Rehabilitation of balanced cantilever bridges

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During the sixties and seventies, a number of bridges using balanced cantilever superstructure with suspended spans have been constructed in different parts of the country. However in view of inadequate detailing of reinforcement and lack of proper precautions during concreting of the crucial articulation portion, many of these bridges experienced problems in service. The paper explains the salient design features of a balanced cantilever system, highlights common distresses noticed and offers possible corrective measures. Four case studies of rehabilitation of such bridges are described.

In the first three decades after independence, new systems for bridge decking as well as their methods of construction were developed in India. One of the commonly adopted types of decking for highway bridges was that of balanced cantilevers with suspended spans. This method of construction combines the advantages of simply supported superstructure and compares favourably with continuous type of superstructure, where long-term foundation settlements may be expected. The other popular method adopted was hammer-head type construction, in which the deck, upto a certain length on either side of the pier, is cantilevered out and constructed monolithically with the pier. These cantilevers on either side of the pier supported the suspended spans.

In this type of decking, the joints were invariably articulated. The construction of articulations was little clumsy compared to the other portion of decking. Besides, this area was more crucial and important as the mechanism for transfer of reaction had to be provided here. lnspite of all precautions taken during the construction of articulations, experience in the eighties and nineties reveals problems of cracking, spalling, malfunctioning of bearings associated with this type of articulated joints.

Benefits of cantilever system

A number of benefits can be derived with the use of cantilever system. Providing cantilever arms to the decking and transferring the reactions from the suspended spans to the tip of the cantilever helps in balancing the moments, Figure 1. The benefit accrued from this typical arrangement is that the amount of bending moments can be made equal or near to the bending moment in the middle of spans, which enables the designer to provide a longer span length between piers economically when compared to a simply-supported span of similar length.

With such arrangement, it is possible to design the bridge in such a manner that the weight of the beams can be minimised and differences in sections throughout the bridge can be reduced with consequent economy in shuttering, staging and labour.

In our country, there are a number of rivers where the strata is such that differential settlement cannot be avoided, particularly in the alluvial plains of Uttar Pradesh, Bihar and a few other northern states. In such a situation, construction of decking with articulated joints is suitable. It has not only better flexibility but the advantage of economy afforded by a continuous type bridge is also achieved, to some extent, due to provisions of cantilevers at both ends.

Design aspects

Design of articulation essentially envisages determination of the principal plane on which tensile stress is maximum and providing the necessary inclined steel to resist the tension. Analysis to evaluate the requirement of horizontal steel to resist flexure arising out of vertical loads and horizontal frictional forces generated during thermal movements of bearings, braking effect, etc, has to be thoroughly done. Shearing effects need thorough investigation and necessary

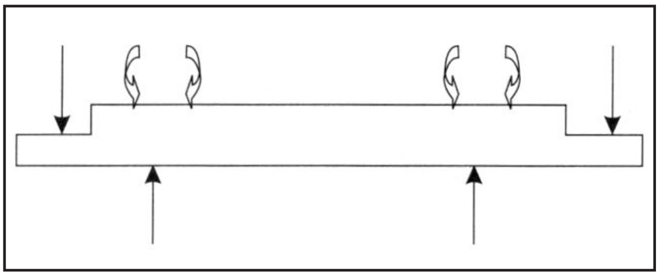


Figure 1. Balancing moments

shear reinforcement as required, is to be provided to cater to the shear.

While designing the articulation, it is desirable to reduce the length of seating along the span to minimise the flexural moments. Area of the support should be increased to reduce unit shear stress.

Typical arrangement of reinforcement as generally provided in the articulation is shown in Figure 2. The articulation is the most vulnerable part and it needs to be given special attention while detailing the reinforcement and placing concrete.

It is clear from the section at articulation that sudden reduction in the depth of a beam at the seating would induce tensile stresses of high magnitude due to bending and it would necessitate determining the inclined plane on which the effect would be maximum. This can be done by using arterial method.

