

## REDUCING THE STRUCTURAL MASS OF A REAL-WORLD DOUBLE GIRDER OVERHEAD CRANE

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### ABSTRACT

Overhead cranes are often subjected to heavy stresses on its structure as they carry heavy loads. Stress on its structure leads to unwanted vibrations that lead to structural damages and thereby reduced life span. In companies where the use of crane is of prime importance stresses acting on it plays a major role in its structural behaviour. One way of reducing its stresses and there by its life span is by optimization and mass reduction. The main aim here is to reduce the structural mass of a real-world double girder overhead crane, through the use of modern computer modelling and simulation methods and applications. The structural mass reduction are designed and verified by structural static stress simulations.

**KEYWORDS:** overhead crane, stresses on Double Girder Overhead Crane, structural optimization in a Double Girder Overhead Crane, Stress Analysis of Crane Hook

### I. INTRODUCTION

There are various types of overhead cranes with many being highly specialized, but the great majority of installations fall into one of three categories:

- a) Top running single girder bridge cranes
- b) Top running double girder bridge cranes
- c) Under-running single girder bridge cranes

For high capacities, over 30 tons, usually Electric Overhead Cranes (EOT) are the preferred type. In this work we prefer a Top running double girder bridge crane.

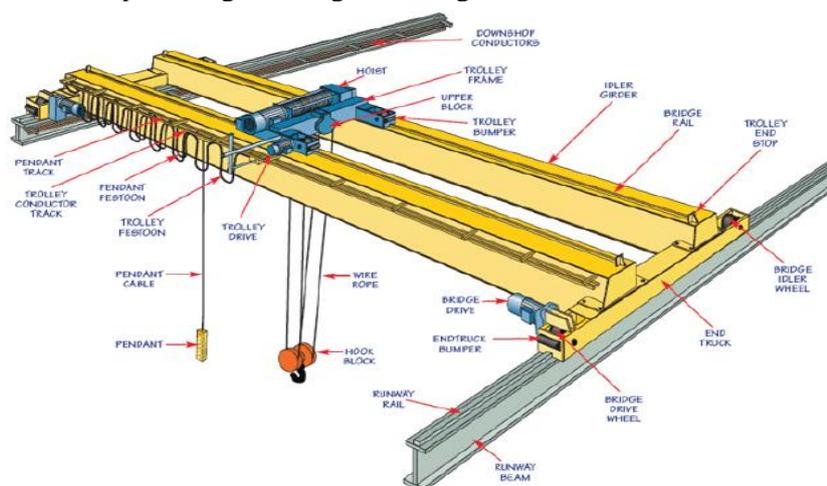


Figure. 1 Double girder electric overhead crane

The basic components in an EOT crane are: 1) Bridge 2) End trucks 3) Bridge Girder(s) 4) Runway 5) Runway Rail 6) Hoist 7) Trolley 8) Bumper (Buffer).

## II. GUIDELINES FOR SELECTING AN EOT CRANE

To select the correct crane envelope that will fit in the building foot print, the user must identify and pass on some key information to the supplier. The following are the various considerations for selection of an EOT crane a) Crane capacity, b) Required lifting height, c) Runway height, d) Clearance, e) Building Width f) Clear Span, g) Building Height, h) Runway Size & Length, i) Hook Approach & End Approach.

## III. STRUCTURAL DESIGN CONSIDERATIONS

A crane structure is subjected to following types of loads (forces):

a) **Dead Loads** – A load that is applied steadily and remains in a fixed position relative to the structure. The dead load is a steady state and does not contribute to the stress range.

b) **Live Load** - A load which fluctuates, with slow or fast changes in magnitude relative to the structure under consideration.

c) **Shock Load** – A load that is applied suddenly or a load due to impact in some form. All these loads induce various types of stresses that can be generally classified in one of four categories:

- Residual stresses
- Structural stresses
- Thermal stresses
- Fatigue stresses

Of all these stresses, the fatigue stresses demand the maximum attention. Crane runway girders are subjected to repetitive stressing and un-stressing due to number of crane passages per hour (or per day). Since it, is not easy to estimate the number of crane passages, for design purposes it is assumed that the number of stress fluctuations corresponds to the class of the crane as specified in the codes.

