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Analytical Approach for Assessment of Fatigue Life of Steel Girders of Bridge

(ACROSS RIVER GANGA ON LUCKNOW-KANPUR SECTION OF INDIAN RAILWAYS)

Dr.A.Vijayabaskar

Abstract— Assessment of residual fatigue life of Steel bridges is done in case of major bridges referred by Zonal Railways. Conventionally, such assessment requires gauging & instrumentation on the important and critical members of the bridge and fatigue testing of steel samples drawn from the bridge. A review of fatigue provisions of British Standard has shown that BS-5400 takes into account a factor for design life. This factor is dependent on type of loading and the traffic volume being carried on the bridge. The MBG loading of Indian Railways is found matching with RU loading given in British Standard. Therefore, the parameters given in BS-5400 for RU loading were considered applicable to analyze the fatigue life of steel girders on Indian Railways. The paper describes the simplified approach of British Standard and analyses the life of the existing girders. The results are compared with those obtained after instrumentation and testing of the bridge. The fatigue life estimated by using the simplified approach of BS: 5400 is found on higher side as compared to the estimation based on actual testing where concentration factors at joints have been assumed on conservative side in absence of actual measurements. Therefore, the simplified approach of BS-5400 Part-10 can be satisfactorily adopted for quick assessment of fatigue life of steel girders on Indian Railways.

Index Terms— EDUL-Equivalent uniform disturbed load ,Fatigue life, Girders ,IRS MBG loading, R_{max}, RU, S_{max}- Stress maximum, S_{min}-Stress minimum, ST -Stress limiting range

1 INTRODUCTION

Indian Railways in its vast network is having 1,19,984 bridges, out of which, large numbers are of steel. The bridges constructed upto 1905 have been declared as early steel bridges, which are to be replaced as a matter of policy. There are still a large number of steel bridges in service which are not of early steel and field engineers, quite often find themselves in dilemma, to decide about their replacement. It is difficult to ascertain, from fatigue consideration, whether sufficient residual life of the bridge exists or not. To assist the Zonal Railways, Research Design and Standard Organization take up such works of major bridges on specific request of the railways. In this context, the work of fatigue life estimation of Ganga Bridge No.110 Up line of Lucknow-Kanpur section was taken in hand. Based on detailed study it was concluded that the bridge is still having life of about 40 years and hence the sanctioned work of regirdering was pended, thus saving the public money of approximately 15 crores.

There are different approaches to determine residual life of steel girder brides. Palmgren Miner's theory is most common and easy to understand. The work involves strain gauging of the critical members and getting actual time histories for a period for 24 hrs and testing the samples of the steel for fatigue characteristics. Thereafter, the recorded data is analyzed to work out the residual fatigue life of the bridge components. The method is time consuming and a period of more than six months is required to complete the fatigue tests. A new approach based on British Standard BS:5400 part 10 was applied to assess the fatigue life of various members of the steel girders of the bridge to get a quick result, in order to decide not to replace the girders of the bridge. The analysed values of the residual fatigue life were subsequently confirmed by the conventional approach.

2.0 OBJECTIVE OF THE STUDY

To analytically assess the residual life of the girders of Br. No.110 Up between Lucknow-Kanpur section, which is not a early steel girder bridge and already given a service life of about 79 years.

3.0 DETAILS OF BRIDGE

The existing bridge having double BG track consisting of 25x30.4m+1x12.19m span The Up line girders are of 1926. The general arrangement and the configuration of the girder are shown in fig.1.

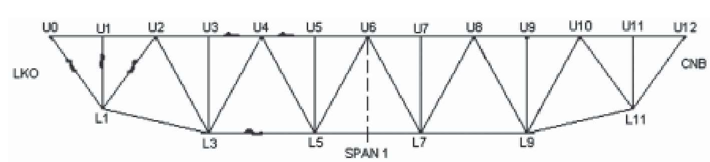

Fig: General configuration of Ganga Bridge, Br. No. 110 (UP Line), Span - 25 X 30.48 M + 1 X 12.19 M

Fig :2 View of Up/Dn line bridge girders from the river bed

Fig. 3 - View of the bridge girder from the river bed

4.0 IRS PRACTICE OF FATIGUE DESIGN

The Code of Indian Railway Standards for Steel Bridge recommends method to allow for the effect of fatigue in design of parts of steel bridges, which are subjected to repeated fluctuations of stress. These fluctuations may cause fatigue failure of members or connections at lower stresses than those at which they would fail under static load.

