

Rehabilitation of Meghna and Meghna-Gumti bridge superstructures

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ABSTRACT: The two bridges on Meghna and Meghna-Gumti rivers on Dhaka-Chittagong highway have been serving road traffic for the last 15-20 years. They had deteriorated significantly and their safety and serviceability threatened due to a virtually non-existent maintenance program. Mid-span hinge bearings of both the balanced cantilever box girder bridges had worn out and the reinforced rubber expansion joints had all but disappeared. The deck deflected and vibrated significantly as heavy vehicles passed, the piers swayed, riding over the expansion joints became bumpy and dangerous. A major rehabilitation work was recently undertaken which involved installation of new expansion joints and replacement of hinge bearings to stabilize the bridges. This paper describes the rehabilitation works, including inter alia design of new expansion joints, and material and method adopted for replacement of hinge bearings. It also addresses implementation issues and experience including bridge closures for minimum interruption.

1 INTRODUCTION

The two bridges on Meghna and Meghna-Gumti rivers on Dhaka-Chittagong highway (N1) are part of the essential road link between Dhaka and Chittagong. Dhaka is the capital of Bangladesh as well as its commercial nerve Centre. Chittagong is the major port of Bangladesh forming gateway to outside world for international trade and commerce. Although the two cities are connected by road, rail, river and air, presently road communication is the most efficient and popular mode of transport for both goods and passengers. A two-lane undivided highway dubbed the N1 (presently being upgraded to four-lane divided highway) forms the only direct road link between the two cities. The Meghna Bridge and the Meghna-Gumti Bridge are two two-lane bridges some 12km apart on this important road.

The bridges have been serving road traffic for the last 15 to 20 years and are being plied by a great number of vehicles. Recent toll records show more than 20,000 vehicles a day, many of which are overloaded. They have deteriorated significantly over the years due to a virtually non-existent maintenance program. In the recent years it was realized that both the bridges have deteriorated to an extent that threatens their safety and serviceability. The mid-span hinge bearings of both the bridges had worn out and the deck expansion joints made of reinforced rubber had all but disappeared. In addition, for the Meghna Bridge, river bed scour occurred, exposing the pile caps and piles and increasing free length of the cantilever piers.

All these combined to cause the bridges to be visibly distressed; the deck deflected and vibrated significantly as heavy vehicles passed over the joints, the piers swayed, riding over the expansion joints became bumpy and dangerous. Realizing the deterioration, the owner of the bridges Roads & Highways Department (RHD) of Government of Bangladesh took some immediate measures which included prohibition of passage of vessels between piers worst affected by river bed scour and some makeshift arrangement for temporarily stabilizing the superstructure. The makeshift arrangements included fixing of steel plates and rubber sheets over the deteriorated expansion joints, insertion of steel plate and rubber packing in gaps of the hinge bearings created by worn out pot bearings etc.

The Government has undertaken a program for construction of two new bridges adjacent to the existing Meghna and Meghna-Gumti bridges to serve the new four-lane highway. Continued performance of the bridges is essential until the adjacent new bridges are commissioned. Thereafter, a retrofitting of the existing bridges may be undertaken to strengthen them, especially against earthquake, and to give them a new lease of life. An

elaborate program for rehabilitation of the bridges to ensure performance until the new bridges are commissioned was therefore undertaken. The rehabilitation works included inter alia the following:

- i. River bed correction and pier protection by sand bags and sand filled geobags for the Meghna Bridge,
- ii. Replacement of expansion joints by a more permanent form of joint for both Meghna and Meghna Gumti bridges, and
- iii. Replacement of pot bearings in hinges inside the box girder deck and rehabilitation of the hinge bearings for both the bridges.

Besides the above, the bridges would also be given a facelift which included repair of wearing course, road markings, replacement of light fittings and electrical lines, repair of railings, painting etc. The rehabilitation works needed to be performed in several segments of a few days at a time when traffic was kept off the bridges. The job has now been successfully completed and the rehabilitated bridges reopened to traffic in March 2013.

