I. Introduction

There were four trunk lines: Beijing to Shanhaiguan, Tianjin to Pukou, Tongxian to Tuozitou and Tianjin to Jixian and more than 100 branch lines including Tangshan to Zunhua, Hangu to Nanbao, etc. and there were special lines for mines and factories in the Tangshan region. The distribution of railways and seismic intensity is shown in Fig. 1.

The Beijing to Shanhaiguan Line, a Class I trunk line, was constructed by Britain and Japan in 1887, had a total length of 414.5 kilometers, all double lines. It was an important trunk line between the Northeast and the North, and the Northeast and central part of China. After the liberation rebuilding or reinforcing of some railway facilities of this line was done, consequently, the design standard, structural type and material, design data, and geology and foundation of this line were not known. Crossing the Jidong Plain the Beijing to Shanhaiguan Line was mainly laid on a smooth terrain of alluvium and diluvium with loose saturated fine sand stratum locally.

The Tongxian to Tuozitou Line, a Class I trunk line with a total length of 189.8 kilometers, was constructed from 1973 to 1976. To the west of Fengrun Station was smooth terrain and to the east was hilly land with better geological conditions and deep ground water.

The design standards, type of structure and material of the trunk line and branch line constructed after the liberation were uniform. All railway engineering in the Tangshan region was done with no consideration for earthquake resistant design. After the Haicheng earthquake in 1975 the Beijing Railway Bureau adopted some earthquake resistance measures for large and medium bridges which survived the Tangshan earthquake with only slight damage.

In the earthquake region rails, embankments and bridges were damaged to different degrees and collapsed buildings broke communications, electricity, water supply, and locomotive equipment, consequently, traffic was stopped as shown in Table 1.

A large amount of railway damage showed that the damage was closely related to the site condition, i.e. geology and hydrogeology mainly. The Beijing to Shanhaiguan Line, Tongtou Link Line and the Nanbao Special Branch Line were constructed on a saturated loose sand layer (Class III soil) with a high water table so embankments, bridges and rails of these lines were seriously damaged even if they were in an intensity VII region. On the contrary, in Tangshan

* The First Survey and Design Institute, Ministry of Railway
City, intensity XI, the railway located on dense soil (Class II) with deep ground water had embankments, bridges and rails that were slightly damaged.

The experience of rapid repairing of the railway in the seismic region indicated that bridges, which were difficult to repair, controlled opening of traffic. For example, the repair of the Ji Canal Bridge and the Luanhe Bridge controlled the Beijing to Shankaiguan Line and the Douhe River Bridge controlled the Tangshan to Zunhua Line. After repairs to the Beijing to Shankaiguan Line were made it was opened to traffic again on August 10, 1976. By September 16, 1976 the train velocity over a 287 kilometer section reached 60-80 kilometers per hour and over a 175 kilometer section reached 110 kilometers per hour, which was the level before the earthquake. But there were still 27 bridges that restricted travelling velocity to 15-60 kilometers per hour, which controlled transportation over this line. During the repair of railway lines most of the manpower was spent on bridges. But the repair of communication, signal, water supply, electricity and machinery, which were mostly broken by collapsed buildings, were easy to restore by taking temporary measures within a short time. Some data from the Beijing to Shankaiguan Line and the Tongxian to Tuozitou Line are shown in Table 2. This experience shows that the earthquake resistant design of railway bridges and buildings with important equipment (including communication, electricity, water supply and locomotive, etc.) is very important. During the repair and restoration of the Beijing to Shankaiguan Line and the Tongxian to Tuozitou Line stone ballast of 102,760 m³ and 20,000 m³ were used respectively.

II. Trains

When the earthquake occurred there were 28 freight trains and 7 passenger trains travelling on the railway; 7 freight trains and 2 passenger trains were turned over or derailed. A derailed train is shown in Fig. 1. No passengers were injured. On the damaged trains only part of the cars were turned over or derailed. The damaged trains are shown in Photos 1-4. The No. 40 express train partly derailed and the locomotive caught on fire (Photo 3).

Two locomotive drivers talked about what they experienced during the earthquake.

(1) Train No. 117, No. 0017 locomotive driver Ma Decai, deputy driver Wu Jian and trainee Liubaozhu said that the train was travelling at a velocity of 100 kilometers per hour on the section from Beitang to Chadian on the Beijing to Shankaiguan Line (intensity VII). They saw the signal mast shaking and the locomotive shook from right to left then the emergency brake was put on at once. The derailed locomotive is shown in Photo 1.

(2) Train No. 129, No. 4278 locomotive driver Zhang Yaowu and deputy driver Han Zhonghua said that the train was travelling at a velocity of about 90 kilometers per hour to Guye Station (intensity X) at 3:40 a.m. in the morning. They saw flashes of lightning, the locomotive shook up and down and then right to left, the emergency brake was put on and the train stopped at 3:43 a.m.

III. Rails

Damage to rails on loose foundation soil can be divided into two types:
(1) Embankments which had a height of more than 2 meters were generally damaged causing the rail to become deformed both in profile and in plan. A typical section was located on the uplink line (plan as shown in Fig. 7, profile as shown in Fig. 8) from Tongxian to Tuozitou (intensity IX area). It was founded on loose saturated fine sand and the height of the embankment fill was about 2-14 meters. The embankment was damaged and the rail was seriously deformed during the earthquake (Photos 5 and 6) but at section K0+920-K1+350 of this line the railroad was located on a sandstone cut and the rail was undamaged (see Photo 7).

(2) Some of the embankments that had a height lower than 2 meters were damaged. The ground surface deformed during the earthquake causing the rail to bend seriously in plan and slightly in profile. Near the Beitang Station on the Beijing to Shanhaguan Line (intensity VII area) the bent continuous rail is shown in Photo 8. The Nabao Branch Line (intensity VIII) was used for salt transport from Hanggu to Lutai. It was a total of 33.7 m in length built on a saturated silt layer with a shallow ground water table (<1.0 m). The embankment height was only 1 to 2 m, water and sand spouts occurred at the foot of the embankment (Photo 9) and the rail bent (Photo 10). There were 32 bent rails with a maximum rise of 1.56 m on this 33.7 m branch line as shown in Table 4. Figure 2 shows the rail bending on the Nanbao Branch Line from K1+650 to K1+703.1.

At the Lutai Station yard (intensity IX) on the Beijing to Shanhaiguan Line water and sand spouting occurred (Photo 11) causing some rails to bend (Photo 12 and Fig. 3)

At Xugezhuang Station (intensity X) and at Tangshan Station (intensity XI) the foundation soil was dense and stable; the ground water was deep (Tangshan Station, 4.7-6.3 m) and the rail was basically intact even in the epicentral zone (Photos 13 and 14).

IV. Road Subgrades and Retaining Walls

Most of the railway subgrade in the Tangshan earthquake region were embankments with a few cuts and retaining walls. During the strong ground motion the railway subgrades were seriously damaged which interrupted traffic on the Jing-Shan, Tong-Tuo, Tong-Tuo Up-link and Nanbao lines, etc. (Table 1). The distribution of embankment damage to all main lines and branch lines is shown in Fig. 4. In the restoration of these embankments over 100,000 m³ of stone ballast and rubble was used and approximately 1.5 kilometers of steel rail was replaced.

The following describes earthquake damage to railway subgrades.
1. Embankments

In the Tangshan earthquake region the embankment height is about 1-3 m, 4-11 m in some special sections and the tallest is 14 m on bridge approaches. Cohesive soil is mostly used as filling material and silty, fine and medium sand is also used in some places.

The degree of damage to embankments was clearly related to the intensity of ground shaking, site condition (mainly geology and hydrogeology), embankment height and filling material, etc. (Table 5). The embankment damage phenomena mainly included sinking, cracking, slope sliding and cave-in, etc. Some took place individually but many occurred simultaneously. Embankment subsidence is a general damage case. Generally, the embankment subsidence took place in soft clayey soil and liquefied sandy subsoil. Especially in liquefied sandy subsoil a great deal of sinking and cave-ins occurred within a short section so as to severely damage the embankment. There were many cases of rail suspending, lateral displacement, bending and distorting, etc. as a result of the embankment subsidence. But at rock or dense soil sites damage to the embankment was reduced. Tables 6-9 show embankment damage on the Jing-Shan and Tong-Tuo lines, etc.

1) Examples of damage to embankments on soft cohesive soil foundations

On the Jing-Shan Line from Tanggu to Chadian (K178+000-K203+000) and on the Nanbao Branch Line the soil consists of marine deposit with mucky sandy clay or clayey sand or clay with silty fine sand. The ground water table is shallow. According to the information from the foundation drilling test at the Yongdingxin River Bridge on the Jing-Shan Line (K194+48) and at the Douhe River Bridge on the Nanbao Branch Line, the physical mechanical index of the soft cohesive soil is similar to soft soil as presented in Table 10.

