Fatigue Reliability Evaluation of Railway Steel Bridges - A Critical Review

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***Abstract*—** Assessment of the residual fatigue life of railway steel bridges is drawing the attention from the railway departments and researchers all over the world due to the increase in quantity of such bridges attaining their theoretical fatigue lives. In Indian scenario the railway steel bridges are still in service and some of them are reached service life of 50 years. The government of India and department of railways are looking for the fatigue life, inspection, repairing intervals and the capability to enhance the capacity of such bridges. This paper elaborates the various theories, models and methods based on theory of probability, fatigue and fracture mechanics approaches for evaluating the residual fatigue life of railway steel bridges.

Keywords- steel bridges, fatigue life, theory of probability, fatigue and fracture mechanics approaches

1. INTRODUCTION

One of the important criteria for an engineer during the process of design of structure is consideration of fatigue failure when the structure undergoes repeated application of loads. With the advent of high strength materials and advances in structural analysis techniques, fatigue within desired life has become a reality. The old railway steel bridges are frequently to convey the growing capacity of traffic and goods than the original capacity. Therefore the bridge establishments are concentrating on the remaining actual fatigue strength of the bridges. In the following sections the overviews of the researches were made to find the residual fatigue life of the railway steel bridges are discussed.

2. LOAD MODEL, LOAD HISTORY ANALYSIS AND FEM MODELS

The research studies on assessment of structural fatigue life of railway steel bridges through load models, load history analysis and FEM models are dealt in the following section.

John Leander et al., (2018) presented that the assessment of steel railway bridge can be performed using the simplified characteristic load models in a deterministic safety format as three features like knowledge content, model sophistication and uncertainty consideration. The models can be used to establish the different alternatives to increase the confidence in evaluating the fatigue life of railway steel bridges in existing method of analysis [1]. The residual fatigue life of railway steel bridges can be evaluated by using Weigh-In-Motion measurements. A single load model proposed to quantify the characteristic stress range. By using the bridge weigh in motion and load models new functions have been derived and obtained consistency in reliability level by using the new functions John Leander (2018)[2]. The remaining fatigue life of railway steel bridge can be found out by using load interactions, load sequence and load level by considering the strain responses of the critical sections. The low stress cycles were found and which were very common in steel bridges N. K. Banjara et al., (2012) [3].

Alessio Pipinato et al., (2012) conducted detailed loading history analysis to evaluate the residual fatigue strength railway bridges. The procedure of detailed history analysis is based on assumption by considering the expected increase in the growth of rail traffic and probability of failure in relation with expectation of reaching the assumed crack length [4]. R. K. Goel (2007) developed a load model of traffic movements for fatigue assessment of a connection in railway steel bridges. The relevance of load model in assessing fatigue life has been illustrated and a load model has been developed for IRS MBG loading with traffic classification as suburban, light, medium and heavy type. This load model can be adopted for assessment of fatigue strength of bridge details in a rational manner [5].

Sang-Hyo Kim et al., (2001) adopted the assumed loading models to assess fatigue life of the railway steel bridges. The load models comprised of three different procedures like simplified, probabilistic and deterministic procedure. The total cumulative fatigue damage was obtained and log-normal distributions model were developed. The stress time histories obtained by the train loads were obtained using FEM. Authors concluded that the simple deterministic procedure is a quite consistent with acceptable accuracy and this procedure can be adopted to find residual fatigue life of bridges [6].

3. STRUCTURAL HEALTH MONITORING(SHM)

The works related to assessment of fatigue strength of bridges using SHM Data is projected in the following section.

X. W. Ye et al., (2012) developed a method to get the fatigue valuation of railway steel bridges based on SHM data. Stress spectrum were constructed using the monitoring data the and by the usage of the stress spectrum the fatigue characteristics of the bridge were studied. The proposed method can be even valid for calculating the growth factor for different individual stress ranges [7]. John Leander et al., (2010) studied the crack propagation of the Soderstrum Bridge in Central Stockholm. To understand the theoretical fatigue life of the bridge the monitoring data was used. Based on the results the author suggested both field and theoretical measures to keep the Soderstrum Bridge in service. The critical members of the bridge fatigue damage can be assessed by local and probabilistic approaches [8]. The SHM data will be useful to get the reliability of fatigue damage of old steel bridges. By using the rain flow counting method the moment stress and axial load spectrum were constructed and intern fatigue reliability was found with utmost accuracy He Xu-hui et al., (2006) [9].

4. PROBABILISTIC FRACTURE MECHANICS (PFM)

The research paper published related to fatigue reliability assessment using probabilistic fracture mechanics is dealt in this section.

