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FRONT AND SIDE IMPACT ANALYSIS OF SPACE FRAME CHASSIS OF FORMULA CAR

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ABSTRACT: One of the popular types of formula car chassis is space frame chassis. There are many issues to design and analyze formula car chassis. For driver, Front and side impact are the main issue for design and analysis with accurate and safety. In this article, the 2017-2018 formula SAE (the Society of Automotive Engineers) rules are used for analysis. SolidWorks 2016 are used to construct the CAD models of formula car chassis. Finite element method (FEM) is used to analyze the CAD models using SolidWorks Simulation. The results show that all formula car chassis models satisfy the 2017-2018 formula SAE rules. For the front impact, the maximum stress and the maximum deflection are not significant affected by varying the distance of the side members. While varying the distance of the front impact members affects both of the maximum stress and the maximum deflection. For the side impact, the maximum stress and the maximum deflection are not significant affected by varying the distance of the front members. While varying the distance of the side members affects both of the maximum stress and the maximum deflection. The criterions of the formula car chassis design are to make maximum stress lowest and maximum deflection lowest. The distance of the front members joint and the distance of the side member joint should be as low as possible.

Keywords: Formula, Space Frame Chassis, Side Impact, FEM Design and Analysis

1. INTRODUCTION

In the present day the Formula Society of Automotive Engineers (Formula SAE) main activity is a student-level design competition of formula car which is the beginning event of the Formula One car racing; the most popular car racing event in the world. There are many subjects to design formula car such as engine and electronic system, chassis, suspension, break system, power train, aerodynamics, impact attenuator, and materials, [1]-[6].

One of the most important part of the formula car is formula car chassis. There are many types of the formula car chassis. Space frame chassis, ladder frame chassis and composite monocoque are the popular types of the formula car chassis [6]-[9]. The circular or square tube are used to construct the space frame chassis by welding. The ladder frame chassis has a shapes of the ladder style. Meanwhile, the composite monocoque is made from composite material.

For the formula car chassis design, torsional rigidity, modal analysis, vibration analysis, front impact and side impact are the main analysis. Finite element method (FEM) are usually used for these analysis [10]-[11].

Torsional rigidity or torsional stiffness can be determined using FEM. the torque is applied at one end of the formula car chassis and the other end is fixed. The torsional deflection and the torque are applied to determine the torsional stiffness [8].

The mode shapes and the natural frequencies of the formula car chassis are determined using modal analysis for avoiding the resonant frequency [7]. High vibration occurs at resonant frequency when the engine frequency equals the natural frequency.

The mass-spring-damper with the road shapes are used in the vibration analysis of the formula car. The quarter-car model is performed for determination the vibration of the tire deflection, the suspension deflection and the car acceleration [12].

The front impact and the side impact are the impact analysis in FEM. Impact analysis can be simplified to static analysis using the relation of the force due to the formula car chassis in a short time and the changing of the formula car momentum [13]

$$F\Delta t = m(v_2 - v_1), \tag{1}$$

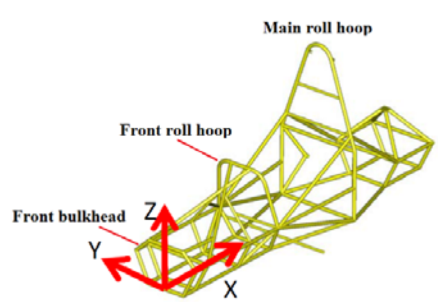


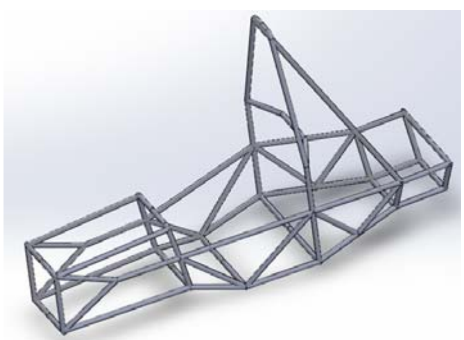
Fig. 1 Formula SAE space frame chassis [1].

where F is the impact force, Δt is the time duration of the impact force due to the formula car chassis, m is the total formula mass (with the driver), v_1 is the car velocity before crashing, and v_2 is the car velocity after crashing ($v_2 = 0$).