(1) From Beitang Station to the Yongdingxin River Bridge on the Jing-Shan Line (K190+100-K193+800), the embankment was founded on soft cohesive soil with a shallow ground water table and a salty surface layer. The embankment was 1-3 m high built with cohesive soil, the slope foot extended into the water and was located in an intensity VIII zone. Vertical cracks between the slope foot and ground surface occurred after the earthquake (Photo 15). The subsoil deformation caused the embankment to sink and crack. For example, at the K190+000-K192+850 section the longitudinal cracking at the embankment slope foot totaled 2.8 km, the worst was found at K191+796 with a crack width of 10-30 cm (maximum 50 cm), the height difference was 10-15 cm (maximum 40 cm) (Photos 16 and 17).

At the Beitang Railway Station the embankment of the No. 1 to 8 tracks sank about 100 cm and the rail moved 50 cm in a cross direction (Fig. 5). At the No. 9, 12, 14, 16, and 17 turnout areas the maximum sinking of the embankment was up to 150 cm which caused the turnout to become suspended and the spikes to rise. The station site fill sank irregularly (a maximum of 60-80 cm) which made the station platform uneven. On the south side of the No. 1 track the maximum crack width of the embankment was up to 50 cm.

At the Tanggu Station and Tanggu South Station most of the embankment for all the special branch lines of factories and enterprises sank about 50 cm. The rail gap increased about 8 cm, the rail bent and distorted and moved horizontally.
(2) The Nanbao Branch Line was located in the seashore region (Fig. 4) on low-lying land. The embankment foot extended into the sea during high tide season. The embankment was built with cohesive soil and founded on mucky sandy clay or clayey sand with a silty fine sand layer and the height was 1-2 m with a shallow ground water table. Because the silty fine sandy soil liquefied in the intensity VIII area, water ejected and sand boiled at the embankment shoulder on both sides (Photo 9). After the earthquake it was found that the ground surface sank evenly and in some areas with a loose slope slide. Near the entrance of the Xiejiafen Station a ground fissure about 65 m long and 40 cm wide crossed the road subgrade (Photo 18).

2) Examples of damage to embankments on liquefied sand foundations

The embankment subgrade on loose saturated silty and fine sand layers was liquefiable. It caused water and sand boiling, subgrade subsidence, embankment settlement and cracking and other serious damage.

(1) On the Kaiping to Guye section of the Jing-Shan Line (K277+000-K284+000), intensity X, the embankment was 1-3 m high filled with cohesive soil and founded locally on loose saturated silty fine sand. Due to liquefaction during the earthquake 18 segments of the embankment (including the bridge approach) sank over an accumulated length of 3 km amounting to 40% of the total length in this section. K281+750-K282+088 (350 m long) and K283+300-K284+400 (about 1,000 m long) were damaged most seriously on the Jing-Shan Line. For example, the K281+750-K282+088 embankment which was about 4 m high settled 3.4 m (Photos 19 and 20). The embankment was located on an old course of the Shiliuhe River (Fig. 6) which was deposited by a saturated silty fine sand layer and the ground water table was 1.25 m. The liquefaction depth was 6.3 m which was determined by a standard penetration test. After the earthquake the ejected water and sand was near the slope foot (Photo 21), the embankment sank, cracked and caved-in, the row of trees on both sides inclined toward the center of the tracks (Photo 20).

(2) On the Tong-Tou Up-link Line from Jiugezhuang to Tuozitou, a total length 5.06 Km, the plane diagram shown as Fig. 7 was built in 1973. The line crossed the old course of the Yi River, the ground water table was 0.5-1.0 m, the subsoil was sandy clay or clayey sand in 0-4 m of stratum, from 4 m down there was a loose saturated silty fine sand layer according to the standard penetration test, and the liquefaction depth was 6.5 m as shown in Fig. 8. The embankment height was 3-14 m filled with local soil and the slope was 1:1.5. At the K1+800-K3+500 section the embankment was built with silty fine sand with 20 cm of thick red cohesive soil for slope surface protection. At the K2+504-K3+150 section the embankment could be submerged by the Yi River flooding, the upstream slope was revetted by rubble 25 cm thick, the downstream slope was revetted by a row of trees, the design diagram is shown in Fig. 9. During the ground shock water and sand spouted near the slope foot on both sides (Photo 22). After the M7.8 earthquake, in an intensity VIII area there was no obvious damage to the embankment section. But during the dusk of that day an M7.1 earthquake occurred (intensity IX) and the road embankment settled about 2-3 m and the line was seriously damaged. Especially, the embankment which was filled with silty fine sand and revetted by a red cohesive soil protection layer sank, cracked, the protection slope slid and dropped, and the track distorted and transversely moved or suspended (Photo 23). At the K1+800-K3+500 section which was about 2 Km long, on the basis of the profile and cross section surveyed after the earthquake, the line...
sank more than 2 m, the slope slid and changed to 1:2.25, and the center line displaced 0.8-1 m transversely. The line profile is shown in Fig. 8 and the surveyed cross section is shown in Figs. 10-12.

(3) On the Jing-Shan Line from Tangfang to Xugezhuang (K243+000-K245+000 and K246+000-K253+000) the embankment height was 1-3 m filled with sandy clay. On the west slope was the Meishui River which could float small boats; and on the east side was an irrigation ditch which had water all year. According to the survey information from September 1981, 4 m of the underground surface was cohesive soil, below that there was mucky sandy clay with silty-fine sand intercalated layers, and the ground water table was 1.0-1.5 m. It was located in an intensity IX-X zone. The embankment, about 9 km long, settled and cracked intermittently. The slope slid and slumped and the general subsidence was 30-60 cm with a maximum of up to 100 cm. Due to sliding of side slopes of the embankment along the river 2-3 longitudinal cracks formed at the slope foot and on the shoulder of the road. The crack width was 20-30 cm and the soil block between two cracks caved in by 15-20 cm (Photo 24, Fig. 13).

In addition, the shoulder of the road slid, settled and cracked on the K249+600-K249+800 section which was about 200 m long. The sliding amounted to 90-100 cm and the track was bent in an S-shape (Photo 25).

(4) Damage to bridge approaches was more universal. Statistics showed that the bridge approach damage on the Tanggu to Changli section on the Jing-Shan Line was about 57% of the total amount of embankment damage (Table 6) and on the Beiliuzhuang to Tuozitou section, and on the Tong-Tuo Line it was 55% of the total embankment damage (Table 7). On the Tong-Tuo Up-link Line all the bridge approaches from the No. 1 to No. 10 bridges sustained earthquake damage, especially at K2+600 at the No. 6 bridge approach where the damage was the most serious which was located in an intensity IX zone, its original height was 12 m and it settled 2.3-3.0 m after the earthquake (Photos 26 and 27). On the Nanbao Special Line, located in an intensity VIII zone, the bridge approach settled 30-50 cm generally and the maximum was 80 cm. On the Tang-Zun Line at the Douhe River Bridge approach, in an intensity X zone, it sank and cracked and the riverbank slid toward the center of the river (Photo 28).

2. Cuts

In the Tangshan earthquake region there were few cuts. For the two cases investigated the cut slopes were intact. Namely, on the Tong-Tou Line K168+400-K169+400 the Qijialing cut section was about 1 km long; the dolomite slope height was about 12 m and the slope was 1:0.75 (Fig. 14). On the K169+000-K169+100 section in an intensity VIII zone the cut slope was of a diluvial soil layer with a good cohesive property, the height was 8 m with a retaining wall protection at the lower part. Both the cut slope and retaining wall were all intact (Photo 29). On the Tong-Tou Up-link Line on the K0+900-K1+350 section the cut was of weathered sandstone and shale layers, the height was 2-8 m and the slope was 1:1 (Fig. 15). It was intact during the two earthquakes of intensity VIII and IX (Photo 7).

3. Retaining walls

In the Tangshan earthquake region there were few supporting and retaining walls along the railway line but there were some retaining walls used in subways cut across the railway and
highways, railway embankment shoulders, station platform walls and waterlogged protection walls. The retaining walls were 2-7.5 m high built with good construction quality masonry. They were slightly damaged after the earthquake as shown in Table 11.

