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Design and Analysis of Motor Operated Load Carrying Stair Climber

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Abstract - One of the basic problems of Load Carriers is overcoming architectural barriers (kerbs, stairs etc.) on its way. The commercially available Load carriers do not have functionality for climbing Stair case. Even though many research studies have been reported in different fields to increase the mobility of load carriers, the question of overcoming obstacles by load carriers always remains as topic of discussion for many researchers. In our project a motor operated stair climbing wheelchair concept which can overcome the architectural barriers to a considerable extent has been developed. This paper involves the design and analysis of an ergonomically designed battery powered load carriers for multipurpose use. Stair climbing functionality is embedded in the design through its structure and mechanism. All the design parameters of load carriers were based on the standard design of the stairs in India. Major part of this paper focuses on the proposed design concept and concludes by discussing upon the physical working model developed for the proposed design solution. In this paper five different dimensions for square hollow section used in the chassis are analyzed and best of these is taken for our proposed model and all other components are selected based on the calculations obtained. Final assembled model is designed and analyzed using CATIA and ANSYS softwares. The final model is found safe on plane surface and on stairs.

Key Words: Architectural barriers, motor operated, stair climbing, Design and Analysis, Finite element analysis, ANSYS workbench, CATIA.

1. INTRODUCTION

In everyday life we may have to carry so many goods of various quantities through stairs especially in offices, schools, colleges, hotels, industries, apartments etc. where the lifts may not be available, may be full with the people or under repair. It is very tiresome to carry the various objects through stairs manually for higher floor for so many times. In most of building lifts are not installed so there only human labor is solution for carrying material. Labor is becoming costly as well as time consuming, where growth rate is getting negative. This problem can be solved if a trolley can lift loads while traveling through stairs.

This paper introduces a new option for the transportation of the loads over the stair. The vehicle is designed in such a way that it has four wheels. It is working on the principle of four wheel drive and belt drive mechanism. This project focuses on the maximum ergonomically beneficial to human being. The present project related to load carrying equipment of a type that is automatically operated of moving upwardly and downwardly on flight of stairs. Load carrier is a wheeled mechanism device, is generally used to carry loads. It reduces human efforts.

Nomenclature

L	Length of Belt
C	Wheel centre to centre distance
D	Diameter of wheel
Fn	Normal Force
g	Acceleration due to gravity
F_f	Frictional Force
Rw	Radius of Wheel
Ø	Slope of Stairs
µ	Coefficient of Friction
Fo	Opposing Force
DC	Direct Current
AH	Ampere Hour
RPM	Rotations per Minute

1.1 Standard Stair Size

The standard stair size is shown in the Figure 1. The stairs are constructed in every building based on International Residential code.

- The average foot size of an adult for tread length i.e., 28.57 cm.
- The riser height is based on the way the foot comes while coming down the stairs, the recommended height is 18.73 cm.

1.2 Modeling and Analysis Tools Used

CatiaV5R9 is used for Modeling and Ansys R18.1 (Workbench) is used for Analysis of the designed model.

