrete single columns in the mill building were placed on an earth-filled layer of ground (the level of the foundation was 1.15 m).

2. Arrangement of structures

The central south building was a three-story cast-in-site reinforced concrete rigid frame mill building. The first story was used as a fabric weaving mill, the second story was used for drying yarn, and the third story was used for storage of semi-finished products of yarn. The plan and profile of the structures are shown in Fig. 1. The dimensions of cross-sections of the rigid frame beams and columns are listed in Table 3.

This building was designed and constructed in 1958. The rigid frame was designed as a continuous beam-column system without giving consideration to earthquake resistance. The design load on the roof was 200 Kg.f/m$^2$ while the floor was 800 Kg.f/m$^2$. During the earthquake there was no load on the roof and only 100 Kg.f/m$^2$ floor load, which was estimated according to the distribution of machine tools and storage of the yarn.
The internal part of this building was open. Only in the third story there was a transverse filler wall built of hollow bricks, while in the longitudinal direction there was a filler wall between columns with windows 2.4 m high running the full length of the building. The thickness of the wall was 240 mm and the mortar was #4.

In collapsed mill building the concrete was #150 as measured after the earthquake. From a collapsed column three specimens of reinforcing bars were taken. For one of these (un-notched bar) the elastic limit could not be measured but the strength limit reached 8,000 Kg.f/m² and for the other two the test elastic limits were 3,800 K.g.f/cm² and strength limits were 4,500 Kg.f/cm².

3. Damage

During the magnitude 7.8 Tangshan earthquake and the magnitude 6.9 Ninghe aftershock the intensity in the area at this factory was VIII. In the factory not only was this building seriously damaged but other buildings and structures were also damaged to different degrees. The sandboils and waterspouts that occurred were extremely serious at the factory; the number of waterspouts was 65, and two ground fissures (east-west and south-north direction) passed through the factory area.

The rigid frame structure of the central south building was seriously damaged; the damage to columns on the second story was most severe. 45% of column heads and 22.5% of column footings were seriously damaged and the concrete of columns fractured, hooks of hoop reinforcement were straightened, and main bars were exposed and buckled. There was residual displacement in the stories. 62.5% of column tops in the top story were damaged to different degrees while only one column footing was damaged; and columns in the first story were lightly damaged. The positions (top or bottom of column) of damage (fracture, peripheral cracks) of columns on every story are shown in Fig. 2. The damage to rigid frame beams was very light and a vertical crack appeared only at the bottom end of one beam.

Curtain walls of this building were seriously damaged. On the top story parapet walls at the back and filler walls at the front were seriously damaged and collapsed. The filler wall at the back on the second story in large part was seriously damaged and collapsed, but the filler walls at the back and front eave walls were lightly damaged above the second story.

Production work stopped while the central south building was being restored. The procedure was to strengthen damaged column tops, to strengthen damaged column footings, and to strengthen the whole column if top and bottom were both damaged. For general cracks guniting or plastering was used for restoration. The strengthening locations on columns of every story are shown in Fig. 3; 23 columns were strengthened in all.

During the magnitude 6.9 Ninghe earthquake the strengthened central south building collapsed as a whole in the direction of the back (Photos 10 and 11), and one end of the mill building displaced 1 m while another end displaced 0.3 m. The main reinforcement was twisted. When collapsed portions were removed, it was found that columns on the first story were broken in an s-shape and one column collapsed only 0.8 m from its original position, but strengthened columns on the second story fell down in one piece.
The southwest building by the central south building was a two-story cast-in-site reinforced concrete rigid frame mill building, the structural plan of which was similar to the central south building. During the magnitude 7.8 earthquake the southwest building was seriously damaged, and after strengthening this building was seriously damaged during the magnitude 6.9 earthquake but did not collapse. Figure 4 shows the records of measured displacement at the tops of rigid frame columns in the southwest building.

(B) Ceramic warehouse of the Tianjin Light Industry and Arts Import and Export Company

1. Geological features

The ceramic warehouse near the railway station was situated in the Beicang industrial region in the north suburban area of Tianjin. In the region of the warehouse the topography was level. There was about 2 m of farmland soil or back-filled soil and under this surface layer clay and clayey soil layers were alternately distributed. There was a layer of muddy clayey soil 5-6.4 m underground. The distribution of the foundation soils and related indexes are listed in Table 4. The site soil was Type II-III of the design code.

2. Structure of the building

The ceramic warehouse was a three-story pre-cast reinforced concrete rigid frame structure. The plan is shown in Fig. 5. The dimensions of the rigid frames are listed in Table 5.

