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Research on effect of horizontal load and steel plate size up to the optimal size of double bridge rectangle girders of crane

Nguyen Hong Tien[1], Le Van Nghia[1], Tran Anh Son[1]
[1]*Faculty of Mechanical Engineering, Hanoi University of Industry, 298 Cau Dien street, Bac Tu Liem District, Hanoi, Vietnam*
Corresponding Author: Le Van Nghia
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Abstract: This paper presents research findings related to the optimal design of metal structures for double rectangle girder cranes, using trolley mounted on rails fitted on the centre of upper edge of girder. The optimum objective is to minimize weight of the bridge girder with constraints on strength, stiffness and local stability of the metal structures. Technological constraints are also taken into account by restricting thickness and other dimensions of steel plate formed bridge girder in a set of standard or preferred values. The cranes with different load and aperture types are considered to evaluate influence of several factors such as type of load for design (girder weight, cross-inertial load), structural parameters (thickness of steel plates, steel plate sizes, crane aperture) on optimum dimensions of bridge girder cross sections.
Keywords: Optimal design, Rectangular girder, Crane.

I. INTRODUCTION

Crane is the most common type of crane used to mechanize and lift heavy objects in workshops and warehouses. Crane is widely used and convenient to lift heavy objects, goods in mechanical workshops, warehouses, yards.

Metal structure inside crane accounts for 60-80% of the machine's total weight. Therefore, it is very important to select materials and calculate how durable metal structures are during working to achieve economic targets. Metal structures usually have two main forms: seamless and rectangular, connecting those structural parts together by welding or riveting.

In recent years, the optimal design of structural steel crane has an important role and significance, in order to determine reasonable size of the structures in ensuring sufficient strength with the smallest weight, corresponding to the minimum material cost, not only allows reducing product costs but also good impact on features of crane structures. Such a request, it is extremely necessary to calculate structures with optimal theory. This paper only put into issue and calculates 16 tone loads and 4 tone cars with aperture of 16m. Other cases can be appplied the similar calculation basis.

II. CALCULATION BASIS

2.1 Theory basis

Cranes are widely used in industries to move heavy objects vertically and horizontally at restricted distances. Many standards [1, 9, 10] and documents [2,3,7,8,11] mentioned the design and use of this type of device, which showed that they are important to industry. A crane is generally structured of structure mechanisms for necessary movements and a metal structure for support these structures. Main metal structures of crane consist of bridge girders and two end trucks. Numbers of bridge girder can be one (single girder crane) or two (double girder crane). For double girder crane, lifting loads are handled by a runway trolley on rails mounted on the bridge girders in open type I or rectangular girder. The rails are arranged in the centre of upper boundary block or side walls of girder as shown in Figure 1 [2,3,11]. For rectangular girders with rails centered in the upper boundary block, the girder drive’s cross section is vertical symmetry across center of rail.

Metal structures weight a very large part of overall weight of crane. For this reason, mass reduction of metal structure plays an important role in reducing the overall cost of cranes.

The calculation of metal structure design is usually carried out in 2 steps: calculate design to determine dimensions of structure elements and test strength and stiffness (deflection, variable off time) and stability (overall and local). Loads impacting to structures include many types but probability of simultaneous occurrence of all types of loads is not possible, so they are often combined into computational load cases. Testability is applied to all load combinations.

