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Design and Optimization of the Geometric Properties of a Crane Hook

Niranjan Desai, Nuri Zeytinoglu

Department of Mechanical and Civil Engineering, Purdue University Northwest, Westville, IN, USA
Email: desai39@pnw.edu, nz@pnw.edu

Abstract

Cranes are used in many industries to transport heavy loads from one position to another. These loads are fastened to a crane hook which makes it a critical aspect of the crane itself. The purpose of this study is to optimize the performance of the crane hook based on stress, geometry, and weight. A single load is considered and multiple cross sections—including square, circular, and trapezoidal—are analyzed. The analysis takes the form of theoretical calculations and finite element analysis through the use of SOLIDWORKS Simulation. The trapezoidal cross section is determined to be the most efficient and the weight and stress of this cross section are optimized by varying the cross sectional parameters.

Keywords

1. Introduction

The stress and deflection in the crane hooks for this study are determined both using theoretical calculations as well as finite element analysis simulation in SOLIDWORKS. The theoretical calculations are based on **Figure 1** shown below. It is possible to calculate the eccentricity (e) and normal stress (σ) in a curved hook based on Equation (1) and Equation (2), respectively. The neutral radius (r_n) and eccentricity are determined based on the different cross sections shown in **Figure 2**. Square, trapezoidal, and circular cross sections are considered in this study [1].

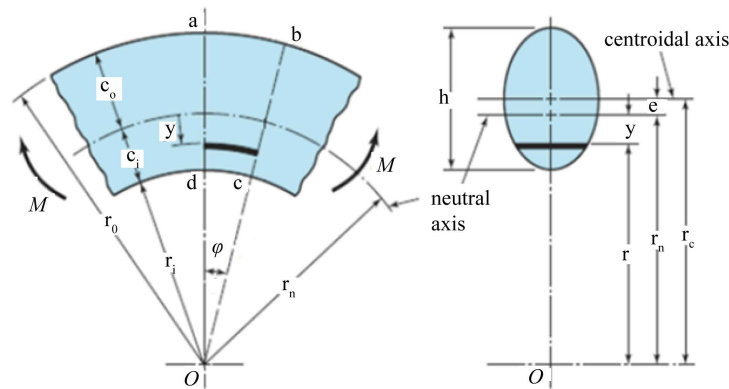$$e = r_c - r_n \tag{1}$$

$$\sigma = \frac{My}{Ae(r_n - y)} \tag{2}$$

Figure 1. Parameters of a curved hook for stress calculations.

$$r_c = r_i + \frac{h}{2}$$

$$r_n = \frac{h}{\ln(r_o/r_i)}$$

$$r_c = r_i + \frac{h}{3}\left(\frac{b_i + 2b_o}{b_i + b_o}\right)$$

$$r_n = \frac{A}{b_o - b_i + \left[\frac{b_i r_o - b_o r_i}{h}\right]\ln\frac{r_o}{r_i}}$$

$$r_c = r_i + R$$

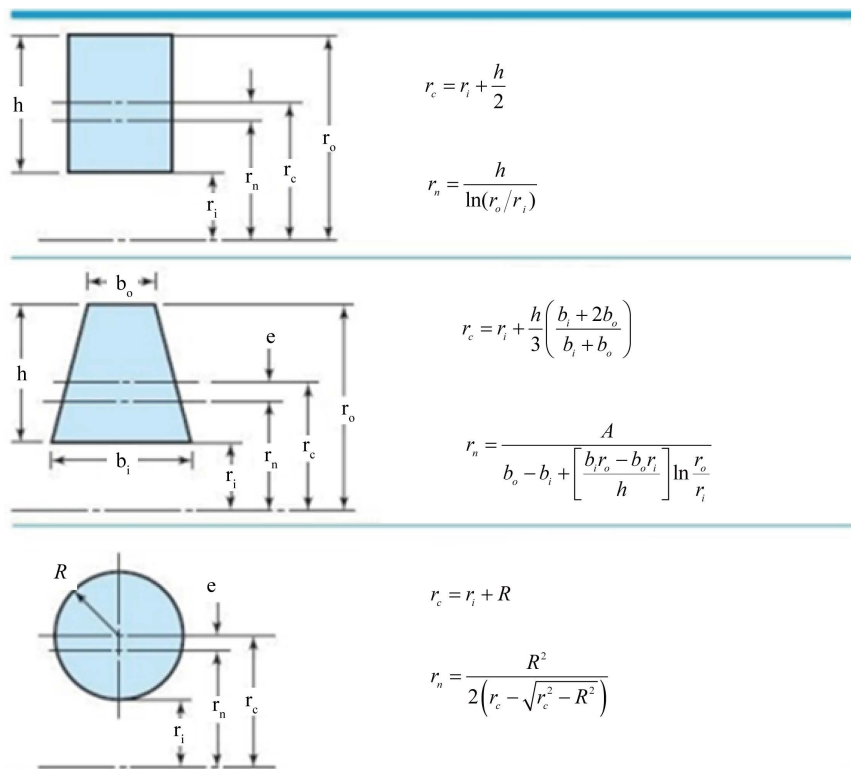$$r_n = \frac{R^2}{2\left(r_c - \sqrt{r_c^2 - R^2}\right)}$$