Nirosha D. Adasooriya (2016) suggested a method to find fatigue evaluation of railway steel bridges by usage of new Damage Indicator (DI). The DI have obtained by using the both new probabilistic fatigue assessment and deterministic approaches and observed that the effect of variable amplitude loads were most accurate compared to Miner's rule [10]. Chun-sheng Wang et al., (2015) proposed models of fatigue evaluation of railway steel bridges using probabilistic fracture mechanics approach. Both deterministic and probabilistic evaluation methods were adopted and obtained residual fatigue life, maintenance strategies and inspection intervals and intern determined a strategy to avoid fatigue damages and to decrease the life-service cost of the bridges [11]. B. M. Imam et al., (2008) suggested a procedure for the usage of PFM based fatigue evaluation of steel bridges. This method is having ability to account for the effects raised by the inspection and repair processes the fatigue life of the bridge [12].

5. S-N CURVE AND MINORS' RULE APPROACH

The research paper published related to fatigue reliability assessment using S-N approach is dealt in this section.

Fernando Marques et al., (2018) proposed an alternative tool to evaluation the residual fatigue life of railway steel bridges over conventional and over conservative S-N curve approach. The random block loading and Monte-Carlo technique was used with Paris law and MAT lab programs. The initial crack size, geometric shape functions, critical crack size and stress ranges were considered as random variables [13]. Mohamed Soliman S. M. et al., (2013) used bilinear S-N curve approach to evaluate the residual fatigue life of existing railroad steel spans. The outcomes were contrasted and the single incline AASHTO and found that the bilinear S-N approach predicts longer exhaustion life than AASHTO strategy. [14] B. M. Imam et al., (2010) proposed a general strategy to assess the rest of the fatigue life of steel bridges. The procedure depends on nominal stresses and the S-N approach and concentrates on the fatigue strength of riveted steel bridges [15].

R. K. Goel et al., (2006) presented a study of existing provisions of Indian Railway Standard Steel Bridge Code and the BS-5400, Part-10 in respect of fatigue design of Railway Bridges. The fatigue design concepts of the two codes have been discussed and the observed short comings of IRS Steel Bridge Code have been listed. Provisions of BS-5400 Part-10 which were based on S-N curve approach were found quite elaborate, covering different loadings, loading situations, route GMT, class of connection etc. Standard type RU Loading adopted in BS-5400 is found heavier in comparison of IRS Loading; therefore the fatigue life assessment made is expected to be on conservative side [16]. A limit state equation for fatigue reliability of steel bridges is formulated based on S-N curve approach and Miner's law. Parameters representing cycle ratio, volume ratio, weight ratio, section modulus or cross sectional area ratio, stress ratio, impact factor ratio, influence factor ratio and model uncertainty were taken as random variables. Using the results of load and structural analyses, and established or suitably assumed statistics of random variables, fatigue reliability analysis ids carried out and inherent safety levels in terms of reliability index are determined for plate girder bridges and tension members of truss bridges used in Indian railway . New safety checking formats for fatigue evaluation and design were proposed incorporating a reliability factor. From the results, a common reliability factor of two is recommended for proposed methods of fatigue evaluation and design. It is found that the proposed procedure provides a more consistent level of safety in comparison to the provisions G. Ravi et al., (2000) [17].

6. LINEAR ELASTIC FRACTURE MECHANICS (LEFM)

The research studies on fatigue reliability of railway steel bridges using LEFM are dealt in the following section.

Tong Guo et al., (2011) assessed the residual fatigue life of an old steel girder bridge using LEFM and the long term stress monitoring. Limit state of ultimate was developed as crack propagation function. By using probability density functions and stress ranges a model was established. The fatigue strength of various parts and joints of the bridge was estimated using the model [18]. Zhengwei Zhao et al., (1994) proposed a methodology substitute to the exciting AASHTO method to assess the remaining fatigue life of railway steel bridges. The LEFM approach is preferred instead of AASHTO approach where the crack size information cannot be incorporated. The authors concluded that the LEFM approach can also be used to analyse the bridges by considering the bridge inspections [19].

7. FIRST ORDER RELIABILITY METHOD (FORM)

The research papers published related to assessment of fatigue reliability of railway steel bridges are dealt in this section.

John Leander et al., (2016) performed the fatigue reliability of bridge by FORM with a model correction factor. The model correction factor has taken the importance of crack propagation, shape of crack and material properties. The uncertainties in material parameters in the fatigue crack growth law having most decision making impact and this obtained by omission sensitivity factors[20]. Ravi G. et al., (1993) developed a limit state equation based on Minors' rule to decide the strength of unwavering feature examination of early steel support spans. AFOSM technique applied to evaluate β index for different bridge elements for different cases. The AFOSM technique helps in choosing about the ideal interval for assessment and review of bridge structure [21].

