

Design, Analysis and optimization of crane Girder via Buckling analysis

Ashutosh Kumar¹, Vidyasagar R Bajaj², Rachayya R. Arakerimath³

¹ME Student, Department of Mechanical Engineering, ACEM, Pune, India

²Professor, Department of Mechanical Engineering, ACEM, Pune India

³ Professor, Department of Mechanical Engineering, GHRCOEM, Pune, India

Abstract - Girders are the longest and biggest structural part of EOT crane. There are many design principle and process defined by various standard. Even then there is a huge scope of optimization of weight as these standards are providing boundaries for the design of the structure. Buckling is one parameter which can be considered for optimization of the structural thickness. The nature of load on the crane girder is complex and is the summation of bending and shear. This paper deals with the way to compute the buckling stress and to optimize the structural weight. This analytical process is further approved by the Finite element analysis.

Key Words: Complex Loading; Optimization; Buckling; Buckling Stress.

1. INTRODUCTION (Size 11 , cambria font)

EOT Cranes are widely used in the industries in order to assist the manufacturing process. It consists of various parts out of which major structural part is girder. It is the longest and heaviest part of the crane. It forms the bridge between the two gantry girders on which the trolley moves. Trolley is the moving part of crane which moves on the girder.

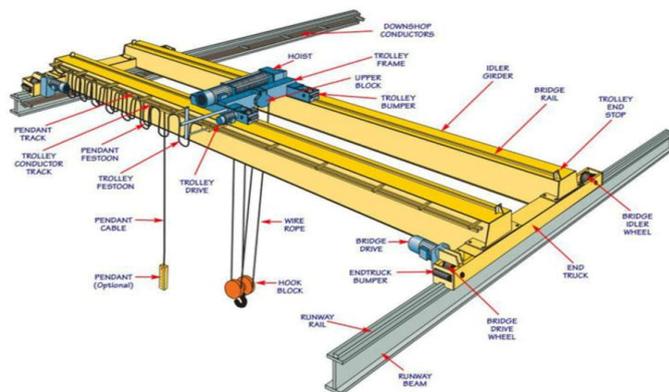


Figure-1 Crane layout

In the figure shown above yellow part represents the structure. The blue part is known as the trolley which moves on the girder to lift the loads. The crane has three motions-Hoisting, cross travel and long travel. All these motions impose load on the structure. The whole crane is running on the gantry girder which again creates one

source for developing the loads on the crane structure. Three prime movers along with power resource are required to provide the required crane motions. As discussed we have to target to reduce the crane weight so one such possible source for weight reduction is crane girder. In the next point crane girder is introduced.

2. NEED OF RESEARCH

Cranes are being used in industries. These are running on the gantry girders. The effect of reducing the weight of the crane has many effect as represented below:-

- a) Reduces the Gantry girder size
- b) Optimize the structure of workshop
- c) Reduces the motive power requirement to move the crane
- d) Lowers the power consumption and hence low running cost.
- e) Low selling price of crane.

Above parameters provide good reasons for the research to be carried on.

3. CRANE GIRDER

Crane Girder is an assembly of steel plates, angle and rails. Steel plates forms the flange and web of girder while the angle forms the stiffening part of the web plate. Steel plates are also used as diaphragms of the girder. Together all of these make up a box section. The girder box section is shown below:

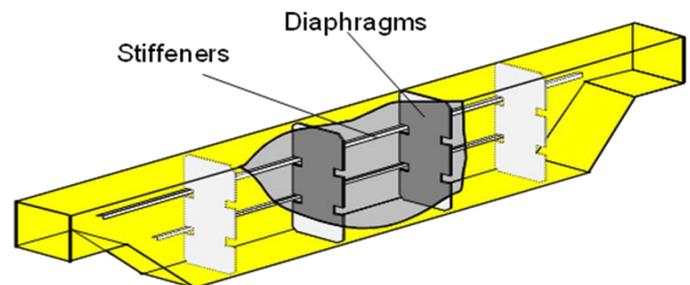


Figure-2 Crane Girder

After the formation of the box the rail is welded on the top flange so that the trolley wheel can move on it. It is not necessary to have the girder of box section only. It may be of I beam shape, tapered box section or another sections.

