Damage Evaluation and Partial Retrofitting of Old Steel Bridge

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ABSTRACT

This study presents the method of evaluating the damage level of opposite trusses of a bridge through deflection test. The work is carried out on a damaged old deck type steel bridge using total Station and Dial Gauges under similar environmental conditions with the midpoint loading. Further the strength of the bridge is increased as per existing codal provision with partial retrofitting. Serviceability, or deflection, is very important in monitoring the health of not only a structural system, but also in analyzing the affects of a new technology applied in the field. The study presents the use of general survey equipment such as total station because of limited access for specific monitoring equipments with the owner agencies.

Keywords: steel truss bridge, deflection, total station, retrofitting

1. INTRODUCTION

Among the various issues being faced by the infrastructure maintenance authorities retrofitting deficiency in the bridges is one of the biggest challenges. Further the lack of fund availability forces the state authorities to use the bridges beyond their service life. Among various countries which are facing this type of problem of bridge, India is among such countries. The structural members of the any bridges are subjected to dynamic loading leading to degradation of their constituent material. These bridges are subjected to heavier and faster moving loads, compared to their original design loads. Such overloading of bridges along with their deterioration with age can lead to either catastrophic failure or improper functionality of the bridge((10). The poor quality of construction, defects in the material in the form of cracks, inefficient working of bearings and expansion joints and excessive deflection may require the replacement and retrofit of same. To strengthen the bridges, they should be firstly categorized so that bridges damaged more can be retrofitted sooner by appropriate retrofitting method (2). The relatively good condition of the bridge is primarily attributed to the systematic and periodic inspection and maintenance(5). The detected defects may be then be strengthened and further retrofitted as per the respective codal provisions of load and stresses (11). The work presented in this paper is on steel bridges in one of the states of northern part of India i.e Himachal Pradesh. Many of the bridges in the state of Himachal Pradesh in India has been designed and built several decades ago.

2.STATUS OF BRIDGES

The northern part of India at the foothills of Himalaya is mainly a mountainous region with large of bridges constructed on naturally developed perennial and non-perennial rivers. In order to have present status of bridges in this state, the data was collected from the different parts of state for about 650 bridges above 25m span. It has been observed that about 45% bridges have been constructed before the year 1990. Due to different revisions of IRC code 6 from 1964 onwards and continuous increase in volume of traffic and axle loading, it is necessary to develop a strengthening mechanism to make the bridge fit for present loading condition(2). As per the data collected about 3% bridges have been declared as structurally and/or geometrically deficient. Some of the deficient bridges are in service with speed and/or load restrictions and some are out of service. Deficiencies that may be found in bridges are numerous, including uncertainty in load carrying capacity, damage to bridge members due to accidents, excessive loss of the member cross-sectional. Most of the bridges are having a span of 25 to 40m. About14% bridges have been designed based upon IRC Class 18R,Class 24R and Class B loading which is for temporary bridges(11)and due to increase in traffic volume and loading these Bridges require immediate rehabilitation as replacement of these require lot of revenue. About 17% bridges had been designed on IRC Class 40R loading In the State of HP India about 44% bridges are RCC Bridges ,20% bridges are Prestressed bridges and about 28% bridges are made of steel structure . Built maps and construction data of large number of old steel bridges are not available. In addition, because of the seismicity of Himachal Pradesh India being in Zone V, development of technology and increased weight and volume of vehicles, different suitable techniques that matches to vulnerabilities are required as retrofitting techniques(1).

It is necessary to monitor these bridges so that the necessary precautions can be made before the bridge damaged completely. The systematic and periodic inspection and maintenance has primarily attributed to the relatively good condition of the bridge(13).Accordingly an old deck type steel bridge was taken from the PWD authority for structural health monitoring and research work.

