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Structural Analysis of Chassis Frame for Solar Car

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Abstract -- Automotive chassis is an important part of an automobile. The chassis serves as a frame work for supporting the body and different parts of the automobile. Also, it has to withstand the shock, twist, vibration and other stresses caused due to sudden braking, acceleration, road condition and forces induced by its components. When the loads acting on chassis, weight, loads and equivalent stresses are generated that can cause failure occurred. So, maximum bending stress, and deflection are important criteria for the design of the chassis. This research is the work performed towards the optimization of the automotive chassis with constraints of maximum bending stress, maximum shear stress, von-Mises stress and deflection of chassis under maximum load. The solar car for C cross section chassis with three different materials namely, structural steel AISI 1030, AISI 1020 and Alloy Steel. In this research, structural steel AISI 1030 is more strength and less deformation than other two materials. The result of side longitudinal rail for optimum dimensions are outside depth 0.076m, outside width 0.05m, thickness 0.003m, inside depth 0.07m, inside width 0.047m respectively. The result of C cross-section type for cross member dimensions are outside width 0.032m, outside depth 0.07m, thickness 0.003m, inside width 0.029m, inside depth 0.064m. The result of von-Mises stress is 202.4 MN/m2 and deflection 0.00189m for structural steel AISI 1030. SolidWorks software is used for modelling and analysis of stress on chassis frame.

Indexed Terms -- Chassis frame, Bending, Deflection, Materials, Shear stress

I. INTRODUCTION

A solar car is a solar vehicle used for land transport. Solar cars only run on solar power from the sun. To keep the car running smoothly, the driver must monitor multiple gauges to spot possible problems. For solar car, solar energy was main power source which can be stored into battery charger after charged it under sunlight in certain period by convert the solar energy into electrical energy. The amount of energy stored in the battery charges is depend on area of photovoltaic panel on the car which can directly convert the solar energy into electrical energy. The solar car has many components such as solar panel, batteries, chassis frame, brakes, steering system, motor, wheel etc [6].

Automotive chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes steering etc. are bolted [4]. The chassis is considered to be the most significant structures of an automobile. It is usually made of a steel frame, which holds the body and motor of an automotive. At the time of manufacturing, the body of a vehicle is flexibly molded according to the structure of chassis. Automobile chassis is usually made of light sheet metal or composite plastics. It provides strength needed for supporting vehicular components and payload placed upon it. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile. The different types of automobile chassis include ladder chassis, monocoque chassis, backbone chassis and tubular space frame chassis.

Ladder chassis is considered to be one of the simplest and oldest forms of automotive chassis that is still used by most of the SUVs (Sport Utility Vehicles) till today. It consists of two symmetrical rails, or beams, and cross members [1]. Monocoque chassis is a one-piece structure that prescribes the overall shape of a vehicle. This type of automotive chassis is manufactured by welding floor pan and other pieces together. Since monocoque chassis is cost effective and suitable for robotized production, most of the vehicles today make use of steel plated monocoque chassis[3].

Backbone chassis has a rectangular tube like backbone, usually made up of glass fibre that is used for joining front and rear axle together. This type of automotive chassis or automobile chassis is strong and powerful enough to provide support smaller sports car. Backbone chassis is easy to make and cost effective [2].The tubular space frame chassis is used for urban car. Tubular space frame is a three dimensional design. Tubular space frame chassis employs dozens of circular-section tubes(some may use square-section tubes for easier connection to the body panels though circular section provides the maximum strength), position in different directions to provide mechanical strength against forces from anywhere. These tubes welded together and form a complex structure. For higher strength required by high performance sports cars, tubular space frame chassis usually incorporate a strong structure under both doors [6].In this study, ladder chassis is used for solar car. The chassis frame is composed with two side rails and two cross members for the purpose of withstanding both bending and twisting moments by road shocks. The frame is more affected by vertical loads comparing other components because it is the most important member as a contact mechanism with road. Figure 1 shows the ladder chassis frame of C cross-section for solar car [2].

