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Simulation of Roll cage of an All-Terrain Vehicle considering inertia, using Transient Multi-body analysis

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Abstract: *Design and simulation of the chassis of any automobile for validation against crash and its consequences is the major area of research done by the designers in the automobile industry today. It is common for off road vehicles to encounter large obstacles including trees and rocks. The structure must be designed well enough to ensure that these loads do not cause damage that immobilize the vehicle. Generally the chassis design is made considering standardized impact loads and constraints. But the problem with such simulation is that, it does not consider the effect of inertia of individual components, thus leading to failure at mount supports. A complete dynamic analysis considering all the components of the vehicle should be done, but it is not a simple task even for the automotive companies. So an approximate model is developed using different elements in ANSYS APDL and a transient multi-body analysis is carried out to check for failure in the roll cage due to inertia of major components.*
Keywords: *COMBIN14, Inertia, MASS21, MPC184, Multi-body analysis, PIPE289, Roll-cage, Transient*

I. Introduction

Unlike the conventional passenger vehicles, All Terrain Vehicles need distinctive approaches and testing during design and fabrication stages, the obvious reasons being multiplicity of loading conditions, fatigue stresses and impacts daunting the chassis at critical points. The loads associated with rigid body motion, such as longitudinal acceleration and steady state turning, are generally smaller in amplitude, for the off road case, than those associated with impact events. By making this assumption, designing the vehicle for only impact loads guarantees to provide enough strength to satisfy the rigid body loading conditions as well. These loads are often difficult to quantify, however, off road racing can quickly lead to suspension and frame damage, or even failure, if these loads are not properly accounted for. It is therefore necessary for a deeper and meticulous study of design considerations, loads and constraints.

II. Staticstructural Analysis

A simple off-road vehicle frame is considered for the present study, which is of a vehicle designed for a BAJA SAE competition.

In general, static simulations have been used to study the structural issues associated with Baja SAE vehicle frames. Static models are relatively simple to construct and require very minimal computing resources. A typical Baja frame model may be assembled using beam or pipeelements in a commercially available finite element package. This model can be analyzed under a wide range of load cases, and the results are quickly made available due to the simplicity of the static model.

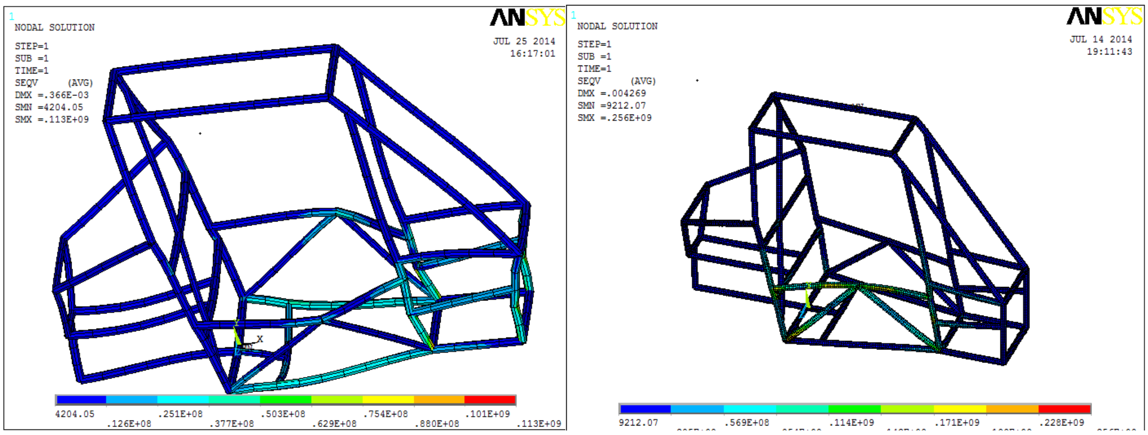
II.IModelling of Roll cage: Modelling of the basic frame is started with the driver's cabin. A 95th percentile male is assumed to be driving the vehicle and with sufficient spatial clearances throughout and accordingly a cabin is designed. Further, members to support subsystems like suspension, steering, brakes, transmission and engine are added. This geometry of various subsystems is deduced by considering several concepts of vehicle dynamics. The material being used for the frame is AISI 4130 chromoly tubes with yield strength 460 MPa.

II.II FE model development: After the structure is modeled, corresponding key points are given in ANSYS and the FE model is developed. The model is meshed with PIPE289 element with suitable element length. The model was checked for impacts such as front impact, side impact and roll over, using standard loads and constraints.