This warehouse was built in 1975 and at the same time three others were also built. They were in use before the earthquake. In this building transverse structural frames carried loads. The columns were pre-cast at the site and the joints of beams and columns were rigid connections constructed with concrete brackets and laminated ledger beams, while the joints of beams and columns of longitudinal frames were rigid connections constructed with welded steel brackets and laminated ledger beams. There were no internal partition walls in the warehouse and exterior curtain walls were built with solid bricks 240 mm thick and #50 mortar in the first story and #25 in the other two stories. The windows were just under the bottom of the beams and the dimension of the windows on the eave walls and gable walls were 1.2 x 3.8 m.

A reinforced concrete raft foundation with a 400 mm thick slab and 1,400 mm deep beams was used. The depth of the embedded foundation was 2.3 m under the interior ground and the difference between the levels of the exterior ground and interior ground was 0.3 m.

The design floor load was 1.5 t.f/m² and in the warehouse the actual load was 0.8 t.f/m² during the earthquake.

3. Damage

The No. 1 and No. 2 Warehouses each consisted of two single buildings, i.e. 4 single warehouses in all. The damage to the north part of the No. 2 Warehouse was most serious and it was classified as moderate damage. The damage to the other three single warehouses was similar but they were classified as light damage.
Damage to the north part of the No. 2 warehouse mainly occurred at the two end gable walls (Fig. 6, Photos 12 and 13). X-shaped and diagonal cracks occurred on 4 frame columns at the center of the gable wall in the height range of the windows (1.2 m). Damage to columns beside the door was most serious (Fig. 7), and the width of the crack reached 2 cm. In the frame the dislocation of the crack on the columns was 1.8 cm and the main reinforcement bars of the column buckled. In addition, there were several horizontal cracks (maximum width was 0.5 mm) on the column 0.2-1.5 m above the floor. The damage to the corner column on the first story near the joint of the beam and column is shown in Fig. 8.

The damage to the gable wall on the first story was also serious. Serious breaks occurred on walls either with or without entrances, but no collapse occurred (there were small tie bars between the walls and columns). Comparatively large cracks occurred between the gable wall and frames on the second story and there were inclined cracks on the wall, but the gable wall on the top story was fundamentally intact.

In addition, on the first story inclined cracks occurred near the anchor bars of embedded plates on the tops of brackets of side columns in two longitudinal rows. Longitudinal frames and brick filler walls were fundamentally intact, but only partition walls on the first story were lightly damaged.

(Translator: Jin Guoliang)

