EFFECTS OF THE AUGUST 17, 1999 IZMIT EARTHQUAKE ON THE TURKISH STATE RAILWAYS

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ABSTRACT

A magnitude 7.4 earthquake, one of the largest earthquakes on the North Anatolian fault in the 20th century, occurred on August 17, 1999 near Izmit, Turkey. Approximately 165 line miles of the Turkish State Railways, with 181 bridges of various types and 29 tunnels, lie within 50 miles of the epicenter. Approximately 70 miles, with 76 bridges and 11 tunnels, lie within ten miles of the fault rupture, which crossed the tracks.

During the week of September 19, effects of the earthquake on the railroad were investigated. The investigation included observation of characteristics of facilities that were undamaged or only slightly damaged and development of information on damage that had been repaired. Investigation of the characteristics of facilities that performed well in the vicinity of a large earthquake, as well as of those that were significantly damaged, is of importance to the railway engineering profession.

The most severe damage to railroad facilities was the nearly total destruction of a passenger car shop at Adapazari. Track damage was all in an area close to the fault. It included offsets in the line where it was crossed by the fault, buckled track and pulled apart insulated joints in welded rail. There was damage to the catenary system at the fault rupture and to one substation serving the electrified line. There was no damage to railway bridges. Several tunnels had minor damage. There was damage, of varying degrees, to railway buildings but no critical structural damage except to the Adapazari shop.

KEY WORDS

Earthquakes, Earthquake Damage, Track Damage, Bridges, Tunnel Damage
INTRODUCTION

A shallow earthquake with surface wave magnitude of 7.8 and moment magnitude of 7.4 occurred at 3:01:37 a.m., local time, on August 17, 1999 south of Izmit, Turkey. It occurred on the North Anatolian fault, which has a long history of seismic activity and has been compared to the San Andreas fault in California. The earthquake was caused by primarily right-lateral strike-slip along a rupture zone with a length in the order of 100 miles (160 to 170 km), including surface faulting observed over a distance of 68 miles (110 km) [1]. The earthquake lasted 37 seconds and involved two sub-events which ruptured 4 segments separated by offsets of less than 1 km [2]. It was one of the largest earthquakes on the fault in the 20th century and one of a series of recent earthquakes that ruptured this fault. A segment of the fault immediately to the east was ruptured by a magnitude 7.1 earthquake, which caused no railroad damage, on November 12, 1999. Ten earthquakes, with magnitudes of 6.7 or greater, ruptured 1,000 km of the fault between 1939 and 1992 [3]. The region south of Izmit has been considered to have a high probability of a major earthquake since the last of these events [2,3]. Other earthquakes affecting the immediate area occurred in 1719, 1754, 1878, 1894 and 1943 [2]. Fig. 1 shows the epicenter and the approximate location of the fault rupture [4], together with the location of railway lines in the area.

During the week of September 19, effects of the earthquake on the railroad were investigated. In addition to observation of severely damaged facilities that had not been repaired, the investigation included observation of facilities that were undamaged or only
slightly damaged and development of information on damage that had been repaired. Plans of selected bridges in the affected area were reviewed to determine details of construction, which could not be determined by observation in the field. Investigation of the characteristics of facilities that performed well in the vicinity of a large earthquake, as well as of those that were significantly damaged, is of importance to the railway engineering profession.

CHARACTERISTICS OF RAILROAD

Approximately 70 miles of the Turkish State Railways (Turkiye Cumhuriyeti Devlet Demiryollari) line between Haydarpasa (the Istanbul end of the line in Anatolia) and Ankara, plus the 5 mile line from Arifiye to Adapazari, lie within ten miles of the fault rupture. The rupture crossed the tracks at three locations. Approximately 165 miles of these lines lie within 50 miles of the epicenter. The affected portion of the railroad and the fault rupture zone are shown in Fig. 1.

