19 Roads and Bridges

INTRODUCTION

Bridges in the Kachchh region are generally stream or railway crossings. The affected area has significant road and rail networks. There are several major highway and railway bridges, and many small to medium bridges. As per Roads and Buildings (R&B) Department of the Government of Gujarat, 900 km of roadways and over 500 bridges were damaged in the January 26, 2001 earthquake.

Bridges in the area are typically composed of short spans with span lengths of approximately 15 m. Bridges are simple spans with expansion joints at each pier and supported on elastomeric bearings with no continuity of the superstructure or any fixity at the intermediate diaphragms. L-shaped abutments are typical for all newer concrete and older masonry bridges. The substructure of most bridges is wall piers supported on shallow foundations with no consideration for ductility. Use of deep foundations is not prevalent, even though liquefaction and lateral spreading is to be expected in the region in a seismic event.

Both existing bridges and those under construction suffered extensive damage during the earthquake (Jain et al., 2001).

Precast concrete members are occasionally used in the construction of bridges. Precast/prestressed concrete bridges performed better, relatively, than cast-in-place concrete or other types of bridges. The better performance of the precast/prestressed bridges can be attributed to the higher quality of construction in the fabrication of precast members.

The State Highway system suffered damage primarily to road surfaces, while the National Highway system's main damage was to bridge structures. A summary of damages sustained by the roads and bridges along State Highway and National Highway in the affected area is presented in Tables 19-1 and 19-2.

ROADS

The road system consists of National Highways, State Highways, Major District Roads, Other District Roads, and Village Roads. In the affected area, there are over 5400 km of roadways. Worst affected was the Kachchh district itself. Types of damages sustained include:

- Longitudinal cracks along the central carriageway and shoulders of elevated road embankments.
- Transverse cracks between the bridge spans and the roadway.
- Longitudinal/transverse cracks along ground fissure lines crossing the road system.
- Settlement/uplift of road at some locations.

The Gujarat Roads and Buildings Department administers the design, construction, and maintenance of roadways, bridges, and other structures in the State of Gujarat. National Highway 8 (NH8) is the most important road in the Kachchh region. NH8A connects local ports and towns to

Table 19-1. Damages caused to the State Highway network during the earthquake (as per Roads and Buildings Department of the Government of Gujarat).

Item	Total Affected Number or Length	To be taken up in Phase 1	To be taken up in Phase 2	Cost of Repair/ Rehabilitation/ Reconstruction (Approx.)
Bridges				
Culverts	896	186	710	
Minor bridges (less than 60m in length)	275	115	160	US$32 million
Major bridges (of length more than 60m)	97	57	40	
Roads				
Roads	~900 km	~200 km	~700 km	US$80 million
Total estimated cost				US$112 million

Table 19-2. Damages caused to the National Highway network during the earthquake (as per Roads and Buildings Department of the Government of Gujarat).

Item	Total Affected Number or Length	Cost of Repair /Rehabilitation / Reconstruction (Approx.)
Bridges		
Culverts	164	
Minor bridges (of length less than 60m)	98	US$65 million
Major bridges (of length more than 60m)	38	
Roads		
Roads	~20 km	US$45 million
Total estimated cost		US$110 million

Figure 19-1. Roadway cracking between the towns of Gandhidham and Bhachau.

Figure 19-2. Collapse of roadway drainage structure between towns of Anjar and Bhuj.

India's highway system. The New Surajbadi Highway Bridge on NH8A, a four-lane divided modern toll road, was still under construction at the time of the earthquake. This new replacement bridge is constructed at a higher elevation than the existing road to better accommodate monsoon flooding.

Local roads in Gujarat are mostly two lanes between towns, and one lane to and between villages. Such roads are generally subject to a low volume of vehicular traffic with very few heavy trucks. After the earthquake, these roads were crucial for accessibility and emergency response to remote areas.

