Strengthening Of Bridge By Pre-Stressing At JNPT And Testing Its Efficacy

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Synopsis:

Jawaharlal Nehru Port Trust (JNPT) manages one of the busiest port in india, Nhava- Sheva port. This port handles 65% of India's container traffic has a berthing period of 37 hours which is considered to be very long. GTI one of the three container terminals in JNPT has set national record for berth productivity of 236 moves/hour on January 25, 2010 with the vessel M.V EVER RACER (WCIX service). The entire operation was performed in just 13 hour and 10 minutes, during which 3,295 moves (4,136 TEUs)1 were performed. The Rail over bridge (ROB) has heavy vehicles moving day and night all the time. The bridge is crucial for functioning of the port if it is stopped it will make the container transportation very long and time consuming. The bridge had started showing cracks and distress. This paper describes the detailed repairs that were carried on this bridge. An elaborate instrumentation system was installed to check the effectiveness of the repair work and both the static and dynamic load tests were carried out. The paper presents results obtained by the tests and sensors installed at the bridge before and after the repair work carried out for future monitoring of the structural health (SHM), which is believed to be an important feature of such work in India probably for the first time in India.

ACI India Chapter Member Dr. Gopal Rai is the Chief Executive Officer and Chairman of R&M International Group, a major Construction Company in Mumbai, India specialized in FRP work. He completed Graduation and Masters from Penn Engg. College and Sardar Patel Engg. College Mumbai, respectively both in Civil Engineering. Then he obtained PhD from IIT (B), Mumbai. Since then I have been involved in civil industry especially in Repairs and retrofitting of structures. He introduced laminate Pre-Stressing in the Indian market which is today widely used. He was part of organizing committee of many grand workshops such as WSRR at IIT Bombay and Workshop on construction chemicals with FICCI and Govt. Of India. He has also been a lecturer and visiting faculty at many colleges and institutions such as IIT Madras, SPCE. He had presented his work in more than 60 seminars and conferences & also published many papers in journals & magazines like ACI, ICJ, ISSE. He have also been working as a part of committee's for design code development of Composites (ACI 440-2002) and recently as a part of Indian Standards codes formation committee for repairs and rehabilitation. He was involved in formation of Association of Structural Rehabilitation, ASTR which has more than 1000 members over India including great academicians and experts with it. ACI India Chapter Member Dr. A. N. Bambole is Professor at Sardar Patel College of Engineering, Mumbai, India. He completed his Post Graduation from SPCE and PhD from IIT Bombay, Powai. His area of interest includes Composite Mechanics, Finite Element Method, Non-Destructive evaluation techniques, Fiber Reinforced Composites in Repair, Retrofitting and Strengthening of structures, Fire Endurance of RC structures, and Waterproofing of RC structures. He recently got selected as a "Senate Member" in Mumbai University. He is a member on board of management of college as per Statute for autonomous institutes. He has played wide role in development of laboratories and other facilities in the college. Dr. A. N. Bambole has also been involved in many consultancy works some of the clients are JNPT, National Highway Authority of India, Indian Oil Corporation, MMRDA, BSNL etc. He has also been instrumental in organizing conferences and seminar in IIT Bombay and other Colleges in Mumbai. He is presently an active member in Indian Society for Technical Education (ISTE), Indian Society for Steel Development and Growth (INSDAG), American Society of Civil Engineers (ASCE), Indian Society for Non-Destructive Testing (ISNT) and Association for Structural Rehabilitation (ASTR) where he holds the position of secretary Maharashtra chapter.

INTRODUCTION

In today's growing economy, Infrastructure development is also raising its pace. Many reinforced concrete and masonry buildings are constructed annually around the globe. A is a large number of them, are deteriorated or become unsafe to use because of changes in use, changes in loading, change in design configuration, inferior building material used or natural calamities. Thus repairing and retrofitting these structures for safe usage of these structures has a great market.