1) The railroad shoulder retaining wall

On the Jing-Shan Line, K267+374, the shoulder retaining wall of the No. 74 bridge was founded on cohesive soil which connected the abutment of the Shanhaiguan end of the upstream side and was 3-4 m high, 9 m long, built with masonry, filled with cohesive sand with 23° of internal friction and 0.45 Kg/cm² of adhesion and was located in an intensity X zone. After the earthquake the wall slipped outward about 20 cm (Photo 30) but the road shoulder wall which connected the abutment on the Tangshan side was undamaged.

2) The station platform wall

On the Nanbao Branch Line, K7+750, the station platform wall at the Xiejiafen Station was 1.2-1.5 m above the ground surface, built with masonry, and founded on mucky sandy clay intercalated with silty fine sandy soil with shallow ground water. In an intensity VIII zone, water and sand spouted in front of the wall and covered the track. The ground sank unevenly after the earthquake, and the wall cracked along the mortar joint and collapsed locally (Photo 31).

3) Highway cut retaining wall

(1) On the Tong-Tuo Line the subway cut wall of the Fengrun Station’s east end was 2-4.5 m high and the foundation depth was 1.1 m. The cross section shown in Fig. 16 was built in April 1976 and was founded on dense fine and medium sand with a deeper ground water table. The backside soil was sandy clay, built with masonry and grade 50 mortar with better construction quality, it sustained intensity VIII and was undamaged (Photo 32).

(2) In Tangshan City the retaining wall of the Yunhong subway cut was 2.8-7.5 m high, was embedded 0.8-3.0 m underground and was constructed with masonry. The foundation was 30 cm thick, built with C50 concrete and paved with rubble. The subsoil was clay (layer thickness 2-3 m) intercalated with a thin fine sand layer with 5-6 m to ground water table. The wall which was located in the extreme earthquake region of intensity XI was intact (Photo 33 and Fig. 17).

4) Highway shoulder wall

The shoulder wall of the Tang-Feng Highway Grade Separation Bridge over the railway was 3-7.4 m high, 582 m long with a 1.55 m deep foundation and was built in 1974 (cross section shown in Fig. 18). Located in an intensity VIII zone, the wall was undamaged after the earthquake (Photo 34).

5) Immersed retaining wall

(1) On the Nanbao Branch Line, K11+740, the retaining wall along both sides of the three-hole-culvert water entrance was 2-3 m high, 20 m long, built with masonry, founded on mucky sandy clay. After the intensity VIII earthquake there were three vertical cracks in the wall body with spacing of about 5 m (Photo 35).
(2) On the branch line of the Tangshan Steel Factory the 5 m high masonry road retaining wall along the Dou River was 3-4 m above the water level (water depth was estimated to be 1-2 m in front of the wall) (Fig. 19). The C140 concrete foundation was 30 cm thick founded on soft clay. Located in an intensity X zone, the wall was intact after the earthquake (Photo 36).

V. Bridges

The topography of the Tangshan earthquake area is flat, the subsoil is spongy, bridges are low in height and the forms of foundation are varied. All the bridges on the railway lines in this area are simply supported beam bridges with stone masonry or concrete gravity piers and abutments. The longest span of a steel truss bridge is 62.8 m and the highest pier is about 10 m. Among 850 spans of beam on the Beijing to Shanhaiguan Line, steel beams account for 74%. All other beams are reinforced concrete. The types of foundation are: spread foundations, wood pile foundations, a few open caisson foundations on the Beijing to Shanhaiguan Line, mainly bored pile foundations for big and mid length bridges on the Tongxian to Tuozitou Line, and wood pile foundations and reinforced concrete pile foundations on the Nanbao Special Line.

1. Statistics of earthquake damage

Statistical results of earthquake damage to bridges on trunk and branch lines within the earthquake area are listed in Table 12.

Brief descriptions of the bridge sites and damage to the railway lines are listed respectively in Tables 13-17 (there was no evident damage beyond the scope listed in the tables).

2. Characteristics of earthquake damage

It can be seen from the above mentioned statistics of bridge damage that the degree of damage to bridges was closely related to site conditions (mainly conditions of geology and hydrogeology) and the type of foundations. Damage to bridges with shallow ground water, loose subsoil and shallow foundations on some sections of the Beijing to Shanhaiguan Line, Tongxian to Tuozitou Up-Link Line and Nanbao Special Line was more and serious. But in the high intensity area of Tangshan City damage to bridges was less than in the lower intensity area because of the stable and dense ground with deep ground water. It can be seen from the earthquake damage distribution of railway bridges in the Tangshan region (Fig. 20).

On the Nanbao Special Line damage was generally heavier because the subsoil was a soft silty sandy clay. But when wood pile or reinforced concrete pile foundations were used the damage was less. Damage to bridge No. 6 at K2+600 and bridge No. 7 at K2+ 804 on the Tongxian to Tuozitou Up-link Line was more serious because the subsoil was saturated fine sand and a shallow embedded spread foundation was used. A piece of beam on bridge No. 6 fell down. It indicated that pile foundations have an anti-seismic effect on weak ground.

Due to the influence of the above factors, damage to bridges in the Tangshan earthquake showed the following characteristics:
1) Serious damage to bridges resulted from riverbank sliding

On soft or liquefied ground, when the slope of the riverbank is steep, sliding of the slope occurs easily during an earthquake. As a result, piers and abutments near the bank will move toward the middle of the river thus, the length of the bridge will be decreased. Damage related to displacement and breaking of piers, abutments, and foundations is very difficult to repair. Bridges where the riverbank slid are listed in Table 18.

2) Damage to abutments is more than to piers

Table 19 shows a percentage of statistics of damage to piers and abutments for some bridges on railway lines in the earthquake area. It can be seen that the percentage of earthquake damage to abutments is nearly twice that of piers because of the influence of bank sliding.

3) Subsidence of bridge approach embankments is a universal damage phenomenon

An abutment is a structure which connects the bridge and embankment. It is usually constructed of stone masonry or concrete with an independent foundation. But the embankment of a bridge approach is an earth structure which naturally subsides during an earthquake. This is a phenomenon hard to prevent. Typical data of subsidence of approaches are listed in Table 20. The maximum subsidence is up to 3.0 m. Subsidence of approaches caused damage to taper and abutment fill, and caused rail hanging and suspension of service. Photo 37 is one example.

4) Bridge bearing damages

Damage to bridge bearings was mainly caused by large displacement of piers and abutments. Piers and abutments displaced greatly on soft ground which lead to serious damage to bridge bearings. For example, rollers on movable bearings inclined and dislocated, and anchor bolts of bearings sheared (Photo 38).

5) Beams displaced transversely

The most striking example of a beam moving crosswise (perpendicular to the railway line) was on the Tongxian to Tuozitou Up-link Line. Seven of the nine bridges displaced crosswise accounting for 78% (Table 21). Maximum displacement was 210 cm and one of the beams fell into the river. Transverse displacement of these bridges occurred in the magnitude 7.1 earthquake. The macro-intensity of this earthquake on the Tongxian to Tuozitou Link Line was IX. This section of line is a curve in plan. The epicenter was located inside the curve and most of the beams moved towards the outside of the curve (Photos 39 and 40).

6) Untreated concrete construction seams slid

Most of the concrete piers and abutments were damaged in untreated construction joints, which caused the piers and abutments to break, dislocate and the concrete to locally break into pieces. On the Tangshan to Zunhua Line K2+955 at the Douhe River Bridge the abutment on the Tangshan side, pier No. 1 and No. 2, were all sheared at the concrete construction joints, as shown in Photo 41. But at this same bridge the abutment on the Zunhua side was constructed continuously, thus, no construction joints existed, it was intact as shown in Photo 42. For piers and abutments on the Beijing to Shanhaiguan Line, Tongxian to Tuozitou Line and Tongxian to Tuozitou Link Line, the damage happened mostly at untreated construction joints as shown in
Photo 43. Damage to piers and abutments with stone masonry usually happened in mortar joints as shown in Photo 44.

3. Typical examples of damage

1) New Yongding River Up-line Bridge at K194+048 on the Beijing to Shanghaiguan Line

Built in 1971 this superstructure had pre-stressed concrete beams of 23.8 m and had 20 spans. It had a gravity pier with a side-wall abutment. Topographical conditions were not good, silty sandy clay was buried about 12 m underground. Pier Nos. 1-11 and pier No. 19 had foundations with four bored piles of diameter 105 cm, the pile length was 32.5 m. Pier Nos. 12-18 had foundations with eight steel-pipe piles of diameter 80 cm and the length was 28.0 m. Both abutments had foundations with four bored piles of diameter 105 cm and length 30.0 m.