3. Background

This bridge under study has been constructed in the year around 1920 or so as per the survey conducted with the local people of the nearby area. The bridge has been constructed by the British Company named as DORMAN. LONG&Company Limited Middlesbrough England (3)on National Highway 20 on Bander Khad near the village Samloti Himachal Pradesh India. The company had their stockyard at Karachi(now in Pakistan) and their head office at Clive Street Calcutta India. The steel sections used were as per British Standard specifications. These were imported from the Karachi Stock yard and were assembled at the site.Due to increase in traffic on National Highway and having single lane with carriageway of 3m only, the State Authorities were forced to replace it with new Prestressed Concrete Bridge. After the construction of new bridge, this has been shifted to a village road on Chughera kandi Road on Bathu Khad in District Kangra Himachal Pradesh India in the year 1985 and reassembled by HPPWD Authorities. This bridge was working with the satisfactory servicability criteria for the past 25 years but In December 2009 settlement were observed in Bridge Deck. Bridge was closed for traffic due to distress in bridge by HPPWD officials. The owner of bridge HPPWD desired to evaluate the condition and identify necessary strengthening to bring the bridge up to modern standards, while respecting the historic fabric of the bridges. The project also included strengthening
schemes and bridge member replacement based on the extent and cost of the required upgrade. The present work presents salient features of the procedure as well as the results of an extensive study on a particular and characteristic deck-truss highway bridge (Fig. 1). .An extensive investigative program was chalked out comprising of preparation of as built drawings at the site, a brief FEM analysis and field tests. The sequential order of the investigative program detailed below was carried out between Oct,2010 and March 2011:

- Preparation of inbuilt drawings by taking the measurements of structural members at the site and geotechnical information furnished by HPPWD official. The sectional members were verified from the Handbook of Dorman Long &Co.Ld company(3)
- Developing Analytical model based on the inbuilt structural drawings and the material characteristics details as per the actual properties from the manufacturer's handbook (3).
- Conducting static test on the Bridge with load at different locations and measuring deflection at various nodes using Dial Gauges and Total Station
- Designing restoration measures based on the inferences drawn from the analysis and design.
- Presenting a scheme of restoration measures and sequence of operations with explanatory sketches and drawings

Figure 1: 40m span Steel truss bridge in HP India

4. DESCRIPTION OF THE STEEL TRUSS BRIDGE MODEL

The Deck type steel bridge considered for study was about 100 year old. This single span 47.50m steel truss road bridge is situated on Chughera Kandi Road in District Kangra Himachal Pradesh India. The bridge is deck type steel bridge with 3 m carriageway. The bridge span is divided into 10 equidistant panels of 4.75m. The deck of the bridge is made up of corrugated metal sheets of 6mm thickness with overlay of Bituminous premix carpet of about 40mm thickness as wearing coat The vertical and diagonal members of the bridge are built up member section. The Vertical members are made up of two T-section128x65x10mm joined with double diagonal bracing of 7.5mm thick plate section, diagonal members are made up of four angle 77x87x10mm with double cross lacing of plate section. The main function of the bracings is to hold the main component members of built-up column in their relative position and equalize the stress distribution in them [book].

End members are made up of two Channels section 254x101.60 mm placed back to back and joined with 10mm thick plate. The top and bottom horizontal members are made of two channel member254x101.6mm fabricated back to back and revitted with 10 mm thick plate. The members of the trusses have been joined with rivet connections.

Figure 2: Side View of 40 m steel truss bridge

The analytical model of the bridge was generated in SAP2000 [13] with the structural element as the truss members. The members are assigned specifically as built cross-section to achieve analytical model as accurate as possible. Although the structural system is a truss system, all joints of the model are modelled as rigid connections [13]. It is prime facia that upto 50% reduction in rotational Stiffness of the joints has less effect on structural stability of Steel Truss Bridge. [8]. Any variation in the expected behavior of the trusses can be due to the reason that a particular steel member is ineffective in taking the stress or the joint has lost its rigidity and is transferring the load to other members with partial rigidity or the bearing has become ineffective in transferring the load to the ground.

