Rehabilitation of Timber Brdige Case Study -Rehabilitation of Zero Bridge over River Jhelum at Rajbagh, Srinagar-J&K-India

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***Abstract*—For thousands of years, timber bridges and other timber structures were built primarily by trial and error and rule of thumb. Designs were based on past experience, and little concern was given to efficient material usage or economy. Timber bridges which still exist in the 21st century are considered a symbol of an age old heritage and as such arises the need to rehabilitate and reconstruct them as per the modern design and accurate engineering methods which have been developed after years of research on wood as a construction material. This case study is aimed at the rehabilitation of one such old age heritage timber bridge, situated at Srinagar, J&K, India, to preserve the historic and the cultural significance it brings to the place, with the application of engineering principles and design philosophies.**

Keywords*— Deterioration; Floor Joists; Piers; Settlement; Symmetrical And Unsymmetrical Members; Continuous And Discontinous Members; Realignment; Load Settlement Test;

I. INTRODUCTION

Many recent developments have increased the interest in timber bridges such as materials, improvement in chemical treatment (preservatives) and manufacturing methods. These developments reflect the advancement in the behavior of wood as a structural material. The age of wood spans human history. It has provided a resounding choice of being used as a construction material commonly known as timber. Timber has been widely used in the construction of bridges since middle ages since these bridges do not require any special equipment for installation and can normally be constructed without highly skilled labor. They also present a natural and aesthetically pleasing appearance, particularly in natural surroundings. Many of these bridges which still exist today are termed as heritage because of their history and cultural significance

During the 1900's, a number of wooden bridges were built in Srinagar, J&K. Many different types and designs made up the once-abundant population of Srinagar's covered bridges, of which only a few remain. Some of the remaining structures must be completely replaced, others are being moved to local fairgrounds or parks to be used as pedestrian crossings, and in some cases new bridges are being built alongside the old to divert all traffic away from the existing structures. But the ideal preservation practice involves rehabilitation of the existing bridge, leaving it in place with the ability to carry modern loads, to remain a part of the local transportation system. In Rajbagh, Srinagar, located in the central part of the State, one such bridge named as "Zero bridge" remains, which was once an integral part of the state road system . The J&K Government have recognized the importance of preserving this structure as an important part of preserving the heritage & connectivity it offers. The decision was made to upgrade the bridge by rehabilitating it.

II. NEED FOR REHABILITATION

A. Understanding the Problem

The bridge was chosen based on its symbolic significance, low traffic volume and generally poor condition throughout the bridge. Over the period of year, the zero bridge had become structurally or functionally deficient. Structurally, the deficiency resulted from deterioration, damage, or increased load requirements in excess of the design capacity. Hydraulically, the original waterway opening under the bridge had become inadequate as a result of changing drainage patterns in the watershed or because the hydraulic parameters on which the original design was based were inadequate.. Some members of the superstructure & substructure had a noticeable twist caused primarily by nearly broken 10-13 lower chords at opposite corners of the members. The ends of some diagonals and lower chords were decayed and crushed from years of termite attack and general deterioration. The timber members had not only been damaged because of the deterioration due to decay but they were also subjected to temperature exposures which had caused further damage due to temperature differential, as the part of timber members in the substructure remained below the water level while the other parts were way above it. Two additional piers were placed under the bridge in the 1980's, along with other various supports added in attempts to keep the bridge standing. An accurate analysis of the bridge was nearly impossible because of the unique design, the poor condition of the truss, and all the supports installed over the years. The bridge had a posted load limit of only 3 tons & a significant settlement had been observed in the recent years which had also been confirmed by the load settlement tests conducted near the bridge site during the recent years.