Newly finished roadways between the towns of Gandhidham and Bhachau suffered some damage. Longitudinal cracks 50 to 100 mm wide and approximately 300 mm deep cracks developed along the shoulder and edge of the traffic lanes on the embankment (Figure 19-1). Settlement of the shoulder edge and holes about 600 mm in diameter and 450 mm deep are also visible in the photo. A longitudinal crack separated the entire guardrail system from the roadway shoulder. While rock blocks were laid and mortared in place on the face of the slope, earthquake caused settlement and down slope movement of the underlying soil.

TRAFFIC-BEARING DRAINAGE STRUCTURES

Lack of structural adequacy resulted in the collapse of several traffic-bearing roadway drainage structures, as shown in Figure 19-2. Such roadway drainage structures were, in most cases, concrete box culverts, concrete pipes and unreinforced masonry box culverts. To accommodate postearthquake traffic, temporary detours were provided across adjacent dry-season riverbeds. Damaged drainage structures are not repairable, and need to be rebuilt with adequate attention to quality in design and construction.

BRIDGES

Due to poor construction, a harsh environment (monsoons, typhoons, saline groundwater, hot dry weather) and little maintenance, bridges of the area were in substandard condition prior to the earthquake. Lack of suitable materials, poor quality of construction, deterioration of concrete, and rusting of reinforcing steel is common to most roadway bridges.

Bridge structures include major bridges, minor bridges, and slab and pipe culverts. In India, bridges of length exceeding 60 m are termed major bridges; others are classified as minor bridges. Most highway bridges are constructed of stone masonry or reinforced concrete, while

Figure 19-3. Old Surajbadi Highway Bridge.

Figure 19-4. Relative longitudinal movement between the piers and the superstructure spans in the Old Surajbadi Highway Bridge.

the railway bridges included some steel superstructures as well. Damages include movement, damage and collapse of piers, abutments and wing walls; cracking of main girders; disintegration of bearing pedestals; damage to elastomeric bearings; collapse of parapet walls; damage to pier caps; collapse of approach embankments; and displacement, movement or breakage of reinforced concrete Hume pipes.

Excluding the damage from the earthquake, the condition of cast-in-place concrete bridges is in general unsatisfactory and substandard. Earthquake damage to bridge structures can be attributed to the lack of seismic design and detailing of both old bridges and bridges under construction. The seismic design forces for highway bridges are specified in IRC6 (IRC6 2000), seismic provisions of which have not been revised for over three decades (Jain and Murty, 1998). A more detailed discussion is available in Chapter 17, Codes, Licensing, and Education.

OLD SURAJBADI HIGHWAY BRIDGE

The Old Surajbadi Highway Bridge across the Little Rann of Kachchh on National Highway 8A (NH8A), is the longest bridge in the region. It was built in the 1960s at the same time as the Surajbadi Railway Bridge (see below) and parallel to it. It suffered significant damage in the January 26, 2001 earthquake due to lack of ductility, damage to bearings, shear failure of the hinges, and significant ground movement and liquefaction.

This 1205 m bridge (Figure 19-3) has cast-in-place reinforced concrete balanced cantilever box-type superstructure (35 interior spans of 32.93 m each, two end spans 26 m each). The superstructures rest on steel rocker and roller bearings placed on top of reinforced concrete wall piers. The wall piers are supported on well foundations of different diameters (ranging from 7-10 m). The depth of the well foundations ranges from 13-18 m. Given the age of the bridge, seismic analysis and detailing may not have been considered in its design.

Further, over the years, the superstructure seems to have severely deteriorated (spalling of concrete, corroded reinforcement bars) due to exposure to the highly saline environment. Steps to protect this exposed reinforcement from further corrosion are evident from the highly uneven shotcreted surfaces of the superstructure.

Sand boils, lateral spreading and settlement were widespread in the Little Rann of Kachchh region. The entire area under and around the bridge liquefied as a result of the earthquake. Sand boils up to 600 mm wide were widespread along the bridge alignment (also see Chapter 7,

Figure 19-5. Roller bearing on the north side abutment of the Old Surajbadi Highway Bridge.

