EARTHQUAKE REPORT

TO

COMMITTEE 9
SEISMIC DESIGN FOR RAILWAY STRUCTURES

AMERICAN RAILWAY ENGINEERING
AND
MAINTENANCE-OF-WAY ASSOCIATION

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JANUARY 26, 2001 GUJARAT, INDIA EARTHQUAKE

Earthquake

An earthquake with moment magnitude of 7.7 occurred on a southward dipping, east-west trending thrust fault northeast of Bhuj, Gujarat, India at 8:26 AM local time on January 26, 2001. The hypocenter depth was between 20 and 25 km. There was no observed surface rupture. Aftershocks were concentrated in a volume defined by 23.3 to 23.6 degrees latitude, 70.0 to 70.6 degrees longitude and depths between 10 and 35 km.

Railway System Description

A number of separate railways were constructed in India beginning in 1853. In 1951, they were combined into a national system consisting of 9 zones. Three different gages are used for tracks on the divisions affected by the earthquake. They are narrow gage (762 mm), meter gage (1000 mm) and broad gage (1676 mm). Only meter gage and broad gage are in the damaged areas. Some of the heavier traffic meter gage lines are being converted to broad gage. Much of the system is electrified but the portions affected by the earthquake are not. Crossties are primarily concrete or steel as use of wood for railroad crossties is essentially prohibited.

Response and Recovery

Four of the 8 divisions of the Western Railway sustained damage in the January 26, 2001 earthquake. Response to the earthquake was determined by the managers on the respective divisions. All trains on about 4900 km of line on all of 3 divisions and a significant part of the fourth were stopped at the first station reached after the earthquake. Trains were held until it was determined that track and bridges were safe for operation. Significant damage to railway facilities occurred over about 850 km of line shown in Figure 1. The most severely damaged area was between Bhachau and Anjar.

Although a number of trains, including 8 scheduled passenger trains, were operating in the area, none were derailed. A freight train running between Chirai and Bhachau was stopped when the earthquake was felt by the train crew, who suspected a derailment, but was able to proceed to Bhachau. Chirai, the first station to the west, is about 13 km from Bhachau. Two tank cars loaded with water and standing in the yard at Bhachau were derailed and a third had the body overturned with the trucks apparently remaining on the track.

Inspections were completed and operation was resumed on lines without major damage within about 3 hours after the earthquake. This is significantly less time than was required after several recent earthquakes affecting other railroads, probably as a result of a favorable distribution of inspection personnel. All lines except the line from Dahinsara to the port of Navlakhi were restored to service by January 29 with most lines in service by January 28. Recovery was accomplished in stages starting with operation of trains with speed restrictions.

Where there was significant damage to signal and interlocking systems, operation was resumed with manual operation of switches and reduced speed for facing point moves in accordance with interlocking operating standards. Where signals were inoperative, paper authority was used for track occupancy within absolute blocks. The latter would be similar to track warrant operation in North America with the track warrants delivered to trains by operators instead of by radio. As repairs were made, speed restrictions were removed until normal operation was restored.

Damage

Significant damage to railway facilities occurred over about 850 km of line shown in Figure 1. The epicenter is shown by a star. Broad gage lines run through Khakhrechi, Maliya Miyana, Samakhiali and Gandhidham to Bhuj, from Gandhidham to Kandla Port , from Maliya Miyana to Wankaner, from Dahinsara to Navlakhi Port, through Wankaner and Rajkot to Okha and from Rajkot to Veraval. Meter gage lines run through Kidyanagar and Samakhiali to Gandhidham, from Gandhidham to Kandla Port and from Bhuj to Naliya. The most severely damaged area was between Bhachau and Anjar.

Track Damage

About 1 km of embankment and track shifted and settled into the Gulf of Kachchh near Navlakhi as a result of liquefaction and lateral spreading as shown in Figure 2. This track segment was replaced on a new alignment. The line was returned to service on March 31. Additional roadbed damage and track displacement occurred at a number of locations from slides and cracking due to lateral spreading. These locations were primarily northeast of Gandhidam, in an 18 km stretch around Bhachau. Settlement at bridge ends occurred as far east as the vicinity of Maliya Miyana. Ballast was displaced due to shaking at locations over a wide area. Examples of this damage are shown in Figures 3 through 5.

