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Stress Analysis of a Cross over Electric Car Chassis

*Tarsisius Kristyadi, Alexin Putra, Tito Santika, Liman Hartawan, Trinaldo
Mechanical Engineering, Institut Teknologi Nasional Bandung, Indonesia
Corresponding Author: Tarsisius Kristyadi

Abstract : *This paper presents, stress analysis of a ladder type cross over electric car chassis structure using FEM. The commercial finite element package SOLIDWORK was used for the solution of the problem. Two type of chassis was analysed, solid plate beam and porforated plate beam chassis. To reduce the weight of the chassis of the cross over electric car, the chassis structure design was modified by porforating the beam so that the main beam is not solid. The boundary conditions applied to this model of chassis can be classified into four general cases: static condition., the car climb 30^o. the car is passed through a descend road about 30^o and when the car is brake from 40 km/h until stop for 5 second. Output parameter analysed include stress, deflection and safety factor. It was concluded that porforate the plate beam reduce the chassis weight and did not have significant affect on the chassis safety factor, stress and deflection hence suitable for electric car.*

Keywords: *chassis, electric car, cross over, stress, porforate*

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I. Introduction

Now days, the increased demands on electric car have been increased not only on cost and weight, but also on improved complete vehicle features. Electric drive vehicles are becoming an attractive alternative to combustion engine cars with global gradual fossil fuel prices rise. In addition, increasing energy prices also have led to an increase interest in the development of electric vehicles. In addition, concerns over climate change and reduction of greenhouse gas emissions, and dependence of economies on foreign energy sources, have also become an initiative for extensive research on the use of electric cars as an alternative [1, 2, 3]. Cars with electrical drive systems represent a solution for the future, and will in a steadily increasing degree be seen on the roads. The history of electric cars is closely related to the history of batteries [4, 5, 6]. Electric cars appear to be the most suitable candidates to fulfill the environmental demands. In electric cars, efficiency of energy usage is very important. Indonesia is a large country. Roads in Indonesia generally have varied terrain. Cross over type vehicle is suitable for Indonesia. In order for an electric car cross over type to perform at its best it must have adequate structure, this means it must have a stiff frame. Since most of the car's weight is between the front and rear suspension, frame stiffness is absolutely the key between these points where it will not easily bend. For the electric car, stiffness is very important. Apart from safety requirements the chassis structure in itself should also provide torsional and bending stiffness as well as direct support for the front suspension and steering system mounting points. Some value of the safety factor for various condition of loading and material of structures was recommended by Vidosic [7]. Two aspects of frame stiffness should be considered which are beaming and torsional. Therefore the chassis is considered as the most important element of the vehicle as it holds all the parts and components together. In this study, an attempt is made to design an cross over electric car chassis that would reduce the weight and able to provide high specific strength and high specific stiffness, and easy to be manufactured. The main structure is ladder sturcture. Ladder chassis is thought to be one of the most established types of car chassis or vehicles chassis that is still utilized by the greater part of the SUVs till today. As its name indicates, ladder chassis takes after a state of a ladder having two longitudinal rails entomb connected by a few horizontal and cross supports. It should be noted that this 'ladder' type of frame construction is designed to offer good downward support for the body and payload and at the same time provide torsional flexibility, mainly in the region between the gearbox cross member and the cross member ahead of the rear suspension.

To reduce of weight of the chassis structure design was modified by perforating the beam so that the main beam is not solid. The characteristic of the chassis was checked by stress analysis. This paper presents, stress analysis of a ladder type cross over electric car chassis structure using FEM. The commercial finite element package SOLIDWORK was used for the solution of the problem. Two type of chassis was analysed, solid plate beam and porforated plate beam chassis. The porforated plate beam chassis that form a ladder chassis is the new contribution in electric car thechnology. This paper is divided to (5) five parts, and starting with introduction. Literature review is the second part that discuss of previous study followed by stress analysis procedure in the third part. In the fourth part is presented the result and discussion and conslussion will be presented in the last section.

II. Literatur Review

Many researchers had conducted analysis on chassis of various vehicles. Abd Rahman et. al. investigated stress analysis on a truck chassis using finite element method [8]. Finite element result had shown that the critical point of stress occurs at opening of chassis which is in contact to the bolt. Thus it is important to reduce stress magnitude at the specific location. Previous FEA agrees well with the maximum deflection of simple beam loaded by uniformly distributed force. Ebrahimi et. al. constructed a car model and its components analysis were carried out [9]. Sane et. al. performed stress analysis on a light commercial vehicle chassis using iterative procedure for reduction of stress level at critical locations[10].Koszalka et. al. accomplished stress analysis on a frame of semi low loader using FEM[11]. Two versions of frame design were analyzed, focusing on the part of beam where the highest stresses were located.

Rane et.al [12] did their work in the use of optimization techniques for redesign of the forklift chassis by the use of finite element analysis. Author focused their work on the study of the optimum material distribution to get an idea of the load flow path based on which new design with higher strength to weight ratio as compared with original design could be obtained. Assembly fitment parameters/functional requirements were to be kept as it is. Methodology used by the author for structural optimization was in three phases. In first phase chassis was subjected to topology optimization to obtain optimum density plots to reduce its weight. In second phase after topology optimization, size optimization is performed to obtain the optimal thickness of all the structural members. The output model is run for remaining load cases in the third phase. Author concludes how optimization techniques can be used as a tool in finite element analysis for achieving weight reduction. Through optimization techniques weight of the chassis was reduced by around 14.5 %.

Marco et al. [13] focused their study on weight reduction of the automotive chassis by using structural optimization method linked with finite element analysis. Various optimization techniques were explained. The methods were briefly introduced, and some applications were presented and discussed with the aim of showing their potential. A particular focus was given to weight reduction in automotive chassis design applications. The author provided a quick overview on structural optimization methods. Author explained how topology and topometry optimizations were more suitable for an early development stage, whose outcome could be further refined through size and shape optimizations.

Prabhakaran et al. [14] focused their work towards weight reduction of chassis by performing structural analysis. Basic calculations for the chassis frame were done analytically based on the bending theory and values of stress and deflection were obtained. Finite element analysis for the existing chassis was performed for overload condition and stress and deflection values were obtained. For weight reduction design modifications were made by doing a sensitivity analysis. In sensitivity analysis section modulus and flange width were kept constant. Three cases were considered for weight reduction in which thickness and height of the flange were varied. Comparison of the results showed that out of three cases third case resulted in about 6.7% of weight reduction

III. Methodology

The main objective of the study is to obtain a preferable design safety factor, maximum stress and deflection for a cross over electric car chassis using finite element method. Two model of ladder chassis was analysed, there are solid plate beam and porforated palte beam chassis. The analysis was conducted using Commercial version of SOLIDWORK.. There are three main steps, namely: preprocessing, solution and postprocessing. The preprocessing (model definition) step is critical. A perfectly computed finite element solution is of absolutely no value if it corresponds to the wrong problem. This step includes: define the geometric domain of the problem, the element type(s) to be used, the material properties of the elements, the geometric properties of the elements (length, area, and the like), the element connectivity (mesh the model), the physical constraints (boundary conditions) and the loadings [15].

The next step is solution, in this step the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s) are assembled. The computed results are then used by back substitution to determine additional, derived variables, such as reaction forces, element stresses and heat flow. Actually the features in this step such as matrix manipulation, numerical integration and equation solving are carried out automatically by commercial software [16].

The final step is postprocessing, the analysis and evaluation of the result is conducted in this step.

Model

Components of cross over electric car chaissis is shown in Fig. 1 (a,b,c). The beam is porforated at vertical (Fig. 1.a. and horisontal beam plate (Fig. 1.b).

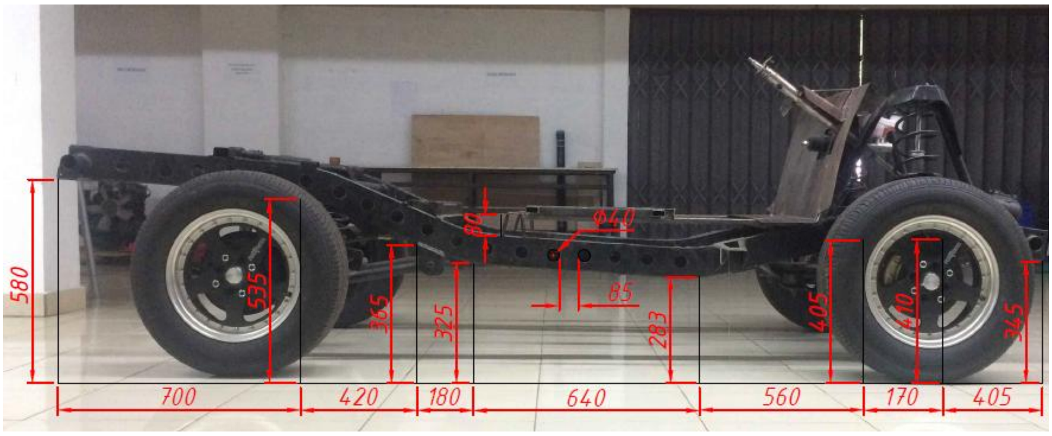

Figure 1 a. General structure of cross over electrical chassis and showing porforated plate beam at vertical