Table 1. Results of Static structural analysis

Test/ Impact	**Loads**	**Constraints**	**Deflection (mm)**	**Stress (Mpa)**	**FoS**
Front	4G load on front LC	SHP and rear frame points	0.3	113	4.07
Side	2G on SIM	SHP and Left SIM	3.7	254	1.81
Roll over	4G at 45 degrees on RHO- LC	SHP and rear end base points	2.9	253	1.81
Drop	Gradual gravity load as G , 0.5G and 0.25G towards front on nodes	SHP and SIM points	0.4	47	9.78
Single Wheel landing	2G load on front right end suspension point	Front left and Rear SHP	2.3	236	1.94

SHP: Suspension hard points; SIM: Side impact members; LC: Lateral cross member;
RHO: Roll hoop overhead



(a) (b)

Figure1: Static structural analysis. (a) Frontal impact (b) Side impact

As the factor of safety for all the impact tests is within limit, the structure was considered to be safe. But there are two major concerns associated with static modeling. The first is that, usually there is uncertainty in the constraints that should be applied to the model. These constraints may not be present in actual case. Second, the load applied is derived by considering the whole vehicle as a single unit, which will not be true during the real time behavior of the vehicle.

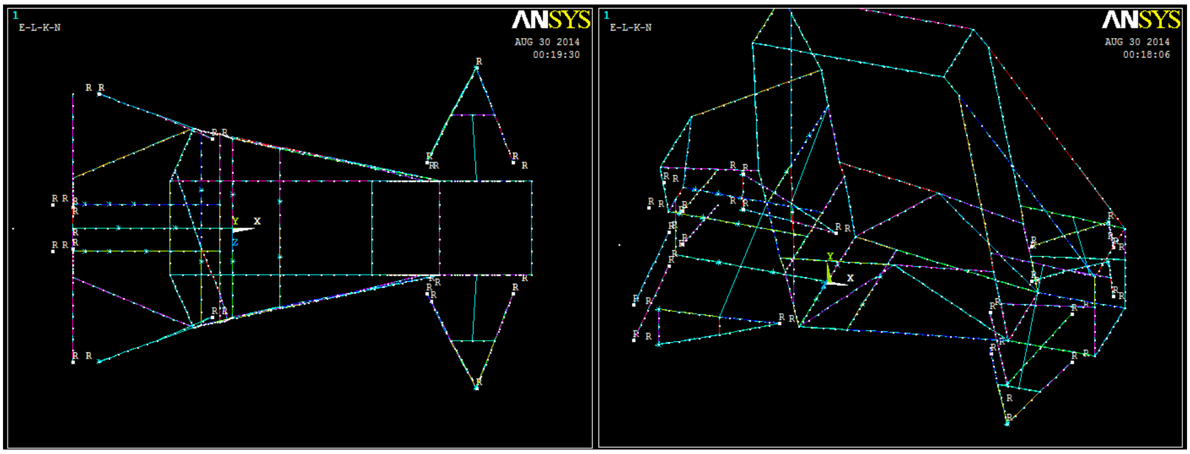
III. Transient Multi-Body Analysis

Instead of using static analysis, transient multi-body analysis can be performed using mass elements to study the effect of inertia of individual components of the vehicle. An approximate model is developed using various elements present in ANSYS APDL.

Table 2. Elements used for the model

S.No.	**Components**	**Element used**
1	Roll cage	PIPE289
2	A-arms and Trailing arm	PIPE289
3	Shocks	COMBIN14
4	Revolute joints	MPC184
5	Driver, engine, gearbox, wheel assembly and steering system	MASS21

The keypoints of A-arms and trailing arms were added to the FE model and meshed with PIPE289 element. MPC184 x-axis and z-axis revolute joint elements were used to join them to the roll cage. COMBIN14 Spring-damper, with appropriate stiffness value, was used for the shocks. The major masses in the vehicle whose inertia has to be considered for the analysis are that of driver, engine, gearbox, wheel assembly and steering assembly. The force due to the inertia of these masses, during an impact, act through their respective mount points. So the masses were divided and added at the corresponding nodes in the roll cageusing MASS21 element.



