5 DAMAGE TO TRANSPORTATION FACILITIES

In the Kocaeli, Turkey earthquake of August 17, 1999, extensive damage of transportation facilities occurred in the Kocaeli and Sakarya region, Turkey as shown in Fig. 5.1. A part of the right-lateral strike slip Anatolian fault ruptured in east-west direction for about 100-km from Golcuk to Duzce. Since the Trans European Motorway was almost parallel to the fault, the fault rupture crossed the Motorway at several locations. The fault rupture crossed railways at least three sites. Damage of transportation facilities concentrated at the locations where the tectonic ground movement crossed the roads and railways.

5.1 DAMAGE OF ROAD FACILITIES

5.1.1 Fault-Induced Ground Dislocations in the Damaged Sites

Damage of road facilities was investigated around the city of Arifiye, where extensive damage of roads and bridges occurred. The survey was concentrated for Overpasses No. 1-No. 4 at the Motorway and a bridge at Sakarya River as shown in Fig. 5.2. Various evidence of right-lateral strike slip rupture in the area is described first, since it provided the dominant effect on the damage of transportation facilities.

In the east of Arifiye area, the fault rupture was first observed at the Toyota S.A. Factory. At an approaching road to the entrance of Factory (Point A, refer to Fig. 5.2), the fault rupture crossed the road with a shallow angle, and damaged the concrete pavement as shown in Photo 5.1. From the movement of equally spaced steel guardrail poles along the road, the road offset was estimated 1.2 m and 2.65 m in transverse and axial directions, respectively.

The fault rupture continued west to reach Point B where it collapsed the Sakarya Bridge. Detail of the bridge damage will be described in 5.1.4. The fault rupture then crossed the Motorway at Point C (near south abutment of the Overpass No. 1), and passed through the Overpass No. 2 near its north abutment. It then developed a 4.3-m offset of a concrete fence of an automobile factory (Arbas Arac Kadlama Fabzikasi) at northeast corner (Point D), as shown in Photo 5.2.

The fault further continued west. It offset a reinforced concrete fence of an army base at Point E. The fault then passed a cone field, and crossed a railway at Point F, resulting in a damage described in 5.2.4.

After crossing a cone field again, the fault rupture reached a poplar grove at Point G. The largest fault offset measured from displaced poplar trees originally planted in lines was 4.3-m as shown in Photo 5.3.

The fault continued further west. After crossing a cone field and damaging several buildings, it reached the Arifiye Overpass that spanned the Motorway and two local roads. The damage of the Overpass will be described in 5.1.2. The fault developed an offset of an about 1-m diameter sewer pipe embedded at Point H as shown in Photo 5.4. The offset appeared to be on the order of at least 3-m and probably 4-m. There was another fault movement that crossed the approaching road at about 30-m behind the north abutment (A1), and caused a 1.5-m deep settlement. The first fault rupture continued further west parallel to the Motorway and resulted in a 3.6-m offset of a 1.4-m diameter drainage pipe at Point I, as shown in Photo 5.5. The fault then crossed the Motorway with a shallow angle at Point J, and it continued further west after passing through the south abutment of the Overpass No. 4.

The fault rupture described above developed various damages on the Overpasses and a road bridge as follows.

5.1.2 Arifiye Overpass

The Arifiye Overpass was of 4 span simply supported prestressed concrete bridge as shown in Fig. 5.3. It was supported by two end-abutments and 3 wall-type reinforced concrete piers. It was skewed bridge with a skew angle of 65-degree. Two center spans overpassed the Motorway and a side span each on both sides overpassed a local road. The substructures and the decks are denoted herein as A1, P1, P2, P3 and A2, and D1, D2, D3 and D4, respectively, from north to south. The D2, D3 and D4 dislodged from their supports at south ends and fell down with the north side still being supported by the piers as shown in photo 5.6. It was not clear from which side the D 1 dislodged from the support first, but it rested on ground almost horizontally.

The decks were of 5 precast concrete U-beams as shown in Fig. 5.4. They were supported by 5 elastomeric bearings with 300mm x 300mm and 100mm high per substructure. As shown in Fig. 5.5, the piers were 1-m thick and 14-m wide in longitudinal and transverse directions, respectively. The design strength of concrete was 30 MPa. This was a standard overpass type in this area.