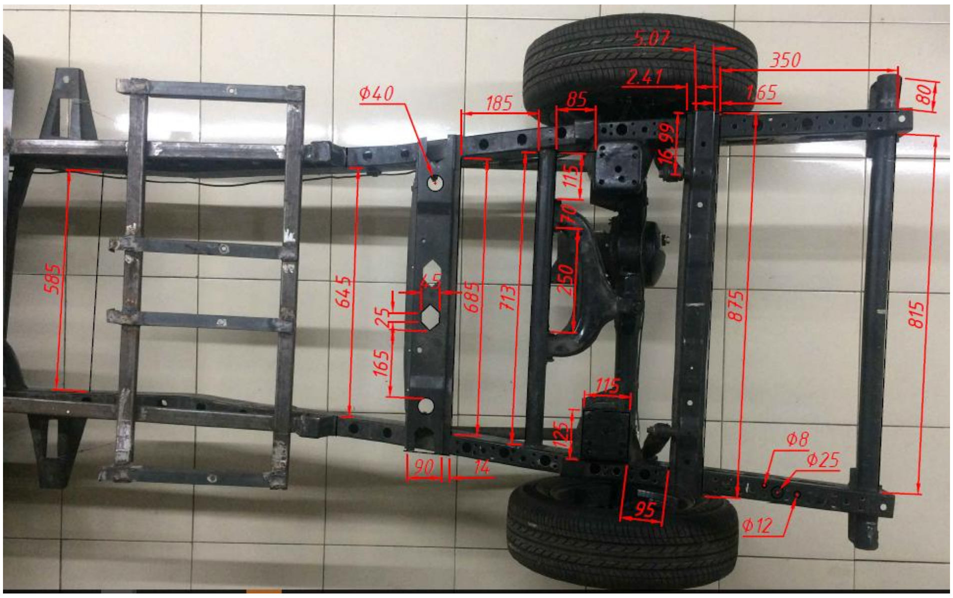

Figure 1.b. Showing porforated plate beam at horisontal direction

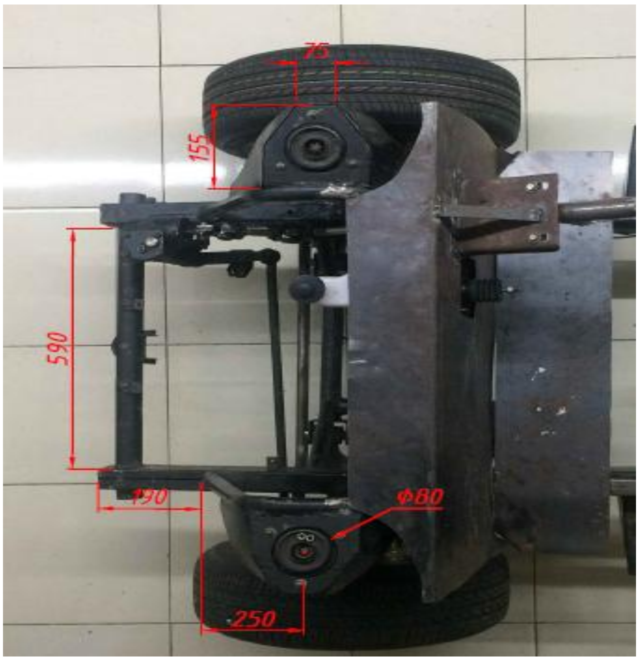

Figure 1.c. Front part of chassis

Due to uncertainty in estimating the vehicle loads and the dynamic and oscillating nature of it, the quasi-static method is used to conceptual design of ladder frame (chassis). In order to design a chassis at the first step, the force exerted on the chassis and its location is determined. Then, note to the boundary condition, bending moments and shear forces diagrams along the chassis are extracted. Finally, appropriate profile section which reduces the weight and endures loads is selected from handbook [17] and Maximum allowable stress and strain theories are used to design a chassis. In this analysis, following basic equation were used:
Bending moment *M*b(*x*) and shear force *V*(*x*) along the chassis are [17]:

$$V(x) = -\int w(x)\, dx \quad (1)$$
$$M_b(x) = \int V(x)\, dx \quad (2)$$

Where w(x) is expanded load on chassis

Regarding the bending moment and shear stress diagrams maximum normal stress along the chassis can be evaluated from [17]:

$$\sigma_{max} = N(M_{b\ max}/S_{\ min}) \quad (3)$$

where σmax is maximum normal stress, *N* is dynamic factor load (includes safety factor) and *S*min is minimum section module. Therefore, according to maximum allowable stress, the section module is determined by considering the dynamic load factor. Optimal section module should be larger than *S*min and have minimum density to reduce chassis weight. Maximum strain theory, which is based on the maximum allowable chassis deflection, is more conservative than maximum stress theory. The relation between chassis strain and bending moment is described as follows [17]:

$$E.I.y(x) = \int dx \int M_b\ (x)\ dx + C_1x + C_2 \quad (4)$$

where *E* and *I* are modulus of elasticity and inertia moment of chassis respectively. *y*(*x*) is function of deflection along chassis deflection, and *C*1, *C*2 are constant coefficients.
In elasto-static problem, each element forms a stiffness matrix [K], relating force [F] and displacements [u] at nodes. The size of stiffness matrix is equal to the number of nodes per element multi;plies by the number of freedom per nodes, as the following [17]:

$$[F]=[K][u]. \quad (5)$$

In eigenvalue problem te characteristic matrix is formed as

$$\{[K]-\omega^2[M]\}[U]=0 \quad (6)$$

Where M is the mass matrix, ω^2 is eigenvalues and u is eigen vector.

In this study two model of electrical chassis are developed, there are solid plate beam model and porforated plate beam model. Figure 2 show the solid plate beam model of cross over electric car chassis and firgure 3 show the porforated plate beam.

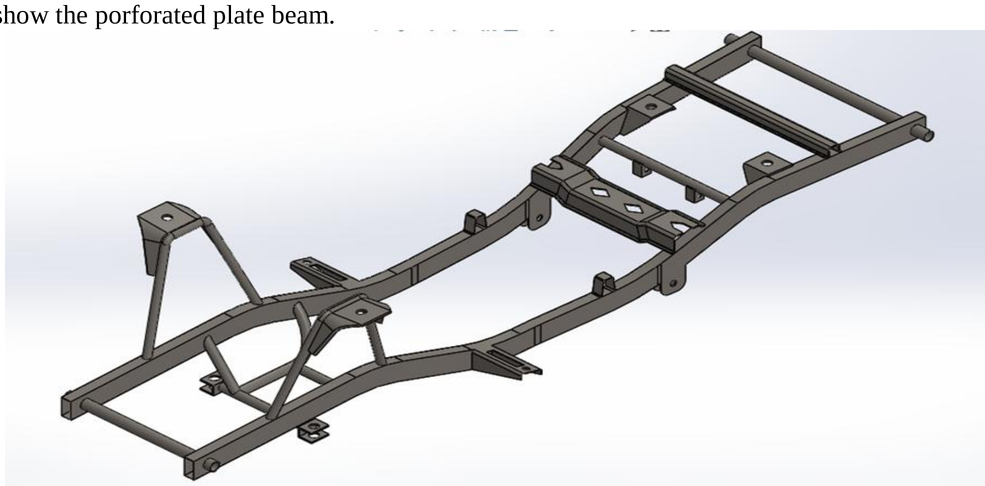

Figure 2. Solid plate beam model

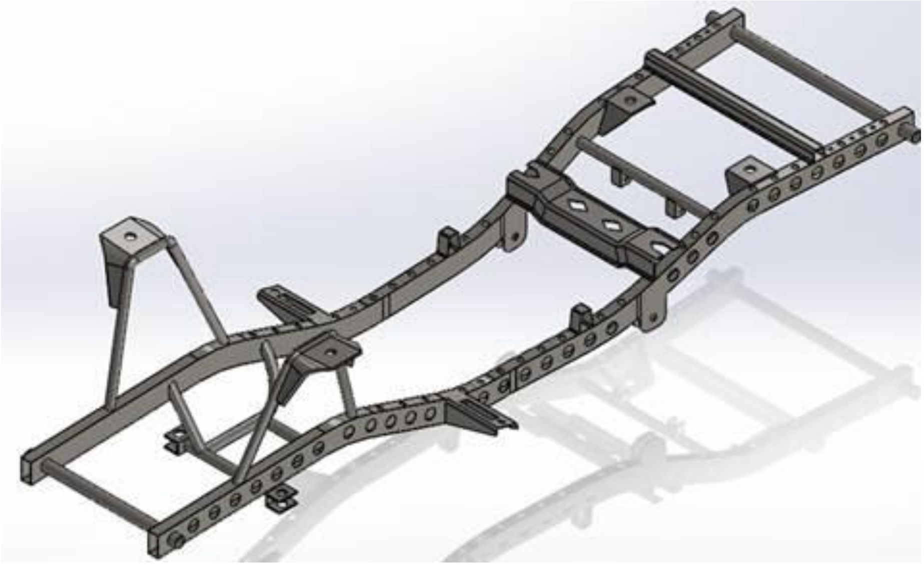

Figure 3 Porforated plate beam model

Load

The cross over electric car chassis model is loaded by static forces from battere, motor and passenger. For this model, batere load is 27 batere with 25 kg each, motor load is 45 kg and 2 passenger with 70 kg each. Position of each load is described in Figure 4 below. In this situation the peperties of material is described in the following Table 1.