All these section types are acceptable provided that the condition that they satisfy the load carrying capacity. Manufacturing process of the girder is very simple and the allowable tolerance of manufacturing are wide enough that they don't require very skilled workers to manufacture it. Box section is associated with easy manufacture, high sectional properties, high torsional strength property, which makes it more reliable for the crane girders. I beam shape can also be one option but they suffer low lateral rigidity. Box section being higher in strength from lateral direction makes it idle choice.

4. THEORY FORMULATION

4.1 Abbreviations & Nomenclature:

Geometric Properties

- a Longest Dimension of the plate
- b Second Longest Dimension of Plate
- t Plate Thickness
- γ Ratio of Flexural rigidity of plate-stiffener
- I Moment of Inertia
- ν Poisson's ratio

Material Properties and Stress Parameters

- $\sigma_{1c} = \sigma$ Compressive stress
- $\tau_{xy} = \tau$ Shear Stress
- σ_{crit} Critical Buckling stress
- σ_{cr}^v Critical Bending stress
- τ_{cr}^v Critical Shear stress
- ψ Stress ratio factor

General Parameters

- EOT Electrically operated overhead travelling crane
- FEA Finite Element Analysis
- UTS Ultimate Tensile Stress

4.2 Basic Theory

4.2.1 Exact bending moment condition

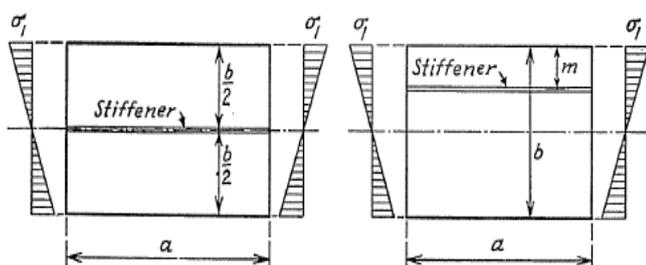


Figure-3 Exact bending moment condition of Crane girder web plate [13]

The above shown figure is for the exact bending moment condition of the plate with stiffener at mid of the plate.

$$\sigma_{1.cr} = \frac{\pi^2 D (1 + \alpha^2)^2 + 2\gamma}{b^2 t \alpha^2 (1 + 2\delta)} \quad \text{where, } \alpha = \frac{a}{b}, \gamma = \frac{EI}{Db}, \delta = \frac{A}{bt}, D = \frac{12EI}{bt^3}$$

4.2.1 Plate subjected to shear

When the plate is subjected to pure shear then the below mentioned formula can be used:

$$\tau_{xy} = \frac{9}{32} \frac{\pi^4 E}{12(1 - \nu^2)} \left(\frac{t}{b}\right)^2 \frac{(1 + \alpha^2)^2}{\alpha^3} \quad (2)$$

4.2.2 Exact Condition of Crane girder plate

Below shown figure shows the actual condition of crane girder web plate.

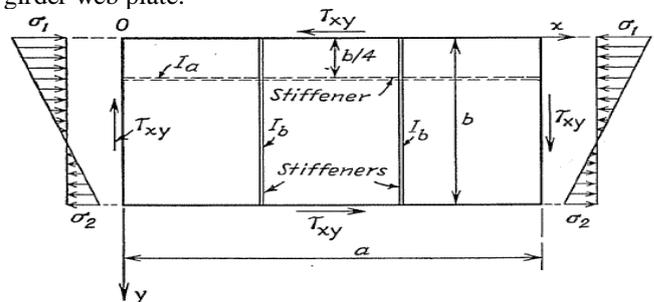


Figure-4 Exact condition of Crane girder web plate [13]