The superstructure was already demolished and A1, A2 and a part of the footings of P1 and P2 were left as shown in Photo 5.7, when we visited the site. Photos 5.8 and 5.9 show A1 and A2, respectively. Six reinforced concrete stoppers were provided at both abutments to limit relative displacement of the decks in transverse direction. At A2, they suffered damage at the east face with the west face not being damaged at all, as shown in Photo 5.10. The elastomeric bearings were displaced in the west direction. It was obvious from such evidence that the stoppers on A2 were subjected to a large lateral force from east to west associated with a clockwise rotation of D4. It is well known that a skewed bridge rotates when a deck collides with an abutment[1)-3)]. However no evidence showing collisions of D4 with the parapet wall of A2 was seen. It appeared therefore that D4 rotated subjected to the fault movement at the foundations. One the other hand, the stoppers on A1 were not damaged. The seat length at the abutments and piers was about 0.6-m and 0.45-m, respectively.

The reinforced concrete footing that supported P1 was 5.3-m long and 14-m wide in longitudinal and transverse directions, respectively, and it did not suffer damage as shown in Photo 5.11. The footing of P3 was supported by 8 1-m diameter cast-in-place reinforced concrete piles as shown in Photo 5.12. The piles were reinforced by 12 20-mm plain bars. The averaged concrete strength investigated with the Shumit hammer was 56 MPa and 47 MPa at the front wall of A2 and the upper surface of P1 footing, respectively.

As shown in Fig. 5.3, the fault rupture passed through between A1 and P1 with an angle of about 70-degree. The right-lateral strike-slip fault forced A1 to move in east and north directions with respect to other piers and A2. If one idealizes a ground rupture as shown in Fig. 5.6 (a), the ground displacement at north and south of the fault rupture line, d_N and d_S, may be obtained as

$$d_N = \frac{D_0}{2}; \; d_S = -\frac{D_0}{2} \qquad (1)$$

in which D_0 is relative displacement of ground at the fault rupture line. Thus, the ground movement in transverse and longitudinal directions may be written as

<u>At north of fault line</u>

$$d_{N,TR} = \frac{D_0}{2}\cos\theta; \; d_{N,LG} = \frac{D_0}{2}\sin\theta \qquad (2)$$

<u>At south of fault line</u>

$$d_{S,TR} = -\frac{D_0}{2}\cos\theta; \; d_{S,LG} = -\frac{D_0}{2}\sin\theta \qquad (3)$$

in which θ is angle of fault rupture from the bridge axis.

Assuming $D_0 \cong 4$ m and θ=70 degree, the ground displacements in Eqs. (2) and (3) may be obtained as shown in Fig. 5.6 (b) and (c). The relative displacement between A1 and P1 in longitudinal direction D_{LG} may be obtained as

$$D_{LG} = d_{N,LG} - d_{S,LG} = D_0 \cos\theta = 1.37\text{m} \qquad (4)$$

This was much larger than the seat length of about 0.6 m at A1 and 0.45 m at P1. It seems that D1 dropped due to such a large relative displacement induced by the fault rupture between A1 and P1. On the other hand, the foundations of P2, P3 and A2 were forced to move in south direction. It appears that such a southward movement of foundations resulted in dislodging D2, D3 and D4 from their support at the north ends.

Assuming the reinforcement as shown in Fig. 5.5 and concrete strength of 30 MPa, the lateral force vs. lateral displacement relation was evaluated based on the standard moment-curvature analysis[4] as shown in Fig. 5.7. The stress-strain relation of concrete developed by Hoshikuma et al was used to represent the confinement effect[5]. Assuming that the tributary mass of a pier is 5800 kN, the response acceleration that resulted in yielding of piers was approximately 0.2 g.

5.1.3 Overpasses near Arifiye Overpass

Damage of 3 Overpasses of the Motorway, i.e., No. 1, 2 and 4 Overpasses in Fig. 5.2 was investigated. They had the same structural type with Arifiye Overpass.

No. 1 Overpass was located about 1 km east of the Arifiye Overpass close to Toyota S.A. Factory and Toyota S.A. Hospital. It was a two-span simply supported overpass as shown in Photo 5.13. The fault rupture crossed the Motorway at about 100-m west of the Overpass and passed through the south abutment of the Overpass. Residual displacement of about 50 mm was developed in the elastomeric bearings in transverse (west) direction. Since the Overpass was located north of the fault line, the foundations were forced to move in east direction, which resulted in the deformation of elastomeric bearings in west direction. Except the bearings, the damage was less significant; only covering concrete protecting the surface of embankment in front of the south abutment (A2) spalled off due to settlement of the abutment. It was confirmed that a short-span bridge supported by short and rigid wall-type piers and abutments performs well in an earthquake.