Table 1. The properties of chassis material

Name	Alloy Steel
Model type	Linear Elastic Isotropic
Default failure criterion	Max von Mises Stress
Yield **strength**	6.20422e+008 N/m^2
Tensile strength	7.23826e+008 N/m^2
Elastic modulus	2.1e+011 N/m^2
Poisson's ratio	0.28
Mass density	7700 kg/m^3
Shear modulus	7.9e+010 N/m^2
Thermal expansion coefficient	1.3e-005 /Kelvin

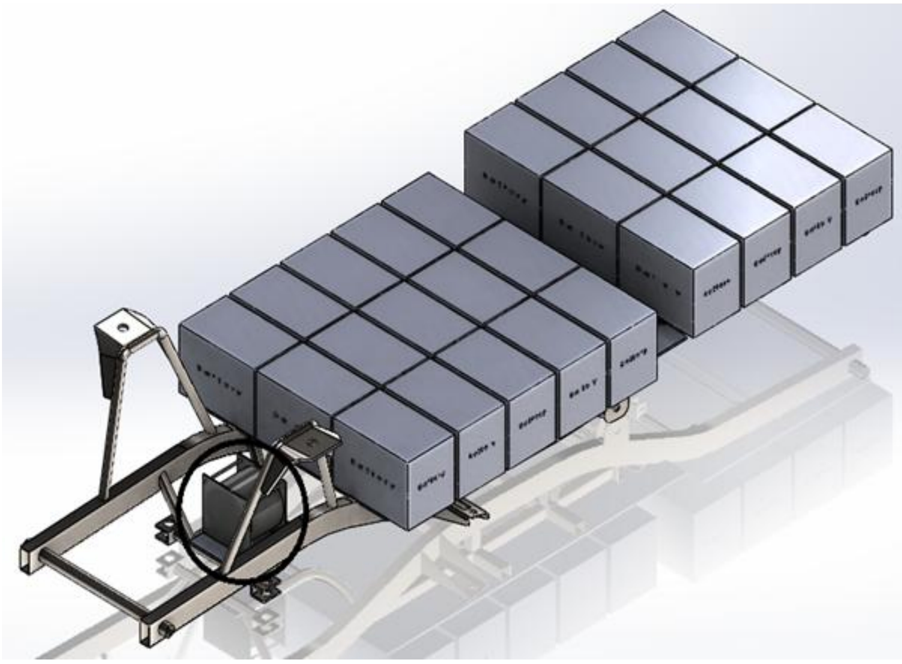

Figure 4 Load position of chassis

Boundary Condition

The boundary conditions applied to this model of chassis can be classified into four general cases: the first boundary condition case applied in static condition. The second case of boundary condition is applied when the car climb 30^o. in this condition the load concentration will move on rear part. The third case of boundary condition is applied when the car is passed through a descend road about 30^o. In this situation the load concentration move at front part of chassis. And the fourth case of boundary condition when the car is brake from 40 km/h until stop for 5 second. All condition represent the actual condition for electric car operation in Indonesia street. Parameter analysed for above boundary condition include stress, deflection and safety factor where all parameter are applied at solid plate beam chassis and perforated plate beam chassis.

IV. Result And Discussion

Figure-5 (a and b) shows a comparison between the stresses among the solid plate and perforated plate beam chassis at static condition. For the solid plate beam, maximum tress is about while maximum stress for perforated plate chassis is about . This figure clearly that porporate the beam plate does not have significant effect of stress at static condition..