For the above shown figure the Calculation can be performed to get the critical stress as per below mentioned formula [17]

$$\sigma_{crit} = \frac{\sqrt{\sigma^2 + 3\tau_{xy}^2}}{\left[(1 + \psi) * 0.25 \right] \left(\frac{\sigma_1}{\sigma_{cr}^v} \right) + \left\{ \left[0.25 * (3 - \psi) * \left(\frac{\sigma_1}{\sigma_{cr}^v} \right) \right]^2 * \left(\frac{\tau_{xy}}{\tau_{cr}^v} \right)^2 \right\}^{0.5}} \quad (3)$$

The details of the above calculation symbols are elaborated in Appendix-A. The Position shown for the stiffener is derived from the data analysis of the existing cases. It is shown in next section

5. DATA ANALYSIS

Based on available stiffener sizes and the web plate of size of 2000x1600x6 thick detailed analysis is done to get the desirable position of stiffener which is shown below:

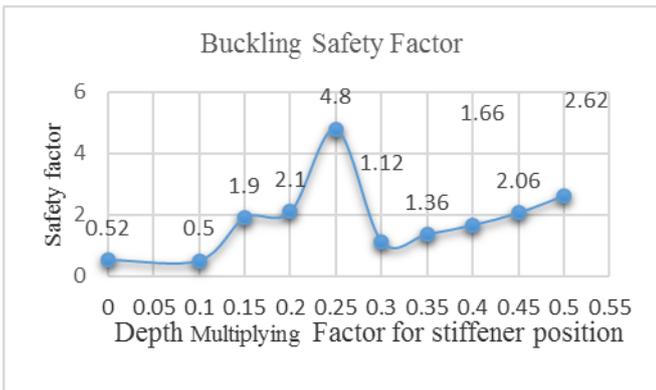


Chart-1 Optimum position of stiffener.

Based on the available sizes of stiffeners and the considered web plate weight and stiffness ratio analysis is also done as shown below:

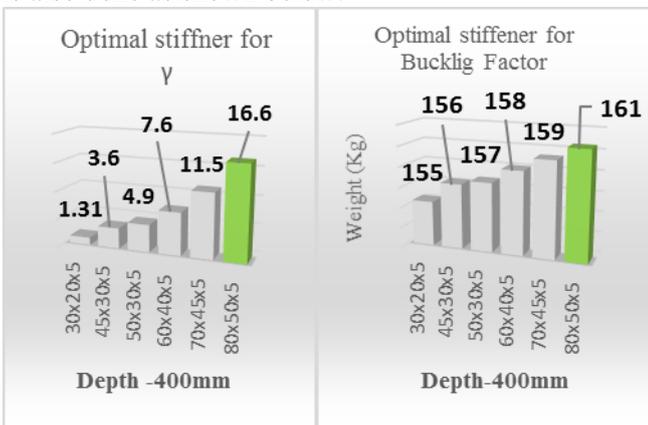


Chart-2 Optimal stiffener selection

Outcome of Data analysis- Optimum position of stiffener is 0.25 times depth of web plate ie 400mm from the compression edge with stiffener as 80x50x5.

6. PROBLEM DEFINITION

The three cases are as per below:-Case-1: Box Girder with web height of 1600mm and effective panel dimension of 2000mm will be considered with 6 mm thickness without any stiffener.

Case-2: Box Girder with web height of 1600mm and effective panel dimension of 2000mm will be considered with 6 mm thickness with stiffener (80x50x5) at 400mm depth from top compression edge.

Case-3: Box Girder with web height of 1600mm and effective panel dimension of 2000mm will be considered with 10 mm thickness without any stiffener.