B. Understanding the Possible Solution

Various design options were considered, many of which would have worked well. Most centered around the concept of reducing the dead load of the bridge by providing symmetrical members instead of the existing unsymmetrical members of the bridge superstructure. This would decrease the pressure & weight on the existing foundation system of the bridge and ensure proper distribution and transmission of load through its members, thereby resulting in zero settlement, if the reduced load to which the foundation system of the bridge is subjected to, is well within the limits which it can bear & conveniently transfer and transmit to the ground below. This concept was especially attractive to us because of the uncertainty of the live-load capabilities of the old bridge system. Armed with this central idea, other more specific design parameters were formulated, including the following:

1. The waterway adequacy must not be constricted by the improvement.

2. Bridge capacity must be increased to handle single tandem axle loads without any settlement.

3. Timber will be used in the improvement for aesthetic compatibility.

4. The new system will help support the superstructure against further sag and twist, and straighten the members.

5. Original appearance must be maintained as much as possible.

6. The project must meet economic criteria.

III. REHABILITATION/FINAL DESIGN SOLUTION

A final design solution was selected based on a great deal of discussion, preliminary design calculations and sketches, and help from reputed engineers & designers, who have experience in the works of bridge rehabilitation and construction programs and are known nationwide. The final design solution is tabulated in a comparative manner to understand the rehabilitation much better. Table I shows the comparative design differences between the old design and the new design which is finally adopted in the rehabilitation of the same. The design for loading, in excess of AASHTO (American Association of State Highway and Transportation) H 15-44 loading, was based on the current AASHTO specifications [6]. The floor beam spacing (12 cm on-center) was a result of the AASHTO wheel-load distribution guidelines [7][8][9]. The main aim of all these recommended changes in the design is to decrease the overall dead load of the bridge system by replacing unsymmetrical members with symmetrical ones and realignment of members wherever it is deemed necessary for proper distribution of load stresses and thereby ultimately resulting in bringing the settlement values of the overall structure within permissible limits, which is later confirmed by the load settlement test.

TABLE I. COMPARATIAVE DESIGN DIFFERENCES BETWEEN THE OLD DESIGN AND THE NEW DESIGN ADOPTED DURING REHABILITATION

Existing Design	New Design	Remarks
The number of floor joists were 28 in each span with a spacing of 8 cm between each joist	The number of floor joists are 20 in each span with a spacing of 12 cm on centre between each joist	The total dead load of the new design was reduced by decreasing the number of floor joists & increasing the spacing in between.
The ends of the main longitudinal beams were connected to each other by mild steel strips/bolts (butt to butt joint/fish joint)	The ends of the main longitudinal beams are connected to each other by fevicol, epoxy and light weight nails.	The extra weight that the connection, hinges and the ends of the beam members were subjected to was reduced considerably
The use of beam sections was very random & nonuniform. Varying cross sections of the beam members were used in the bridge system disproportionately (5 cm x 9 cm, 5 cm x 8 cm, 5 cm x 7 cm)	Only two distinct sizes & cross sectional beams are used in the bridge system. The use of beam sections is very uniform & proportional. (3 cm x 6 cm/ 5 cm x 6 cm)	The use of symmetrical members at proper places enabled to get rid of a number of extra beam members, thereby reducing the overall dead load of the structure & moment of inertia of the whole beam member system
The under strut or the inclined member of the bridge was fixed on the top ledger by means of cleat angles	The under strut is fixed on the middle ledger by means of groove blocks.	The realignment of the inclined member of the bridge enabled proper distribution of the overlying load by distributing the axial forces uniformly in the under strut members to prevent the load settlement
Double piers were provided at many places without any proper justification & reasoning and their placing was very nonuniform	The use of double piers is restricted to only on need basis at the proper locations where it is deemed necessary & they are placed in a very uniform arrangement	The symmetrical placement & reduction of unnecessary members, reduced the overall load coming on to the ground[4][3][2]
Mild steel sections were used at some places in the bridge system in 1980's as a part of rehabilitation to compliment the timber members in relieving the load stresses coming onto them.	The use of steel sections has been totally avoided. The existing steel sections have been reviewed and replaced again by timber sections, if needed necessary	The homogenous use of materials not only reduced the dead load of the structure but also enabled the overall load system to avoid eccentricity and act as a monolithic unit in the transmission of the loads through a well defined and noneccentric, centre of mass[1][7]
Some of the beam members were discontinuous and did not provide a continuous load transmission path from the superstructure to the underlying sub structure	The placement & fixity of all beam members was reviewed & many beams were re aligned with proper connections & fixtures to provide continuous beam members.	The strength of the overall bridge system was considerably increased by providing continuous members & their proper participation in the load transmission path resulted in reducing the pressure on the foundation system & thus zero settlement which was later confirmed by the load settlement test.