This bridge is located in the Tangshan earthquake area of intensity VII as shown in Figures 21-22. The riverbank slid when the earthquake occurred, the bridge length shortened 1.126 m, the Beijing abutment moved 0.54 m forward, the clearance between two beams squeezed together, the top of the abutment inclined, and eight anchor bolts were cut on the top side of the bearing (Photo 45). The clearance between two beams on pier No. 2 was compressed and concrete at the beam ends shattered. Bearings on pier Nos. 6-11 were normal. Pier No. 12 moved 0.139 m towards the middle of the river. Pier No. 13 moved 0.078 m, the movable bearing of the 13th beam on pier No. 13 fell down, bolts on the anti-seismic plate were cut, and the clearance between two beams was enlarged to 0.32 m (Photos 46 and 47). A fixed bearing on pier No. 15 moved 2.0 cm towards the middle of the river and four anchor bolts were cut. A fixed bearing on pier No. 16 moved 7.5 cm towards the middle of the river and eight anchor bolts were cut (Photo 48). A fixed bearing on pier No. 17 moved 2.0 cm towards the middle of the river and eight anchor bolts on the bottom side of the bearing were pushed and bent. In all, 52 anchor bolts of bearings were sheared on this bridge. The Shanghaiguan abutment moved 0.59 m towards the middle of the river. The approach embankment of both ends of the bridge subsided about 1.0 m. The riverbank slid. Cracks occurred on the embankment 18-29 m behind the Beijing abutment and 22-29 m behind the Shanghaiguan abutment (Photo 49).

2) Ji Canal Bridge at K210+827 on the Beijing to Shanghaiguan Line

This bridge was built by the Japanese from 1940 to 1941. There were two spans of top bearing steel plate girders of 20.7 m and two spans of pass-through steel trusses of 63.7 m in the superstructure of the bridge. It consisted of concrete gravity piers and abutments as well as an open caisson foundation. The depth of the open caissons of both abutments and piers Nos. 1 and 3 was 8.9 m. And the depth of the open caisson of pier No. 2 was 16.0 m. The subsoil, about 13 m deep under the ground surface of the bridge site was silty clay as shown in Figs. 23, 24 and 25.

The earthquake intensity at the bridge location was IX. The riverbank slid which caused the piers and abutments to move toward the middle of the river. The length of the bridge shortened 2.309 m. The bridge was seriously damaged. On the Beijing side the abutment moved 1.64 m and on the Shanghaiguan side the abutment moved 0.66 m towards the middle of the river. Pier No. 1 and No. 3 moved 2.43 m and 2.25 m towards the middle of the river respectively. A steel
truss was displaced on the pier top (Photos 50 and 51). The length of the bridge shortened. The rail on the approach embankment bent (Photo 52). After the earthquake pier No. 1 and No. 3 sank 0.58 m and 0.66 m respectively relative to pier No. 2 because of the shallow open caisson foundation, which made the profile of the bridge become an angle (Photo 53). There were cracks on the bank 6 to 30 m behind the abutment (Photo 54). The embankment of the bridge approach sank 1.4 m on the Beijing side and 0.8 m on the Shanhaiqian side. The abutment on the Beijing side sank 0.7 and the Shanhaiqian side sank 0.48 m. All of the bearings and anchor bolts were damaged.

3) Ji Canal Bridge at K210+827 on the Beijing to Shanhaiqian Down Line

The bridge was built by the English in 1887. Its superstructure was a one span I-shaped girder with a span length of 8.4 m, three spans of the deck bridge were steel plate girders with spans of 10.2 m, 10.0 m, and 16.0 m, and two spans were through steel trusses with a span of 63.45 m. The substructure consisted of gravity piers and abutments. The foundations were wood piles. The surface layer of the bridge site was silty clay. Sketches of the structure and damage distribution are shown in Figs. 26, 27 and 28.

The bridge was located in an intensity IX area. The banks slid. Piers and abutments moved towards the middle of the river. The length of the bridge shortened 2.372 m and the bridge was severely damaged. The bridge deck and rail on the embankment on the Beijing side were compressed and curved (Photos 55 and 56). The I-girder extended into the back wall of the abutment on the Beijing side up to 50 cm (Photo 57). The No. 6 steel plate girder stretched into the back wall of the abutment on the Shanhaiqian side 1.3 m (Photo 58). Pier No. 1 moved 0.99 m towards the middle of the river and broke 0.8 m under ground level. The I-girder was hanging by a rail (Photo 59). Pier No. 2 broke 1.2 m from the pier top (Photo 60). Pier No. 3 moved 1.215 m towards the middle of the river (Photo 61). Pier No. 4 in midstream was slightly damaged (Photo 62). The steel truss on pier No. 4 moved transversely 1.12 m towards the upper reaches of the river. The central line of the bridge structure was a broken line in plan. Pier No. 4 moved transversely 0.27 m towards the down reaches of the river. Pier No. 5 moved 1.734 m towards the middle of the river. All bearings and anchor bolts were damaged. Two movable bearings of the truss fell down into the river. Abutments and piers moved and tilted horizontally and transversely as shown in Fig. 26. The approach embankment on the Beijing side subsided 0.8 m and the Shanhaiqian side subsided 0.5 m. The physical and mechanical data of the soil layers at the bridge site according to the drilling results are shown in Table 22.

4) Luanhe River Bridge at K318+995 on the Beijing to Shanhaiqian Line

The Luanhe River Bridge was located between Luanxian and Zhugezhuang on the Beijing to Shanhaiqian Line. It consisted of two spans of concrete arches and twenty spans of 31.75 m deck bridge steel plate girders both up-line and down-line. The length of the bridge was 677.4 m as shown in Figs. 29 and 30. All foundations were caissons except for the Beijing abutment to pier No. 3 which was spread footings. Foundations of pier No. 1 to No. 9 and the abutment on the Beijing side were on a rock layer. Pier No. 10 and No. 11 were on cobble. Pier No. 12 to No. 21 and the abutment on the Shanhaiqian side was on clay.

When the magnitude 7.8 earthquake occurred the bridge site was in an intensity VIII area and damage to the bridge was slight. That afternoon during the magnitude 7.1 earthquake the
intensity reached IX, damage was more serious. The abutment on the Shanhaiguan side moved 18.3 cm towards the middle of the river and 5 cm downstream. The steel girder squeezed onto the back wall of the abutment and the back wall broke (Photos 63, and 64). The protective taper fill was damaged. The embankment fill on the Shanhaiguan side was 13.9 m high before the earthquake but the embankment subsided more than 1 m. Piers No. 10, 14, and 18 were sheared at the joint between the pier body and caisson top. Pier No. 10, which was damaged most seriously, moved 24 cm towards the Beijing side and 5 cm downstream. The width of the fissure of this pier was up to 1 cm. Pier No. 9 moved 18.8 cm towards the Beijing side and 7 cm towards upstream. It was found by excavating after the earthquake that damage existed between the supporting platform and caisson at pier Nos. 11, 12, 13, 14, 15, 17, 18, 19 and 21, and that damage existed between the supporting platform and pier body at pier Nos. 12, 16 and 20 (Photo 65); small cracks occurred at the bottom of the supporting platform of pier No. 20.

The bearings were seriously damaged. For instance, some anchor bolts of bearings were cut, some bearings overturned. A top plate bent and its bolts sheared, a tooth plate bent and its bolts sheared, a side plate bent and the middle plate dislocated, and the shaft nut separated, etc. The bearings of the 20th span were damaged most seriously. All the anchor bolts of movable bearings were cut. Bearings of the up-line were seriously damaged. Bearings of the down-line were less damaged. Seventy bearings of the bridge were damaged to various degrees. All steel plate girders from No. 9 to No. 20 moved longitudinally and transversely in varying degrees which caused the rail on the deck to curve in which the 20th girder moved 21 cm transversely and 15 cm longitudinally. The girder separated from its supports (Photo 66).

A 150 m embankment on the Beijing side subsided 0.6 m and a 300 m embankment on the Shanhaiguan side subsided up to 1 m. All taper rubble masonry with cement mortar and all slope protection of the embankment on the Shanhaiguan side were damaged.

5) Douhe River Bridge at K2+980 on the Tangshan to Zunhua Line

This bridge was built in 1970. The superstructure consisted of 3 spans of 16 m reinforced concrete beams (Fig. 31), gravity piers and abutments. The subsoil was soft. The foundations were laid on saturated silty and fine sand stratum. The central line of the bridge crossed the river in plan with 15°. The piers had foundations with four bored piles of diameter 100 cm, the length of the piles were about 24 m. Two abutments had spread foundations.