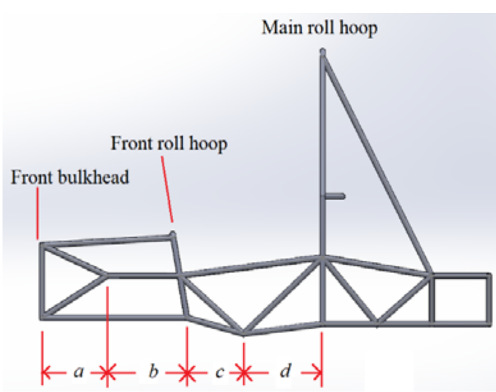
The stress and the deflection of the formula car chassis must not over the allowable limit of the chassis materials. Figure 1 shows the Formula SAE space frame chassis. For front impact, the 2017-2018 formula SAE rules define that F_x = 120 kN applied at the actual attachment points between the impact attenuator and the front bulkhead. Boundary Condition: Fixed displacement (x, y, z) but not rotation of the bottom nodes of both sides of the main roll hoop and both locations where the main hoop and shoulder harness tube connect. For side impact, F_y = 7.0 kN applied at all structural locations between front roll hoop and main roll hoop of the formula car. For boundary conditions, the bottom nodes of both side of the front and main roll hoops are fixed. Failure must not occur at anywhere and the maximum allowable deflection of 25 mm [1].

In this study, the space frame chassis is performed. The shapes of all member locations between front bulkhead and main roll hoop will be investigated with the best condition of stress and deflection of the formula car.

2. CHASSIS DESIGN



(a)



(b)

Fig. 2 (a) 3d view (b) side view.

Figure 2(a) and Figure 2(b) show the 3d view and the side view of the formula car chassis used in this study, respectively.

Six of front members between front bulk head and front roll hoop are changed by varying the distance of the front member joint of a as show in Table 1.

Nine members of side members between front roll hoop and main roll hoop are changed by varying the distance of the side member joint of c as show in Table 2.

Table 1 Design of members between front bulk head and front roll hoop.

Front members Fa	a
F1	$(a+b)/6$
F2	$2(a+b)/6$
F3	$3(a+b)/6$
F4	$4(a+b)/6$
F5	$5(a+b)/6$

Note: $a+b$ = 700 mm.

Table 2 Design of members between front roll hoop and main roll hoop.

Side members Sc	c
S1	$(c+d)/12$
S2	$2(c+d)/12$
S3	$3(c+d)/12$
S4	$4(c+d)/12$
S5	$5(c+d)/12$
S6	$6(c+d)/12$
S7	$7(c+d)/12$
S8	$8(c+d)/12$
S9	$9(c+d)/12$
S10	$10(c+d)/12$
S11	$11(c+d)/12$

Note: $c+d$ = 654 mm.

3. MATERIAL SELECTION

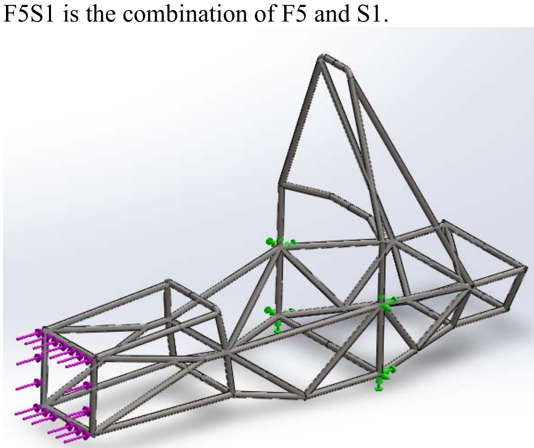
All members of the formula car chassis are made of carbon steel pipe with the outer diameter of 25.4 mm and the thickness of 2.5 mm. The mechanical properties of the carbon steel are shown in Table 3.