Figure 19-6. Damaged bearing on Old Surajbadi Highway Bridge. The New Surajbadi Highway Bridge (under construction) can be seen in the background.

Figure 19-7. Failure of in-span hinge and traffic railings at Old Surajbadi Highway Bridge.

Liquefaction). The shallow well foundation with wall pier supported on top moved in the liquefied sand. Damage to the bridge indicates that there was both longitudinal and transverse movement of the bridge superstructure and substructure (Figure 19-4). The embankment at the north end of the bridge settled approximately 300 mm and moved toward the channel. This settlement and lateral spreading of the embankment extended to the bridge abutment and resulted in settlement of the roadway. The north abutment also moved westwards toward the channel. The foundation under Pier No.12 from the northern abutment has significantly tilted, shifting the alignment of the highway. Pier 14 rocked off its foundation.

There is no continuity or ductility in the structure; therefore each span acted independently and the entire structure experienced a collection of out-of-phase dynamic motions. As a consequence, the bridge suffered damage due to pounding of the superstructure spans at the balanced cantilever joint locations. The expansion joints were closed, rotated, and had popped out throughout the bridge. The concrete handrails and balusters at the expansion joints sheared off at the connections. The cracks in the balusters extend into the bridge deck slab.

During the earthquake, all bearings under the superstructure of this bridge have been damaged (Figures 19-5 and 19-6). Due to liquefaction and ground movement, some piers moved and associated spans shifted on bearing supports. The bearings broke due to excessive lateral load at the inclined surface of the in-span hinge of the suspended span, which also sustained shear failure (Figure 19-7). This damage allowed the superstructure to slide off the bearings at several intermediate piers.

Figure 19-8. Girder-pier support system on the New Surajbadi Highway Bridge. Well foundation is not visible.

Figure 19-9. Severely strained elastomeric bearings of the New Surajbadi Highway Bridge.

The bearings and expansion joint at the abutment are completely dysfunctional and may not be repairable. Even though there were no transverse stops to prevent such lateral movement of the superstructure spans, the large size of the pier cap prevented the spans from dislodging.

As a result of this damage, the bridge was closed to traffic for a couple of days. It was temporarily restored for slow, single-lane traffic after the dislodged superstructure spans were jacked back to their original positions and seated on wood blocks as temporary measure. Five weeks after the earthquake, the New Surajbadi Bridge was commissioned and the Old Surajbadi Bridge was closed to traffic pending a decision to repair or abandon.

It is interesting to note that high voltage transmission line towers supported on four circular piles and running parallel to the two Surajbadi Highway Bridges, were completely undamaged.

NEW SURAJBADI BRIDGE ON NH8A UNDER CONSTRUCTION AT TIME OF EARTHQUAKE

The New Surajbadi Highway Bridge, parallel to the old one, was nearly complete (two spans were still to be completed) at the time of the earthquake. The bridge was completed and commissioned on March 3, 2001, five weeks after the earthquake, and the traffic was diverted from the old damaged bridge to the New Surajbadi Highway Bridge.

The New Surajbadi Highway Bridge consists of cast-in-place concrete tee-beam girders. It has 39 simply supported girder-slab superstructure spans, each of 32.2 m. There are three prestressed concrete girders under the deck. The girders were pretensioned and precast at the site in a shop on the south end of the bridge, and then brought to the span location by cranes for installation. The bridge girders are rested on the piers with elastomeric bearings in between. Reinforced concrete piers that flare out on top support the superstructure spans. The adjacent spans do not share the same pier; they are rested on different piers. These two piers are together supported on one foundation. Figure 19-8 shows two piers supported on the well foundation underneath (not visible). The bridge was designed for a static horizontal seismic coefficient of 0.09g.

Figure 19-10. Damaged concrete pedestals of the elastomeric bearing of the New Surajbadi Highway Bridge.

Figure 19-11. Damaged soffit of the girder at the span ends of the New Surajbadi Highway Bridge.