8. MISCELLANEOUS METHODOLOGIES

Mrinal Chanda et al., (2017) determined residual life of servicing steel railway bridge using probabilistic approach and Palgren-Miner rule. The direct Monte Carlo simulation (MCS) and probabilistic formulations were used to obtain stress range time spectra and reservoir method is used to assess the fatigue damage. The MCS was found to be most accurate assessment tool in finding the fatigue reliability of steel bridges [22]. A fatigue assessment model consisting of modified strain curve, new strain based damage index considering effect of high amplitude loading, to predict the residual life of railway steel bridges. The model gives the outputs in the form of starin life curves interms of Coffin-Manson relation in low cycle fatigue region and in high cycle fatigue region the new strain life curve were obtained K. Karunananda et al., (2011) [23].

P. B. R. Dissanayake et al., (2008) proposed a methodology to determine the residual fatigue life of riveted wrought iron bridge. In this work combined effect of fatigue and corrosion effect were considered and intern it helps to bridge maintenance by reducing the cost expenditure and to identify the weaker parts of the bridge [24]. S. S. Chaminda et al., (2007) proposed three distinct ways to evaluate the residual fatigue life of railway bridges. First method based on the combinations of measured stress histories, Miners rule and Wohler curve. Second approach consists of stress histories of the bridges and Wohler curve and these approaches were based on primary stresses and fatigue curve as per codal provisions. The third approach consists of secondary stresses, sequential law and experimental Wohler curve. Authors concluded that from above three approaches the second approach is more advisable general and for detailed study of bridges. [25].

9. DISCUSSIONS

The overview of experimental procedures, different approaches and conclusions made by the researchers all over the during last decade world to determine the residual fatigue life of the old, historic railway steel bridges were presented in this paper. From the past studies it is observed that all the approaches to find the fatigue life and fatigue reliability are having shortcomings and all are not giving the cent percent accurate results. All approaches were based on some assumptions of fatigue metal theories. In some approaches it is observed that the environmental effects like corrosion of steel bridge elements was not considered while modelling, analysing and evaluating of fatigue life of the steel bridges. The accurate fatigue life evaluation is needed to find the optimal inspection interval and to know remaining fatigue life of bridge.

10. CONCLUSION

This paper reviews the various assessment techniques made by the researchers of structural fatigue life of railway steel bridges all over the world. The review of the methods and strategies of other research works were presented in this paper encourages the importance of the assessment of the steel bridges.

References

[1] John Leander, Daniel Honfi, Oskar Larsson Ivanov and Ivar Bjornsson (2018) "A Decision Support Framework for Fatigue Assessment of Steel Bridges", Engineering Failure Analysis, Vol. 91, pp.306–314.

[2] John Leander (2018) "Reliability Evaluation of the Eurocode Model for Fatigue Assessment of Steel Bridges", Journal of Constructional Steel Research, Vol. 141, pp. 1–8.

[3] N. K. Banjara and S. Sasmal (2012), "Evaluation of Fatigue Remaining Life of Typical steel plate girder Bridge under Railway Loading, Sri Lankan Journal, Vol.8, No.1, pp.37-52.

[4] Alessio Pipinato, Carlo Pellegrino and Claudio Modena (2012), "Fatigue Damage Estimation in Existing Railway Steel Bridges by Detailed Loading History Analysis", International Scholarly Research Network ISRN Civil Engineering, Vol. 2012, pp. 1-13.

[5] R. K. Goel (2007) "Emerging Load Model (MBG) for Fatigue Assessment of Railway Steel Bridges", Golden Jubilee Special issue of Indian Railway Technical Bulletin, R.D.S.O. Lucknow,pp.183-190.

[6] Sang-Hyo Kim, Sang-Woo Lee and Ho-Seong Mha, (2001) "Fatigue Reliability Assessment of an Existing Steel Railroad Bridge" Engineering Structures, Vol. 23,pp.1203–1211.

[7] X.W. Ye, Y.Q. Ni , K.Y. Wong and J.M. Ko (2012) , "Statistical Analysis of Stress Spectra for Fatigue Life Assessment of Steel Bridges with Structural Health Monitoring Data", Engineering Structures, Vol. 45, pp. 166–176.

[8] John Leander, Andreas Andersson and Raid Karoumi, (2010) "Monitoring and Enhanced Fatigue Evaluation of a Steel Railway Bridge", Engineering Structures, Vol. 32, pp. 854-863.