This paper describes development of design of the superstructure rehabilitation works, including inter alia design of new expansion joints, and material and methods adopted for hinge bearings. It also addresses implementation issues including bridge closures for minimum interruption, high early strength concreting procedure, quality assurance etc. The rehabilitation measures were designed based on measurements taken during installation of the temporary measures, and as-built drawings of the bridges, with details being worked out paying due attention to present condition and evidences of past performance of the bridges. Design aims included among others, safety and stability, riding comfort over the deck, and durability.

2 BACKGROUND AND HISTORY OF THE TWO BRIDGES

Meghna Bridge was commissioned in 1991 and Meghna-Gumti Bridge in 1995. Both the bridges were built under a Japanese Government Grant Aid Project. Prior to commissioning of the bridges, road link was provided by ferry service for vehicle transportation. Gumti River at the ferry crossing point is subjected to siltation and frequent formation of shoals. Ferry channel maintenance was a challenge incurring continuous expenditure and effort. Congestion at the ferry crossing especially during peak holiday traffic season caused unbearable traffic delays and economic hardship. The bridges provided uninterrupted road link across the two rivers. The bridges were designed by Pacific Consultants International in association with Nippon Koei Co Ltd and constructed by Obayashi Corporation.

2.1 Salient Information of the Two Bridges

Both the bridges are balanced cantilever box girders made of prestressed concrete. Each span of the bridges has a central hinge bearing connecting the tips of cantilevers springing from piers. The location is also marked by an expansion joint of the deck. Salient data of the bridges are provided below:

Meghna Bridge

Length: 930m (abutment to abutment)

Number and length of spans (starting from Dhaka end):

1 span box girder = 48.5m

9 spans box girder = 9×87m

1 span box girder = 48.5m

2 viaduct spans = 2×25m

Width: 9.20m (7.20m Carriageway+2@1m footpath)

Meghna-Gumti Bridge

Length: 1410m (abutment to abutment)

Number and length of spans:

1 span box girder = 52.5m

15 spans box girder = 15×87m

1 span box girder = 52.5m

Width: 9.20m (7.20m Carriageway+2@1m footpath)

Both Bridges

Foundation system: Cast-in-situ concrete piles

Superstructure construction method: Balanced cantilever segmental construction

Hinge and expansion joint location for main spans: Mid-span (at end of cantilever)

Hinge configuration: Pot bearing with brass top piston sliding against SS plate

Expansion joints: Reinforced rubber

2.2 Hinges and Expansion Joints

The bridges are balanced cantilever spans with mid-span hinges and expansion joints. The hinges are made of male and female couplings made of steel and embedded in concrete at ends of the cantilever. End of each cantilever has either a pair of male or female couplings housed in webs of the single-cell box girder. The connection of the male and female elements has to be able to transmit vertical shear force from one side to the other but should also be able to undergo rotation and relative horizontal sliding freely. This is achieved by inserting two pot bearings one at the top and the other at bottom of the male elements. Top of the pot would fit against the female element but be able to slide freely. To facilitate sliding, contact faces of the female element were lined with stainless steel plates and the corresponding piston head of pot bearing fitted with brass elements. A total of four pot bearings with sliding provision were used to form each hinge joint at mid-span. In service, both the SS plates and the brass lined piston heads abraded away causing development of gaps between corresponding contact faces of male and female elements of the hinge.

The deck expansion joints bridge across two ends of cantilever meeting at mid-span and cover the gap in deck over the hinge bearing below. Expansion joints are also used at abutments, and in the case of Meghna Bridge at ends of two viaduct spans, which are reportedly addition to original design needed due to bank erosion noticed during construction. A reinforced rubber type expansion joint was originally employed. The number of hinge bearings and expansion joints in Meghna Bridge are 9 and 13 respectively, and in Meghna-Gumti Bridge 15 and 17 respectively. All the expansion joints and hinge bearings wore away and needed replacement.