Table 1. Comparison of degrees of damage.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Assigned Intensity (degree)</th>
<th>Collapsed Buildings (%)</th>
<th>Seriously Damaged Buildings (%)</th>
<th>Moderately Damaged Buildings (%)</th>
<th>Lightly Damaged Buildings (%)</th>
<th>Fundamentally Intact (%)</th>
<th>Total Buildings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangshan Earthquake</td>
<td>VII (Tianjin)</td>
<td>1 (2.5)</td>
<td>5 (12.5)</td>
<td>9 (22.5)</td>
<td>3 (7.5)</td>
<td>22 (55)</td>
<td>40 (100)</td>
</tr>
<tr>
<td>Haicheng Earthquake</td>
<td>VII, VIII</td>
<td>1 (3.22)</td>
<td>2 (6.45)</td>
<td>8 (25.81)</td>
<td>20 (64.52)</td>
<td>31 (100)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Material about the Haicheng earthquake was excerpted from "Haicheng Earthquake Damage" compiled by the Institute of Engineering Mechanics of the China Academy, Earthquake Publishing House, 1979.
<table>
<thead>
<tr>
<th>Layers</th>
<th>Depth (m)</th>
<th>Manner</th>
<th>Soil Type</th>
<th>Description of Soil</th>
<th>Allowable Bearing Capacity (t/m²)</th>
<th>Depth of Specimens (m)</th>
<th>Water Content (%)</th>
<th>Unit Wt. (g/cm³)</th>
<th>Void Ratio</th>
<th>Index of Plasticity</th>
<th>Index of Liquidity</th>
<th>Compressional Coefficient (cm²/kg.f)</th>
<th>Modulus of Compressibility (kg.f/cm²)</th>
<th>Cohesion (kg.f/cm²)</th>
<th>Internal Friction Angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8</td>
<td>mixed back-filled soil</td>
<td>various color, containing mire, iron and lime scream</td>
<td>13</td>
<td>2.0</td>
<td>29.1</td>
<td>1.87</td>
<td>0.87</td>
<td>14.1</td>
<td>0.8</td>
<td>0.02</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>alluvial back-filled soil</td>
<td>gray-yellow, containing mire, iron and shells</td>
<td>13</td>
<td>3.0</td>
<td>30.6</td>
<td>1.85</td>
<td>0.91</td>
<td>11.2</td>
<td>1.2</td>
<td>0.03</td>
<td>54</td>
<td>0.07</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>clay</td>
<td>gray-yellow, containing mire, iron and grass</td>
<td>20</td>
<td>4.0</td>
<td>27.4</td>
<td>1.94</td>
<td>0.81</td>
<td>17.7</td>
<td>0.4</td>
<td>1.03</td>
<td>68</td>
<td>0.3</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.5</td>
<td>clayey soil</td>
<td>yellow-gray, containing mire and iron</td>
<td>23</td>
<td>5.0</td>
<td>25.7</td>
<td>1.99</td>
<td>0.72</td>
<td>14</td>
<td>0.6</td>
<td>0.03</td>
<td>67</td>
<td>0.03</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.5</td>
<td>sandy loam</td>
<td>gray, containing mire and iron</td>
<td>16</td>
<td>7.0</td>
<td>25.8</td>
<td>1.91</td>
<td>0.96</td>
<td>11.6</td>
<td>1.1</td>
<td>0.02</td>
<td>134</td>
<td>0.10</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>15.0</td>
<td>clayey soil</td>
<td>gray, containing mire and organic matters</td>
<td>10</td>
<td>9.0</td>
<td>34.7</td>
<td>1.85</td>
<td>0.96</td>
<td>10.7</td>
<td>1.7</td>
<td>0.04</td>
<td>54</td>
<td>0.20</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>15.3</td>
<td>clay</td>
<td>gray-black, containing mire</td>
<td>14</td>
<td>15.0</td>
<td>36.6</td>
<td>1.78</td>
<td>1.11</td>
<td>19.3</td>
<td>0.8</td>
<td>0.04</td>
<td>46</td>
<td>0.34</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>21.0</td>
<td>clayey soil</td>
<td>French gray, gray-yellow, khaki, yellow-gray, containing mire and iron</td>
<td>20</td>
<td>18.0</td>
<td>25.6</td>
<td>2.05</td>
<td>0.63</td>
<td>11.9</td>
<td>0.5</td>
<td>0.03</td>
<td>59</td>
<td>0.20</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>22.0</td>
<td>moderately dense fine sand</td>
<td>yellow, containing mire, iron, grass and rocks</td>
<td>20</td>
<td>20.0</td>
<td>23.8</td>
<td>2.04</td>
<td>0.64</td>
<td>10.3</td>
<td>0.7</td>
<td>0.01</td>
<td>100</td>
<td>0.24</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>23.0</td>
<td>sandy loam</td>
<td>yellow, containing mire, iron, grass and rocks</td>
<td>20</td>
<td>23.0</td>
<td>30.2</td>
<td>1.89</td>
<td>0.88</td>
<td>10.5</td>
<td>0.8</td>
<td>0.01</td>
<td>206</td>
<td>0.34</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>24.5</td>
<td>clayey soil</td>
<td>brown, containing mire and iron</td>
<td>20</td>
<td>24.5</td>
<td>34.8</td>
<td>2.10</td>
<td>0.86</td>
<td>13.7</td>
<td>0.8</td>
<td>0.03</td>
<td>127</td>
<td>0.32</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Geology at the central south building.
Table 3. Dimensions of cross-section of beams and columns in the central south building of the Tianjin Second Wool Mill.

<table>
<thead>
<tr>
<th>Story</th>
<th>Column</th>
<th>Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 K-1</td>
<td>300×350</td>
<td>250×500</td>
</tr>
<tr>
<td>2</td>
<td>300×300</td>
<td>250×500</td>
</tr>
<tr>
<td>3</td>
<td>300×300</td>
<td>250×450</td>
</tr>
<tr>
<td>4</td>
<td>350 (300)×350</td>
<td>250×500</td>
</tr>
<tr>
<td>5 K-2</td>
<td>300×300</td>
<td>250×500</td>
</tr>
<tr>
<td>6</td>
<td>300×300</td>
<td>250×450</td>
</tr>
</tbody>
</table>

Note: The item with ( ) is for an edge column; the mean thickness of the cast-in-site floor slab was 8 cm.
Table 4. Boring log at the ceramic warehouse.

