Optimum Design of Bridge Girder of an EOT Crane Structure

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***Abstract*--Bridge Girder which carries various dead loads and live load is heavily stressed part of Crane structure. Along with the strength it should provide sufficient rigidity to maintain the proper and safe movement of the load. Failure to sustain the load while in operation could lead to loss of material and in worst case persons working nearby the crane. It is also the need of the Industry to reduce the weight of the structure thereby reducing the cost of fabrication and also the running cost of the crane. In this paper weight optimization of the crane girder is carried out using a custom made C program based on the Davidon-Fletcher-Powell (DFP) method and the solution is verified using ANSYS software. The C program and finite element results also meet the stringent requirements stipulated by Indian Standard IS: 807.**

***Keywords*-- bridge girder, Design variables, Objective function, Constraints.**

I. Introduction

Electrically-Operated Overhead Traveling (EOT) cranes are widely used to transport objects in many factories, ports, and work places[1].

Crane structure is made up of bridge girder and end-truck[2]. Bridge girder is that component of a crane structure on which trolley travels to provide the traversing motion. Box girders are widely used because of it design efficiency in providing strength and stiffness. To provide rigidity to the structure Full depth stiffeners and additional partial depth stiffeners are used.

Before putting the crane into operation Testing is carried out to check the operational performance of the crane. Standard weights are attached to the crane and the deflection of the Bridge Girder is checked when the crab position is at the centre. The deflection should be below the permissible value which is given by the equation,

$$\delta_p = \text{span}/900 \qquad (1)$$

Hence during the test if the Bridge Girder fails to meet the requirements than it cost time and resources in rework. To avoid this sort of problems and to improve the design of the Bridge Girder analysis can be carried out which will ensure the validity of the analytical solution before starting to fabricate the Bridge Girder.

There are many published studies on solid modeling and Finite Element Analysis of Crane structure. Solid modeling of bridge structures and finite element analysis to find the displacements and stress values have been investigated by Alkin [3]. Design evaluation of Overhead Traveling crane was carried out by Mahanty [4] to validate the design.

In this paper Optimization program is prepared in C language. The Program prepared gives optimum values of the design variables while checking all the possible modes of failures and meeting the stringent requirement imposed by various Indian Standards. Optimized girder design is verified using ANSYS software. Analysis of the Bridge Girder is carried out in two different positions:

1. Crab position is at the center
2. Crab position is at the corner

II. Analytical Solution

TABLE 1
NOMENCLATURE

Symbol	Quantity	Unit
δ	Deflection	mm
B	Overall width of Box girder	mm
H	Overall depth of Box girder	mm
b	Inner width of Box girder	mm
h	Inner depth of Box girder	mm
h_w	Height of Web	mm
l	Length of Girder	mm
w_F	Width of Flange	mm
t_F	Thickness of Flange	mm
t_W	Thickness of Web	mm
r_X	Different ratio	*Unitless*
f_X	Different stresses	N/mm^2
τ_s	Torsional shear stress	N/mm^2

1) Objective function chosen here is to reduce the weight of the girder which can be formulated as below in terms of design variables.

$$f(X) = (B \times H - b \times h) \times l \times \rho \ \ kg \qquad (2)$$

As span and density are constant for a particular crane above objective function can be simplified as

$$f(X) = (B \times H - b \times h),\ mm^2 \qquad (3)$$

Problem consists of four design variables: Outer width of box, Overall height of Box, Inner width of box and Inner height of box.

2) Height of web is calculated from the following empirical relation to ensure adequate stiffness at midspan.

$$h_W = \frac{l}{15} \, to \, \frac{l}{10}, \; mm \tag{4}$$

3) Width of flange is calculated from the following empirical relation to ensure transverse stiffness of the girder.

$$w_F = \frac{h_W}{3} \, to \, \frac{h_W}{2}, \; mm \tag{5}$$

4) Thickness of Flange and Thickness of Web can be selected from available standard sizes of 6 to 63 mm.

5) As per IS: 807[5] ratio of equivalent length of girder to the width of flange should be less than 60.

$$r_{LEWT} = \frac{l_E}{t_W} \tag{6}$$

6) As per IS: 800[6] ratio of Height of web to thickness of web should be less than 200 when vertical stiffeners are used.

$$r_{WHWT} = \frac{h_w}{t_W} \tag{7}$$

7) As per IS: 807 Slenderness ratio of the girder should be less than 300.

$$r_s = \frac{l_E}{r_Y} \tag{8}$$

8) Designed stresses should be less than permissible stresses given in IS: 800.