3 INTERIM MEASURES TAKEN BY BRIDGE OWNER

RHD intended to address the issue of protecting the bridges from immediate damage by taking some temporary measures aimed to reduce vibration of the bridge by inserting rubber and steel plates in gap of hinge joints of Meghna Bridge. Before actually inserting these packing plates, measurements of total gaps (sum of upper and lower sides of hinge) on both sides of each hinge were taken. These data are presented in Table 1.

Table 1. Gap measurements of Meghna Bridge hinges before interim packing.

| Hinge Number (numbered from Dhaka end) | Gap as per measurement on 26.03.2012 | |
|--|--------------------------------------|------------|
| | Left (mm) | Right (mm) |
| H-1 | 10 | 10 |
| H-2 | 30 | 25 |
| H-3 | 60 | 55 |
| H-4 | 45 | 35 |
| H-5 | 30 | 45 |
| H-6 | 40 | 45 |
| H-7 | 30 | 50 |
| H-8 | 35 | 30 |
| H-9 | 35 | 40 |

As the gaps were of variable thickness, steel plate and rubber sheets of two thicknesses (10mm and 5 mm) were used in required number to fill the gaps and then tied together with bolts. The job was done with traffic plying above, the packing inserted at the opportune moment of a maximum gap created due to movement of a heavy vehicle. The work was difficult and only five of the nine joints of Meghna bridge could be partially filled with packing plates and no work was done on Meghna-Gumti bridge. Even in these, rubber plates could not be inserted in six locations due to not getting sufficient clearance in the gap. Photograph of a typical gap before and after insertion of the packing is shown in Figure 1. While this measure reduced relative vertical movement between male and female parts of the hinge, it did not facilitate free sliding and rotational movements required for proper function of the hinge.

During the course of this work it was discovered that the packing plates easily came off due to vibration caused by passing traffic. Various arrangements were tried to prevent slipping out of the packing from the hinge gaps but none was satisfactory. One such attempt is shown in Figure 2.



a) Gap before packing



b) Steel and rubber packing

Figure 1. Gap in hinge joints and interim packing.



Figure 2. Failed attempt to stop slipping out of packing due to deck vibration.

4 CONDITION OF BRIDGES PRIOR TO REHABILITATION

Condition of the bridges remained critical as the interim measures were not successful. Most of the hinges of both bridges continued deteriorating with abnormal vertical movement and vibration as traffic passed. As vehicles passed over the joints, male and female parts of the hinge hit each other creating loud hammering noise that caused safety concern among drivers and passengers. As a result most vehicles would stop before the joint and cross it very slowly creating long tailbacks on the bridge. Such stopping and slowing down of vehicles were also prompted by the deteriorated expansion joints which no longer could be viewed as serviceable. Deterioration of hinge bearings at the mid-span expansion joint locations had resulted in significant vertical movements being imposed on the joints. The type of expansion joint used did not cater for any significant vertical movement between two sides of the joint. Condition of a typical expansion joint prior to rehabilitation is shown in Figure 3. Wheels of loaded vehicles would frequently get stuck in the damaged joints creating traffic disruption.



Figure 3. Expansion joint before rehabilitation.

5 REHABILITATION REQUIREMENT

Severe movements of the bridge structure resulted due to damaged hinge bearings as a result of poor maintenance. In some cases, the hinge bearings fell out of their seating causing severe vertical movements at the joint which was beyond its design parameter. Expansion joints deteriorated because of four factors: its construction (reinforced rubber), excessive vertical movement due to deteriorated hinges, increased traffic volume, and overloaded vehicles. Examination of the hinges revealed that all pot bearings together with the sliding surfaces need total replacement. The bearings need to be designed anew because of changed dimensions of the

gaps and increased traffic. Design of bearings should pay special consideration to sliding movement and the resulting abrasion of bearing surfaces. The expansion joints employed in the original design were extremely maintenance hungry and short lived as rubber would soon deteriorate under prevailing extreme traffic conditions. All of the expansion joints needed replacement by a more durable form of joint with little maintenance needs.