5. VISUAL INSPECTION

Visual inspection can provides up-to-date, accurate and informative data representing the current condition of bridges for the effective use of Bridge Management Systems (BMS) [2]. This data allows for proper development of maintenance, repair and rehabilitation programs including those addressing preventive care. As the owner agencies have not develop such type of system and bridges lacks in maintenance and ultimate leads to failure if not attended timely. During visual inspection , the riveting in some of members are found to be loose and missing in some members and also holes for rivets are lying empty as shown in Fig.4The rocker and roller bearings were found to be not functioning due to the soil deposition in the rollers. The roller bearing provided towards the Chughera side have become fixed as

Figure3(a),(b),(c): Loose Rivets, Bearing Filled up with Soil, Roller filled with soil

the earthsoil has been filled up in the rollers and has changed the behavior of bearings and therfore members joining this node have been stressed and failed(Fig 3) at higher loads of 9.56 tone as checked with analytical model.The horizontal stiffener joining the end member was joined with 5mm thick plate in place of 75x75x10mm angle. The deck plates heve damaged as shown in fig. 5 and top surface of deck of the bridge was damaged and surface was uneven. Due to uneven surface the additional impact load had also been added to the structure. It has also been observed that one number bridge was under construction on the same road and this bridge was only approach to that bridge. The over Loaded trucks carrying the construction material were crossed over this bridge which was the main region of failure of the bridge.

Figure 4 (a)End Member Buckled (b) Inadequate Horizontal stiffener (c) Corroded and damaged Deck

6. EXPERIMENTATION

A visual inspection was carried out in order to know the reasons for failure. Serviceability or deflection, is very important in monitoring the health of not only a structural system, but also in analyzing the affects of a new technology applied in the field[6]. The full-bridge deflected shape in long-span bridges is an important parameter that evaluates the safety state of a structure[9] For measuring defection, surveying equipment was employed in attempt to make serviceability measurement more practicable because of limited access for traditional monitoring equipment for bridges in the remote region. Until recently, surveying equipment would not have produced the accuracy required for structural monitoring use; however, manufacturers of this equipment have developed new technologies to increase the accuracy of the instrumentation. The major component used in this study, the total station, can measure deflection accurate to 0.2 millimeters[7]. This monitoring system useful because there is no site restriction, less labour and time requirement. A basic parameter such as displacement was selected for investigation of damage in bridge. Displacement was recorded at different nodes using firstly with dial gauges and after the bearings was cleared of the debris, the deflection was measured with Total station and dial gauges to know the behavior of bridge under static truck load of 9.56 Tone(Fig 6). The corrosion in the members has been obtained from the half cell potentiometer.

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Fig.5 Truck placed to measure defection

(a) **(b)**

Figure6: Deflection measurement using Total Station and Dial Gauge

7. PARAMETERIC STUDIES

Although steel is a homogenous material but various component of the structure i.e. structural member, connection plates, rivets, all made of steel undergo different mode of vibration when subjected to static and dynamic forces. The variation in the applied forces leads to different amplitude of displacement in the structure. In the present study these different applied force are generated by the moving vehicle of 9.56 tone load. The displacement has been measured at different nodes by moving the truck along the span. The vertical deflections are significant [10] and can be measured with Total station while vehicle is moving on bridge. The bridge was tested for obtaining defections at nodal points before and after retrofitting. Initially (State 1) the testing was done in month of Feb 2010 when the end members had buckled. The testing was carried out with same instrument set up in the month of October 2010 (State II) after the damaged bridge members were replaced; bearing rectified and partial retrofitting was done.

Fig. 7 Node 10 settles down & acted as support **Fig. 8 The Support of Debris removed at Node 10**

The displacement measured at different nodes on both upstream and downstream side when the truck was placed at centre at 1/3rd spans and at 1/4th span. The displacement at different nodes is as shown in figure 9. This shows that the node 10 acts as support and there was no displacement at these points. In 2nd test The levels of all the nodal points have been taken and it was observed that maximum level difference between the different nodes is about 40cm (Fig.9). The bridge has settlement towards roller side bearings as the end members have buckled. D/S truss has more settlement than U/S Truss of the bridge. Roller bearings have also got some settlement.