When designing structures supporting crane, the main loads and forces to be considered are:

a) **Vertical loads** – The predominant loading on the crane supporting structure is vertical loads and is usually supplied by manufactures by way of maximum wheel loads.

These loads may differ from wheel to wheel depending on the relative positions of the crane components and the lifted load:

b) **Side thrust lateral loads** - Crane side thrust is a horizontal force of short duration applied transversely by the crane wheels to the rails. Side thrust arises from one or more of:

- Acceleration and deceleration of the crane bridge and the crab
- Impact loads due to end stops placed on the crane runway girder
- Off-vertical lifting at the start of hoisting.
- Tendency of the crane to travel obliquely.
- Skewing or crabbing of the crane caused by the bridge girders not running perpendicular to the runways. Some normal skewing occurs in all bridges.
- Misaligned crane rails or bridge end trucks.
- The forces on the rail are acting in opposite directions on each wheel of the end carriage and depend on the ratio of crane span to wheel base.

c) **Traction Load** - Longitudinal crane traction force is of short duration, caused by crane bridge acceleration or braking.

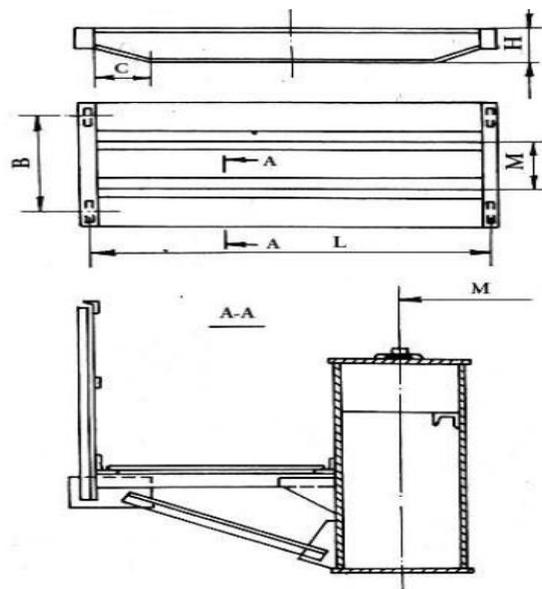
d) **Bumper Impact** - This is longitudinal force exerted on the crane runway by a moving crane bridge striking the end stop.

## IV. BRIDGE CRANE STRUCTURAL CALCULATIONS

A solid walled construction has been taken into consideration where the bridge is welded to the end trucks. The major calculation pertain to double girder overhead crane 50/12,5, produced by NEW TECHNO INDUSTRIES–CHENNAI. The crane has normal duty cycle main load capacity 50 tons and auxiliary load capacity 12,5 tons. Some of the major crane parameters are listed in Table 1.

**Table 1** Parameters of crane, type 50/12, 5

Crane span	$L = 28,5m$	Main girder cross-section area (+ rail)	$A = 0,05056m^2$
Main girder mass	$M = 11523kg$	Crab mass (no ropes)	$M_{c1} = 8200kg$
Area moment inertia of the main girder section	$J_z = 0,02m^4$	Crane structure material	CT 3
<b>Hoisting velocities</b>		<b>Travel velocities</b>	
Main hoist	$v_0 = 0,04m/s$	Crab	$v_2 = 0,333m/s$
Aux hoist	$v_1 = 0,233m/s$	Crane	$v_3 = 0,8m/s$
Main hoist capacity	$Q = 50t$	Aux hoist capacity	$Q = 12,5t$
Mode of operation	Average	Total bridge mass	28173kg



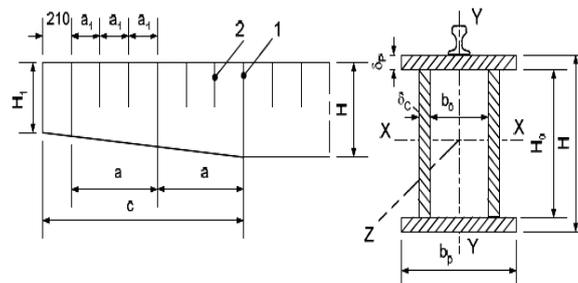
**Figure. 2** Metal structure with major dimensions

Bridge span is given  $L = 28500$  mm; crab base is given  $M = 2850$ mm; Crane base  $B$  is predefined by the relation.

$$B \geq \frac{L}{5 \div 7} = \frac{28500}{5 \div 7} = 5700 \div 4070mm.$$

**B = 4600mm.**

All other dimensions are determined by recommendatory relations.