The bridge was located in an intensity X area. The saturated silty and fine sand stratum was liquefied when the earthquake occurred. With a standard penetration test it was estimated that the depth of the liquefied stratum was about 8 m underground. Foundations of the abutments were laid in the liquefied stratum. The two abutments slid towards the middle of the river together with the sliding bank. There were many fissures on both sides of the banks (Photos 67 and 68). The total length of the bridge shortened 3.73 m but the distance between the two piers did not shorten. The two piers broke along the concrete working joints and inclined toward the Tangshan side (Photo 69). Damage to the bridge after the earthquake is shown in Fig. 32.

The abutment on the Tangshan side broke into three pieces along the concrete working joints. The abutment moved 1.50 m towards the middle of the river (Photo 70).
The abutment on the Zunhua side moved 2.23 m towards the middle of the river. The body of the abutment did not break because the concrete was continuously cast in place and there was no construction joint (Photo 42). All anchor bolts of the bearings were cut. All beams stretched to the Tangshan side, the central line of the bridge became a broken line in plan. Transverse ribs of the beam ends were sheared. There was a clearance of 40 cm between two beams of one span. The entire bridge was damaged, thus, during the emergency repair a temporary bridge was used to recover traffic.

6) Bridge No. 6 at K2+600 on the Tongxian to Tuozitou Up-line

The superstructure of the bridge was a span of 23.8 m of pre-stressed concrete beams, a gravity abutment and spread foundations. The bridge was in a gentle curve; the maximum curvature radius was 600 m. The foundations laid on medium dense sand stratum. There was ground water. The load-bearing capacity of the stratum was 4.2 to 4.7 Kgf/cm². There was water in the river as shown in Fig. 33.

The bridge was located in an intensity VIII area during the magnitude 7.8 earthquake and the damage to the bridge was slight. That afternoon when the magnitude 7.1 earthquake occurred the intensity in the area reached IX, the saturated silty and fine sand stratum liquefied and water and sand spurted out from underground (Photo 71). The bridge was seriously damaged. The embankment of the bridge approach subsided about 3.0 m and some rails were hanging. The taper fill was seriously damaged (Photo 26). A piece of beam outside the curve fell down into the river (Photo 72).

The abutment on the Tongxian side was broken along the construction joints at the top of its foundations and 2.5 m above ground. Concrete at the lower reaches of the lower part of the abutment was broken vertically (Photo 73 and Fig. 33). The abutment on the Tuozitou side was broken horizontally along the concrete construction joints at the bottom of the ballast box, at the middle of the abutment and 1.3 m above the top of the foundation. There was a vertical joint in the middle of the foundation (Fig. 33). The abutment on the Tuozitou side inclined backward and the front of the abutment was higher than the back by 30.5 cm. The movable bearings inclined (Photo 74).

7) Bridge No. 9 at K3+278 on the Tongxian to Tuozitou Up-link Line

The superstructure of this bridge was a reinforced concrete beam with a span of 16 m. A highway passed under the bridge. The bridge had gravity abutments and spread foundations. The subsoil was fine sand and the bearing capacity was 2.5 Kgf/cm² (Fig. 34).

When the magnitude 7.8 earthquake occurred the bridge was slightly damaged. When the magnitude 7.1 earthquake occurred on that same day the intensity of the bridge site was IX and the bridge was seriously damaged. The beam at the lower reaches moved transversely and slid toward the margin of the abutment top. The space between the two pieces of beam was 125 cm on the Tuozitou side and 57 cm on the Tongxian side (Photo 75 and Fig. 34). Bearings and their anchor bolts were all damaged.

The ballast box was sheared along the construction joint. The concrete tray of the abutment was sheared horizontally (Fig. 34). The lower part of the abutment and its foundation moved
towards the middle of the river, the abutment tray moved 24 cm backwards, and the front of the Tongxian abutment became higher than its back by 26 cm.
4. Effective anti-seismic measures for bridges

1) Measure of joining beam ends

Before the Tangshan earthquake of 1976, under the jurisdiction of the Beijing Railway Bureau, measures had been taken to join beam ends in order to prevent beams on some big and medium sized bridges from falling.

(1) Reinforced concrete beam: Join the two beam ends with each other using steel bars of diameter 20 mm, so it will prevent the beams from moving longitudinally and falling down (Photo 76). But when the joint between the two beams was too narrow, compression would shatter the concrete (Photo 77).

Another method was to weld a steel bar of diameter 20 mm onto the upper plate of the bearings at the beam ends, which would bear tension forces only. As the strength was not enough, some steel bars broke (Photo 78).

(2) Steel plate girder: Join beam ends with steel side plates and retain certain room around the hole for the bolts for expansion or contraction so that normal usage would not be influenced. This measure can bear pulling forces and pressure. It was used successfully on the K266+ 962 Douhe River Bridge on the Beijing to Shanhaiguan Line. It prevented the two abutments from moving towards the middle of the river during the earthquake, thus, damage was reduced (Photo 79 and Fig. 35).

2) Paving of the riverbed

In order to protect the shallow foundation the riverbed of some small and medium sized bridges on the Beijing to Shanhaiguan Line were paved with rubble and cement mortar. It braced abutments horizontally during the earthquake and prevented abutments from moving towards the middle of the river. As a result, damage was reduced (Photo 80). In addition, because of the concrete deck for grade separation bridges there was less damage during the earthquake (Photo 81).

VI. Communication

1. Communication lines

1) Beijing to Shanhaiguan

From Tanggu (K178.8) to Shanhaiguan (K414.5) the communication line was an overhead open-wire structure with three rows of cross bar in the inter-region or five in the station according with the grade I strength of Ministry standards. The section from Tangshan to Beidaihe extended 208 km and the damage was as follows:

(1) Twisted wires caused communication not to work. There were 160 places where lines were twisted from Zhangguizhuang (intensity VIII, K150.5) to Lutai (intensity IX, K219.7) a distance of 69 km.
(2) Communication masts sank near loose and soft riverbanks. For example, the New Yongding River bridges (K194+048) i.e., No. 49 and No. 50 bridges from Beitang to Chadian, the communication masts No. 1272 to No. 1289 (intensity VII); from Chadian to Hangu, the Ji Canal Bridge, communication masts No. 1612 to No. 1616 (intensity IX); and Kaiping to Wali No. 77 bridge communication mast No. 412 to No. 440 (intensity X); all sank to various levels. Especially, communication mast No. 430 near the riverbank sank one third of its height. Communication masts No. 893 to No. 899 near the No. 97 Bridge in the section from Beijiadian to Leizhuang sank about one meter.

(3) Displacement of communication masts were caused by displacement of bridges. Communication masts No. 514 to No. 573 on the No. 82 Bridge (intensity X) were pushed laterally up to 0.15 meters.

(4) Communication masts inclined. From Tangfang (intensity IX, K242.3) to Xugezhuang (intensity X, K254.8) the communication masts inclined transversely caused by sliding of the embankment slope (Photo. 82). From Xugezhuang (intensity X, K254.8) to Tangshan (intensity XI, K264.4) and Tangshan to Kaiping (intensity X, K273.6), the top of the communication masts of No. 0 to No. 6 and No. 32 to No. 70 inclined to about <50 cm along the line direction, and masts No. 148 to No. 159 and No. 161 to No. 172, inclined 30-40 cm similarly.

2) Tongxian to Tuozitou

The communication line was an embedded cable type HYFLZ 7×4. Damage was more serious in the section from Fengrun (intensity VIII, K134.6) to Tuozitou (intensity IX, K189.8). The high-frequency line was suspended. After an investigation it was found that the cable was pressed at two places near K185.5 (intensity IX). One of them was compressed like a rope, the other like the letter "N" standing vertically. The experience in the Fengrun electrical section was that the embedded cables were damaged more seriously in the soil liquefaction region and where ground fissures occurred.

2. Communication equipment

Communication equipment was mostly damaged by collapsed buildings where the equipment was installed. The damage was as follows:

(1) One collapsed building in which all the equipment was destroyed. The equipment that was damaged in the laboratory of the Tangshan Station (intensity XI) included 500 telephone exchanges of type 47, three long distance stations of type CT-58, five 12-channel transformers, four 3-channel carriers, seven chargers and four batteries.

(2) Two buildings which partly collapsed had some of the equipment in them destroyed. For example, the equipment that was damaged at the laboratory of the Guye Station (seismic intensity X) included 400 telephone exchanges of type 55, etc.

(3) Five buildings with badly cracked walls had equipment turned over. They included laboratories in Luanxian (intensity IX), Hangu (intensity IX), Changli (intensity VII), Fengrun (intensity VIII), and Jixian (intensity VII), etc.
VII. Signals

1. Beijing to Shanhaiguan

There were 20 stations between Beitang (intensity VIII, K190.1) to Changli (intensity VII, K354.1) which included 4 large stations with electrical signals (Beitang, Guye, Beijiaidian, Tuozitou), 11 little stations with relays and 5 with color lamps, and they were part of 173 km of an automatic block district with 6 auto-transformers.

