Design and Analysis of Structure for Rotary Bike Parking System

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Abstract: **People living in metropolitan cities as well as small cities encounter a major common problem of parking bikes in public areas. Due to crowded streets parking bikes becomes very difficult and often causes many accidents due to improperly parked bikes on the sides of the streets. In order to solve these problem many types of parking systems have been developed out of which multilevel parking system is popular one, which is mostly employed. Multilevel parking system makes use of vertical space by stacking vehicles on floors built one over the other. This Project focuses on designing the structure for parking bikes which is compact and can be mobilized when required. The Structure houses a circular ring which is attached with flat pallets where bikes will be parked. the chain and sprocket mechanism is used to rotate the ring. When driver arrives at parking station, he parks bike on the vacant pallet. The ring then rotates and the bike is transported to parking slot and next vacant pallet arrives at entry point of the parking system. For retrieving bike, operator presses the required button which brings the bike to the exit point of the parking structure. Driver then arrives at exit and drives the bike out of the structure. This Parking system can be built in area with very scarce space and can be used to accommodate bikes on airport, bus station, malls and many more public areas. With governments mission to electrify vehicles these structure can be further develop to couple it with charging station so that bikes will be charged when they are parked in these structure.**

Index Terms: multilevel, pallets, mobilized, chain and sprocket, etc.

1 INTRODUCTION

There has been significant rise in use of personal two wheelers for travelling locally or for long distance rather than using public transport due to pandemic. There are some facilities or structures developed for parking four wheelers but proper provision for parking 2 wheeled vehicles has not yet been optimised. This project work involves design and analysis of structure for parking 2 wheelers. The project consists of the pallets which are used for parking bikes onto them. When the driver arrives at entry point of parking station he parks the bike on to the vacant pallet.These pallets have capacity to carry 2 to 4 bikes. When pallet is completely filled it rotates processed by computer system. This project operates just as people occupy seat in giant wheel. Whenever driver arrives for retrieving the vehicle from parking station based on the time spent in to the parking station the token is generated. After paying token charges the pallet on which required bike is parked is brought to the point of exit. The driver then arrives at exit point and rides away with the bike. This structure can be operated with minimum human interference and is also very mobile.

2 FINITE ELEMENT ANALYSIS

The parts were modelled in solid works 2017 and then they were analysed in ANSYS. Following major parts for design of parking system are designed and analysed.

1) Bike holding pallet
2) Pallet Side structure
3) Supporting shaft
4) Outer side structure

2.1 Pallet:

Major element which will hold the bikes is Pallet. This Pallet is made of mild steel. The pallet is assembly of sheet plate, C Section or L section frame which supports the sheet plate. C section and L section frame is analyzed for designing pallet.

The following specified dimensions used for the platform for parking four bikes: Length (L) =3500mm, Width (B) =2000mm.The load applied on steel sheet is maximum when the platform is completely filled with bikes (5 bikes).

Total load imposed on full parking considering the weight of each bike to be approximately = 200Kg [1]

2.1.1 Sheet Plate:

Sheet plate is designed in solid works as follows: Model for Design Sheet: Dimensions = 3500×2000mm, Thickness=10mm

Assume FOS = 1.5 MS (Yield Strength = 250×10^6) [2]

Allowable stress, $\sigma_{all} = \frac{250\times106}{1.5} = 166.66\times106$ N/m^2

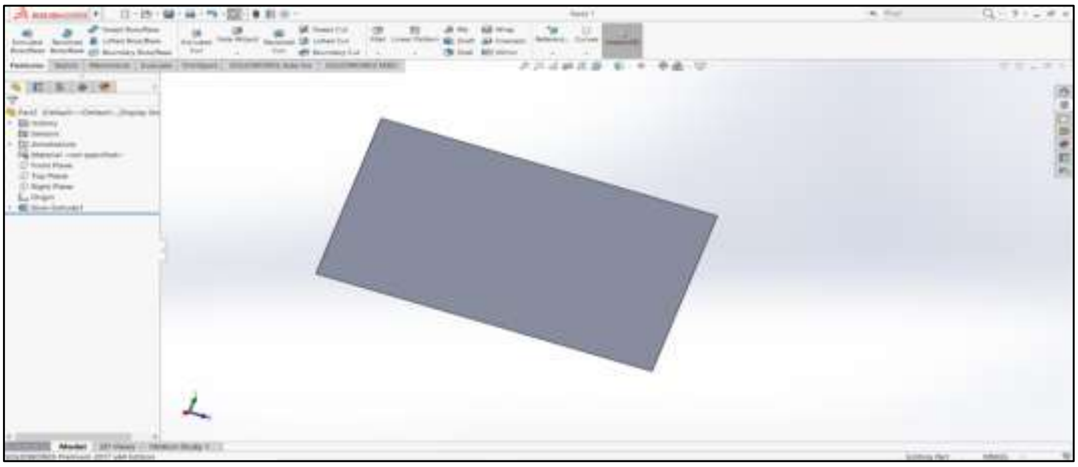

Figure 1: Sheet Plate.