Port at Nhava-Sheva, Navi Mumbai is managed by the Jawaharlal Nehru Port Trust (JNPT) [1]. This port is one of the busiest port and handles about 70% of container traffic of whole India has constructed Rail over bridge at Karal (Fig. 1)for efficient traffic flow. The construction of this bridge was completed and opened for traffic since 1991. This bridge consists of 36 spans of varying lengths with 37 expansion joints. The total length of bridge is 2297 m.

Depending on the desired properties, usage and level of damage involved members can be repaired and/or strengthened by several widely used methods.

One of the methods to strengthening is concrete jacketing but it has a lot of limitations [2]. The jacket should be of minimum thickness 39.4 inch. The sizes of members are increased and the free available usable space becomes less also adding a huge dead load and increasing the stiffness which reduces the efficiency of the structure. Its durability has also often found to be limited. Furthermore the whole process is slow and takes lot of time for completion.

Jackets may also be made of steel [2]. It's a popular technique to use steel plates bonded with epoxy to external surfaces of beams and slabs. This technique is simple and effective as far as both cost and mechanical performance is concerned, but suffers major disadvantages. Corrosion of steel plates hurdles its use in structures in/near river, lake and sea. Furthermore difficulty in manipulating heavy steel plates in tight construction sites, need for scaffolding, and limitations in available plate lengths which results in need of joints. Sometimes higher modulus of steel causes it to take large portion of axial load resulting in premature buckling.

The conventional jackets, sheets, plates may be replaced with Fiber Reinforced Polymer (FRP) fabrics, sheet and laminates in view of above limitations [3].

The pre-stressing of concrete is known to be very effective way of using the higher compressive strength property to much greater extent. Moreover, permanent deformations in the structure can be recovered by this technique. This technique of prestressing concrete is possible only in new structures. External prestressing with other materials of the existing structures have always been difficult especially in view of the materials to be used, reinforcement corrosion, lateral instability, end anchorages and of course space constraints.

The advantages of resistance to corrosion and high specific strength make these materials ideal for reinforcing existing structures with minimum intrusion. Popular method adopted is bonding them adhesively to concrete structures [4]. However, we can seldom fully use the superior strength properties of these Fiber Reinforced Composites (FRC's) due to poor capacities of concrete and interfaces formed. Pre-stressing of these materials allows us to better utilize these properties.

Details Of The Bridge

The Rail Over Bridge at Karal had heavy traffic movement and had started showing signs of distress. Layout of the bridge is shown in Fig. 2, the portion marked by blue line is a slab-girder (T-Beam) bridge system and the pre-stressed slab system portion marked in red. The bridge was functionally designed for crossing railway line and was structurally designed for Indian Road Congress (IRC) 45R loading. As per the revised recommendations of IRC and prevailing practice, the bridge is now required to sustain IRC Class 70 R loading.

Figure 1.* *ROB (Rail Over Bridge) at Karal Junction, JNPT

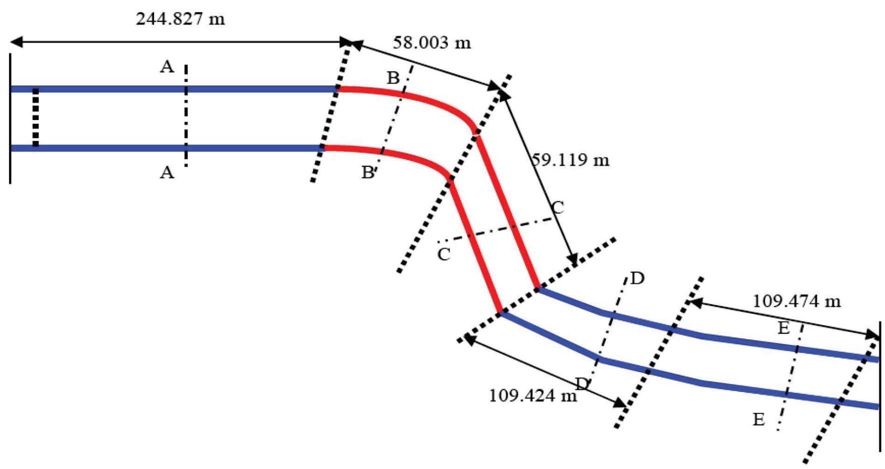


*Figure 2. **Alignment of the Karal Bridge***

Inspection Findings

To assess the information about the bridge current status and the repair methodology as it was inspected by consultants and structural experts. The major observations during the site visit were as follows.