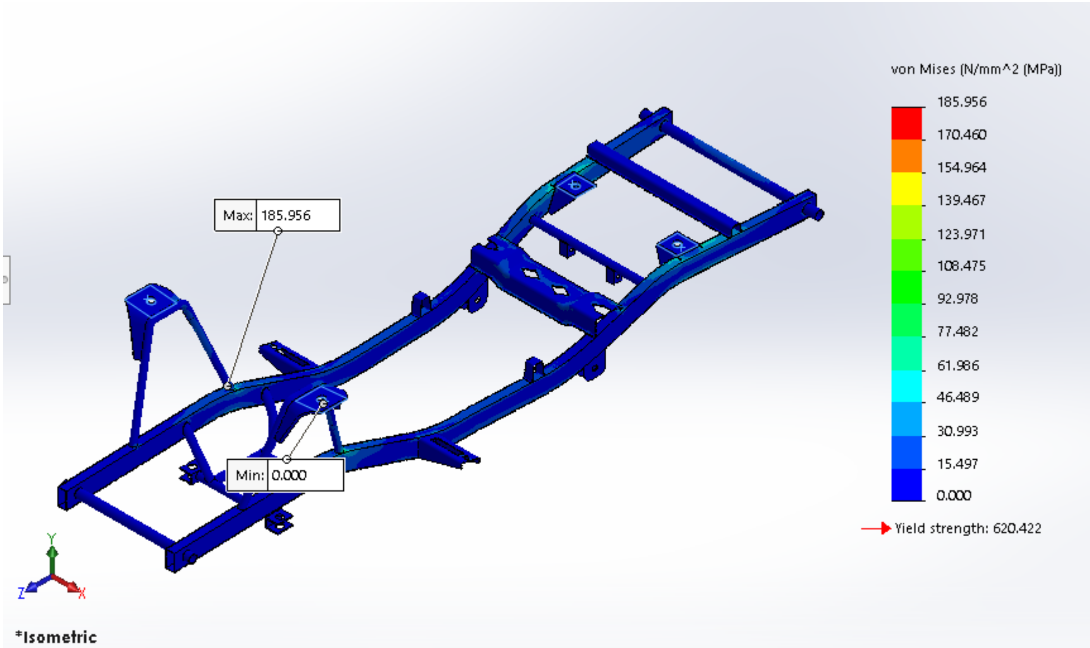

Figure 5.a. Solid plate beam stress at static condition

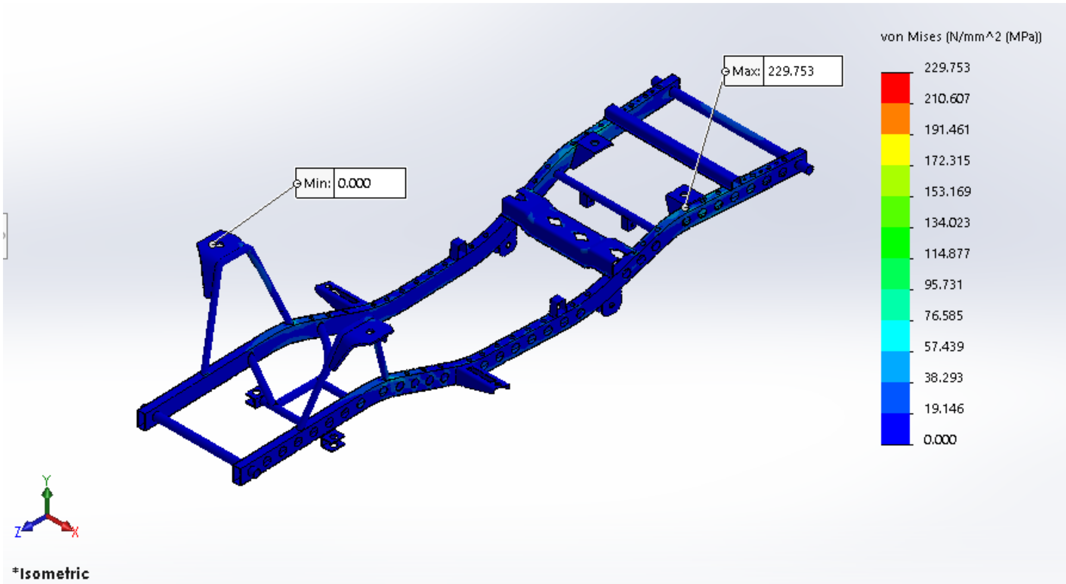

Figure 5.b. Porforate plate beam stress at static condition

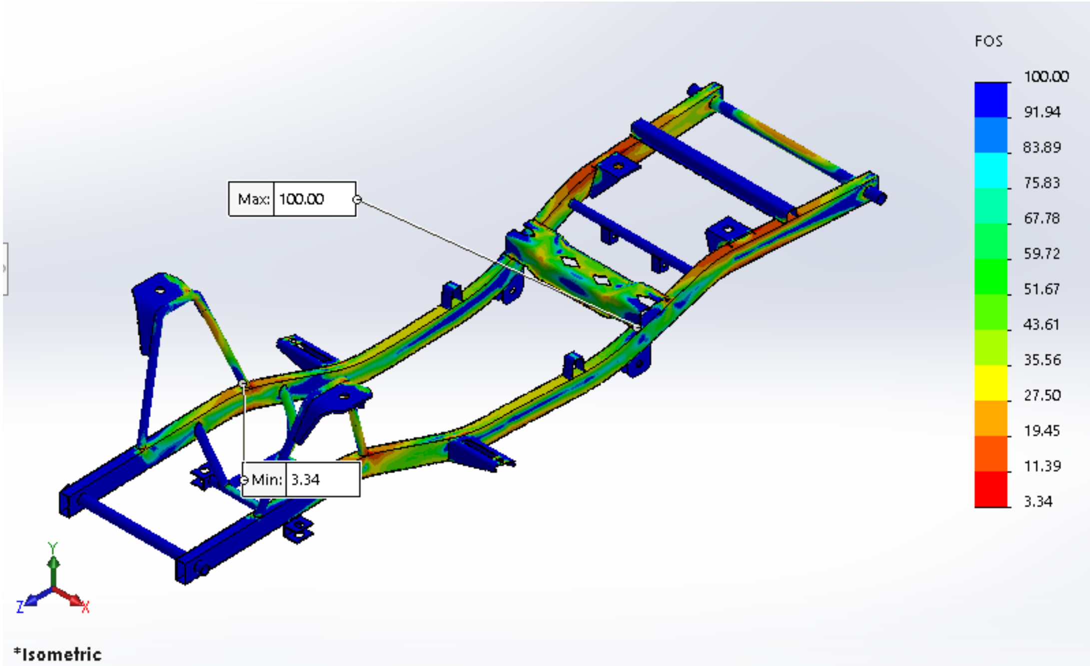

Figure 6.a Safety Factor of solid plate beam chassis at static condition

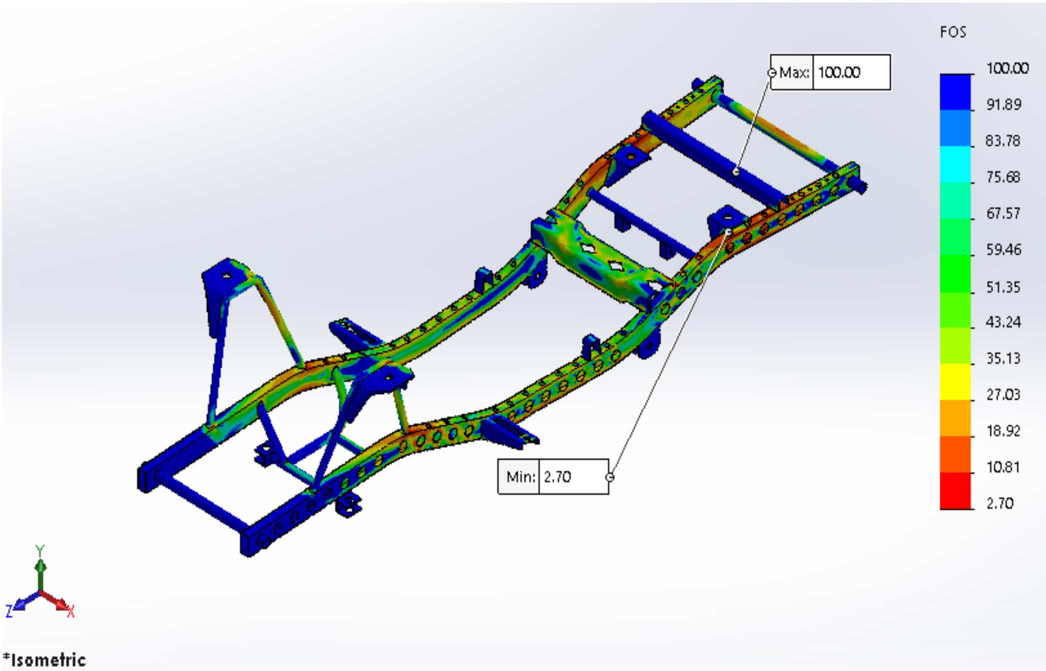

Figure 6.b. Safety Factor of perforated plate beam chassis at static condition

Safety factor analysis of both solid and perforated beam at static condition is described at Figure 6.a and Figure 6.b. It can be seen that minimum safety factor of solid plate beam chassis is 3.34 while perforated plate beam have 2.7 or lower than solid plate. Although the safety factor is lower than solid plate, the perforated plate beam still satisfy for electric car chassis where still more than 1. Similar result is shown at Figure 7.a and 7.b for deflection of both solid and perforated plate beam at static condition. Maximum deflection of solid plate beam is 1.141 mm and deflection of porforated plate beam is 1.312 at the same location.