On any plane inclined at an angle g the effect of vertical reaction 'P' acting at the centre of articulation is,

$M = P \cos\theta \, xy$

$N = P \sin\theta$, and

$S = P \cos\theta$

where,

M = bending moment

N = normal tension

S = shear force

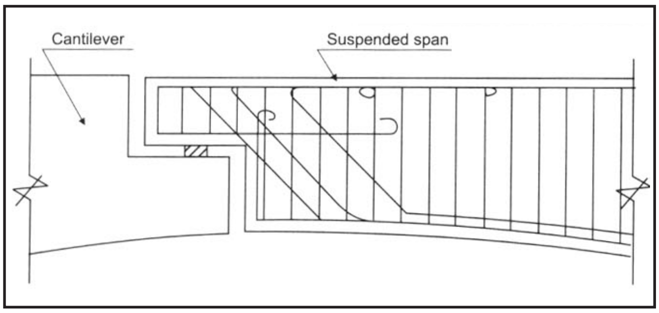


Figure 2. Typical reinforcement at articulation

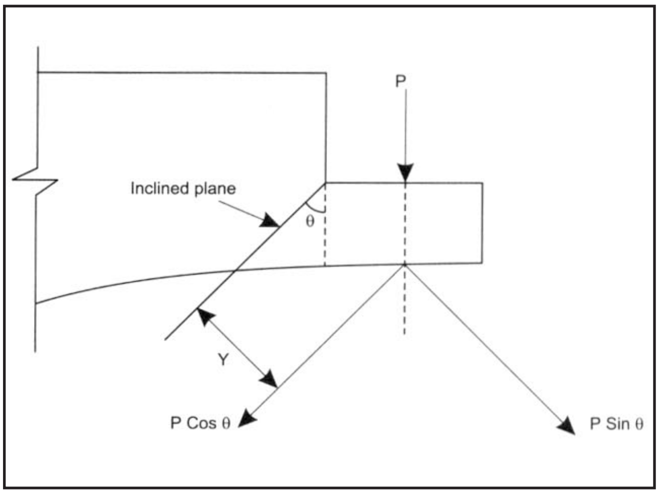


Figure 3. Forces at articulation

The tension is mainly resisted by the bent up inclined bars. Although the inclined bars are similar in character to the diagonal shear bars of the cantilever, they are required mainly from the consideration of tension across the inclined planes at the corner of the articulation, Figure 3.

In order to reduce the shear stress, the section is increased by widening the rib of the beam to the maximum that is possible at the articulation section.

The elastomeric bearings provided under the suspended spans are superior in achieving the most economic longitudinal load shared among bridge supports in both continuous and balanced cantilever type of bridges.

Common distresses

Several bridges were constructed in the sixties and seventies with articulation. Some of the problems observed during service are enumerated below.

Cracking

Cracking has been the most commonly observed phenomenon in the articulation. The general pattern of cracks is shown in Figure 4.

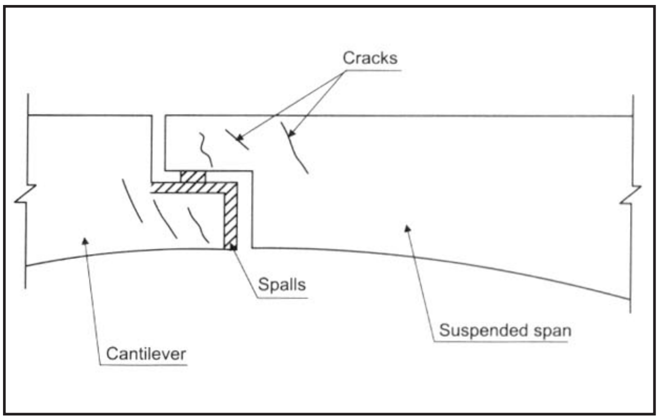


Figure 4. Typical cracking and spalling pattern

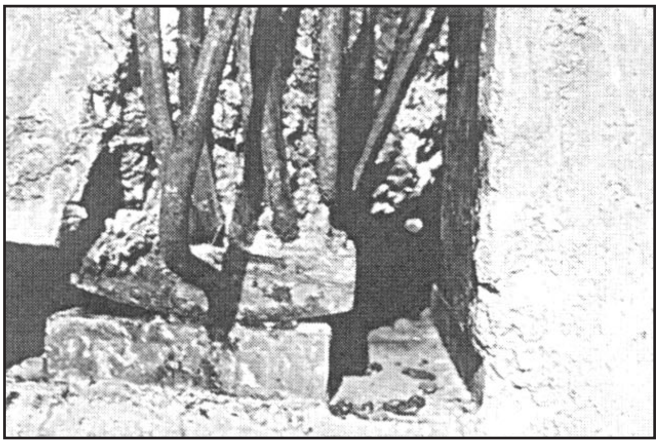


Figure 5. Spalling of concrete at articulation, exposing the reinforcement

Spalling

The concrete in the cover portion to the vertical and horizontal steel is damaged and at times found dislodged, as shown in Figures 4 and 5.