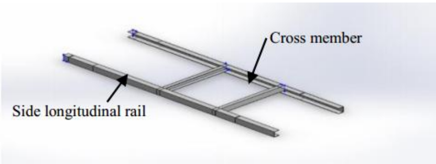

Figure 1. Ladder Chassis Frame of C Cross Section

II. DESIGN PROCEDURE OF THE SIDE LONGITUDINAL RAIL FOR CHASSIS FRAME

Table 1 illustrates the design data of the side longitudinal rail of chassis.

Table 1 Specification Data for Solar Car

Technical category	Value	Unit
Vehicle gross weight	4806.9	N
Overall length of frame	2.15	m
Overall Width of frame	1	m
Overall Height of frame	1.8	m
Weight of solar panel	451.26	N
Weight of motor	235.44	N
Weight of batteries	1648.08	N
Seating capacity	2	passengers
Weight of two persons	1765.8	N
Front wheel distance track	0.7	m
Rear wheel distance track	0.7	m

A. Calculation of Unsprung weight

The weight of unsprung components is normally in the range of 13 to 15 percent of the vehicle net weight [13]

Unsprung weight = 0.15× vehicle weight (1)

B. Calculation of sprung weight

Sprung weight can be calculated as follows:

Sprung weight = gross weight – unsprung weight (2)

C. Loading Consideration of side rails

Shear force and bending moment diagrams for static condition are shown in Figure 2.

Side rails for uniform distributed load are as follows:

Body weight for one longitudinal = 350.707 N

Total distributed load = 285.0819 N/m

Weight of Point D and E

for one longitudinal = 853.45 N

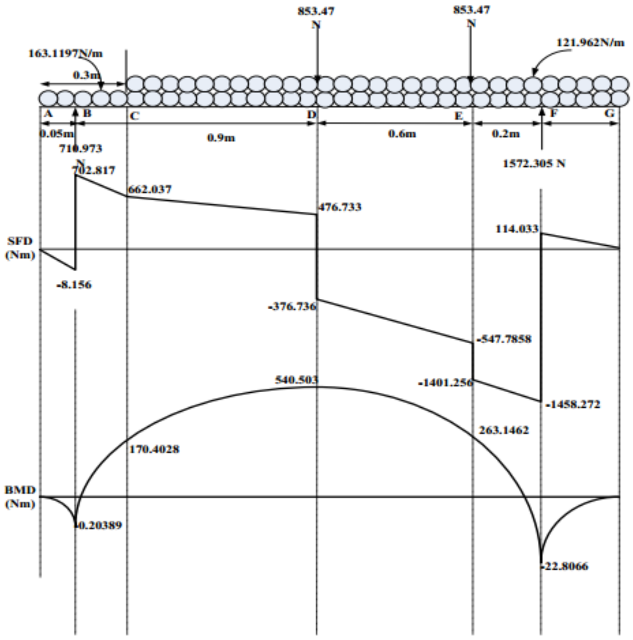

Figure 2: Shear Force and Bending Moment Diagram of Side Longitudinal Rail for Static Condition.

D. Dynamic load for side rail

The dynamic load can be calculated as follow:

Dynamic Load = static Load × factor of safety (3)

The Factor of safety 2 is used for dynamic load condition [10].

Shear force and bending moment diagrams for dynamics load condition are shown in Figure 3