Such failures are primarily due to stress concentrations introduced by the constructional details. Thus all the details are designed to avoid as far as possible the stress concentrations likely to result in excessive reductions of the fatigue strength of members or connections. Care is also taken to avoid a sudden reduction of the section of a member or part of a member, especially where bending occurs.

To allow for the effect of fatigue the allowable working stress is determined from the of IRS Steel Bridge Code for wide range of constructional details. The code covers mild and high tensile steel fabricated or connected by welding, riveting or bolting. The allowable stress 'P' depends on the ratio of minimum stress smin to maximum stress smax, number of repetitions of stress cycle 'N', the method of fabrication and the type of connection. In determining the ratio smin/smax gross area is considered and the bridge members are generally designed for 10 million cycles of stresses produced under minimum and maximum of the design load.

Concept of EUDL (Equivalent Uniformly Distributed Load) is used to determine the maximum bending moment and maximum shear force for the type of IRS loading. The EUDL for maximum bending moment and maximum shear force depends upon the span and the dynamic augment increases with speed. IRS Bridge Rules gives tables for determination of EUDL for maximum bending moments and shear forces along with the coefficient of dynamic augment for maximum speed of 160 kmph.

There is no rational basis for adopting counts of 10 million number of cycle to determine the allowable stress levels. As per latest research available, Fatigue is a cumulative phenomenon; which is not reflected in the above procedure. Stress-ratio procedure does not take into account the effect of all stress ranges experienced by a member. World over, the stress range concept is followed and material S-N curve forms the basis of all fatigue analysis and design. Due to these short comings, it is not considered proper to analyze the fatigue life of existing bridge by using the provisions of IRS Steel.

5.0 DESIGN PROVISIONS OF BS-5400

BS-5400 part 10 is a comprehensive code which is based on the concept of cumulative fatigue damage. The code concerns with the fatigue design methodology for highway and railway bridges and take into consideration the various drawbacks of IRS approach. Fatigue life assessment is based on the S-N curve approach using Palmgren-Miner's damage summation model wherein the number of cycles to failure is dependent only on stress range and not on maximum stress values. The methodology for determination of stress range has been described for welded and non-welded details and a simplified method has been given for determining the limiting value of the maximum range of stress for the specified design life for two different types of standard loadings. The code specifies different factor k1, k2, k3, k4 & k5 for design parameters such as design life, multiple cycle of stress loading, type of standard loading, annual GMT and multiple lane loading respectively. The code gives specific methodology and tables to calculate the factors for different design parameters.

5.1 Calculation of Limiting Stress Range, sT

The constant amplitude non-propagating stress range, so for the constructional detail is chosen appropriately on the

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basis of Table - 17 & Table 8 of the code. The limiting stress range

sT can now be calculated for RU loading as under:

sT = k1. k2. k3. k4. k5. s0 …………….(1)

5.2 Fatigue Criteria for Design Adequacy

The design adequacy of the given detail is now checked as per Clause 9.2.2.2 and Clause 9.2.2.3 of the code. If maximum stress range (sRmax) does not exceed limiting stress range (sT), i.e sRmax sT, the detail may be considered to have a fatigue life in excess of the specified design life.

6.0 STANDARD TYPE LOADINGS

Two type of standard loadings, namely RU loading & RL loading have been considered in BS:5400, which are shown in Fig.1 & Fig. 2 respectively.

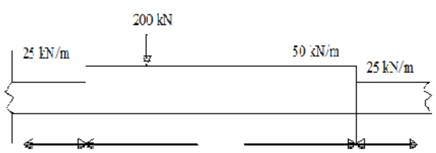

Fig:4 RU Loading

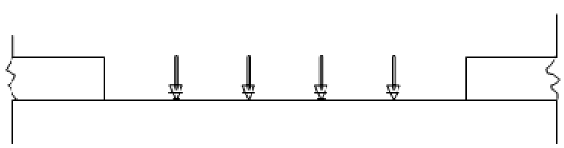

Fig.5 RL Loading

7.0 COMPARISON OF RU LOADING WITH IRS-MBG LOADING

A comparison of EUDL values of Bending Moment as per RU loading was made with corresponding values for IRS-MBG loading (Table-1). It is found that the EUDL values as per RU loading are on higher side as compared to IRS-MBG loading. Therefore, the various factors developed for RU loading as given in BS:5400 Part 10 have been used for fatigue life analysis of the members of the bridge subjected to MBG loading which is expected to give a fatigue life on a conservative side.

