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Optimization of Crane Cross Sectional Area by Using BEM and FEM

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ABSTRACT

In this study we are concerned to investigate the deflection of the cantilever crane and optimize the cross sectional area, where the BEM techniques has been used to estimate the deflection for four shapes of cross sectional area with constant weight of cantilever crane. A simplified cantilever has been modeled to optimize the cross sectional area, thereby the deflection will be better. A visual basic program has been designed to evaluate the moment of inertia and the deflection for any isotropic material and any dimension of cross sectional area of these four shapes, which are I-Section, squared, circular, or triangular cross sectional area. Furthermore, ANSYS program has been used as verification tool.

Keywords: Cantilever crane, BEM, Optimization.

1. Introduction

Cantilever cranes that shown in figure.1 are cranes that runs on an aerial runway. Unlike the EOT cranes, the runway is located in the same vertical level and has the advantage compared to the semi gantry cranes to avoid the legs on the floor, allowing more useful space.

A jib crane is a type of crane where a horizontal member (*jib* or *boom*), supporting a moveable hoist, is fixed to a wall or to a floor-mounted pillar. Jib cranes are used in industrial premises and on military vehicles. The jib may swing through an arc, to give additional lateral movement, or be fixed. Similar cranes, often known simply as hoists, were fitted on the top floor of warehouse buildings to enable goods to be lifted to all floors.

Superior Hoist Technical Features

- Smooth running. Acceleration/deceleration control to prevent dangerous swing
- Electric braking, allowing the service brake to work as a safety brake in practice
- Compact design for the closest approaches, making efficient use of available space
- No Counter weight = lower moments of inertia
- Minimum duty service classification ISO M5
- I-Shaped design for better approaches
- Reduced weight, transmitting less stress to the structure

Accordingly, cantilever crane will be used with four different shapes of cross sectional area but with the same value ($0.0132 mm^2$). Different shapes of cross sectional area gives different value of moment of inertia that leads to different value of deflection. In the present study we will investigate which one is the best cross sectional area for the cantilever crane which means the greatest value of moment of inertia and the smallest value of deflection as shown in table2.