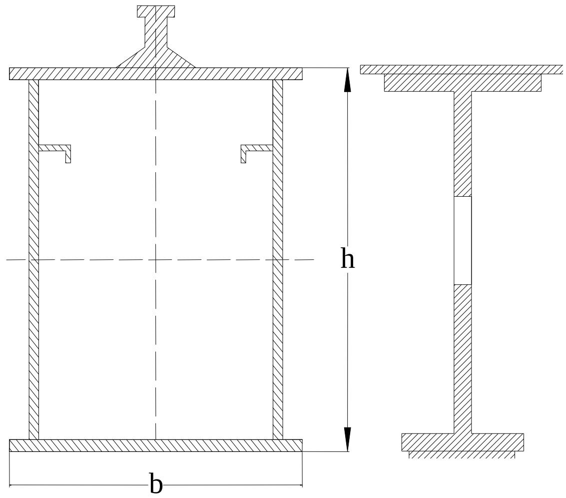

Figure 1: Crosss section of bridge girder of double girder crane

Structure elements are determined dimensions via experienced formulas [2,3,11] or by building and solving the optimal problem. The target function used is the girder weight [4,5,6,11], while the constraints are considered satisfactory requirements of strength, stiffness and local stability. In order to simplify the optimal issue, [11] modeled cross section of element of 2 symmetric masses, ignoring the thickness difference of the upper and lower boundary blocks. The studies usually consider cases of vertical load-bearing structures, ignoring horizontal inertia loads. On the other hand, technological limitations are also not taken into consideration, resulting in unrealistic results, such as steel plate's thicknesses that cannot take any odd value but must be chosen from standard values. The research's objective is to evaluate the effect of some load parameters such as self structure load, horizontal inertial load as well as the effect of structural parameters such as ignoring discontinuity of steel plate's thickness, aperture of crance on optimal dimension of girder cross-section.

2.2 Calculation basis

For double rectangular girder crance, total girder weight can be calculated approximately according to the following formula:

$$m = 2.A.L.C_s.d_m \qquad (1)$$

where: A – cross-section of the girder, (m2); L -girder aperture, (m); Cs – coefficient refers to the influence of reinforcement plate; dm – density of fabricated material, (kg/m3) (with steel material dm = 7860kg/m3).

The above equation shows that the girder weight is directly proportional to sectional area of girder, so optimal issue of girder weight is brought to optimal issue of girder sectional area. Sectional area of rectangular girder is placed on the centre of upper boundary block (at central cross section) with sizes of elements, loads and bending stress distribution shown in Figure 2.

Sectional area of girder is calculated as follow:

$$A = B(t_T + t_D) + h(t_1 + t_2) \qquad (2)$$

where: B – width of girder cross section, (m); h – height of girder cross section, (m); t_T – thickness of upper boundary block, (m); t_D - thickness of lower boundary block, (m).

height of girder cross section:

$$H = h + t_T + t_D \qquad (3)$$

The optimal problem is stated as follows:

Target function:*Cross section A →min*

Constraints:*Satisfy conditions of durability, stiffness and local stability of the formed plates, thickness of steel plate under standard series and boundary dimensions of sections to priority ranges.*

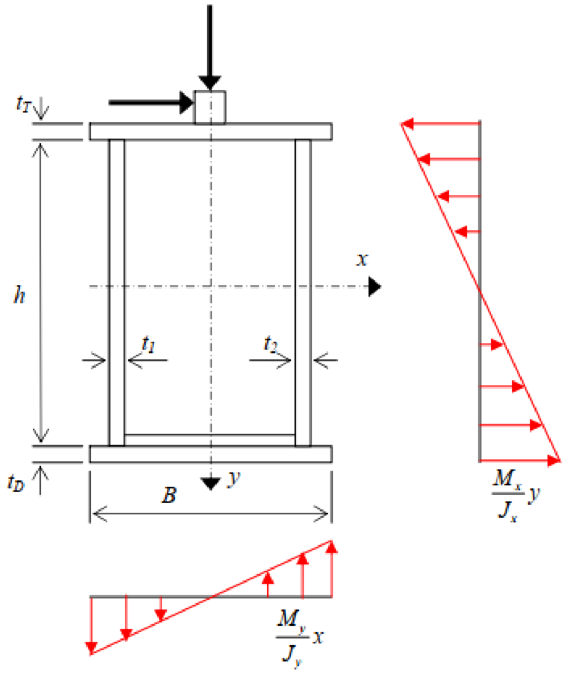

Figure 2: Dimensions of girder cross-section, loads and stresses.