<table>
<thead>
<tr>
<th>No.of Layer</th>
<th>Depth (m)</th>
<th>Manner</th>
<th>Soil Type</th>
<th>Description of Soil</th>
<th>Permissible Bearing Capacity (t.f/m²)</th>
<th>Depth of Specimen (m)</th>
<th>Water Content (%)</th>
<th>Unit Wt. (g/cm³)</th>
<th>Void Ratio</th>
<th>Index of Plasticity</th>
<th>Index of Liquidity</th>
<th>Consistence</th>
<th>Compression Coefficient (cm²/kg.f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.10</td>
<td>loose</td>
<td>back-filled clayey soil</td>
<td>khaki, containing bricks, khaki, containing mire, iron and bricks</td>
<td>11.0</td>
<td>11.0</td>
<td>1.00</td>
<td>29.1</td>
<td>1.892</td>
<td>0.862</td>
<td>16.7</td>
<td>0.58</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>2.05</td>
<td>plastic</td>
<td>clayey soil</td>
<td>black brown, containing mire, iron, bricks and grass</td>
<td>---------</td>
<td>2.00</td>
<td>2.00</td>
<td>26.3</td>
<td>1.979</td>
<td>0.755</td>
<td>17.7</td>
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</tr>
<tr>
<td>3</td>
<td>2.50</td>
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<td>clay</td>
<td>gray green, containing mire, iron and grass</td>
<td>---------</td>
<td>3.00</td>
<td>3.00</td>
<td>27.7</td>
<td>1.935</td>
<td>0.780</td>
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<td>4.00</td>
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<td>clayey soil</td>
<td>yellow-gray, containing mire, iron, and spalls</td>
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<td>4.50</td>
<td>38.8</td>
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<td>1.10</td>
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<td>5</td>
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<td>clay</td>
<td>gray, containing mire and iron</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>37.3</td>
<td>1.837</td>
<td>1.040</td>
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<tr>
<td>6</td>
<td>6.40</td>
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<td>mud, clayey soil</td>
<td>gray, containing mire gray, containing mire and iron</td>
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<td>10.0</td>
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<td>0.946</td>
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<td>1.1</td>
</tr>
<tr>
<td>7</td>
<td>12.5</td>
<td>plastic</td>
<td>clayey soil</td>
<td>gray yellow, containing mire, shells and spalls</td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
<td>10.0</td>
<td>1.977</td>
<td>0.757</td>
<td>15.8</td>
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Note: 1) Unit of every index is the same as in Table 2.
Table 5. Dimensions of cross-section of beams and columns at the ceramic warehouse.

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<tr>
<th>Story</th>
<th>Columns</th>
<th>Beams</th>
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</thead>
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<td>Central rigid frame</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>400×400</td>
<td>300×850</td>
</tr>
<tr>
<td>2</td>
<td>400×400</td>
<td>300×850</td>
</tr>
<tr>
<td>3</td>
<td>400×400</td>
<td>200×550</td>
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<td></td>
<td>Edge rigid frame</td>
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</tr>
<tr>
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<td>300×850</td>
</tr>
<tr>
<td>2</td>
<td>400×400</td>
<td>300×850</td>
</tr>
<tr>
<td>3</td>
<td>400×400</td>
<td>200×550</td>
</tr>
</tbody>
</table>
Photo 1. Serious damage to eaves at the No. 11 workshop of the No. 754 factory in Tianjin.

Photo 2. Impact at settlement joint at the assembly workshop of the Bohai radio factory.

Photo 3. Damage to the rigid frame column at the No. 11 workshop of the No. 754 factory.

Photo 4. Serious damage to the top of the column of the rigid frame on the third story of the emergence workshop at the Tianjin second woolen mill.
Photo 5. Damage at the top of the edge column at the printing and bindery workshop of the Tianjin printing factory.

Photo 6. Damage at the top of the rigid frame column of the gable wall on the first story of the ceramic warehouse at the Beicang warehouse of the Tianjin Light Industry and Arts Import and Export Company.

Photo 7. Damage to the joint of the beam and column of the rigid frame at the printing and bindery workshop of the Tianjin Printing Factory.

Photo 8. An example of damage to a longitudinal beam and column joint of a rigid frame.
Photo 9. A horizontal crack on the lower part of the wall of the elevator shaft.

Photo 10. Collapse of the central south building at the Tianjin Second Wool Mill.

Photo 11. Damage to rigid frame columns on the first floor of central south building at the Tianjin second wool mill.

Photo 12. Damage to rigid frame columns beside the door on the gable wall of the ceramic warehouse.
Photo 13. Damage to rigid frame columns of the gable wall of the first story of the ceramic warehouse.
Figure 1. Structural plan of the central south building at the Tianjin Second Wool Mill.

Figure 2. Positions of damage of rigid frame columns in the central south building of the Tianjin Second Wool Mill.
Figure 3. Strengthening of columns in the central south building at the Tianjin Second Wool Mill.

Figure 4. Records of measured displacements of rigid frame columns of the southwest building at the Tianjin Second Wool Mill. (vertical displacement/horizontal displacement; unit: mm)
Figure 5. Structural plan of the ceramics warehouse of the Arts Import and Export Company.

