Optimization of Box Type Girder of Overhead Crane for Different Spans with Fixed Capacity

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Abstract

Overhead cranes one the most common material handling equipment available in industries. Recently, designers and analysts have shown their interest in optimization of such cranes. This paper deals with the parametric optimization of box girder of overhead crane with different spans and fixed loading capacity. Initially, the effect of each design variable is studied individually and later their combined effect is analyzed. Using 3D finite element analysis box girders of spans of 10-32 m were analyzed and optimized. The study yielded some generalized relations which may be used to calculate design variables of any box girder with 100 ton capacity and above mentioned spans.

Keywords
Box girder, optimization, bending stress, structural analysis, finite element analysis.

1. Introduction

The specifications of over-head cranes cannot be standardized as the requirements of each firm depends on various factors. One of the most important factors is the floor area of the factory or ware-house. Other factors include the floor height, amount of load to be handled, type of load to be handled, power mechanism (electric or hydraulic etc.), service time and etc. It is therefore, not just sufficient to optimize an over-head crane with specific parameters, but an optimization that also offers a generalization and flexibility according to individual consumer needs. Several studies of analysis and optimization have been published in the recent years (Luo and Edlund (1994), Otani and Nagashima (1996), Niezgodzinski and Kubiak (2005), Alkin *et al.* (2004), Pinca *et al.* (2009), Gerdemeli *et al.* (2010), Gąska and Pypno (2011), Ajla *et al.* (2011), Abid *et al.* (2008)). But, these analysis are performed for fixed span and load. In 2008, Rehan H Zuberi *et al.* performed optimization of various span and capacity cranes, yet, do not offer a generalization of the analysis. Fatigue analysis using FEA of cranes was done by Caglayan *et al.* in 2010. Multi-axial fatigue problem was the dealt by Eulerand and Kuhlmann (2011)**.** Gerdemeli *et al* (2010) studied gantry cranes. Gasic *et al.* (2011), preformed dynamic analysis of over head cranes, trapezoidal velocity pattern was used for applied force. The present study offers analysis and optimization of over-head crane box-girders with variable span length and concludes with a generalization of design variables which produce safe state variables as output. Some industrial design aspects were also considered during the finite element modelling.

2. Methodology

The analysis is begun by studying the influence of each design variable on the output variables. These parameters include the number of vertical (web) stiffeners, N_{VST}, the maximum height of the box girder, H_{MAX}, top-plate thickness, T_{TP} (using the plate thickness ratio factor, ***PT)***, side plate thickness, T_{SP} (using reduction factor, ***RF)***, the support height, H_{MIN}. The state variables for each case were optimized and the corresponding parameter was noted. The optimization methodology is presented in Figure 1. Various cases with different spans and a fixed of 100 ton capacity are studied and compared and a relationship is developed in the form of an interpolation equation.