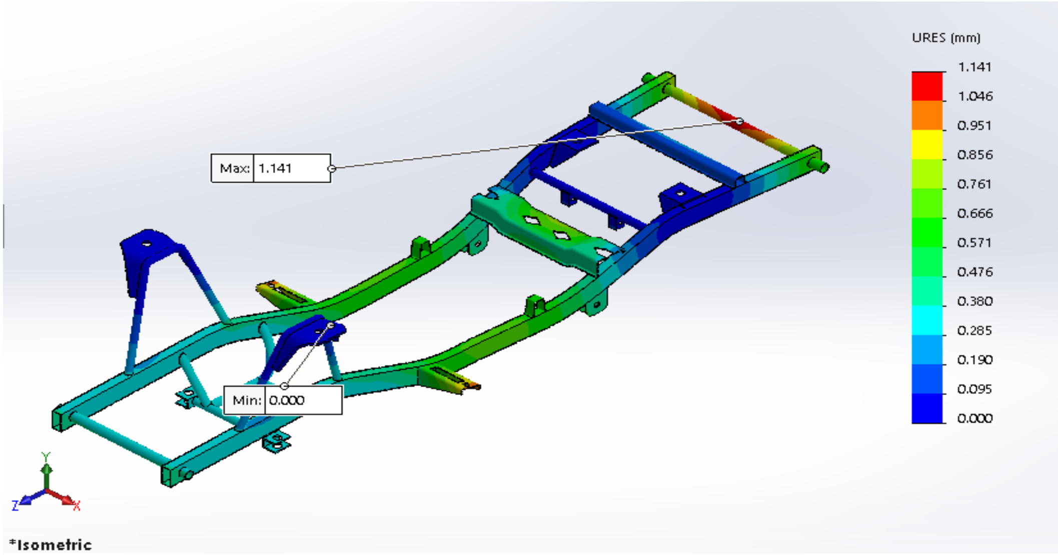

Figure 7.a Deflection of solid plate beam chassis at static condition

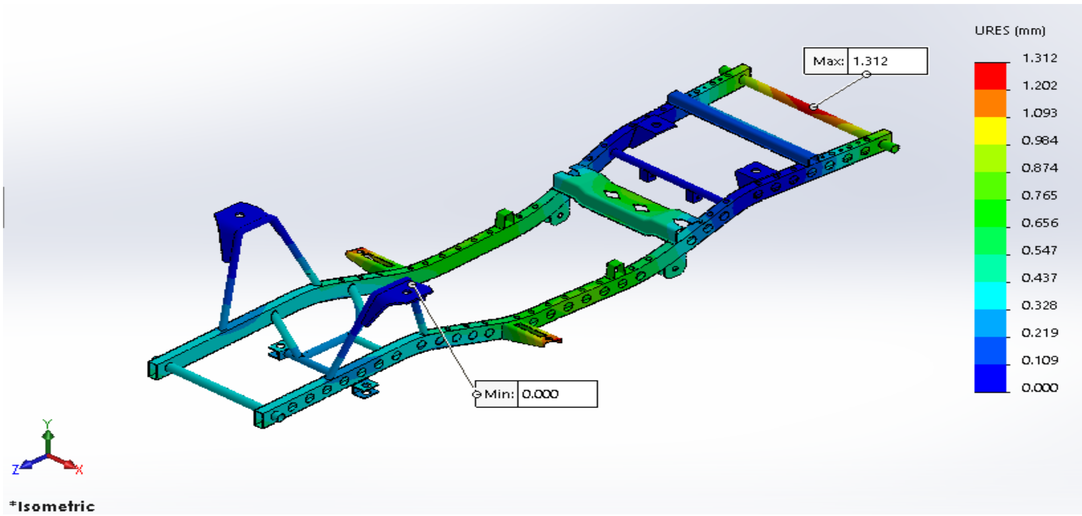

Figure 7.b Deflection of perforated plate beam chassis at static condition

The second case of boundary condition is applied when the car climb 30^o. In this condition the load concentration will move on rear part. In this case, result of stress computation are shown at Figure 8.a for solid plate beam chassis and Figure 8.b for perforated plate beam chassis. From these figure it can be seen that maximum stress of solid plate beam 205.84 Mpa and lower than perforated plate beam of 324.599 Mpa stress.

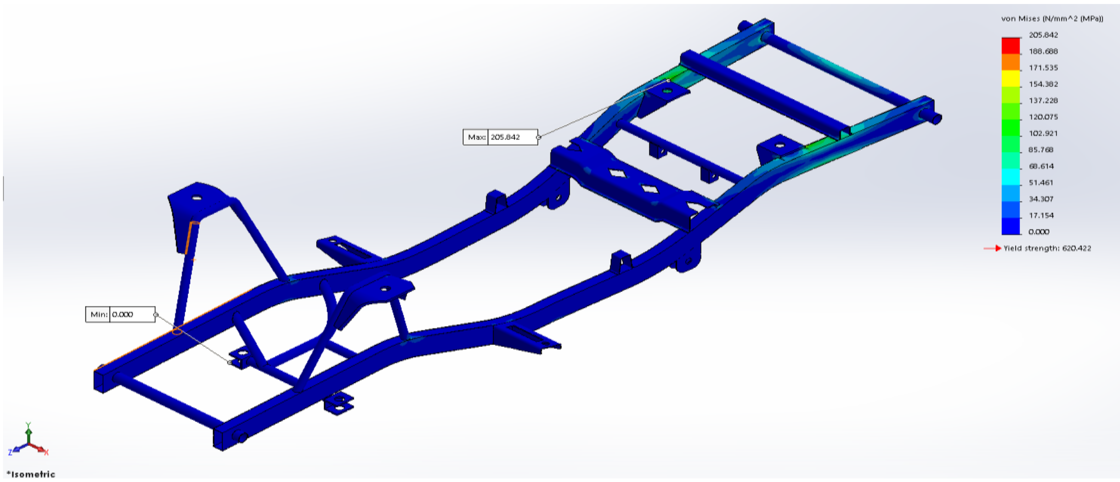

Figure 8.a. Solid plate beam stress at climb condition

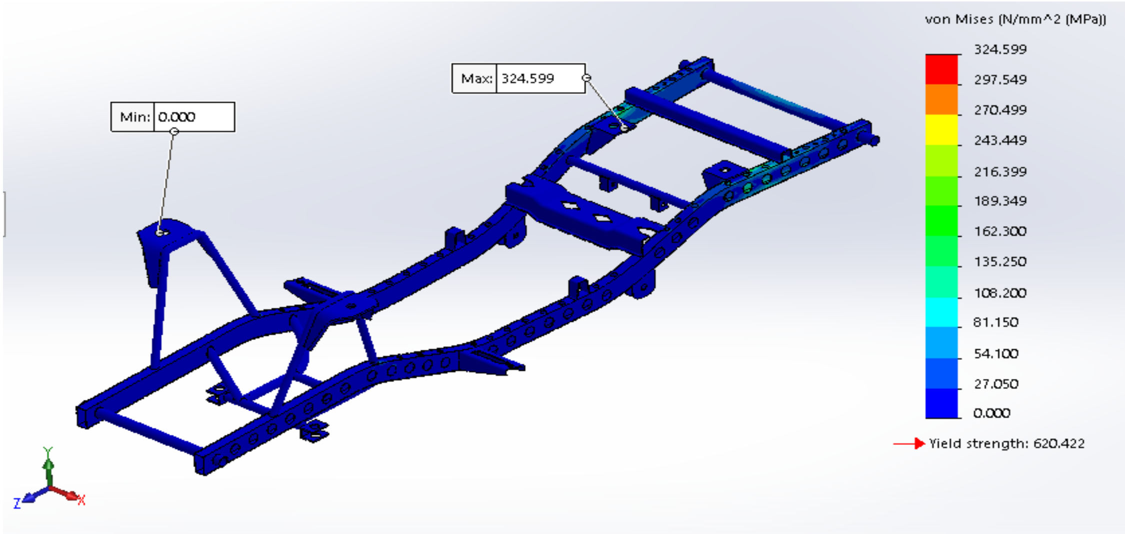

Figure 8.b Porforated plate beam stress at climb condition

Similarly at climb condition, the maximum deflection of solid plate beam is 2.433 mm and for perforated plate is 2.765 mm. The result of computation are shown at Figure 9.a for solid plate beam and Figure 9.b for porforated plate beam.