Bridge Damage

Bridges were damaged on 135 km of broad gage line between Bridge 161 across the Little Rann of Kachchh and Bhuj and 50 km of meter gage line between Samakhiyali and Gandhidham, which contained about 240 bridges and culverts, including 22 major bridges with spans greater than 12.2 meters or total length greater than 18.3 meters. A total of 12 bridges sustained significant damage. Six of 24 arch bridges, 5 of 75 girder bridges and one of 41 reinforced concrete slab bridges are included in this group. Arch bridge damage included failures caused by outward earth pressure against parapets and spandrel walls, cracking in mortar joints of arch rings and displacement of stones in arch rings due to outward movement of abutments. Girder bridge damage included movement of girders relative to piers and/or pier displacement resulting in unacceptable track geometry and, in some cases bearing and/or anchor bolt damage. Cracking of horizontal mortar joints of stone substructure units occurred in both girder and concrete slab bridges. Other bridge damage included separation of wing walls from abutments and other damage to wing walls. One reinforced concrete box had wing wall damage. Examples of bridge damage are shown in Figure 6 which shows parapet failure and displacement of stone in arch ring and in Figures 7 and 9.

Three arch bridges required installation of temporary falsework to carry traffic before they could be returned to service. Falsework was either girders spanning between piers as shown in Figure 10 or rail clusters supporting the ties on shorter spans as in Figure 11 (right side). Two of these bridges lost major portions of their parapet and spandrel walls with a resulting loss of fill supporting the track. The third, shown in Figure 8, had been extended on both sides to allow conversion from meter gage to broad gage track. Longitudinal joints near the boundary between the original arches and the extensions separated (Figure 9). A fourth arch bridge suffered collapse of a portion of the parapet wall and about 50 mm downward displacement of stones in both end spans due to 6 to 10 mm outward movement of the abutments (Figure 6). Partial repairs were required before it was returned to service. One reinforced concrete slab bridge and two girder bridges with severely cracked masonry joints in substructure units were placed in service with restrictions. The restrictions included monitoring of cracks and a requirement that trains stop before crossing the bridge at a speed not exceeding 10 km/hr. Temporary repairs are shown in Figures 11 showing temporary shoring to retain fill over arches and 12 showing rails set in concrete to restrain movement above cracked mortar joints. Figures 13 and 14 show permanent repairs, including epoxy injected joints between stones.

Building Damage

Damaged railway owned buildings numbered in the thousands with about one third damaged beyond repair. To keep this number in perspective, it should be noted that it includes housing units for a large percentage of railway employees, schools, hospitals and other facilities no longer typically owned by railroads in North America. It also includes a large number of minor structures, such as interlocking towers and cabins at road crossings with gates, which are all operated by employees at the crossings. Most stations between Samakhiyali and Bhuj were damaged beyond repair. The station at Samakhiyali is shown in Figure 15 together with a foot bridge over the tracks which had to be supported on falsework due to shear failures in the supporting concrete piers. Stations were also damaged over a much wider area. The station at Morbi is shown in Figure 16.
About 875 housing units for railway employees will have to be replaced and a comparable number will require major repairs. Buildings that were not useable were replaced with temporary buildings such as the station and interlocking tower shown in Figure 17.

Relief Services

A total of 57 special passenger trains for evacuating earthquake victims were run from Gandhidham, Ahmedabad etc. Thirty six special freight trains were run to carry relief supplies and equipment to Gandhidham. Other relief material was handled to affected areas in cars of the baggage-express type in passenger trains. The broad gage converted section between Gandhidham and Bhuj, which was due for Commissioner for Railway Safety inspection, was rehabilitated and opened for movement of relief material by February 4. Relief passenger trains were run between Gandhidham and Bhuj. Relief workers were issued special passes.

Five railway owned accident relief medical equipment units, including one each from Central, Northern and Southern Railways were sent to the area. The Railways mobile hospital, a six car train, was sent to Gandhidham and, later, to Anjar.

Recommendations

Certain lessons learned from this earthquake are applicable to all railroads in seismically active areas.

Consideration should be given to structurally connecting the parapets and spandrel walls of filled-spandrel arch bridges. Retrofitting existing bridges appears practical.

Restoration of track to normal standards following an earthquake may require sizeable quantities of ballast.