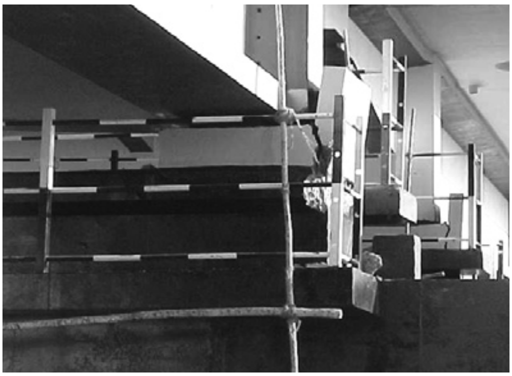

Figure 19-12. Cracked stoppers with separation as wide as 5 inches, New Surajbadi Highway Bridge.

Figure 19-13. Damaged reinforced concrete stoppers showing poor bond between the epoxy-coated rebar and the adjoining concrete at the New Surajbadi Highway Bridge.

Elastomeric bearings displaced from their original locations by as much as 0.25 m and were severely stressed (Figure 19-9). This suggests that the shaking intensity may have caused either the uplifting of the girder or the sliding of the girders over the concrete pedestal along with the bearings. The use of plain elastomeric bearings is not suitable for high seismic regions and a shear pin is required to prevent sliding during earthquakes. Indian codes do not prevent plain elastomeric bearings from being used in high seismic regions. Damages were also observed to the concrete pedestals (Figure 19-10) and to the soffit of the girder at the ends (Figure 19-11).

Reinforced concrete stoppers were provided on the pier supports to limit the lateral seismic displacement of the girders. The gap on either side between the girders and the stoppers was about 115 mm. Almost all stoppers were damaged in the earthquake due to pounding by the girders, indicating a significant lateral motion of the girders during the earthquake. These stoppers definitely came into use during the January 26 earthquake. Although they have been damaged in their service, they also seem to have stopped the bridge deck from coming off its support. Figure 19-12 shows two damaged stoppers, one of them with a large 127 mm wide crack. The fusion-bonded epoxy-coated rebar showed poor bond characteristics (Figure 19-13).

Figure 19-14. Transverse displacement of the superstructure decks of the New Surajbadi Highway Bridge.

Figure 19-15. Pounding between two adjacent bridge spans, New Surajbadi Highway Bridge.

Figure 19-16. Near the south side abutment of the Surajbadi Railway Bridge.

There was no apparent or reported damage to the piers and foundations. But, large lateral (204 mm) and vertical (64 mm) relative displacements of the decks at some deck joints were observed (Figure 19-14). These vertical displacements indicate a possible settlement of the foundation. Damage to the deck joints due to mutual pounding of the two spans was observed (Figure 19-15).

The girders were jacked up and repositioned, the alignment of the bridge was restored, the last two spans were completed, and the damaged reinforced concrete stoppers were reconstructed.

SURAJBADI RAILWAY BRIDGE

The Surajbadi Railway Bridge and embankment near Surajbadi were completed in 1969-70.[1] The railway bridge consists of 62 spans of 18 m steel plate girders. The girders are simply supported on flat plate bearings on the piers. The railway track is directly supported on the railway ties that are placed on and anchored to the girders. There is no ballast under the rails on the bridge (Figure 19-16). The bridge performed well in the earthquake.

The substructure consists of concrete piers supported on well foundations. The well foundations go through the layer of the blue marine clay to a competent soil with adequate bearing capacity.

[1] EERI Reconnaissance Team member, M.P. Singh, started his professional career as a civil engineer on the construction of this bridge and embankment with Western Railways in India in 1964, and was involved in the initial stages of the design and construction.

The bridge substructure was designed for a lateral force equal to 10 percent of gravity. The piers are about 15 feet above the well caps. The team was not able to visit the bridge, as it was not easily accessible without railway trolley, and it could only be viewed from a distance. However, a railway Chief Engineer on the site mentioned that the bridge did not suffer any major damage. There was dislocation of girders on several bearing plates, which affected the alignment of the track. In addition to the sliding of the girders on the bearing plates, the approach embankment on the south side also settled, but railway crews were able to repair the embankment and realign the girders and track well enough to resume running the trains within a few hours.