At No. 2 Overpass about 400 m east of the Arifiye Overpass, the deck collided with the parapet wall of the abutment resulting in spalling off of a part of the parapet concrete wall. Opposite to the No. 1 Overpass, the elastomeric bearings displaced 20-30 mm in transverse direction (east direction). The overpass was located south of the fault line.

No. 4 Overpass located about 400 m west of the Arifiye bridge also suffered damage at the concrete parapet of the north abutment.

5.1.4 Sakarya River Bridge (No. 5)

A bridge spanning the Sakarya River near the Toyota S.A. Hospital (No. 5 Bridge) collapsed as shown in Photo 5.14. The bridge was of either 4 or 3 spans simply supported decks. The deck(s) at center was/were completely collapsed and both side-decks dropped at the riverside with the embankment-side being up. At the north abutment (A1), the side-deck dislodged from the abutment and fell down about 3 m downstream from the original position. The fault rupture directly hit A1 resulting in the collapse of the total bridge. The seat length was 600 mm, but this was not adequate to prevent the collapse.

5.1.5 Approaching Bridge in a Paper Factory

This was not a road bridge but an approaching bridge to quay in SEKA Paper Factory. The concrete slab decks settled about 2 m over 30 spans as shown in Photo 5.15. They were supported by 800-mm diameter circular reinforced concrete columns with the bottom underneath the sea surface being the circular steel piles. The reinforced concrete columns were reinforced by 30 mm round bars, and were confined by 10 mm diameter round bars placed 150 mm interval. About 11 reinforced concrete columns failed in shear as shown in Photo 5.16. No evidence of fault movement was observed around the bridge.

5.2. DAMAGE OF RAILWAYS

5.2.1 General

The railways connecting Istanbul and Ankara suffered damage due to the fault movement at least three locations.

5.2.2 Damage of Railways near Tepetarla

The fault crossed railways at 150 m north of Tepetarla station, and developed a lateral buckling of rails. The rails were placed on an embankment about 1.5 m high. It was evaluated from the picture taken after the earthquake that the lateral movement of the rails at the buckled section reached 3 m. When we visited the site, it was already repaired. However some deformation of the rails was still left for an interval of about 300-m. It was found that the fault was almost EW direction, and crossed the rails (N30E) with an angle of 60 degree. Photo 5.17 shows the damaged rails and reinforced concrete sleepers (supporters) removed after the earthquake. The right-lateral fault rupture measured at nearby popular grove was 2.5 m (refer to Photo 5.18).

5.2.3 Damage of railways at South of Sapanca Lake

At south of Sapanca Lake, railways suffered damage due the fault rupture. The railways and a local road were in almost NS direction under an 8-10 m high terrace. On the terrace, the Motorway was running parallel to the railways. The fault was almost in EW direction, and crossed the railways as well as the local road and the Motorway. A reinforced concrete coastal fence offset 230 mm and reinforced concrete wall along the cliff of the terrace suffered damage as shown in Photo 5.19. Thirty-eight reinforced concrete sleepers located north of the fault line rotated in north direction, showing that the rails were pulled in north direction. The removed rails were laterally bent and the sleepers were damaged to expose the reinforcing bars as shown in Photo 5.20.

5.2.4 Damage of Railways near Arifiye Overpass

At about 500-m northeast of the Arifiye Overpass, the same fault, which damaged the Arifiye Overpass, crossed railways and caused damage. The railways were almost in NS direction, where the fault rupture crossed the railways in almost EW direction. The repair was being conducted so that 1.8-m offset developed by the fault rupture was adjusted by changing the alignment for a distance of about 100m. Photo 5.21 shows the removed rails and sleepers. It should be reminded that the fault rupture measured from the offset of poplar trees located at about 300 m west of the site was 3.6-4.5 m (refer to Photo 5.3).