The vulnerability of track adjacent to coastlines should be considered in any earthquake response plan.

A sufficient number of inspection personnel, properly located at the time of the earthquake, can significantly reduce the time lines without major damage are out of service due to the earthquake.

Acknowledgement

The investigation providing the basis for this report would not have been possible without extensive assistance from members of the Railway Board and operating and engineering officers of the Western Railway, particularly Anirudh Jain, Chief Engineer (Works) and O. P. Agrawal, Chief Engineer (HQ). Their assistance is gratefully recognized.

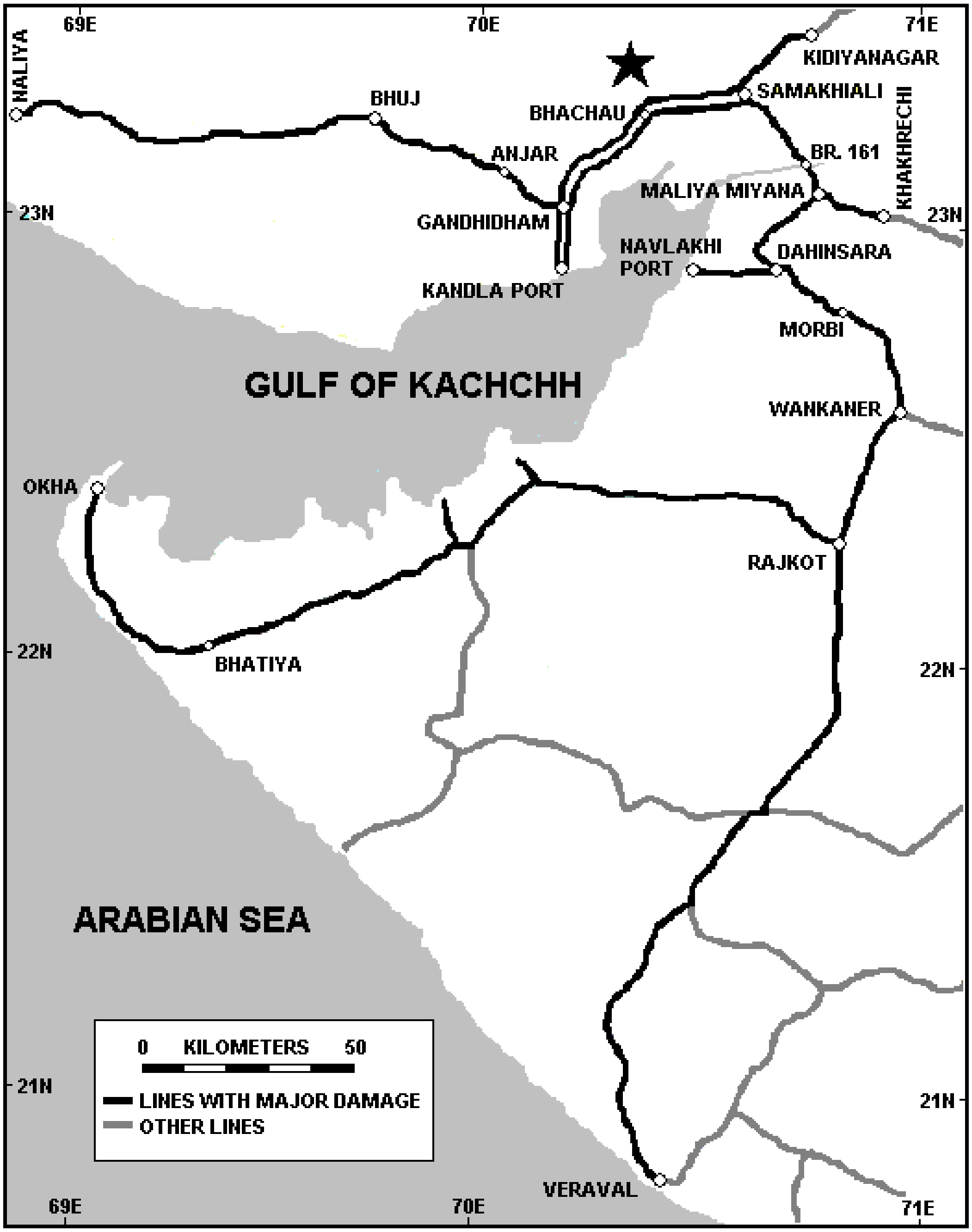

Figure 1. Rail lines in area of earthquake.