(a) **(b)**

Figure 2: Full model with suspension. (a) Top view (b) Isometric view

III.I Conversion of static model into transient model

Front impact: Standard load- 4G

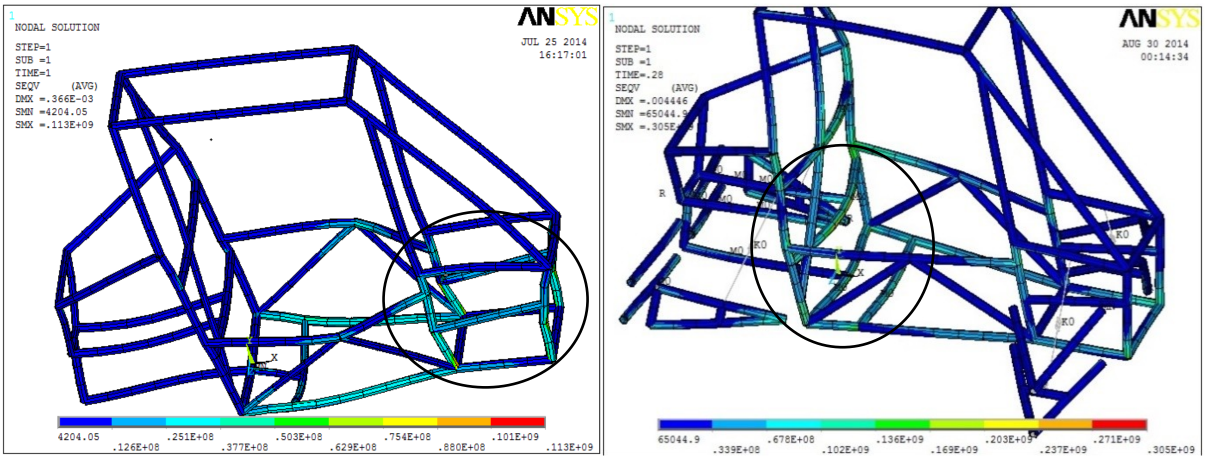
Force= 4 x 9.8 x 300 N (vehicle weight + driver G=300kg)

Acceleration= 4 x 9.8 m/s^2

Considering the impact to take place at a speed of 45 kmph (11m/s),

Impact Time= 11/ (4x9.8) = 0.28sec

Thus the static model can be converted into a transient one using 11m/s initial velocity and time step 0.28sec and constraining the nose of the vehicle in x-direction to imitate frontal impact.



(a) **(b)**

Figure 3: Frontal impact stress concentration areas (a) Standard static analysis (b) Transient multi-body analysis

Stress intensity: (a) 113MPa (b) 305Mpa

FoS : (a) 4.07 (b) 1.50

For the same impact load the stress intensity and concentration in the rollcage is different in the two cases as seen in the above figure. The standard analysis shows stress concentration at the nose. But, as the engine and gearbox are located at the rear of the vehicle, more stress is concentrated at the rollcage members which support them, as seen in the results of transient multi-body analysis. So there is more chance of failure at the rear of the frame than the front during the real impact situation.

Therefore, there is a need to strengthen the roll-cage members supporting the engine and the gearbox to increase the safety of the driver. The roll-cage design is changed accordingly and the analysis is carried out and checked for failure.

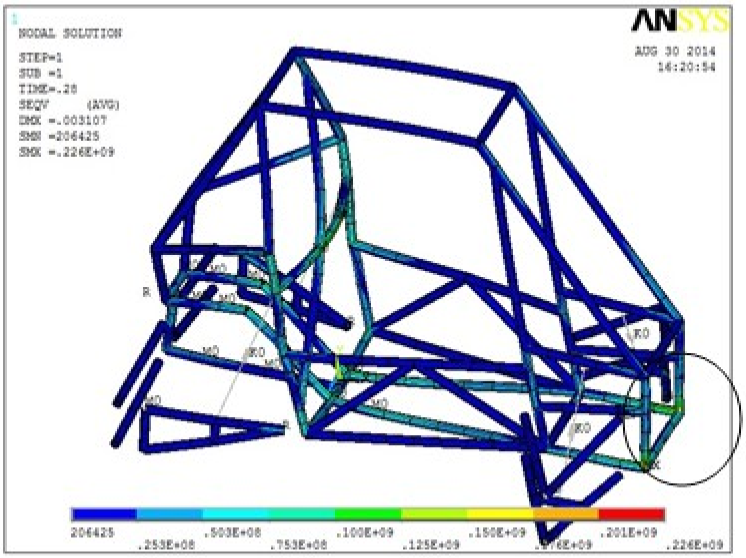


Figure 4: Stress intensity after modifying rollcage design

Stress intensity: 226 MPa
FoS : 2.03

Thus the design changes ensured good stress transmissibility. Similarly, the model has to be checked for failure due to other impact cases mentioned earlier, converting static models into transient ones.

IV. Conclusion

Inertia is the key factor for the damage occurring to a vehicleduring impacts. All the components of a vehicle need to be considered for the analysis to validate it against failure during different possible impact cases. The presented FEM is built using various elements which display the properties of major components of an all-terrain vehicle. This paper thus provides the method to study the effect of inertia of individual components on the rollcage during an impact and helps in designing a safer vehicle.

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