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# A Review Paper on the Fatigue of Steel Bridges

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***Abstract: Steel bridges plays an important role in the transportation industry, they are preferred for their ease in construction, maintenance and strengthening capabilities. Steel bridges are serving transportation industry since many decades. Majority of the bridges have completed significant design life, in addition to this there is significant increase in the traffic intensity and the axle loads. Many incidents all over the world have reported cracks in the main members. The primary reason was identified as fatigue, which can trigger at working load. Factors like corrosion, impact loads are acting as a catalyst for the process of fatigue failure. Hence all over the world many attempts have been taken up to determine the residual fatigue life of the existing steel bridges with a due consideration to the increased traffic intensity. In addition to this design guidelines have also been given attention to incorporate the effects like increased traffic intensity, corrosion etc. The present paper focuses on the review of the literature for fatigue analysis of the steel bridge.***
***Keywords: Fatigue, Residual life, Steel Bridge***

## I. INTRODUCTION

Pivotal role has been played by the bridges in the transportation industry. History can be traced back to the wooden logs to cross the water bodies, small valleys etc. The bridge design has been evolved over centuries resulting in a competition to build longer spans, along with iconic aesthetical features. Railway system shares a majority of transportation industry. As far as India is concerned, the railway remains as a preferred option due to its economy and reach to common people. Length of rail network is about 64,000 KM, spanning across the country. Bridges have been an integral part of the railway systems in India. Steel bridges are the preferred option for the railway systems in India considering the ease of maintenance, strengthening point of view. However, it is observed all over the world that the bridges have served a significant design life, as they were designed significant years back e.g. Golden Gate Bridge (USA), commences in 1937, Howrah Bridge (India) constructed in 1942 etc. Hence it is understood that the bridges have completed a significant design life. In addition to the age, there is significant increase in the railway traffic, axle loads of the trains etc. Therefore it is necessary to ensure that the structural health condition of the bridge remain satisfactory, which in turn ensure the life safety of the occupants. Especially developing country like India where a tremendous growth related to infrastructure is proposed, the bridges should be ensures to have adequate strength to fulfil their purpose. In the present paper an attempt is made to carry out a review of the fatigue life estimation of the existing bridges carried out all over the world.

## II. FATIGUE FAILURE INCIDENTS

*A.* Silver bridge [1] in USA has suffered a sudden collapse in year 1967. The bridge was built as a suspension bridge, the suspension mechanism was made up of in form of the eyebar chain, which are connected through a bolt. Unfortunately, more than 40 lives were lost as the bridge did not give any warning. Three primary reasons were identified as

*1)* The single eye bar pin has failed due to the fatigue crack formation which led into the chain reaction of failure
*2)* Loads considered in design were less than the operational load.
*3)* The redundancy of the eye bar was very low. In comparison with the other suspension bridges, where the cables have very high rate of redundancy, the failure has also forced the designers to revise the design practices. This incident has also has resulted in the revision of the AASTHO guidelines for the design of the bridge.

Fig.1 : Silver Bridge Failure

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*B.* Songsu Bridge in Korea [2] has suffered a collapsed in the year 1994 (constructed in 1979). The bridge was a balanced cantilever formation bridge, the mid span collapsed suddenly during operation. The bridge has given warning just before its collapse. An extensive research has concluded that there were three primary reasons, viz. Poor welding of the joints, improper connection (pin failure), corrosion. An important aspect was the increase in the traffic, causing the probable fatigue damage.

Fig. 2: Songsu Brige Collapse, Korea

*C.* In terms of structural cracks, there are significant numbers of crack detection has been reported all over the world. The study conducted by the Structure and Bridge Department, Public Works Research Institute, Concrete division, Japan [3] have reported numerous incidents of crack detection in many steel bridges (Fig. 1). Authors have also highlighted that the practices during the design of these bridges did not take into account the effects of fatigue which resulted due to the increased traffic, heavier axle loads etc. Cracks were detected mainly in the cross members, deck intersecting with the cross webs, welded connections. Authors have identified three primary reasons for the crack initiation which are listed as follows

1) *Overloaded Vehicles:* The fatigue resistance of the structure reduced in proportion to the cube of the wheel load. Authors have suggested in motion monitoring of the weight of the vehicles, and stringent measure to avoid overload
2) *Improper Structural Detailing:* Authors have identified that the detailing of the structure was not proper. Authors have also suggested that the detailing should be improved i.e. should be given proper importance
3) *Secondary Stress or Distortion-Induced Stress:* It was observed that most of the members were failed due to this stress component. This arises due to the relative motion of the members inducing a distortion stress.