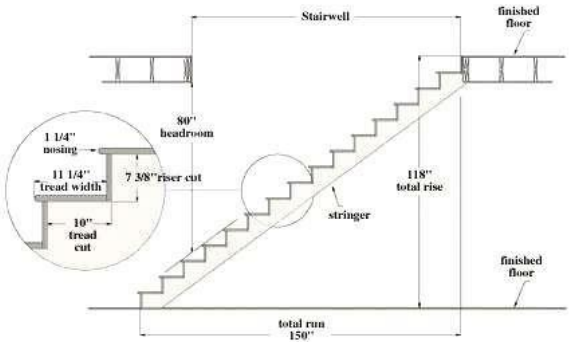

Figure-1: Standard stair size As per International Residential code

1.3 Methodology

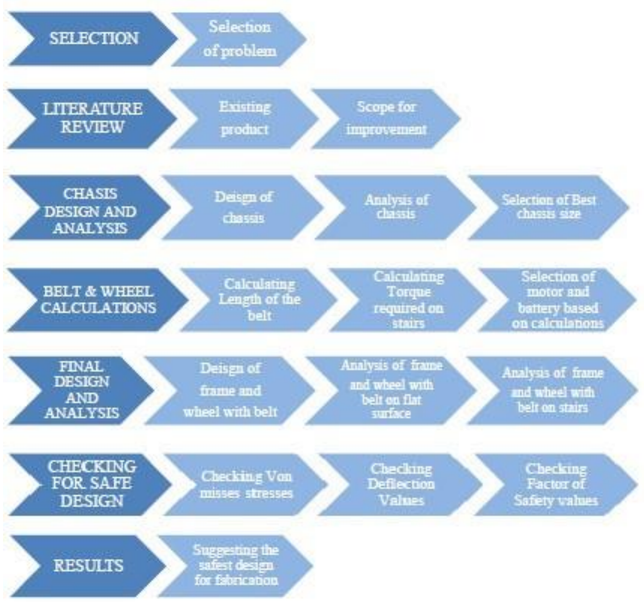

Figure-2: Methodology process chart

2. Material used for Chassis Design

Material used: Structural steel

Composition: Carbon : 0.20 % - 0.30%

Manganese : 0.30% - 0.60%

Properties: Tensile Yield strength : 250 MPa

Tensile Ultimate strength : 450 MPa

Hardness : 170 BHN

Density : 7850 kg \m^{3}

3. Chassis Design

Our chassis design consists of square hollow sections and plate with hole and plate.

Square hollow sections are considered as per standards (IS-4923(Grade-43)).

a) 20×20×2 (mm)

b) 25×25×3 (mm)

c) 30×30×3 (mm)

d) 40×40×4 (mm)

e) 50×50×4.5 (mm)

So as per above dimensions five types of chassis part designs in CATIA were designed. Figure-3 shows different views of one of these dimensions of chassis.

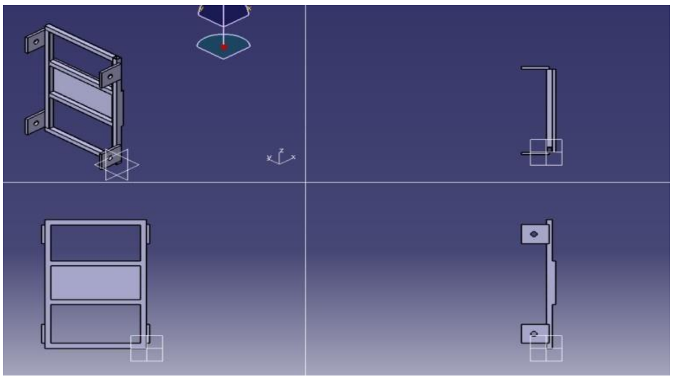

Figure-3: Chassis Design

4. Chassis Analysis

Those five dimensions of chassis in ANSYS WORK BENCH was done and analyzed for different factors like stress, factor of safety and total deformation. Our aim is to design the chassis to its safe working properties. In the analysis of the chassis, load is applied on the plate. An average weight of 150 kilo grams acting on the body is considered and pressure on the plate surface is applied in this analysis. Plates with hole are considered as fixed supports. As per analysis it is observed that maximum deformation occurs on the center of the plate. Maximum stress occurs on the edges of the plate with hole.

Figures-3, 4, and 5 shows designed model, loads and constraints respectively. Figures 6, 7 and 8 shows Von Misses Stress, Total Deformation and Factor of Safety Value for chassis with dimensions 20×20×2 (mm) are shown and for rest all types are shown in the table-1.