[9] HE Xu-hui, CHEN Zheng-qing, YU Zhi-wu, and HUANG Fang-lin,(2006) "Fatigue Damage Reliability Analysis for Nanjing Yangtze River Bridge Using Structural Health Monitoring Data, Journal of Central South University of Technology, Vol. 13, No. 2, pp. 201-204.

[10] Nirosha D. Adasooriya (2016) "Fatigue Reliability Assessment of Ageing Railway Truss Bridges: Rationality of Probabilistic Stress-Life Approach", Case Studies in Structural Engineering, Vol. 6. pp.1–10.

[11] Chun-sheng Wang , Mu-sai Zhai, Lan Duan and Qian Wang (2015) "Fatigue Service Life Evaluation of Existing Steel and Concrete Bridges", Advanced Steel Construction, Vol. 11, No. 3, pp. 305-321.

[12] B.M. Imam and G. Kaliyaperumal(2012) "Fatigue Assessment of a Railway Bridge detail using Dynamic Analysis and Probabilistic Fracture Mechanics", The 6th International Conference on Bridge Maintenance Safety and Management (IABMAS-2012).

[13] Fernando Marques, Jose A.F.O. Correia, Abilio M.P. de Jesus, Alvaro Cunha, Elsa Caetano and Augusto A. Fernandes (2018) "Fatigue Analysis of a Railway Bridge based on Fracture Mechanics and Local Modelling of Riveted Connections", Engineering Failure Analysis, Vol. 94. pp.121–144.

[14] Mohamed Soliman, Dan M. Frangopol and Kihyon Kown, (2013) "Fatigue Assessment and Service Life Prediction of Existing Steel Bridges by Integrating SHM into a Probabilistic Bilinear S-N Approach", Journal of Structural Engineering, Vol. 139, pp. 1728-1740.

[15] Boulent M. Imam and Timothy D. Righiniotis (2010), "Fatigue Evaluation of Riveted Railway Bridges through Global and Local Analysis, Journal of Constructional Steel Research, Vol. 66, pp. 1411-1421.

[16] Ravindra Kumar Goel and Dinesh Kumar (2006), "Fatigue Life Assessment of Steel Bridges", IPWE Seminar on Bridge Design, Construction, Rehabilitation and Maintenance at Chennai, India. pp. 148-159.

[17] G. Ravi and R. Ranganathan (2000) "Fatigue Reliability Evaluation, Design and Code Calibration of Steel Bridges, Proceedings Structural Engineering Convention, IIT Bombay, India.

[18] Tong Guo and Yu-Wen Chen, (2013) "Fatigue Reliability Analysis of Steel Bridge Details Based on Field-Monitored Data and Linear Elastic Fracture Mechanics", Structure and Infrastructure Engineering, Vol. 9, No. 5, pp. 496–505.

[19] Zhengwei Zhao, Achintya Haldar and Florence L. Breen (1994) "Fatigue Reliability Evaluation of Steel Bridges", Journal of Structural Engineering, Vol.120, pp.1608-1623.

[20] John Leander and Mohammad Al-Emrani (2016), "Reliability-Based Fatigue Assessment of Steel Bridges using LEFM – A Sensitivity Analysis", International Journal of Fatigue, Vol. 93, Part 1, pp. 82-91.

[21] Ravi, G. and Ranganathan, R. (1993), "Fatigue Reliability Analysis of Early Steel Railway Bridges in India", Colloquium Remaining Structural Capacity, Copenhagen, pp.46-52.

[22] Mrinal Chanda, Kishore Chandra Misra and Soumya Bhattacharjya (2017). "Fatigue Life Assessment of an Existing Railway Bridge in India Incorporating Uncertainty", International Conference on Theoretical, Applied, Computational and Experimental Mechanics December 28-30, IIT Kharagpur, India, pp. 1-10.

[23] K. Karunananda, M. Ohga, P. B. R. Dissanayake and S. Siriwardane (2011), "Effect of High Amplitude Loading on Fatigue Life Prediction of Steel Bridges" , Procedia Engineering, Vol. 14, pp. 521–528.

[24] P. B.R. Dissanayake and P. A. K. Karunananda (2008), "Remaining Service Life Prediction of Riveted Wrought Iron Railway Bridges using System Reliability Approach", Journal of the National Science Foundation Sri Lanka, Vol. 36, Issue 2, pp. 151-156,

[25] Siriwardane Sudath Chaminda, Mitao Ohga, Ranjith Dissanayake and Kazuhiro Taniwaki, (2007), "Different Approaches for Remaining Fatigue Life Estimation of Critical Members in Railway Bridges", Steel Structures, Vol. 07, pp. 263-276.