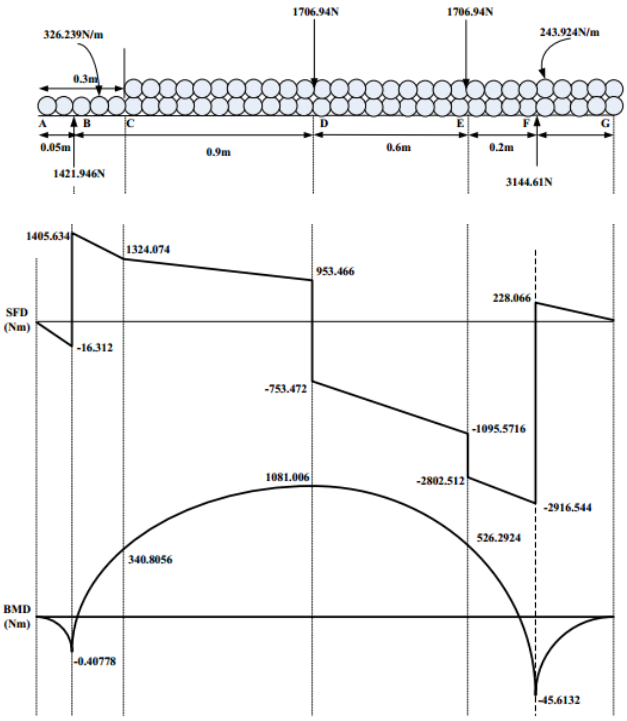

Figure 3: Shear Force and Bending Moment Diagram of Side Longitudinal Rail for Dynamic Condition

Table 2 Material Properties of Chassis Frame

Type of material	Tensile stress (MN/m^2)	Yield Stress (MN/m^2)	Allowable Stress (MN/m^2)	Modulus of Elasticity (GN/m^2)
Structural steel AISI 1030	470	5.91	215.19	499.73

Table 2: shows the mechanical properties of structural steel [5,9].

E. Calculation of allowable stress, σ_a

The allowable stress as follow: $\sigma_a = \frac{2}{3} \times \sigma_{yield}$

(4)

F. Calculation of torsional moment, T

Front and rear torsional moment

$$T_f = R_1 \times t_f \quad (5)$$

$$T_R = R_2 \times t_R \quad (6)$$

The maximum torsional moment can be chosen from front and rear torsional moment [11,12].

G. Section modulus for bending case and torsion case

For bending case,

$$Z = \frac{M_{max}}{\sigma_a} \quad (7)$$

For torsion case,

$$Z = \frac{T_{max}}{\sigma_a} \quad (8)$$

The section modulus of bending case and torsion case are calculated and chosen the maximum section modulus for safe condition [7].

H. Design of cross-section for longitudinal side rail

In this research, C channel type cross section is used for chassis design. Figure 4 shows the C cross-section type of chassis frame.

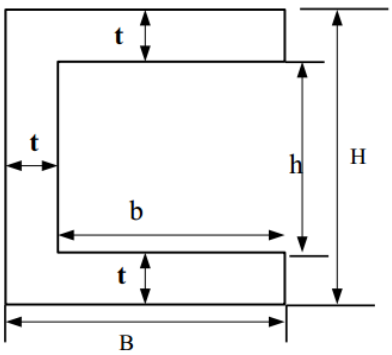

Figure 4: C Cross Section Type of Chassis Frame

Section modulus for C cross section type equation as follows $Z = \frac{BH^3 - bh^3}{6H}$ (9)

I. Calculation of maximum bending stress

$$\sigma_b = \frac{M_{max} c}{I} = \frac{M_{max}}{Z} \quad (10)$$

J. Calculation of Maximum shear stress

$$\tau = \frac{VQ}{It} \quad (11)$$

K. For Principal stresses

Figure 5 shows the stresses in the x-y plane for the principal stresses [8].

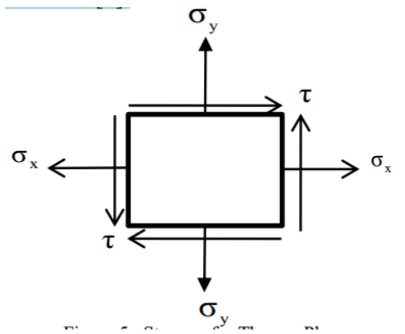

Figure 5: Stresses for The x-y Plane

$$\sigma_{1,2} = \frac{1}{2}\left(\sigma_y + \sigma_x\right) \pm \frac{1}{2}\left[\left(\sigma_y + \sigma_x\right)^2 + 4\tau^2\right]^{1/2} \quad (12)$$

Where, σ_x = bending stress

σ_y = 0

L. For von-Mises stress

$$\bar{\sigma} = \sqrt{\frac{1}{2}\left[\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right]} \quad (13)$$