Authors have concluded that the primary reason of overloading as identified above should be properly considered at the design stage as well as monitoring during the operation should be done, to avoid such incidents. It was suggested that the increase in loading should be considered at the design stage considering possibility of the fatigue. In addition to this it was suggested to reduce the secondary stresses which can produce damage significantly.

Primary reason identified in these studies is the increased traffic over time. This has resulted into the fatigue induced cracks and the failures. It is becomes a necessity of time to assess the present structural health condition of the existing old steel bridges. In case of new design of the bridges, the fatigue effect including the projected traffic growth should be properly considered to ensure the safe life of the bridge for the intended usage. Fatigue failure incidents have also highlighted that the real time monitoring of the bridge is also essential aspect to carry out remedial measures if the cracks are detected.

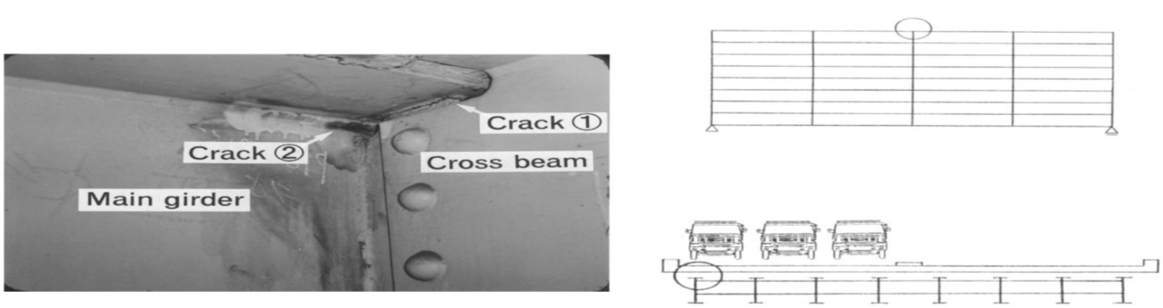


Fig.3. Cracks detected in bridges [3]

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## III. ASSESSMENT OF RESIDUAL LIFE OF EXISTING STEEL BRIDGES

Considering the concern about the residual life of the steel bridges, many attempts have been carried out in order assess the structural condition of the existing bridges.

*A.* George N. Stamatopoulos [4], a School of Civil Engineering, National Technical University of Athens, Greece have carried out a fatigue assessment of an existing riveted steel bridge in order to facilitate the increase in the traffic, as the trains were proposed for an upgraded configuration. An extensive work has been carried out to check the structural condition. The following steps were followed

1) *Verification of the Drawings with the Existing Structure:* As the bridge was built in 19th century, there was not much data available. In 1960's few modifications (strengthening) were carried out. Hence in order to verify the same, a visual verification of the available drawings with the in-situ structure
2) *Visual Inspection:* It was carried out to check the existence of cracks if any.
3) *Verification of the Stress Response:* As the structure has completed a significant life, an assessment of the stress is carried out in order to verify the stiffness offered by the structure. A standard vehicle was used to verify the stress with the analytical calculations.
4) *FEA Modelling:* Depending upon the response of the structure a 'tuned up' FE model was prepared to assess the response of the structure. In analytical model the joints were modelled as 'rigid' in order to account for the secondary stresses.
5) *In-Situ Material Testing:* As the structure has completed a significant amount of life, fatigue testing of the existing material from the actual structure was carried out. Depending upon the results, S-N curves were derived.
6) *Fatigue Assessment :* Assessment of the fatigue was carried out based on two option
   a) Fatigue assessment of the beam TMB before strengthening
   b) Fatigue assessment of the beam TMB after strengthening

Fatigue calculation was carried out based on the ASTM detail category of 112. Palmgren Miner Rule was used to carry out the fatigue damage calculation subsequently fatigue life was obtained in the number of years.