Operation in the affected area is electrified. Power is obtained from the commercial electric power system. The operating system is CTC, with two main tracks between Haydarpasa and Arifiye and between Arifiye and Adapazari. The portion of the Arifiye – Ankara line in the affected area is single track CTC operation. Lines carry both passenger and freight traffic with a high density of passenger trains between Haydarpasa and Arifiye.
Track gage is 4’-8 \( \frac{1}{2} \)”. Continuous welded rail is used in main tracks. Rail is generally in the 90 lb/yd range. Main track ties are either concrete or wood with concrete typical of the heavier traffic segments. In concrete tie segments, wood ties are used in the immediate vicinity of insulated joints. Rail is attached to both concrete and wood ties with rigid clips bolted to tie plates which are attached to concrete ties with bolts (or threaded studs) and to wood ties with lag screws.

If bridges are defined as structures with lengths of 4 meters or more, which essentially agrees with the current FRA definition, there are 181 bridges within 50 miles of the epicenter. Nearly half of these are within 10 miles of the fault rupture. Bridges consist of four types, steel spans on masonry piers and abutments, reinforced concrete spans, masonry arches and bridges with spans described as concrete reinforced with rails or structural steel. In American practice, the last type would probably be considered steel encased in concrete and will be referred to as composite. None of the bridges observed have a noticeable skew. Most bridges are on spread footing foundations. Any on pile foundations are on timber piles. Most were built in 1912 but bridges for the portion of the second track between KM 31 and Arifiye appear to have been added in 1960.

For most bridges, the design live load is a locomotive with seven 25 ton axles at 1,600 mm spacing and 1,600 mm from the end axle to the end of the locomotive, followed by cars with four 20 ton axles spaced at 1,500 mm – 4,000 mm – 1,500 mm and 1,500 mm beyond axles to the end of the car. Longitudinal force is 12.5 percent of the live load. Longitudinal load at expansion bearings is 20 percent of vertical for sliding bearings and
3 percent for rollers. Wind load is 250 kg/sq. meter on unloaded bridge or 125 kg/sq. meter on bridge and train.

Sixty steel bridges with a combined length of 5,649 feet are within 50 miles of the epicenter. With the exception of two open deck continuous through trusses, they are ballasted deck simple spans. Types include through girders, deck girder and beam spans, through trusses and deck trusses. Sixteen steel bridges, predominantly relatively shallow through girders with less than 12 foot clearance under the span, are within 10 miles of the fault rupture. Their combined length is 991 feet. More distant steel bridges include a 300 foot two span continuous through truss with 33 foot height under the bridge, a 461 foot three span continuous through truss with 23 foot clear under the bridge and a bridge with seven 84 foot deck truss spans with 59 foot clearance under the spans. Expansion bearings for the shorter spans are, typically, single rollers with diameters of about 6 inches. Lateral movement is prevented by either flanges on the rollers or groves in the rollers engaging ribs on the span and masonry plate. The through truss spans have segmental roller expansion bearings for the trusses. The stringers are supported directly on the abutments and piers on sliding bearings. Substructures are typically concrete or stone gravity abutments and “semi-gravity” piers. “U” abutments are used on the higher bridges. Plans for several bridges, including some of the larger ones, indicate stone piers and abutments have concrete cores. In reinforced concrete substructures, reinforcing is relatively light. The through truss bridges have timber ties and inside steel guard rails.
Seventy five reinforced concrete bridges with a combined length of 2065 feet are located within 50 miles of the epicenter. Fifty four of these are located within 10 miles of the fault rupture. Most of these bridges were built in 1912 or 1960 and have span lengths in the 10 foot to 20 foot range. Two bridges with significantly longer spans are listed as reinforced concrete but are probably prestressed concrete. Both are located over 20 miles from the fault rupture. One, built in 1982, consists of eight 82 foot spans and has a height of over 60 feet. The other, built in 1996, consists of two 41 foot spans and has a 13 foot clearance under the spans.

Fourteen concrete or stone masonry arch bridges, with a combined length of 849 feet, are located within 50 miles of the epicenter. Three of these, with a combined length of 46 feet, are located within 10 miles of the fault rupture. With the exception of one 16 foot arch built in 1950, all were built in 1912. Most are single span structures. The longest span is 75 feet with 9.5 foot rise. The two longest structures consist of 49 foot spans. One, a 6 span structure, has a clear height of 86 feet. The other, a 7 span structure, has a clear height of 131 feet.