Table 3 Material properties of carbon steel pipe

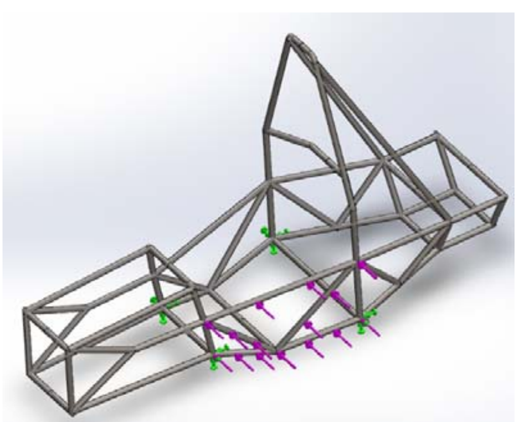
Property	Value	Units
Elastic modulus	205	MPa
Poisson's ratio	0.29	-
Shear modulus	80	GPa
Tensile strength	365	MPa
Yield strength	305	MPa

4. FINITE ELEMENT METHOD

In this study, using the 2017-2018 formula SAE rules, the front and side impact force acts directly on the front and side members with the magnitudes and the boundary conditions as shown in Fig. 3. The CAD models of the formula car chassis are modeled using SolidWorks 2016. For front impact, SolidWorks Simulation is applied to analyze the stress and the deflection of the formula car chassis in some cases of the side member; S1, S5, and S11 combining with all cases of the side members in Table 1; S1 to S11 with the abbreviation F*a*S*c*. For side impact, some cases of the front member; F1, F3, and F5 are combined with all cases of the side members in Table 2; S1 to S12. For example, the F1S*c* is the combination of the front member F1 and all cases of the side members S*c*. The F*a*S5 is the combination between all cases of the front members and the side member S5. Moreover, the F5S1 is the combination of F5 and S1.



(a)



(b)

Fig. 3 Load and boundary condition; (a) front impact (b) side impact.

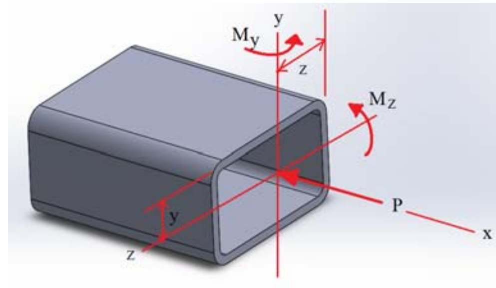


Fig. 4 Combine loading in beam element.

The CAD models are meshed with beam element. The upper bound axial and bending stress (σ) is used to compare the yield strength (σ_y).

Failure not occur anywhere in structure for $\sigma < \sigma_y$. The upper bound axial and bending stress can be computed from

$$\sigma = \frac{P}{A} + \frac{(M_y I_z + M_z I_{yz})z + (M_z I_y + M_y I_{zy})y}{I_y I_z - I_{yz}^2}, \quad (2)$$

where P is the axial force, A is the beam cross section area, M_y and M_z are the moment in the direction y and z, respectively, I is the moment inertia of area of the beam cross section and the subscript indicates its rotation direction as shown in Fig 4.

The beam deflection can be computed from

$$u = \sqrt{u_x^2 + u_y^2 + u_z^2}, \quad (3)$$

where u is the beam deflection, u_x, u_z and u_y are the beam deflection in x, y and z directions, respectively. The beam deflection is used to compare the allowable deflection of 25 mm.

5. RESULT AND DISCUSSION

5.1 Front Impact

In case F5S6 with front impact, Figure 5 and 6 show the stress and the deflection of the formula car chassis respectively. For all cases of F*a*S*c* (*a* = 1, 2, …, 5 as shown in Table 1 and *c* = 1, 6, and 11 as shown in Table 2, respectively), the results of the maximum stress σ_{max} can be plotted with *a* as shown in Fig. 7. The results show that the relationships of the maximum stress and the distance *c* are the upturned parabolic equation with R^2 more than 0.92. The maximum deflection and the distance *a* can be plotted with the upturned parabolic equation with R^2 more than 0.91 as shown in Fig.8. The maximum deflections are less than 25 mm for all cases. The lowest maximum stress and maximum deflection occur at cases F5S*c* (*a* = 5(700)/6 = 583.3 mm).