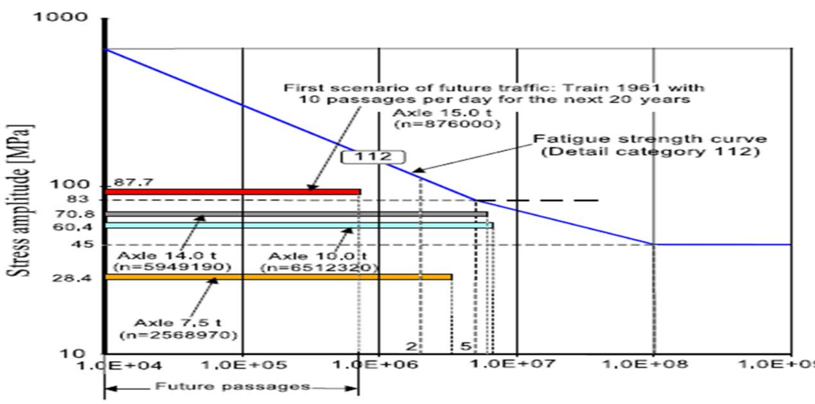


Fig.4: Damage Calculation for a detail

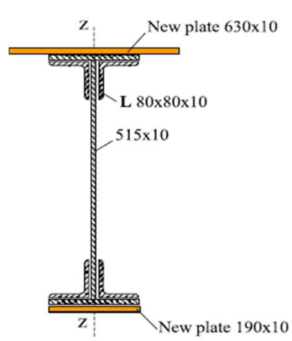


Fig. 5: Proposed Strengthening for a typical member

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Obtained fatigue damage factor was 1.011, for transverse main beams which were not strengthened during the retrofitting phase, which indicated that the strengthening was required to fulfil the design life satisfactorily.

In conclusion author has observed that the overall condition of the bridge was satisfactory. There was not significant corrosion, the joints were intact, in addition to this the main members were having sufficient residual fatigue life hence there was no requirement of the strengthening. However a transverse member beams required strengthening.

*B.* Fernando Marques , Carlos Moutinho, Filipe Magalhães, Elsa Caetano, Álvaro Cunha [5], Faculty of Engineering of the University of Porto, Portugal, have carried out dynamic and fatigue analysis of the existing old metallic riveted bridge. The bridge was opened to traffic in year 1956, made up of two warren truss spanning 48 meters as central span. The bridge was analysed for the dynamic loads as well as the residual fatigue life was estimated.

During the first stage, the beam model (1-D elements) was used to determine the global behaviour of the bridge. The global modes of vibration were determined. The same were verified with the in-situ measurements in form of ambient vibration tests. Local modes of vibration were determined by the means of local model and its vibration analysis, which were also verified by means of the local vibration measurements.

In addition to the dynamic analysis, the fatigue life was determined based on the actual strain measurements based on the real time data. The strain measurement was carried out based on the sensors located at the critical locations which were identified prior to the studies. The effects of the local vibration were also taken into consideration.

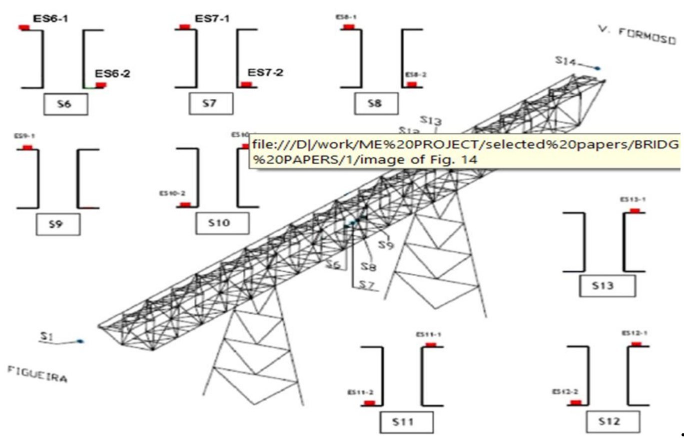


Fig. 6: Locations of strain measurement

Using the data authors have computed the fatigue damage index and which was further used to estimate the fatigue life in terms of number of years. Palmgren Miner rule was used to estimate the damage index. During study the authors have observed that the cross girders have the total life of 77years, which in turn concludes that 23 years is the residual fatigue life.

Fig. 7: Fatigue critical locations.

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Authors have also identified that the bottom chords (tension members) are also fatigue critical. A colour coding also have been carried out by authors to identify the fatigue critical locations.