Thirty two composite bridges, with a combined length of 611 feet, are located within 50 miles of the epicenter. Three of these, with a combined length of 102 feet are located within 10 miles of the fault rupture. These are, typically, single span bridges with span lengths of 13 feet to 26 feet. The longest bridge consists of three 23 foot spans. All except one, which was built in 1960, were built in 1912.
Eleven tunnels are located within 10 miles of the fault rupture and a total of 29 within 50 miles of the epicenter. In general, tunnels have stone portals. Linings are typically stone, concrete or partially stone and partially concrete although some steel linings are used.

Retaining walls are used more than is typical on American railroads. They include both low walls supporting sections of embankment which are typically stone masonry and high, typically concrete, walls retaining hillsides or highways above and adjacent to the tracks.

Signal lines are underground cable, carried across bridges in conduits attached to the spans. In territory with two main tracks, signals are mounted on steel signal bridges. Catenary poles are concrete with steel arms and, typically, support the catenary for only one track.

**EARTHQUAKE DAMAGE**

**General:**

Timetable schedules indicate that four scheduled trains were operating within 50 miles of the epicenter at the time of the earthquake. Their approximate locations at that time, none of which are within the area of track damage, are shown in Fig.1. No trains were derailed. Post-earthquake inspection was completed by 6:00 p.m., August 17, approximately 15 hours after the earthquake. One of the two main tracks of the line between Haydarpasa and Arifiye was repaired and returned to service with a 30 km/hr speed restriction at
11:30 p.m. on August 18 and the second track at 8:30 p.m. on August 22. Normal track speed is 110 km/hr. The line was closed between Haydarpasa and Izmit until 8:00 p.m. August 22 due to a fire at the Tupras refinery adjacent to the right-of-way near KM 74.

**Track:**

Significant track damage was all in an area that is located less than 5 miles from the fault. Most was in the segment with two main tracks that is essentially parallel to the fault.

At KM 104+758, the south track was buckled. The north track was undamaged. The south track is shown in Fig. 2.

At KM 104+950, both tracks were offset over 10 feet where they were crossed by the fault as shown in Fig. 3. Details of damage, including split and broken concrete ties, are shown in Fig. 4. The fault trace to the southwest of the tracks, as it appeared on September 21, is shown in Fig. 5. Fig. 6, an enlargement of part of a photograph published on the internet, shows the narrow zone of disturbance and settlement of ballast where the rupture crossed the north track. One track was restored to service with a speed restriction of 30 km/hr at 11:30 PM on August 18, less than 45 hours after the earthquake, and the other track, with the same restriction, at 8:30 PM on August 22. In late September, the speed restrictions were still in place due to a less than optimum track alignment and difficulty maintaining track surface due to disruption and softening of the underlying soil in the fracture zone. Operation in the area was also protected by a flagman. It was expected that track surface problems would exist until the soil disrupted
by the fault rupture is consolidated to a depth that can span the rupture zone by arch action.

At KM 116+100, the south track buckled and the north track settled.

At KM 128+564, the north track settled and moved laterally away from the south track.

At KM 128+600, both tracks pulled apart at insulated joints as shown in Fig. 7. This appears to be the result of a second crossing by the fault rupture. The nature of the damage and some of the damage farther to the east are consistent with the rupture crossing the tracks east of this location.

At KM 128+690 the north track settled and moved laterally.

At KM 129+200 the south track buckled.

At KM 129+600 There were joint failures and minor buckling at joints in both tracks, as shown in Fig. 8, indicating crossing by the fault west of this location.

Between KM 110 and KM 130, Lake Sapanca is a short distance north of the tracks. The tracks are closest to the lake between KM 126 and KM 129. The area with track damage is shown in Fig. 9.
At some locations the nature of damage to the two tracks differed. These differences may be related to differences in rail neutral temperature in the case of track buckling. Differences in settlement may be the result of localized differences in liquefaction potential of soils or other local differences in soil properties.

The fault rupture crossed the single track line between Arifiye and Ankara a short distance south of Arifiye causing an offset in the track in the order of 5 ft. [5].

**Bridges:**

No bridges were damaged. However one bridge, at KM 116+713, within 5 miles of the fault rupture, had channel paving under the bridge broken during the earthquake with a resulting loss of scour protection.