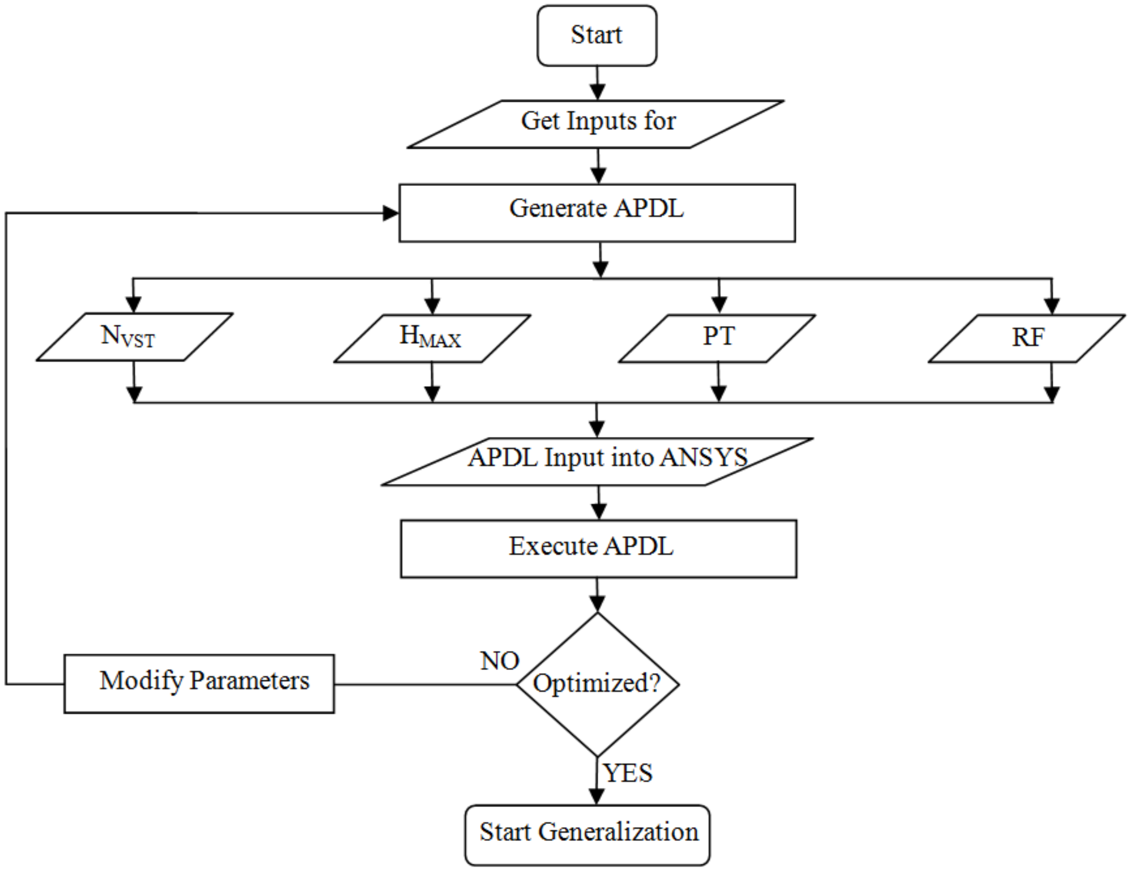
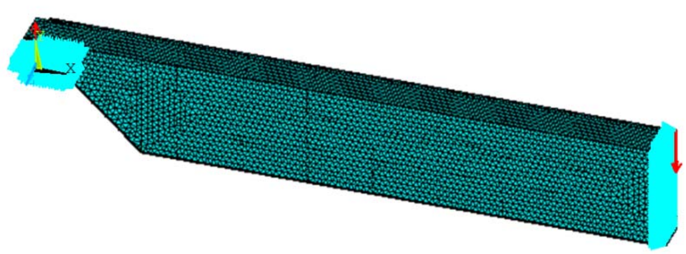


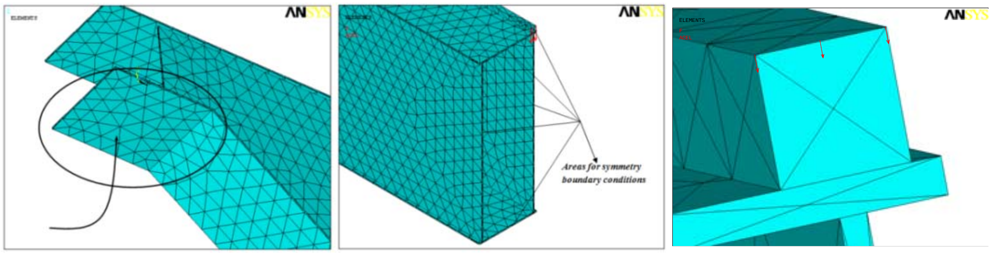
Figure 1: Optimization Methodology

3. Modelling and Meshing

The girder optimized for 100Ton capacity has the specifications identical to the optimized girder of the same capacity mentioned by Abid and Khan. The only difference was that the span was varied to 28m. Therefore, the results of initial optimizations have a 100 ton capacity and a 28m span. Other considerations like industrial aspects as well as the finite element modelling and meshing technique was unchanged. The modelling conditions are shown in the Figure 2.



(a)



(b) (c) (d)

Figure 2: Boundary conditions; (a) meshed model; (b) areas to be fully fixed; (c) areas for reflective symmetry; (d) nodes to apply load on rail.

