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Design and Construction of Single Lane Road Bridge

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Abstract

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.

INTRODUCTION

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. Lshaped 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.

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Table 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	Phase 2	Cost of Repair/ Rehabilitation/ Reconstruction (Approx.)
Bridges				
Culverts	896	186	710	US$32 million
Minor bridges (less than 60m in length)	275	115	160	
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 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	US$65 million
Minor bridges (of length less than 60m)	98	
Major bridges (of length more than 60m)	38	
Roads		
Roads	~20 km	US$45 million
Total estimated cost	US$110 million	

Figure 1: Roadway cracking between the roadway drainage towns of Gandhidham and Bhachau.

Figure 2: Collapse ofstructure 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. 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

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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.

Figure 3. Old Surajbadi Highway Bridge

Figure 4. Relative longitudinal movementbetween the piers and the superstructure spans in the Old Surajbadi Highway Bridge.

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, whilethe 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 andMurty, 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.

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.

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Figure 5. Roller bearing on the north side

Figure 6. Damaged bearing on Old Surajbadi abutment of the Old Surajbadi Highway Bridge.

The New Surajbadi Highway Bridge (under construction) can be seen in the background.

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

The shallow well foundation with wall pier supported on top moved in the liquefied sand. 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.

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

Figure 9. Severely strained elastomeric 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.

NEW SURAJBADI BRIDGE ON NH8AUNDER 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 10. Damaged concrete pedestals of the elastomeric bearing of the New SurajbadiHighway Bridge.

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

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.

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Figure 12. Transverse displacement of the New Surajbadi Highway Bridge.

Figure 13. Pounding between two adjacent superstructure decks of the New Surajbadibridge spans, Highway Bridge.

Figure 14. Near the south side abutment of the Surajbadi Railway Bridge.

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.

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.

Some older bridges suffered more damage than the others. The traffic barriers are in most cases post-andbeam 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 slab at the expansion joint grew to include the cantilever slabThe 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.

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Figure 15. Failure of the girder end and expansion joint of a bridge between the towns of Gandhidham and Bhachau.

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 16. Failure of approach slab of a bridge at the village Vondh.

Figure 17. 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. To accommodate this

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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.

Figure 18. 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:

- 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.
- 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.
- 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.

- 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.
- 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.
- Due to the saltwater environment, the use of high performance concrete (HPC) is recommended for improved durability. Epoxy-coated rebars, or other type of corrosionprotected 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.
- 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.
- 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 indepth investigations of structural failures.

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