**Tunnels:**

The tunnel at KM 35+430, which has a stone masonry lining and portals, had minor cracking of mortar joints in one portal and a few stones loosened in hillside slope protection adjacent to the portal.

The tunnel at KM 146+389 had pre-existing cracks in one portal widened.

The tunnel at KM 146+551 had pre-existing cracks at joints in the lining widened.
The tunnel at KM 240+869 had pre-existing cracks in the lining and the adjacent portal widened. The crack in the lining is the only tunnel damage that requires repair. However, repair work is not of an emergency nature and can be handled in a normal maintenance schedule. The lining crack consists of approximately horizontal offset and connected segments located in the left wall near the spring line. It begins about 10 feet back of the portal, near the point where the top of the tunnel extends beyond the hillside, and extends to the portal. Near the portal, the left side of the tunnel is close to the surface of the ground as it slopes into a canyon. This results in very limited available passive pressure on the left side. The tunnel originally had structural connections between the walls below the track which were removed to allow lowering the track to improve vertical clearance.

The tunnel at KM 242+580 has a transverse crack, located in the roof near one portal, which was widened during the earthquake.

**Buildings:**

The most severe damage to railroad facilities was the nearly total destruction of a major part of a passenger car shop at Adapazari. The shop, in service since 1951, produced about 200 cars per year for the railway at approximately 45 percent of the cost of comparable imported cars. Damage included partial to total collapse of steel framing in a number of bays. Fig. 10 shows a heavily damaged portion of the shop. However, in some bays the frames remained standing and the most obvious damage was non-structural as shown in Fig. 11. It is not known whether differences in behavior were the result of
differences in loading due to localized differences in supporting soil or to differences in response due to differences in structural framing and distribution of mass in the structure.

Other buildings, including a number of depots, suffered damage ranging from cracked plaster to minor structural damage but remained useable.

**Power for Locomotives:**

An electric company owned substation at Arifiye, which supplied power for locomotives, was inoperative as a result of the earthquake. However, power for locomotive operation was supplied through adjacent substations. The catenary system was damaged where the fault rupture crossed the line.

**Other Damage:**

In addition to building damage, other damage close to, but not involving, the tracks was indicative of the severity of the earthquake. West of Arifiye, in the area where the line is near Lake Sapanca, vertical construction joints were spalled in a high concrete retaining wall supporting a highway and hillside on the south side of the track, probably in the vicinity of the second location where the fault crossed the tracks. Near KM 146 and KM 152, significant landslides occurred on hillsides adjacent to the right-of-way but did not damage the track. At KM 153+231 lateral spreading caused cracking in the flood plain immediately upstream from the bridge.
SUMMARY

In this major earthquake, railroad structures, other than buildings, performed well. Construction details were typical of many railroad structures built in both North America and Europe in the late 19th century and the first half of the 20th century. Track damage was related to permanent ground displacements. The fault rupture crossed the tracks at three locations and caused significant lateral displacements at two of them. At these locations, disruption of the underlying soil caused difficulty in maintaining track surface for an extended period of time after the earthquake.

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REFERENCES


LIST OF FIGURES

Fig. 1. Affected Portion of Railway and Locations of Trains (map)

Fig. 2. Buckled Track at KM 104+758 (Turkish State Railways Photo)

Fig. 3. Tracks Offset at Fault KM 104+950 (Turkish State Railways Photo)

Fig. 4. Detail at Fault Crossing KM 104+950 (Turkish State Railways Photo)

Fig. 5. Fault Trace at KM 104+950, September 21, 1999

Fig. 6. Fault Rupture in Ballast KM 104+950

Fig. 7. Pulled Apart Joints KM 128+600 (Turkish State Railways Photo)

Fig. 8. Buckled Rail Joints at KM 129+600 (Turkish State Railways Photo)

Fig. 9. Damage in Area of Fault Rupture

Dashed line shows estimated location of fault rupture (map)

Fig. 10. Portion of Adapazari Shop, September 21, 1999

Fig. 11. Portion of Adapazari Shop, September 21, 1999
Fig. 3

Fig. 4