Separation of concrete

In case of some bridges, it is noticed that the portion of articulation beyond the reinforcement is physically separated. Shorter length of reinforcement thereby, increasing the length of un-reinforced cover contributes to such problem.

Shifting of suspended spans

The suspended spans are found to be shifting laterally on account of the failure of supporting bearings. Such a problem arises when alignment of the bearings is not true. A typical case is shown in Figure 5.

Maintenance of bearings

It is experienced that access to the bearings is quite difficult and in some cases not possible. The gaps available between cantilever and suspended spans are so minimal that it is impracticable to carry out any work pertaining to bearings.

Settlement of suspended spans

Due to rotation of cantilever arms and also spalling of concrete, the riding surface of the deck develops a kink. At times, it is not possible to ply the traffic over these joints.

Bearing distress

The bearings at articulation are, at times, toppled or jammed as

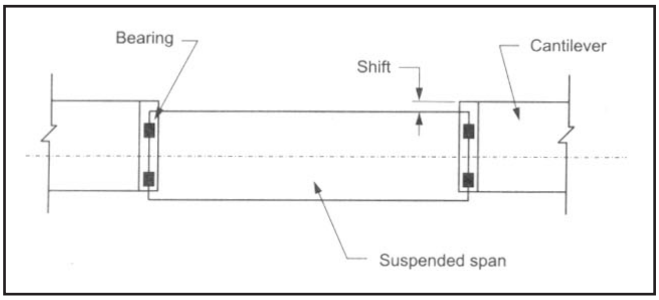


Figure 6. Shifting of suspended span

Figure 7. Ramganga bridge - toppled bearing

shown in Figure 7. In particular, cut roller bearings are more vulnerable to misalignment and collapse. Regarding plate bearings and rocker bearings, it has been generally experienced that they stop functioning over a period of time on account of corrosion, seizure, etc. Sometimes due to misalignment the bearings get displaced and the lugs get sheared.

Possible solutions

Depending upon the type of distress noticed, it is possible to take appropriate measures to strengthen the articulations and overcome the problem. Following remedies can be used singly or in combination as required.

Lifting of suspended spans

Normally, suspended spans are required to be lifted irrespective of the problem. Articulation is a confined and intricate space and as such, unless the load is relieved from the cantilever, it is not practicable to take up remedial action. If it is possible to divert the traffic, lifting can be done from the top of the deck by using lever principle, as shown in Figure 8. If traffic cannot be diverted, lifting can be done from temporary supports from the bed and using temporary transition arrangement at the joints.

Spalls

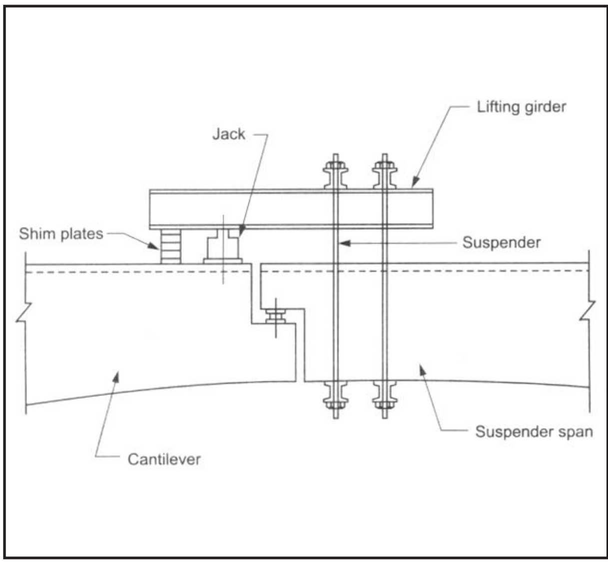
The spalled and damaged concrete should be removed and replaced by a suitably designed and applied polymer concrete. If the volume is high, fresh concrete can be used with suitable bonding medium between old and new concrete. Polymermodified concrete/mortar can be used in certain situations.