5.3. SUMMARY

Damage of road and railways facilities in the 1999 Kocaeli, Turkey earthquake was investigated in areas of Kocaeli and Sakarya. The damage of transportation facilities may be summarized as follows:

(1) Two road bridges, i.e., Arifiye Overpass and Sakarya River Bridge collapsed due to the fault rupture-induced ground movement. Extensive damage, such as damage of parapet wall, reinforced concrete stoppers, elastomeric bearings and prestressed concrete decks, occurred. Reinforced concrete columns of a bridge in a paper factory suffered damage in shear.
(2) Railways suffered damage at three locations, at least, around Sapanca Lake due to the fault rupture-induced ground movement. The rails were laterally buckled and sleepers were badly damaged.
(3) Major contribution to the damage in roads and railways was the fault rupture. The relative displacement at ground surface along the fault rupture measured from the offset of concrete fence, poplar trees and pipes, was as large a 4.3-m.

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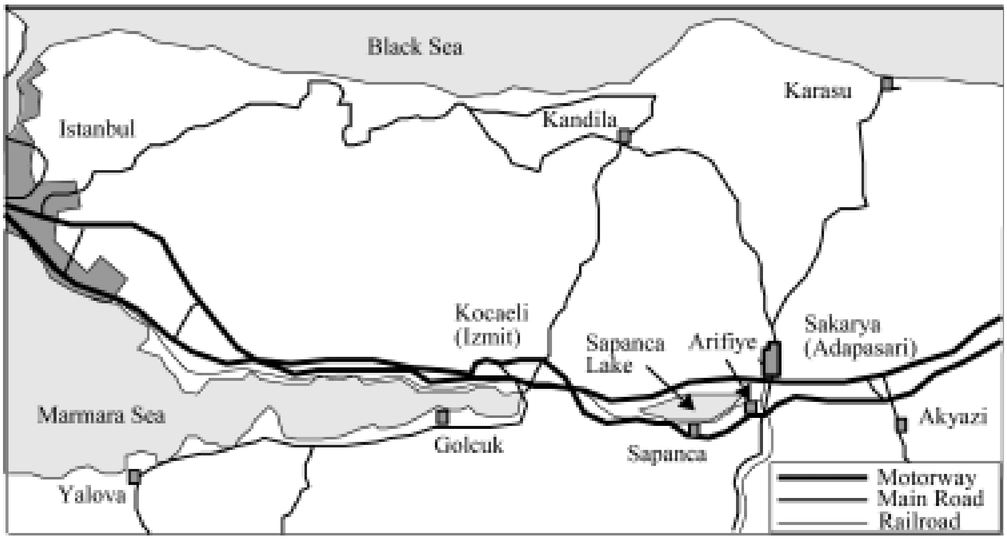


Fig. 5.1 Damaged Area

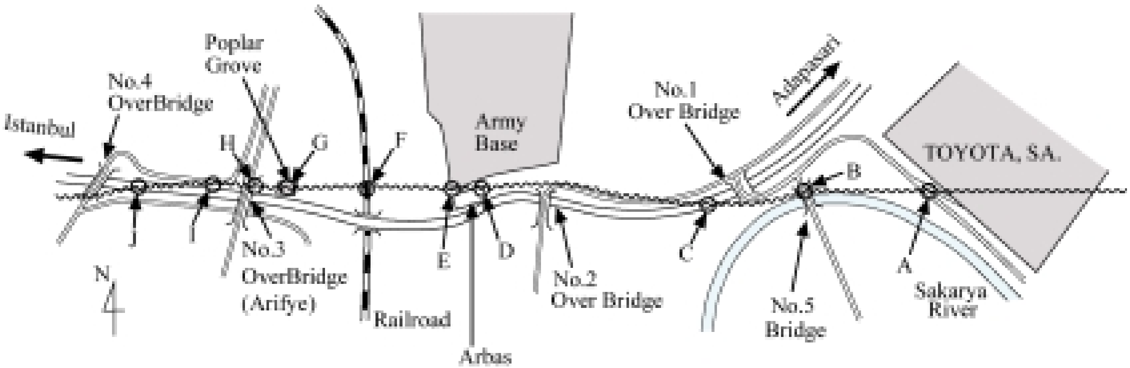


Fig. 5.2 Damaged Transportation Facilities and Fault-Induced Ground-Dislocations near Arifiye