Figure 6. Record of damage to the gable wall in the north part of the No. 2 warehouse in the ceramics warehouse.
Figure 7. Record of damage to the frame column of the gable wall on the first story of the ceramics warehouse of the Arts Import and Export Company. (unit: mm)

Figure 8. Record of damage at the joint of the corner column on the first story of the ceramics warehouse of the Arts Import and Export Company. (unit: mm)
A. General Features

At the time of the Tangshan earthquake there were 6 lift-slab structures plus one that was under construction in Beijing, and a similar six in Tianjin. After the earthquake 12 completed buildings were investigated. They included 4 warehouses, 3 markets, 3 chemical installations, and 2 multistory mill buildings for light industry built in 1968. The floor area of these buildings was more than 33,000 m² and the highest was 5 stories or about 23 m high. They had unbonded pre-stressed reinforced concrete slabs, ordinary reinforced concrete slabs, or a crossbeam system. Poured-in-place column caps, load bearing keys, shear blocks and other forms were used, and floors had both uniform loads and large concentrated loads. The architectural layouts of an open pattern, inner spacious pattern, and a pattern with inner partition walls were used. Except that there was no curtain wall in the 2nd union installation solvent retrieve pump house of Beijing Dongfanghong oil refinery and chemical fertilizer decompose evaporate workshop of the capital steel mill and that the curtain walls were built on floors in Tianjin Great Wall radio factory, in other 9 buildings there were out built curtain walls and girds connecting with floors.

One half of the 12 lift-slab structures were situated in Tianjin in an intensity VIII area and the other 6 were in Beijing in an intensity VI area. Anti-earthquake design was not considered except at the 902nd warehouse of the Tianjin Telecommunication Bureau where after the earthquake the main structure was basically intact only the staircases, elevator shafts and curtain walls were damaged to various degrees. In Tianjin the curtain walls in one structure collapsed, in two the walls were seriously damaged, one was slightly damaged, and two were basically intact while in Beijing the curtain walls, staircases and elevator shafts of 6 such buildings were all fundamentally intact. Independent cantilever columns in 2 lift-slab structures under construction were not damaged at all. At the chemical fertilizer lift-slab structure of the Beijing Xiangyang Chemical Plant with large concentrated loads no damage was found. The damages are shown in Table 1.

In Table 1 it can be seen that the main characteristics of damage to lift-slab structures in Beijing and Tianjin were as follows:

(1) Except for 1-3 circular cracks that appeared on columns in the top story of the 902nd warehouse of the Tianjin Telecommunication Bureau, the columns of other lift-slab structures were all intact.

(2) Floors of the lift-slab structures were all intact even those with large openings or with large concentrated loads.

1 China Academy of Building Research
2 Tianjin Institute of Architectural Design
B. Examples of Damage

(A) 902nd Warehouse of the Tianjin Telecommunication Bureau

1. Layout of the building structure

This warehouse was situated on the 8th Latitude Road of Hedong District in Tianjin. The soil at this warehouse was Class II consisting of 1.5-2.5 m of loose miscellaneous fill and below it was quaternary deposit cohesive soil. The soil was uniform without unfavorable soft soil. During construction the miscellaneous fill was cleared away and plain fill compacted by layers was employed. Concrete poured crossbeam foundations with embedded depth of 2.5 m were used for the main structures of the warehouse but reinforced concrete strip foundations were used under the curtain walls. The plan and profile of these structures are shown in Fig. 1.

In this warehouse 300# pre-cast reinforced concrete columns were used with cast-in-site concrete slabs, and 300# concrete poured-in-place column caps at joints between floors and columns were used. 240 mm thick exterior walls were built with #100 brick and #50 mortar and each floor and the roof slab were connected to the walls by φ6 connection rebars @200 mm. There was no earthquake separation between the staircases of the original warehouse with the inner frame structure.

Quality was affected because the walls were built and column caps were poured in winter. Besides, due to limitation of construction conditions the column caps at the roof were not poured according to the design requirements.

2. Damage

During the earthquake this warehouse was not being used and there were no goods in it. After the earthquake the floors of the 2nd and 3rd stories were intact and cracks due to differences of lifting did not expand; 1-3 0.05-0.1 mm wide horizontal circular cracks about 20-70 cm above the floors generally appeared on columns in the top story. The filler concrete at joints between slabs and columns fell off and displacement was found between slabs and load bearing keys (Photo 1).

Brick curtain walls at this warehouse were seriously damaged, i.e. diagonal cracks with 1 cm width appeared on the north gable wall and vertical cracks were found at the connection of longitudinal and transverse walls. A V-shaped crack was found at the corner of the longitudinal and transverse walls at the top of the 3rd story and part of the corner collapsed.

There were horizontal cracks at the levels of the upper and lower edges of window openings on two longitudinal walls and this phenomenon was more serious on the 3rd story than on the 1st and 2nd stories (Photo 2). Obvious X-shaped cracks were found on most of the walls between two windows and they were more obvious on the 1st story than on the 2nd and 3rd stories. Since the connection rebars at the sides of slabs were not thoroughly anchored to the bond beam 2 cm seams were produced between bond beams and slabs on the 2nd and 3rd floors.
The connection of the two warehouses on the south gable wall, which was also the side wall of the staircase of the adjacent original warehouse, diagonal cracks appeared and the walls were seriously damaged so that part of the eave walls and parapet walls collapsed and the asphalt felt roofing separated due to tension.