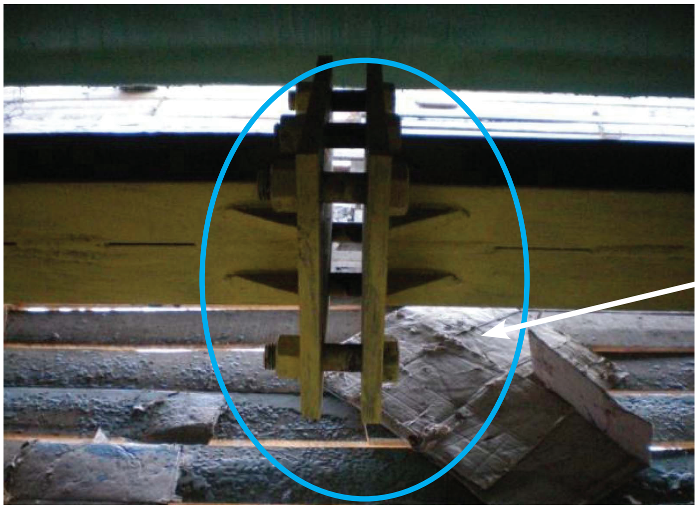
1. Expansion joints were not functioning properly. In the original design there was no provision of appropriate expansion joint.
2. Slab area of expansion joint was found to be damaged severly due to heavy vehicular movement. The gap between two spans has become significant and concrete had deteriorated.
3. The neoprene/elastomeric bearings provided in bridge were inadequate for heavy vehicle movements. They appeared to be bulging out and damaged.
4. There was a visible sag in the superstructure in many spans. The typical structural failure cracks in the girders were observed.
5. The new expansion joints could not last long due to excessive vibrations and the poor quality of deck concrete at the end of span.
6. The substructure/piers appeared to be sound.

Procedure For Rehabilitation [5]

In view of above observations it seemed that the structural health of the bridge was not very good. The proposed strengthening measures for the bridge by the consulting team are as follows.

1. Strengthening of girder by steel truss system- The girders and slabs are to be strengthened by placing additional steel truss systems, which will support the bridge deck/slab/girders with M32 high strength bolts. This was designed to take about 50% of load carrying capacity of girders. (Figure 3)
2. Replacement of bearings The existing neoprene/elastomeric bearings should be replaced by new elastomeric bearings. Shore-Ahardness hardness of rubber material used should be 60. (Figure 4)

(a) Connection of Truss over Diaphragm Beam



(b) Pre-stressing Mechanism in Truss

Figure 3(a) and 3(b) ***Installation of Steel Truss System***

Fig. 4 ***Replacement of damaged Bearings with new***

3. Provision of new expansion joints- It was recommended to replace the expansion joints with WaboCrete Strip Seal Expansion Joint System. It is a superior joint system, which can be rapidly installed in failed expansion joints and also is suitable for heavy vehicle bridges.
4. Pre-Stressing using C-fiber Laminate and Carbon fiber wrapping of girder and slab:
   To further increase the structural strength of the bridge, it was recommended to strengthen the bridge using the Carbon fiber composite wrapping around the girder and slab. At the bottom of each girder 3 Pre-stressed Carbon Fiber Composites (CFC) laminates i.e. 2- 80/1.4mm and 1- 50/1.4mm was proposed to be placed. The load to be given to prestressed laminates should be 8-9 tons. The deck slab was also recommended to be strengthened by putting CFC laminates 80/1.4 at 50 mm c/c at the bottom. The properties of required laminates and wrap were specified. (Figures 5 and 6)

***Figure 5.* Pre-stressing in process and the finished laminate with anchor plates at end.**

***Figure 6.* Enclosing the girders with Carbon Fiber Wrapping**

Test Procedure

The procedure followed for taking measurements on each span before and after strengthening is explained in the following paragraphs[5].