2.1.2 L Section Frame:

There are 8 loads on various nodes and each has force 1500N load. The dimension of L-section is 75×75×5 mm and self-weight of L-section per unit length is 608 kg (for mild steel).

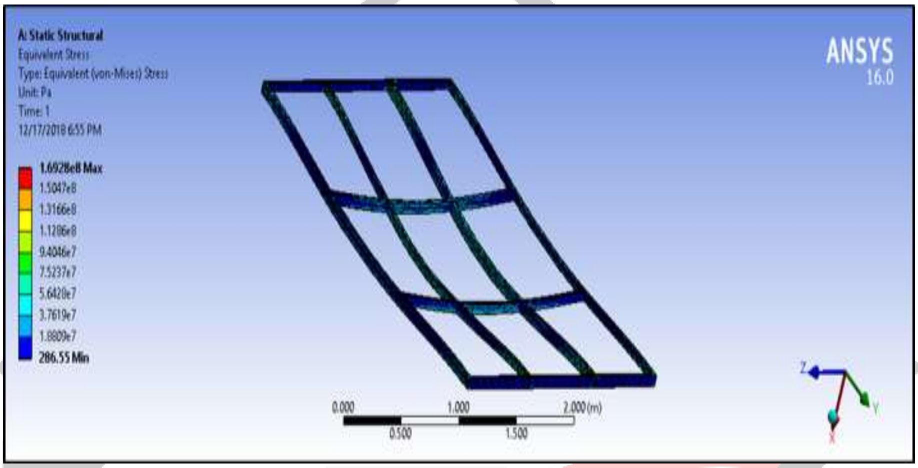

Figure 2: Frame Analysis L Section.

Result-Maximum stresses = $1.69e^8$ pa, Minimum stress= 286.55 pa.

Number of Elements - 22563

Number of Nodes – 55429

Result:

L-Section Frame - Allowable stress $\sigma_{all} = 1.66\times10^8$ pa & Maximum Stress $\sigma_{max} = 1.69\times10^8$ pa

Hence $\sigma_{max} \leq \sigma_{all}$

Therefore,the analysis by L-section is not safe. Hence L section is not selected for designing.

2.1.3 C section Frame:

According to new frame of pallet, the C-section is used having dimensions 100×50×10 mm**.** The overall self-weight of that C-section is 1882N.

Number of Elements =19041

Number of Nodes = 43043

Pressure = 1450 N/m^2

Results: Maximum Stress σ_{max}= 2.527e7 pa, Allowable stress σ_{all} = 1.66e8 pa.

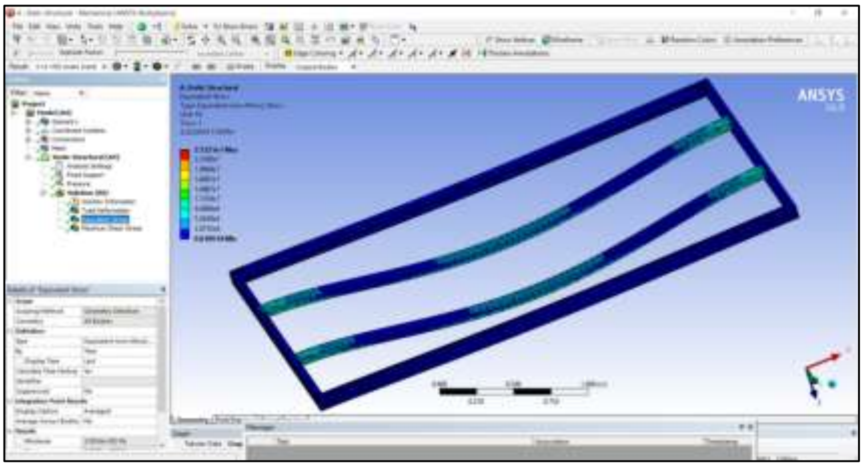

Figure 3: Analysis for Equivalent stress (C-section).