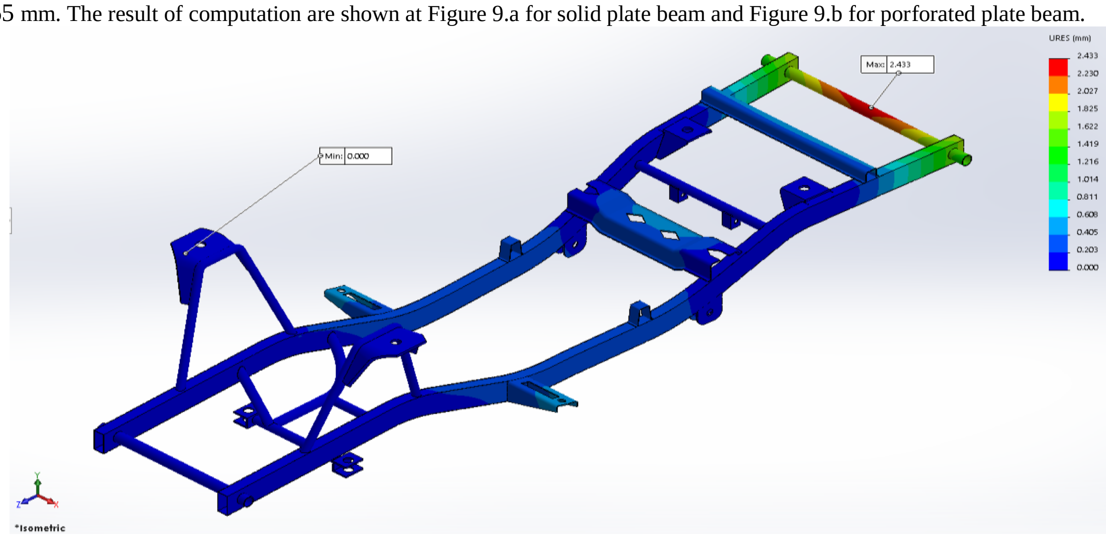

Figure 9.a Deflection of solid plate beam at climb condition

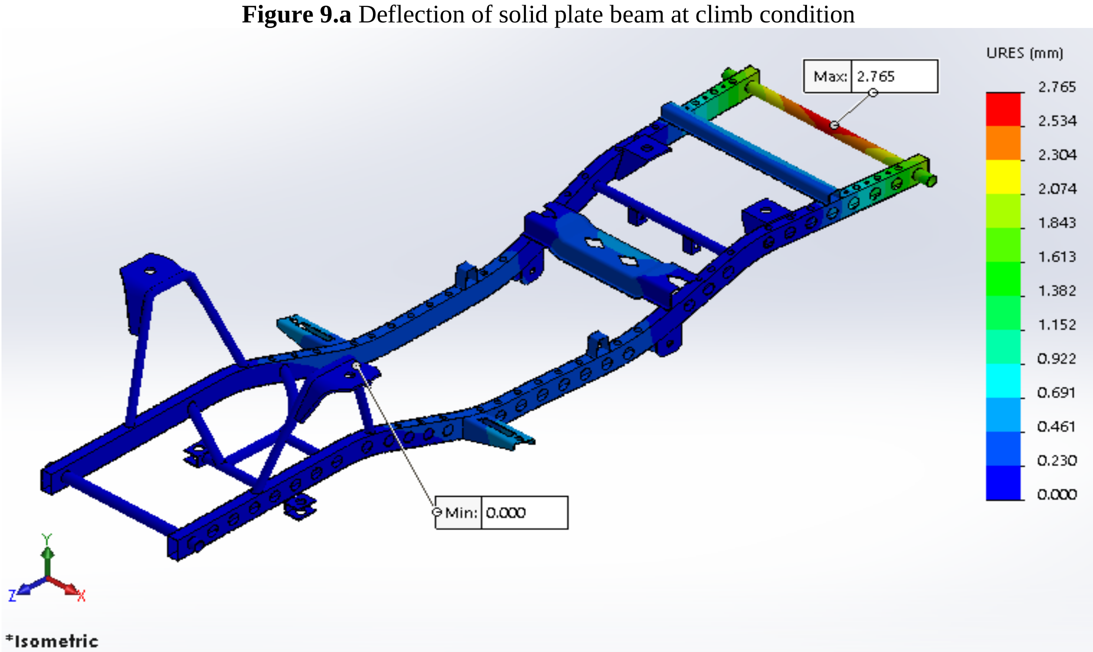

Figure 9.b Deflection of porforated plate beam at climb condition

Figure 10.a and 10.b show safety factor of solid plate beam chassis and perforated plate beam respectively at climb condition based on computation result. The safety factor of both chassis type are above 1 although safety factor of perforated plate chassis lower than solid plate.

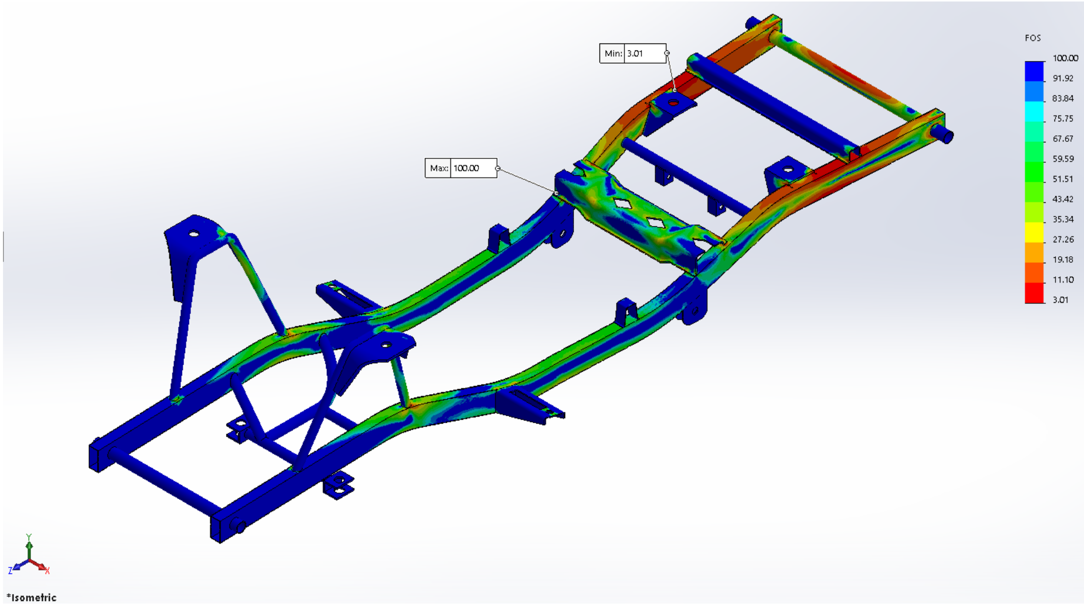

Figure 10.a Safety factor of solid plate beam at climb condition

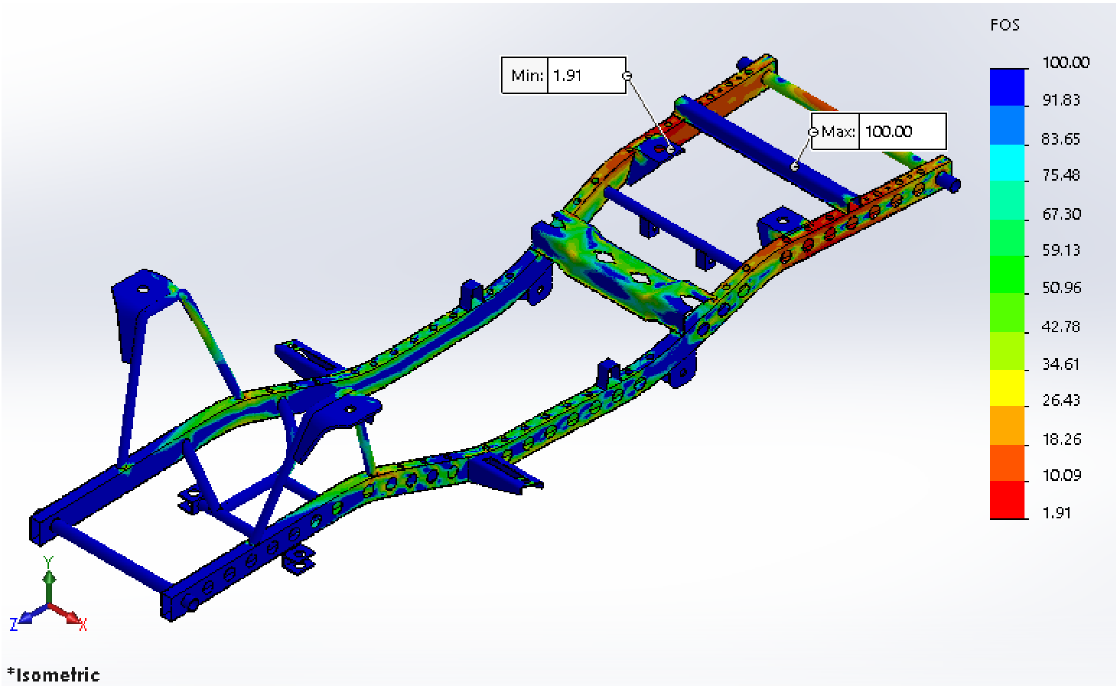

Figure 10.b Safety factor of perforated plate beam at climb condition

Computation result of chassis at descend road for both chassis are shown at Figure 11, 12, and 13. In this situation the load concentration move at front part of chassis. The result of computation have the same tendency as the previous case unless the position of maximum deflection, maximum stress and minimu safety factor Where it is concentrated on the front of chassis. Detail of value of these parameter can be seen at following figure.