The successful performance of this bridge can be attributed to the fact that Indian Railways requires that safety related structures, such as bridges, be designed conservatively with high safety factors. Because of the importance of the precision required to run trains on a trouble-free track, Indian Railways demands a higher level of quality in their construction and maintenance practices. At the time of construction of the Surajbadi Railway Bridge, it was considered necessary to use salt-free water imported from remote areas for concrete mixing, because the local water—being saline—was considered unsuitable. A conservative design approach with good construction and maintenance practices apparently helped this bridge perform well in this major earthquake.

RUDRAMATA BRIDGE

The Rudramata Bridge, built in 1966, is located on State Highway 45, 16 km north of Bhuj. The bridge is 7.3 m wide and is composed of 10 simple spans of 16.8 m each, with expansion joint at the piers. The superstructure consists of two precast/prestressed girders with cast-in-place concrete deck and diaphragms. Elastomeric bearings support the prestressed girders at both abutments and at intermediate piers. There were no longitudinal restrainers or transverse stops to control the superstructure movement on the piers. The substructures consist of reinforced concrete A-frame towers (Figure 19-17). These are each supported on a large diameter caisson. The main structure of the bridge performed relatively well during the earthquake, but the north end suffered approach damage, resulting in the closure of one lane of traffic.

Due to the seismic excitation, lateral spreading and ground cracking at the north abutment resulted in settlement of the bridge approach (Figure 19-18). Also, cracks developed at the north abutment parallel to the stream bank (Figure 19-19). These cracks were 150 to 300 mm wide and up to 1.2 m deep. These are attributed to lateral spreading of the soil in the riverbed and extended on both the upstream and downstream sides of the bridge for a distance of about 450 m. However, there was no apparent damage to the south abutment due to this lateral spreading. There was no noticeable displacement of the abutments or intermediate piers due to ground movement. But, gapping or separation between the pier caissons and the surrounding ground of up to 300 mm occurred due to movement of the surface soil.

Further, each expansion joint shifted off center on its pier. Different openings of the expansion joints on opposite sides of the deck indicate that rotation of superstructure occurred. This behavior is typical for continuous bridges made of simple spans supported on elastomeric bearings. The concrete bed blocks that support these bearings sustained severe cracking.

The A-frame tower at Pier 2 experienced horizontal flexural cracks along the exterior face of the column members and primarily shear cracks in the beam-to-column joint (Figure 19-20). These cracks are primarily due to the bending of the tower under seismic loads. The maximum crack width is approximately 6 to 12 mm. Some of the cracks have since been patched, though proper procedure for crack repair requires removal of spalled concrete, sandblasting and provision of adequate cover, which apparently was not done. Smaller cracks can be repaired by epoxy injection.

Figure 19-17. The Rudramata Bridge, the tallest in the region, supported on open-type reinforced concrete A-frame piers.

Figure 19-18. Collapse of the north end approach earthwork and of the parapet walls at Rudramata Bridge.

Figure19-19. Ground cracks at intermediate and end piers. The ground around the Rudramata Bridge experienced extensive lateral spreading in the riverbed parallel to the south side riverbank on both the upstream and downstream sides of the bridge.

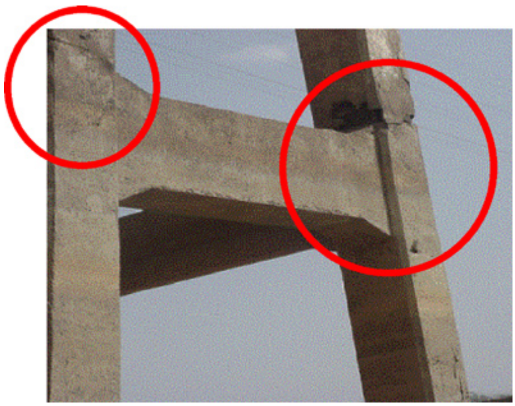

Figure19-20. Flexural cracks in the columns and shear cracks in the beam-to-column joints occurred at the RC frame member junctions in the A-frame Pier No.2 of the Rudramata Bridge. The girders are deeper than columns, and use of flared beam-ends are noticeable. Spalling of cover concrete and corrosion of reinforcement bars is also evident at these locations.