**Figure. 3** Main girder partial view and cross section

The main elements and dimensions on the main beam are as follows:

1- main diaphragm, 2- auxiliary diaphragm, H- girder height, H<sub>1</sub> – Height of supporting cross section, C- Chamfer length, b<sub>p</sub> – Flange width, δ<sub>C</sub> – Plate thickness, δ<sub>P</sub> – Flange thickness, a- main diaphragm, a<sub>1</sub>- auxiliary diaphragm distance

The calculations for the various parameters are as shown below;

$$H = \left[ \frac{1}{16} \div \frac{1}{20} \right] L - \text{accepted equal to } 1535\text{mm}$$

$$H_1 = [0,3 \div 0,6] H - \text{accepted equal to } 840\text{mm}$$

$$c = [0,1 \div 0,2] L - \text{accepted equal to } 3900\text{mm}$$

$$b_p = [0,55 \div 0,33] H - \text{accepted equal to } 500\text{mm}$$

$$\delta_C \geq \frac{H}{180 \div 240} - \text{accepted } 8\text{mm (at the presence of longitudinal diaphragms)}$$

The following are accepted as:

$$\delta_p = 20\text{mm}, a = 1845\text{mm}, a_1 = 615\text{mm},$$

## V. MAIN GIRDER CALCULATIONS

Main girder calculations are performed considering the influence of constant loadings and moving loadings. Constant loadings are: main girder weight - Girder as well as weights of all components connected to the girder such as – cab, deck, fences, driving units, etc.

One of the moving loadings is the crab wheels loading when the crab moves along the bridge.

There must be considered also inertia loadings due to crane starting/stopping as well as any torsion loadings. When the crane works in the open, there must be included the wind loadings.

### Loading evaluation

a) Main girder weight

It is assumed to be distributed loading with intensity

$$q = \varphi \cdot \frac{G_M}{L} [N / m]$$

$$G_M = G_{girder} + G_{deck} + G_{others}$$

$$G_{girder} = 134 \cdot 10^3 N - \text{main girder weight}$$

$$G_{deck} = 20 \cdot 10^3 N - \text{maintenance deck weight}$$

$$G_{others} \approx 10 \cdot 10^3 N - \text{weight of fences, power supply, etc.}$$

$$L = 28,5 m - \text{bridge span}$$

$$\left. \begin{array}{l} \varphi = 1,1 \rightarrow v = 60 m / \text{min} \\ \varphi = 1,2 \rightarrow v > 60 m / \text{min} - \text{coefficients accounting for thrusts during crane motion} \\ \varphi = 1,3 \rightarrow v > 120 m / \text{min} \end{array} \right\}$$

#### b) Moving loadings

These are defined according to figure

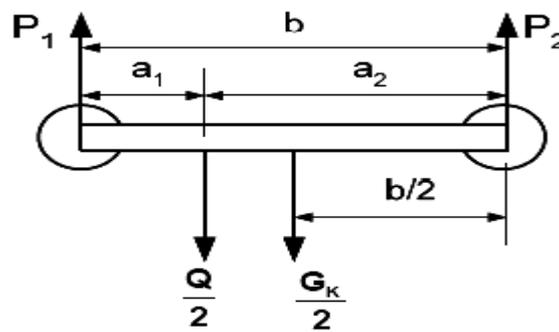


Figure. 4 Moving loadings evaluation scheme

For general load Q position ⇒

$$P_1 = \frac{G_{crab}}{4} + \psi \cdot \frac{a_2}{2b} \cdot Q$$

$$P_2 = \frac{G_{crab}}{4} + \psi \cdot \frac{a_1}{2b} \cdot Q$$

When the load Q center of mass coincides with the crab center of mass ( $a_1 = a_2$ )

$$P_1 = P_2 = \frac{R}{2} = \frac{1}{4}(G_{crab} + \psi \cdot Q)$$

$\psi = 1, 2$  - dynamic coefficient for normal duty cycle

2.2.2. Main calculations. I<sup>st</sup> calculation scheme

Calculations are performed by the main calculation schemes:

I – first calculation scheme – sharp load lift at stationary crane

II – second calculation scheme – sharp stop of the crane with lifted loading

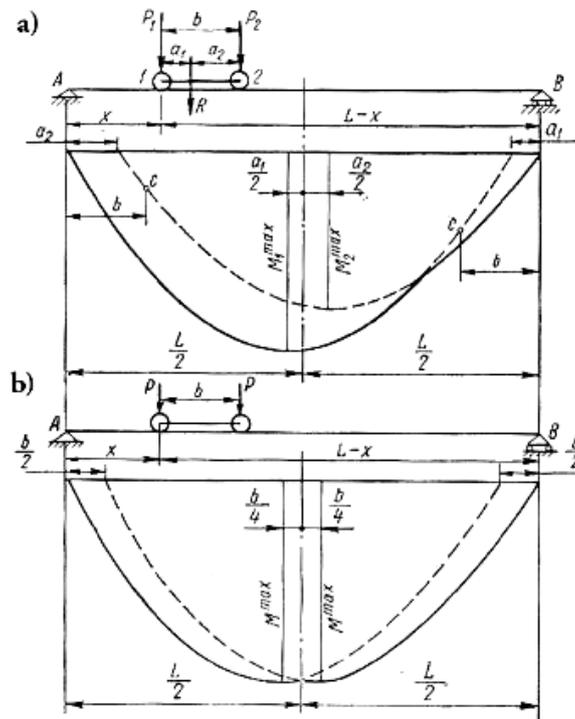


Figure. 5 Main girder calculation scheme due to moving loadings a – unequal loadings; b – equal loadings

Calculations are proceeded as shown in figure 5. Now the difference, here is that loadings are applied in the vertical and horizontal planes.

- Loadings in vertical plane

$$q_v = \varphi \frac{G_M}{L}; \quad R_1 = R_2 = \frac{1}{4}(G_{crab} + Q)$$

$$M_{q_v} = \varphi \cdot \frac{G_M \cdot L}{8}; \quad M_P = \frac{1}{2} \frac{(G_{crab} + Q)}{4 \cdot L} \cdot \left(L - \frac{b_1}{2}\right)^2$$

$$M_{bending}^{V, \max} = \frac{\varphi \cdot G \cdot L}{8} + \frac{(G_{crab} + Q) \left(L - \frac{b_1}{2}\right)^2}{8 \cdot L}$$

$$\sigma_{bending}^{II} = \frac{M_{bending}^{\max}}{W_x}$$

- Loadings in horizontal plane

When the crane or the crab starts/stops in the regular way, certain inertia force that bring additional loading to the construction.

Inertia forces could be calculated as follows:

$$P_{inertia} = \frac{G}{g} \cdot a_{ave}$$

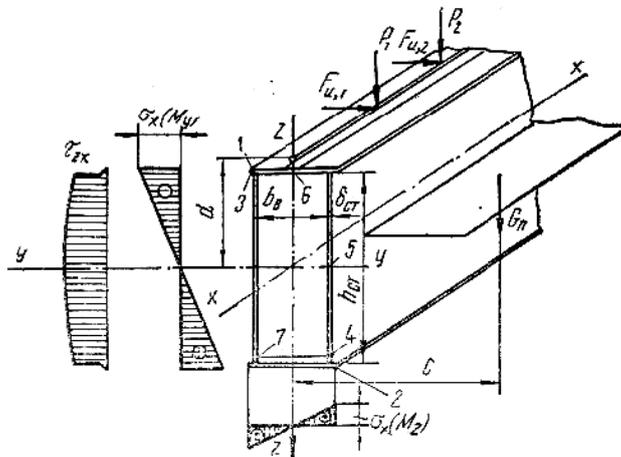


Figure6. Stresses acting on Main Girder

$$M_{bending}^{\max} = \frac{1,1 \cdot 164 \cdot 10^3 \cdot 2850}{8} + \frac{635 \cdot 10^3 \cdot 742,5 \cdot 10^4}{8 \cdot 2850} = 271059,5 \cdot 10^3 \text{ N.cm};$$