*C.* Ravindra Kumar Goel, Director RDSO,[6] India has carried out the fatigue life estimation of the existing steel bridge situated on river Ganga, India. The attempt was made to estimate the residual life of the bridge to check whether the bridge to be replaced or which can have significant residual fatigue life. Author has used method available in BS: 5400 part 10 to assess the fatigue life of the bridge. The method of actual strain measurement was not used. The approach was theoretical, author also has carried out the comparison between the Indian codal loads and the British standard loads. The fatigue life obtained by the method was 40 years residual life. Authors have also commented that the method used has certain area of improvements and which can be by means of actual stress concentration determination. But the method used in this approach was time saving and a quick estimation of the results is possible.

## IV. STRUCTURAL HEALTH MONITORING (SHM)

Although the design is carried out considering all aspects including fatigue, there is a necessity of continuous monitoring of bridges. It is an essential aspect since cracks can generate at micro level and can propagate subsequently. Hence in order to get a warning call, if any the SHM becomes a need of time. SHM can be defined as the process of implementing a damage detection and characterization strategy for engineering structures. Health monitoring of large bridges can be performed by simultaneous measurement of loads on the bridge and effects of these loads. It typically includes monitoring of:

*A.* Weather conditions
*B.* Traffic intensity
*C.* Prestressing / stay cable
*D.* After the data acquisition, following actions can be taken
*E.* Load estimation and their effects
*F.* Estimation of fatigue damage
*G.* Residual design life estimation

Many real life structure have implemented SHM, though which continuous monitoring of the health of structure is in progress primary examples can be Millau Viaduct bridge in France, Rio–Antirrio bridge in Greece, Sydney Harbour Bridge, Australia mad many more. Out of many studies referred, a few are presented as below

Amir H. Alavi , Hassene Hasni, Pengcheng Jiao, Wassim Borchani, Nizar Lajnef [7], Department of Civil and Environmental Engineering, Michigan State University, USA have made an attempt to develop a method of estimation of the secondary stresses using a newly developed sensor. As the studies have concluded that the secondary stresses which are also known as distortion induces stress are the primary reason for the fatigue cracks, and the calculation of these stresses is difficult. The method developed by the authors is based on the energy generated by the mechanical loading and hence no additional power source is required. The data acquired is then fed to an algorithm which works on the Paris Law and J integral which can predict the accurate propagation of the cracks. However authors have also stated that the accuracy of the results depends upon the proximity of the sensor. i.e. sensor near the flaw, predicts more accurate results.

X.W. Ye, Y.Q. Ni, K.Y. Wong, J.M. Ko, from China have studied the effect of the dynamic strain on the fatigue life of the bridge. An attempt has been made to carry out a statistical analysis of the stress spectra. The primary reason behind this is to obtain a stress spectrum which represents a real time strain history/ stress which is more realistic i.e. based on the actual strain variation. In the theoretical calculations an estimate is carried out regarding the increased traffic based on the traffic studies. During such studies a standard statistical predictions are used. However these predictions may lead to a conservative fatigue life. Real life application was implemented on a bridge in which the strain history data was obtained daily and the strain history is converted to a stress spectrum through the rain flow algorithm. The method possesses advantages such as the data obtained is on daily basis which includes the effects like accidental loading, the environmental effects etc. In addition to this the optimum number of statistical data to be used are also worked out.

## V. CONCLUSIONS

The present paper describes a brief summary of the bridge failures, residual life estimation studies and structural health monitoring attempts to detect cracks. From various studies, the authors have highlighted that fatigue phenomena is very crucial for the steel bridges, especially for the existing bridges which have completed a significant number of years. Cross girders, transverse beams, bottom chords are especially prone to fatigue. In addition to this secondary stresses resulting due to the uneven displacements can lead to fatigue cracks.

Fatigue has also resulted into collapse of bridges like Silver Bridge. In order to avoid such incidents and to ensure the safety of the structure, the residual fatigue life estimation becomes a need of time. Especially country like India, where many steel bridges are still operational and out of that many bridges are built in early 19th century. In addition to the significant years of operation, traffic have also increased over decades hence, the residual fatigue life estimation should be carried out to check whether they possesses sufficient residual fatigue life. Design against fatigue, structural health monitoring also becomes

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