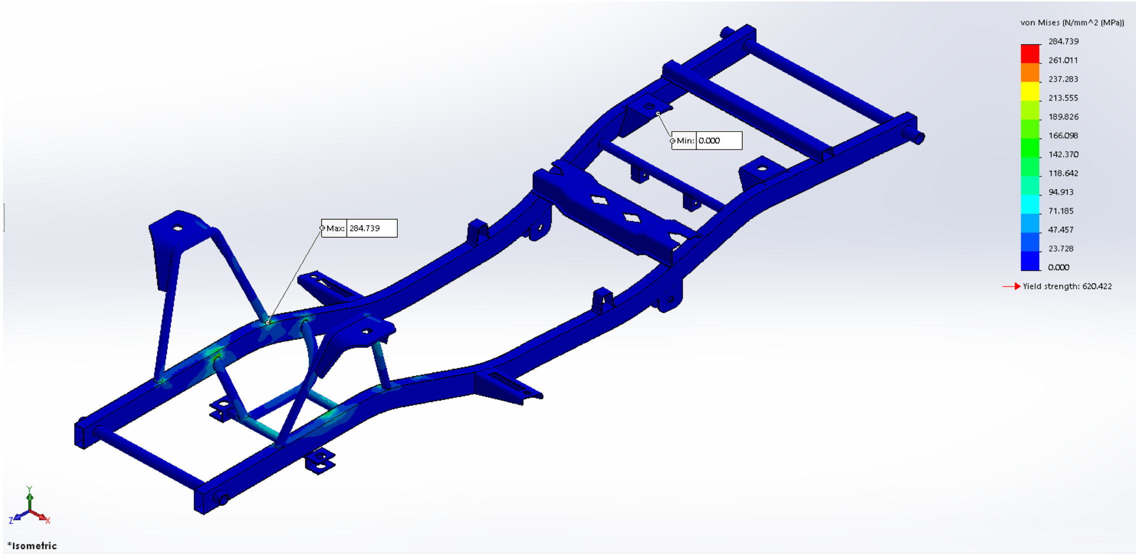

Figure 11.a Solid plate beam stress at descend road condition

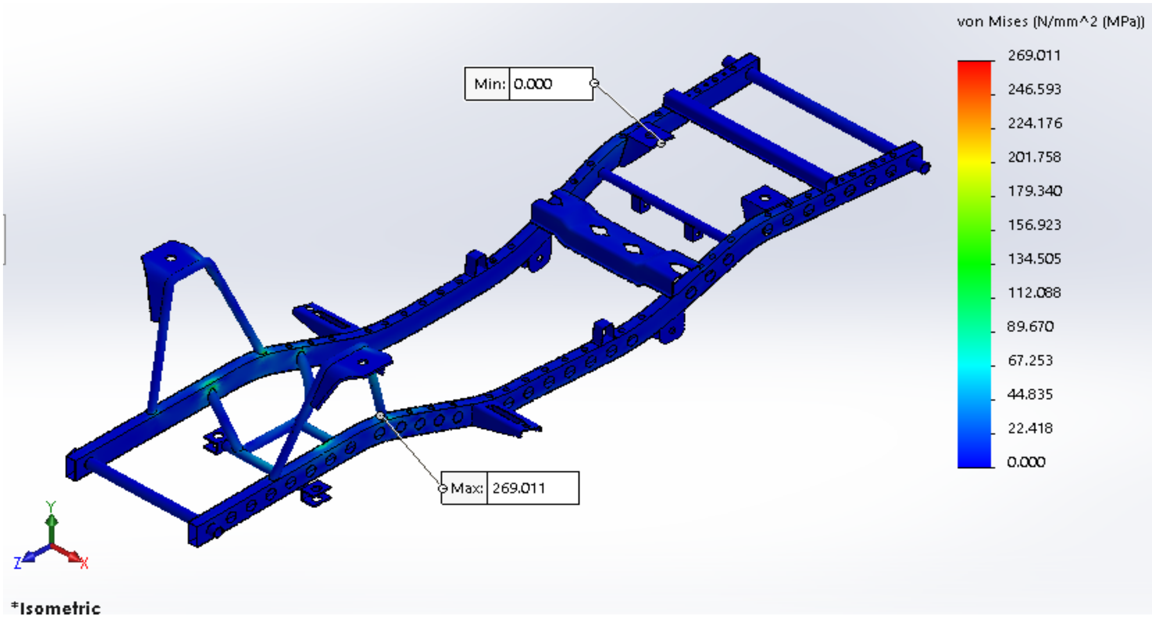

Figure 11.b Perforated plate beam stress at descend road condition

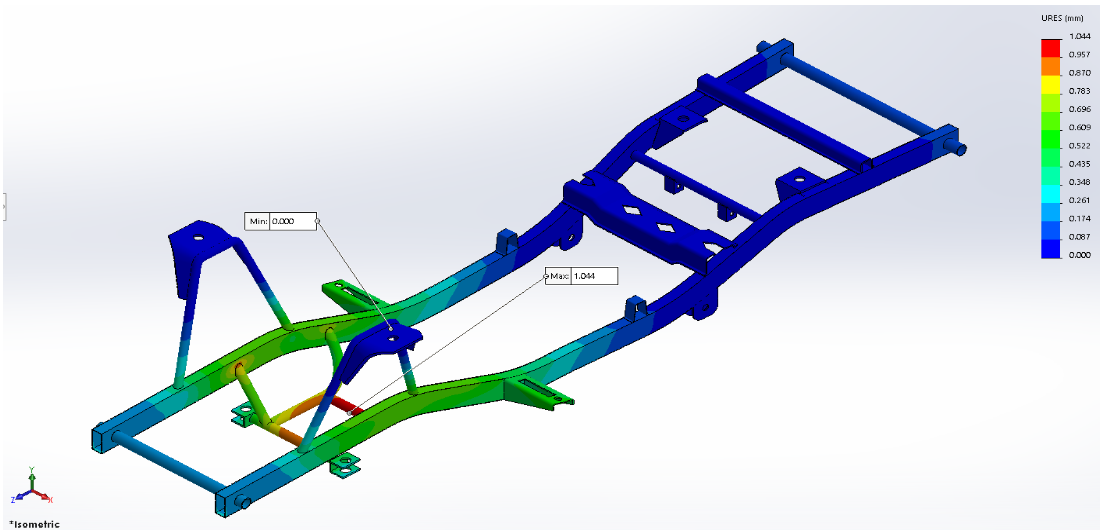

Figure 12.a Deflection of solid plate beam chassis at descend road

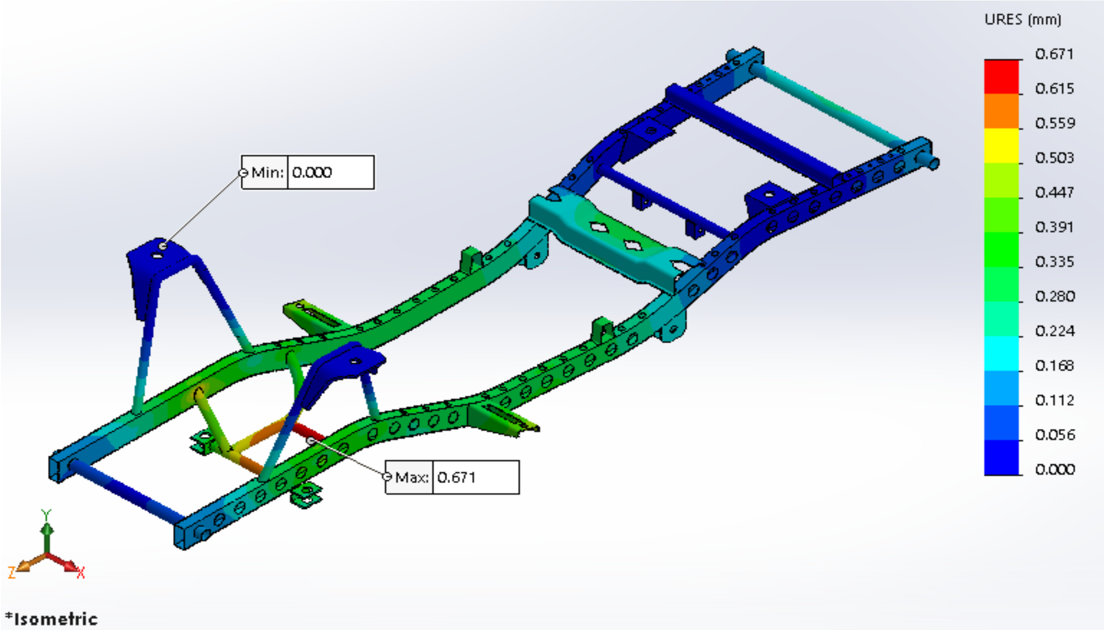

Figure 12.b Deflection of Porforated plate beam chassis at descend road

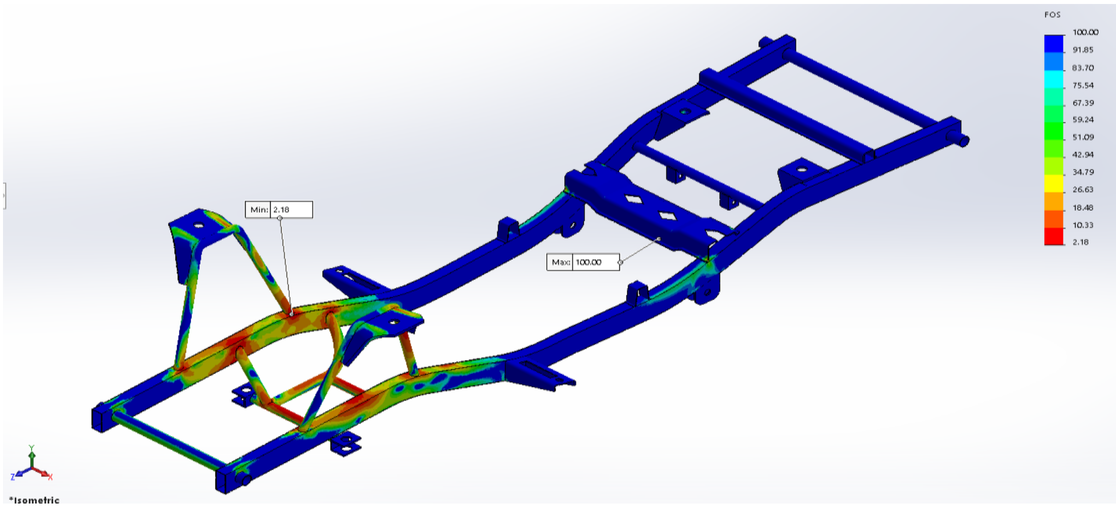

Figure 13.a Safety Factor of solid plate beam chassis at descend road

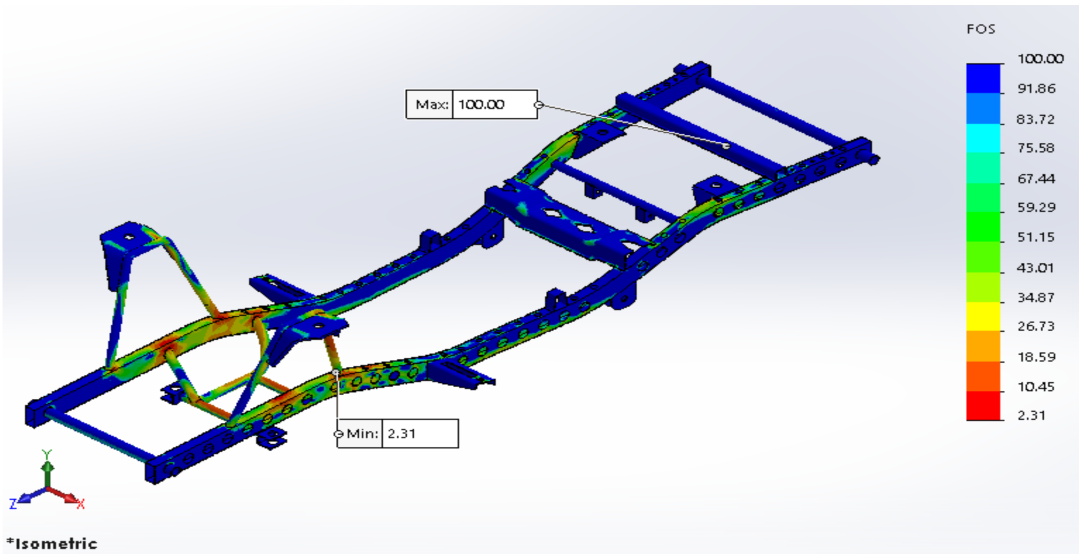

Figure 13.b Safety Factor of Porforated plate beam chassis at descend road

The fourth case is when the car is brake from 40 km/h until stop for 5 second. In this condition it is assumed that most of load is concentrated at front of chassis. In this case, the maximum stress of solid plate is 284.738 Mpa (Figure 14.a, while porforated plate stress is 374.682 Mpa (Figure 14.b). Maximum deflection of solid plate and porforated plate are 1.044 mm (Figure 15.a) and 1.055 mm (Figure 15.b) respectively. And minimum safety factor is 2.18 for solid plate (Figure 16.a) and 1.66 for perforated plate beam chassis (Figure 16.b).

