Replacement Decision Of Bridge Girder Of A Working EOT Crane Based On Fatigue Life Calculation

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Abstract

Bridge girder is an important structural member whose fatigue life decides the life of an EOT crane. In this paper, the fatigue life of bridge girder of a working EOT crane is calculated based on Palmgren & Miner's rule for the important decision of replacing or maintaining the girder. The variable loadings coming on the bridge girder at the exact loading points of a working crane and stress spectrums by reservoir counting method are presented. A working crane of class of duty 4 as per BIS "M8" commissioned in 1983 is selected for this. The fatigue life considering probabilistic survival of 97.5% comes out to be 25.68 years. It is suggested that the bridge girder has lived its fatigue life and needs replacement.

Keywords: EOT, Fatigue life, Palmgren & Miner's rule, Reservoir counting method, S-N curves, BIS.

Notations

d_i	:	Damage Fraction of a structural detail at a particular stress range of cyclic loading
$N_{f\,i}$	:	The number of cycles that will cause fatigue failure for that particular stress range from S - N curve.
n_i	:	The number of cycles to which the component has been subjected in a particular stress range 'i'.
D_{tot}	:	Summation of all the damages.
Q_i	:	Pay load of crane in KN
Vi	:	Support reaction of wheel load of crab (Trolley) at various location on bridge Girder.
a	:	value of S-N Fatigue curve constant
m	:	Inverse slope of the S-N Fatigue Curve.
$\Delta б$	:	Stress range in N / mm^2
t	:	Thickness of the structural detail under consideration in mm.
t_0	:	Thickness associated with S-N Curve in mm.
q	:	Thickness correction Exponent

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1. Introduction

The fatigue situation of a bridge girder in an EOT crane is characterized by variable repeated load effects. The fatigue process leads to progressive failure and total decrease of the service life of the components of the crane. Figure 1 shows the components of an EOT crane. Figure 3 and Table 1 show the details of the girder section of the crane under consideration. Amongst the mechanical structural components, the worst sufferer of the fatigue situation is the crane bridge girder. The parameters of fatigue failure are the loading history, geometry of the girder, construction details of the structure, and the loading pattern. Out of these the primary influencing factors for the fatigue damage of bridge girder are loading pattern and its history, inducing cyclic pattern of the variable stresses [5]

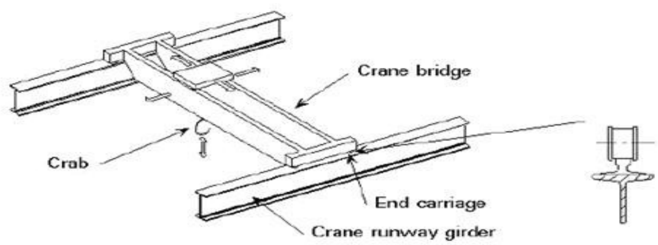


Fig. 1 Components Of An Eot Crane

EOT crane has to sustain the static wheel loading of the trolley, according to its position ranging from the minimum (Tmin) at the end carriage, to the maximum at the mid span as shown in Figure 2. The dynamic loadings are acceleration & deceleration of the trolley (crab) travel, degree of control over the hoisting speed, oblique vertical lifting at the start of hoisting, oblique traveling of the crane (skewing) and impact and collision effect of crab on end stoppers. Thus the bridge girder experiences variety of spectrum of stresses, which complicates the calculation of the fatigue life [4]

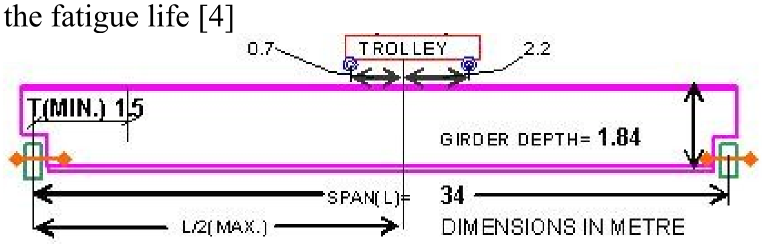
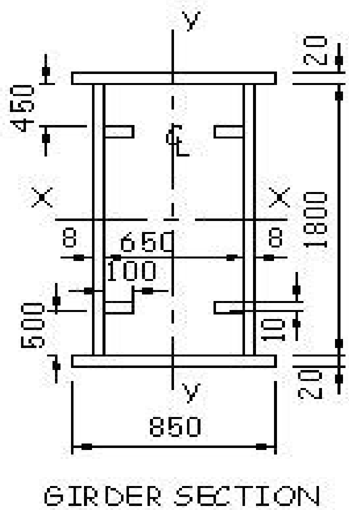