The strength's constraint is shown by ensuring stresses in sections which are smaller than the allowable values. At cross section in the centre of girder are dangerous bending stress, which has the maximum value at sucking points, the following conditions should be satisfied:

$$\sigma_{\max} = \frac{M_y}{J_y}|x|_{\max} + \frac{M_x}{J_x}|y|_{\max} \leq [\sigma] \tag{4}$$

At bending section of girder, the main stress is cutting one, and the following condition is satisfied:

$$\tau_{\max} = \frac{Q_y}{h_0(t_1 + t_2)} \leq [\tau] \tag{5}$$

In these expressions M_x, M_y are bending moments around the x and y axes at the central cross-section of girder, Qy is the cutting force at the end of the girder (position connected to end truck- where h0 usually equals 0,5 h). These quantities depend on the load acting on the girder (lift load, vehicle weight, self girder weight, inertial load ...), according to documents [2,3,11]. In practical calculations, the girder horizontal load due to inertia at start-up or braking of bridge moving mechanism is usually taken 10% compared to the vertical. Quantities Jx and Jy are the inertial moment of the girder cross, which is determined as per document on material strength. Permissible bending and shear stress [σ], [τ] are selected by fabrication material.

The stiffeness constraint is expressed by limiting deflection of girder in y direction and variable off time [11]:

$$y \leq [y] \text{ và } t \leq [t] \tag{6}$$

The local stability of the side walls is ensured if slenderness of plate walls are less than allowed value:

$$\lambda = \frac{t_{1,2}}{h} \leq [\lambda] \tag{7}$$

Value of permissible slenderness [λ] depends on the stresses in the plates, yield limit of materials and arrangement method of reinforcement plate for wall plates [11].

Finally, apart from selecting standard thickness, plates shouldn't be too thin. In this research, minimum thickness of the selected plates is 5 mm.

The optimal parameters of girder cross sections are determined from solving the above optimization problem. This research is applied Generalized Reduced Gradient (GRG2) method integrated in Solver tool of MS Excels software. Survey subjects are 2 girder cranes with aperture from 5 m to 32 m, 16-tone load, 4-tone car, working mode A6, horizontal load from 0% to 25% compared to vertical load. The girder itself is assumed to be uniformly distributed over girder length. The girder is stiffened only by horizontal stiffeners, the distance between stiffeners is almost 2 times the girder height.

III. FINDINGS

3.1. Effect of horizontal load on the optimum cross section

In order to evaluate the effect of horizontal load on the optimum parameters of the bridge girder section, the loading model in Figure 2 is used, including vertical and horizontal loads, ignoring girder itself weight. The horizontal load is varied from 0 to 25% of the vertical load. The problem is solved on a discrete domain according to the standard dimensions of plate thickness and preferred size of structure. Findings of 16m apertune is shown in Table 1 and graph in Figure 3.

Table 1: Effect of horizontal loads on optimum findings

My/Mx, %	A dm^2	Ratio B/H	B mm	H mm	t_1 mm	t_2 mm	t_T mm	t_D mm
0.0	1.290	0.29	240	830	5	5	10	10
2.5	1.290	0.29	240	830	5	5	10	10
5.0	1.290	0.29	240	830	5	5	10	10
7.5	1.296	0.43	350	820	5	5	7	7
10.0	1.296	0.43	350	820	5	5	7	7
12.5	1.300	0.5	410	820	5	5	6	6
15.0	1.317	0.49	400	810	5	5	7	6
17.5	1.346	0.54	430	800	5	5	7	6
20.0	1.362	0.57	450	790	5	5	7	6
22.5	1.385	0.58	460	800	5	5	7	6
25.0	1.408	0.61	500	820	5	5	6	6

It is obvious that the horizontal load acting on the girder will increase the section size. When the horizontal load is large, its effect on the section is significant with torque $M_y = 20\ \%M_x$, sectional area is increased by nearly 6%, and when $M_y = 25\ \%M_x$, this sectional area increases by nearly 10%. My torque depends on values of the inertial forces (due to vehicle, load and girder weight), depending on acceleration of engine and braking mechanism of bridge moving. According to [11], torque $M_y = 0{,}8.M_x.a/g$, where *a* is the engine acceleration, *g* is gravitational acceleration. Therefore, when designing cranes working with great acceleration, attention should be paid to the influence of this horizontal load. For cranes working with non-great acceleration (M is about 10% Mx), the influence of horizontal inertial force can be neglected when designing cross section.