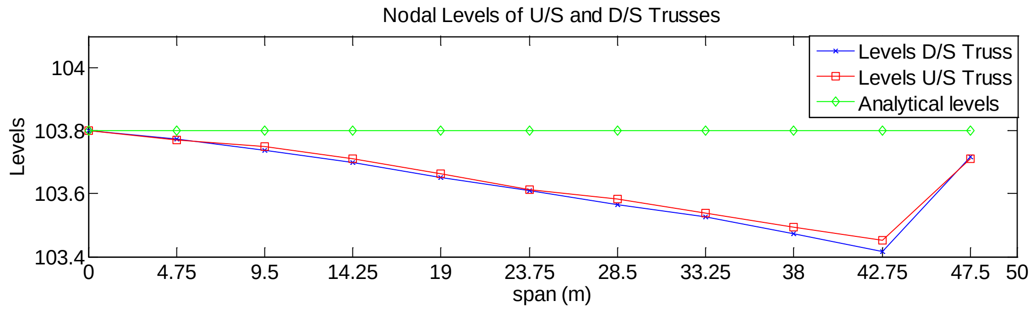


Fig 9 Level Difference between the Support Points

Initially the deflections at the different nodes were measured when the truck load of 9.56 tones was placed at the centre. The nodal point 10 at 42.75m acted as support as the deflection at these points is least. As per visual inspection this point has settled down and was resting on the ground below. The deflections in the downstream truss were more than those in upstream truss showing that bridge has been tilted towards downstream side.

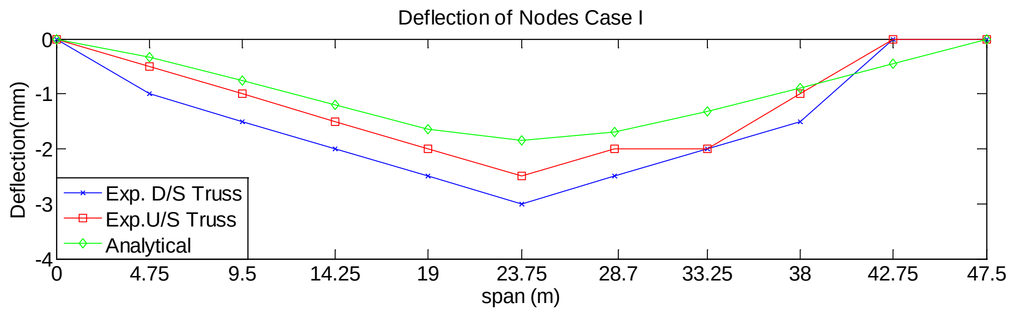


Fig.10 Nodal Deflections of Damaged Bridge (Case I)

The debris was cleared off and the nodal point 10 was cleared off debris and support was also cleared off debris and load was transferred to roller support. The deflection was measured with same instrument set up and truck with load of 9.56tone placed at the centre (Fig.9). Maximum deflections were observed at nodes 8,9 and 10 and not at centre because end member(node 11) was not transferring load to support as it had already buckled and maximum load is being transferred through node 10.The node no 10 shows the maximum deflection and deflection at nodes 3, 8, 9 is appreciable due to the reason that these points are flexible and damaged as compared to other points. The governing difference between the damaged and undamaged portion is that the response of the damaged region is softer in nature than that of the undamaged region[4]. A primary cause for this softened response is illustrated in Figure 16, where the damaged region shows an increased level of lateral deformation than that of the undamaged region. The nodes of truss towards u/s side does not shows much deflection which shows that the deflection in D/S truss is much more than U/S truss. Thus the retrofitting is required to make the bridge workable