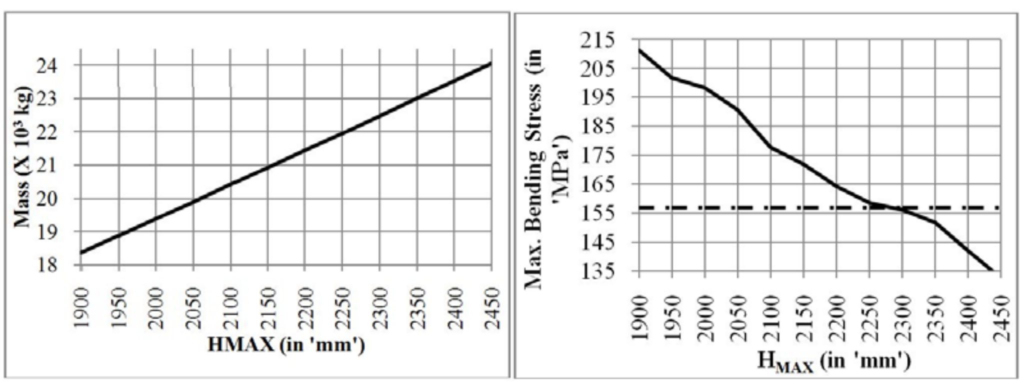
The Figure 2 (b) shows that all the nodes at the lower surface of both the end supports are fully constrained. The other half girder (right portion) are not modeled as the symmetric boundary conditions were applied (see Figure 2(c)). The load is applied on three points (nodes) over the rail. Also, as the symmetry is considered, therefore, load applied on each of the 2 nodes is 1/6th of the total load for which the girder is being optimized. It is important to mention here that the applied load on the girder contains an impact factor of 1.25, i.e., a for a 100 ton girder the applied load is 100 X 1.25 =125 ton and load applied on each node is 20.833 ton. Due to point load the calculated stresses contain stress singularities which are neglected by removing the elements containing unnecessarily high values.

4. Optimization

The optimization 28m span is performed as a reference. The procedure is then repeated for other spans and finally using linear interpolation the relationship between H_{MAX} and other parameters, optimization factors are developed which are later mentioned in this paper.

4.1 Optimization Case-1: using H_{MAX} only

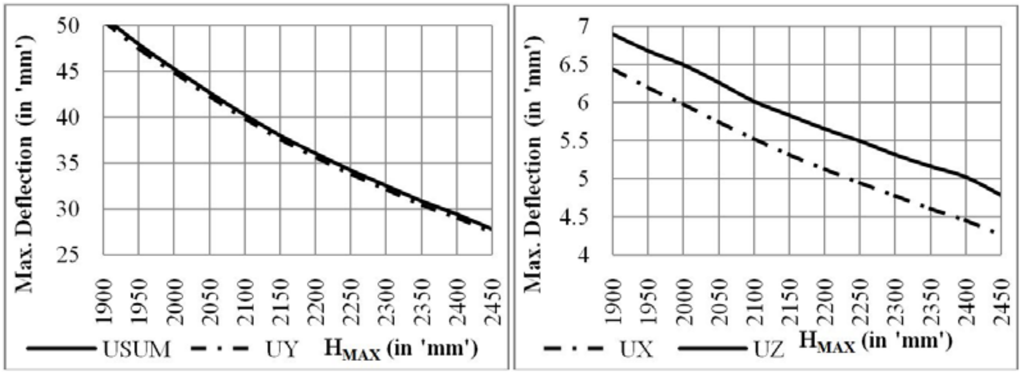
This optimization is performed by varying the height of a 28m span girder all other parameters constant. The resulting mass, bending stress and deflection is observed and plotted graphically. It can be noted from the Figure 3(a) and (b) that as the H_{MAX} is increased the mass is also elevated but on the other hand the maximum bending stress is decreased. The most optimum case is when the height is 2300mm. The maximum bending stress for this case is just below the allowable stress 157MPa (i.e.156.23 MPa). The deflections are also well within the safe limits (see Figure 4(a) and (b)).



(a) (b)

Figure 3: Optimization case - 1 (a) Mass; (b) Max. Bending stresses.

The decrease in the stresses is due to the increase in the structural strength as the H_{MAX} increases. The self weight of the structure might affect the stresses to increase to instability.