(B) Chenlinzhong Warehouse of the Tianjin Branch of the China Textile Import and Export Corporation

1. Layout of the building structure

This warehouse was situated in Chenlinzhuang in the Hedong District of Tianjin. The site soil at this warehouse was Class II consisting of 1.0-2.0 m of filled clayey soil and filled fly ash at the surface, and quaternary deposit clayey soil below; the layers were uniform without unfavorable soft soil. During construction the filled clayey soil and fly ash were cleared away and replaced with plain soil compacted in layers to the design level. R.C. crossbeam foundations were poured to a 2.0 m depth. The plan and profile of the structure are shown in Fig. 2.

Pre-cast reinforced #300 concrete columns, #300 concrete pre-cast at site reinforced concrete slabs and 400# concrete poured-in-site column caps at joints between the slabs and the columns were used. The original design considered earthquake resistant requirements of intensity VII. Between the northeast and southwest corner columns of the warehouse, earthquake resistant walls 200 mm thick were poured with 150# concrete from preset holes in slabs (Fig. 2), but on the 3rd story they were not poured due to difficulty of construction. Curtain walls 240 mm thick were built with 100# bricks and 50# mortar and on every story all the floors and roof slabs were connected to bond beams.

2. Damage

This warehouse was situated on the east side of the Tianjin urban district in an area of intensity VIII. At the time of the earthquake this warehouse was not being used and there were no goods in it. After the earthquake there was no damage to slabs, columns and joints of the main structure. On post-poured earthquake resistant walls some 45° oblique cracks with a maximum width of 0.1 mm appeared and they were more serious on transverse walls than on longitudinal walls. Figure 3 is a sketch of cracks on transverse earthquake resistant walls at the southwest end.

The story height of this warehouse was high and longitudinal walls were 60 m long but there was no connection between these walls and the main structure except for the connection rebars into slabs. After the earthquake the walls were seriously damaged, i.e. the west gable walls on the 2nd and 3rd stories collapsed entirely, and the wall on the 1st story mostly collapsed and on the remaining wall there were oblique cracks 5 cm wide (Photo 3). The north longitudinal wall that connected with the west gable wall partly collapsed. There were X-shaped cracks on the south and north longitudinal walls between windows and horizontal cracks level with the upper and lower edges of window openings. Bond beams in exterior walls with rebar connection at sides of floors collapsed with the walls and turned and separated outward. Photo 4 shows turning and separating of the bond beams at the 2nd floor of the west gable wall; the maximum torsion angle was up to 30°.
The landing beam of the staircase at the east end of the warehouse was simply supported on brackets of the reinforced concrete buttress pier of the east gable wall. After the earthquake the brackets were broken and adjacent walls pounded each other and broke down (Photo 5). A portion of the pre-cast slabs of the staircase collapsed and cracks on the walls were serious.

After the earthquake all the walls were removed and rebuilt, 240x360 mm buttresses were added, window openings became smaller, and a bond beam was added under the windows. Earthquake resisting walls on 3 stories were added, the rebuilding work was finished in the last ten days of October but the new brick walls collapsed again during the Ninghe earthquake of magnitude 6.9 on 15 November of that year.