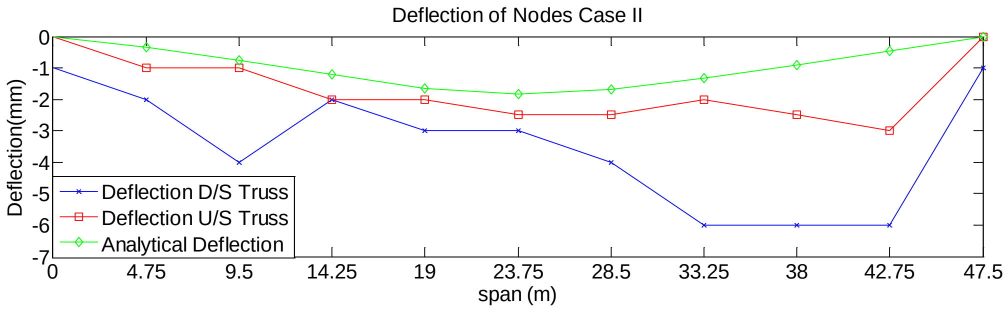


Fig.11 Nodal Deflections When Debris Cleared and roller cleaned (Case II)

The damage level of different nodes with respect to analytical value has been determined using following equation

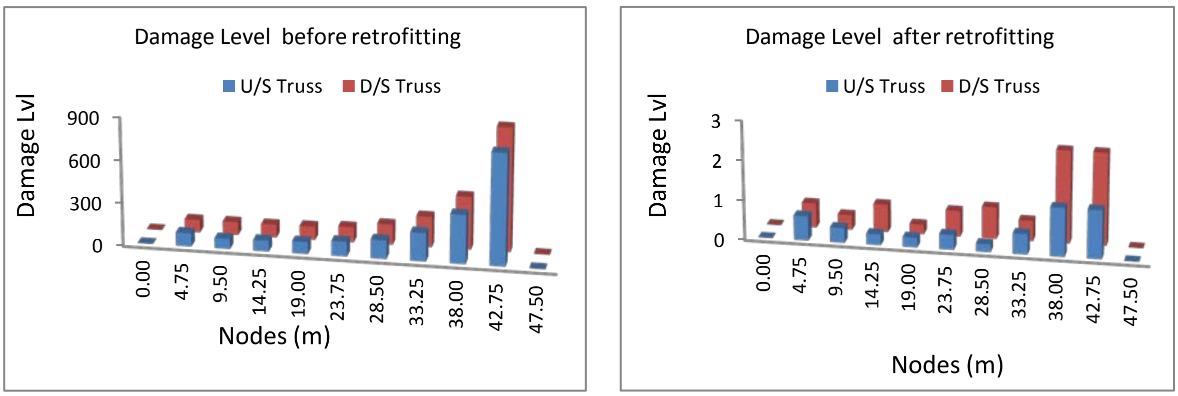
$$\text{Damage Level} = (D_1-D_2)/D_1$$

In order to determine the improvement in level of damages at different nodes, the damage level (DL) with respect to analytical value has been determined as

Damage Level DL= DE-DA)/DA

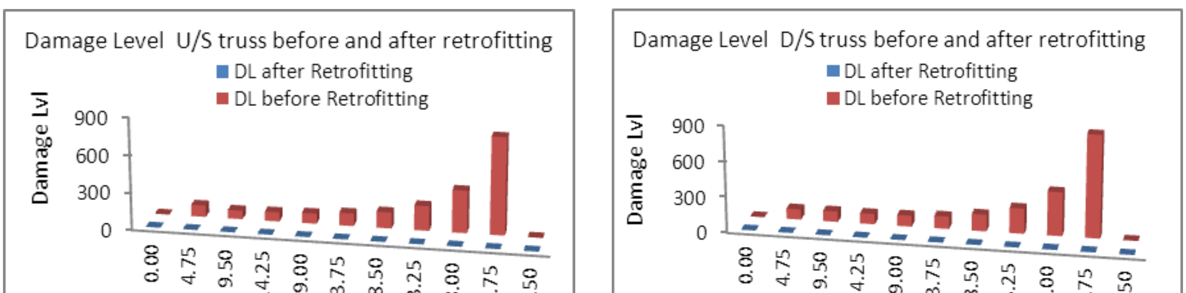
Where, DE and DA are the experimental and analytical deflections.