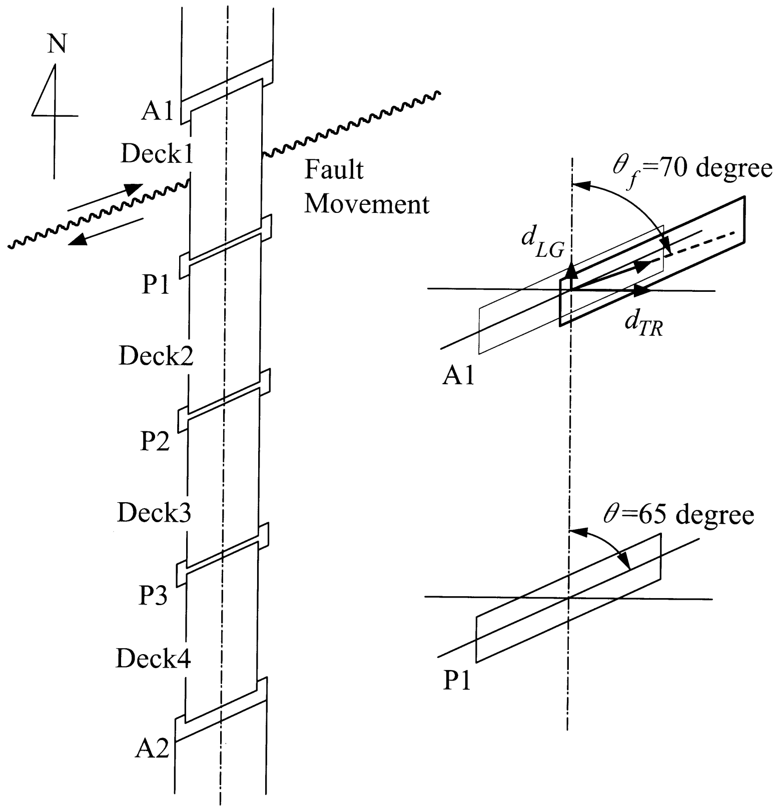


Fig. 5.3 Arifiye Overpass

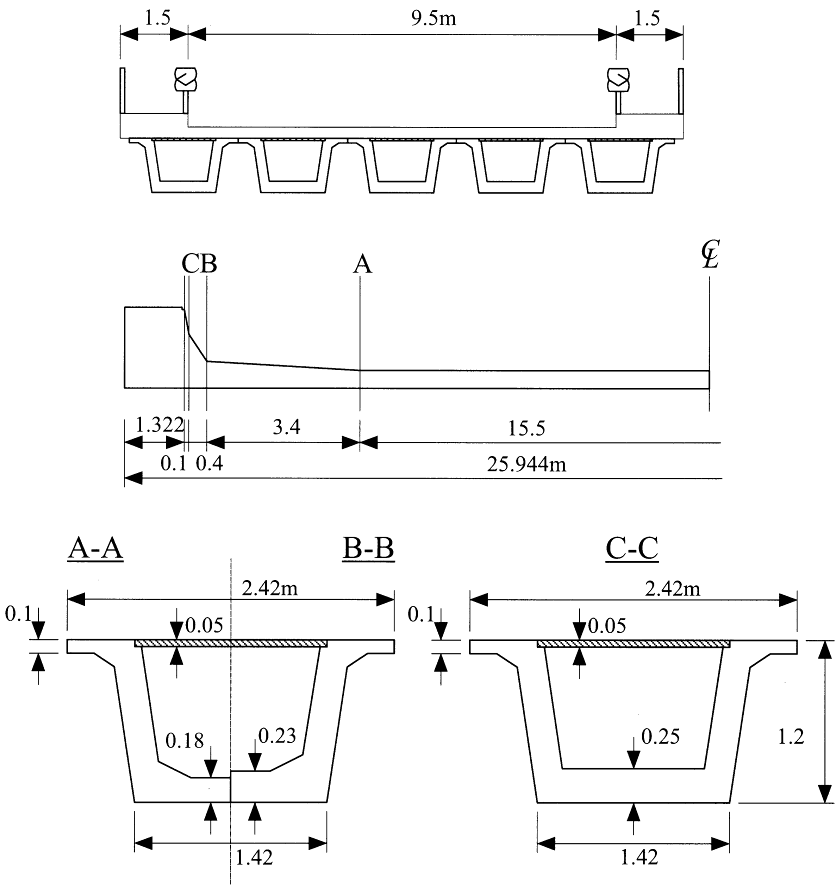


Fig. 5.4 Deck Section, Arifiye Overpass

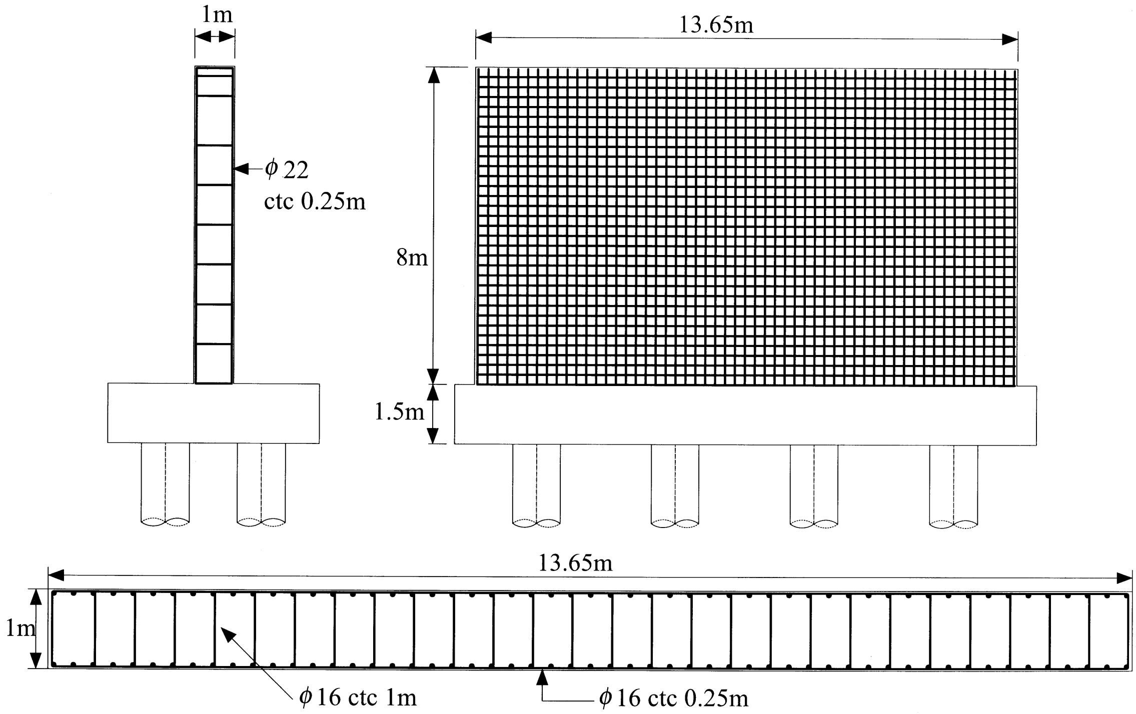


Fig. 5.5 Section of Piers, Arifiye Overpass

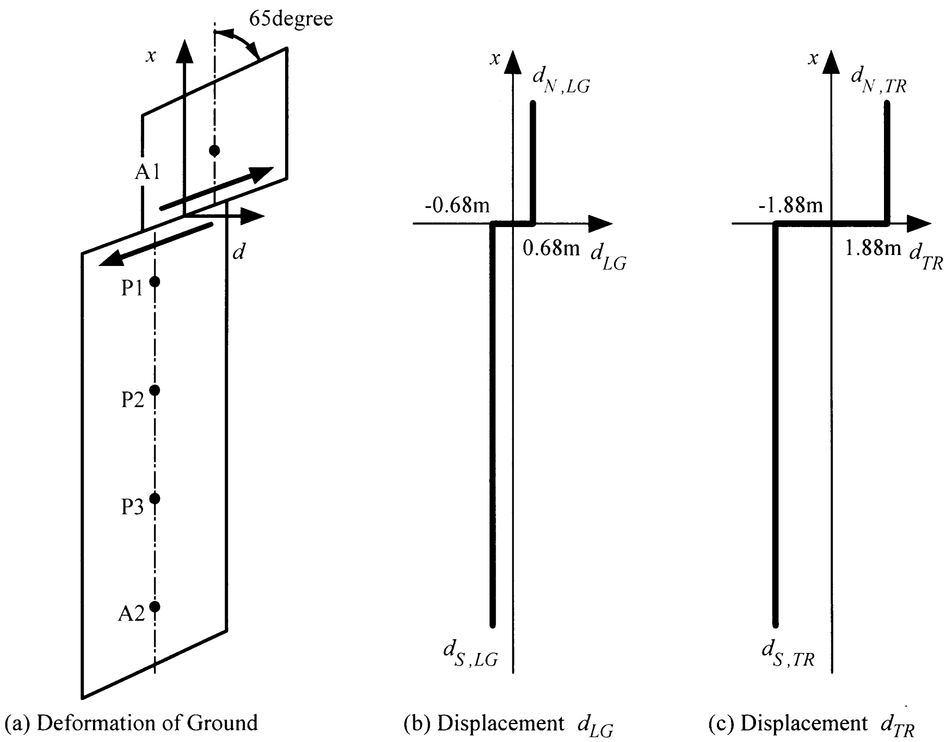
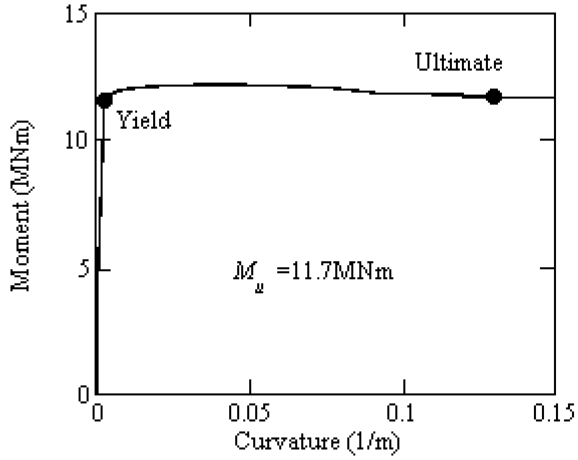
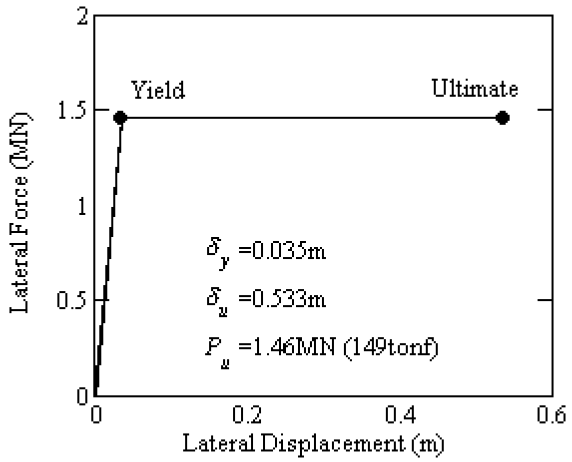


Fig. 5.6 Effect of Fault Movement



(a) Moment-Curvature Relation



(b) Lateral Force-Lateral Displacement Relation

Fig. 5.7 Lateral Force vs. Lateral Displacement Relation of Piers

Photo 5.1 Damage of an Approaching Road to Toyota S.A. Factory (Point A, refer to Fig. 2)