(1) Signal equipment in stations. Collapsed houses and changed topography caused damage to signal cables over 130 km long for example at: Xugezhuang (intensity IX), Kaiping (intensity X), Wali (intensity X), Beijiaidian (intensity IX) and Zhugezhuang (intensity VIII). All of the signal equipment at these five stations were broken. And the trunk cable in Beitang broke, the relays in Guye (intensity X) and Tuozitou (intensity IX) were smashed.

(2) Signal equipment in the automatic block district. 40% of signals and relays were damaged and some cables were cut. The signal at five road junctions broke.

(3) Power supply of automatic block. Deformed ground caused telephone poles to incline and cables to droop. The length of such signal lines was more than 70 kilometers. At the Douhe Transformer Station collapsed buildings destroyed all equipment in them. At the transformer stations on Jixiang Road and Luanxian, the damaged buildings damaged the equipment. At the other 4 transformer stations and 5 electrical sections, buildings were all damaged to various degrees.

2. Tongxian to Tuozitou

The buildings at the Shaheyi Electrical Station, communication office and relay building were cracked seriously and subsided, some relay frames turned over. To the east of Fengrun Station at four stations (Shilangzhuang, Langwopu, Fushan Temple, Maliu) and at two signal houses (Haozhuang, Jiugezhuang) the buildings were damaged and signal equipment and cables were damaged to different degrees.

VIII. Locomotives

There were only two locomotive depots in the earthquake area, namely the Guye Depot on the Beijing to Shanhaiguan Line and the Fengrun Depot on the Tongxian to Tuozitou Line. Collapsed buildings at the locomotive depots destroyed locomotives and equipment causing the locomotive depots to stop operating (Photos 83-85, Table 23).

IX. Power Supply

1. Beijing to Shanhaiguan

From Tanggu (intensity VIII, K178.8) to Changli (intensity VII, K354.1) there were five transformer stations (Tangshan, Guye, Beijiaidian, Kaiping, Tuozitou). Because the collapsed buildings destroyed the equipment in them the power supply was suspended. Photo 86 and Table 24 show the damage situation.
2. Tongxian to Tuozitou

In Jixian (intensity VII, K92.3) and Fengrun (intensity VIII, K134.6) the transformer station building cracked but the equipment was undamaged.

On the Beijing to Shanhaiguan Line and on the Tongxian to Tuozitou Line the electrical poles collapsed and the wires broke, more than 63 kilometers of line was seriously damaged. It caused 190 kilometers of line to have no power supply after the earthquake.

X. Water Supply

There were 58 stations on the Beijing to Shanhaiguan and Tongxian to Tuozitou lines. All water supplies and power supplies were disrupted after the earthquake. At 18 water supply points with 40 deep wells the water supply stopped because 20 wells were damaged and could not be repaired. 46.5 kilometers of water pipe was damaged in which 2.0 kilometers could not be repaired. There were 223 places where water leaked out of water pipes. A water tower collapsed and five cracked and inclined.

1. Beijing to Shanhaiguan

From Tanggu (intensity VIII, K178.8) to Changli (intensity VII, K354.1) there were six water supply points. The main damage to them was as follows:

(1) Tangshan water supply point (intensity XI): All buildings collapsed destroying the equipment and breaking water pipes. A cylindrical reinforced concrete water tower full of water suffered medium damage. The tower cracked horizontally at 1.8 m above ground. The concrete was compressed along N33°E, the elongated bars bent (Photo 87 and 88). Water pipes broke.

(2) Guye water supply point (intensity X): The machinery house, water supply section and water pump all collapsed. In 3 out of 7 deep wells the pipes broke, subsided, and some pipes at the pump station fractured, the centrifugal pump and 55 kW motor were damaged.

(3) Hangu water supply point (intensity IX): A 180 t water tower cracked vertically and the well pipe inclined and broke.

(4) Lutai water supply point (intensity IX): Of five wells one broke and another one spouted sand. A 120 t brick masonry water tower partly collapsed and the water container fell onto the skip tower (Photo 89). Water towers of 100 t and 200 t inclined slightly.

(5) Luanxian water supply point (intensity IX): A section of the well tub was pulled out about one meter. The boiler displaced.

(6) Changli water supply point (intensity VII): The generator house cracked and the equipment in it was slightly damaged.

2. Tongxian to Tuozitou

There were five water supply points from the south of Jixian (intensity VII, K66.2) to Tuozitou (intensity IX, K189.8) which were slightly damaged.
XI. Examples of Earthquake-Proof Railway Structures

In the Tangshan earthquake region some of the railway structures stood up to the high earthquake intensity and were damaged slightly or remained intact.

1. Reinforced concrete structures

In the intensity VIII-IX regions all reinforced concrete box or circular culverts were intact, no matter if they were full of water or empty. Only in special cases local damage occurred at the wing walls of the exits and entrances. On Yonghong Road in Tangshan City an overhead culvert in an intensity XI area with two spans of 6.0 m was a R.C. box structure and was intact after the earthquake (Photo 90). Some R.C. culverts on the Jing-Shan Line and Nanbao Special Line all stood up to the earthquake being intact or damaged slightly (Photos 91-93).

The R.C. water tower was also earthquake-proof. At Tangshan Station a 300 t reinforced concrete water tower in an intensity XI area only had damage to a medium extent (Photo 87). At Lutai Station in an intensity IX area two reinforced concrete water towers were slightly damaged (Photos 94 and 95).

2. Steel structures

At the Tangshan Station (intensity XI) two steel overpass bridges were intact (Photos 96 and 97). At the Lutai Station (intensity IX) the subsoil was soft and the water and sand spouted repeatedly and the steel overpass bridge was damaged slightly (Photos 98 and 99). Some steel lamp towers over 20 m high were intact (Photos 100 and 101). And an iron water crane also was intact (Photo 102).

3. Wood structures

At the Tangshan Station two wood canopy structures, which were joined with steel bolts and with diagonal members connecting the truss and column, were damaged slightly though they were in an intensity XI area (Photo 103).

(Translators: Liao Shuqiao, Li Zhengyang, Gong Xun, and Ma Youqiang)
Photo 1. In the intensity XI area 7 carriages on the Beijing-Shanhaiguan Line (train No. 117) derailed.

Photo 2. In the intensity IX area 3 oil tank cans on the Beijing-Shanhaiguan Line (train No. 041) overturned.

Photo 3. In the intensity IX area the No. 40 an express passenger train on the Beijing-Shanhaiguan Line was damaged (Earthquake-Resistant Office, Ministry of Railway).

Photo 4. In the intensity IX area 4 cans on the No. 1017 train on the Beijing-Shanhaiguan Line overturned (Beijing Railway Bureau).

Photo 5. In the intensity XI area rails in plan and longitudinal profile on the Tongxian-Tuozitou Line deformed (Institute of Railway Science).

Photo 6. Similar to Photo 5 (Institute of Railway Science).
Photo 7. In the intensity IX area rails at K0+920 to K1+350 on the Tongxian-Tuozitou Line were undamaged.

Photo 8. In the intensity VII area continuous rails on the Beijing-Shanhaiguan Line curved.

Photo 9. In the intensity VIII area sand spouted along the base of the ballast slope on the Nanbao Special Line.

Photo 10. In the intensity VIII area rails on the Nanbao Special Line curved.

Photo 11. In the intensity IX area soil liquefaction deposited sand near the Lutai Station.

Photo 12. In the intensity IX area rails near the Lutai Station curved.
Photo 13. In the intensity X area rails at the Xugezhuang Station on the Beijing-Shanhaiguan Line were undamaged.

Photo 14. In the intensity XI area rails at the Tangshan Station on the Beijing-Shanhaiguan Line were undamaged.

Photo 15. In the intensity VIII area vertical cracks occurred at the base of the embankment slope at K191+96 on the Beijing-Shanhaiguan Line.

Photo 16. In the intensity VIII area longitudinal cracks with a height difference of 40 cm occurred near the foot of the embankment slope at K191+796 on the Beijing-Shanhaiguan Line.

Photo 17. In the intensity VIII area longitudinal cracks occurred near the foot of the embankment slope at K191+796 on the Beijing-Shanhaiguan Line.

Photo 18. In the intensity VIII area ground fissures occurred near Xiejiafen Station on the Nanbao Special Line.
Photo 19. In the intensity X area the embankment at K281+750 to K282+088 on the Beijing-Shanhaiguan Line cracked and settled (Railway Army).