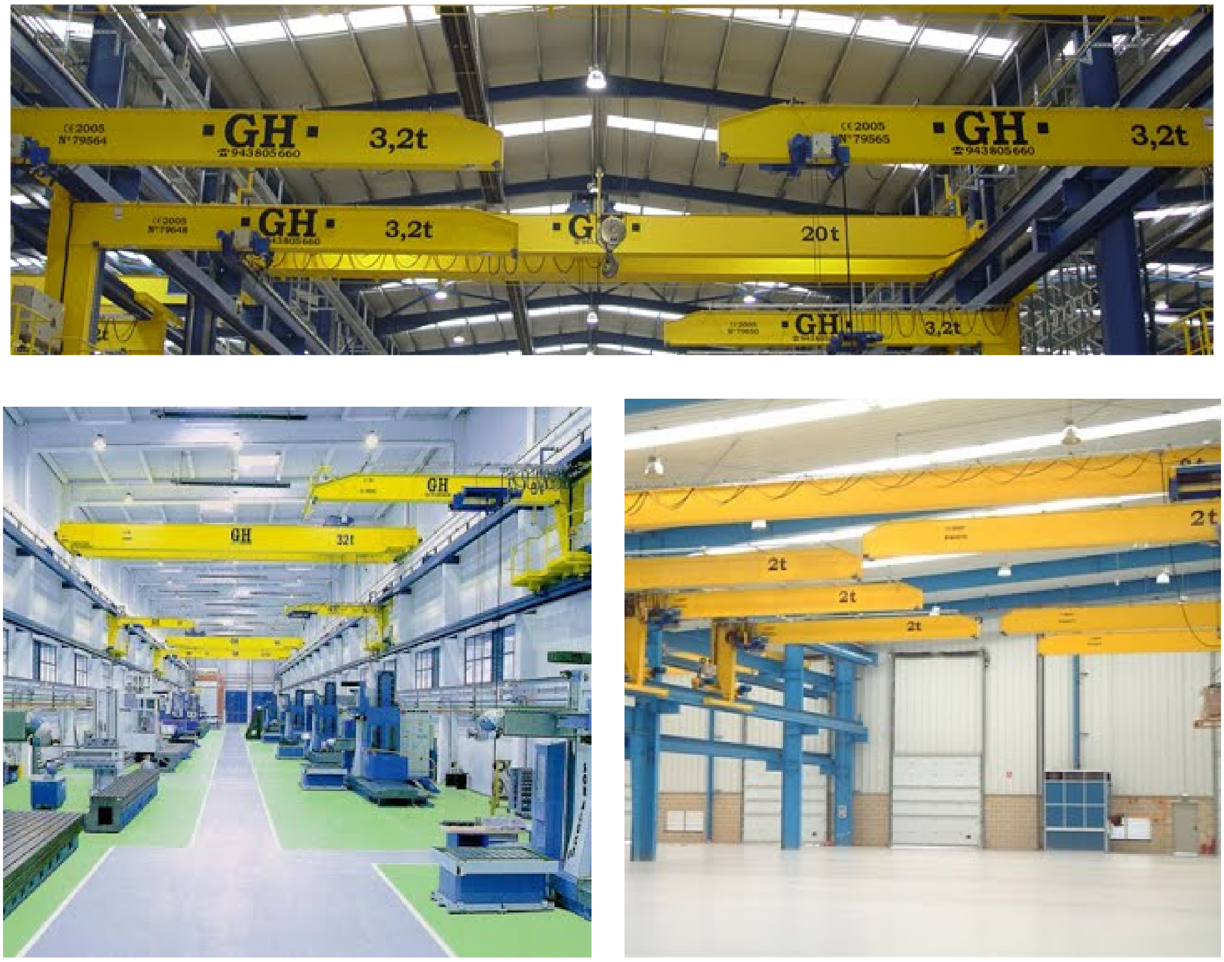

Figure (1): Cantilever cranes

2. BEM Model & Boundary conditions

BEM method will be used to find out the governor equation by which the deflection will be estimated at any distance (x) and as indicated in the following procedure [1]**:**

For i=1 the force p=1 acts at x=0
For i=2 the force p=1 acts at x=*l*
For i=3 the force M=1 acts at x=0
For i=4 the force M=1 acts at x=*l*

As generally known:

$$Ku= p + f \quad \text{.................. (1)}$$

Where: k: stiffness matrix,
U: displacement,
P: applied load,

Then for beam of length 4m which is loaded by uniformly distributed load, one can gets for l=4m:

W(x)= xw(l)+ (1-x)w(0)+ x(1-l)w'(x)+(1/6EI){[-3(l − x)^2-a(x)+3 l^2(1-x)]M(l)+a(x)M(0)+[(1 − x) ^{3}+a(x)l-(1-x) l^2}Q(l)+$\int_0^x [a(x)y - (1 - x)y3]p(y)dy$+$\int_x^l [(y - x)3 + a(x)y - (1 - x)\, y\text{^}3]p(y)dy]$ ------------------ (2)

Where: a(x) =x(1-x)(2-x)

In the present work the max value of deflection must be satisfied, so the loading are implemented as cantilever beam, with following boundary conditions:
w (0)=0, w' (0)=0, m(l)=0, Q(l)=0, with the Wight of cantilever as the total load , and different shapes of cross sectional area as shown in figure.2 which lead to different value of moment of inertia as shown in table. 2 but with the same value of cross sectional area.