M. The deflection of side longitudinal rail

Figure 6 shows longitudinal side rail is subjected loading condition

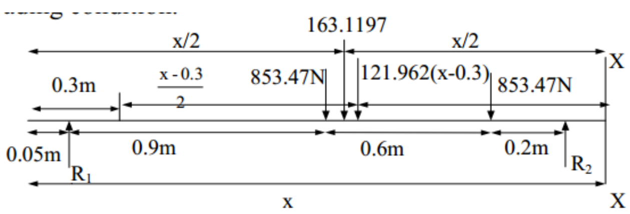

Figure 6. Deflection of Side Longitudinal Rail

The deflection of side longitudinal rail by using Macaulay'Method[7],

$$EI = \frac{d^2y}{dx^2} = M \quad (14)$$

The deflection equation of side longitudinal rail as follows:

$$EI\frac{d^2y}{dx^2} = -853.47\left[x - 0.95\right] - 163.1197\frac{x^2}{2} - \frac{121.962}{2}\left[x - 0.3\right]^2 - 853.47\left[x - 1.55\right] + 710.9725\left[x - 0.05\right] + 1572.305\left[x - 1.75\right] \quad (15)$$

Table 3: Design Result of Side Longitudinal Rail

H (m)	B (m)	t (m)	h (m)	b (m)	Z (m3)
0.08	0.05	0.003	0.074	0.047	1.3655E-05
0.079	0.05	0.003	0.073	0.047	1.3434E-05
0.078	0.05	0.003	0.072	0.047	1.3215E-05
0.077	0.05	0.003	0.071	0.047	1.2997E-05
0.076	0.05	0.003	0.070	0.047	1.2780E-05
0.075	0.05	0.003	0.069	0.047	1.2564E-05
0.074	0.05	0.003	0.068	0.047	1.2348E-05
0.073	0.05	0.003	0.067	0.047	1.2134E-05

The result data of side longitudinal rail for cross sectional dimensions are as shows in Table 3.

Where,
B=outside width
b= inside width
H=outside depth
h= inside depth
t= thickness
Z= section modulus

Table 4: Stress and Deformation of Side Longitudinal Rail

Type of material	von-Mises stress (MN/m^2)	Deformation (m)
Structural Steel AISI 1030	167.629	0.0028

The result data of von-Mises stress and deformation for side longitudinal rail as shown in Table 4

III. DESIGN PROCEDURE OF THE CROSS MEMBER FOR CHASSIS FRAME

In this research, there are two cross members to design for solar car frame to withstand bending moments by the passengers.

The cross members carry the weight of six batteries and two persons which are transmitted to cross members as uniformly distributed load. Figure 7 shows cross member

With uniformly distributed load and maximum bending moment of one cross member.

A. Load acting on one cross member

$$\omega_1 = \frac{\frac{1}{2}\left(\omega_{person} + \omega_{batteries}\right)}{\text{Length of cross member}} \quad (16)$$

r (17)