Figure 2. Diagrams and equations for determining the neutral axis and central radius for various cross sections.

2. Results

2.1. Cross Section Selection

The concept of loading a curved beam is used to determine the maximum stress and displacement in multiple cross section shapes including square, circular, and trapezoidal. A common cross sectional area and hook radius are used for all geometric selections and each cross sections centroid lies on the radius of curvature. The cross sections along with the parameters used for testing are shown in **Figure 3**.

These three cross sections are used to create solid models of a hook that has a radius of curvature of 4 in. The resulting solid models are used to perform finite element analysis in SOLIDWORKS. In this finite element analysis, a load of 8000 lbs is considered and the resulting normal stress and deflection are analyzed. The finite element models shown in **Figures 4-6** indicate the location of maximum stress, and **Figures 7-9** show the de-
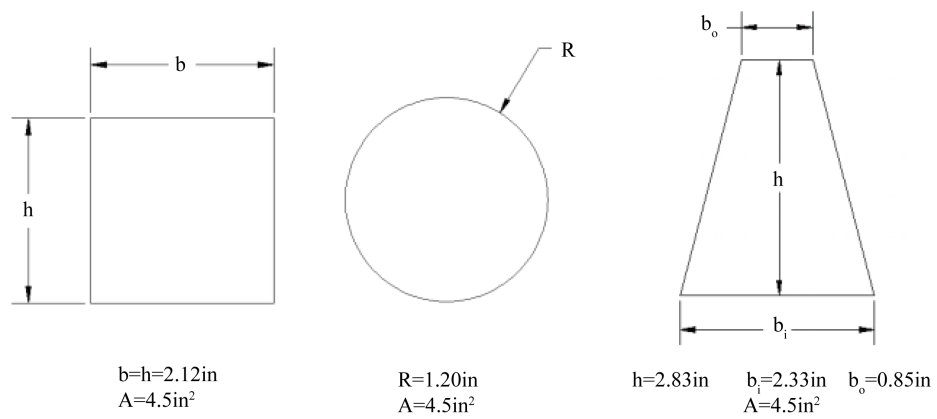
b=h=2.12in
A=4.5in²

R=1.20in
A=4.5in²

h=2.83in   b$_i$=2.33in   b$_o$=0.85in
A=4.5in²

Figure 3. Square, circular and trapezoid cross sections and parameters used.
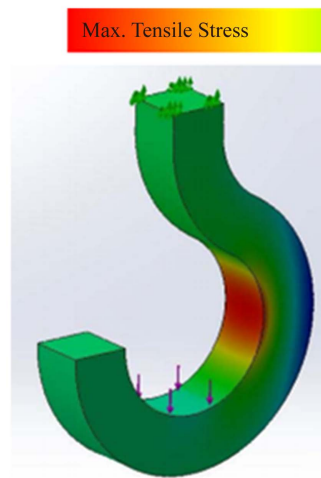

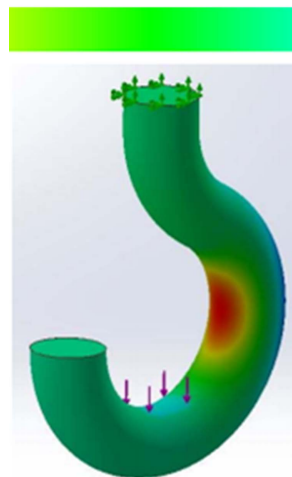**Figure 4.** Square cross section normal stress plot.