Fig.2 Typical Arrangement Of Trolley On Bridge Girder

Table 1 Section Details Of Girder



Ixx	4154259.48 cm^4
Zxx	42266.44 cm^2
Iyy	554315.99 cm^4
Area	668 cm^2
Zyy	12805.92 cm^2

Fig. 3 Details Of Bridge Girder Section (Dimensions in mm)

A program is developed using MS-EXCEL for which the input parameters of the crane considered (Class Of Duty 4, BIS "M8") in this paper are shown in Table 2. These parameters are checked against the BIS standards. Apart from the input parameters given in Table 2 the details of the additional stiffeners also go as input to the program

Table 2.Input Parameters [2,3]

S.NO.	PARAMETER	UNIT	VALUE
1.	Class of duty (1,2,3,4,)	As per BIS "	4
2.	Capacity (Main Hoist)	Tonne	40
3.	Capacity (Aux. Hoist)	Tonne	0
4.	Span	m	34
5.	Hoist Speed (Main.)	m/min	14.8
6.	Hoist Speed (Aux.)	m/min	0
7.	Trolley Base	m	2.9
8.	Trolley Gauge	m	5.4
9.	Trolley Base Distance	m	1.45
10.	Trolley Base Distance	m	2.7
11.	Trolley Gauge Distance	m	2.7
12.	Trolley Gauge Distance	m	2.7
13.	Wheel Base	m	7.3
14.	Wt. of Tackle	Tonne	17

15.	Weight of Trolley	Tonne	22.35
16.	Total Crane Wt.	Tonne	104.4
17.	Wheels Nos.	Number	4
18.	No. of Driving Wheels	Number	2
19.	Speed of LT Drive	M/Min	96
20.	Dia of Wheels	MM	900
21.	LT Rail size	MM	120
22.	LT Rail size (BSR)	MM	--
23.	CT Speed	M/Min	44.5
24.	Dia of C.T. Wheels	MM	600
25.	Hook Approach (Non Cabin)	MM	1500
26.	No. of falls (Main Hoist)	NO	8
27.	Wt. of Bottom Block (Main))	Tonne	0.8
28.	Wt. of Bottom Block (Aux).	Tonne	0
29.	Wt. of Girder	Tonne	20.3
30.	Wt. of Platform	Tonne	3
31.	Wt. of Electricals	Tonne	0.5
32.	Wt. of LT Machinery	Tonne	3
33.	Wt. of Cabin	Tonne	1.2
34.	Hoist Reducer Stages (Main)	Number	3
35.	Hoist Reducer Stages (Aux.)	Number	0
36.	LT Reducer No. of stage	Number	3
37.	Derating Temperature	Celsius	50
38.	MH Motor RPM	RPM	750
39.	Motor RPM (Aux. Hoist)	RPM	0
40.	LT Motor Capacity	KW	25
41.	LT Motor RPM	RPM	960
42.	Factor of Safety for Rope	--	7

2. Fatigue Life Estimation Of Girder

Using the linear damage accumulation concept suggested by Palmgren & Miners[1], one can calculate the damage of a bridge girder, provided the load spectrum is made available. The damage "d_i" caused to a particular structure by one load cycle at a particular stress range "i", is reciprocal to the fatigue resistance of that structure at the same load range, $N_{f\,i}$

$$d_i = 1/N_{f\,i} \qquad (1)$$

The damage due to the n_i load cycles of the load range i, is

$d_{i,n} = n_i d_i = n_i / N_{fi}$ (2)

and the total damage caused to the structure by the load cycles of different load levels is

$D_{tol} = \Sigma d_i \times n_i = \Sigma n_i / N_{fi}$ (3)

Amongst the different fatigue life prediction methods, "S-N Curve" based approach – using stress range (Δ6R) and cycles (N) as parameters of the load-life relationship is used. If variable amplitude loads are applied on the structural detail, like a situation similar to crane girder, then direct calculation of the fatigue life is not possible. The three steps involved are i) Arranging the applied load history in a load range histogram using some cycle counting method like Reservoir method[2]. ii) Calculating the damage due to the entire load range histogram, "D_{tol}", using the linear damage accumulation rule, and finally iii) Calculating the fatigue life using the Equation $N_f = 1/ D_{tol}$

2.1. Calculating Stress Along Span

The total length of girder is divided in to 34 segments and loadings can be done at the required location and corresponding stresses developed can be calculated. By calculating the trolley wheel load as per the pay load "Q_i", according to its position "X" within the Span "L" with limiting length of the end as "T", X min = T and X max.=L/2.

Load vector is {Q} =[Q1,Q2,----Qi------Qn] (4)

Crab (Trolley) position vector is {X} = [X1, X2, -----Xi-----Xn] (5)

Then wheel loading for "i" location can be expressed in the form of reaction of simple beam "Vi" as,

$Vi = ½(Qi + Gt) X/L$ (6)

Where"Q_i" = Pay load at different situation and Gt is Wt.of crane crab.