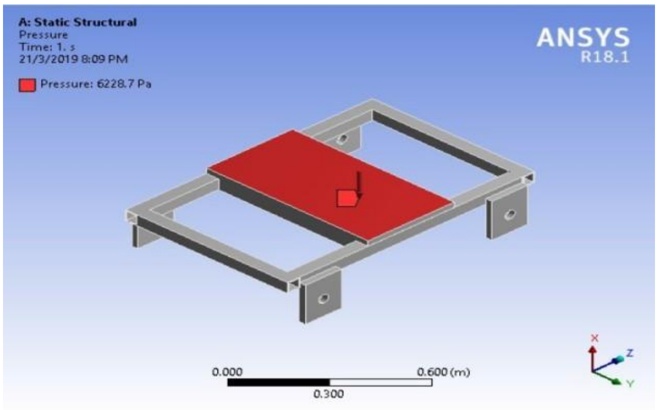

Figure-4: Pressure applied on chassis

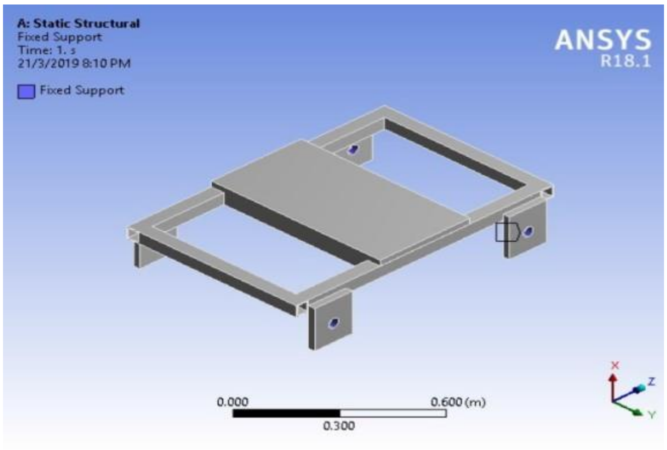

Figure-5: Fixed support on chassis

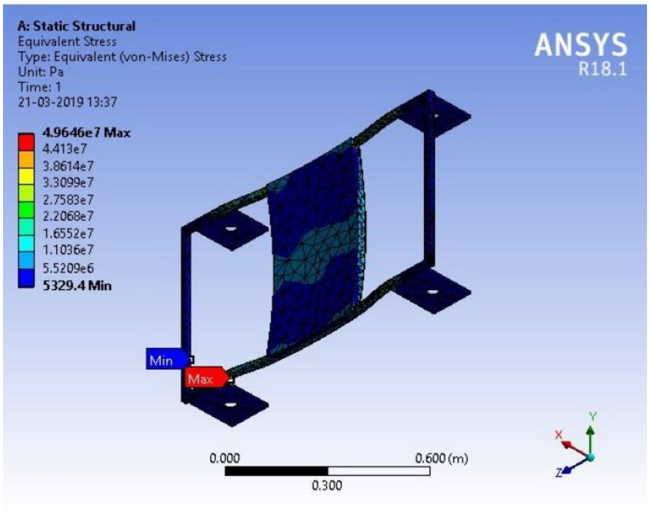

Figure-6: Stress values for chassis made of 20×20×2 (mm) sized hollow square tube

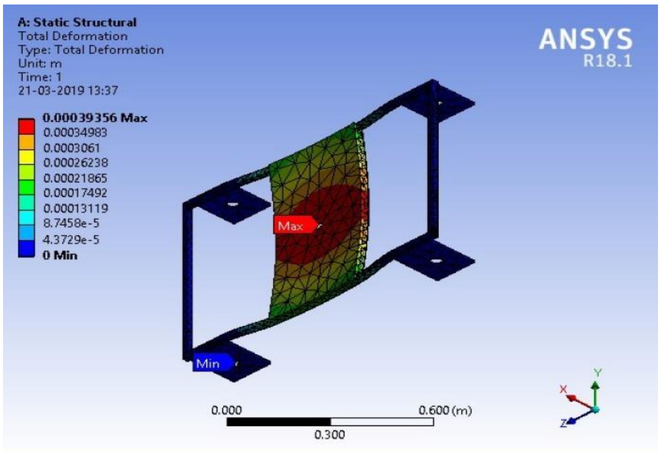

Figure-7: Total Deformation for chassis made of 20×20×2 (mm) sized hollow square tube