Standard vehicle (Figure 7) having distance of 3.1 meter between front and middle axel and 1.4 meter between two rear axels and weighing 32 Ton each (average weight) were used for loading each span before and after strengthening. Six different static load cases and two dynamic load cases were considered for measurements.

Two standard vehicles have been placed side by side for static measurement. Fig. 8 shows position of standard vehicle in Load Case -1, generating maximum shear stress on main girders near support B (towards JNPT) of the span for east side carriageway.
Dynamic load cases were recorded with an initial no load signal for ambient vibrations, if any.
Vibration signals were recorded on multi-channel vibration recorder and analyzer, for load case A.
Similarly vibration signals were recorded for load case B.

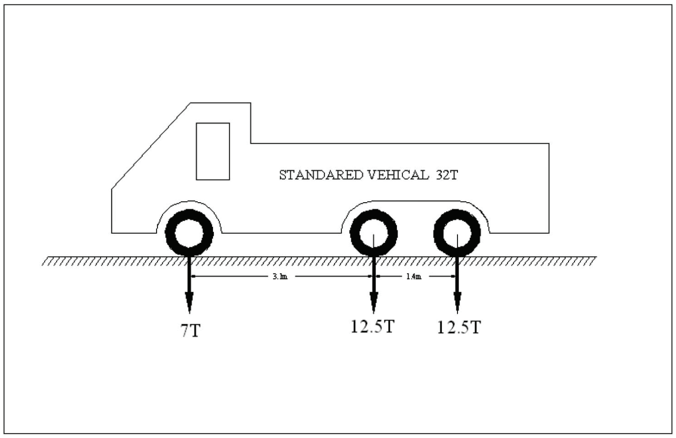


Fig. 7 Standard Vehicle (Total Load and Axel Loads)

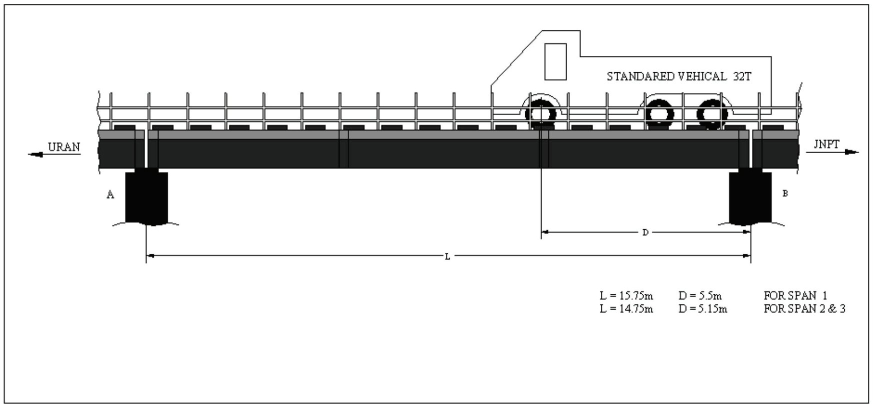


Fig. 8 Position of Vehicle on East-Carriageway for Maximum Shear Force at Support B

Observations and Results

It can be summarized that this exercise was useful to know the behavior of these spans before and after strengthening. It can be seen that almost all the deflection and strain values show the effect of strengthening. Some of the sensors were not responding during test hence the corresponding readings have not been included while drawing the conclusions. In the case readings obtained from shear strain gages, no useful information could be obtained. Conclusions have been drawn on the test results before and after strengthening.