Total Deformation:

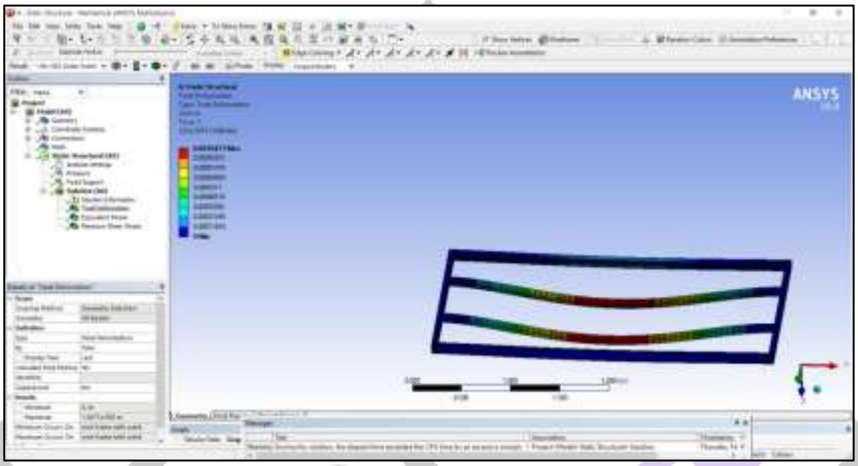

Figure 4: Total Deformation (C-section).

Total Deformation = 0.001047 m
Number of Elements = 19041
Number of Nodes = 43043
Pressure = 1450 N/m^2.

Maximum Shear stress:

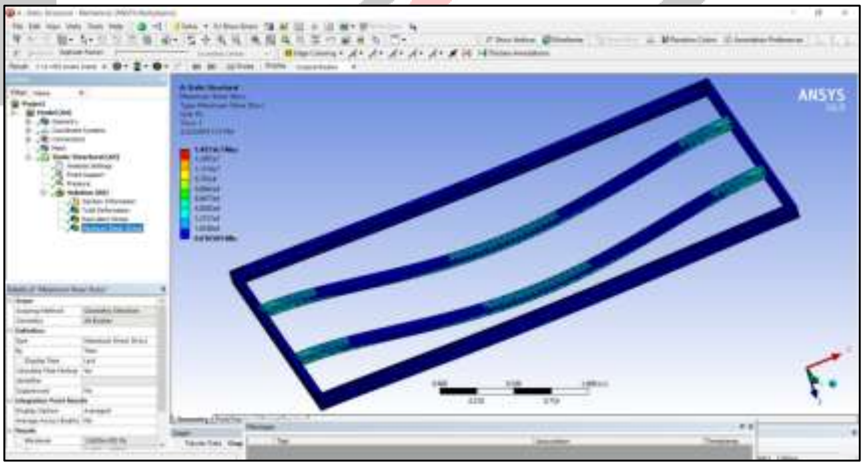

Figure 5: Analysis for Maximum Shear Stress (C-section).

Number of Elements =19041
Number of Nodes = 43043
Pressure = 1450 N/m^2
Result:

Maximum shear stress τ_{max}= 1.455×10^7 Pa and Minimum shear stress τ_{min}= 0.016×10^7 Pa

Allowable shear stress , $\tau_{allw} = \frac{Sys}{FOS} = \frac{0.5Syt}{1.5} = 8.33\times10^7$ Pa [3]

Hence $\tau_{all} > \tau_{max}$

Design is safe for maximum shear stress. Hence C section is selected for designing.

2.2 Side Structure of Pallet

The Total load applied on structure by considering weights of bikes and self-weight of pallet is 6000 N.

Equivalent Von-Misses Stress:

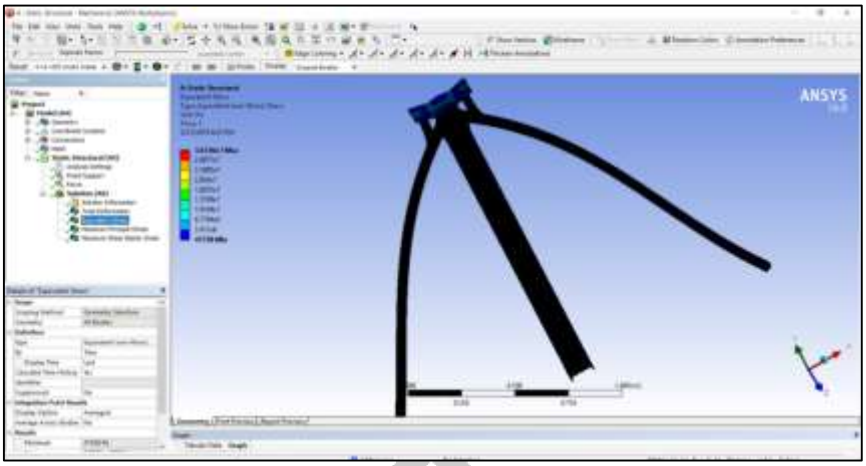

Figure 6: Side structure analysis (Von misses stress)

Number of Elements = 25423
Number of Nodes = 58352
Result :- maximum stress, $\sigma_{max=}$ 3.033e7pa and Minimum stress, σ_{min} = 47558pa.