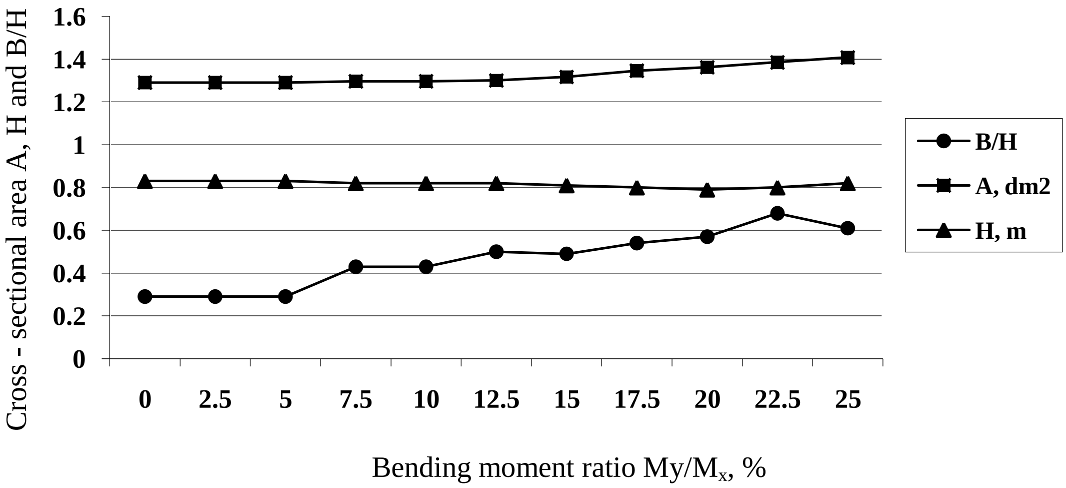

Figure 3: Effect of horizontal load on the optimum cross section of girder

3.2. Effect of horizontal load on the optimum cross section of girder

To assess how girder weight impacts, meaning that we have solved the optimal problem for two cases: taking and not taking into account girder weight for 16 tone crane and 4 tone truck, horizontal load takes 10% compared to vertical load. The result is shown in Figure 4.

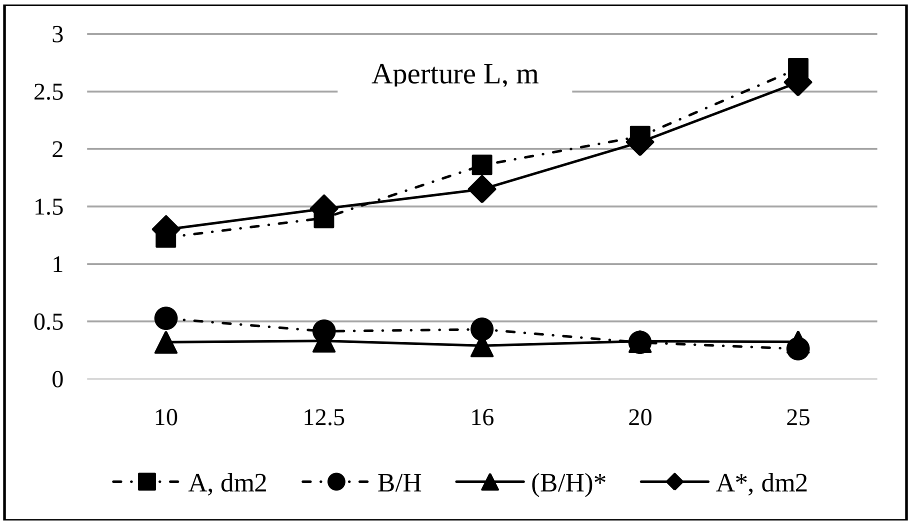

Figure 4: Effect of girder weight A*, (B/H)* - in the case of ignorance of girder weight.

Girder weight does not much affect the optimum cross-sectional area of girder. When ignoring girder weight, the cross-sectional area is reduced negligibly, its largest value is only about 4%. However, cross section shape has a significant change, B/H ratio decreases if girder weight is ignored, so the girder shall be calculated higher, especially when the aperture is large,10% more than an aperture of 32 m. Therefore, in order to have a reasonable structure, we need to consider girder weight during design process.