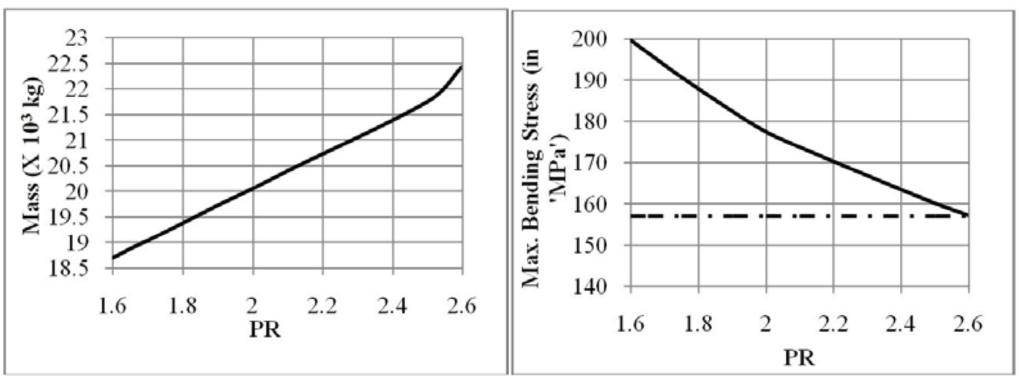


(a) (b)

Figure 4: Optimization case - 1 (a) Maximum USUM and UY; (b) Maximum UX and UZ.

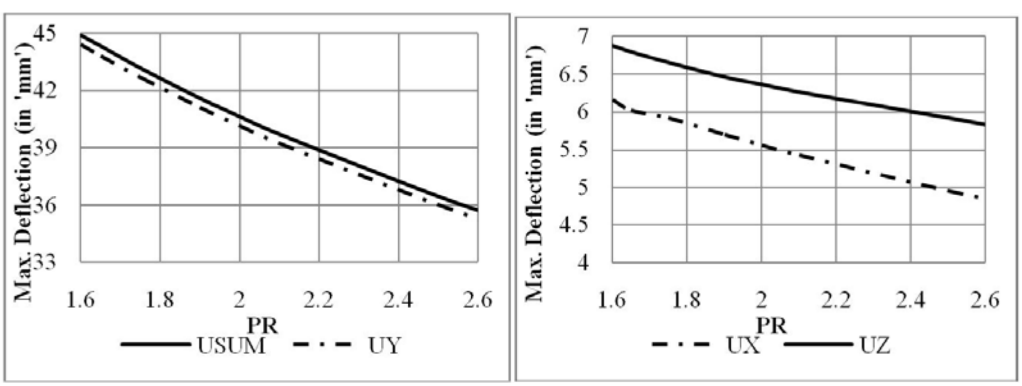
4.2 Optimization Case 2: using PT only

The results of this optimization are presented in Figure 5 and Figure 6. The optimization concluded a PT value of just above 2.6 for safe output stresses and deflections. The optimized mass was 22260kg. The result here are quite impractical because 2.6 means a top plate thickness of at least 41.6mm to a corresponding side plate thickness of 16mm (as T_{TP} also depends on RF along with PT). Also the mass is quite high, therefore, the other parameters are necessary to be changed as well along with PT.



(a) (b)

Figure 5: Optimization case - 2 (a) Mass; (b) Max. Bending stresses.



(a) (b)

Figure 6: Optimization case - 2 (a) Maximum USUM and UY; (b) Maximum UX and UZ.

It is evident from the Figure 5(b) that any value of PT below 2.6 will produce stresses above the allowable limit.

4.3 Optimization Case -3: using RF w.r.t. PT and H_{MAX}

The optimization in the previous section yielded impractical results and concluded to follow an optimization procedure considering all optimization factors in parallel. Moreover in case-1 the mass of the most optimized height was 22484kg which is more than that in case-2. Thus, this optimization was performed by varying RF at different H_{MAX} and PT values and the resulting values were plotted graphically. The results yielded by the most optimized case are mentioned in Table. 1. The variation of maximum bending stresses is shown in Figure 7.

