Chassis Frame Torsional Stiffness Analysis

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Abstract— In automotive industry, weight reduction is important and active demand because of payload capacity improvement, fuel efficiency and emission reduction. Reduction of the chassis frame weight represents one of the keys to reaching this goal, but requirements on chassis frame stiffness generally make any weight reduction difficult. The problem of finding the compromise between stiffness and weight of chassis frame is therefore of high importance. In this work, vehicle road load significance of the heavy vehicle ladder type chassis frame torsional stiffness studied, and the two method analysed to obtain chassis frame stiffness using finite element analysis based on the vehicle loading. Obtained stiffness will be closer in case of spring bracket loading which can be used to analyse the vehicles handling behaviour. The method yields insights into analysing chassis frame stiffness which is closer to vehicle actual running condition and highlights critical aspects of chassis frame design.

Key words: Chassis Frame, Roll Stiffness, Torsional Stiffness, Vehicle Handling

I. INTRODUCTION

The chassis frame is the backbone of all heavy-duty vehicles. The main body of the frame on vehicle is shaped like a ladder. In fact, it is commonly refer to a heavy-duty truck frame as a ladder frame[1] which supports the components of the vehicle like Cabin, Load Body, Engine, Transmission System, Suspension, Controlling Systems like Braking, Steering etc,. The chassis frame consist of two long members called side rails which are generally made of C-channels [2], riveted/bolted together with the help of number of cross members in the form of ladders, together side members and cross members forms an integral structure as shown in Fig 1. Reduction of the overall vehicle weight represents one of the keys for reaching this goal. On the other hand, requirements on chassis stiffness generally make any weight reduction difficult and expensive. The problem of finding the best compromise between chassis stiffness, weight and cost is therefore of high importance for the development of both high-performance and cost-effective fuel-efficient road vehicles. This requires to understand all the implications of chassis frame stiffness and suspension compliance on the overall vehicle behaviour. Despite this fact however, no general agreement on the amount of stiffness required exists. Reducing the twist in the chassis by increasing the torsional rigidity and can control the handling of the vehicle better. Increased torsional stiffness improves vehicle handling by allowing the suspension components to control a larger percentage of a vehicle's kinematics [3]. Chassis frame's structural components reinforcements, cross members must be strategically located in order to reduce twist of the frame and minimize local deflections of suspension mounting brackets. In order to reduce twist and deflections of suspension mounting brackets, a minimum chassis stiffness must be achieved in its design, while at the same time keeping the overall weight to a minimum.

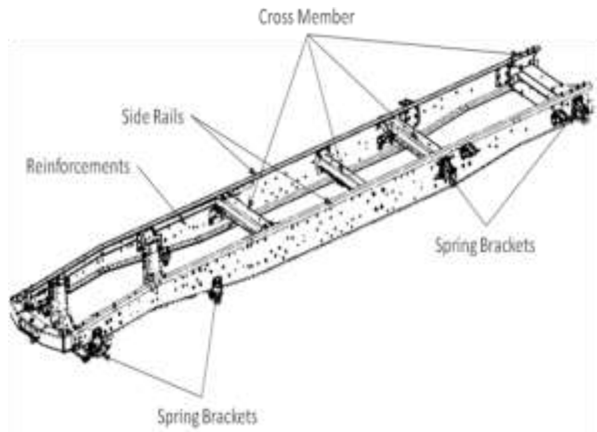

Fig. 1: Heavy Vehicle Chassis Frame

II. CHASSIS FRAME LOAD CASE AND STIFFNESS

The design of a vehicle frame, or any structure, is to understand the different loads acting on the structure. The main deformation modes for an automotive chassis are shown in below Fig. The different road load cases are responsible for the frame stiffness are as follows.