6 REHABILITATION APPROACH

In view of the urgency to provide a solution to the problem, the rehabilitation team decided to implement a temporary solution immediately allowing time for measurement of the hinge gaps and design, manufacture and performance testing of the permanent solution.

6.1 Temporary Solutions

Main design criteria for the temporary solution adopted has been the shortest delivery time.

6.1.1 Expansion joint

Temporary expansion joint was designed to immediately and temporarily bridge over the gaps by cover plates. This would allow traffic to pass relatively more smoothly without having to slow down. The design consisted of three plates hinged together, with the outer plates being anchored to deck concrete. Service movements, mainly rotations and longitudinal movements were accommodated respectively by hinges on both ends of the bridging plates and slotted holes on anchor plates on one side (Fig. 4).

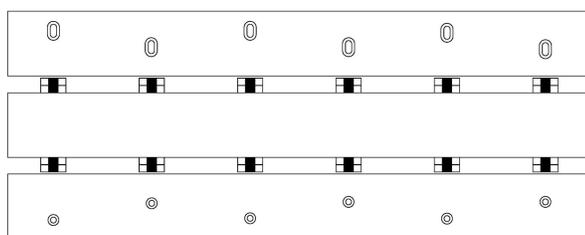


Figure 4. Temporary expansion joint.

6.1.2 Hinge bearings

All the old pot bearings were removed; the gaps thus created would eventually be filled by new sliding pot bearings. Until the new bearings are designed, manufactured and performance tested, some temporary packing that would transmit vertical force yet allow rotation and sliding needed to be devised. Elastomeric bearing complete with dimpled polytetrafluoroethylene (PTFE) disc was adopted as this design could be produced in short time. The upper PTFE disc was smeared with silicon to facilitate sliding due to horizontal deck movements. The bearing lower assembly was designed with tapered face; tapered packer plates were used so that the bearing assembly could be fitted tightly into its location between male and female couplings of the joint. Figure 5 shows such a temporary bearing.



Figure 5. Temporary PTFE topped elastomeric bearing.

6.2 Permanent Solutions

A 10-year service life was the main design criteria for the permanent solution. It was desired that the permanent solution shall remain effective until new bridges are built adjacent to the existing bridges.

6.2.1 Expansion joint

In design of the permanent expansion joints, riding comfort and low maintenance need were given the topmost priority. A finger type joint was preferred mainly because it satisfies both these conditions. Additionally it would accommodate large vertical movements. Figure 6 shows a typical section of the designed finger joint. Although it is an open joint, deck water could be collected in a channel made of polyester fibre reinforced rubber and drained into the river. Thus the bearing area underneath would remain protected. The permanent finger type expansion joints with 50mm and 80mm longitudinal movement capacities were designed with Grade 50 steel to provide good riding comfort under service movements and to accommodate design wheel loads in excess of 130 kN due to overloaded trucks. Protection angles were incorporated into the finger joint design to protect the transition concrete against cracking due to impact loads. Looped anchors were used to firmly anchor the joint assembly to concrete deck. All exposed surfaces of the finger joints and the protection angles were protected against corrosion by chlorinated rubber anti-corrosion protection system having total DFT=450 μm .

The finger joint was fatigue tested after manufacture to evaluate performance under repetitive loading conditions (Fig. 7). Figure 8 shows an assembled finger joint prior to installation.

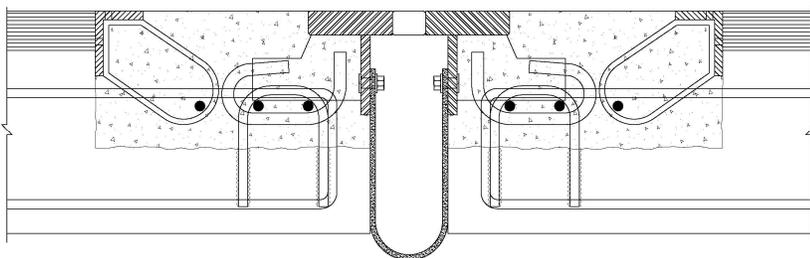


Figure 6. Expansion joint section.