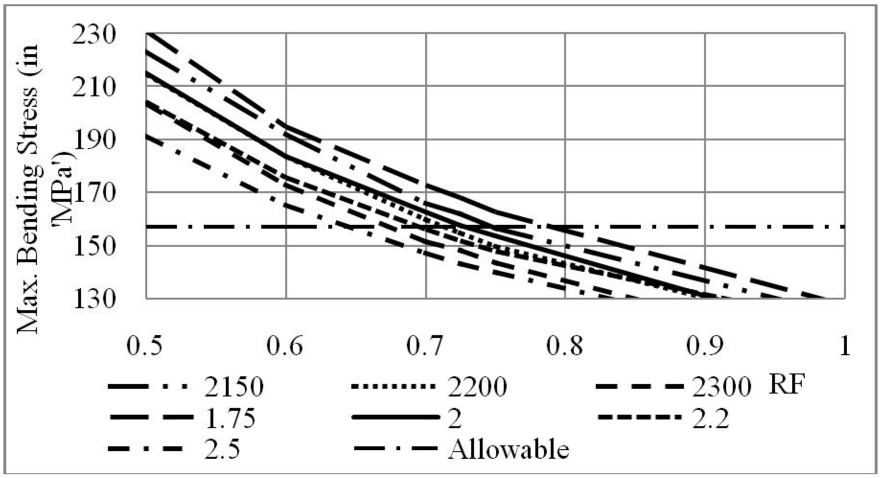


Figure 7: Optimization case - 3: Max. Bending stresses.

Table 1: Conclusions of optimization case - 3

Capacity	100Ton
RF	0.69
PR	1.6
H_{MAX}	2255mm
Mass observed (At 17 Vertical Stiffeners)	22254 kg
Max. Bending Stresses=150.242 MPa	150.242 MPa
Max. Deflection (USUM)=31.257 mm	31.257mm

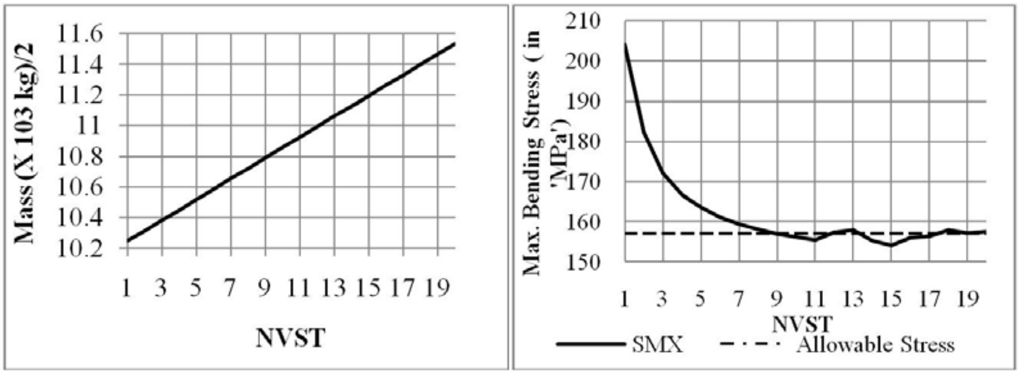
Abid and Khan used 17 vertical stiffeners during the optimization 32m span girders and the number was unchanged for all the capacities mentioned in their work, this was done because all the capacity girders had the same span. Therefore, it is necessary to understand the effect of vertical stiffeners on the structural strength for varying spans.

4.4 Optimization Case -4: Using N_{VST} only

The design parameters obtained during the optimization case-3 were used to optimize the number of vertical stiffeners. The number of vertical stiffeners was varied only along the uniform height portion of the box girder. The number of Vertical stiffeners along the supports and the variable height portion remain the same i.e. 2 and 6 respectively. The results indicate that the max. Bending stresses reduce with increase in the number of vertical stiffeners at initially. But, after a certain quantity the stress starts fluctuating above and below the allowable stress limit .Yet, on an average it becomes constant. The most optimized state for 28m span is observed to be 9 vertical stiffeners. The results of this optimization are presented in Figure 8 and Figure 9.