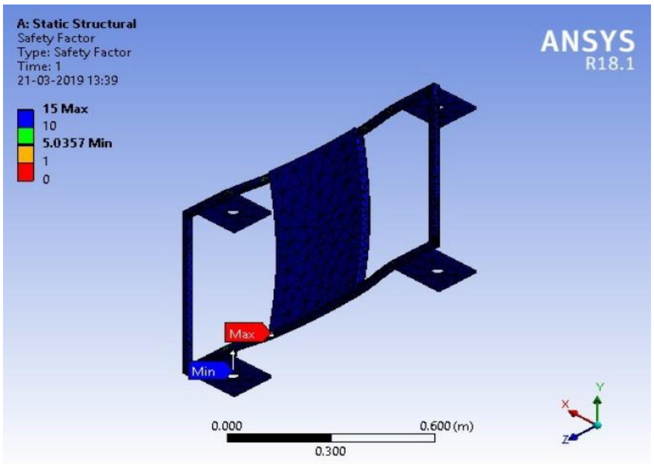

Figure-8: Factor of Safety for chassis made of 20×20×2 (mm) sized hollow square tube

From Table 1 it is observed that as the size of rod increases maximum stress acting on the chassis part design decreases, total deformation of the chassis part design decreases. But for our design we don't require that much high factor of safety and also Chassis weight must be less. So we considered chassis with 20×20×2(mm) square hollow section size to use for our design for optimum conditions.

Table -1: Comparison of chassis analysis

S. No	Size (mm)	Stress (Pascals)	Total Deformation (mm)	Factor of safety	Weight (Kg)
1	20×20×2	4.96E7	0.393	5.035	30.723
2	25×25×3	2.28E7	0.162	10.953	41.524

3	30×30×3	1.76E7	0.078	14.152	56.849
4	40×40×4	8.34E6	0.030	15	71.662
5	50×50×4.5	3.88E5	0.014	15	95.287

5. Belt and Wheel

Wheel is designed on the basis of standard steps. We considered wheel diameter as the double the size of rise in the steps. Belt is designed on the basis of wheel design. We have given projections to the belt to decrease the vibrations and increase the grip. The Belt is also an important component because when belt grips to the stairs, the more it can climb easily and get down as well.

5.1 Length of Belt

Length of belt (L) = 2C+3.14×D
Where C=Distance between the center of wheel
D=Diameter of the wheel

L=2×834.8+3.14×374.65=2846.001 mm

5.2 Material used for Belt Design

Material used : Synthetic Rubber
Properties :
Tensile Yield strength : 20- 25 MPa
Tensile Ultimate strength: 40-46 MPa
Density : 900-940kg\ m3

6. Selection of Battery and Motor

6.1 Torque required on a flat surface

Normal force (F_n) = force applied = mg

= (150/4) ×9.81

= 367.875N

Friction force (F_f) = μF_n

= 0.2×367.875

= 73.575N

Torque required = $F_f \times R_w$ (R_w=Radius of Wheel)

= 73.575×0.1873

= 13.7805 N-m

6.2 Torque required on Stairs

Stair dimensions

Land: 285.75 mm

Rise: 187.325 mm

Slope of stair (Ø) = $\tan^{-1}$(187.325/285.75) = 33.24^0

Total mass acting (including setup) =150kg

= (150/4) ×9.81

=367.875N

Normal force acting (F_n) = mgcosØ

= (150/4) ×9.81×cos (33.24^0)

= 92.18N

Frictional force (F_f) = μF_n

= 0.2×92.18

= 18.436 N

Opposing force (F_o) = mgsinØ

= (150/4) ×9.81×sin (33.24^0)

= 356.1385 N

Torque required = ($F_f + F_o$) R_w

= (18.436+356.1385) 0.1873

= 70.15 N-m

6.3 Specifications of Motor and Battery

As per the calculations the required Torque for our design is 70 N-m. So we consider the 70 N-m Torque Motor.