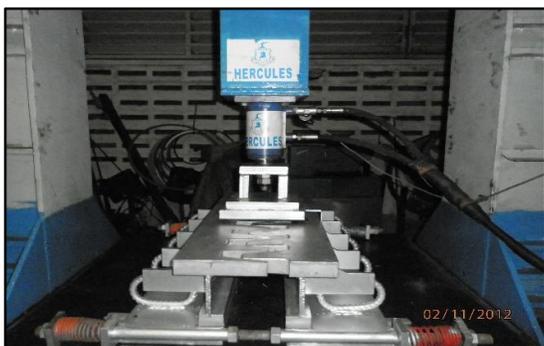


Figure 7. Fatigue testing of expansion joint.

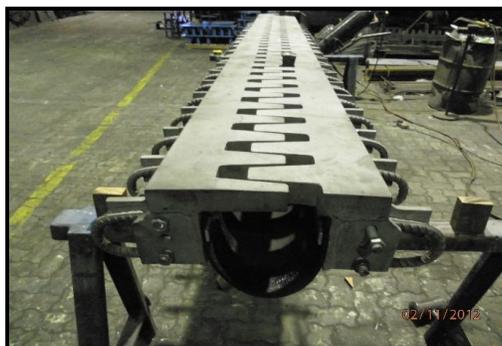


Figure 8. Fabricated expansion joint assembly.

6.2.2 Hinge bearings

The permanent bearing was a modified version of the original design to BS 5400 with dimpled brass sliding disc (Fig. 9). The new design has a thicker sliding plate, the stainless steel material having been changed from S304 to the more durable S316. Although long term deterioration tests were conducted on the assembled hinge bearing (Fig. 10), when tried in field, this modified version of original design was not very successful because the dimpled brass disc could not withstand the prevailing frequency of combined movements. Despite having greased the brass discs frequently, they were worn out within a short period after installation. It was felt that a non-metallic material would form a more abrasion-resistant sliding surface. After considerable test and trial, ultra high molecular weight polyethylene (UHMWPE) was chosen as material to be used on piston tops of pot bearings to act as the sliding surface. Originally installed dimpled brass discs were replaced with custom-designed and machined dimpled discs using UHMWPE material. This special design UHMWPE disc has proven to be successful ever since under extreme service movements and rotations (Fig. 11).



Figure 9. Assembly of permanent hinge bearings.



Figure 10. Long term deterioration test on hinge bearing.



Figure 11. UHMWPE disc in excellent condition after months of service.

The other additional item supplemented to the original hinge bearing design was the introduction of clamps at the hinge using M36 stress bars. The clamps were introduced as preventive measure to “walking” of hinge bearings under extreme frequency of rotational and torsional movements at the hinge. The stressed clamping bars held together tongues of the female coupling which deflected under dynamic action of heavy traffic (Fig. 12).



Figure 12. Stress bar clamping system in hinges.

6.3 Site Installation Works

Owing to poor maintenance, there was no street lighting. The site installation works had to be carried out with limited spotlights. As a result, the working condition was difficult.

6.3.1 Temporary solutions

The aim and purpose of the immediate temporary measure was to buy time for production and performance testing of permanent solutions. The bridges were closed to traffic from 12 midnight to 6 am, one night at a time. During the nightly closures, neutral state of the bearings and joints were achieved with no traffic on the deck. Existing worn out pot bearings were taken out of the hinges and measurements of gaps were taken in neutral condition, which had changed from original installed dimensions after years of heavy use. Temporary elastomeric packing blocks were inserted in the hinges. Existing deteriorated rubber expansion joints were taken off and temporary hinged sliding cover plates were installed at expansion joint locations. Finally asphalt premix was laid and rolled at expansion joint locations to offer a relatively comfortable riding surface. All these works of temporary solution had to be completed within the limited nightly isolation period. The operation saw engagement of five independent crews backed by Army engineers. Expected life of the temporary solution would be about three months.