$$\omega = \omega_1 + \omega_2 \quad (18)$$

B. Maximum bending moment of one cross member Figure 7 shows shear force and bending moment diagrams of cross member.

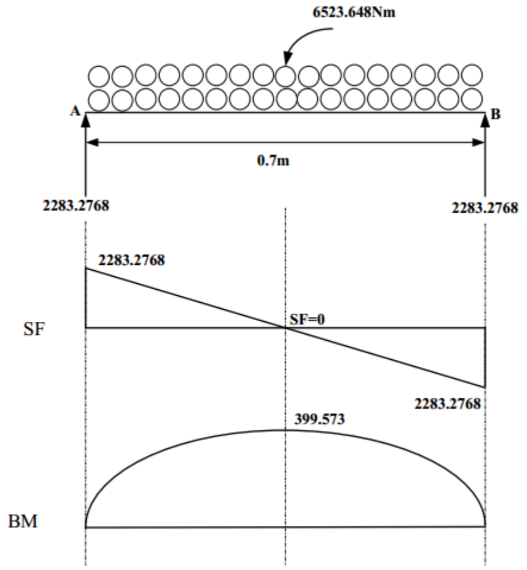

Figure 7: Shear Force and Bending Moment Diagrams of Cross Member

C. The section modulus for cross member

$$Z = \frac{M_{max}}{\sigma_a} \quad (19)$$

D. The defection of cross member, y

The maximum deflection

$$y = \frac{5\omega L^4}{384EI} \quad (20)$$

Table 5 Design Result of Cross Member

B (m)	H (m)	t (m)	h (m)	b (m)	Z (m^3)
0.038	0.07	0.003	0.064	0.035	9.188E-06
0.037	0.07	0.003	0.064	0.034	8.995E-06
0.036	0.07	0.003	0.064	0.033	8.8029E-06
0.035	0.07	0.003	0.064	0.032	8.6104E-06
0.034	0.07	0.003	0.064	0.031	8.4179E-06
0.033	0.07	0.003	0.064	0.030	8.2254E-06
0.032	0.07	0.003	0.064	0.029	8.0329E-06
0.031	0.07	0.003	0.064	0.028	7.8404E-06

The result data of cross member for section modulus and cross sectional dimensions as shows in Table 5.

Table 6 Result For Cross Member

Type of material	Von-Mises stress(MN/m^2)	Deformation(m)
Structural Steel AISI 1030	198.293	0.000177

IV. STRENGTH CHECK ON CHASIS FRAME

Side longitudinal rail and cross member have to withstand the vertical dynamic load in running condition. This is fluctuation load may cause the variable stress which fail the material below the yield point. Therefore, the materials have to be analyzed by variable stress theory.

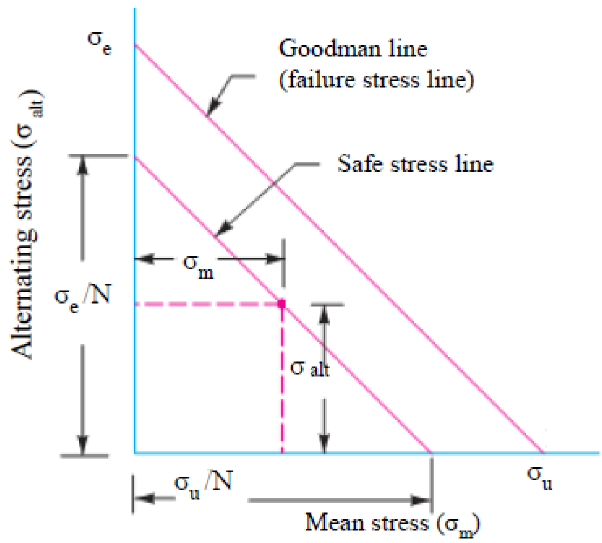

Figure 8. Goodman Diagram[10]

A straight line connecting the endurance limit and ultimate strength as shown in Figure 8. The line connecting the endurance limit and ultimate tensile strength is called Goodman line. According to the Goodman diagram, any point that lies below Goodman line cannot be failed by corresponding loads [10].

1. Mean stress, σ_m

The mean stress as follow:

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad (21)$$

2. The alternating stress, σ_{alt}

$$\sigma_{alt} = \frac{\sigma_{max} - \sigma_{min}}{2} \quad (22)$$

3. Safety factor, N

$$N = \frac{1}{\frac{\sigma_{alt}}{\sigma_e} + \frac{\sigma_m}{\sigma_u}} \quad (23)$$

4. Endurance Stress, σe

$$\sigma_e = 0.5\sigma_u \quad (24)$$

The tensile stress σ_u is 470MN/m2 for structural steel AISI 1030 from material properties [11].