$$M_{bending, inertia}^{(F)} = 20679,2 \cdot 10^3 \text{ N.cm}; \quad M_{bending, inertia}^q = 6426,8 \cdot 10^3 \text{ N.cm};$$

$$\sigma_{(z)} = 104,25 + 41,06 = 145,31 \text{ MPa (rail included);}$$

$$\sigma_{(z)} = 130,6 + 41,06 = 171,7 \text{ MPa (rail not included);}$$

## VI. DESIGN AND ANALYSIS OF MAIN GIRDER

The design and analysis for the main girders has been carried out and a comparative study has been done.

There are two identical main girders. Each one is 28100mm long and consists of:

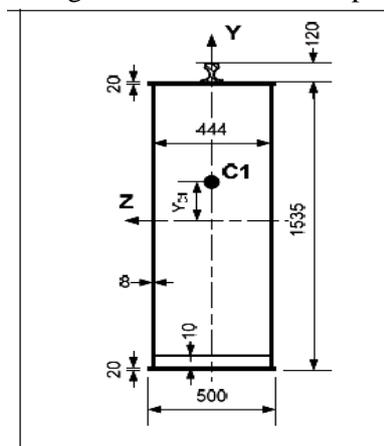
- top flange and bottom flange (thickness 20mm, width 500mm).
- side plates (thickness 8mm).
- main and aux diaphragms (thickness 6mm).
- rail (type KP70) fixed by sleepers to the main girder's top flange - 52 -

The mass of a single main girder is 11523kg. The major components of the girder are listed in Table 2 and the cross-section parameters of the girder are shown in Fig. 7.

**Table 2** Major Components in a girder

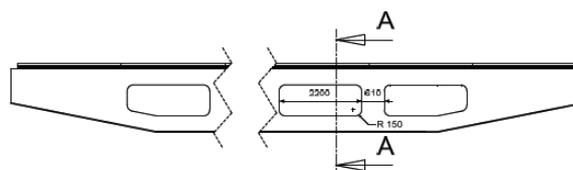
Component name	Quantity
Side plate	2
Top flange	1
Bottom flange	1
Diaphragm1	30
Diaphragm2	2
Diaphragm3	2
Diaphragm4	12
Crab runway rail	2
Sleepers	102

The cross sectional view of the main girder indicates various parameters



**Figure. 7** Main girder cross-section parameters

The main girders are drawn in various views with and without side plates.



**Figure. 8** Main girder model2 (front view)

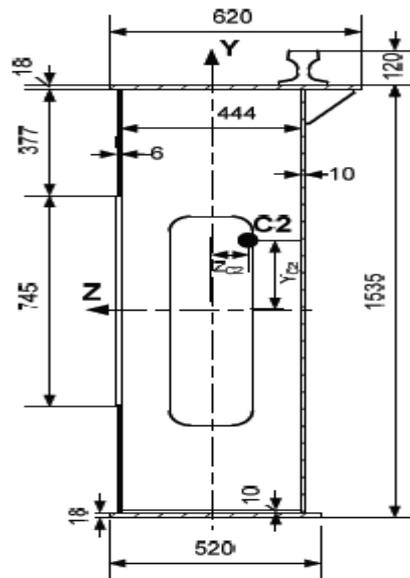


Figure.9 Main girder model2 cross-section A-A parameters

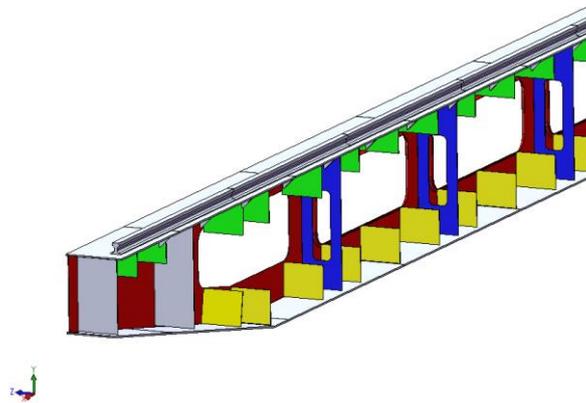


Figure.10 3-D isometric view of the main girder model3 (side plate hidden)

An isometric view of main girder (side plate hidden) is drawn using CATIA.