From Fig.7 and 8, three graphs of case FaS1, FaS2, and FaS3 by varying the distance *c* show the similar graphs. The results show that the distance *c* does not affect the maximum stress and the deformation of the formula car chassis. #

5.2 Side Impact

Figure 9#and 10 shows the stress and the deflection in the formula car chassis in case F5S6 with side impact respectively. Fig. 11 shows the maximum stress for all cases of F*a*S*c* (*a* = 1, 3, and 5 and *c* = 1, 2, …, 11). The results show that the relationships of the maximum stress and the distance *c* are increasing linear equation with R^2 more than 0.9 except the case of F5S*c* has R^2 of 0.8363. The maximum stress will be increased by varying the distance *c*. The lowest maximum stress occur at cases F*a*S3 (*c* = 3(654)/12 = 163.5 mm). For comparing with yield strength, failure not occurs anywhere in structure for all cases.

The maximum deflection and the distance *c* can be plotted with the upside down parabolic equation with R^2 more than 0.87 as shown in Fig. 12.

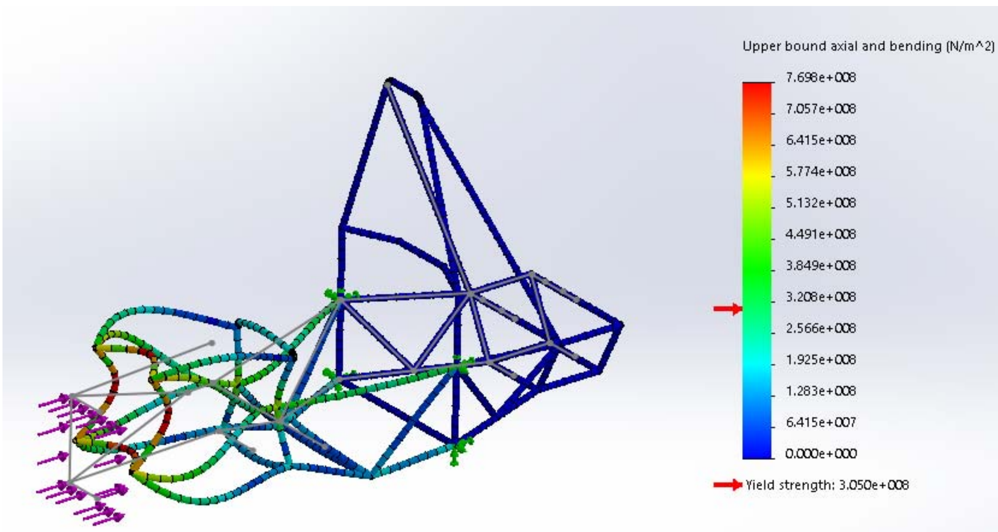


Fig. 5 Stress in the formula car chassis with front impact (case F5S6).

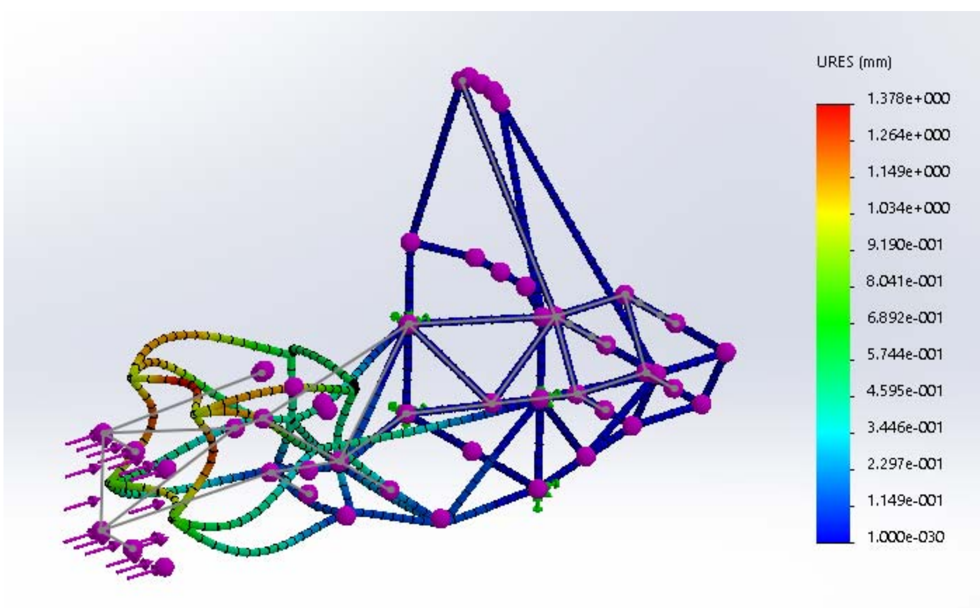


Fig. 6 Deflection of the formula car chassis with front impact (case F5S6).