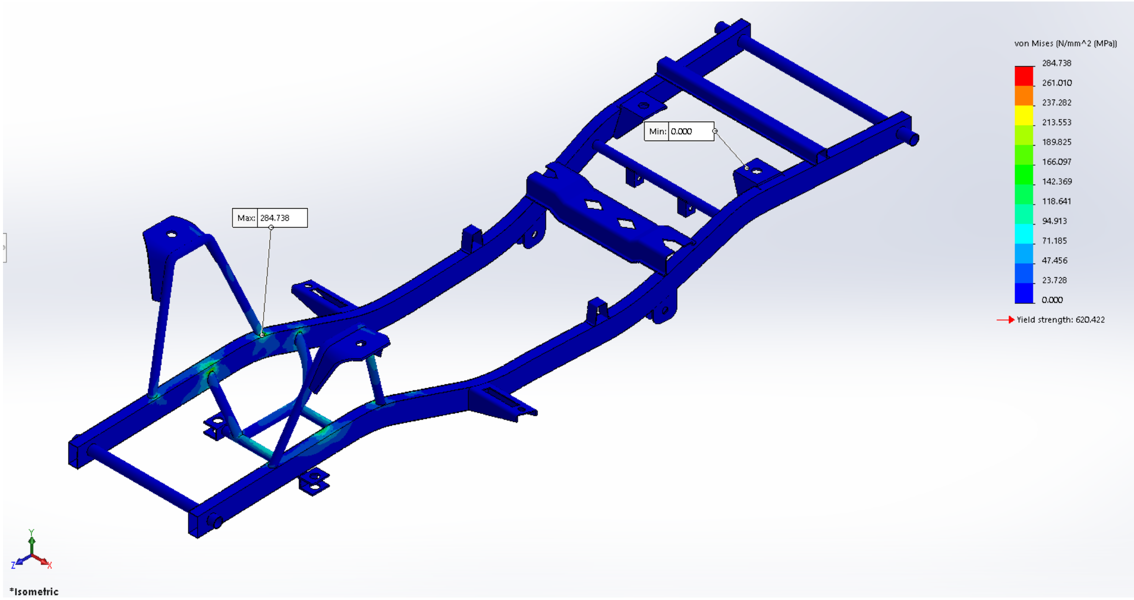

Figure 14.a. Solid plate beam stress at braking condition

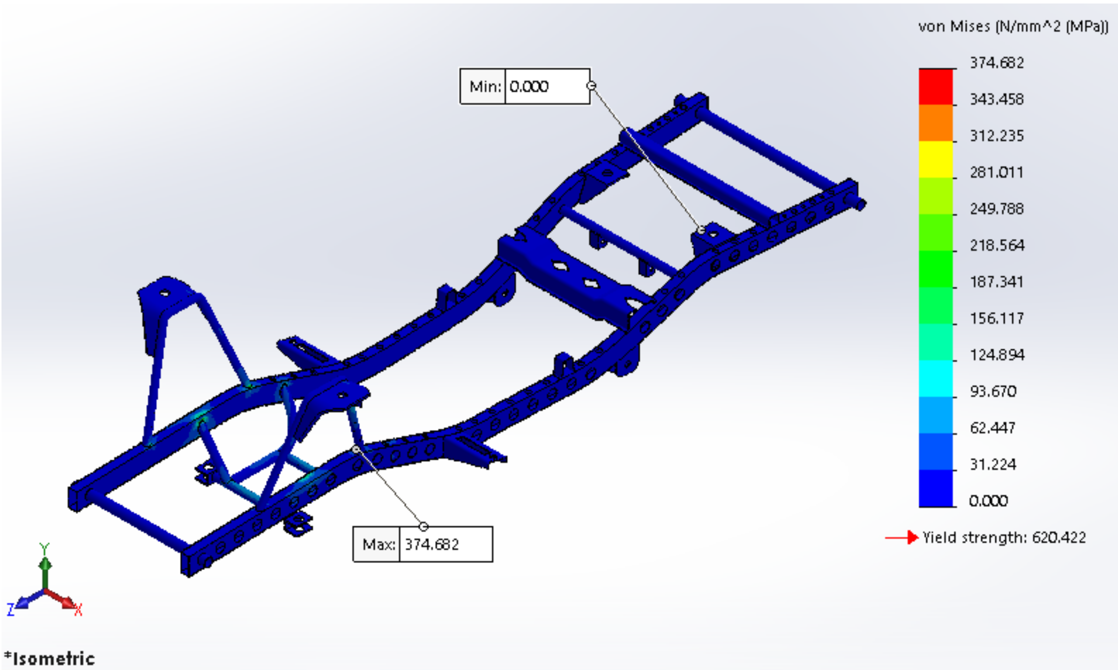

Figure 14.b Perforated plate beam stress at braking condition

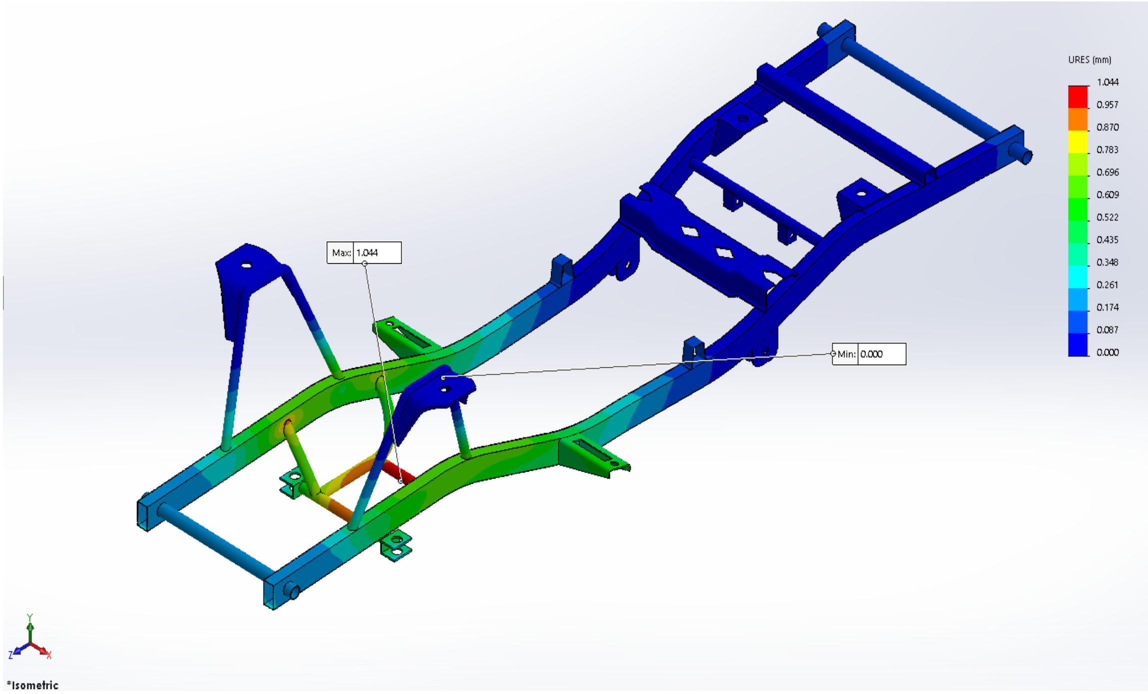

Figure 15.a Deflection of solid plate beam chassis at braking condition

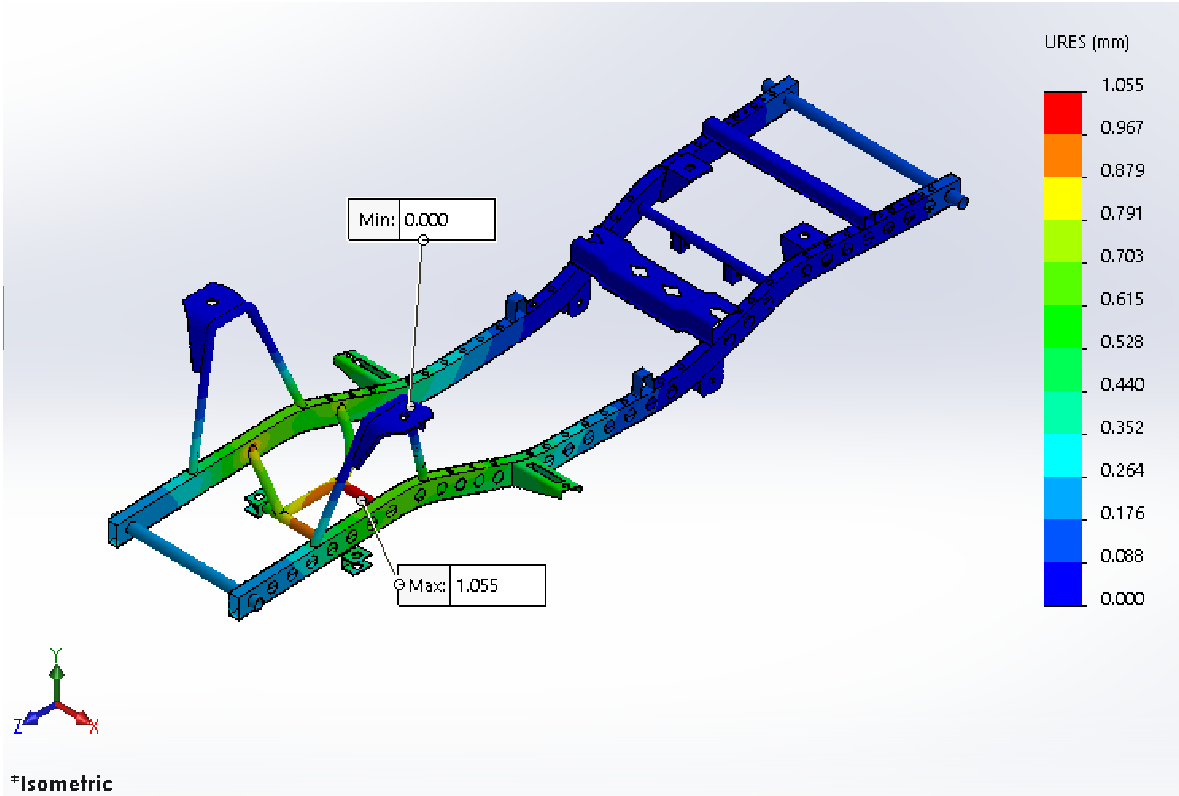

Figure 15.b Deflection of Perforated plate beam chassis at braking condition

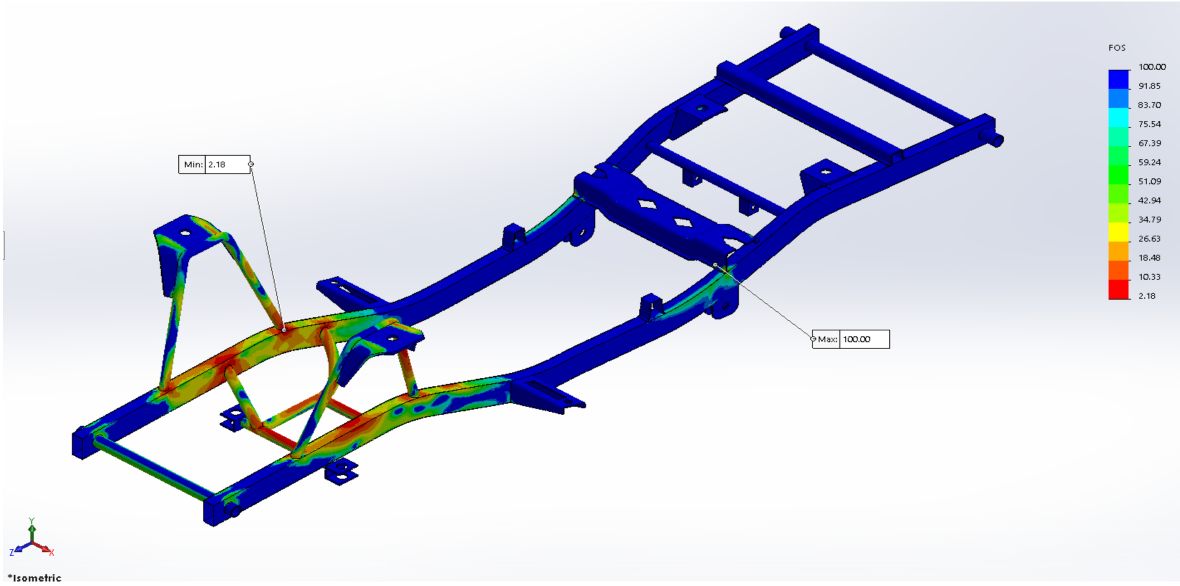

Figure 16.a Safety Factor of solid plate beam chassis at braking condition

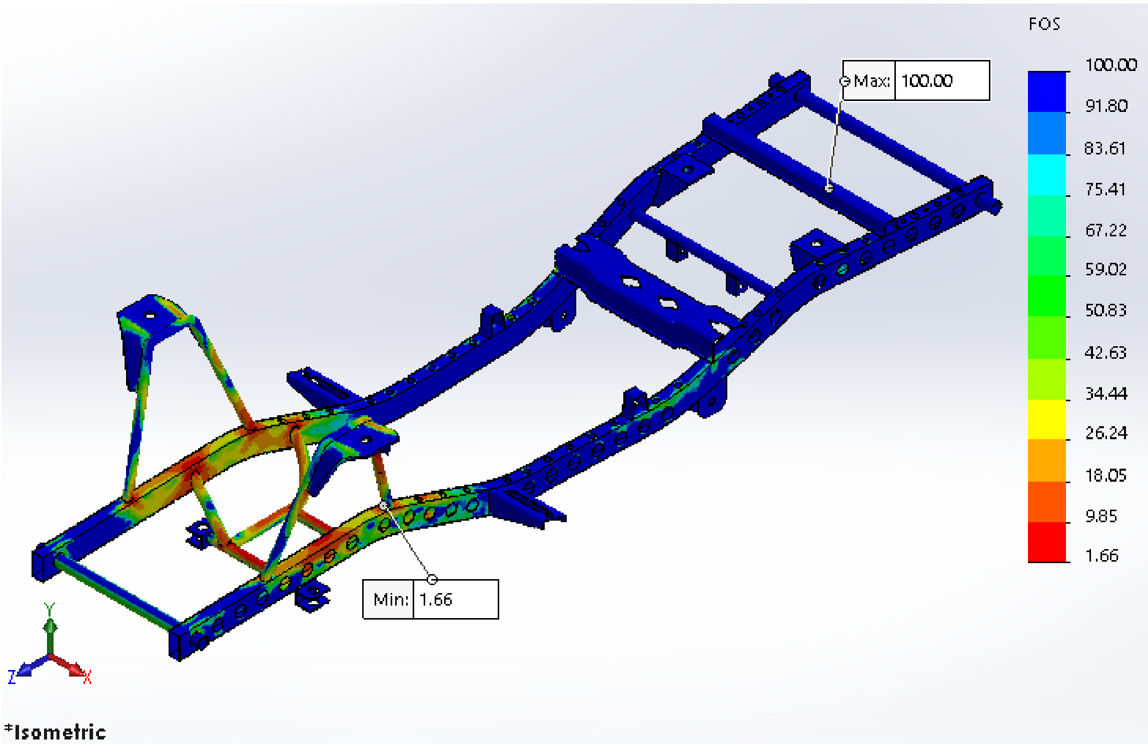

Figure 16.b Safety Factor of porforated plate beam chassis at braking condition

V. Conclusion

Two type of lader chassis was analysed by Finite Element Methode performed using SOLIDWORKS, solid plate beam and porforated plate beam chassis. Purpose of porforate the plate beam is reducing of chassis weight and finally incressing of battery live in electric car. The result of study performed in four case that are static condition, car climb, car pass through descend road and braking condition show that porforated plate beam chassis has lower performance. It can be seen that maximum stress of porforated plate is 25 % (everage) higher than solid plate, maximum deflection of porforated plate chassis is 20 % higher than solid plate and minimum safety factor of porforated plate is 20 % lower than solid plate. Safety factor as a critical parameter of both cases are above 1, and its can be say that all cases are recommended for electrical car chassis. Porforate the beam can reduce of about 22.5 % of chassis weight, hence it is conclude that porforated plate beam chassis is suitable for electrical car application.

Acknowledgements

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