Also considering the loadings due to uniformly distributed load of girder, platform, electricals, cabin, and long travel machinery fixed on the girder, one can calculate the bending moments i) due to trolley wheel load without impact, ii) due to trolley wheel load with impact, iii) due to uniformly distributed load of girder, platform electricals, iv) due to cabin & long travel machinery fixed on to the girder, v) shear stress due to live load with impact, vi) total shear stress due to live and dead weight, vii) diagonal shear stress due to over hang of platforms & machineries, viii) stress due to acceleration & deceleration, according to the crab's position.

The Table 3 below shows the stress range at various locations on the span. The minimum stress is 28.3755584 N/mm^2 and the maximum stress is 87.1621722 N/

mm^2. Stress Range is 58.7866138 N/mm^2. Stress due to acceleration and deceleration is 12.1775129 N/mm^2. and total stress range due to Load & acceleration/deceleration is 70.9641268 N/mm^2

Table 3 Stress Range Along Span [7]

Position From Mid-Span	**17m**	**15m**	**13m**	**11m**	**9m**	**7m**	**5m**	**3m**	**1m**
Stress(Min)	28	30	34	39	43	48	52	57	61
Stress(Max)	46	46	47	50	54	59	66	73	82
Stress бmin = 28.3755584 N/mm^2 Stress бmax = 87.1621722 N/mm^2 Stress Range Δб = 58.7866138 N/mm^2									

2.2 Reservoir Counting Method For Variable Amplitude Loadings

All the loadings transferred into corresponding stresses for the span of 34m are used to form stress reservoirs. The minimum stress, maximum stress and the stress **r**ange Δб are calculated from these stress reservoirs neglecting the stress range below the cutoff limit for the structural member. The basis of selection of structural member is explained in IS 1024[3], AS 5100[4] and Euro Code 3[1]. The structural detail chosen here is Detail "D" with stress range of 90N/mm^2. The Figures 4 & 5 show stress reservoir for the span for unladen and laden trolley movement respectively including acceleration and deceleration. As per the reservoir counting method, at the stress range of 44N/mm^2, the tip of the reservoir is assumed to be cut so that maximum amount of stress accumulated during travel from one end to the other end is drained out, that is this amount of fatigue stress is suffered by the girder during a cycle.

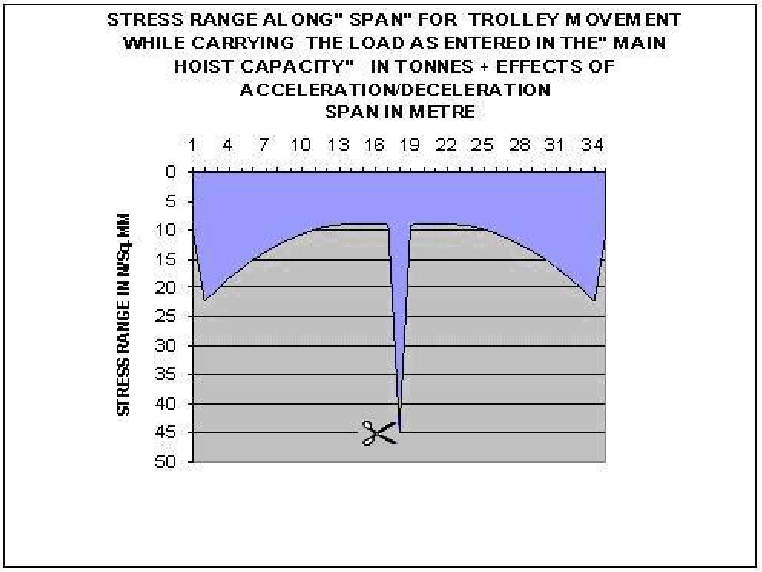


Fig. 4 Stress Range Along Span For Unladen Trolley Movement (Including The Effect Of Acceleration And Deceleration)