The damage level at span 38.0m and 42.75m was more than other nodes even after retrofitting and shows flexibility at these nodal points which is not evident from visual inspection. The damage level of downstream truss is higher than that of upstream truss both before and after strengthening and retrofitting (Fig. 12). However for both trusses of the bridge the damage level decreased drastically after retrofitting irrespectively of the damage level (Fig. 13).



(a) (b)

Fig. 12 (a) Damage level before retrofitting (b) Damage Level after retrofitting



(a) (b)

Fig. 13 (a) Damage level U/S truss before and after retrofitting (b) Damage Level D/S truss before and after retrofitting

RETROFITTING: - The Bridge was analyzed using SAAP 2000 (12) as and the bridge was checked for Class A loading and Class B Loading [11] and the retrofitting was suggested. The bridge in general was safe for class B loading but required retrofitting for Class A loading. Since the road is a village road and traffic intensity is low so bridge was retrofitted for class B loading only. As the End members have buckled due to overloading. These members were replaced with same section. The state PWD have carried out the retrofitting of the bridge as Suggested. In order to hold the main component of the built-up section in their relative position and to equalize stress distribution[14], the end members were stiffened with 300x10mm thick plate at a spacing of 31 cm c/c. The bottom longitudinal girder was also strengthened by providing 300x10mm plate at the top of the member (Fig.14).The missing horizontal stiffener of angle section 75x75x10mm provided at a height of 1.35m from the bottom longitudinal member has been provided. The strengthening of top longitudinal girder and replacement of deck with corrugated sheet of same section will be executed at later stage. The load was relieved from the bearings by jacking the superstructure and temporary support system was introduced. The rollers of bearings were reset at correct alignment. The base plate was replaced with new one. The members which have been buckled were replaced with same section. The bridge was restored for traffic after partial retrofitting to avoid inconvenience to local residents.

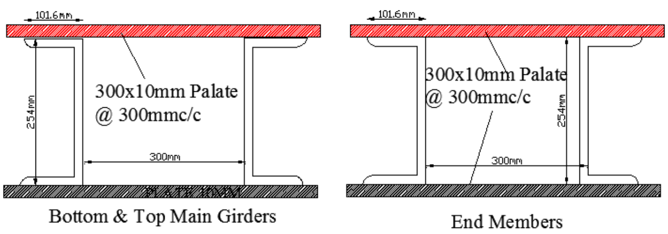


Fig.14 Retrofitted Sections

The defection after retrofitting with same instrument and under same loading of 9.56 tone of same vehicle was recorded to see the improvement in the structure. The Experimental defections of upstream and downstream trusses are less than the analytical deflection after retrofitting. There is a kink in the deflection curve at 38m.

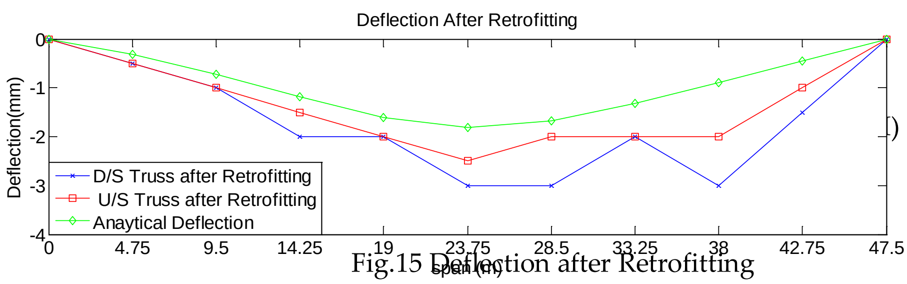


Fig.15 Deflection after Retrofitting

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After the retrofitting damage level is as shown in fig.16. Damage level of node 10 was more than other nodes. Some damage has been observed in different nodes because the top longitudinal girder has not been strengthened as this will be retrofitted along with replacement of deck.