Cracks

The standard method of injecting the cracks with a suitable quality epoxy resin is found to be useful and can be resorted to here too.

Bonded plates and reinforcement

In case of cracks, diagonal reinforcement can be provided to contain them and prevent their propagation further. A typical arrangement is shown in Figure 9. For improving shear rating, bonded plates can be used.



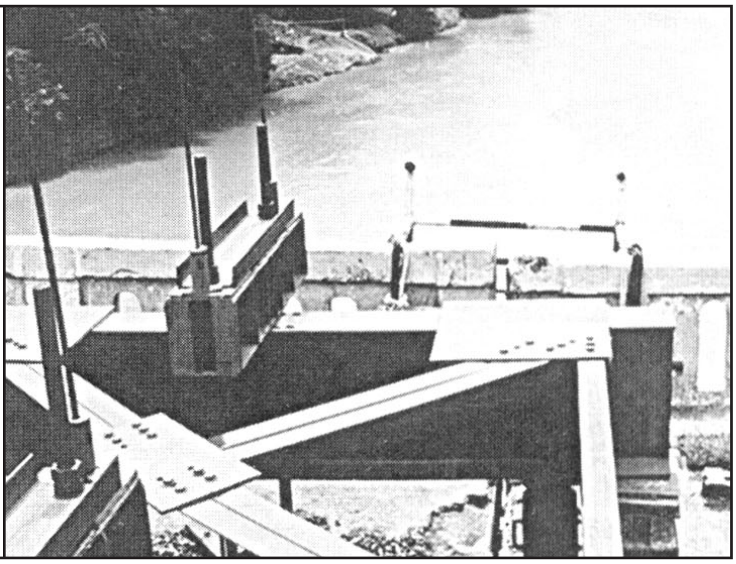


Figure 8. (left Typical arrangement for lifting; (right) Lifting of suspended span from top

Opening in diaphragms

The space around the bearings is blind and mostly inaccessible. Invariably, diaphragms are provided at these sections, particularly when a box section is adopted. It is useful if the openings are kept. If not provided, such openings can be made to facilitate maintenance and replacements, etc, Figure 10.

Strengthening of hammer-heads

The hammer-heads undergo deterioration due to rebar or cable corrosion and other usual concrete distresses. It is rather difficult to provide external cables for restoring the hammerhead strength. In such situations, these can be strengthened by providing independent supports from the well/pile cap or footing. Alternatively, additional steel brackets could be provided under the hammer-heads as shown in Figure 11. The brackets can be designed in such a way that part of the load from the suspended span is transferred to the piers on to which brackets are fixed.

Some examples

Many bridges with articulations and hammer-head arrangements have suffered damages particularly in the vulnerable portion of articulations. These bridges are successfully repaired and strengthened. Some of the important cases are described here.

Girna bridge

It is located on State Highway near Chalisgaon in Maharashtra. Constructed in 1967, it is a 267-m long bridge with 9-m tall masonry piers supported on twin wells of 4.27-m diameter.

The superstructure consists of three RC balanced cantilever beams and RC decking. Main spans are of 27.4-m length with 6.86-m long cantilever and suspended spans of 13.7-m length rest on cantilever spans. Steel rocker and roller bearings are provided at piers and plate bearings at articulations.

In 1980, it was noticed that the articulations of suspended spans were damaged on account of improper functioning of bearings, wrong placement of reinforcement and honeycombed concrete. In case of one particular span, the damage was so severe that a chunk of 150-mm thick concrete had fallen off and the span had settled by 40 mm. Propagation of cracks continued and it was imperative to suspend the traffic.