A. *Torsional Load Case*

In case of one wheel bump, the vertical load in opposite directions of left and right side wheels gives a combination of bending and torsion on the vehicle as shown in Fig 2. The frame deflection caused by this torsion load case is the Torsional Stiffness. The pure torsional load cannot be induced on frame, since the weight of the vehicle is always acting in downward direction so that there cannot be a negative wheel reaction. It has been found that torsion is a more severe case for frame design than bending due to different internal loads [2].

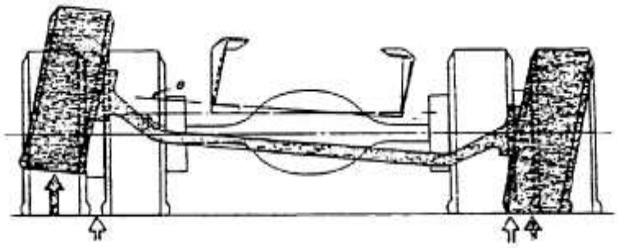

Fig. 2: One wheel of a axle on road bump - Torsion Load [4]

B. *Vertical Bending Load Case*

As shown in Fig 3.vertical load due to vehicle components and pay load acts vertically on chassis frame causing vertical deflection which represents like simply supported beam. Bending load also can be experienced by an axle wheels running on road bumps, in this condition frame deflection can be similar to cantilever beam. The frame

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deflection caused by this bending load cases is the Bending Stiffness.

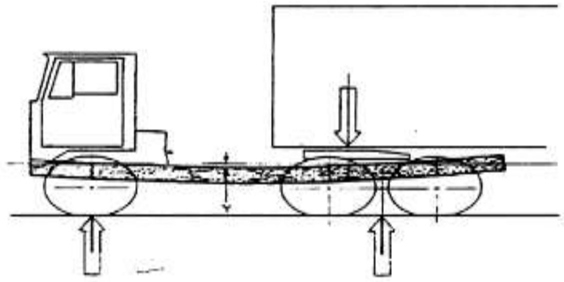

Fig. 3: Vehicle components and Pay Load - Bending Load [4]

C. Lateral Bending Load Case

Lateral bending loads are induced in the frame for various reasons, such as asymmetric breaking, road camber, side wind loads and centrifugal forces caused by turning. The sideways forces will act along the length of the vehicle and will be resisted at the tires. This causes a lateral load and resultant bending as shown in Fig 4. The frame deflection caused by lateral load cases is the Lateral Stiffness.

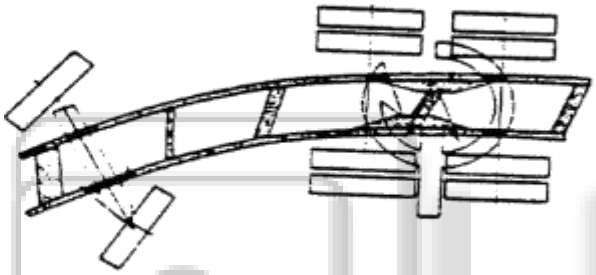

Fig. 4: Lateral bending due cornering - Lateral Load[4]

D. Importance of Chassis Frame Stiffness

Different categories of deformation modes play different roles in the definition of the behaviour of the vehicle. Symmetrical deformations, like the bending ones, mainly affect the ride qualities while the skew symmetrical ones, for example those induced by the torsional flexibility, have their main impact on vehicle handling [5]. This fact, together with the fact that torsional stiffness is the most difficult target to achieve during chassis design, justifies the fact that chassis stiffness is often represented by torsion stiffness. There are several factors that make the rigidity of the chassis an important figure in vehicle dynamics, especially when racing vehicles are considered. Effects of compliances are often unknown and tend to make vehicles unresponsive to the standard changes to which other cars respond. As a consequence, they make the prediction of the performance of a race car difficult, [6]. One important indicator of performance, which is given by largest amount of attention in the chassis frame is the torsional rigidity. When comparing longitudinal torsion to vertical and lateral bending, two things can be observed; firstly, the bending cases will not affect the lateral wheel load distribution much. Secondly and more importantly, it can be seen that with a correctly designed chassis with high enough torsion stiffness the requirements of the bending stiffness is already met [6]. From the service load analysis and the load acting on the chassis frame, the torsional load case is the worst loading on the chassis frame compared to bending and lateral stiffness. And also the vehicle handling affected by the torsion stiffness of the frame than the bending and lateral stiffness. On this basis, the main part of this analysis will focus on torsional stiffness.