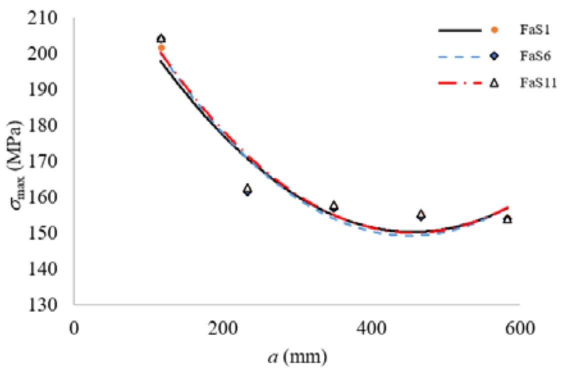


Fig. 7 Maximum stress with front impact.

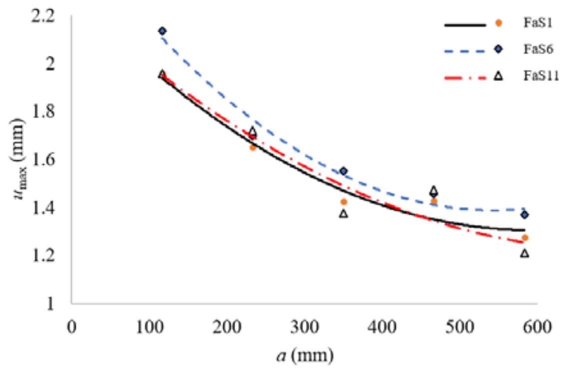


Fig. 8 Maximum deflection with front impact.

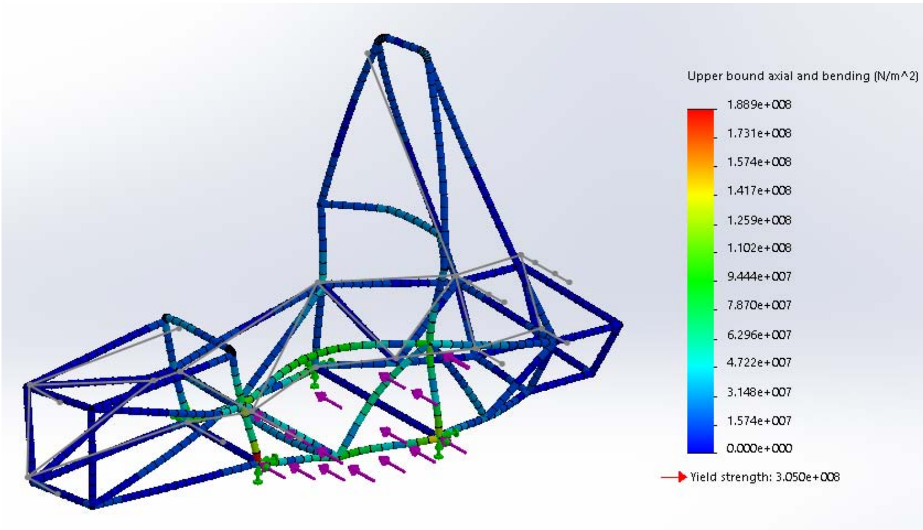


Fig. 9 Stress in the formula car chassis with side impact (case F5S6).