Total Deformation:

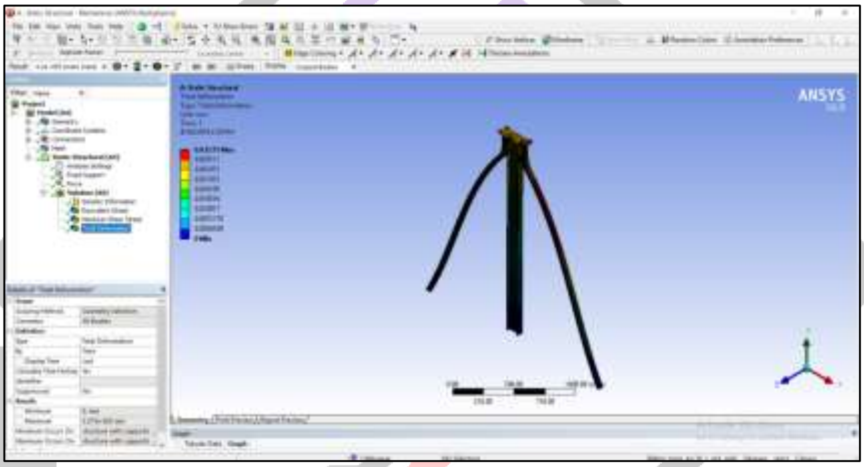

Figure 7: Side Structure Analysis (Total Deformation).

Number of Elements = 25423
Number of Nodes = 58352
Result: - Max. Deformation = 0.0327mm

Equivalent Stress:

Number of Elements = 25423
Number of Nodes = 58352
Result: - maximum stress σ_{max}=2.3322e7 pa and minimum stress σ_{min}= 0.00891e7 pa.

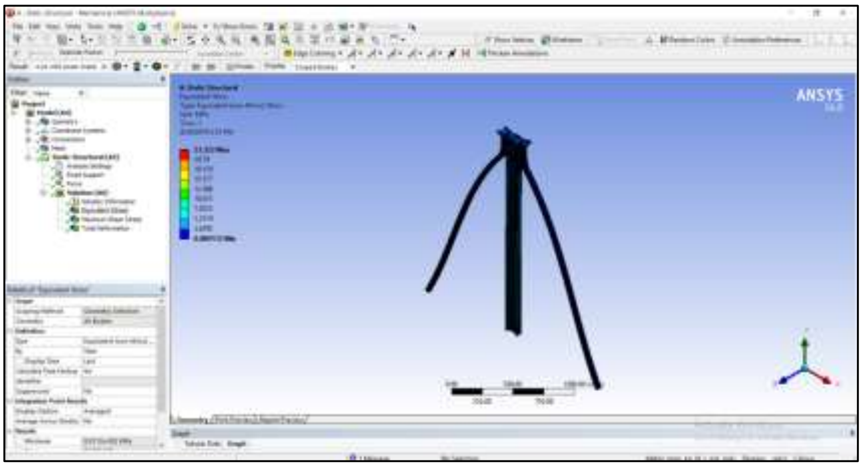

Figure 8: Side Structure Analysis (Equivalent Stress).

Analytical Calculation of Side structure:

Self-weight of C-Frame:

Total weight = 20×9.57 (self-weight)

= 191.94 Kg

Self-weight of I-Section= 4.31 KN/m

Total weight = C-frame + Support structure

= 12000 N

Total weight on side structure is 11692N by considering truss as side structure having 3 elements in which 2 elements are of square section having dimension 40×40×10 and element of I-section is having dimension of 120×60×12.