Table 7 Mean Stress and Alternating Stress for Side Longitudinal Rail and Cross Member of Structural Steel AISI 1030

	σ_m(MN/m2)	σ_{alt} (MN/m^2)	N
Side rail	103.0368	67.6647	1.971
Cross member	24.871	24.871	6.299

The result data of mean stress and alternating stress for side longitudinal rail and cross member of Structural Steel AISI 1030 as shown in Table VII. The Goodman diagrams are as follows:

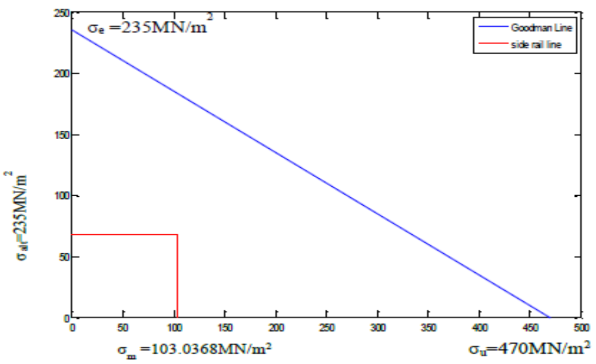

Figure 9: Goodman Diagram for Side Longitudinal Rail

Figure 9 shows the point at the intersection of mean stress 103.0368 MN/m2 and alternating stress 67.67MN/m2 is under the goodman line. Therefore, the design of side longitudinal rail is satisfied.

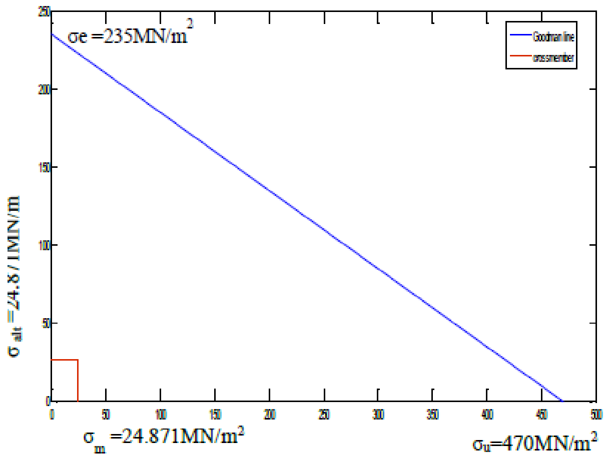

Figure 10: Goodman Diagram for Cross Member

Figure 10 shows the point at the intersection of mean stress 24.871 MN/m^2 and alternating stress 24.871 MN/m^2 is under the Goodman line. Therefore, the design of cross member is satisfied.

The Goodman diagram, combined stress is the sum of the stress and alternating stress lies below the Goodman line. Therefore, design of side longitudinal rail and cross member is satisfied.

V. NUMERICAL SIMULATION OF CHASSIS FRAME

To estimate the following stress and deformation, SolidWorks software has been used. The design of chassis frame was analyzed with materials namely structural steel AISI 1030, AISI 1020, Alloy Steel.

A. Loading and boundary condition

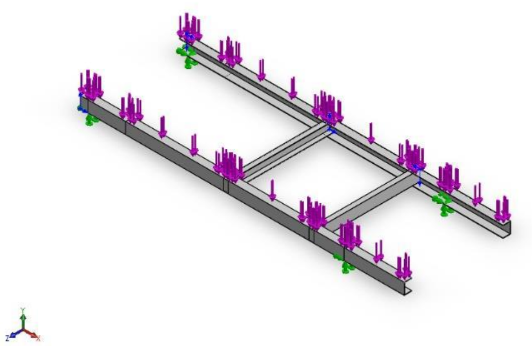

Figure 11. Fixed Position and Loading Condition of Chassis Frame

Fixed supports are provided at the contact region of wheel and chassis frame. The person's weight, batteries weight, body's weight and solar weight are exerted as uniformly distributed load on upper side of chassis. Fixed position and loading condition of chassis frame as shown in Figure 11. Figure 12 illustrates the meshing diagram of chassis frame.