All three models have different parameters of their main girder mid cross-sections. For the purpose of better analyzing them, all major parameters such as centroid position, area moments of inertia, area and girder mass are tabulated as shown.

Table 3. Main girder mid cross-section parameters for the three models

Model	Zc [cm]	Yc [cm]	Jz $\times 10^5$ [cm <sup>4</sup> ]	Jy $\times 10^5$ [cm <sup>4</sup> ]	Area A [cm <sup>2</sup> ]	Girder mass [kg]	Lighten %
1	0.00	10.95	19.92	1.64	506.21	11523	0
2	-8.99	14.78	19.72	1.44	467.35	10880	5.6
3	-8.87	14.72	19.75	1.45	469.25	10906	5.4

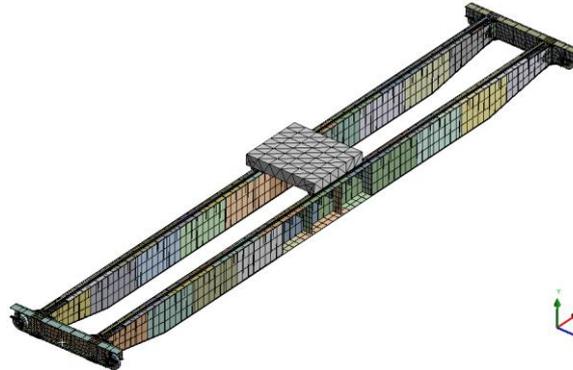
Jz, Jy – measured with respect to corresponding point C

The total lightening for both girders:

model2 – 1286kg

model3 – 1234kg

It is evident that model 1 has the heaviest girder – 11523kg. The introduction of the new main girder design, through model 2 and 3 lightens the girder with an average of 5.5%. It means that the crane mass could be decreased with 1200 to 1300kg, by just making these main girder redesign procedures. Table 3 also shows that the new designs follow closely the parameters of the basic crane model. The area moments of inertia, critical for the stressed behaviour, do not deviate significantly, which is an indication that the new models should have stressed behaviour similar to the basic crane. It is compulsory to check for this stress response by using the FE method.



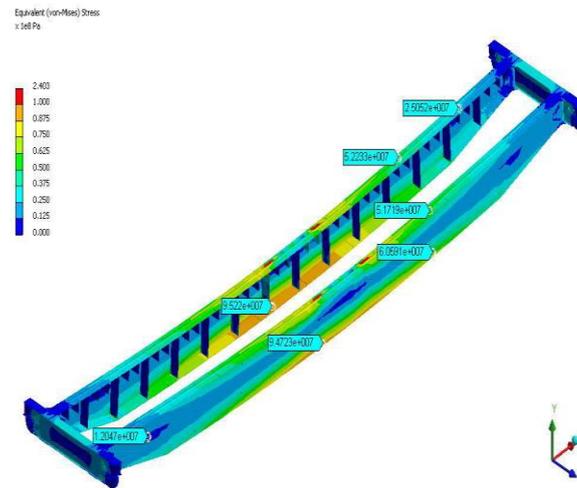
**Figure. 11** 3-D basic model final mesh (some main girder and end truck plates are hidden)

The mesh consists of 38962 finite elements and 72937 nodes. The major element types used are:

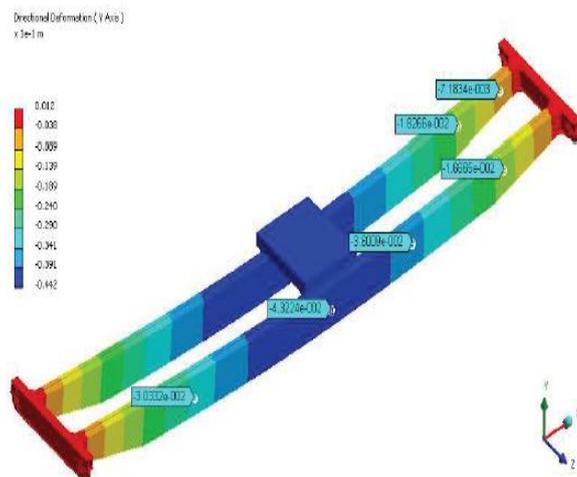
- 10-Node Quadratic Tetrahedron Solid187- 10-Node Tetrahedral Structural Solid
- 20-Node Quadratic Hexahedron Solid186 - 20-Node Hexahedral Structural Solid
- 20-Node Quadratic Wedge Solid186 - 20-Node Hexahedral Structural Solid
- Quadratic Quadrilateral Contact Conta174 - Hi-order Surface to Surface Contact
- Quadratic Quadrilateral Target Target170 - Surface Contact Target;
- Quadratic Triangular Contact Conta174 - Hi-order Surface to Surface Contact

**Table 4.** Properties of Steel bridge structure

Elastic modulus	$E = 2 \times 10^{11} Pa$
Poisson's ratio	$\nu = 0.3$
Density	$7850 kg / m^3$
Tensile yield strength	$250 MPa$
Tensile ultimate strength	$460 MPa$

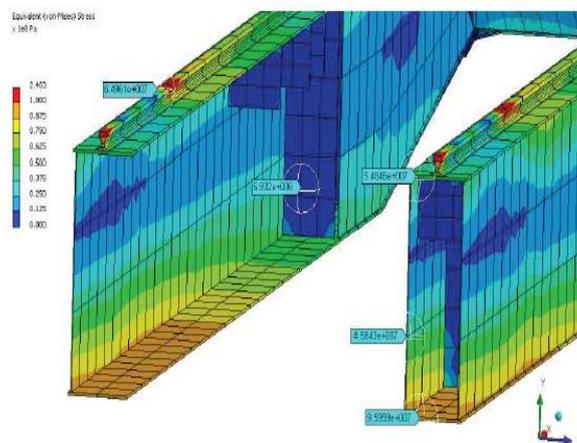


**Fig.12** Equivalent (von-Mises) stresses in the bridge structure (crab and side plate of the far girder are hidden; stress values are measured at certain points)



**Figure. 13** Vertical (Y-axis) deformation of the crane (Deformation values are measured at certain points)

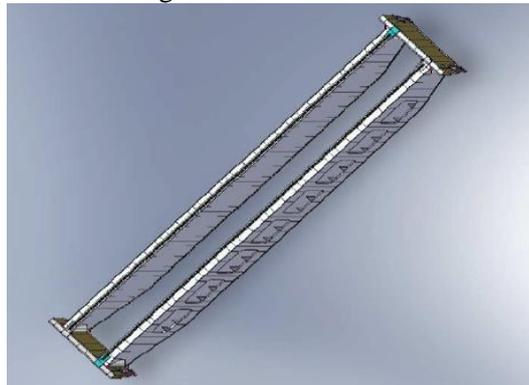
The model allows us to measure at points and cross-sections that are inaccessible to the real gauging experiments, Figure. 14



**Figure. 14** Equivalent stresses measured at points on the diaphragms, inner walls of side plates and main girder mid cross-section

## VII. CONCLUSION

From the results obtained using analytical and from the software oriented results suggest that the two models – model2 and model3 of lighter crane structure have been designed in which the modified side plate has the same thickness but two types of holes are cut – simple holes and rimmed holes. These new designs succeed in reducing the model1 crane mass respectively by 5.6% and 5.4%. The new models, however, are set to various checks in order to prove their conformity to theoretical considerations and prove that their static response is similar to that of the original crane. The varieties of checks go primarily through stress analyses, horizontal and vertical deflection analyses of the bridge. The new design models – model2 and model3, are set to various checks in order to prove their conformity to theoretical considerations and prove that their static response is similar to that of the original crane. The varieties of checks go primarily through stress analyses, horizontal and vertical deflection analyses of the bridge. The models proved to conform to theory and their static structural response preserves the response of the original crane structure.



**Figure 15.** Model2 is one of the options to reduce the bridge mass

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