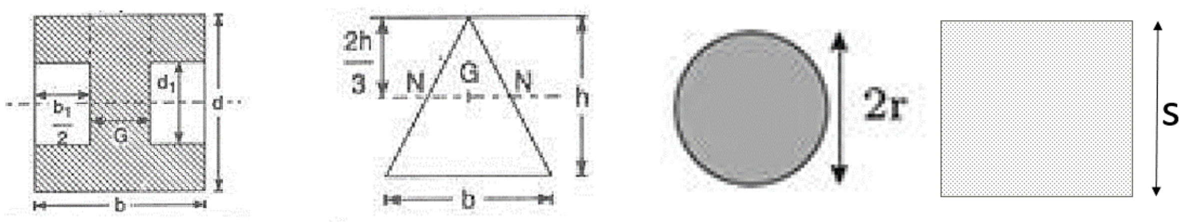

Figure. 2 Different shapes of cross sectional area with the same value

Table. 1 Moment of inertia ($\boldsymbol{I_{xx}}$) for different shapes of cross sectional area

Shape	Moment of inertia ($\boldsymbol{I_{xx}}$)
I-section	$\frac{bd^3}{12} - \frac{b_1 d_1^3}{12}$
square	$\frac{s^4}{12}$
circle	$\frac{\pi r^4}{4}$
triangle	$\frac{b\mathrm{h}^3}{36}$

Now, for the unknown displacement terms and then by substituting the B.Cs and solving of eq.

(1) one gets:

$$w(l)=32p/EI\ ,\quad w'(l)=10.67p/EI\ ,\quad M(0)=-8p,\quad Q(0)=4p$$

Then by substituting the complete set of Betti's data into influence function and so obtain the solution [1]:

$$W(x) = p/24EI\,(96x^2-16x^3+x^4) \qquad \text{……….. (3)}$$

In the present work a visual basic program has been designed to determine the moment of inertia by using the equations in table. 1, and the maximum deflection by using equation (3). The design and the programming are shown in figure (3) and (4) respectively.

3. Material Properties

In this work the material properties assumed to be with homogenous isotropic properties in both BEM and FEM, all the required properties illustrated in table.2

4. Finite element method Model

4.1 FEM

The finite element (FEM) can now be considered as the most popular theoretical technique ever known to man, and it has been applied successfully to many engineering disciplines, such as structural mechanics, computational fluid dynamics, tribology, heat transfer , electromagnetism, biomechanics,… etc.
In the present work a comparison between both BEM and FEM has been presented. A three dimensional model has been simulated in ANSYS software version15, figure (5.a, b, c, and d) Shows the model used in this study, where this model is built by using programming technique and by applying the B.Cs mentioned above with material properties the run can be done.

4.2 Element Description

The model which was used should be discretized to small elements for finite element analysis; the element type that used in this discrediting was BEAM189 that shown in figure.6, The BEAM189 element is suitable for analyzing slender to moderately stubby/thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects. The element provides options for unrestrained warping and restrained warping of cross-sections. The element is a quadratic three-node beam element in 3-D. With default settings, six degrees of freedom occur at each node; these include translations in the x, y, and z directions and rotations about the x, y, and z directions. An optional seventh degree of freedom (warping magnitude) is available. The element is well-suited for linear, large rotation, and/or large-strain nonlinear applications. The element includes stress stiffness terms, the provided stress-stiffness terms enable the elements to analyze flexural, lateral, and torsional stability problems. Elasticity, plasticity, creep and other nonlinear material models are supported. A cross-section associated with this element type can be a built-up section referencing more than one material. Added mass, hydrodynamic added mass and loading, and buoyant loading are available [2].

5. BEM/FEM Results Comparison

After completed the calculations for BEM for the mention model used in this study the authors found high degree of agreement in deflection values of both BEM and FEM when a comparison has been made between these two techniques, this comparison has made for deflection values at x=4 (free edge of loading arm), with four different shapes of cross sectional area (I-section, squared, circular, and triangular).

An important point is that the BEM is nearer to exact results with very small difference from FEM, so this support the opinion that high degree of accuracy had performed by BEM. Values of deflections illustrated in table 2.