Problem definition is shown below which will be analyzed for three different cases

Table-1 Input Data

Variant	Unit	Value
Safe working Load	ton	18
Trolley Weight	ton	12.5
Trolley wheel Base	mm	900
Panel Dimension	mm	2000x1600xt
Material		FE-410
Yield Strength	MPa	235
Service Factor		1.35
Crane Standard		IS:807,FEM
Material Standard		IS:2062

Note: Value of plate thickness "t" will vary as per Case-1, Case-2 & Case-3.

7. SIMULATION AND ANALYSIS

7.1 ANALYTICAL CALCULATION

TABLE-2 Analytical Result Table

Cases	Plate Condition	Used Capacity	Buckling Factor (λ)
Case-1	6mm thick Plate Without Stiffener	2.25	0.6
Case-2	6 mm thick Plate with stiffener	0.82	1.66
Case-3	10mm thick Plate without stiffener	0.75	1.8

7.2. FEA SIMULATION

Case-1

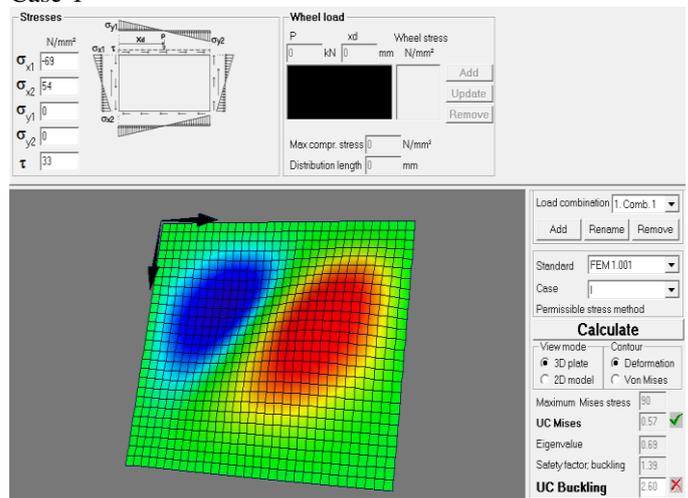


Figure-5: Buckling analysis of case-1

Case-2

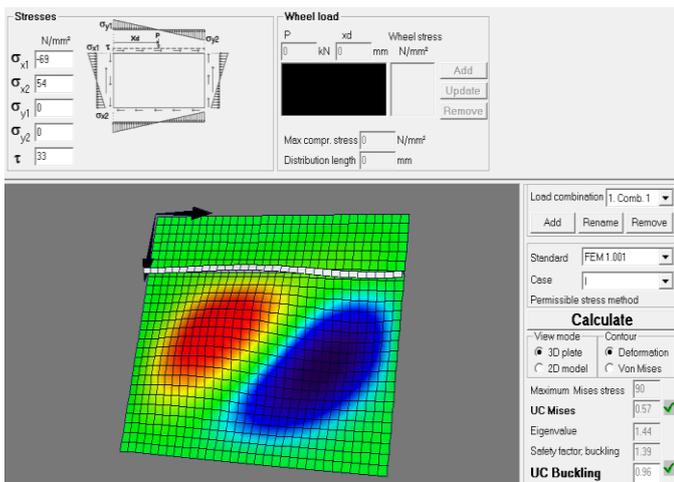


Figure-6: Buckling analysis of case-2

Case-3

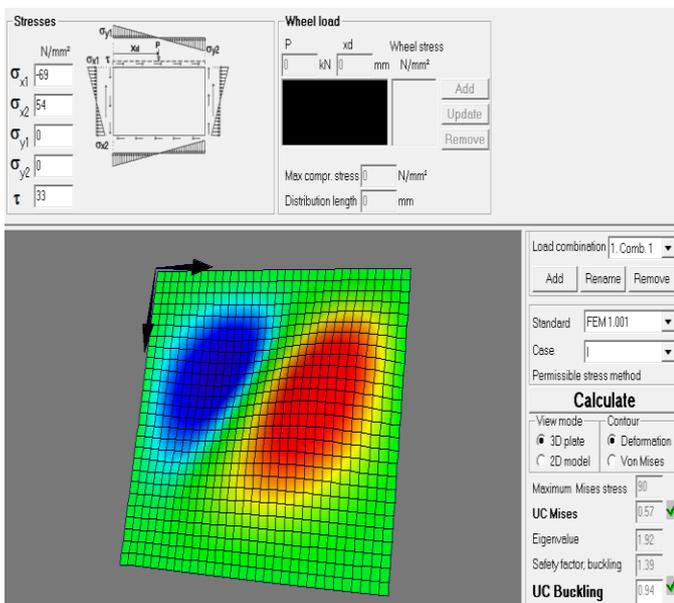


Figure-7: Buckling analysis of case-3

Tabulated result of FEA analysis:

TABLE-3 FEA Result Table

Cases	Plate Condition	UC (shall be <1)	Buckling Factor (1) (shall be >1)
Case-1	6mm thick Plate Without Stiffener	2.6	0.69
Case-2	6 mm thick Plate with stiffener	0.96	1.44