(Translator: Jin Guoliang)
Table 1. Damage to lift-slab structures.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Condition of Structures</th>
<th>Damage to Main Structure</th>
<th>Damage to Auxiliary Structures</th>
<th>Degree of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Warehouse of the Publishing Office in Beijing</td>
<td>Plan dimension: 20.0×42.0 m, Class II site soil, crossbeam reinforced concrete foundation; column layout: 5.5×5.5 m; cross-section: 500×500 mm, 4 stories high; thickness of slabs: 18 cm, poured-in-place column caps, 240 mm brick curtain walls only built to 3rd floor; Design load: 2,000 kg·f/m². Main structure was built during the earthquake.</td>
<td>No damage</td>
<td>370 mm thick brick walls on 1st story were fundamentally intact but on 2nd story V-shaped cracks appeared on walls at four corners, west wall inclined, obvious X-shaped cracks and diagonal cracks were found and individual walls between two windows cracked into pieces.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td>Butyl Octane-Cobalt Catalyst Warehouse of the Beijing Xiangyang Chemical Plant</td>
<td>Plan dimension: 10.2×27.8 m, Class II site soil, independent column foundations; column layout: 6.0×6.0 m; cross section: 400×600 mm, 3 stories high; thickness of slabs: 10 cm, steel keys and steel brackets, 370 mm thick brick curtain walls; design loads: concentrated loads, manufacturing carried on during earthquake.</td>
<td>No damage</td>
<td>Thin horizontal cracks were found at joints between walls and side beams on 2nd and 3rd stories, and walls separated themselves from beams.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td>2nd Union Installation Solvent Retrieval Pump House of the Beijing Dongfanghong Oil Refinery</td>
<td>Plan dimension: 9.5×51.3 m, Class II site soil; pile foundation: independent column footings and joining beams. Column layout: 6.0×6.0 m; cross-sections: 400×600 mm, 3 stories high; thickness of slabs: 20 cm. Great concentrated loads on slabs with many openings, shear block joints 240 mm thick brick curtain walls only on 1st story; design loads: 20-26 t equipment loads. This building was used during the earthquake.</td>
<td>Structures were not damaged and equipment did not displace</td>
<td>Brick curtain walls on 1st story were intact.</td>
<td>Intact</td>
</tr>
</tbody>
</table>
Table 1. Continued.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Condition of Structures</th>
<th>Damage to Main Structure</th>
<th>Damage to Auxiliary Structures</th>
<th>Degree of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing Huashi Department Store</td>
<td>Plan dimension: 19.6×31.6 m, Class II site soil, independent column footings; column layout: 6.0×6.0 m; cross-section: 400×400 mm, there was a settlement joint between this building and the Huashi Xinhua Bookshop, 4 stories high; thickness of slabs: 18 cm, poured-in-place column caps, brick curtain walls; design load: 400 kg·f/m², the building was used during the earthquake.</td>
<td>Intact</td>
<td>Obvious horizontal cracks appeared between inner partition walls and floors on the 3rd and 4th stories and between walls on staircases and top floors. Oblique cracks were found at the upper edges of doors and window openings on the 1st story.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td>Beijing Huashi Xinhua Bookshop</td>
<td>Plan dimension: 19.6×33.1 m, Class II site soil, independent column footings; column layout: 6.0×6.0 m, cross-section: 400×400 mm, 4 stories high; thickness of slabs: 18 cm, poured-in-place column caps, brick curtain walls; design load: 400 kg·f/m², the building was used during the earthquake.</td>
<td>Intact but only on 3rd and 4th stories of the warehouse traces of white wash falling off around the poured-in-place column caps was found.</td>
<td>There were horizontal cracks at the upper edges of the windows on the north walls between two windows of the warehouse on the 3rd and 4th stories, and horizontal hairline cracks were found at the lower edges of windows on the north walls between two windows of the bookshop on the 3rd and 4th stories. Horizontal cracks appeared between brick partition walls and floors, and horizontal hairline cracks only appeared on gypsum partition walls on the 4th story, the others were fine.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td>Decompose Evaporate Workshop of the Chemical Fertilizer Plant of the Capital Steel Mill</td>
<td>Plan dimension: 9.0×17.5 m, Class II site soil; column layout: 5.0×6.0 m; cross-section: 400×600 mm, 3 stories high, this building was connects with reinforced concrete tower through steel trestle. Shear block joints. Brick curtain walls only on the 1st story; design load: 300 kg·f/m², maximum concentrated load: 10 t, production stopped during the earthquake.</td>
<td>Structures were intact, equipment did not displace.</td>
<td>Brick walls on the 1st story were intact.</td>
<td>Intact</td>
</tr>
<tr>
<td>Structure</td>
<td>Condition of Structures</td>
<td>Damage to Main Structure</td>
<td>Damage to Auxiliary Structures</td>
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<tr>
<td>Workers, Farmers and Soldiers Market in Tianjin</td>
<td>Plan dimension: 21.6×26.2 m, Class II site soil with 3.2 m high basement; column layout: 6.3×5.2 m; cross-section: 400×400 mm, one side of this building was connected to the original market but without joining and earthquake separation. 3 stories high; thickness of slabs: 18 cm, load bearing key joints, 240 mm thick brick curtain walls. Design load: 40.0 kgf/m²</td>
<td>Floors, columns and joints were intact, the crack due to lifting error and the displacement from over loading on 3rd floor did not develop further.</td>
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<tr>
<td>Tianjin People's Library</td>