(a) Original alignment about March 1, 2001
(ASCE – TCLEE Earthquake Investigation Committee photo)

(b) New alignment on April 12, 2001

Figure 2. Submerged track near Navlakhi.

Figure 3. Cracks in embankment due to lateral spreading.

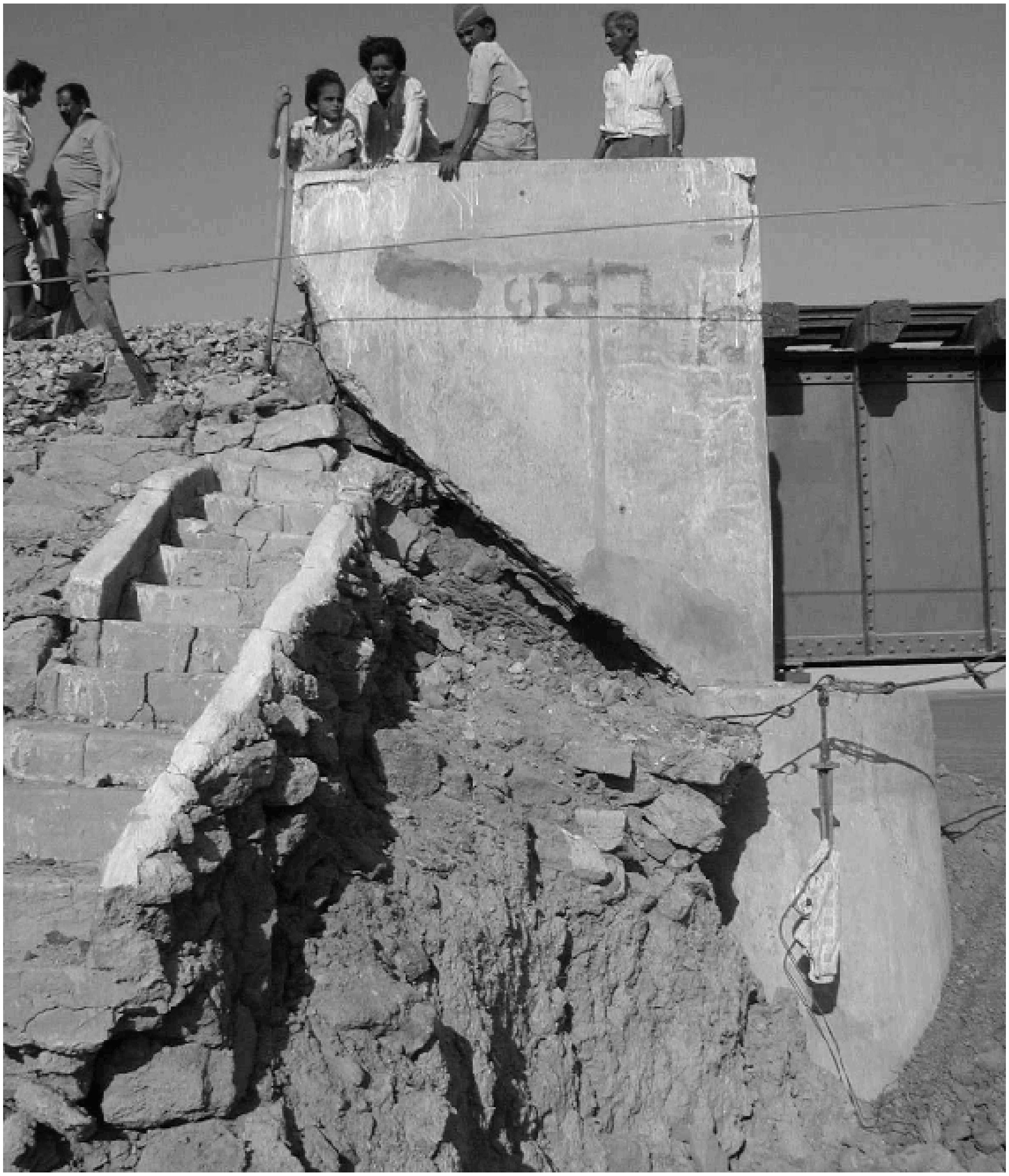

Figure 4. Settlement at Bridge No. 279

Figure 5. Settlement at Bridge No. 161

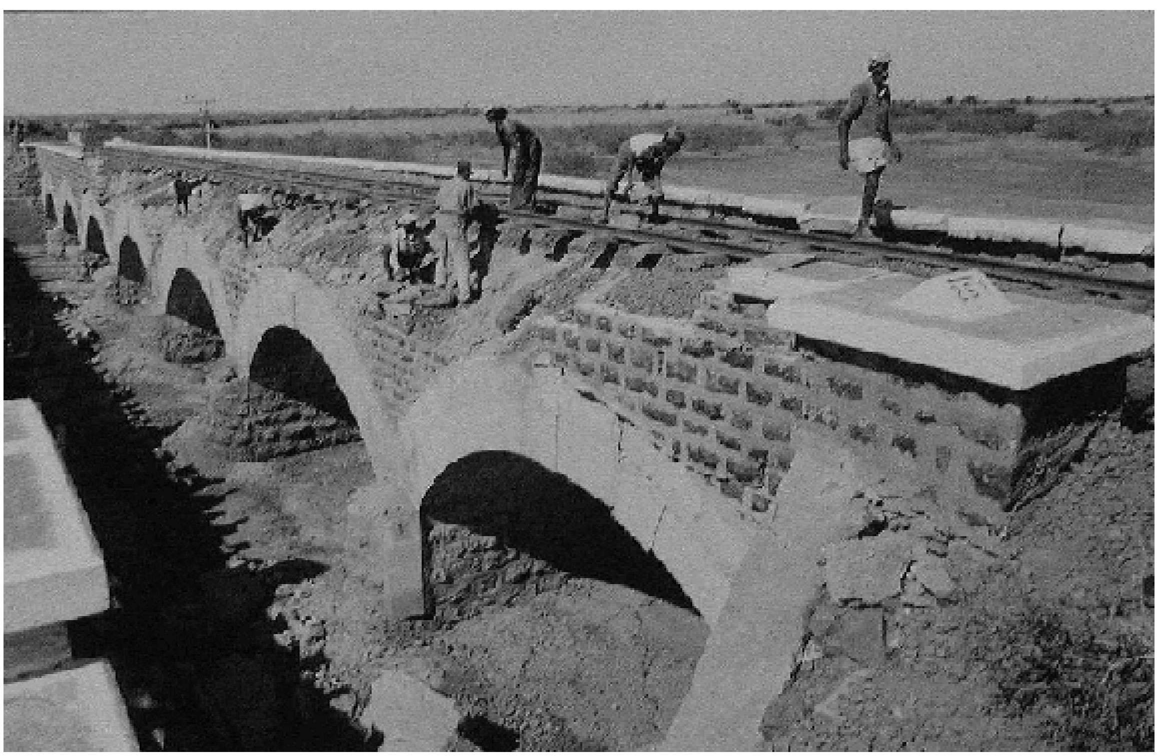

Figure 6. Failed parapet and displaced stone in arch ring at Bridge No. 261 (*Western Railway photo*)