III. METHODOLOGY

The main objective is to analyse chassis frame stiffness by finite element analysis. First method is to consider the loading and boundary conditions at the wheelbase of the vehicle as shown in Fig 6. Second method is to consider loading and boundary condition at the suspension mounting brackets as shown in Fig 8.

The torsional stiffness of the chassis frame can be calculated by finding the torque applied to the chassis frame and dividing by the angular deflection. The actual calculation is done as follows, Fig 5 shows a view looking from the front of the chassis frame.

The torque defined above is the product of the force applied at one corner of the frame, and the distance from the point of application to the centre line of the chassis frame. The deflection is taken to be angle created from the centre of the frame to the location of the deflected corner of the frame. It would be much simpler to add a known weight on one corner of the chassis frame suspension mounting bracket and allow it to pivot about a roller at the center of the frame.

Chassis Frame Torsional Stiffness (Nm/deg) = Ktor = T ÷ Θ
Torque (Nm) = T = F * L
Angular Deflection (deg) = Θ = tan-1 (x ÷ L)
Chassis Frame Linear Stiffness (Nm/deg) = Kch = Ktor / L2

The torque acting on the chassis frame and resisted at the clamped rear is simply the force F, times the lever arm, L. The angle of twist can be simply calculated from the average deflection and the half width of the chassis frame, and substitute in expressions for the torque and angular deflection. This method of frame stiffness measurement is relatively straightforward and the advantage is the frame stiffness can be determined without including the suspension components like springs and dampers. The major advantage is the externally created torque, loads the frame in the similar manner as on the vehicle condition.

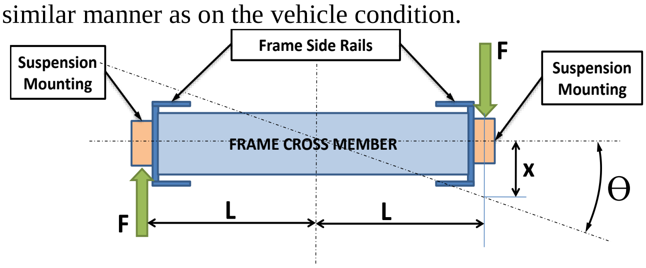

Fig. 5: Chassis frame torsion stiffness loading.

IV. SIMULATION

The Finite Element model is constructed from the CAD model using shell elements and suspension mounting brackets are not considered instead its mounting holes on the frame is considered. All the bolts and rivets are modelled as rigid bar elements. The finite element model with boundary and loading condition at the wheel base of the chassis frame is shown in Fig 6. In wheel base method the Force of 100N is applied in opposite direction at front axle of the wheel base location of the chassis frame and constrained in all degrees of freedom at rear axle of the wheel base location of

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the chassis frame. The finite element model with boundary and loading condition at the leaf spring mounting brackets of the chassis frame is shown in Fig 8. In spring bracket method the Force of 50N is applied in opposite direction at each spring brackets of the front suspension of the chassis frame and each spring brackets of the rear suspension of chassis frame constrained in all degrees of freedom. The chassis frame components and mounting are constructed of steel with Young's modulus E = 200 GPa, Density = 7810 Kg/m3 and Poisson's ratio = 0.3.