Figure 19-21. A damaged stone-masonry arch bridge, built in 1912. Temporary side supports (at left) are being erected to retain the ballast and open the traffic.

Figure 19-22. Damage to a railway masonry arch bridge**.** The sidewalls on the arches have fallen off. One of the stone blocks was loosened and partially dislodged from the center of one of the arches. These bridges were also built in 1912 under the meter-gauge rail line.

INDIA BRIDGE ACROSS THE GREAT RANN OF KACHCHH

The 420 m long 10-span RC girder-slab India Bridge, north of Khawda across the Great Rann of Kachchh, also sustained damage and the adjoining soil underwent widespread liquefaction. The 1973-built bridge with simply supported spans, each consisting of three longitudinal girders of 4 m depth, is oriented along the north-south direction.

India Bridge suffered severe damage to steel bearings. Bearing boxes at the rocker and roller ends were recently re-filled with grease, and the grease was squeezed out due to distortions during the earthquake. The concrete bed blocks supporting these bearings were also damaged. The stone masonry wall piers with RC plastering showed severe spalling at the lower levels. The wing walls at the abutments showed severe movements of the embankment soil. Large gaps up to 15 cm were generated between the abutments and the adjoining spans. The approach embankments on the south side also showed severe cracks at the crest. The damage to the road surface at Piers 1, 3, 5, 7 and 9, suggested significant pounding of the superstructure decks along the longitudinal direction. Some of the handrails of the deck collapsed.

DAMAGE TO OLD RAILWAY BRIDGES

There are several small railway bridges in the area that were damaged. Like the stone masonry houses, the bridges that suffered the most damage were the ones with unreinforced masonry supports. A few of them were constructed in the early 20th century; the mortar between the stone masonry may have deteriorated over the years to provide only insignificant bonding. The masonry arch bridges shown in Figures 19-21 and 19-22 were of this type.

Figure 19-23. Weathered and poorly concreted piers further damaged by the earthquake. The concrete cover simply spalled off the piers.

Figure 19-24. Failure of super and substructure of a bridge; rural area between the towns of Gandhidham and Bhachau.

DAMAGE TO OTHER HIGHWAY BRIDGES

Bridges on NH8A are two lane bridges with wide unpaved shoulders. They are composed of multiple spans with an expansion joint at each pier. Spans about 15 m long are cast-in-place flat slabs or tee-beams. The superstructure is supported on reinforced concrete wall piers, masonry wall piers or concrete arches with masonry fascia walls on shallow foundations. Elastomeric bearings are typical for all bridges.

These bridges are all in poor condition, with spalled concrete and exposed rusted rebar (Figure 19-23). Past attempts at repair using a shotcrete layer did not protect the structures from deterioration. In spite of such poor structural condition, none of the bridges collapsed during the earthquake. This is in part due to over-design, given the use of the short spans and large wall piers.

Some older bridges suffered more damage than the others. The bridge shown in Figure 19-24 did not collapse during the earthquake, but suffered serious damage to end diaphragms, end pier walls, backwall, bearings and traffic barriers. The traffic barriers are in most cases post-and-beam type and their connection to the balusters and slab had completely deteriorated prior to the earthquake. Given the need to maintain traffic flow on NH8, temporary supports allow for its continued use, though the damage incurred dictates that it be replaced.

Shallow foundations moved laterally with the dried crust of near surface soil in which they were embedded. Cracking of the soil surface was likely due to lateral spreading over liquefiable material at depth. Such ground separation (openings of 150 to 300 mm) caused differential pier movements. However, due to the lack of fixity on top of the piers, no significant bending or joint failures occurred during the earthquake. There was some tilting of wall piers, which, due to the large size of the pier cap, did not cause concern.