Bending Tensile: $f_{bt\le} f_{btp}, \; N/mm^2$ (9)

Bending Compressive: $f_{bc\le} f_{bcp}, N/mm^2$ (10)

Shear Stress: $f_{s\le} f_{sp}, N/mm^2$ (11)

Bearing Stress: $f_{b\le} f_{bp}, N/mm^2$ (12)

Equivalent Stress: $f_{e\le} f_{ep}, N/mm^2$ (13)

Torsional Shear: $\tau_{s\le} f_{sp}, N/mm^2$ (14)

Longitudinal : $f_{l\le} f_{lp}, N/mm^2$ (15)

9) As per IS: 807 deflection should be less than permissible value.

$$\delta_T \le \delta_p, \; mm \tag{16}$$

10) With the above information optimization problem can be formulated as minimize,

$$f(X) = (B \times H - b \times h), \; mm^2 \tag{17}$$

Subject to the following constraints:

$$g_1(X) = \frac{h_{WL}}{h_W} - 1 \le 0 \tag{18}$$

$$g_2(X) = \frac{h_W}{h_{WU}} - 1 \le 0 \tag{19}$$

$$g_3(X) = \frac{h_W/3}{w_F} - 1 \le 0 \tag{20}$$

$$g_4(X) = \frac{w_F}{h_W/2} - 1 \le 0 \tag{21}$$

$$g_5(X) = \frac{6}{t_F} - 1 \le 0 \tag{22}$$

$$g_6(X) = \frac{t_F}{63} - 1 \le 0 \tag{23}$$

$$g_7(X) = \frac{6}{t_W} - 1 \le 0 \tag{24}$$

$$g_8(X) = \frac{t_W}{63} - 1 \le 0 \tag{25}$$

$$g_9(X) = \frac{r_{LEFW}}{60} - 1 \le 0 \tag{26}$$

$$g_{10}(X) = \frac{r_{WHWT}}{200} - 1 \le 0 \tag{27}$$

$$g_{11}(X) = \frac{r_S}{180} - 1 \le 0 \tag{28}$$

$$g_{12}(X) = \frac{f_{bt}}{f_{btp}} - 1 \le 0 \tag{29}$$

$$g_{13}(X) = \frac{f_{bc}}{f_{bcp}} - 1 \le 0 \tag{30}$$

$$g_{14}(X) = \frac{f_s}{f_{sp}} - 1 \le 0 \tag{31}$$

$$g_{15}(X) = \frac{f_b}{f_{bp}} - 1 \le 0 \tag{32}$$

$$g_{16}(X) = \frac{f_e}{f_{ep}} - 1 \le 0 \tag{33}$$

$$g_{17}(X) = \frac{\tau_S}{f_{sp}} - 1 \le 0 \tag{34}$$

$$g_{18}(X) = \frac{f_l}{f_{lp}} - 1 \le 0 \tag{35}$$

$$g_{19}(X) = \frac{\delta_T}{\delta_P} - 1 \le 0 \tag{36}$$

The Problem consists of four design variables and nineteen constraints. As the constraints are of nonlinear type it is a nonlinear constrained optimization problem. To solve the above problem Davidon-Fletcher-Powel (DFP) method is selected which is one of the nonlinear constrained optimization methods. The choice is made on DFP method because it is sequential in its solution, reliable and always search point remains within the feasible region [7].

III. VERIFICATION OF THE ANALYTICAL SOLUTION USING ANSYS

CASE I: ANALYSIS WHEN CRAB AT CENTRE

1. SHELL63 element is selected for the analysis because it has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node [8].
2. Values of various forces acting and other parameters required for the solution of analysis is shown in Table-II.
3. Deflection of the Bridge Girder & Von Mises stress induced is shown in Fig. 1 & Fig. 2 respectively.