- Motor Properties: 24V DC geared motors.
- Battery Used: 48V, 20AH.

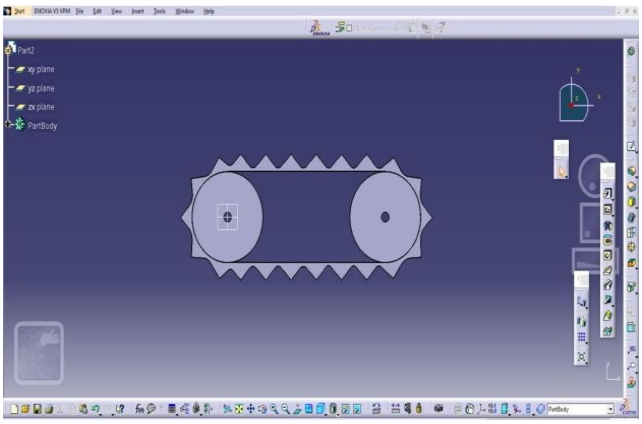

Figure-9: Wheel with Belt

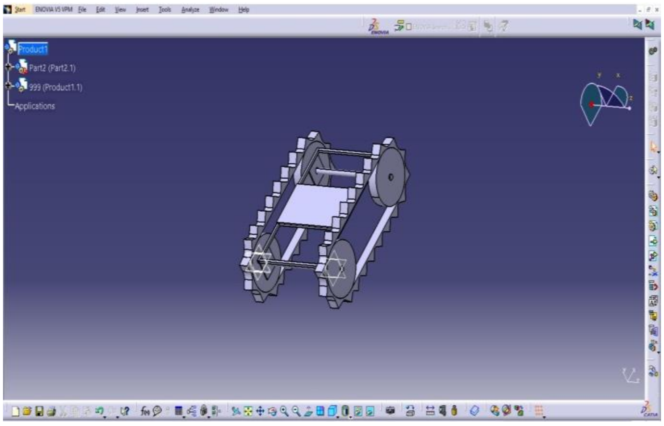

Figure-10: Assembly of Chassis, wheels and belt

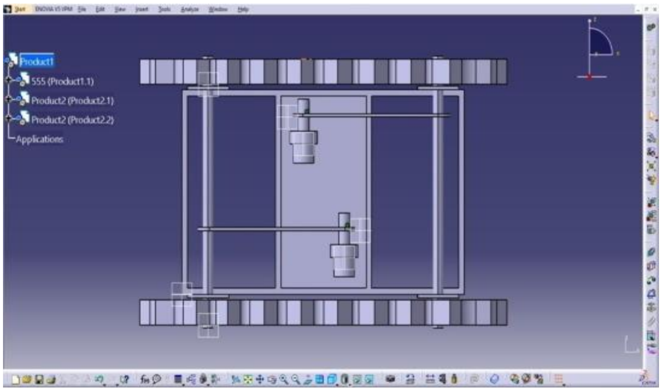

Figure-11: Complete assembly showing power transmission mechanism

7. Analysis on Flat Surface

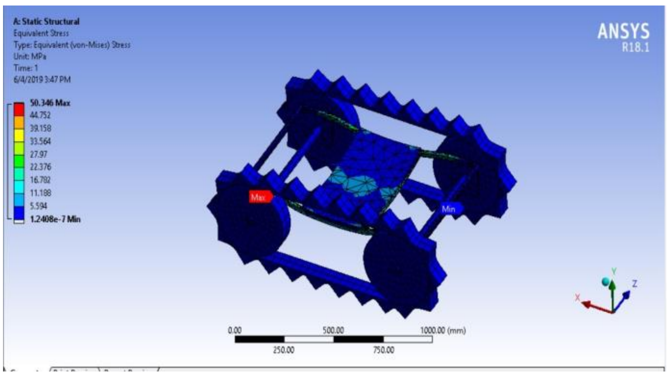

Figure-12: Von-Mises stress

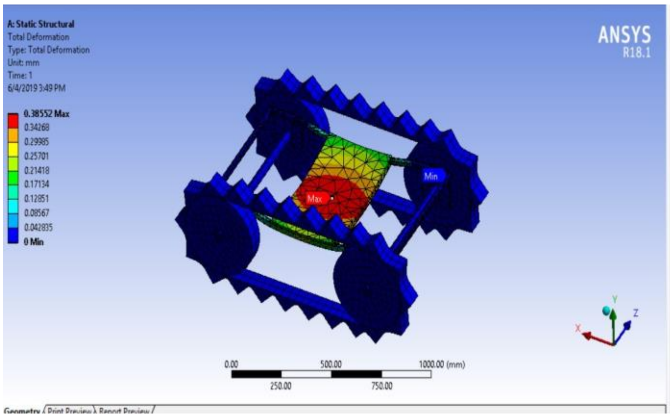

Figure-13: Total deformation

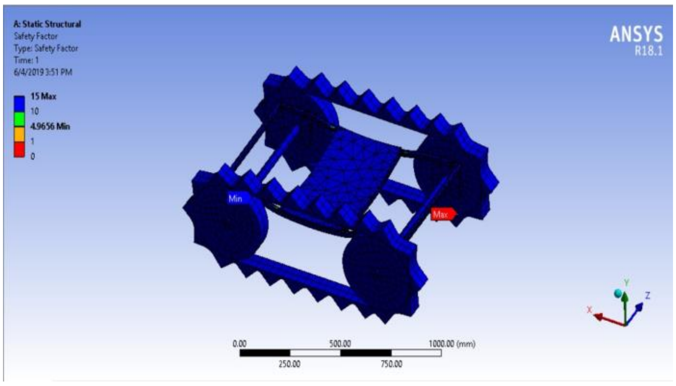

Figure-14: Factor of safety

8. Analysis on Stairs

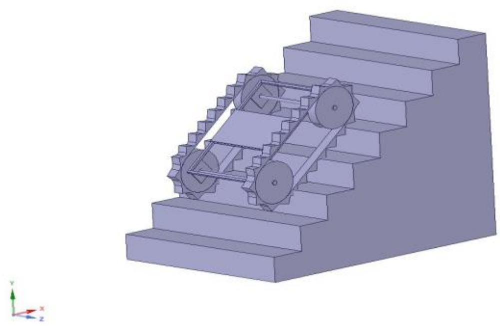

Figure-15: Complete CATIA model on steps

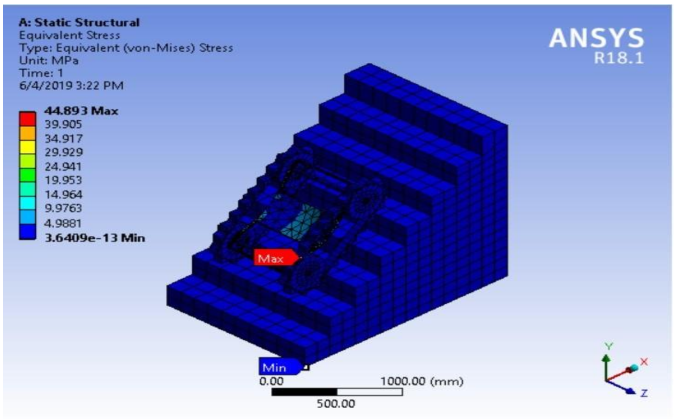

Figure-16: Von-Mises stress

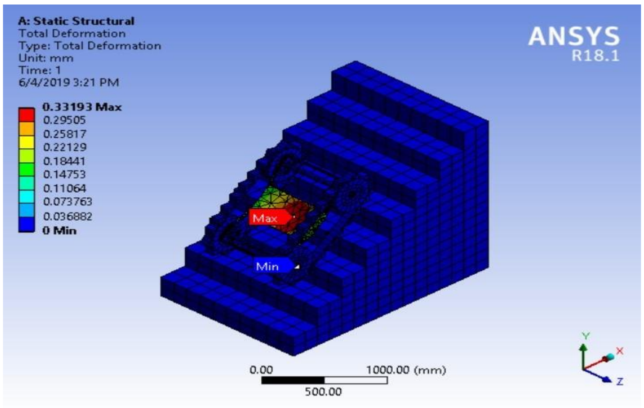

Figure-17: Total deformation

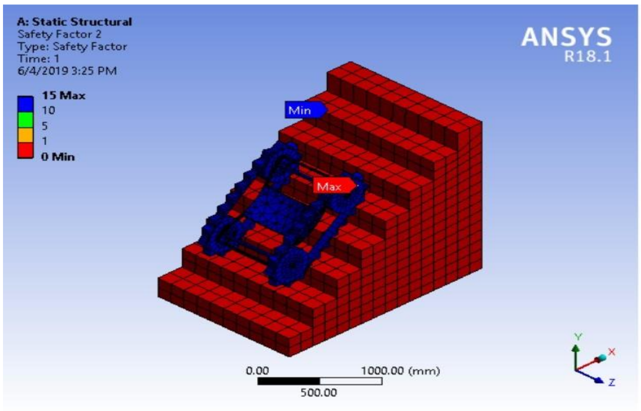

Figure-18: Factor of safety

9. RESULTS AND DISCUSSION

- From the Analysis we observed the safe working properties like Von-Misses stress, Total Deformation and Factor of Safety.