8.0 FATIGUE LIFE ANALYSIS

The general arrangement drawing and the stress sheet of the bridge have been studied. The stresses calculated and the cross sections provided in the existing design have been used to workout the stress ranges to which the members are subjected to and the fatigue life has been estimated as per simplified approach of BS: 5400 Part -X

Following assumptions have been made during this study -

a) The maximum axial stresses due to EUDL for IRS loadings have been worked out and the maximum stress range has been calculated as the difference of dead load stress and the maximum stress likely to come in the member with DL, live load with impact and occasional load.

b) The axial stresses due to load combination with occasional load have been taken into consideration to find out the maximum stress range. This combination with extreme loads rarely occurs in practice, therefore, the analysis is on conservative side.

c) Material properties are assumed to be as per Table-8 of BS-5400 and s0 value has been taken as 47 N / mm2 corresponding to detail class 'E' of this table.

d) The fatigue life has been assessed by calculating the design life factor k . This factor has been worked out as sRmax / (s0 x k3) and fatigue life calculations have been done by inversion, using the equations given in Clause 9.2.3 of BS-5400 Pt.10 by taking fatigue life as minimum of following:

$$\textit{Fatigue life} = 120/k_1^m \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where m = 3.0 taken from Table-8 for detailed Class 'E'.

e) Multiple cycles factor, k has been assumed as 1.0 as the loading event stress range histogram is assumed to have a single stress range for simplicity

f) Value of RU loading factor k3 has been taken from Table-4 of the code considering the case of heavy traffic loading, corresponding to the base length (L) of the influence line diagram for the member.

g) Value of GMT factor k4 is assumed as 1.0 for GMT of 18 to 27 million tones.

h) For a single lane loading value of a lane factor k3 is taken as 1.0

i) Value of design life factor k1 has been worked out now by equating the limiting stress (st) to maximum stress (smax) obtained from analysis as per stress sheet.

The design calculations for assessment of fatigue life of members of truss girders for standard annual GMT of 27 to 18. The verticals U1-L1 and U11-L11 are found to have minimum fatigue life of 141 years. As per record the bridge was constructed in 1926, therefore the remaining fatigue life is estimated as 61 years or say 60 years.

9.0 FATIGUE LIFE ASSESSED USING CONVENTIONAL APPOROACH

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The fatigue life assessment of various members was also done based on strain gauging. The observed values of the stress range and cycles during the 24 hours of period are given in Table - 4. Considering the different safety factors and S-N curve developed for limited number of fatigue testing of samples, residual life of different members has been worked out using conventional Palmgrain - miner technique. The estimated residual life has shown in Table -5.

TABLE 1. EUDL FOR RU LOADING AND IRS MBG LOADING

Sl. No.	Span in m	EUDL for maximum B.M. in (including dynamic augment) RU Loading	IRS MBG loading	%age difference
(1)	(2)	(3)	(4)	(5)
1	1	1000	980	2.04
2	2	10.07	980	2.76
3	3	1089	980	11.12
4	4	1351	1162	16.25
5	5	1541	1391	10 79
6	6	1652	1523	8 50
7	7	1817	1608	13 00
8	8	1951	1688	15 56
9	9	2066	1750	18 04
10	10	2171	1817	19.51
11	11	2268	2078	9.14
12	12	2359	2195	7.47
13	13	2447	2317	5.60
14	14	2531	2415	4.81
15	15	2613	2497	4 64
16	16	2694	2566	4 98
17	17	2773	2623	5 72
18	18	2851	2699	5 63
19	19	2927	2772	5 58
20	20	3003	2864	4.87
21	22	3153	3049	3.42
22	24	3301	3231	2.17
23	26	3447	3403	1.28
24	28	3592	3573	0.52
25	30	3736	3741	0.15

TABLE - 2 GMT OF BRIDGE NO. 110, (UP LINE, SINCE 1981)

1990-91	6.17	45.01
1991 92	5.29	50.30
1992-93	5.67	56.97
1993-94	6.78	62.75
1994-95	6.58	69.33
1995-96	6.58	75.91
1996-97	6.99	82.90
1997-98	6.56	89.46
1998-99	7.58	97.04
1999-00	8.45	105.49
2000-01	16.40	121.89
2001-02	14.60	136.49
2002-03	10.30	146.79