From this comparison and according to known benefit of using the stiffener the authors noticed that the I-section gives the best result for deflection because it has the greatest moment of inertia among the other shapes of cross sectional area that helps the crane to overcome the heavily loaded case with lower deflection values. Figure (5.a, b, c, and d) presents the deflection values the model used in this study with different shapes of cross sectional area. Finally figure. 7 shows graphical representation for the values of moment of inertia for each shape, while figure. 8 shows graphical representation for the values of deflections that obtained by BEM and FEM methods.

6. Conclusion

1. Generally, increasing the moment of inertia decrease the deflection of the cantilever crane For constant value of cross sectional area the deflection varies with the shape of the cross sectional area because of the different value of moment of inertia.
2. I-section gives the best or the smallest value of deflection in comparison with the other three shapes with high percentage reaches to 90%, followed by the triangular, squared, and circular cross section respectively, where the percentage among others is a small percentage varies approximately from 10% to 30%.
3. BEM represents a powerful tool to estimate the best cross sectional area.

References

1." Introduction of Boundary Elements Theory and application",Friedel Hartmann,1989.
2. Release 15.0 Documentation for ANSYS, Elements Reference.
3. A. Keith Esco,"mechanical design of process system.

Table.2 Material properties [3]

Material	Density(g/cm^3)	Young's modulus	Poisson's ratio
Steel	7.85	200e9	0.3

Table.3 Comparison between BEM & FEM results of cantilever crane Deflection for different value of Moment of inertia (I_{xx}) and different shapes of cross sectional area

Shape of cross sectional area	(I_{xx}) [m^4] x10^3	Deflection [mm] at fee end (BEM Technique)	Deflection [mm] at free end (FEM Technique)
I-section	0.18636	1.1636	1.10436
square	0.014519366	14.935	14.0139
circular	0.013170114	16.465	15.4726
triangle	0.018773333	11.551	10.8724