<td>Plan dimension: 10.0×19.6 m, Class II site soil, with basement; column layout: 6.0×5.2 m; cross-section: 400×400 mm, 6 stories high; thickness of slabs: 18 cm, load bearing key joints, 240 mm thick brick curtain walls; design load: 800 kgf/m². During the earthquake, the cracks on walls between two windows on the 2nd story, upper and lower horizontal cracks at window openings were found but cracks on the 3rd story and above were rare. The books on bookshelves over turned entirely on the 3rd story while on the 6th story bookshelves swung out about 1 m but did not overturn due to obstruction of end plates.</td>
<td>Floors, columns and joints were all intact and no settlement was found on foundations.</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Lightly damaged</td>
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<tr>
<th>Structure</th>
<th>Condition of Structures</th>
<th>Damage to Main Structure</th>
<th>Damage to Auxiliary Structures</th>
<th>Degree of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top Hat Workshop of the Tianjin Hattery</strong></td>
<td>Plan dimension: 20.6×43.94 m (divided into two parts), Class II site soil, reinforced concrete cross beam foundation. Column layout: 6.0×6.0 m, cross-section: 450×450 mm, 4 stories high; thickness of slabs: 15 cm with poured-in-place column caps. 240 mm thick brick curtain walls with 240×270 mm brick buttresses; design load: 500 kgf/m². Part of this building was used during the earthquake. After the earthquake measuring periods were $T_L=0.54$ sec. $T_t=0.5$ sec.</td>
<td>No damage was found on floors, columns and joints and no abnormal phenomenon was found at prestressed anchors and joints.</td>
<td>There were oblique and horizontal cracks at connections of ends of longitudinal and transverse walls on the 2nd and 3rd stories and oblique cracks at the upper edge of door and window openings. Between walls and floors on the 4th story there were circular hairline horizontal cracks and on walls of staircases at two ends on every story oblique cracks were found and this phenomenon was more serious on lower stories. The walls at connections between this building and the office building bumped each other and were destroyed. One of the elevator shafts over the roof of the building partly collapsed.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td><strong>Color television attached building of the Tianjin Great Wall Ratio Factory</strong></td>
<td>Plan dimension: 21.2×41.4 m, Class II site soil, cross beam reinforced concrete foundations; column layout: 6.6×5.0 m; cross section: 400×500 mm, 5 stories high; thickness of slabs: 20 cm with load bearing key joints, 240 mm thick brick curtain walls; design load: 800 kgf/m². During the earthquake this building was not used. After the earthquake measuring periods were $T_L=0.85$ sec. and $T_t=1.0$ sec.</td>
<td>Floors, columns and joints were fundamentally intact.</td>
<td>There were two horizontal cracks under the sills of longitudinal walls on the 2nd-5th stories and on part of the walls there were flat X-shaped cracks. Longitudinal joining beams between columns broke away from the joints. There were diagonal cracks on west transverse walls on the 2nd-4th stories from the bottom to the top of the story, on east transverse walls on the 1st story, and on walls of elevator shafts of a corner building on the 1st-5th stories. On most inner transverse partition walls of the building horizontal and X-shaped cracks appeared.</td>
<td>Lightly damaged</td>
</tr>
<tr>
<td>Structure</td>
<td>Condition of Structures</td>
<td>Damage to Main Structure</td>
<td>Damage to Auxiliary Structures</td>
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<tr>
<td>902nd Warehouse of the Tianjin Telecommunication Bureau</td>
<td>Plan dimension: 18.5×47.0 m, Class II site soil, crossbeam reinforced concrete foundations; column layout: 5.5×5.5 m; cross-section: 500×500 mm, 3 stories high; thickness of slabs: 22 cm. Poured-in-place column caps, 240 mm thick brick curtain walls; design load: 1,800 kg.f/m². During the earthquake this building was not used. After the earthquake measured periods were $T_L=0.4$ sec. and $T_T=0.43$ sec.</td>
<td>See damage example (1)</td>
<td>See damage example (1).</td>
<td>Moderately damaged</td>
</tr>
<tr>
<td>Tianjin Chenglinzhuang Warehouse of the China Textile Import and Export Corporation</td>
<td>Plan dimension: 21.0×57.0 m, Class II site soil, cross beam reinforced concrete foundations; column layout: 6.0×6.0 m, cross-section: 500×500 mm, 3 stories high; thickness of slabs: 20 cm with poured-in-place column caps, 240 mm thick brick curtain walls; design load: 1,500 kg.f/m², during the earthquake this building was not used. After the earthquake measuring periods were $T_L=0.52$ sec. and $T_T=0.63$ sec.</td>
<td>See damage example (2)</td>
<td>See damage example (2).</td>
<td>Moderately damaged</td>
</tr>
</tbody>
</table>
Photo 1. Offset between roof slabs and load bearing keys at the 902nd warehouse of the Tianjin Telecommunication Bureau.

Photo 2. Horizontal cracks along the upper and lower edges of window openings at the 902nd warehouse of the Tianjin Telecommunication Bureau.

Photo 3. Walls at the Chenlinzhuang warehouse of the Tianjin branch of the China Textile Import and Export Corporation collapsed.

Photo 4. Turning and separating of the bond beams on curtain walls of Chenlinzhuang warehouse of Tianjin branch of China Textile Import and Export Corporation.

Photo 5. Cracks on curtain walls at the Chenlinzhuang warehouse of the Tianjin branch of the China Textile Import and Export Corporation.
Figure 1. Structural plan of the 902\textsuperscript{nd} warehouse of the Tianjin Telecommunication Bureau.

Figure 2. Structural plan of the Chenglinzhuang warehouse at the Tianjin Branch of the China Textile Import and Export Corporation.

Figure 3. A sketch of cracks on the earthquake resistant walls of the Chenglinzhuang warehouse at the Tianjin Branch of the China Textile Import and Export Corporation.