Case-3	10mm thick Plate without stiffener	0.94	1.92

8. RESULTS AND COMPARISON

Comparison of FEA & Analytical Result

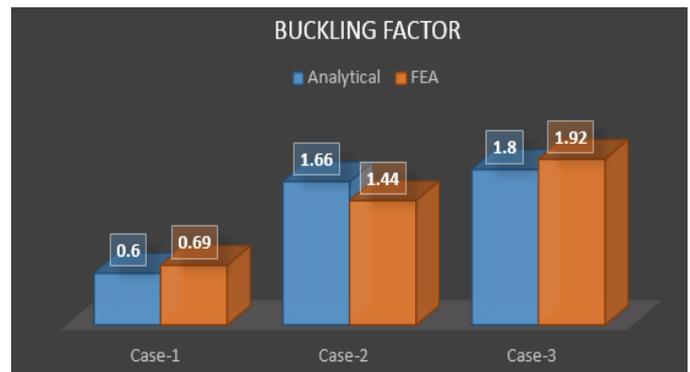


Figure-8: Buckling factor Comparison

From the above figure following points can be concluded:-

- Analytical and FEA results are almost matching with each other with a variation of 6% max.
- Ideal value of buckling factor shall be greater than 1, case-1 is not satisfying the required criteria.
- Case-2 & Case-3 satisfies the required buckling factor criteria.
- From the above results Case-2 and Case-3, both satisfies the requirement but it doesn't tell anything about the best option.

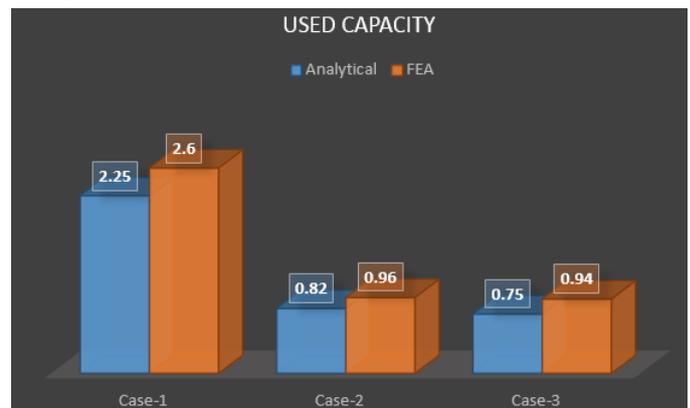


Figure-9: Used Capacity Comparison

From the above figure following points can be concluded:-

- Ideal value of used capacity shall be less than 1, case-1 is not satisfying the required criteria.
- Case-2 & Case-3 satisfies the required used capacity criteria.
- From the above results Case-2 and Case-3, both satisfies the requirement but it doesn't tell anything about the best option.

In order to find out the optimum option it is required to find out the Price and weight analysis. It is detailed now.