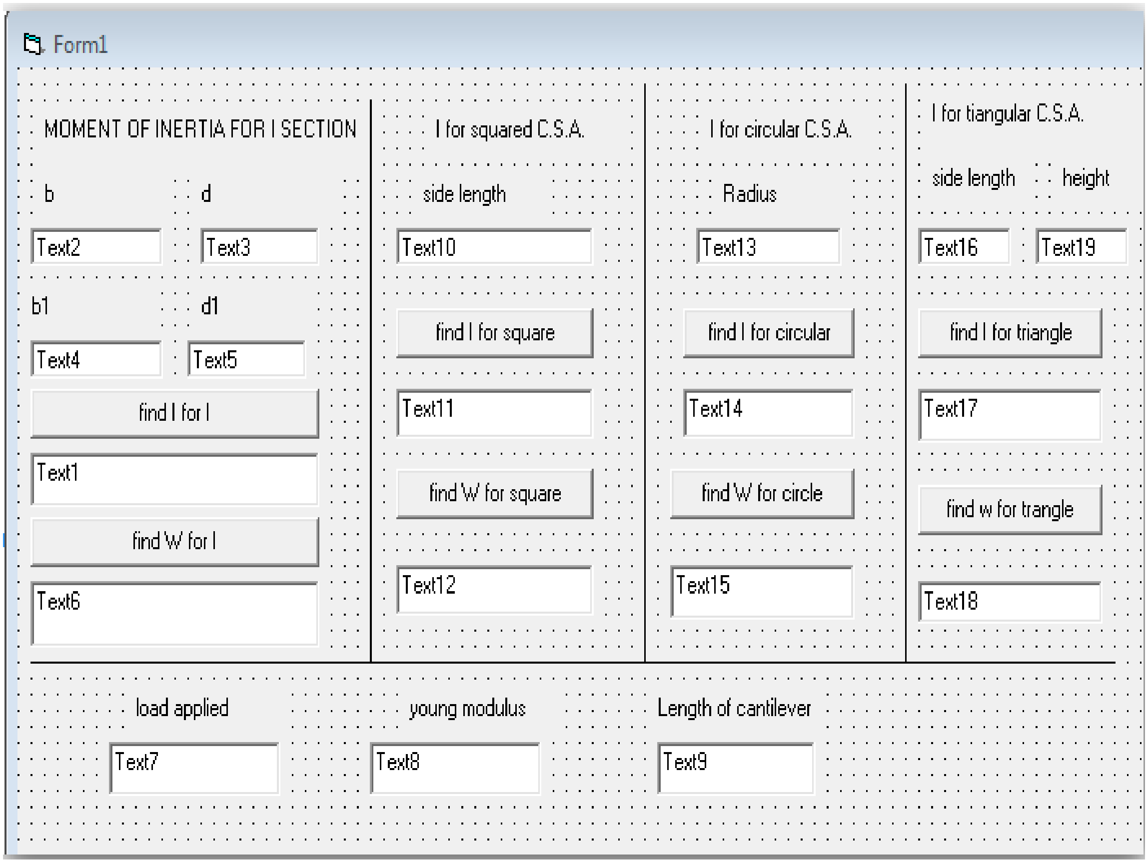

Figure. 3 Design of visual basic program to find the moment of inertia and deflection of cantilever crane.

Visual basic program (Microsoft visual basic 6.0)

```
Private Sub Command1_Click()
Text1 = (1 / 12) * ((Text2 * Text3 ^ 3) - (Text4 * Text5 ^ 3))
End Sub
Private Sub Command2_Click()
Text6 = (Text7 / (24 * Text8 * Text1)) * ((96 * Text9 ^ 2) - (16 * Text9 ^ 3) - (Text9 ^ 4))
End Sub
Private Sub Command3_Click()
Text11 = (Text10 ^ 4) / 12
End Sub
Private Sub Command4_Click()
Text12 = (Text7 / (24 * Text8 * Text11)) * ((96 * Text9 ^ 2) - (16 * Text9 ^ 3) - (Text9 ^ 4))
End Sub
Private Sub Command5_Click()
Text14 = (3.14 * (Text13 ^ 4)) / 4
End Sub
Private Sub Command6_Click()
Text15 = (Text7 / (24 * Text8 * Text14)) * ((96 * Text9 ^ 2) - (16 * Text9 ^ 3) - (Text9 ^ 4))
End Sub
Private Sub Command7_Click()
Text17 = (Text16 * (Text19 ^ 3)) / 36
End Sub
Private Sub Command8_Click()
Text18 = (Text7 / (24 * Text8 * Text17)) * ((96 * Text9 ^ 2) - (16 * Text9 ^ 3) - (Text9 ^ 4))
End Sub
```

Figure. 4 A visual basic program to find the moment of inertia and deflection of cantilever crane.