Out-of-phase and uncontrolled movement of the bridge elements resulted in pounding at the expansion joints and dislocation of the superstructure at the bearings. Most of new bridges were identical in design and construction, and therefore this damage was typical. In some cases, the expansion joint shifted on the pier wall. Due to the poor condition of the concrete, damage of the

Figure 19-25. Failure of the girder end and expansion joint of a bridge between the towns of Gandhidham and Bhachau.

Figure 19-26. Failure of masonry wall pier of a bridge between the towns of Gandhidham and Bhachau.

slab at the expansion joint grew to include the cantilever slab. Concrete at the end of the girder sheared off and the bearing area was significantly reduced (Figure 19-25). Vertical cracks due to shear friction appeared at the end of the girder. The substructure experienced diagonal cracking in the pier cap and vertical cracking in the wall pier. Cracks are 12 to 25 mm wide and will require immediate repair.

The masonry wall piers are supported on a continuous raft footing approximately 900 mm deep (Figure 19-26). The superstructure is supported on bearings, which over the years have completely deteriorated such that their existence is hard to discern. The concrete arches are supported on the mat footing on pedestals. Due to the longitudinal movement of the bridge, the fixed connection failed and the end diaphragm cracked vertically. The end span sagged by about 50 mm resulting in cracking and spalling of the concrete at the bottom of the slab.

The continuity of the arches and footing allowed the bridge to act as a continuous structure during the earthquake. Concrete arches performed well during the earthquake, but they suffered some damage to the masonry fascia walls. Minor cracks were observed in the reinforced arches, but were closed due to the compressive nature of arch action.

Figure 19-27. Failure of approach slab of a bridge at the village Vondh.

Figure 19-28. Failure of crossbeam of a bridge at the village Vondh.

DAMAGE TO BRIDGES UNDER CONSTRUCTION

In addition to the New Surajbadi Highway Bridge (discussed above), there were a total of 10 other bridges under construction on NH8A at the time of the earthquake. Some were almost complete, while others still had formwork in place for superstructure construction. They are located adjacent to older bridges so, once finished, each bridge will carry two lanes of traffic in one direction.

These bridges under construction were designed and detailed with the same structural concepts as the older bridges. They have short simply supported spans approximately 15 m long with expansion joints at each pier, but no provisions for ductility. They have cast-in-place super- and substructures with L-abutments as end piers. There was no indication of seismic design and detailing in spite of the high potential for liquefaction in this Seismic Zone V. Shallow, rather than deep, foundations were employed. The failure of abutments, piers, expansion joints, and settlement of approach slabs (Figure 19-27), was typical among the bridges under construction.

Bridge at Vondh

This bridge offers an interesting case of a poor configuration that does not offer good seismic response. This bridge has four spans, with one short span at the west end towards Vondh. Due to the shorter end span (Figure 19-28), the superstructure was changed from tee-beam in the other spans to a shallower flat slab. To accommodate this difference in superstructure depth, an auxiliary crossbeam (about .5 m deep) was extended from the top of the wall-type reinforced concrete pier; the reinforced concrete bed-blocks for the bearings of the shallow slab of the short span were rested on this. Thus, the end faces of the girders in the adjoining long span were butting against this crossbeam. The longitudinal movement of the girders of the long span during the earthquake caused pounding of the girders on this auxiliary crossbeam; the fixed connection between the crossbeam and the pier cap failed. The expansion joint at this pier shifted about 300 mm from the centerline of the pier.

Further, due to the relative longitudinal movement of the bridge superstructure and the abutment, the superstructure pounded on the abutment backwall and caused cracking and spalling of the concrete at the base of the backwall. In turn, the backwall of the abutment also pushed into the approach slab. The approach backfill settled and spread out toward the wing walls on the side. Consequently, the connection between wingwall and abutment wall failed (Figure 19-29).

Figure 19-29. Failure of abutment of the bridge at the village Vondh.