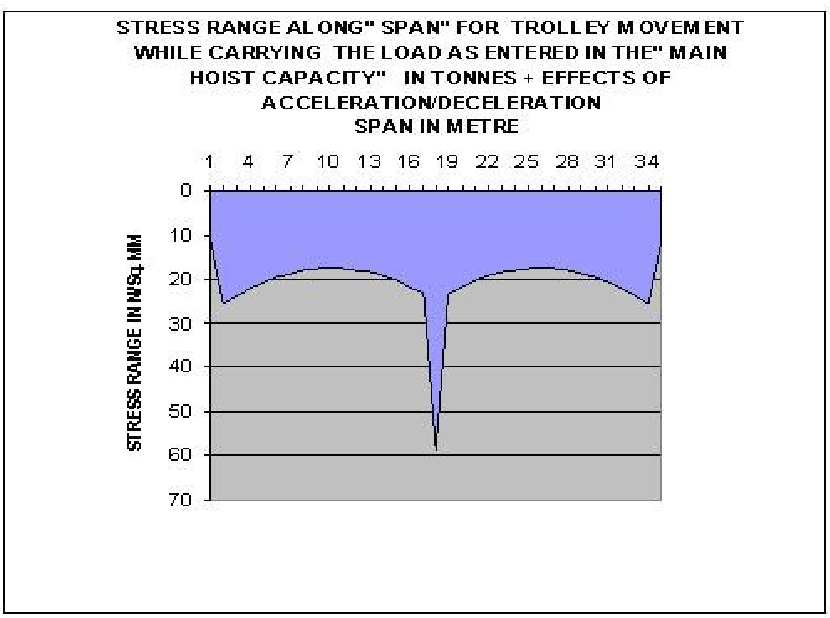


Figure 5 Stress Range Along Span For Trolley Movement With 80 KN (Including The Effect Of Acceleration And Deceleration)

2.3 Fatigue Life Calculation:

The equation of fatigue strength curve is

$$\text{Log N} = \log a - m \log \Delta б \quad [5,1,6] \qquad (7)$$

Where $\Delta б$ = Stress range / fatigue strength

N = Number of cycles of failure or endurance (available design life cycle for the corresponding stress range).

m = Inverse slope of the Fatigue curve.

a = value of the S-N curve constant used for design/ assessment purpose.

Values of **m** and **a** are tabulated by various standards in the documents based on a standard thickness "t_o". Consideration for structural details that have thickness that are in excess of "t_o", the stress ranges are changed in the following way,

$$\Delta бt = \Delta б \, (t/t_0)^q \qquad (8)$$

Where $\Delta бt$, is the increased value of the stress range

$\Delta б$, is the original value of the stress range

For the subject crane construction, from the standard S-N Curve Tables, m is taken as 3 , and log a = 12.151**,** and thickness correction is not required, as the base thickness is more than the thickness of subject construction. Also, considering the duty factor of the class of duty of the crane as 0.85[7]. Considering this, the fatigue life of the crane is calculated. The Table 4 shows the number of cycles for loadings of 80KN to 150KN.

The total damage as per the loading pattern in one year,

$$D_{tot} = \Sigma n_i/N_i = 0.038 \qquad (9)$$

Here one year is being considered, and the same cyclic pattern of the loading is repeated, the fatigue life of the crane is given by

$$N_f = 1/D_{tot} = 1/0.038 = 26.31 \text{ years} \qquad (10)$$

Considering probabilistic survival of 97.5%[8], the life of the subject crane for the cyclic pattern of loading is **25.68** years.

Table 4 Loadings, Cycles, Stress Range And Calculation Of n/N

Sr No	Loadings (kN)	$\Delta б$ (N/mm^2) (Stress Range)	Applied Cycles/Shift (n')	Applied Cycles/Year (n)	Available Cycles (N)	n/N
1	80	55.315	26	28470	8365102	0.0034
2	110	61.249	48	52560	6161735	0.0085
3	150	69.249	20	21900	4263433	0.0051
4	*	52.340	47	51465	9874130	0.0052

5	**	68.952	13	14235	4318763	0.0033
6	***	75.182	24	26280	3331642	0.0079
7	****	83.487	10	10950	2433007	0.0045
Summation of n/N = 0.038						

* Unladen trolley movement inclusive of acceleration/deceleration.
** 80 KN loading with trolley movement inclusive of acceleration/deceleration.
*** 110 KN loading with trolley movement inclusive of acceleration/deceleration.
**** 150 KN loading with trolley movement inclusive of acceleration/deceleration.

3. Results and Conclusion:

The fatigue life of the crane girder under consideration is found to be 26.31 years. Considering probabilistic survival of 97.5%, the fatigue life comes to 25.68 years. It may be interesting to note here, that the subject crane was commissioned in the year of 1983, already it has rendered the service of 25 years, and hence the management has started thinking of replacing the entire crane/girders.
EOT crane's bridge girder fatigue life calculation is made available in the form of MS-Excel program based on Palmgren-Miner rule considering the structural construction detail Tables of Euro code 3 and IS: 1024. It is possible to calculate the stress spectrum of the bridge girder for each and every point of loadings along with variable loadings, considering the effects of acceleration and deceleration of trolley movement. Using reservoir cycle counting method, stress spectrum of variable loadings is calculated. The program developed can be useful to predict preventive maintenance of EOT cranes, and or in taking the larger decision of replacing parts or whole of the bridge girder and also to predict the fatigue life of the girder of a newly commissioned EOT crane.

References:

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[5] British Standard BS 5400: Part 10, code of Practice of Fatigue, British Standards Institution, London.
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[7] IS: 3177 Code of Practice for EOT Cranes and Gantry cranes other than Steel Works.
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