Figure 7. Wing wall separation at Bridge No. 271

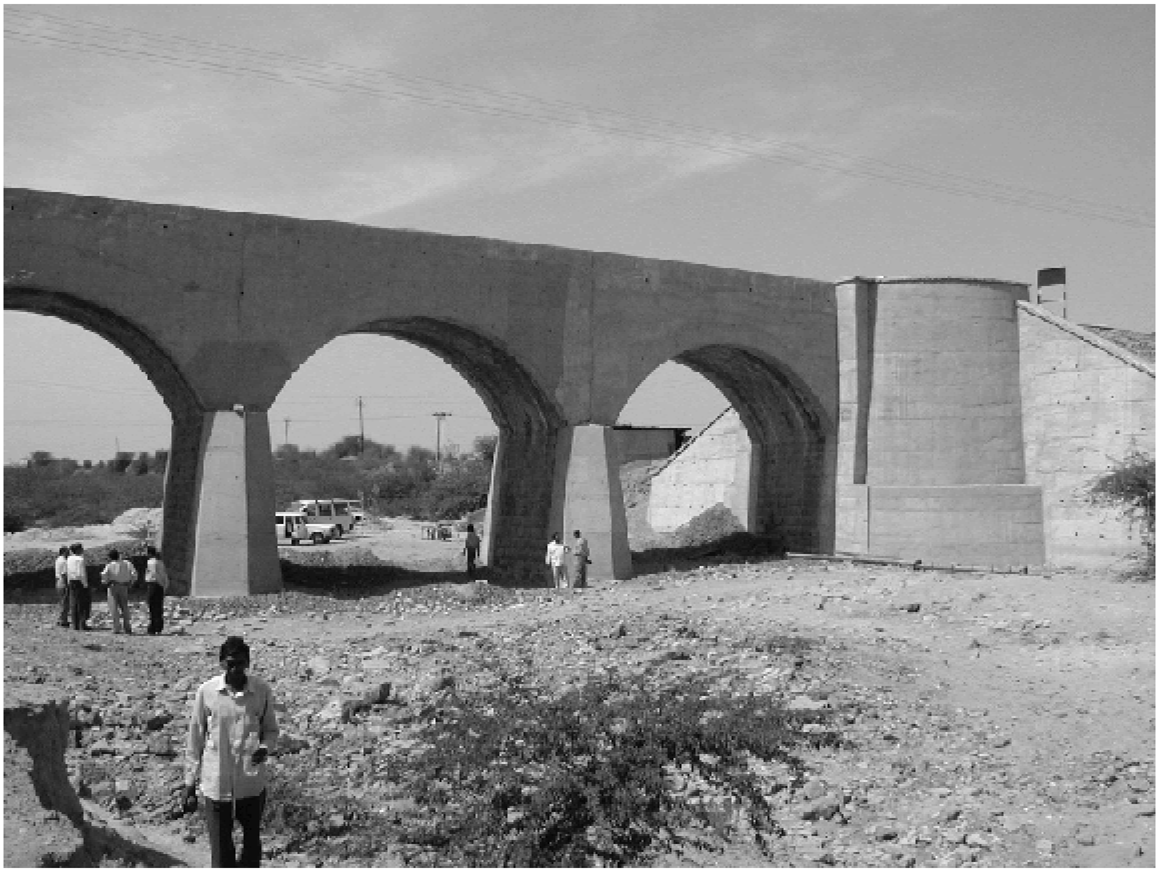

Figure 8. Bridge No. 48 converted from meter gage to broad gage by adding concrete on both sides of stone arches