Photo 20. In the intensity X area at K281+750 to K282+088 on the Beijing-Shanhaiguan Line the embankment settled 3.4 m.

Photo 21. In the intensity X area water and sand boils occurred on both sides of the embankment at K281+750 to K282+088 on the Beijing-Shanhaiguan Line.

Photo 22. In the intensity IX area water and sand boils occurred at K2+400 on the Tongxian-Tuozitou Line (the white areas in the photo are spouted sand).

Photo 23. The damaged embankment at K2+800 on the Tongxian-Tuoziou Line in the intensity IX area.

Photo 24. The embankment cracked longitudinally and the slope slid at K246+000 to K253+000 on the Beijing-Shanhaiguan Line in the intensity IX-X areas.
Photo 25. The embankment at K249+600 to 249+800 on the Beijing-Shanhaiguan Line in the intensity IX area was damaged.

Photo 26. In the intensity IX area the embankment in Tongxian at the end of the No. 6 Bridge on the Tongxian-Tuozitou Line settled 3 m.

Photo 27. Similar to Photo 26. The embankment in Tuozitou at the end of the No. 6 Bridge settled 2.3 m.

Photo 28. In the intensity X area the embankment at the Tangshan end of the Douhe Bridge on the Tangshan-Zunhua Line settled and cracked (Institute of Railway Science).
Photo 29. In the intensity VIII area the cut slope and retaining wall at K168+500 on the Tongxian-Tuoositou Line were intact after the earthquake (Institute of Railway Science).

Photo 30. In the intensity X area the shoulder wall connecting the upstream side and the Shanhaiguan end at K267+374 on the Beijing-Shanhaiguan Line slid outward 20 cm.

Photo 31. In the intensity VIII area the platform wall at the Xiejiafen Station on the Nanbao Special Line collapsed locally.

Photo 32. In the intensity VIII area the wall of the cut in the Fengrun County tunnel was intact after the earthquake.
Photo 33. In the intensity XI area the Yonghong tunnel wall in Tangshan City was basically intact after the earthquake.

Photo 34. In the intensity VIII area the shoulder wall on the Tangshan-Fengrun Highway was intact after the earthquake.

Photo 35. In the intensity VIII area the bank protection wall at K11+740 on the Nanbao Special Line cracked.

Photo 36. In the intensity X area both bank retaining walls of the Douhe Bridge near the Tangshan Steel Plant were intact after the earthquake.

Photo 37. In the intensity IX area at K2+945 on the Tongxian-Tuozitou Line the No. 8 Bridge embankment settled and the rails were suspended.

Photo 38. In the intensity VII area at K194+199 on the Yongdingxinhe River Down-Line Bridge on the Beijing-Shanhaiguan Line, the Beijing abutment slid toward the center of the river, the abutment broke, and the anchor bolts of the bearing sheared.
Photo 39. In the intensity IX area at K2+271 on the Tongxian-Tuozitou Line the beam of the No. 5 Bridge displaced transversely and outward 40 cm.

Photo 40. In the intensity IX area at K2+804 on the Tongxian-Tuozitou Line the beam of the No. 7 Bridge displaced transversely and outward 100 cm.

Photo 41. In the intensity X area at K2+955 on the Douhe Bridge on the Tangshan-Zunhua Line the Tangshan abutment and the No. 1 and 2 piers tilted at the concrete construction joints.

Photo 42. In the intensity X area at K2+955 on the Douhe Bridge on the Tangshan-Zunhua Line the Zunhua abutment which was without a construction joint did not break.

Photo 43. In the intensity IX area at K2+804 at the No. 7 Bridge on the Tongxian-Tuozitou Line the Tongxian abutment sheared along constructing joint and the lower concrete cracked.

Photo 44. In the intensity IX area the stone laid pier on the Beijing-Shanhaiguan Line cracked along the mortar joint (Beijing Railway Bureau).
Photo 45. In the intensity VII area at the Yongdingxinhe River Up-Line Bridge on the Beijing-Shanhaiguan Line, the Beijing abutment displaced forward 0.54 m, the joint between the beams were compressed, and the abutment inclined toward the embankment.

Photo 46. In the intensity VII area the No. 12 pier on the Yongdingxinhe River Up-Line Bridge on the Beijing-Shanhaiguan Line slid toward the center of the river 13.9 cm and on the No. 13 pier the joint between beams enlarged 32 cm.

Photo 47. In the intensity VII area at the Yongdingxinhe River Up-Line Bridge the rocker shaft of the bearing of the No. 12 pier displaced.

Photo 48. In the intensity VII area at the Yongdingxinhe River Up-Line Bridge the anchor bolt of the hinged bearing of the No. 16 pier sheared.

Photo 49. In the intensity VII area at the Yongdingxinhe River Up-Line Bridge the riverbank slid and the embankment behind the Beijing abutment cracked.

Photo 50. In the intensity IX area at the Ji Canal Up-Line Bridge on the Beijing-Shanhaiguan Line the riverbank slid which resulted in the No. 3 pier displacing toward the center of the river 2.25 m (see Photo 51).
Photo 51. In the intensity IX area at the Ji Canal Up-Line Bridge on the Beijing-Shanhaiguan Line the riverbank slid which resulted in the No. 1 pier displacing toward the center of the river 2.43 m and the bridge was seriously damaged.

Photo 52. In the intensity IX area at the Ji Canal Up-Line Bridge on the Beijing-Shanhaiguan Line the riverbank slid and as a result the length of the bridge shortened 2.309 m and the Beijing abutment rails curved.

Photo 53. In the intensity IX area at the Ji-Canal Up-Line Bridge on the Beijing-Shanhaiguan Line the No.1 and No.3 piers subsided relative to the No.2 pier 0.58 m and 0.66 m respectively.

Photo 54. In the intensity IX area at the Ji Canal Up-Line Bridge on the Beijing-Shanhaiguan Line the bank on the Beijing side slid and bank fissures perpendicular to the river occurred.

Photo 55. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the rails buckled.

Photo 56. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the end rails of the bridge on the Beijing side bent.
Photo 57. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the abutment on the Beijing side displaced forward 1.072 m.

Photo 58. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the Shanhaiguan abutment displaced toward the center of the river and the plate beam extended to the back wall of the abutment.

Photo 59. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the No. 1 pier displaced toward the center of the river 0.99 m.

Photo 60. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the No. 2 pier broke.

Photo 61. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the No. 3 pier displaced toward the center of the river 1.215 m.

Photo 62. In the intensity IX area at the Ji Canal Down-Line Bridge on the Beijing-Shanhaiguan Line the No. 4 pier was intact.
Photo 63. In the intensity IX area the Shanhaiguan abutment of the Luanhe Bridge on the Beijing-Shanhaiguan Line displaced toward the center of the river 18.3 cm and the wing-wall type abutment broke (upstream side).

Photo 64. In the intensity IX area the Shanhaiguan abutment of the Luanhe Bridge on the Beijing-Shanhaiguan Line displaced toward the center of the river 18.3 cm and the wing-wall type abutment broke (downstream side).

Photo 65. In the intensity IX area the connection between the pier and platform of the No. 16 pier of the Luanhe Bridge on the Beijing-Shanhaiguan Line fractured locally.

Photo 66. In the intensity IX area the top portion of the hinged bearing on the No. 20 span of the Luanhe Bridge on the Beijing-Shanhaiguan Line dislocated.
Photo 67. In the intensity X area at the Douhe Bridge on the Tangshan-Zunhua Line the riverbank slid and the bank on the Zunhua side cracked.

Photo 68. In the intensity X area at the Douhe Bridge on the Tangshan-Zunhua Line the riverbank slid, a little brick house was broken into three sections, and three fissures crossed through the house.

Photo 69. In the intensity X area at the Douhe Bridge on the Tangshan-Zunhua Line the piers and abutment broke off and the bridge was destroyed.

Photo 70. In the intensity X area at the Douhe Bridge on the Tangshan-Zunhua Line the Tangshan abutment displaced 1.5 m toward the center of the river and the abutment broke in 3 sections along the construction joints.

Photo 71. In the intensity IX area near the No. 4-6 bridges on the Tongxian-Tuozitou Up-Line sand boils occurred on the ground.

Photo 72. In the intensity IX area at the No. 6 Bridge on the Tongxian-Tuozitou Up-Line the beam moved transversely 210 cm.
Photo 73. In the intensity IX area at the No. 6 Bridge on the Tongxian-Tuozitou Up-Line the Tongxian abutment was sheared along the construction joints and the lower concrete cracked.

Photo 74. In the intensity IX area at the No. 6 Bridge on the Tongxian-Tuozitou Up-Line the bearings were damaged.