TABLE II
INPUTS TO ANALYSIS WHEN CRAB AT CENTRE

Model	Bridge girder		
Maximum node number	22928		
Maximum element number	23530		
Displacement restraint	Displacement is restrained by giving constraint on nodes where bridge girder is welded to the end truck.		
Load condition	Vertical N	Horizontal transverse N	Horizontal longitudinal N
	F_{VLL}=200860 at center F_P=6330 at center F_{CTR}=4005 at center F_{VITD}=3924 at center Gravity force	F_{HTLL}=7725.4 at center F_{HTITD}=196.2 at center F_{CTR}=200.25 at center F_P=316.5 at center	F_{HLL}=3862.7 at center
Material	St 42 W E = 2.05 x 10⁵, N/mm² γ = 0.3		
Element type	ANSYS SHELL63 elastic shell		
Permissible stresses	σ_Y = 250, N/mm^2		
Analysis type	Static analysis		
Analysis time taken	1397.68 s		

CASE II: ANALYSIS WHEN CRAB AT CORNER

1. Values of various forces acting and other parameters required for the analysis are shown in Table-III.
2. Deflection of the Bridge Girder & Von Mises stress induced is shown in Fig. 3 & Fig. 4 respectively. Deflection of the Bridge Girder is less when the crab is positioned at the corner compared with that of the crab at the central position. Because of the same reason it is recommended that when crane is not operative crab should be positioned at the corner to avoid permanent set in the Bridge Girder.

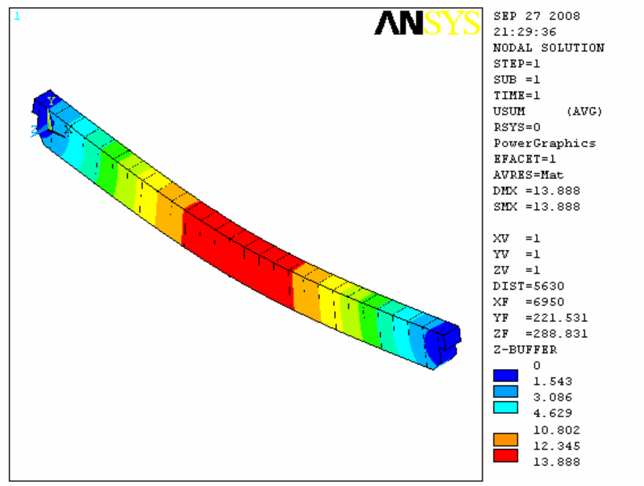

Fig. 1. Deflection of bridge girder when crab at center

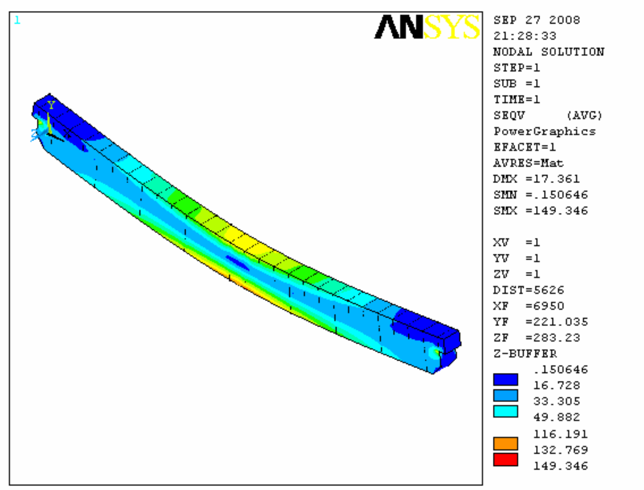

Fig. 2. Von-Mises stress on bridge girder when crab at center

TABLE III
INPUTS TO ANALYSIS WHEN CRAB AT CORNER

Model	Bridge girder		
Maximum node number	22928		
Maximum element number	23530		
Displacement restraint	Displacement is restrained by giving constraint on nodes where bridge girder is welded to the end truck.		
Load condition	Vertical N	Horizontal transverse N	Horizontal longitudinal N
	F_{VLL}=200860 at corner F_P=6330 at center F_{CTR}=4005 at center F_{VITD}=3924 at center gravity force	F_{HTLL}=7725.4 at corner F_{HTITD}=196.2 at center F_{CTR}=200.25 at center F_P=316.5 at center	F_{HLL}=3862.7 at corner
Material	St 42 W E = 2.05 x 10⁵, N/mm² γ = 0.3		
Element type	ANSYS SHELL63 elastic shell		
Permissible stresses	σ_Y = 250, N/mm^2		
Analysis type	Static analysis		
Analysis time taken	1397.68 s		