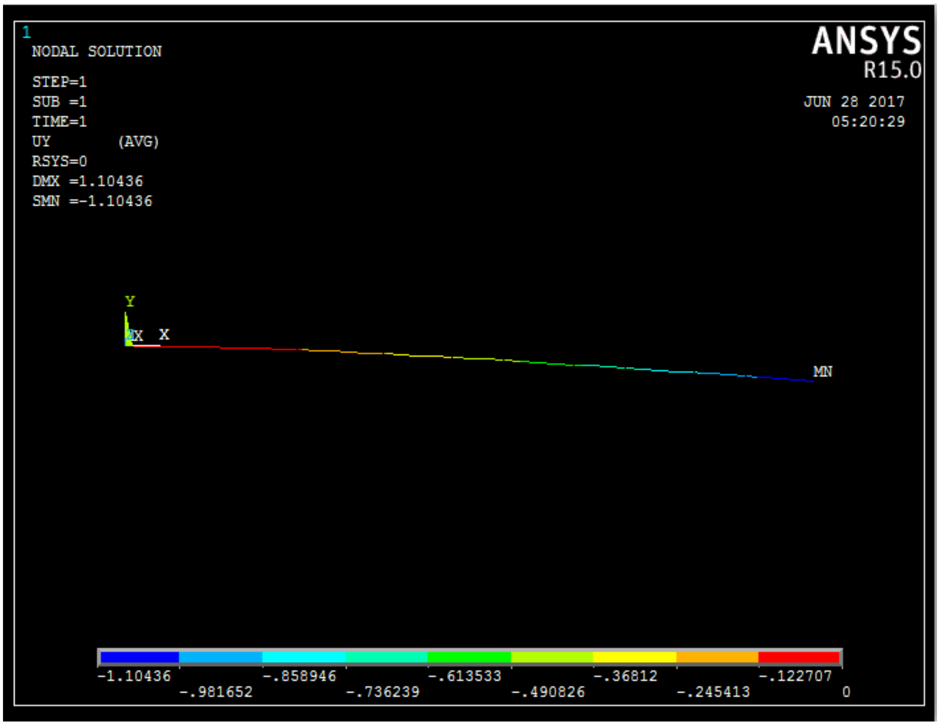

Figure (5.a) Deflection of cantilever crane with I-section

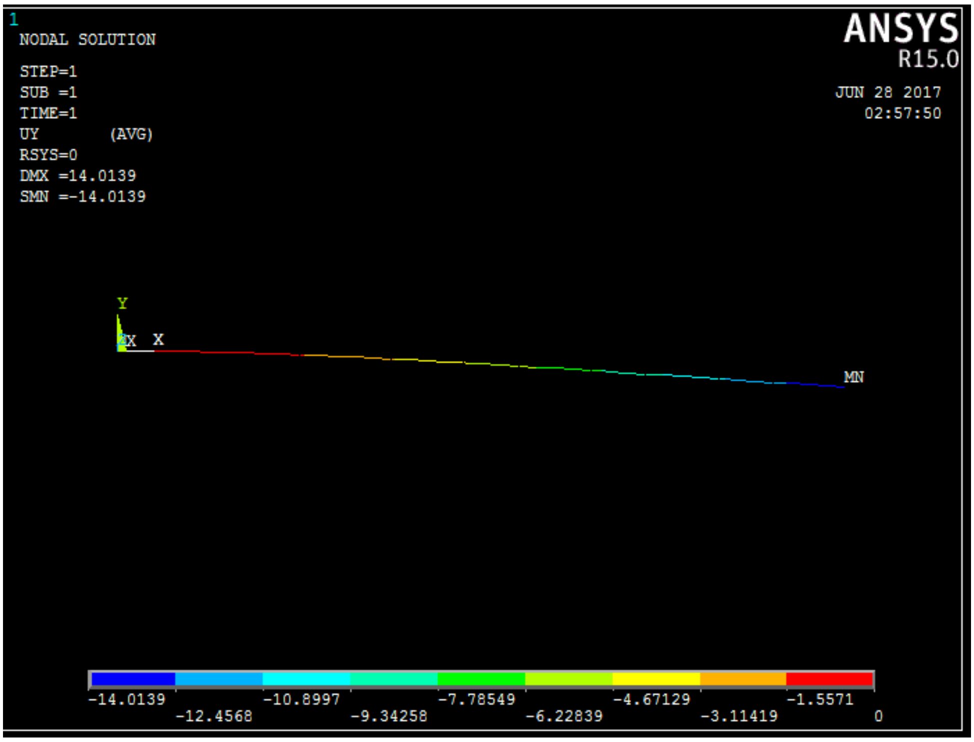

Figure (5.b) Deflection of cantilever crane with squared cross sectional area