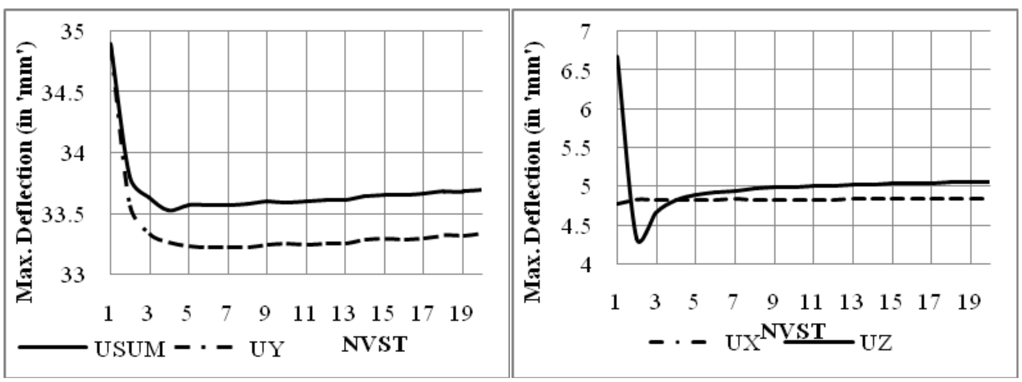
4.5 Optimization Case -5: End support Study

This optimization is performed by changing the height of the support of the box girder. The resulting mass, bending stress and deflection is observed and plotted graphically (see Figure 10). The maximum bending stress is observed to reduce with the reduction in the support height. However, after a certain height (HMIN=800 mm) the bending stresses start reducing again (as in graph above) but still the mass keeps on increasing. The most optimized state is observed to be at $H_{MAX}/3.5$.



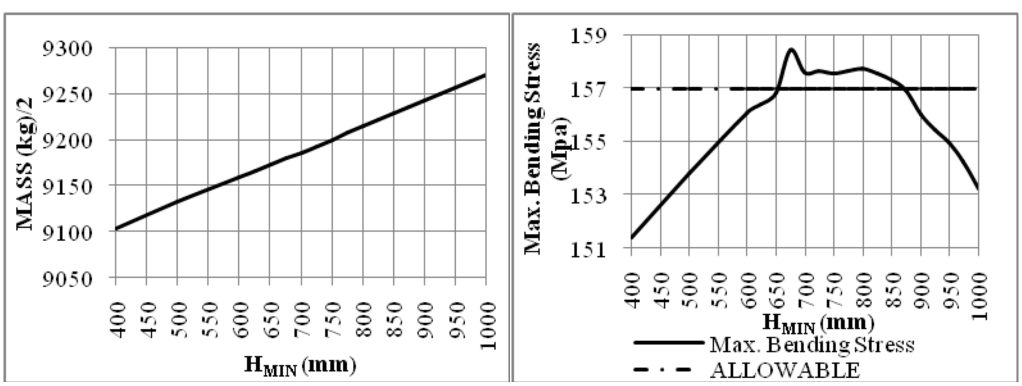
(a) (b)

Figure 8: Optimization case - 4 (a) Mass; (b) Max. Bending stresses.



(a) (b)

Figure 9: Optimization case - 4 (a) Maximum USUM and UY; (b) Maximum UX and UZ.



(a) (b)

Figure 10 Optimization case - 5 (a) Mass; (b) Max. Bending stresses.

4.6 Generalization of Optimization

The relationship between design parameters w.r.t. to the state variables was studied and the following relationships were developed. These equations are valid for spans of 35m and below.

$$(H_{MAX})_C = \{(H_{MAX})_R - \{0.11 \times [(HL)_R - (HL)_C]\}\} + 75 \quad (1)$$

$$(RF)_C = \{(RF)_R + \{0.0000365 \times [(HL)_R - (HL)_C]\}\} - 0.05 \quad (2)$$

$$(PT)_C = \{(PT)_R - \{0.00009375 \times [(HL)_R - (HL)_C]\}\} - 0.002 \quad (3)$$

If the span is greater than 30m then;

$$(PT)_C = \{(PT)_R - \{0.00009375 \times [(HL)_R - (HL)_C]\}\} - 0.03 \quad (4)$$

