COMPARITIVE STUDY OF DESIGN PROCESS USING ANALYTICAL METHOD AND FEM

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Abstract — In material handling, cranes play a vital role in modern manufacturing industries. An automated overhead chain block reduces the effort required to lift heavy loads. In our project, we aim to manufacture an overhead automated crane for the entire workplace of our company and fabricate a motorized, hydraulic floor crane for handling different types of materials. All the designed structures have been optimized for minimum weight.

I. INTRODUCTION

A 'crane' is a type of machine, generally equipped with a hoist, wire ropes or chains, and sheaves, that can be used both to lift and lower materials and to move them horizontally. It is mainly used for lifting heavy things and transporting them to other places. It uses one or more simple machines to create mechanical advantage and thus move loads beyond the normal capability of a man. Cranes are commonly employed in the transport industry for the loading and unloading of freight, in the construction industry for the movement of materials and in the manufacturing industry for the assembling of heavy equipment. In material handling, the cranes play a vital role in modern manufacturing industries.

Hydraulic cranes are heavy equipment used primarily for lifting. These Hydraulic floor Cranes, provide an efficient low cost alternative to other material handling equipment. These cranes are maneuverable and loading, unloading and shifting of heavy load is very easy. Crane structure consists of chassis, vertical column, inner boom and outer boom, and the hydraulic pump with cylinder assembly.

An overhead crane, commonly called a bridge crane, is a type of crane found in industrial environments. An overhead crane consists of parallel runways with a traveling bridge spanning the gap. A hoist, the lifting component of a crane, travels along the bridge.

‘Computer aided engineering’ is the use of computer software to stimulate performance in order to improve product designs or assist in the resolution of engineering problems for a wide range of industries. This includes simulation, validation and optimization of products, processes and manufacturing tools. The study of behavior of components in real time conditions in CAE is achieved through Finite Element Analysis (FEA). FEA is a computing technique that is used to obtain approximate solutions of Boundary Value Problems. It uses a numerical method called Finite element Method (FEM). FEA involves a computer model of a design that is loaded and analyzed for specific results.

II. DESIGN OF COMPONENTS

For our crane structure, we have designed the following components:
1. Beam
2. Column
3. Channel
4. Wheel

Every design is done using the traditional theoretical process as well as the finite element method of analysis.
2.1 Design using theoretical process (analytical method):

2.1.1 Design of beam:

The material selected for the beam is Fe 410. This material is used in 90% manufacturing works as it is cheap and readily available.

The material properties are:

- Ultimate tensile strength \( \sigma_u = 410 \text{MPa} \)
- Considering FOS = 2
- Yield tensile strength \( \sigma_y = 220 \text{MPa} \)
- Young’s modulus \( E = 210 \text{GPa} \)
- Allowable bending stress \( \sigma_b = 110 \text{MPa} \)

Available Data:

- Total weight on beam \( W = 3500 \text{kg} \approx 35000 \text{N} \)
- Total length of beam \( L = 12 \text{m} = 12000 \text{mm} \)

For our application, we have selected an optimized cross-section. The optimization has been done for minimizing weight of the structure which will in turn reduce the cost of material required for manufacturing the structure. For optimization, we followed the iterative approach and kept changing the dimensional parameters of the cross-section. After 11 iterations, we arrived at the conclusion that ISMB 200 which is a standard structure with a plate of 400 x 20 mm welded to it longitudinally yielded the best result in terms of deflection and stress.

For ISMB 200 (with plate of dimension 400mmx 20mm)

\[
I_{xx} = 4.24 \times 10^8 \text{mm}^4
\]

Deflection of beam \( \delta \) = \( \frac{WL^3}{48EI} \) (Standard deflection of beam formula)

\[
= 14.139 \text{mm}
\]

1.1.1 Design of column

By Euler’s formula,

\[
P_c = \frac{\pi^2 E I_c}{L_c^2}
\]

Where, \( P_c \) = Buckling load,
- \( E = 205 \text{ GPa} \)
- \( L_c \) = Length of column.

And \( I_c \) = Moment of inertia of considered column section.