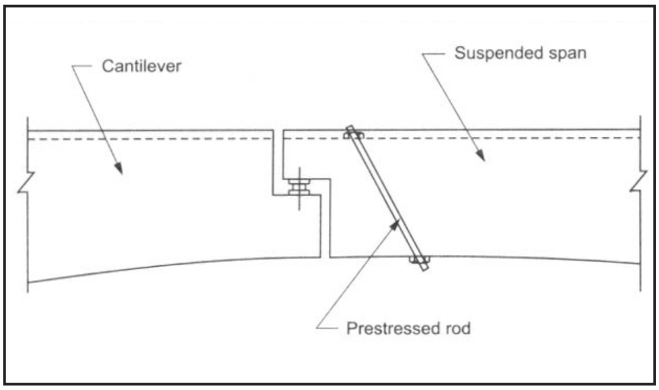


Figure 9. Typical external reinforcement

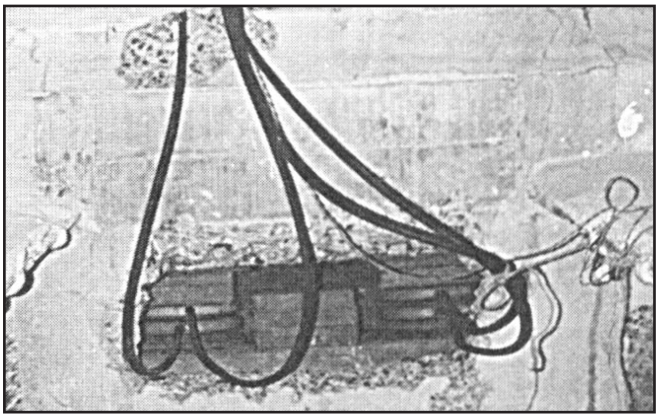


Figure 10. Openings in end diaphragm near articulation

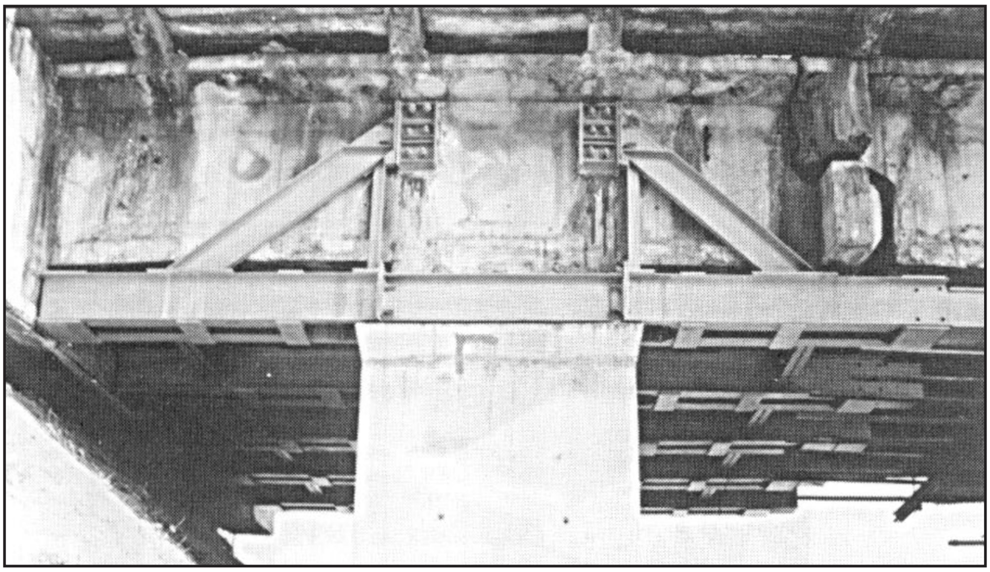


Figure 11. Additional support for hammer-head

The height of the superstructure above the bed was 15 m and lifting had to be done from the deck to re-concrete the damaged portion with additional reinforcement. Built-up steel girders were used in line with RC beam over the articulations. These girders were tied with RC "1" beams with alloy steel bars at a number of locations. These girders were jacked up from the cantilever beams. All six jacks were operated simultaneously. After pressurising the circuit, the suspended span was lifted almost uniformly by 400mm.

The damaged articulation was repaired by removal of bad concrete and providing additional reinforcement. Damaged portion was made good with new concrete, with an epoxy bonding coat at the interface. In one span, external prestressing rods were provided to prevent separation of new concrete from old concrete and to share some vertical load at articulations. These rods were left un-grouted for a period of three months to allow the losses to take place. Subsequently, they were re-stressed and grouted. For other spans, these rods were not required. The steel bearings were replaced by neoprene bearings and the spans were lowered on to them.

In this manner, all the spans were strengthened and repaired successfully. Even after 19 years, the repair work done is holding well.