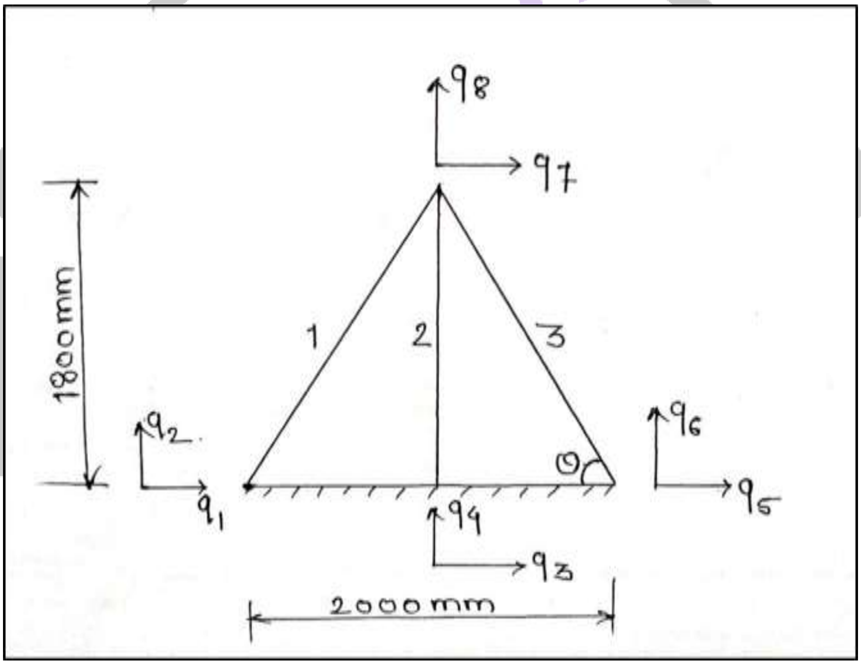

Figure 9: Truss Theory

Area of Truss = 3.603×10^6 mm^2

Modulus of elasticity, E = 200 Gpa

Table 1: Nodal Co-ordinate data:

Node	X	Y
1	0	0
2	1000	0
3	2000	0
4	1000	1800

Table 2: Element connectivity data:

Element Number	Initial Node	Final Node	Length of Element	$l=\frac{Xf-Xi}{Le}$	$m=\frac{Yf-Yi}{Le}$
1	1	4	2060	0.4854	0.8737
2	2	4	1800	0	1
3	3	4	2060	-0.4854	0.8737

Stiffness Matrix of Truss Element: $K_e = \frac{AE}{Le}\begin{bmatrix} l2 & ml & -l2 & -ml \\ ml & m2 & -ml & -m2 \\ -l2 & -ml & l2 & ml \\ -ml & -m2 & ml & m2 \end{bmatrix}$

Global Matrix

$K = K_1 + K_2 + K_3$ [4]

By applying boundary conditions we get,

$10^9\begin{bmatrix} 0.0824 & -0.1483 \\ -0.1483 & 0.2670 \end{bmatrix}\begin{pmatrix} q7 \\ q8 \end{pmatrix} = \begin{pmatrix} 0 \\ 5900 \end{pmatrix}$

$q_7 = 0.1106$ m

$q_8 = 0.06146$ m…… (Deformation)

Stresses of each elements:

$$\sigma = \frac{E}{Le}\begin{pmatrix} -l & -m & l & m \end{pmatrix}\begin{matrix} q1 \\ q2 \\ q7 \\ q8 \end{matrix}$$

Stresses are:-

$\sigma_1 = 10.42$ Mpa

$\sigma_2 = 6.82$ Mpa

$\sigma_3 = -0.0388$ Mpa

Shear stress by using VON-MISES Theory

Yield strength, $Syt \geq 5.454$ Mpa

$\tau = 0.577$ Syt

$\tau = 3.1453$ Mpa

by using FEA analysis Equivalent Von-misses stress are,

Result: -

By Analytical FEA Calculation:-

Maximum stress σ_{max}= 23.322 Mpa and minimum stress σ_{min}= 0.0891Mpa

From theoretical calculation using truss

Element 1 Square Tube: **-** permissible stress **,**σ_{per}=10.42 Mpa

Element 2 I-section: **-** permissible stress σ_{per} = 6.82 Mpa

$\sigma_{max} > \sigma all$

Hence Stresses above structure by Analytical calculation are less than the FEA calculation. Hence, design will be Safe.

2.3 Analysis of supporting shaft: The weight applied on shaft is 12000 N-m.

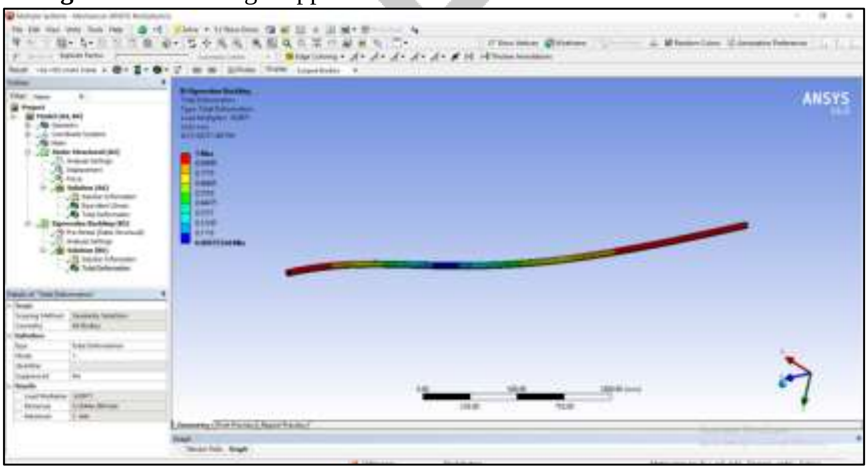

Figure 10: Supporting Shaft Analysis (Total Deformation).