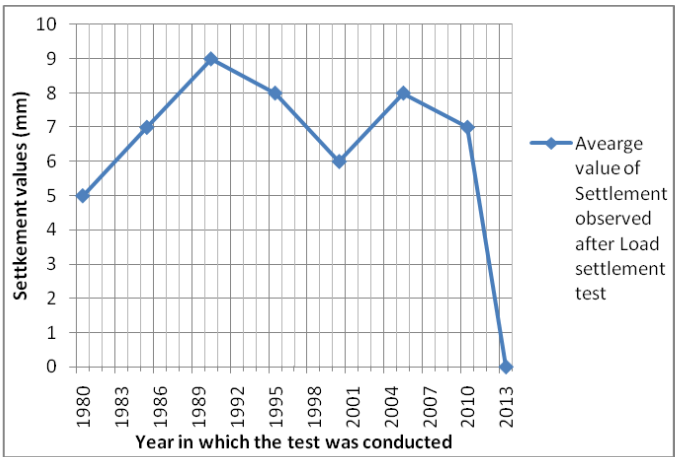
IV. LOAD SETTLEMENT TEST AFTER REHABILITATION

After making the necessary changes in the design as tabulated, it was necessary to make sure that the overall settlement of the bridge prior to the rehabilitation of the structure was brought under control and that the settlement after the rehabilitation was within the permissible limits, which would label the project as success. To carry out the same, the load settlement test was conducted at the various points on the downstream side, middle side and the upstream side of the bridge. The load settlement test was conducted under a load of 84 metric tons with 2400 bags filled with coarse aggregates and each bag weighing 35 kg approximately [10]. The difference in Reduced levels (RL's) at the locations in consideration before and after the test gives us the total settlement observed. After the test, it was observed that the total settlement reported was zero at the selected locations. Ironically, as exclaimed by one of the concerned engineer at the site, "zero bridge having zero settlement has been finally achieved". Table II below gives us the observed results of the load settlement test at the selected locations:

TABLE II. LOAD SETTLEMENT TEST RESULTS BEFORE AND AFTER THE TEST

Location	Initial Reduced Level prior to test (m)	Final Reduced Level after the test (m)	Settlement (m)
Downstream Side	107.80	107.80	zero
Middle Side	98.60	98.60	zero
Upstream Side	115	115	zero
Average of three settlement values			zero

The tests confirmed and authenticated the acceptability of the measures that were adopted during rehabilitation. The process of rehabilitation was thus successful in bringing down the settlement values of the overall bridge structure and thereby ending a three decade year old growing problem of worrisome settlement which had been seen in the recent years through various tests by different independent & government sponsored studies. Figure 1 below gives us the graphical account of various settlement values as they were seen in the studies which have been conducted at zero bridge in the recent years.



V. RECOMMENDATIONS

Since Zero bridge is an age old timber bridge located in Kashmir which experiences a very harsh winter, it is prone to weathering effects like snowfall, rainfall etc. In view of this the use of wood preservative on wooden members is recommended to prevent it from termite attack & subsequent deterioration. Further the use of polycarbonate panel sheets should also be considered to cover the timber members wherever it is deemed necessary as an alternative against the weathering effects due to harsh climate. To strengthen the foundation of timber piles, it is recommended that shelling wires should be fixed & tightened with the group of existing piers, encircling the individual trestle pier. Stones and boulders of specified shape & size should be dumped deep encircling the pier to increase its strength & to withstand the flowing magnitude of water during floods. Use of modern techniques like underpinning and jacketing of columns can also be done to increase the strength of timber columns.

VI. CONLCUSION

In retrospect, the project was a success. An important bridge was saved and left in service. Some historians and bridge purists may argue the methods used, or question the authenticity or aesthetic value that remains, but there is probably no perfect or absolutely correct way to improve these bridge deficiencies and still preserve them. Too many factors are involved to ideally address each problem area of the bridge. It tends to become a give-and-take process.

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