Canal bridge near Durgapur

Located over DVC left bank main canal near Durgapur city in West Bengal, the bridge was completed in 1953 and is being looked after by the Waterways Department of West Bengal. The bridge is a balanced cantilever type with RC solid slab of varying thickness. The central span comprising of two cantilevers of 10.8 m (36 ft) and a suspended span of 5.4 m (18 ft) rest on masonry pier supported by well foundation, Figure 12.

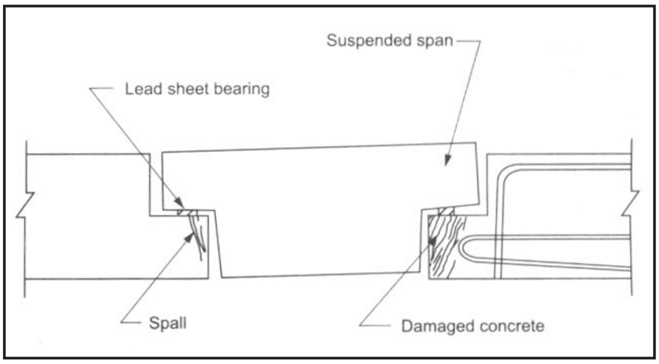


Figure 12. Bridge at Durgapur - Distress in articulation

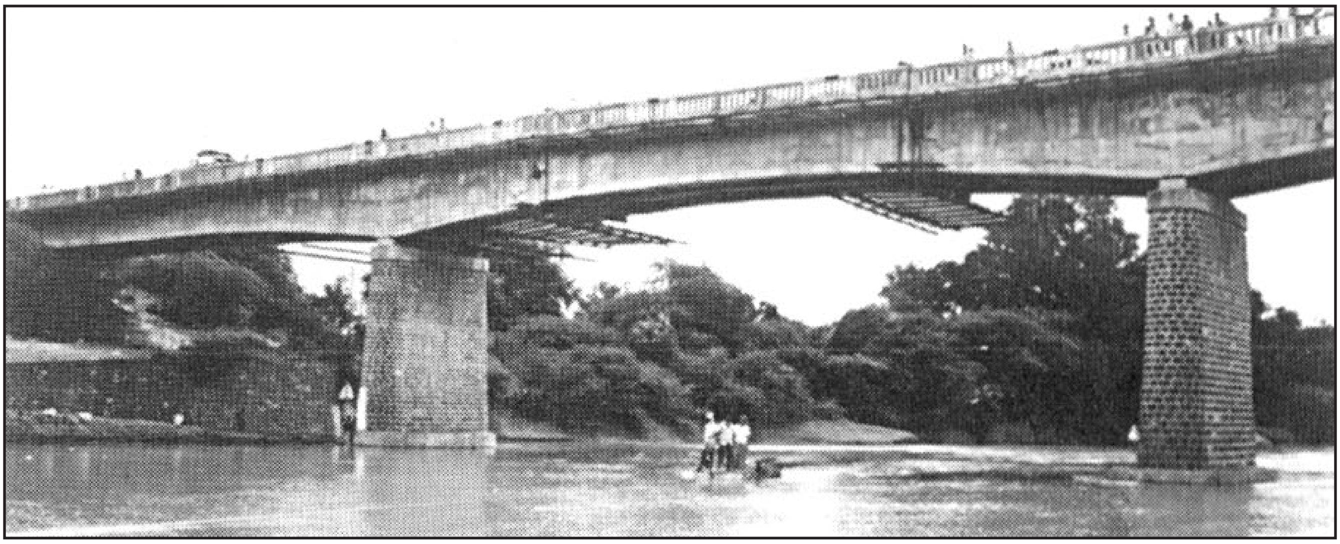


Figure 13. Pravara bridge

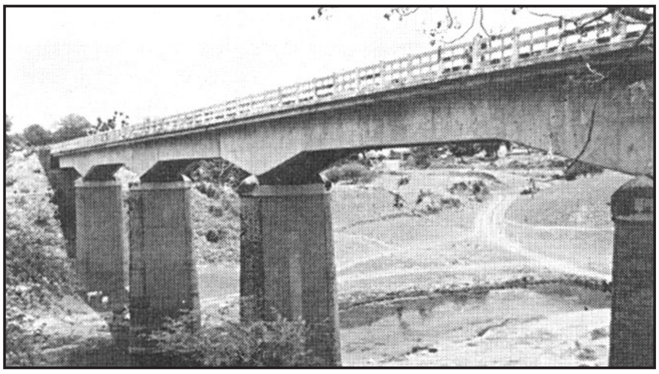


Figure 14. Bridge at Durgapur - Distress in articulation

The damage to the fixed end of the articulation was severe. The concrete of the cantilever tip for the full width of the bridge for a length of about 75 mm along the span and full depth of the cantilever tip had spalled off, thereby exposing the reinforcement of the cantilever tip. A crack in the suspended span was noticed. The suspended span had moved longitudinally towards the free end. The bottom of the suspended span at the fixed end was found to be about 6 mm lower than the bottom of cantilever tip. After thorough investigation, it was assessed that extra cover to the reinforcement was the main cause of the damage. Non-functioning of the concrete rocker bearing system and partial fixity developed through the-dowel bars were contributing to the damage.

The following measures were taken to rehabilitate the articulations.

1. Suspended span was lifted from the deck by providing lifting girder.
2. The damaged concrete was removed.
3. Additional reinforcement was provided in to the required portion.
4. New concrete was laid with bonding layer.
5. Existing bearings were replaced by neoprene bearings.
6. Suspended span was lowered.

During the process of lifting, high resistance was noticed due to dowels connecting the articulated portions. After repairs to the span, load test was conducted with good results.

Pravara bridge

The bridge is located over river Pravara on Ahmednagar-Newasa State Highway and is 38 years old. It carries two lanes of traffic and the main span is 34.8 m (116 ft) with 8.7 m (29 ft) of cantilevers and 17.4 m (58 ft) of suspended spans, Figure 13. The total weight of the suspended span is 228 tonnes. It was decided to lift the span by using six lifting frames. Each frame was placed in position along the three beams at the articulations. Instead of alloy steel bars used in earlier project for connecting the suspended spans, in this case, high tensile strands were used.