Table 1 Average Central Deflection (mm)

	Span-1	Span 2	Span 3
Before strengthening	5.38 mm	5.18 mm	5.08 mm
After Strengthening	3.93 mm	3.65 mm	3.95 mm
Reduction in defection	1.46 mm (27.1%)	1.53 mm (29.5%)	1.13 mm (22.2%)

Table 2 Average Flexural Strain (με)

	Span-1	Span 2	Span 3
Before strengthening	450 με	407 με	311 με
After Strengthening	198 με	188 με	160 με
Reduction in Flexural Strain	262 με (58.2%)	219 με (53.8%)	151 με (48.5%)

Table 3 Crack Width of Diagonal Cracks near Support
(Change in change width over a gauge length of 200mm in με)

	Span-1	Span 2	Span 3
Before strengthening	80 με	90 με	72 με
After Strengthening	42 με	28 με	15 με
Reduction in Shear Strain	38 με 47.5 (%)	52 με 57.8 (%)	47 με 65.3(%)

Table 4: Average Acceleration (mm/s^2)

	Span-1	Span 2	Span 3
Before strengthening	21.38 mm/s^2	35.91 mm/s^2	85.92 mm/s^2
After Strengthening	11.43 mm/s^2	15.93 mm/s^2	42.06 mm/s^2
Reduction in Acceleration	9.95 mm/s^2 46.5 (%)	19.98 mm/s^2 55.6 (%)	43.86 mm/s^2 51.0 (%)

Table 5: Natural Frequency of Vibration (Hz)

	Span-1	Span 2	Span 3
Before strengthening	5.301 Hz	5.344 Hz	5.520 Hz
After Strengthening	5.737 Hz	5.964 Hz	5.833 Hz
Increase in Fundamental Frequency	0.436 Hz 8.2 (%)	0.620 Hz 11.6 (%)	0.313 Hz 5.7 (%)

Conclusions

1. Rebound hammer test performed on each main girder indicated that existing concrete is in good condition.

2. Ultrasonic Pulse Velocity (UPV) test has been performed on each main girder to confirm that the existing concrete is in good condition.

3. Central deflections observed under standard loads indicated significant improvement in the flexural stiffness of the RCC girder beams after rehabilitation and effectiveness of the prestressed steel truss strengthening system. The average reduction in central deflection for loading condition inducing maximum deflection for each of the span is presented in Table 1. Reduction in deflection of all the three spans indicates that the flexural strengthening system (FRP laminate and Pre-stressed steel truss system) is effective in sharing the vehicle loads. An average reduction of 26% in the deflection of bridge superstructure under standard loads was observed.

4. Strains measured under standard flexural loads indicate significant improvement in the flexural stiffness of the RCC girder beams after rehabilitation and effectiveness of the pre-stressed steel truss straitening system. The average reduction in flexural strain for loading condition inducing maximum bending moment for each of the span is presented in Table 2. Reduction in flexural strain of all the three spans indicates that the flexural strengthening system (FRP laminate and Pre-stressed steel truss system) is effective in sharing the vehicular loads. An average of 53% reduction in the flexural strain in RCC girder beams under standard loads has been observed.

Conclusions (Cont...)

5. Change in the width of the diagonal shear cracks on the RCC girder beams near the support have been measured before and after strengthening with the help of omega type strain gage based transducer. The average reduction in shear strain over a gage length of 200mm under loading condition inducing maximum shear force each of the span is presented in the Table 3. An average of 56.8% reduction in the shear strain in RCC girder beams under standard loads has been observed. Reduction in the shear strain after rehabilitation indicates significant enhancement in the shear stiffness as a result of FRP wrap and Steel truss system.

6. Reduction in the vibration of the superstructure was envisaged due to rehabilitation of RCC girder beams and strengthening with steel truss system. Vibration measured at the mid-span of girders has been presented in the Tables 4 and 5. An average reduction of 8.5% in fundamental frequency of vibration is achieved. In addition to this, the amplitude of acceleration has been reduced by 50%. The increase in fundamental frequency of vibration and reduction in amplitude of acceleration indicate that the significant improvement in the overall stiffness of the structure. The rehabilitation methodology used for bridge was found to be successful and yielding desired results in the most cost-effective manner

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