Photo 5.2 Offset of a Concrete Fence at of 4.3 m North-East Corner of an Automobile Factory (Arbas Arac Kadlama Fabzikasi) (Point D, refer to Fig. 2)


Photo 5.3 Offset of Poplar Tress of 3.5-4.3m (Point G, refer to Fig. 2)


Photo 5.4 Offset of a Sewer Pipe of about 4 m (Point H, refer to Fig. 2)

Photo 5.5 Offset of a Drainage Pipe of about 3.6 m (Point I, refer to Fig. 2)

Photo 5.6 Collapse of Arifiye Overpass (Courtesy of H. Hoashi)


Photo 5.7 Arifiye Overpass Being Demolished


Photo 5.8 North Abutment (A1), Arifiye Overpass

Photo 5.9 South Abutment (A2), Arifiye Overpass

Photo 5.10 Damage of Reinforced Concrete Stoppers on A2 (Only west side was damaged), Arifiye Overpass

Photo 5.11 Footing of P1, Arifiye Overpass

Photo 5.12 Piles That Supported P3 Footing, Arifiye Overpass

Photo 5.13 No. 1 Overpass

Photo 5.14 Collapse of Sakarya Bridge

Photo 5.15 Damage of an Approaching Bridge in a Paper Factory

Photo 5.16 Shear Failure of Reinforced Concrete Columns

(a) Rails

(b) Sleepers

Photo 5.17 Damage of Rails and Sleepers, near Tepetarla Station

Photo 5.18 Offset of Popular Trees of 2.5-m, near Tepetarla Station

Photo 5.19 Damage of Railways at South of Sapanca Lake


Photo 5.20 Damaged Rails and Sleepers, South of Sapanca Lake


Photo 5.21 Damaged Rails and Sleepers, near Arifiye Overpass