6.3.2 Permanent solutions

The bridges were closed to traffic for 6 consecutive days on 3 occasions during the installation of permanent solutions. This was unavoidable because the permanent design required concrete box-out to be provided to cast in the finger joints. Hacking of the 20 years old concrete (Fig. 13) and aligning the anchors of finger joints within the obstructive starter bars (Fig. 14) were challenging and had taken up most of the isolation time allowed.



Figure 13. Hacking of concrete box-out.



Figure 14. Finger joint installation in obstructive starter bars.

The casting of concrete box-out using specially designed concrete, mixed at site, proved to be effective. A high early strength, high range water reducing/superplasticising admixture was used as the key ingredient of concrete. Concrete strength reached more than $f_c' = 30\text{MPa}$ at 48hrs and $f_c' = 50\text{MPa}$ at 28days. A curing agent was sprayed on concrete surface after casting to reduce risk of shrinkage cracks due to high early strength. This proved to be satisfactory as there was only a 50mm minor hairline tension crack out of all the expansion joint locations, this again presumably caused by uncalled for movement of construction equipment on the deck when the concrete was still green. Figure 15 shows a concrete casting being finished and Figure 16 shows a finger joint after installation.



Figure 15. Application of curing compound after casting.



Figure 16. Installed finger joint.

7 EVALUATION OF PERFORMANCE AFTER REHABILITATION

7.1 Public Perception

After opening of the bridges on completion of permanent rehabilitation works, huge appreciation has been shown by drivers and passengers of vehicles as the riding is smooth and the scary feeling of large amplitude vibration with passing of every heavy vehicle has disappeared. Both vertical movements of mid-span joints and vibration of bridge cantilevers have reduced perceptively. The vehicles do not need to slow down anymore while passing the joints resulting in faster traffic movement. The general public perception is that the bridges are now out of danger.

7.2 Quantification

Vibration of the bridge was measured before and after the rehabilitation by electronic vibration sensors and loggers that can record vibration in all three dimensions. Figure 17 shows the equipment employed for this measurement and Figure 18 shows vibration monitoring work on bridge deck. Figure 19 and Figure 20 respectively show typical vibration records before and after the temporary rehabilitation works. Peak velocity of 80 mm/s prior to rehabilitation had reduced to below 60 mm/s after the temporary works. The measurements were however taken over a short period of time (30 minutes) and may not represent typical traffic condition on the bridge.



Figure 17. Vibration monitoring equipment.



Figure 18. Vibration monitoring in progress.

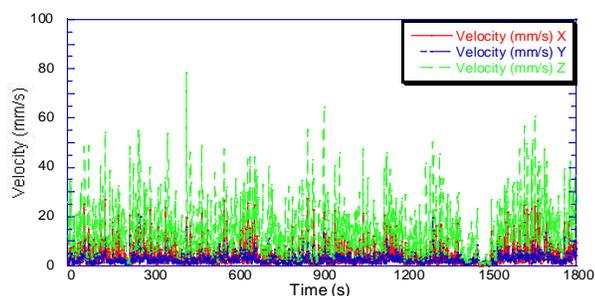


Figure 19. Bridge vibration before rehabilitation.

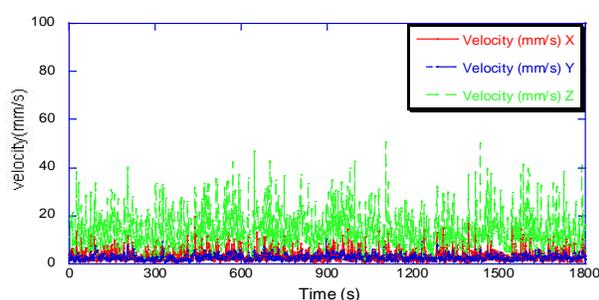


Figure 20. Vibration after temporary rehabilitation works.