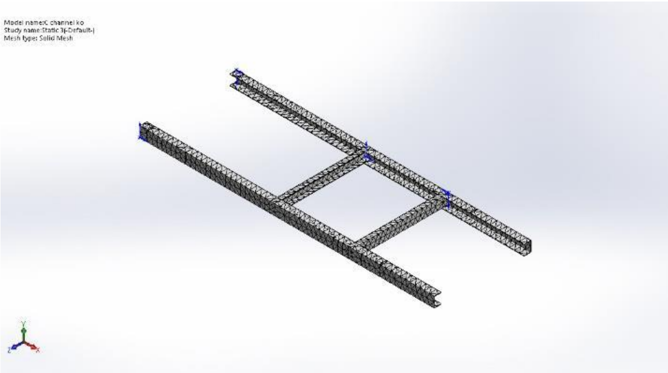

Figure 12. Meshing of Chassis Frame

B. Structural analysis of chassis frame

The equivalent (von-Mises) stress and maximum deformation of chassis with three different materials are shown in Figure 13, 14, 15, 16, 17 and 18.

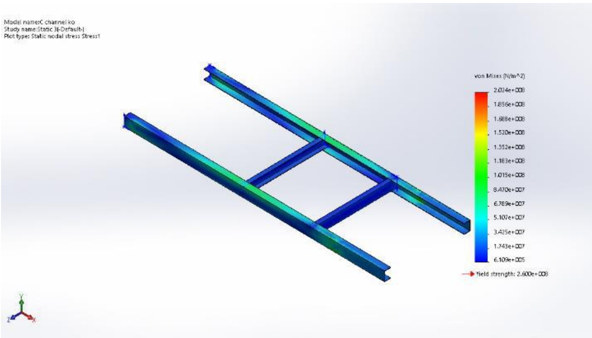

Figure 13. Equivalent Stress in Chassis Frame using Structural Steel AISI 1030

Figure 13 shows the numerical result with equivalent (von-Mises) stress is 202.4 MN/m_2 for structural steel AISI 1030.

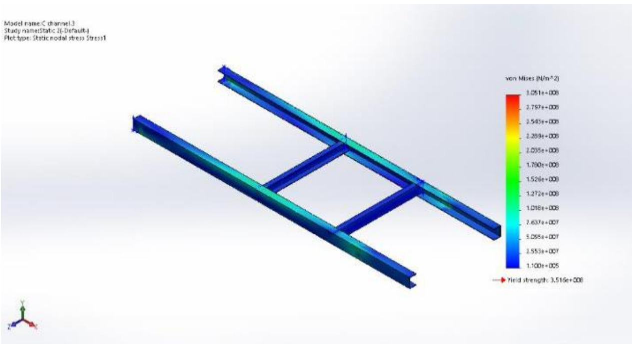

Figure 14. Equivalent Stress in Chassis Frame using AISI 1020

Figure 14 shows the numerical result with (von-Mises) stress is 305.1 MN/m_2 for AISI 1020.

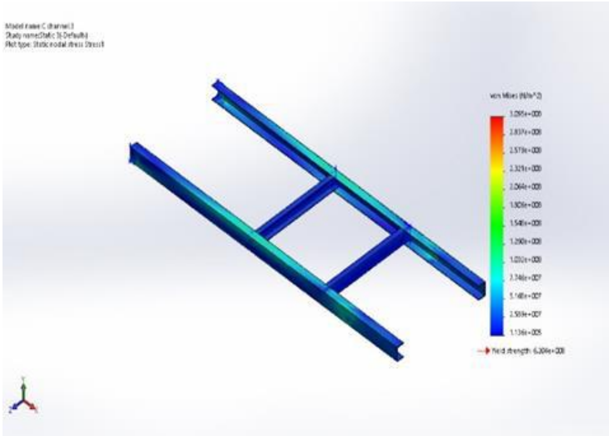

Figure 15. Equivalent Stress in Chassis Frame using Alloy Steel

Figure 15 shows the numerical result with equivalent (von-Mises) stress is 309.5 MN/m_2 for Alloy Steel.