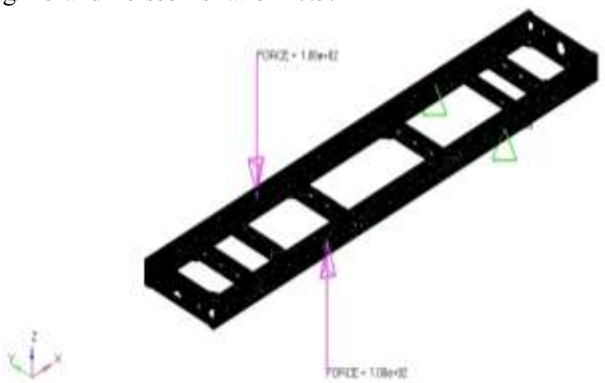

Fig. 6: Boundary and loading condition at wheel base.

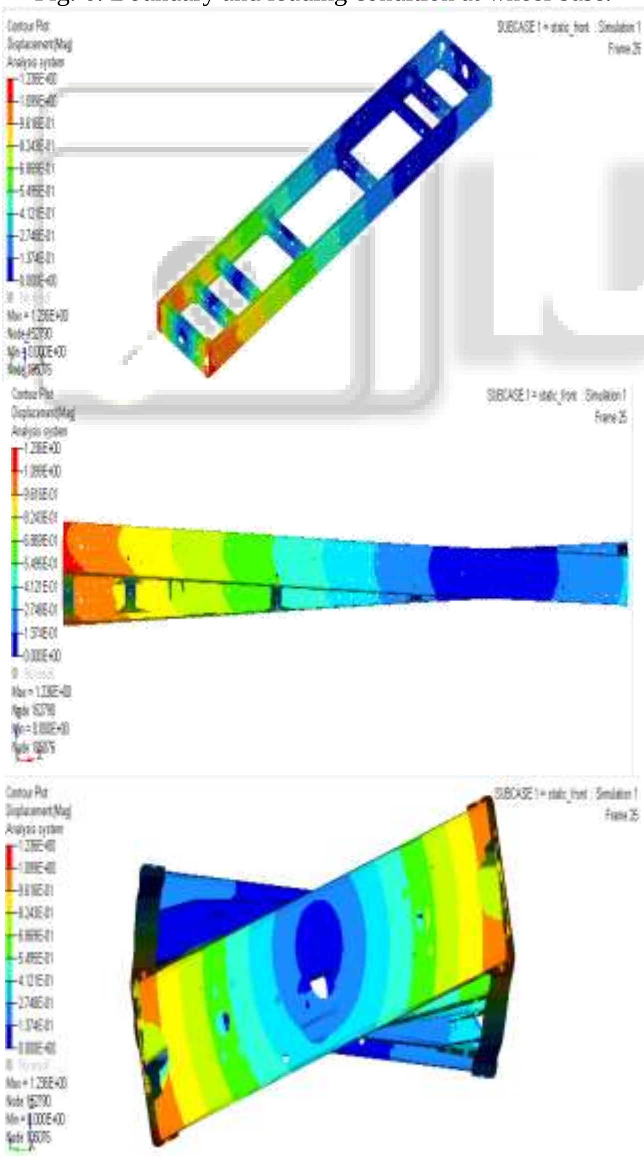

Fig. 7: Deflection Plot - Wheel Base Loading

V. RESULTS AND DISCUSSION

The finite element simulation deflection plot of the wheelbase method is shown in Fig 7. The deflection of the frame is purely in torsion due to the applied opposite force. It is observed that the max deflection of 1.2mm at the front the chassis frame and deflection of 0.8mm at the applied force location. The rear end of the chassis frame is also showing the deflection of 0.4mm, it will not contribute for the stiffness analysis.

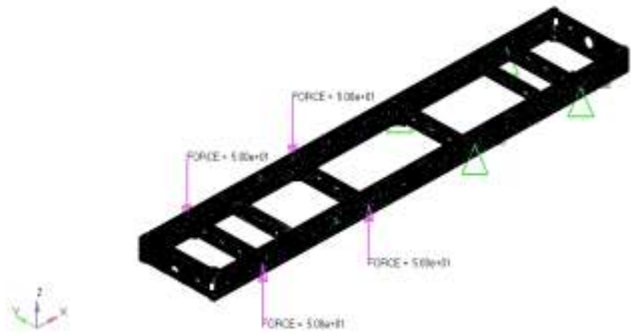

Fig. 8: Boundary and loading condition at spring brackets.