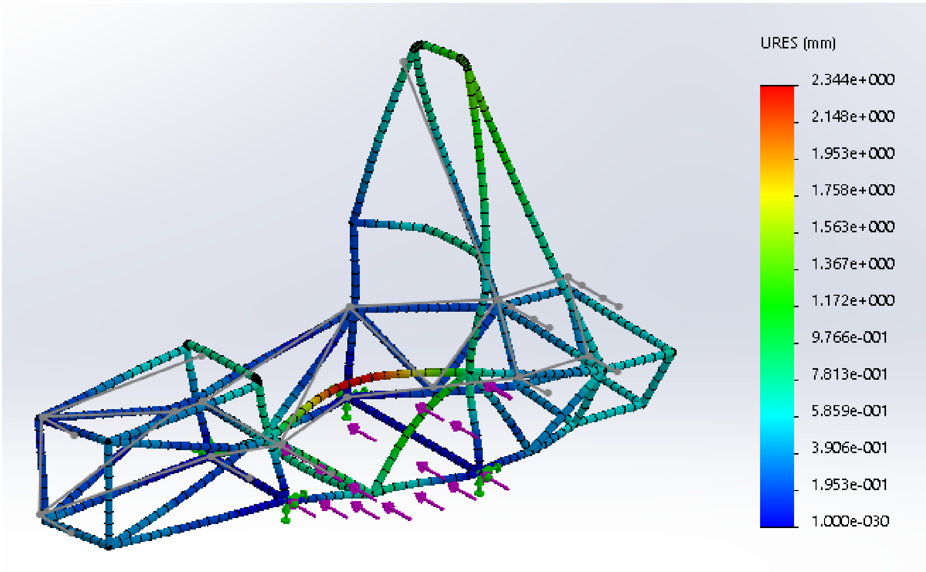


Fig. 10 Deflection of the formula car chassis with side impact (case F5S6).

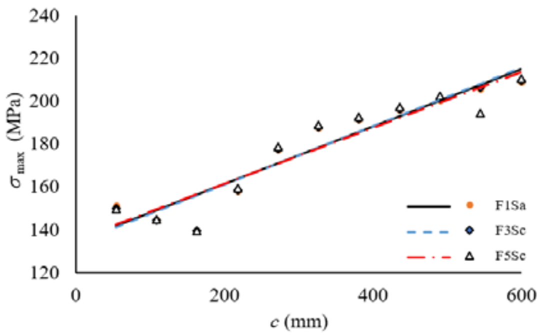


Fig. 11 Maximum stress with side impact.

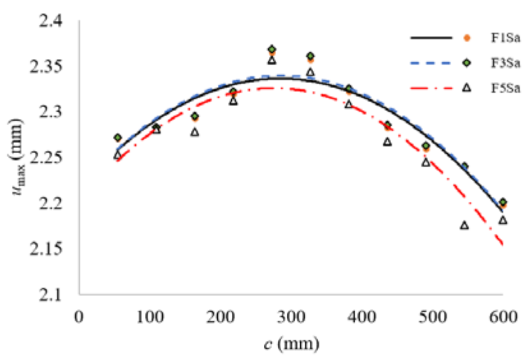


Fig. 12 Maximum deflection with side impact.

The maximum values of the maximum deflection occur in cases F*a*S5 (c = 5(654)/12 = 272.5 mm). The minimum values of the maximum deflection occur in cases F*a*S11 except case F5S*c* occurs in case F5S10. All cases do not exceed the allowable deflection of 25 mm.

From the graphs of the stress and the deflection as shown in Fig.9 and 10, by varying the distance a, the results show that the distance a is not the main factor that affect the maximum stress and the maximum deflection.

6. CONCLUSION

This paper presents the formula space frame chassis design and analysis subjected on front and side impact.

For front impact, by varying the distance a of the front member joint, the results show that the maximum stress and the maximum deflection can be plotted with upturned parabolic equation for all cases. The distance c of the side member joint dose not affects the maximum stress and the maximum deflection.

For side impact, by varying the distance c of the side member joint, the results show that the relationships between the maximum stress and the distance c are increasing linear equation for all cases. The maximum stress can be increased by increasing the distance c. The relationships between the maximum deflection and the distance c are the upside down parabolic equation. The distance a insignificantly affects the maximum stress and the maximum deflection.

The criterions of the formula car chassis design are to make maximum stress and make maximum deflection as low as possible. The distance a should be as high as possible, while the distance c should be as low as possible. All in all, case F5S1 is the best design for this study.#

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