Number of Elements = 5019

Number of Nodes = 12530

Critical load:-9.8971N

Equivalent Stress:

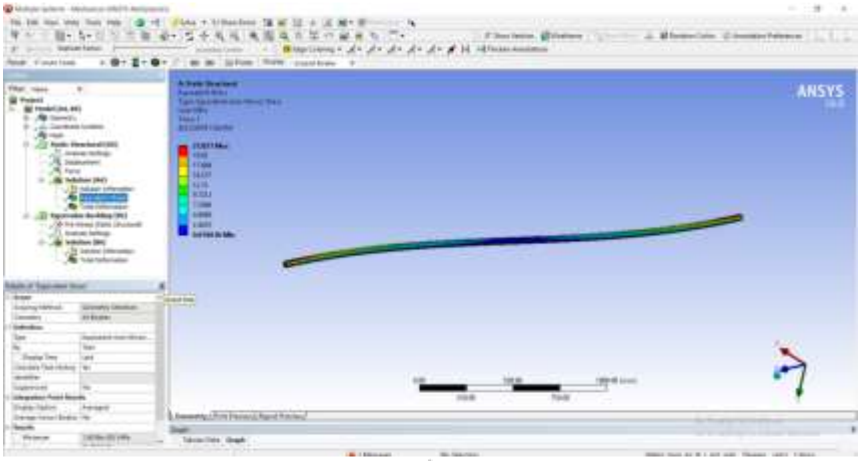

Figure 11: Supporting Shaft Analysis (Equivalent Stress).

Number of Elements = 5019

Number of Nodes = 12530

Result: Maximum stress σ_{max}= 2.108e7 pa and Minimum stress σ_{min}= 0.0016e7 pa.

Analytical Calculations:

Deflection = $\frac{5\,W\,l^4}{384\,EI}$

= 2.21×10^6 mm

By using deflection we did not get accurate Results, because the shaft is fixed on both ends.

Hence we are use Buckling Load Theory.

Critical Load (F_c) = $\frac{\pi^2 EI}{L^2}$

For fixing both end of shaft equivalent length is equal to Original length , L=l

(F_c) = 9.28 N

Critical stress , $\sigma_{cre}= \frac{Fc}{A}$

σ_{cre}= 11.37 Mpa

Following calculations are done form the FEA analysis.

Critical load is 9.8971N

Also from FEA analysis we got equivalent von-misses stress is maximum stress σ_{max}= 21.08 Mpa&

Minimum stress σ_{min}= 0.016 Mpa.

From theoretical calculation , the critical load is 9.28N

Critical stress 11.37Mpa

Von-misses stress 12.47Mpa

Comparison of critical load:- here theoretical load is 9.28N which is less than actual load which is 9.89N.

Comparison of von misses stress; - theoretical stress is 12.47Mpa is less than actual stress 21.08Mpa.

Hence here the theoretical calculation is lesser than actual one.

Therefore design is safe.

2.4 Analysis of Outer Side Structure:

Total load on structure is 102 KN.

Material selection of Structure is Mild Steel and the sections used for structure is C-Section and Square Tube.

C-section = 120×60×12 Square Tube = 80×80×10.

Total Deformation:

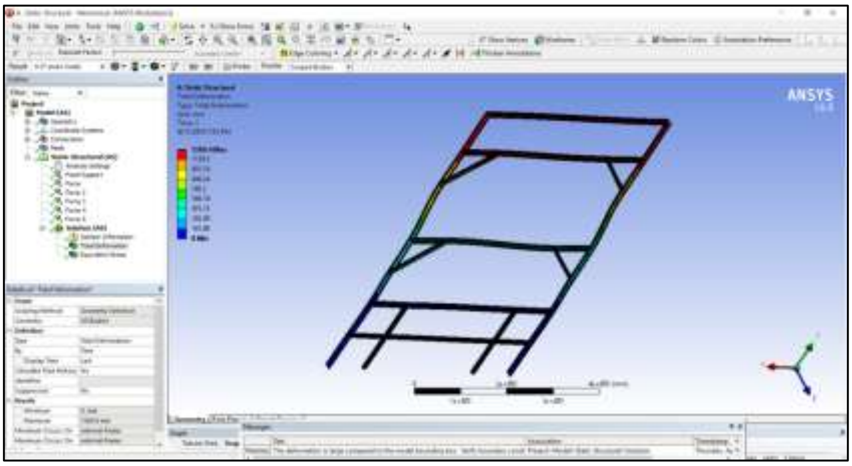

Figure 12: Outer Frame Analysis (Total Deformation).