Settlement of the approach backfill of between 300 and 450 mm was noticed in this short-span bridge. The repair of this bridge will require extensive work, including rebuilding of the abutment wall, expansion joint, backwall, wingwalls, backfill and approach slab.

The segments of the bridge deck compressed and closed the expansion joint, causing spalling of the concrete at and around the joints. Transverse motion caused flexure, resulting in more damage at the outer edge of the slab than at centerline. Due to the restraint provided by the superstructure, it appears that the top of the pier did not move as much as it did at its base (anchored to the moving ground).

The stability of this and other piers should be investigated for eccentric loading and tilt. The adequacy of the bearings should be confirmed when the girders are repositioned. The girders on one side of the pier are barely seated on their bearings, which may result in shear friction failure of the girder end.

CONCLUSIONS

The January 26, 2001 Gujarat earthquake was, once again, for bridge engineers, a demonstration of the need for reliable seismic design and detailing, and for greater focus on the quality of construction and the use of durable materials. As in the past, this earthquake was quite unforgiving to weak structures (Murty and Jain, 1997). The reinforced masonry piers in bridges were especially vulnerable in this earthquake. The earthquake also exposed the weakness of the deteriorated or poor concrete bridge components. Well-constructed bridges in the area generally performed well.

The following lessons emerged from the damages sustained by bridges during the earthquake:

1. The main reason for damages to both bridges under construction and existing bridges was the omission of seismic design provisions and detailing. Appropriate specifications with respect to the regional seismic requirements should be considered in the design and retrofit of such bridges.
2. A seismic retrofit program should be considered for existing bridges as well as bridges currently under construction. The program should provide for longitudinal restrainers, transverse stops, and column strengthening to meet the requirements for shear capacity, ductility and confinement.

3. Use of shallow foundations for bridges should be avoided where the potential for liquefaction is present. Deep foundations, including driven piles, drilled shafts, and well foundations should be considered.
4. Superstructure continuity and use of integral or semi-integral abutments should be encouraged. The seismic performance of a bridge benefits from the elimination of expansion joints. Repair and maintenance of expansion joints are costly and time consuming. If expansion joints are used, special attention should be given to detailing, restraining the adjoining segments, and the quality of the materials employed in construction.
5. More importance should be given to the use of precast/prestressed members for bridge construction. Precast/prestressed concrete members are more desirable than cast-in-place concrete because of the better quality obtained in their fabrication. The practicality of producing, shipping, and erecting of precast/prestressed/prestressed concrete members should be investigated.
6. Due to the saltwater environment, the use of high performance concrete (HPC) is recommended for improved durability. Epoxy-coated rebars, or other type of corrosion-protected rebar, should be considered in bridge construction. However, the epoxy-coated rebar at New Surajbari Bridge showed poor bond characteristics and this should be kept in mind. Improving initial quality will result in longer service life for bridges and will reduce future maintenance and repair costs. Greater importance should be given to the curing of cast-in-place concrete by specifying continuous wet curing for an extended period of time.
7. Elastomeric bearings are not suitable for use in high seismic regions. The partial restraint against translation and rotation offered by the elastomeric bearings are not always accounted for in the design. Use of Pot bearings and PTFE bearings (which can be made completely free, guided along a certain direction, or completely retrained) need to be encouraged.
8. The successful use of seismic stoppers in the New Surajbari Bridge demonstrated the importance of the seismic stoppers to the superstructures. The Indian Bridge Code may include provisions to incorporate such features in bridges.

While there were no dramatic bridge failures in this earthquake, the extent of damage is significant. The inadequacy of the Bridge Code (see Chapter 17, Codes, Licensing, and Education), particularly in the design of bearings and substructure, needs immediate correction. In addition, the extent of damage observed is relatively small primarily because there weren't many unusual bridges with tall piers in the affected region.

It is unfortunate that there was no strong motion instrumentation on or near major structures in the affected area. Such instrumentation would have provided very useful data for further in-depth investigations of structural failures.

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