Photo 75. In the intensity IX area at the No. 9 Bridge on the Tongxian-Tuozitou Up-Line the beam moved 125 cm.

Photo 76. In the intensity VIII area at the Yongdingxinhe Bridge retrofit ties connecting beams came into action during the earthquake.

Photo 77. In the intensity VIII area at the Yongdingxinhe Bridge, retrofit ties where beams compressed against each other fractured on impact.

Photo 78. In the intensity VIII area at the Yongdingxinhe Bridge the steel bar used to prevent the beam from falling off its support broke from tension (Beijing Railway Bureau).
Photo 79. In the intensity X area at the Douhe Bridge on the Beijing-Shanhaiguan Line a retrofit plate for restraining the ends of beams played a role.

Photo 80. In the intensity IX area on the Beijing-Shanhaiguan Line the riverbed pavement prevented longitudinal sliding of the abutment, it reduced the degree of damage to the bridge (Beijing Railway Bureau).

Photo 81. In the intensity XI area at the Tangshan Station on the Beijing-Shanhaiguan Line the highway pavement on the grade separation bridge prevented longitudinal sliding of the abutment, it reduced the degree of damage.

Photo 82. In the intensity IX area near Tangfang on the Beijing-Shanhaiguan Line the poles supporting wires inclined outward.

Photo 83. In the intensity VIII area at the Fengrun Machinery Section the roof and walls of the storehouse collapsed (Beijing Railway Bureau).
Photo 84. In the intensity VIII area at the Fengrun Machinery Section the roof and walls of the storehouse collapsed and the locomotive was smashed (Beijing Railway Bureau).

Photo 85. In the intensity X area at the Guye Machinery Section the roof of the washing and repairing garage collapsed and the locomotive and equipment were smashed (Beijing Railway Bureau).

Photo 86. In the intensity IX area at the transformer substation the building collapsed and smashed the electrical equipment (Beijing Railway Bureau).
Photo 87. In the intensity IX area the 300 t water tower at the Tangshan Station suffered moderate damage.

Photo 88. In the intensity IX area the 300 t water tower at the Tangshan Station was damaged inside.

Photo 89. In the intensity IX area at the Lutai Station the brick body of the 120 t water tower was partly damaged (Beijing Railway Bureau).

Photo 90. In the intensity XI area the bridge which crossed the culvert on the Beijing-Shanhaiguan Line was not damaged.
Photo 91. In the intensity X area the culvert on the Beijing-Shanhaiguan Line was not damaged.

Photo 92. In the intensity X area the double opening culvert on the Beijing-Shanhaiguan Line was not damaged.

Photo 93. In the intensity X area the double opening culvert on the Beijing-Shanhaiguan Line was intact but the wing wall at the entrance was damaged.

Photo 94. In the intensity IX area a R.C. water tower was slightly damaged.

Photo 95. In the intensity IX area a R.C. water tower was slightly damaged.

Photo 96. In the intensity XI area a steel overhead bridge structure was slightly damaged.
Photo 97. In the intensity XI area the column foot bolts of a steel overhead bridge structure were intact.

Photo 98. In the intensity IX area a steel overhead bridge structure was slightly damaged.

Photo 99. The same as Photo 98.

Photo 100. In the intensity XI area a steel beacon structure was not damaged.

Photo 101. The column foot bolts of a steel structural beacon were intact.

Photo 102. In the intensity XI area the cast-iron overhead water pump at the Tangshan Station was not damaged.
Photo 103. In the intensity XI area the wooden canopy structure at the Tangshan Station was slightly damaged.
Figure 1. Railway engineering distribution of the Tangshan earthquake region.

Figure 2. Nanpu Special Line, K1+650 to K1+703.1, rail curved in plan.
Figure 3. Curved rails at Lutai Station were placed on a straight line.

Figure 4. Damage to embankments on the Beijing to Shanhaiguan, Tongxian to Tuozitou and Nanpu Special Lines.
Figure 5. Line profile surveyed after the earthquake (August 15, 1976) of the Beitang Station (K189+200 to K191+100), Beijing to Shanhaiguan.

Figure 6. Damage to the No. 82 Bridge and embankment at K282+109, Beijing to Shanhaiguan Line.
Figure 7. Link-up line of Tongxian to Tuozitou.

Figure 8. A profile of the Tongxian to Tuozitou link-up line before and after the earthquake.
Figure 9. A section of embankment at K2+800 of the Tongxian to Tuozitou up link line. (seismic intensity IX, height of embankment 11.12 m, unit: m)

Figure 10. A section of embankment at K2+510 of the Tongxian to Tuozitou up link line surveyed on August 17, 1976. (original height of the embankment 9 m, unit: m)

Figure 11. A section of embankment at K2+530 of the Tongxian to Tuozitou up link line surveyed on August 17, 1976. (original height of the embankment 9.4 m, unit: m)
Figure 12. A section of embankment at K3+080 of the Tongxian to Tuozitou up link line surveyed on August 20, 1976. (intensity IX, unit: m)

Figure 13. The embankment sank and cracked at K251+420 on the Beijing to Shanhaiguan Line. (intensity IX)

Figure 14. A section of cut at K168+600 on the Tongxian to Tuozitou Line.
Figure 15. A section of cut at K1+050 on the Tongxian to Tuozitou up link line. (unit: m)

Figure 16. A section of subway cut retaining wall in Fengrun County. (unit: cm)

Figure 17. A section of the Yonghong subway retaining wall. (unit: cm)
Figure 18. A section of the Tangshan to Fengrun Highway overpass embankment. (unit: cm)

Figure 19. Douhe River protection wall on the Tangshan Steel Plant Special Line. (unit: cm)
Figure 20. Damage distribution of railway bridges in the Tangshan District.

1. Tangshan Station, 300 t R.C. water tower damaged moderately.
2. Tangshan Station, steel overhead bridge damaged slightly.
3. Tangshan Steel Plant Special Line, Douhe River Bridge undamaged.
4. No. 12 Bridge abutments wing wall cracked, Beijing side cracked 0.02-0.022 m, Shanhaiqian side cracked 2-3 mm clearance between abutment and beam end disappeared, embankment sank.
5. Yonghong subway 2-6.0 m R.C. box culvert undamaged.
6. Douhe River Bridge on the Huaxin Textile Mill Special Line, Shanhaiqian side abutment sank 0.3 m and slid, beam constructed into abutment protecting wall 7 cm, No. 1 pier bearing rocker inclined.
7. No. 73 Bridge with bed paving (Douhe River), Beijing side abutment slid 0.14 m, Shanhaiqian side abutment slid 0.09 m, wing wall broke, all anchor bolts cut.
8. Tangshan to Zunhua Douhe River Bridge, bank sliding caused the length of the bridge to shorten 3.73 m, Tangshan side abutment and No. 1 and No. 2 piers cut, bridge was destroyed.
9. Jinggezhuan Mine Special Line, Douhe River Bridge, masonry abutment, No. 1 pier cut, 2.7 m above ground, and dislocated about 30 cm. Other piers intact.
Figure 21. Damage to the up and down line bridge of the Yongdingxin River, Beijing-Shanhaiguan Line.
Figure 22. Sliding of the up line Yongdingxin River Bridge, Beijing-Shuanhaiguan Line. (unit: m)
Figure 23. Location and damage of the up and down line Ji Canal Bridge, Beijing to Shanhaiguan.
Figure 24. Damage to the up line Ji Canal steel bridge, Beijing to Shanhaiguan.
Figure 25. Abutment of the up line Ji Canal Bridge, Beijing to Shanhaiguan. (unit: cm)
Figure 26. Span changed and sketch of down line Ji Canal Bridge, Beijing to Shanhaiguan.

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Figure 27. Pier of down line Ji Canal Bridge, Beijing to Shanhaiguan. (unit: cm)
Figure 28. Abutment of down line Ji Canal Bridge, Beijing to Shanhaiguan. (unit: cm)
Figure 29. Location of Luan River Bridge, Beijing to Shanhaiguan Line.
Figure 30. Damage to Luan River Bridge, Beijing to Shanhaiguan.

Figure 31. Structural sketch of the Douhe River Bridge, Tangshan to Zunhua Line.
Figure 32. Damage to the Douhe River Bridge, Tangshan to Zunhua Line. (unit: cm)

Figure 33. Damage to the No. 6 Bridge of the Tongxian to Tuoxitou up link line. (unit: cm)
Figure 34. Damage to the No. 9 Bridge of the Tongxian to Tuozitou up link line. (unit: cm)

Figure 35. Intensity IX, K266+962 Douhe River Bridge, Beijing to Shanhaiguan Line, moderately damaged. (unit: cm)