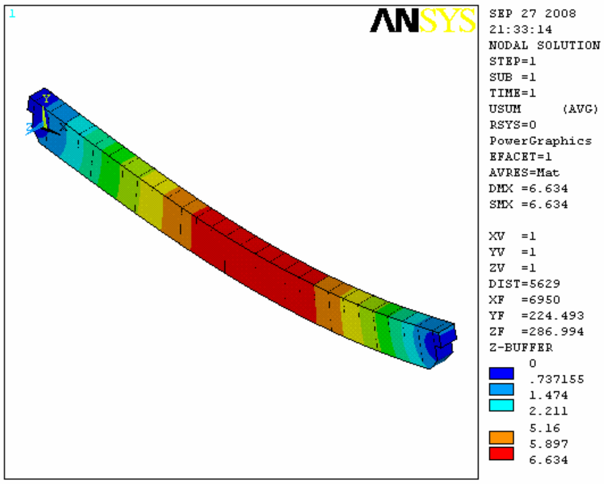

Fig. 3. Deflection of bridge girder when crab at corner

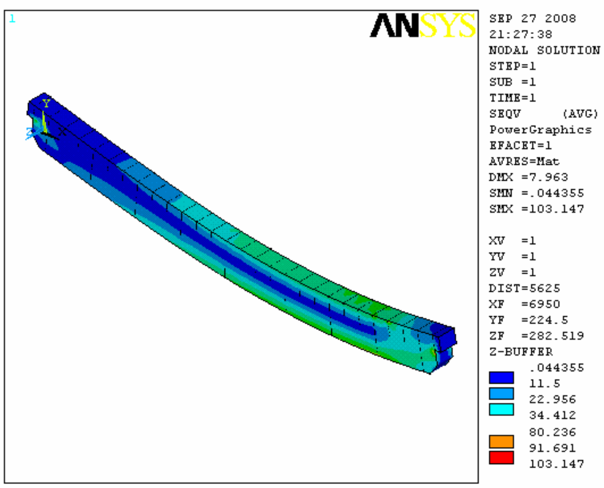

Fig. 4. Von-Mises stress on bridge girder when crab at corner

IV. Results & Discussion

TABLE IV
COMPARISON OF ANALYTICAL AND ANSYS RESULTS

CRAB POSITION	SR. NO.	PARAMETER CHECKED	ANALYTICAL METHOD	ANSYS	Permissible Value
Center	1	Deflection, mm	14.57	13.888	15.22
	2	Von-Mises Stress, N/mm^2	137.268	149.346	250
Corner	1	Deflection, mm	6.7437	6.634	15.22
	2	Von-Mises Stress, N/mm^2	67.85	103.147	250

The stresses and deflection given by analytical and ANSYS are well within limits specified as shown in Table IV. The deflection given by the analytical formulae dose not take into account the effect of Stiffener plate and that of intermediate and bearing stiffener. However the ANSYS does take into account, hence the deflection is quite lower than the analytical value and that of permissible value. Camber which is provided in opposite direction to deflection of the Bridge Girder reduces this value considerably.

The Von-Mises stress is safe within limits analytically as well as by ANSYS. Von-Mises stress calculated by ANSYS is on higher side than analytical method because of the effect of stress concentration at the corner where the Bridge Girder is connected to the End Truck. However the effect of stress concentration and possible danger of failure of Bridge Girder at the corner can be avoided by welding thick plate at the corner.

TABLE V
COMPARISON OF WEIGHT

Sectional Property	As per Safex design	Optimization Program In C
t_F , mm	10	6
t_W , mm	6	6
w_F , mm	440	534
h_W , mm	1100	1074
Cross sectional area, mm^2	22000	19296

The cross-sectional area given by the optimization program is less compared with the existing design of the company. Reduction in weight obtained is 12.29%. This reduction in weight will lead to the low weight design of End truck on which bridge girder is mounted. Also pressure on the wheels will reduce and low weight section of rail can be selected. Thus overall reduction in weight of crane will be much more, which will reduce the initial cost of crane. At the same time the running cost of the crane will reduce because low weight crane will accelerate and decelerate faster reducing the power consumption.

V. References

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