Figure (5.c) Deflection of cantilever crane with circular cross sectional area

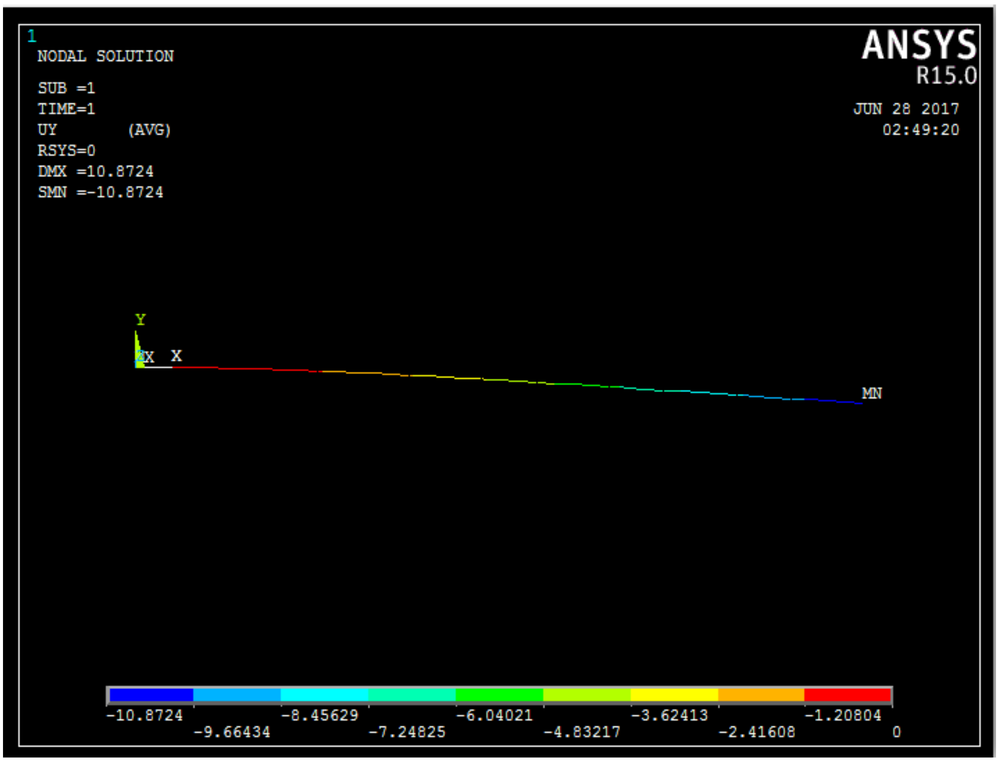

Figure (5.d) Deflection of cantilever crane with triangular cross sectional area

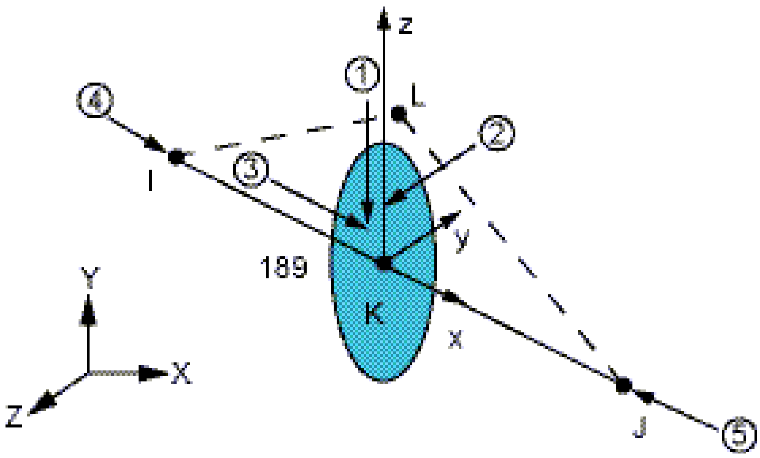

Figure. 6 BEAM189 Geometry [2]