- From Analysis of Chassis:
  Von-Mises stress-49.6 MPa
  Total Deformation-0.393mm
  Factor of Safety-5.035
- From Analysis on Flat Surface:
  Von-Mises stress-50.34 MPa
  Total Deformation-0.385mm
  Factor of Safety-4.96
- From Analysis on Stairs:
  Von-Mises stress-44.89 MPa
  Total Deformation-0.331mm
  Factor of Safety-5
- Modeling was carried out using CATIA, Analysis using ANSYS WORKBENCH softwares and the results achieved were encouraging. Hence, this design can be used for the further development and Fabrication of prototype.
- As per the outcomes, plan is made extremely protected and there is no possibility of disappointment of the edge and wheels under ordinary conditions.

10. CONCLUSIONS

- The load carrier is designed such that it can sustain loads up to 150Kg.
- The load carrier can be used to climb up or climb down the stairs.
- The load carrier can climb stairs up to 7 inches in rise.
- The operation of the load carrier is easy.
- The load carrier is economical compared to the products in the existing market.
- It is used in Hospitals, public places, Institutions, offices, Industries and domestic purposes.
- The motor speed is low so that the load on the load carrier does not feel any jerks or imbalances. Also the belt is designed such that there will be reduction in vibrations during the ascent and descent of stairs.

11. FUTURE SCOPE OF THE WORK

- The frame weight can be reduced by using high strength lightweight materials such as composites, carbon fiber etc.
- Stair climber can be automated by using electronics so that it will automatically sense and climb the stairs. It will indeed be a good future work to fabricate a full size model and subject it to rigorous testing conditions.
- Same mechanism can be used for wheel chair providing high head motor along with more rigid structure. By using hydraulic mechanism to shift and maintain the CG, So that center of gravity easily maintained while ascending and descending of wheelchair on staircase. It affects the stability of system and also it reduces the load on motor.

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