Number of Elements = 27530
Number of Nodes = 68825
Result: - Total Deformation max =1269.4 mm, Total Deformation min =141.4 mm

Equivalent Stress:

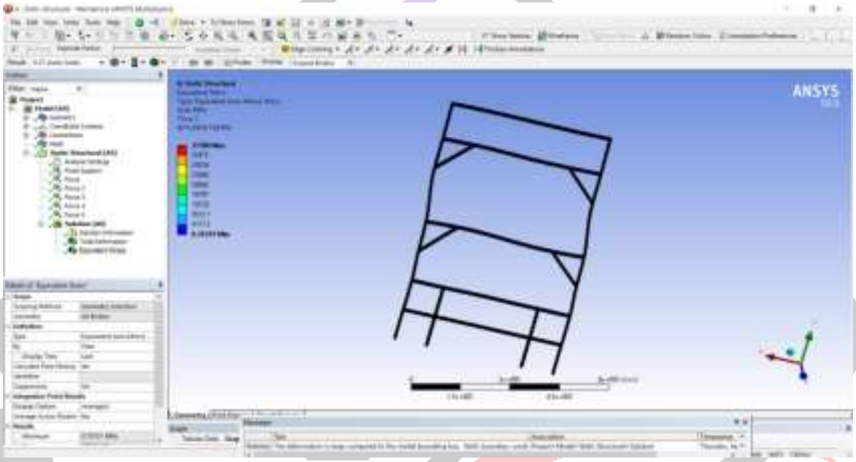

Figure 13: Outer Frame Analysis (Equivalent Stress).

Result: - maximum stress σ_{max} = 37589 Mpa and minimum stress σ_{min}= 0.70701 Mpa.

Analytical calculations:

Material selection of Structure is Mild Steel and the sections used for structure is C-Section and Square Tube.
C-section= 120×60×12
Square Tube = 80×80×10

On this Structure there are two pulley which are mounted on a I-Section And both pulley are attached to each other by using Chain Drive. The mechanism is driven by motor with power of 7.5HP. The total load on structure is 102 KN (By consider pallet, Bike, pallet support structure).

Dimension are Height (H) = 8m and Breadth (B) = 5m
Materials of Side-structure is Mild-Steel and Young's Modules is 250 Mpa
Standard I- section (120×60×12 mm) and square section (80×80×5 mm) frame is used.

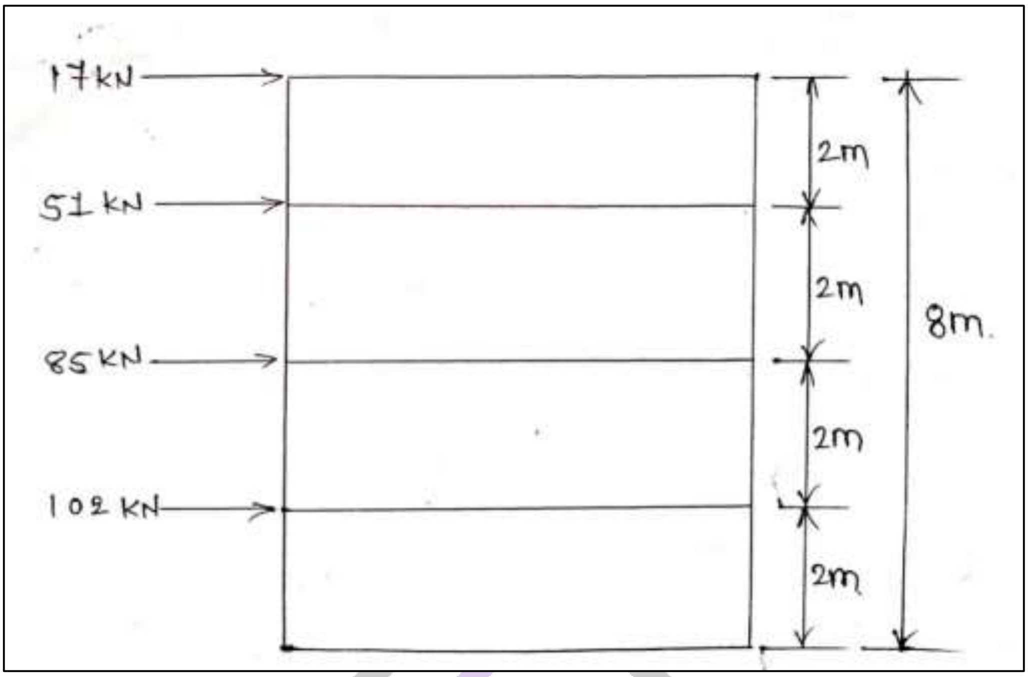

Figure 14: Outer Side Structure

For deflection we use deflection formula

$Mx = EIyy\frac{d^2y}{dx^2}$ [2]