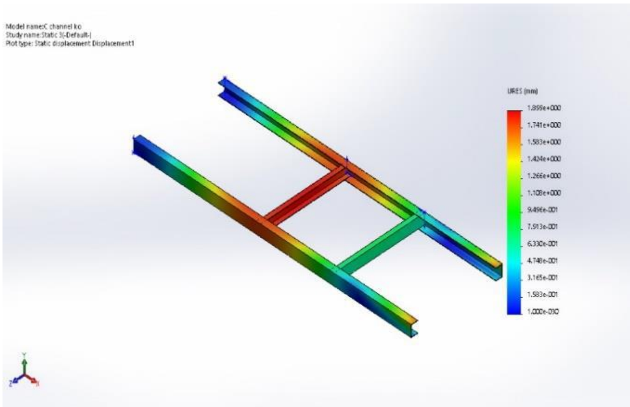

Figure 16. Maximum Deflection of Chassis Frame for Structural Steel AISI 1030

Figure 16 shows the numerical result with maximum deflection is 0.00189m for structural steel AISI 1030.

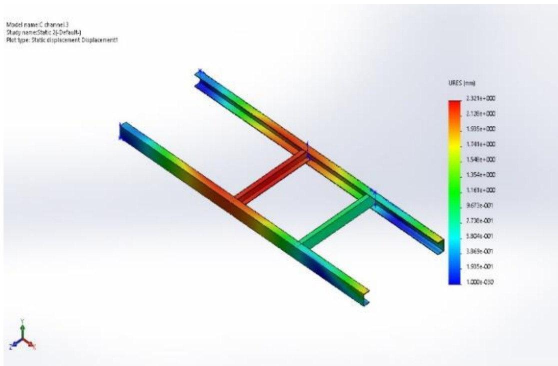

Figure 17. Maximum Deflection of Chassis Frame for AISI 1020

Figure 17 shows the numerical result with maximum deflection is 0.00232m for AISI 1020.

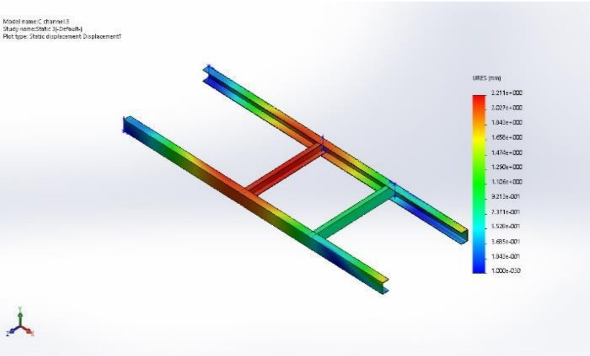

Figure 18. Maximum Deflection of Chassis Frame for Alloy Steel

Figure 18 shows the numerical result with maximum deflection is 0.00221m for Alloy Steel.

Table 8 Numerical Result for Equivalent Stress and Deflection of Three Different Materials

Type of material	Equivalent Stress (MN/m^2)	Deflection (m)
Structural Steel AISI 1030	202.4	0.00189
AISI 1020	305.1	0.00221
Alloy Steel	309.5	0.00232

Table 8 shows the numerical result with equivalent stress and deflection for chassis frame. The most suitable material is structure steel AISI 1030 because the equivalent stress and deflection are smaller than other materials. As numerical and theoretical values are approximately equal within allowable limit of stresses so structural steel AISI 1030 has chosen.

VI. CONCLUSION AND DISCUSSION

In this study, ladder chassis frame type for solar car was analyzed by using SolidWorks software with three different materials. From the results, it is observed that the Structural Steel AISI 1030 has more strength than the AISI 1020 and Alloy Steel. The C cross section type with Structural Steel AISI 1030 has found least von-Mises stress is 202.4 MN/m^2 and maximum deflection i.e., 0.00189 m. The C Cross-section type of Ladder Chassis is having least deflection and von-Mises stress for Structural Steel AISI 1030 in all three types of materials. Therefore, structural steel AISI 1030 is chosen for this research.

ACKNOWLEDGMENT

The first author wishes to acknowledge her deepest gratitude to her parents, to her master student Nang Hsu Thandar Ko and her relatives and friends to carry out this research.

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