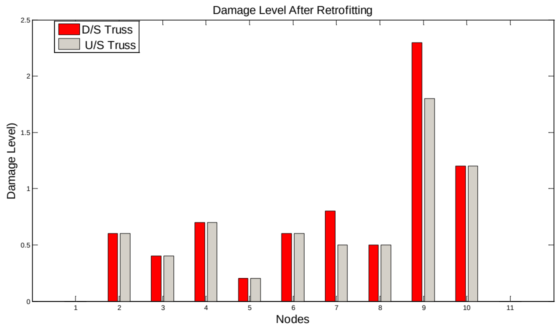

Fig.16 Damage Level of Different Nodes after Partial Retrofitting

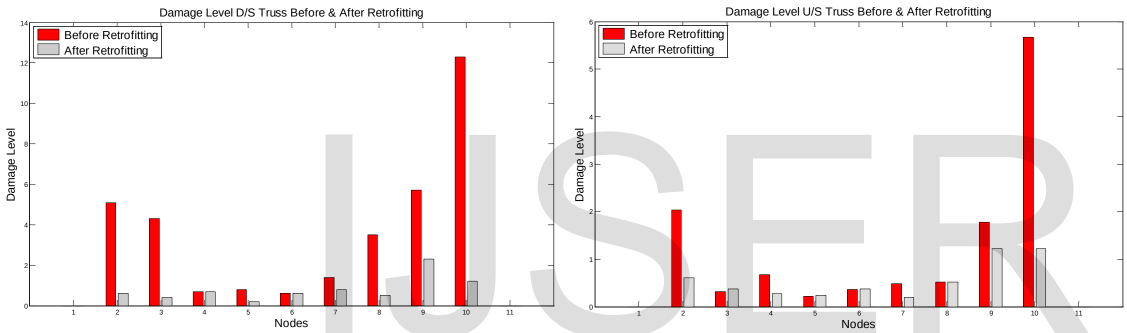

Fig.17 Damage Level of D/S&U/S Truss before and after Partial Retrofitting

Bearings before Retrofitting

Bearings after retrofitting

Fig.18(a)

Figure 18(a) shows the status of bearings before and after retrofitting. The same bearings were used after clearing the soil deposits. Rocker and rollers were in good condition. The bottom longitudinal members were straightened and stiffened with same steel plate of 300x10mm size as shown in fig.18 (b) The End members were replaced with same section and stiffened with steel plate as shown in Fig.18(c). To avoid inconvenience to the local resident of the area, bridge was opened to traffic. However the replacement of damaged Deck plates and retrofitting of top longitudinal member is still pending and owner agency is on the Job.

Bottom members before Retrofitting

Bottom members after retrofitting

Figure 18(b)

End members before Retrofitting

End members after retrofitting

Figure 18(c)

CONCLUSION

The present study provides the rapid assessment technique for the damaged bridge structures with the instruments which are generally available with the owner agencies of the bridges and provide results which are approximate at best. However, considerable effort on the part of knowledgeable engineers possessing background in surveying, and computational mechanics is required. The strengthening of bridges is very important especially in steel bridges. The damage in bridge can be accessed visually and the general instrument can be used to access the damage in the bridges. The deflection in the bridge can be measured with total station and Dial gauges which are generally available with the departments and can be compared with analytical model to access the damage in terms of vertical displacement of bridge, damage levels, displacement in bearings and buckling in the members. By minor retrofitting in the members, the bridge can be made serviceable for present loadings. The routine maintenance of bridges is necessary for long life of structure. The bearings of bridge can lead to damage if not maintained properly.

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