After commissioning of the bridges subsequent to permanent rehabilitation works, a continuous record of vibration spanning over 17 days was taken. The velocity against time measurement for this period is presented in Figure 21. There is clear evidence that deck vibration has reduced considerably due to the permanent rehabilitation works. Peak velocity was about 50 mm/s only once during the recording period of 17 days, this presumably due to passage of a very much overloaded vehicle. The maximum velocity in the vertical direction was generally below 40 mm/s. Velocities in the two horizontal directions were below 10 mm/s.

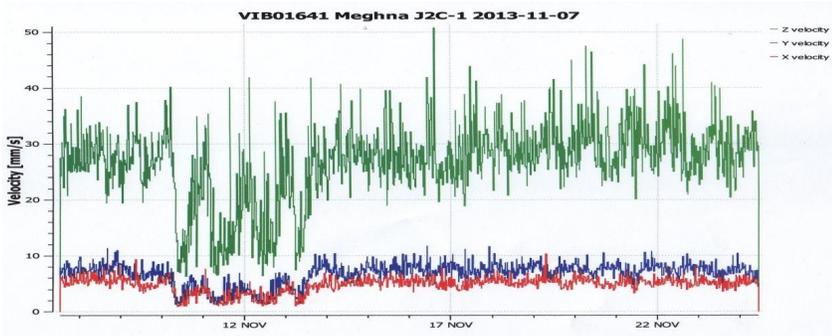


Figure 21. Vibration record after permanent rehabilitation works.

8 CONCLUDING REMARKS

The extensive rehabilitation works were necessitated by slack in regular maintenance. All infrastructure works especially bridges need maintenance. Figure 22 is a conceptual representation of deterioration of bridge condition with age, which can be slowed down by good maintenance. Rehabilitation works cannot make the bridge new; it can at best lift the bridge condition to a level which could have been achieved at this age by good maintenance. The rehabilitated bridge will deteriorate at a greater rate than the original bridge even with good maintenance. Without such continued maintenance even the rehabilitated bridges will soon deteriorate rapidly and return to a condition worse than before.

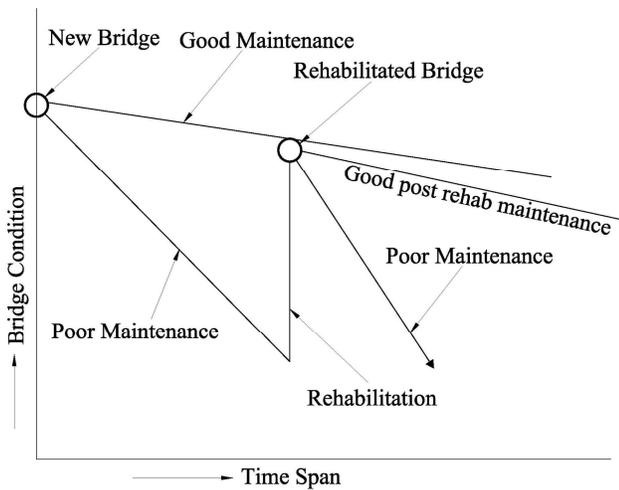


Figure 22. Conceptual representation of bridge maintenance need.

Meghna and Meghna-Gumti bridges are more susceptible to maintenance than other bridges because of their structural form. Such balanced cantilever structures with mid-span hinges are easier to construct but difficult to maintain. The mid-span hinges and deck expansion joints are at the location of maximum simultaneous deflection, translation and rotation. The three movements caused by traffic cause deterioration of these mechanical devices quite rapidly. When coupled with action of overloaded vehicles the deterioration is faster. This structural form has been an unwise choice in a country where maintenance culture is virtually non-existent. With the urgency of implementing new projects, maintenance need of existing bridges has always taken the back seat. Sadly, this realization is yet to come to bridge owners of the country as the same structural form is still being used in bridges built in the recent past.