The optimized results obtained using the above relations are given in Table. 2

Table 2. Optimized 100Ton box girders

Span	H_{MAX}	RF	PT	N_{VST}	Mass	SMX	USUM	UX	UY	UZ
m	mm	-	-	-	kg	MPa	mm	mm	mm	mm
28	2255	0.690	1.5605	9	20908	154.869	32.693	4.798	32.325	5.012
25	2090	0.745	1.41987	8	17574	155.735	27.608	4.175	27.302	4.207
23	1980	0.782	1.32612	8	15498	154.649	24.608	3.784	24.178	3.765
20	1815	0.836	1.18550	7	12414	155.449	19.899	3.211	19.661	3.161
17	1650	0.891	1.04488	7	9646	154.896	15.614	2.647	15.405	2.634
14	1485	0.945	0.90425	6	7066	153.575	11.579	2.708	11.395	2.135
11	1320	1.000	0.76362	5	2405	149.144	7.84	1.494	7.678	1.656

All results in Table 2 are below the allowable values.

5. Mesh Sensitivity Analysis

Mesh sensitivity analysis was performed to validate the element size chosen. The study analyzes the variation of output variables on the density of the used mesh. The density of the mesh is changed by varying the element edge length and the produced bending stresses and the deflections are compared. The trends of the produced stresses and deflections for the different cases is compared and the best element size was chosen. The mesh sensitivity also helps to reduce the errors due to meshing. The analysis was performed for different spans and loads.

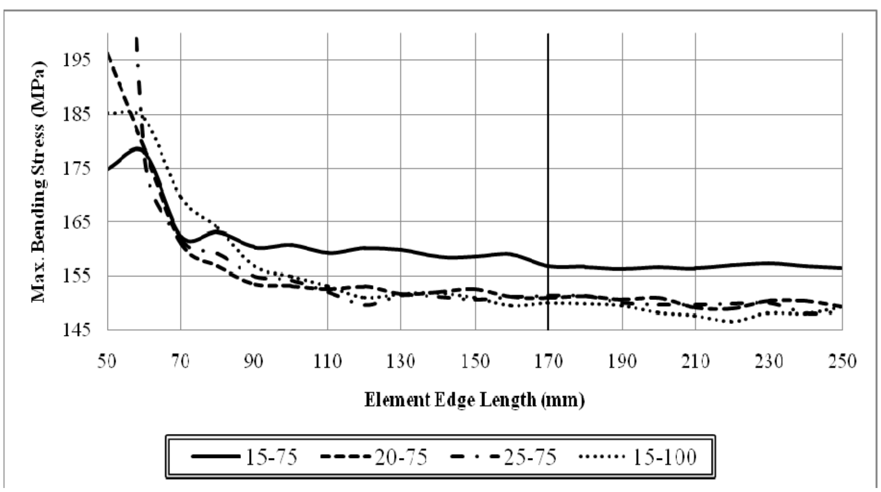


Figure 11: Mesh sensitivity analysis (span-capacity/m-Ton).

The Figure 11 shows that at a very fine mesh (element edge length below 80mm) the model behaviour is quiet abnormal. The variation of stresses is very high. Thus, any element edge length equal to 80mm or below may not be acceptable as it may produce inappropriate results. As, the element edge size is increased above 100mm, the variation in stresses with any further increase is negligible i.e. the trend is now almost linearized. Because, the time needed to solve a finer mesh is more than a coarser one, therefore, a coarser but acceptable mesh may selected by studying the trend in the Figure 11. An element edge size of 170mm was conluded by the study.

6. Conclusion

The only input to the optimization is the span, therefore the developed relations may used to calculate the design parameters for the box-girder that result in safe stresses and deflections. It is important to note that, the other parameters like distance between the side plates, the rail parameters, the horizontal stiffeners, etc. were not studied, but, these parameters are linearly related to the maximum height of the girder, as H_{MAX} changes these parameters change accordingly. A considerable mass reduction was observed for either of the cases (more than 20%). A load impact factor of 1.25 was considered i.e. a 100Ton girder optimization is a 125Ton girder without an impact factor of 1.25. The relations (1) through (4) may be used to calculate the parameters of any 100Ton box girder of spans between 10m and 32m. Futher, the relations mentioned by Abid and Khan (2013) may be combined with the ones mention in this paper to get the parameters of box girders of spans ranging from 10m to 32m and capacities between 50Ton and 120Ton (inclusive of an impact factor of 1.25).

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Biography

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