Figure 9. Separation along longitudinal joints in arch at Bridge No. 48

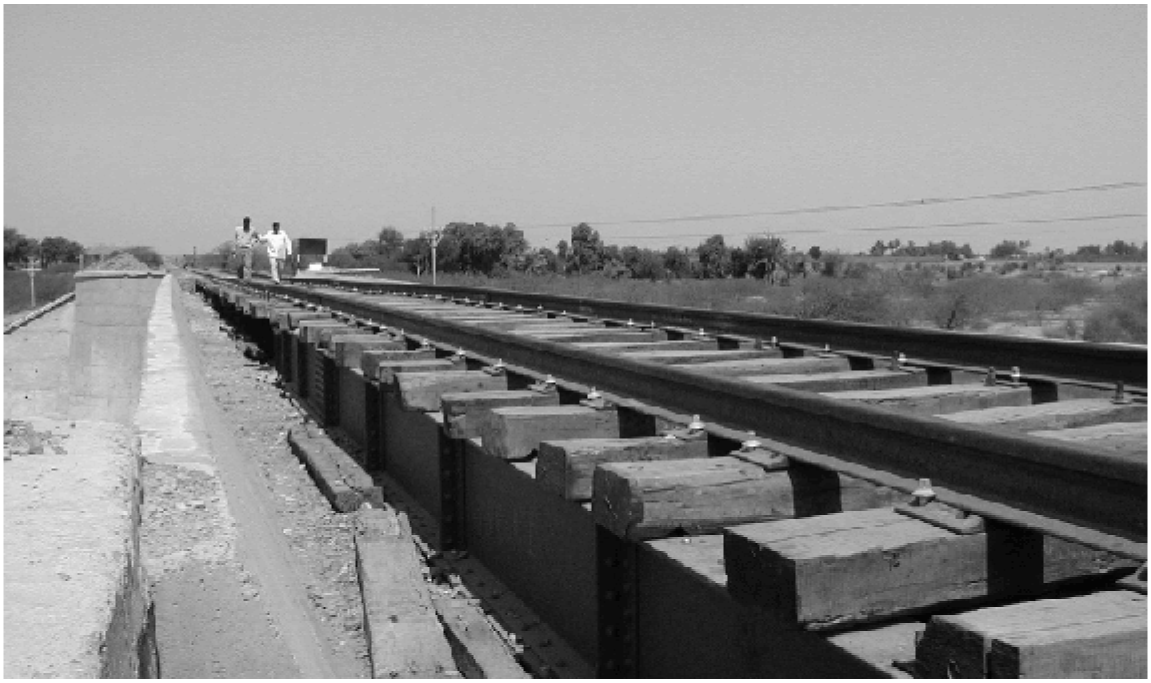

Figure 10. Falsework consisting of girders supported over piers at Bridge No. 48

Figure 11. Shoring to retain spandrel fill and rail cluster falsework at Bridge No. 245

Figure 12. Rails set in concrete to resist movement of portion of pier above horizontal crack until epoxy is injected into joint