3.3 Effect of steel plate dimension on the optimal cross section

In actual rectangular girder fabrication, structural components (wall and reinforcement plate) are cut from standard steel plate. Therefore, these plate’s thickness isn’t any but of the steel manufacturer's standard range. Other dimensions such as height, width is also in manufacturer's priority range. With constraints of structure with 16m aperture crane, the results are shown in Table 1. Result of optimal problem when ignoring above constraints are present in Table 2.

Table 2: Optimal results with constraints of steel plate dimension

M_y/M_x, %	A dm^2	Ratio B/H	B mm	H mm	t_1 mm	t_2 mm	t_T mm	t_D mm
0.0	1.273	0.200	176.91	884.54	5.34	5.34	9.89	9.89
2.5	1.273	0.200	176.91	884.54	5.34	5.34	9.89	9.89
5.0	1.275	0.275	241.84	880.41	5.35	5.35	7.22	7.22
7.5	1.277	0.341	296.26	868.36	5.28	5.28	6.59	6.00
10.0	1.283	0.397	335.42	845.24	5.14	5.14	6.73	6.00
12.5	1.291	0.453	373.25	824.57	5.01	5.01	6.79	6.00
15.0	1.313	0.490	395.26	806.25	5.00	5.00	7.15	6.00
17.5	1.337	0.540	427.88	792.66	5.00	5.00	7.02	6.00
20.0	1.359	0.563	451.77	803.03	5.00	5.00	6.60	6.00
22.5	1.381	0.583	474.31	813.07	5.00	5.00	6.23	6.00
25.0	1.402	0.61	494.34	820.62	5.00	5.00	6.00	6.00

If compared with the results in Table 1, the optimal cross-sectional area is reduced. However, it is not possible to use the steel plate at thick as calculated (5.34 mm; 7.22 mm; 9.89 mm etc.), its height and width are also not realistic. So, after the results in Table 2 are shown, these values are often rounded, and because it isn't sure for down rounding whether shall reduce strength, stifffness and local stability, the designer often rounds up, leading to significant increase in the cross-sectional area, and meaning of the optimal problem is also reduced. Besides, there are some other methods to check optimal dimension. The followings are some results more:

Table 3: Girder calculation result for 16 tone load with rounded dimension [17]

Aperture L	Q = 16 tone				
	10m	12.5m	16m	20m	25m
Width B (mm)	250	290	300	370	410
Height H (mm)	770	870	1020	1130	1270
Side Wall thickness t1,2 (mm)	6	6	7	7	8
Upper wall thickness T_T (mm)	7	7	8	8	9
Lower wall thickness T_D (mm)	6	6	7	7	8
Sectional area A (dm^2)	1.2334	14054	18570	21160	27018
Bending stress in the centre of girder (MPa)	189.80	181.34	156.56	148.19	129.51
Cutting stress of end truck (MPa)	12.66	11.18	8.17	7.37	5.74
Deflection (mm)	12.58	16.74	20.00	27.13	33.05

Table 4: Girder calculation result as per experienced method for 16 tone load with roudned dimensions [17]

Apertune L	Q = 16 tone				
	10m	12.5m	16m	20m	25m
Width B (mm)	380	350	420	360	340
Height H (mm)	720	840	970	1130	1290
Side Wall thickness t1,2 (mm)	6	6	6	7	8
Upper Wall thickness T_T (mm)	6	7	6	7	8
Lower Wall thickness T_D (mm)	6	7	6	7	8
Sectional area A (dm2)	1.3056	14812	16536	20664	25824
Bending stress in the centre of girder (MPa)	159.5	158.8	159.2	153	143.9
Cutting stress of end truck (MPa)	13.54	11.6	10	7.36	5.642
Deflection (mm)	12.19	15.76	22.79	28.43	35.71

IV. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

When optimizing design of the main girder cranes, consideration should be given to constraints on the standard or priority size range of structural elements such as plate thickness, height, width of girder to elimimate unrealistic solutions.

The optimal cross section is influenced by many factors, but each has different levels of influence. The effect of horizontal load and girder itself on the optimal cross-sectional area is negligible, but ignoring these quantities, it will be increased width of girder, especially when its aperture is large and movement is at high acceleration.

4.2. Recommendations

This approach can also apply to optimal designs of other similar structures. However, to finish optimal problem, it is necessary to consider load combinations, together with suitable diagram selection and evaluation.

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