TABLE -3 OBSERVED STRESS RANGES AND CYCLES DURING 24 HRS

S. No.	Member	Observed Stress Range (N/mm^2)	Modified stress range (N/mm^2) Observed X 2.5	No. of Cycl
1.	Bottom Chord	0 - 10	0-25	761
	"	10 - 20	25-50	14
	"	20 - 30	50-75	23
	"	30 - 40	75-100	12
2	End Raker	0 - 10	0-25	845
	"	10 - 20	25-50	17
	"	20 - 30	50-75	32
3.	Vertical	0 - 10	0-25	1448
	"	10 - 20	25-50	173
4.	Diagonal	0 - 10	0-25	845
	"	10 - 20	25-50	20
	"	20 30	50 75	21
5.	Top Chord	0 - 10	0-25	725
	"	10 - 20	25-50	34
	"	20 - 30	50-75	8

TABLE 4* : VALUE OF K3 FOR RU LOADING OF RAILWAY BRIDGES

	Heavy traffic				Medium traffic				Light traffic			
Detail stress	D E F F2 G W	C	B	S	D E F F2 G W	C	B	S	D E F F2 G W	C	B	S
Length,L(m)	Values of k_3											
<3.4	1.00	1.00	1.01	1.14	1.09	1.09	1.13	1.28	1.37	1.60	1.60	1.71
3.4 to 4.0	1.09	1.09	1.13	1.28	1.23	1.22	1.30	1.46	1.53	1.79	1.80	1.71
4.0 to 4.6	1.23	1.22	1.30	1.46	1.37	1.36	1.46	1.46	1.71	1.79	1.80	1.95
4.6 to 7.0	1.37	1.36	1.46	1.65	1.53	1.561.7	1.62	1.65	1.92	2.05	2.00	2.20
7.0 to 10.0	1.53	1.56	1.62	1.65	1.71	5	1.81	1.83	2.19	2.31	2.34	2.20
10.0 to 14.0	1.71	1.75	1.62	165	1.92	1.952.1	2.03	1.83	2.46	2.31	2.50	2.20
14.0 to 28.0	1.92	1.95	2.03	1.83	2.19	8	2.03	1.83	2.74	2.56	2.50	2.20
>28.0	2.19	1.95	2.03	1.83	2.46	2.18	2.03	1.83	3.06	2.87	2.50	

TABLE - 5* VALUE OF K4 FOR RAILWAY BRIDGES

ANNUAL TRAFFIC TONNAGE ON ONE TRACK (MILLION OF TONES)					
42 TO	27 TO	18 TO	12 TO 7	7 TO 5	<5
0.89	1.0	1.13	1.27	1.42	1.6

TABLE - 5 ESTIMATED RESIDUAL FATIGUE LIFE (AS PER CONVENTIONAL APPROACH)

Member	Residual Life in years
Bottom Chord	40
Vertical	50
End Raker	61
Diagonal	85
Top Chord	133

TABLE 8* : SR - N RELATIONSHIPS AND CONSTANT AMPLITUDE NON-PROPAGATION STRESS RANGE VALUES

Detail class	m	K_2	δ_0 (N/mm^2)
W	3.0	0.16×10^{12}	25
G	3.0	0.25×10^{12}	29
F2	3.0	0.43×10^{12}	35
F	3.0	0.63×10^{12}	40
E	3.0	1.04×10^{12}	47
D	3.0	1.51×10^{12}	53
C	3.5	4.23×10^{13}	78
B	4.0	1.01×10^{15}	100
S	8.0	2.08×10^{22}	82

10.0 COMPARISON

It is apparent that the fatigue life assessment based on actual testing is giving a residual life of 50 years for vertical as against the estimate of 60 years given by analytical approach based on BS:5400.

The actual life assessment, however, is found governed by bottom chord as the residual fatigue life for this member is found 40 years only. This can be attributed to conservative factors adopted in the damage calculations as the actual stress concentrations at joints are not measured.

11.0 CONCLUSIONS

1. The RU loading of BS:5400 is found matching with the IRS MBG loading. The design factors given in BS:5400 are therefore applicable for IRS bridges.

2. The analytical approach based on simplified method of BS:5400 can be satisfactorily adopted to make a quick assessment of residual fatigue life of the steel bridges on Indian Railways.

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AUTHOR PROFILE

Dr.Vijayabaskar is currently working as assistant engineer in chennai corporation, Tamilnadu and he has completed his B.E.Civil Engineering in Anna University Guidy, M.E Structural Engineering in Satyabhama University, Chennai and Doctorate in Study On Seismic Behavior of Multi-storey buildings with Vertical geometric Irregularities in Bharath University, Chennai.

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