Figure 5. Circular cross section normal stress plot.

flection. These results are summarized in **Table 1**. These results show that the trapezoid cross section has the most desirable performance due to the lower levels of stress and deflection in comparison to the square and circular cross sections [2].
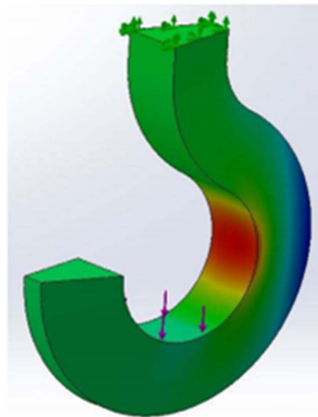
Max. Compressive Stress

Figure 6. Trapezoid cross section normal stress plot.
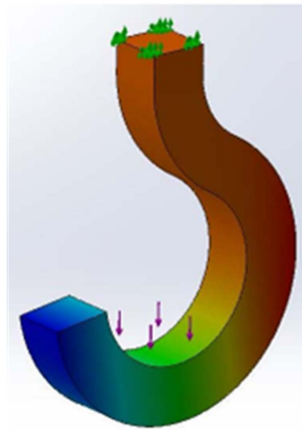
Max. Positive Y-Deflection

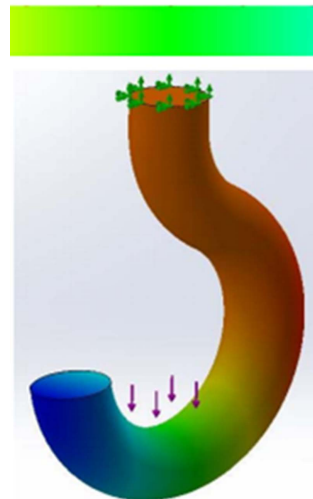**Figure 7.** Square cross section y deflection plot.
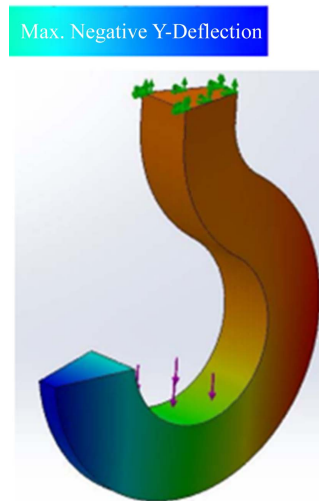
Figure 8. Circular cross section y deflection plot.

Figure 9. Trapezoid cross section y deflection plot.

Table 1. Summary of cross section testing.

Cross Section	Normal Stress (psi)		Von-Mises (psi)	Displacement (in.)
	Maximum	Minimum	Maximum	
Square	27131	−15757	26848	0.0174
Circular	33359	−16970	32418	0.0178
Trapezoidal	20515	−13521	20835	0.0117

2.2. Cross Section Optimization

It is possible to determine the optimal geometric properties with the trapezoidal cross section selected. The parameters of the trapezoidal cross section detail in **Figure 3** are varied to determine the values that provide the optimal performance. In order to achieve this, the value of the neutral radius (r_n) is held constant at 3.5 in, while the values of h, b_i, and b_o are varied simultaneously. The materials being considered in this optimization are A-36 steel, 6061-T6 Aluminum, and Ti-6AL-4V Titanium and their properties are shown in **Table 2** [3]-[5]. By selecting 7 values of the parameter h, it is possible to determine values of b_i, and b_o such that the weight is minimized and the maximum normal stress is constrained to one half of the materials yield strength (σ_y). The results of this optimization are shown in **Figure 10**. Exact parameter values are shown in **Tables A1-A3** in **Appendix A** [6] [7].

3. Conclusions

The results of this research show that for a given cross sectional area, a trapezoid cross section of a hook will have better performance in terms of maximum stress than a circular or square cross section. It is also shown that as the h value of a trapezoidal hook increases, the minimum weight of the hook decreases at a decreasing rate. While the highest value for h will give the lowest weight overall, it is important to keep the proportions of the hook in mind when making the parameter selection. A very large value of h will increase the overall extents of the hook profile and create inefficiencies in packaging and will require a much larger opening on the load that is being moved.

Another observation that is made is in the difference in weight between the three materials while achieving the same goal of maintaining stress levels of one half of the materials yield strength. The percent decrease in weight between steel vs. aluminum or titanium can be as large as 80%. This indicates that in terms of performance, aluminum or titanium will be a clear choice over steel. The difference between aluminum and titanium

Table 2. Material properties.