Figure 13.Epoxy injection repair of joints in arch ring at Bridge No. 261

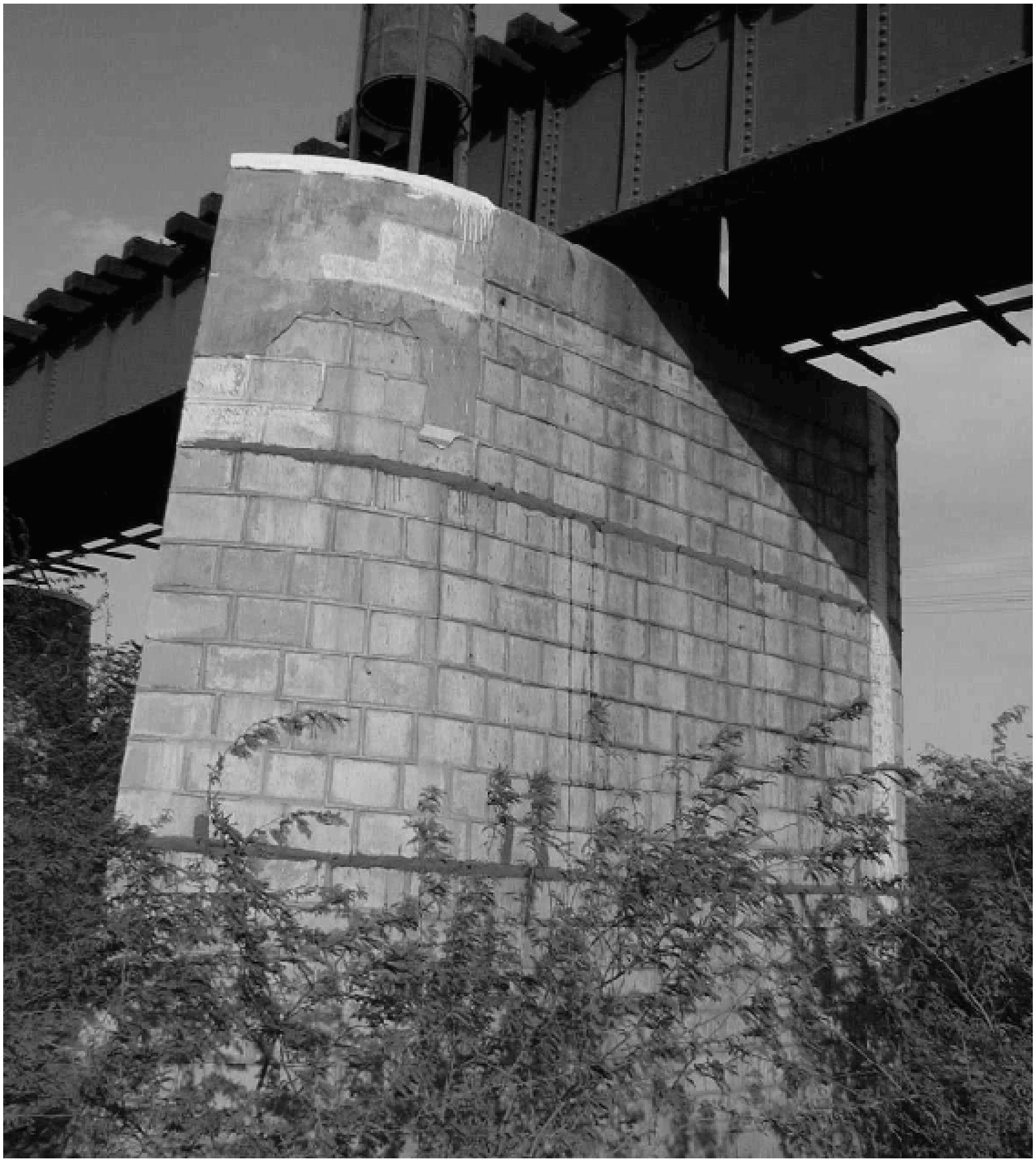

Figure 14. Pier repairs at Bridge No. 290

Figure 15. Samakhiyali station and foot bridge supported on cribbing

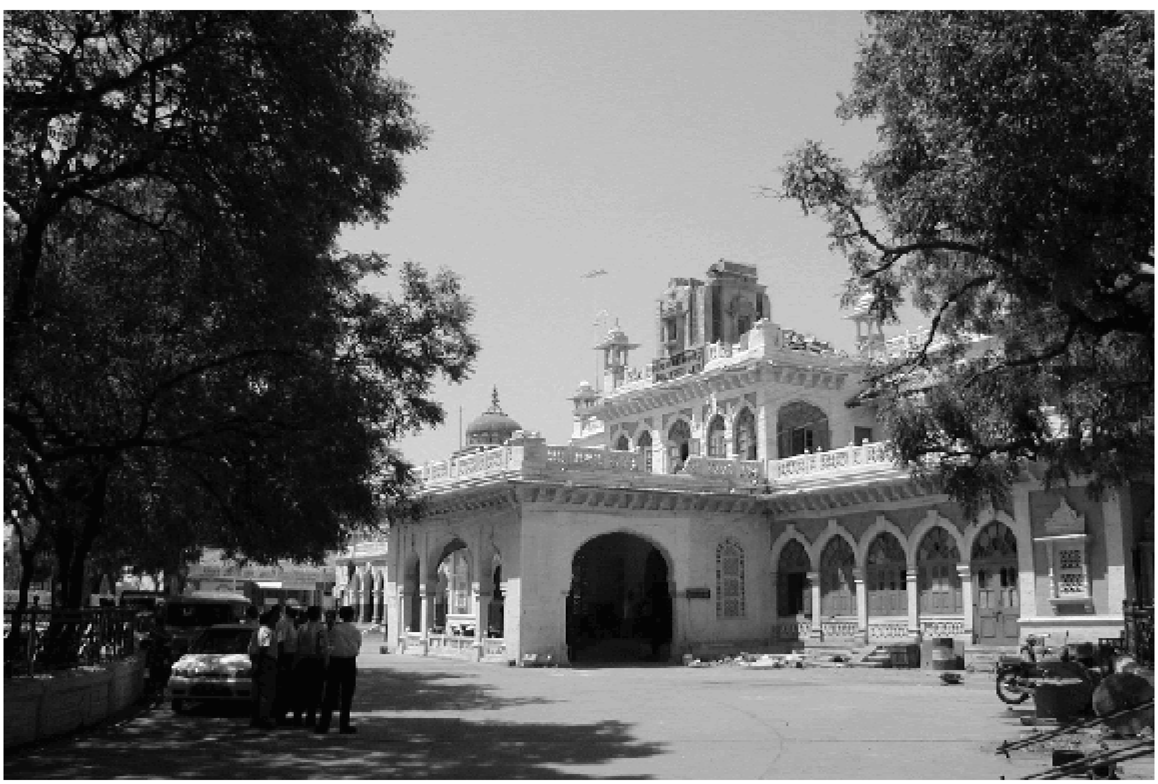

Figure 16. Morbi station after collapse of tower

Figure 17 Temporary station and interlocking tower at Bhatiya