Figure-10: Weight and Price Comparison

From the above figure below mentioned can be concluded:-
Weight & Price wise Case-2 is optimum. Although Case-1 has the minimum weight and price but it is of no use as it is not satisfying the buckling criteria. Hence Case-2 is considered as the best option

9. CONCLUSION

Following points can be considered as the overall conclusion of this research:

- (i) Buckling strength of plate structure can be enhanced by addition of stiffener.
- (ii) There is no need of increasing the thickness of the plate to avoid buckling as the addition of stiffener can avoid the buckling with the same thickness.
- (iii) Overall weight and price can be optimized by addition of stiffener to the existing plate without changing the weight so much.
- (iv) Output of Analytical & FEA analysis are in quite good argument with each other. The difference in their value is within 12% limit and is acceptable.
- (v) Based on above points Option-2 can be selected

Above points clarify the best option in order to reduce the weight of crane by reducing the girder section dimensions.

Thus by doing this the power required also decreases to move the crane. This further reduces the running cost of the crane. Since the weight of the crane has reduced the load on the gantry girder is reduced. This helps in increasing the fatigue life of existing gantry girder. If new gantry girder is to be designed then the weight of gantry girder can also be optimized.

ACKNOWLEDGEMENT

I gratefully acknowledge Mechanical engineering department of ACEM, Pune for technical support and providing the research facilities. I would also like to thank to Dr. S.B. Padwal, Principal (ACEM, Pune) and Prof. V.R. Bajaj, HOD (Mechanical department) for their help and dedication toward my research and related research, also my friends for their directly & indirectly help, support and excellent cooperation.

REFERENCES

- [1]. J Rhodes, "Some observation of the post-buckling behavior of thin plates and thin walled members", Thin walled structures, 2003, pp. 207-226

- [2]. Rhodes J, "Buckling of thin plate members-and early work on rectangular tubes, Elsevier science Ltd, 2002, pp 87-108.
- [3]. Prasad N. Raghu, Singh Jeeoot, Buckling analysis of Rectangular plates with cutout and partial edge compression, IARJSET, 2015, pp 126-129.
- [4]. Ali Reza Pouladkhan, Emadi Jalil, Safemehr Majid, Numerical study of buckling of thin plates, World academy of science, engineering and technology, 2011, pp 152-157.
- [5]. Sang-Rai Cho, Hyun-seung Lee, Experimental and analytical investigations on the response of stiffened plates subjected to lateral collision, Sciencedirect, 2009, pp 84-95.
- [6]. Ghania Ikhenazen, Messaoud Saidani, Finite element analysis of linear plates buckling under in-plane patch loading, Journal of constructional steel research 2010, pp 1112-1117.
- [7]. Khosrow Ghavami, Mohammad Reza Khedmati, Numerical and Experimental investigations on the compression behavior of stiffened plates, Journal of constructional steel research, 2006, pp 1087-1100
- [8]. Richard Villavicencio, Sang-Rai Cho, Carlos Guedes soares, Deformation process of web girders in small-scale tanker double hull structures subjected to lateral impact, ResearchGate, 2013, pp-84-111

Reference Standard

- [9] FEM-1.001-European Standard for cranes, 1998(Chapter-2)
- [10] IS:807-Structural steel design standard, 2006(Chapter-3)
- [11] IS:3177-Crane design standard, 2006(Chapter-4)
Reference Book
- [12] Ventsel Esuard, Krauthammer Theodor, Thin Plates and shell, 2001, pp. 69-76
- [13] Timoshenko and Gere, Theory of Elastic stability., 1985(Chapter-9)
- [14] Reference Manual –Hyperstudy, 2014, pp-104-125

BIOGRAPHIES

Ashutosh Kumar is studying in ME-Mechanical design engineering at Alard college of Engineering and Management.



Dr. Rachayya R. Arakerimath is working as Dean and HOD mechanical engineering Department at GHRCOEM. He is having experience over 20 years



Vidyasagar R. Bajaj is working as HOD mechanical engineering Department at ACEM.