Another feature of the remedial measures taken for this project was the use of external prestressing for reducing the tension developed due to cantilever moments in cantilever portion. A crack was developed near the root of the cantilever. A cap cable was provided to close the crack and make the section act monolithically.

Karmnasha bridge at Chakia

The superstructure of the bridge comprises of "I" girders spanning 32.3 m with 7.31 m cantilevers on either side of the pier. The suspended span of 17.68 m is supported over plate bearings supported on cantilever tips, Figure 14.

The articulation on Chakia side had failed. The cover concrete in the cantilever tips had spalled and the end of suspended span supported over it settled by 100 mm. Therefore, the traffic had to be closed. The other articulation had developed cracks.

It was difficult to take the reinforcement of the girder upto the outer edge of the concrete in the corner portion. The bars have to be bent over a large radius. Thus, it left the outer cover un-reinforced. Besides, jamming of steel plate bearings induced large concentrated forces over a period of time resulting in spalling and cracking of concrete.

The restoration measures included raising of suspended span from the deck as the height of the pier was substantial. The articulation portion was dismantled and it was reconcreted with additional reinforcement and width. The steel bearings were replaced by neoprene bearings.

The work which was carried out in 1993 is performing well.

Conclusion

The bridges constructed in the past with balanced cantilever system need to be kept serviceable and durable for many more years. Under such circumstances, the rehabilitation of balanced cantilever system of bridges assumes significance. The experience has shown that well designed and constructed balanced cantilever bridges can give trouble-free performance for several years. It is, however, necessary to take precautions in light of the problems experienced.

Mr P.Y.Manjure has specialised in the field of prestressed concrete, repair and rehabilitation, heavy lifting and special civil engineering projects. Currently, he is the chief executive of the Freyssinet Prestressed Concrete Company Ltd which he joined in 1970. He has been an active member of the bridges committee and maintenance and rehabilitation of bridges committee of the Indian Roads Congress (IRC). He was also in the managing committee of the International Association of Bridge and Structural Engineering (IABSE). He has written several papers in technical journals and his paper on Nizamuddin bridge and Sharavati bridge won IRC medals. His paper on the erection of the statue of Buddha brought him the ICJ's V.K. Kulkarni best paper award.

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