For the column cross-section, we have similarly performed the optimization process as was done in the design of beam. We found that the following cross-section is best suited for our load conditions. For this structure, \( I_c = 7.88 \times 10^6 \text{mm}^4 \)
Figure 2. Cross-section of column.

\[ P_c = \pi^2 \times 205 \times 10^3 \times 7.88 \times 10^6 / (4 \times 5400^2) \]
\[ = 136688 \text{ N} \]

Considering FOS = 2

Safe load = \( P_c / \text{FOS} = 136688/2 = 68340 \text{ N} \)
\approx 6.9 \text{ tonne}

The total weight of the structure which consists of the beam and crane system is 4.7 tonne. Considering safety to be paramount and taking into account the service factor of the structure, we select a higher FOS of 2.7 and calculate a new safe load.

Safe load = \( P_c / \text{FOS} = 136688/ 2.7 = 5 \text{ tonne.} \)

For this column, stress is found by Stress = Force/ Area = 15.78 MPa
Thus, the selected design is safe.

2.1.2 Design of channel

The material selected for the beam is Fe410. This material is used in 90% manufacturing works as it is cheap and readily available.

Available Data:
Total weight on beam (W) = 5000kg = 49050N
Total length of beam (L) = 5m = 5000mm

Similarly, using optimization, the selected cross-section is ISMB 200 which is a standard cross-section.

For ISMB 200x100

\[ I_{xx} = 223.54 \times 10^6 \text{ mm}^4 \]

Deflection of channel (\( \delta \)) = \( (W \times L^3) / (48 \times E \times I) \)
\[ = (49050 \times 5000^3) / (48 \times 2 \times 10^3 \times 223.54 \times 10^6) \]
\[ = 2.857 \text{ mm} \]

2.1.3 Design of wheel:

Design of wheel is done by considering the wheel supporting the beam on the channel as a shaft.
F = force on wheel 3000+1200 \times 9.81 = 41202 N
L = length of wheel = 115 mm
D = diameter of wheel = 110 mm
d = internal diameter of wheel = 55 mm
p = permissible bearing pressure on wheel =?
\[ p = \frac{f}{l \times D} \]
\[ p = \frac{41202}{115 \times 110} = 3.2570 \text{ N/MM}^2 \]

Permissible bearing pressure 7 to 8 N/mm\(^2\) for splash lubricating bearing hence design is safe.

Direct shear stress:
Allowable shear stress for alloy steel is 10 to 100 N/mm²

\[
\tau = \frac{f}{\frac{\pi}{4} \times (D - d)^2 \times 2}
\]

\[
\tau = \frac{41202}{\frac{\pi}{4} \times (110 - 55)^2 \times 2} = 8.6710 \text{ N/mm}^2
\]

Bending stress for wheel:

\[
\sigma = \frac{4 \times f \times 1}{\pi \times d^3}
\]

\[
\sigma = \frac{4 \times 41202 \times 115}{\pi \times (110 - 55)^3} = 36.260 \text{ N/mm}^2
\]

Allowable bending stress for alloy steel is 140 to 190 N/mm² hence design is safe.

2.2 Design using Finite Element Method:

2.2.1 Design of beam:
The analysis was done using ANSYS R15.0. The deformation image is shown below: Deflection is 13.933mm

![Figure 3. Deflection of beam](image)

Areas of heavy stress concentrations have been strengthened by adding suitable ribs.

2.2.2 Design of column:
Stress of column image: Stress is 16.195 MPa

![Figure 4. Stress concentration in column](image)
2.2.3 Design of channel:
Deformation of channel: Deflection is 2.9447 mm

![Figure 5. Deformation in channel](image)

2.2.4 Design of wheel:
Stress in wheel image: Max stress = 4.7402 MPa

![Figure 6. Stress in wheel](image)

III. COMPARATIVE RESULT TABLE

The results are tabulated as follows:

| SR.NO. | DESCRIPTION            | ANALYTICAL RESULT (A) | FEM RESULT (B) | ERROR |\[(A) \ – \ (B)\] |
|--------|------------------------|-----------------------|----------------|-------|------------------|
| 1.     | Deformation of beam    | 14.139 mm             | 13.933 mm      | 0.206 mm |
| 2.     | Stress in column       | 15.78 MPa             | 16.195 MPa     | 1.17 MPa |
| 3.     | Deformation in channel | 2.857 mm              | 2.9447 mm      | 0.087 mm |
| 4.     | Stress in wheel        | 4.32 MPa              | 4.7402 MPa     | 0.42 Pa  |
IV. CONCLUSION

Thus, we can conclude that both the methods yield similar results with a very negligible error. Hence, any procedure can be used for designing components.

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