For Mild steel modulus of elasticity is 200 Gpa

I section = 120×60×12 mm

Movement of inertia about XX axis is

$Ixx = \frac{bd^3 - b^3(b-t)}{12}$ [2]

Ixx = 7.77e6 mm^4

Movement of inertia about YY axis is

$Iyy = \frac{2 \times s \times b^3 + (ht^3)}{12}$

Iyy = 445.824e3 mm^4

For deflection use 'Macaulay's Method' [2]

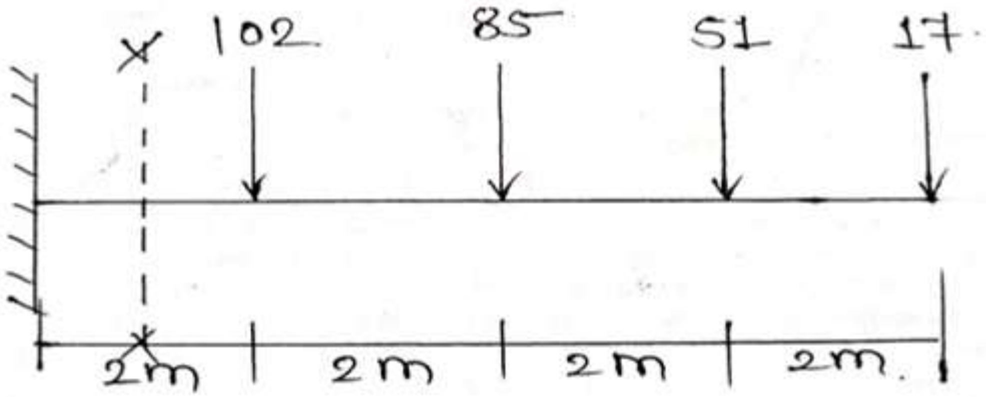

Figure 15: Deflection Diagram

By integrating and calculating by using bellow equation,

$Mx = EI_{yy}\frac{d^2y}{dx^2}$ we get,

Deflection (Y) = 0.2544 mm

For calculating stress of outer side structure use Flexural Formula

$\frac{\sigma}{Y} = \frac{M}{I} = \frac{E}{R}$ [2]

$\sigma = \frac{MY}{Ixx}$

Bending moment, M = 986 KN-m

Y = Central distance of I section is 60 mm

Ixx= Moment of inertia about X- axis is 7.77e6

Stress (σ) = 7608.02 Mpa

Now, It can be concluded that, stress is beyond the material strength

Hence it is assumed that the FOS is **2**

Yield strength of Mild Steel is 250 Mpa

Allowable stress is

$$\text{Stress } \sigma = \frac{\text{Material yeild strength}}{\text{FOS}}$$

$$= 166.66 \text{ Mpa}$$

Now Side-structure is in Safe Condition when compared to analysis.

FEA calculation equivalent von-misses stress is σ_{max}= 37589Mpa and σ_{min}= 0.707 Mpa

Theoretical calculations in which allowable stress is 166.66 Mpa.

In which it is seen that theoretical stress is greater than minimum actual stress therefore the design of outer side structure is safe.

Thus we have designed all major parts required to built the structure for bike parking system with safe design in consideration.

3 SCOPE FOR FUTURE WORK: Nowadays transition phase is seen from Internal combustion Engine vehicles to electric vehicles. When electric vehicles will be completely used for transportation there will be charging sites that need to be developed. These charging sites will require the parking structure so that they can park the vehicle on site for charging. The structure designed in these project can be very useful for accommodating bikes in parking sites. As the charging of one vehicle will require considerable amount of time proper space utilization is very important. These structure can be equipped with electrical connections which will have charging switches. Also in order to have automated entry and exit these sites can be fitted with RFID sensors for billing and user identification.

4 CONCLUSION: It has been understood that L section frame will not be much suitable for pallet design as it may lead to failure when subjected to critical loading. Hence C section Frame is utilised and with dimensions considered the above design is safe. The above design is analysed in Ansys as well as mathematical calculations is done in order to eliminate any failure possibility. The parking structure is thus designed and considering all the required stresses the designed structure is safe for implementation in actual physical design.

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