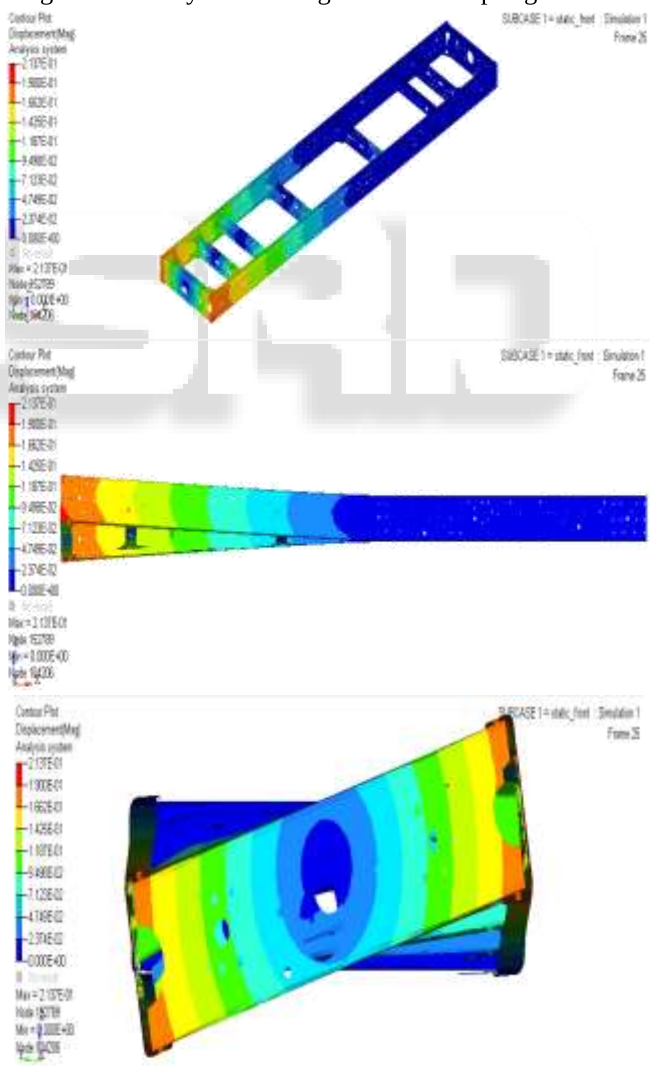

Fig. 9: Deflection Plot - Spring Brackets Loading

The deflection plot of the spring bracket method is shown in Fig 9. The deflection of the frame is purely in torsion due to the applied opposite force. It is observed that the max deflection of 0.22mm at the front of the chassis frame and deflection of 0.16mm at front spring bracket and

0.11mm at the rear spring bracket of the front suspension. The rear end of the chassis frame is rigid since the constraints applied at the both the spring brackets, hence deflection is zero.

VI. CONCLUDING REMARK

Finite element analysis can effectively solve the torsional stiffness analysis of chassis frame. Two method of stiffness analysis is carried out considering the wheel base of the vehicle and considering the spring bracket loading. The FEA torsion stiffness of the wheel base method is 802 KN-m/deg and spring bracket method is 4378 KN- m/deg. The spring bracket method is 5.4 times greater than wheel base method. Actually, it is necessary to get some data based on physical measurement so that there is some evidence to ensure the accuracy of results. According to the comparison of simulated results spring bracket method is closer to the vehicle actual running condition and it also evident that which higher than the wheel base method. Spring Bracket method stiffness can be used in the vehicle handling analysis for increasing the accuracy of the results and also it will help to reduce the weight of the chassis frame by reducing the stiffness if it is higher than the required.

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