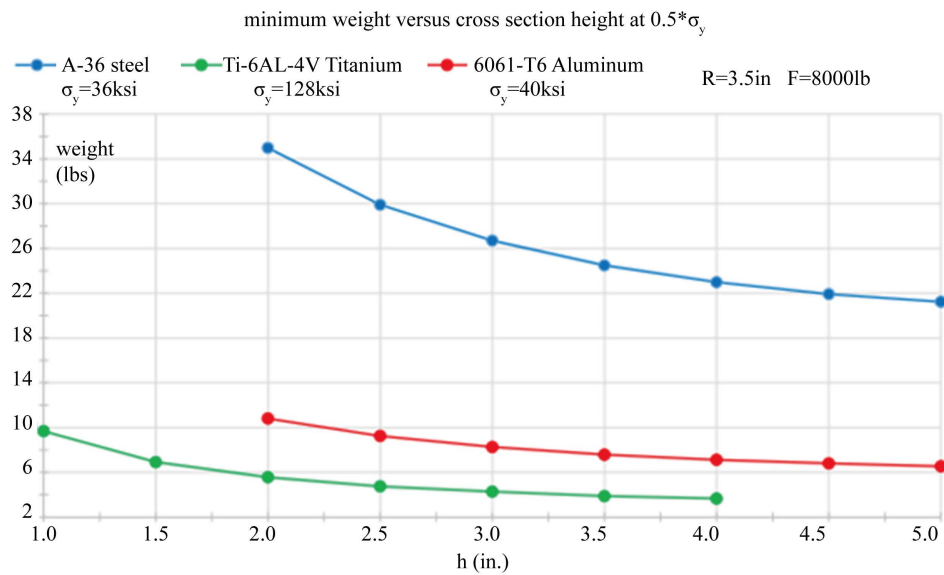| Material	Ultimate Tensile Strength, N/mm² (σ_u)	Tensile Yield Strength, N/mm² (σ_y)	Modulus of Elasticity, N/mm² (E)	Poisson's Ratio (v)	Density kg/m³ (ρ)
A-36 Steel	400 - 550.2	250.3	199948	0.26	7861
6061-T6 Aluminum	310.3	275.8	68947.6	0.33	2713
Ti-6AL-4V Titanium	951.5	882.5	113763.5	0.34	4429

Figure 10. Weight optimization results for three different materials.

however is much smaller. This is where the cost of raw materials and the machinability of the material will factor heavily into the material selection decision.

References

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[2] Sahu, G.N. and Yadav, N. (2013) Design and Stress Analysis of Various Cross Section of Hook. *International Journal of Modern Engineering Research*, **3**, 2187-2189.

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http://www.matweb.com/search/datasheet.aspx?matguid=d1844977c5c8440cb9a3a967f8909c3a

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http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MTP641

[6] Patel, R.B., Pate, B.K., Pate, P.M., Patel, D.H. and Patel, H.S. (N/A) Design and Analysis of Crane Hook with Different Material. *International Journal of Advanced Computer Technology*, **4**, 89-93.

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Appendix A

Optimized Cross Section Values

Table A1. Ti-6AL-4V titanium optimization.

R (mm)	h (mm)	b_i (mm)	b_0 (mm)	Stress (N/mm^2)	Weight (kg)
88.9	25.4	109.2	30.48	440.6	4.391
88.9	38.1	52.32	14.22	440.3	3.134
88.9	50.8	32	8.128	439.4	2.522
88.9	63.5	22.1	5.33	440.1	2.155
88.9	76.2	16.76	3.81	436	1.941
88.9	88.9	13.46	2.54	440.9	1.76
88.9	101.6	11.18	2.032	438.3	1.66

Table A2. A36 steel optimization.

R (mm)	h (mm)	b_i (mm)	b_0 (mm)	Stress (N/mm^2)	Weight (kg)
88.9	50.8	113	29.21	124	15.86
88.9	63.5	78.23	19.05	124.1	13.56
88.9	76.2	59.18	13.21	123.9	12.11
88.9	88.9	47.5	9.4	124	11.1
88.9	101.6	39.88	6.86	123.9	10.42
88.9	114.3	34.8	4.826	123.9	9.943
88.9	127	31.24	3.302	123.7	9.63

Table A3. 6061-T6 aluminum optimization.

R (mm)	h (mm)	b_i (mm)	b_0 (mm)	Stress (N/mm^2)	Weight (kg)
88.9	50.8	101.9	26.16	137.7	4.903
88.9	63.5	70.61	17.02	137.8	4.196
88.9	76.2	53.34	11.94	137.4	3.751
88.9	88.9	42.93	8.382	137.5	3.438
88.9	101.6	36.07	6.096	137.3	3.23
88.9	114.3	31.5	4.318	137	3.084
88.9	127	27.94	3.048	137.9	2.966

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