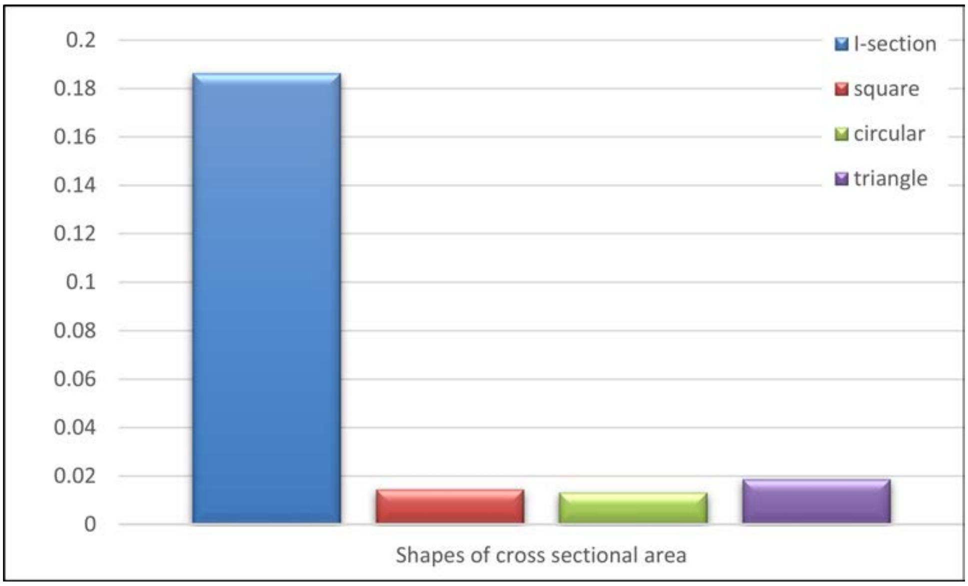

Figure. 7 Graphical representation of moment of inertia for different shapes and same value of cross sectional area

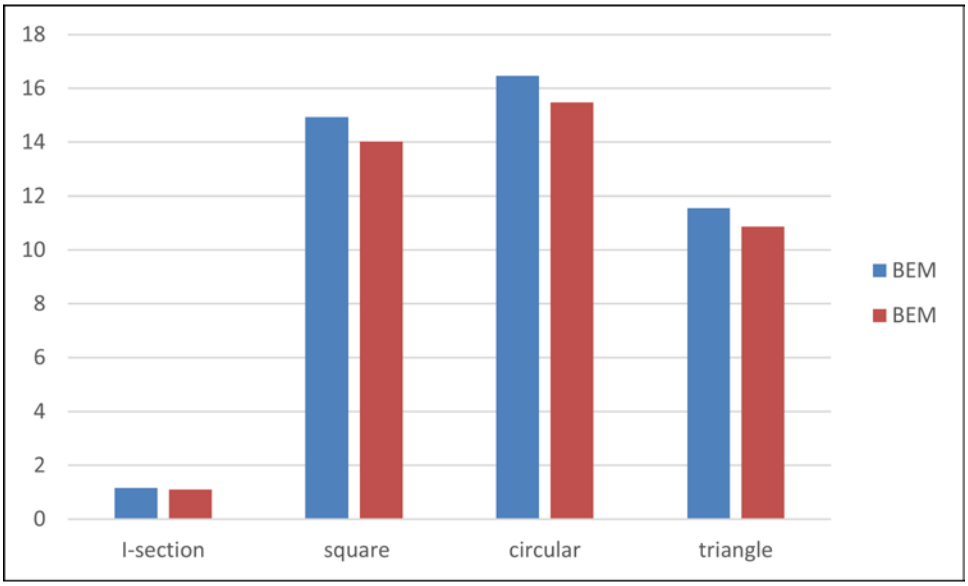

Figure. 8 Graphical representation of the values of deflections that obtained by BEM and FEM methods.