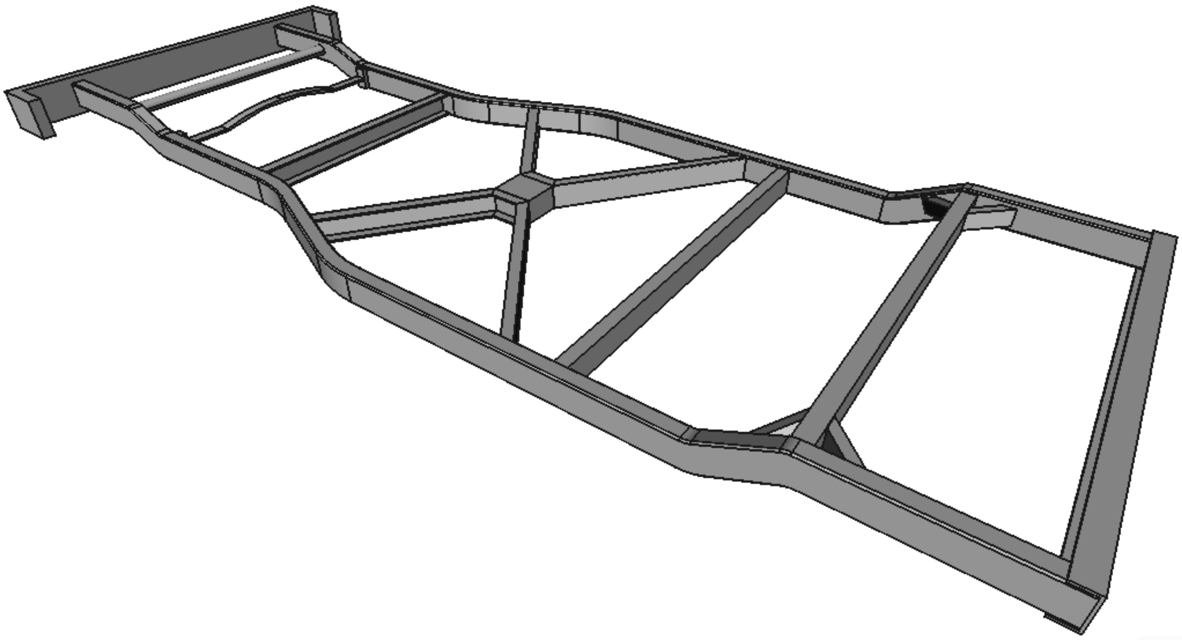
Frontal Offset Crash Simulation of a SUV Ladder Chassis



Part I – Crash simulation of the chassis moving at 64 kmph and 100 kmph, using shell elements.

Part II – Comparative crash simulation of the chassis moving at 100 kmph, using shell and thick-shell elements.

By-

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Introduction

In the history of automotive engineering, the ladder frame chassis stands as an enduring type. Its fundamental design comprises two parallel longitudinal beams (rails), interconnected by shorter cross-members. This skeletal framework serves as the foundation for mounting the vehicle's body and engine components.

Here are the salient technical features of the SUV ladder chassis:

1. Structural Integrity: The ladder frame's robustness lies in its sheer simplicity. The rigid rails resist bending and torsional forces, ensuring stability even under extreme loads. This structural integrity is vital for off-road excursions and heavy-duty applications.

2. Payload Capability: SUVs equipped with ladder frames excel at carrying substantial payloads. Whether hauling cargo or towing trailers, the ladder chassis handles the weight efficiently, distributing it evenly across the rails.

3. Off-Road Prowess: When navigating treacherous terrain, the ladder frame shines. Its inherent strength allows SUVs to tackle rocky trails, steep inclines, and uneven surfaces without compromising stability.

4. Modularity: The ladder frame's modular design facilitates customization. Manufacturers can adapt it for various wheelbases, accommodating different vehicle sizes and configurations.

5. Challenges and Trade-Offs: Despite its merits, the ladder frame has limitations. It tends to be heavier than monocoque structures, affecting fuel efficiency. Additionally, the rigid frame can transmit vibrations and impacts directly to the cabin. The higher centre of mass also negatively affects the cornering dynamics (rollover).

In the evolving landscape of automotive design, where monocoque (unibody) structures dominate, the SUV ladder chassis remains a niche choice.

Ladder Chassis CAD and Pre-Processing(Part I)

- Developed a 3D CAD model of the SUV ladder chassis in *FreeCAD*.

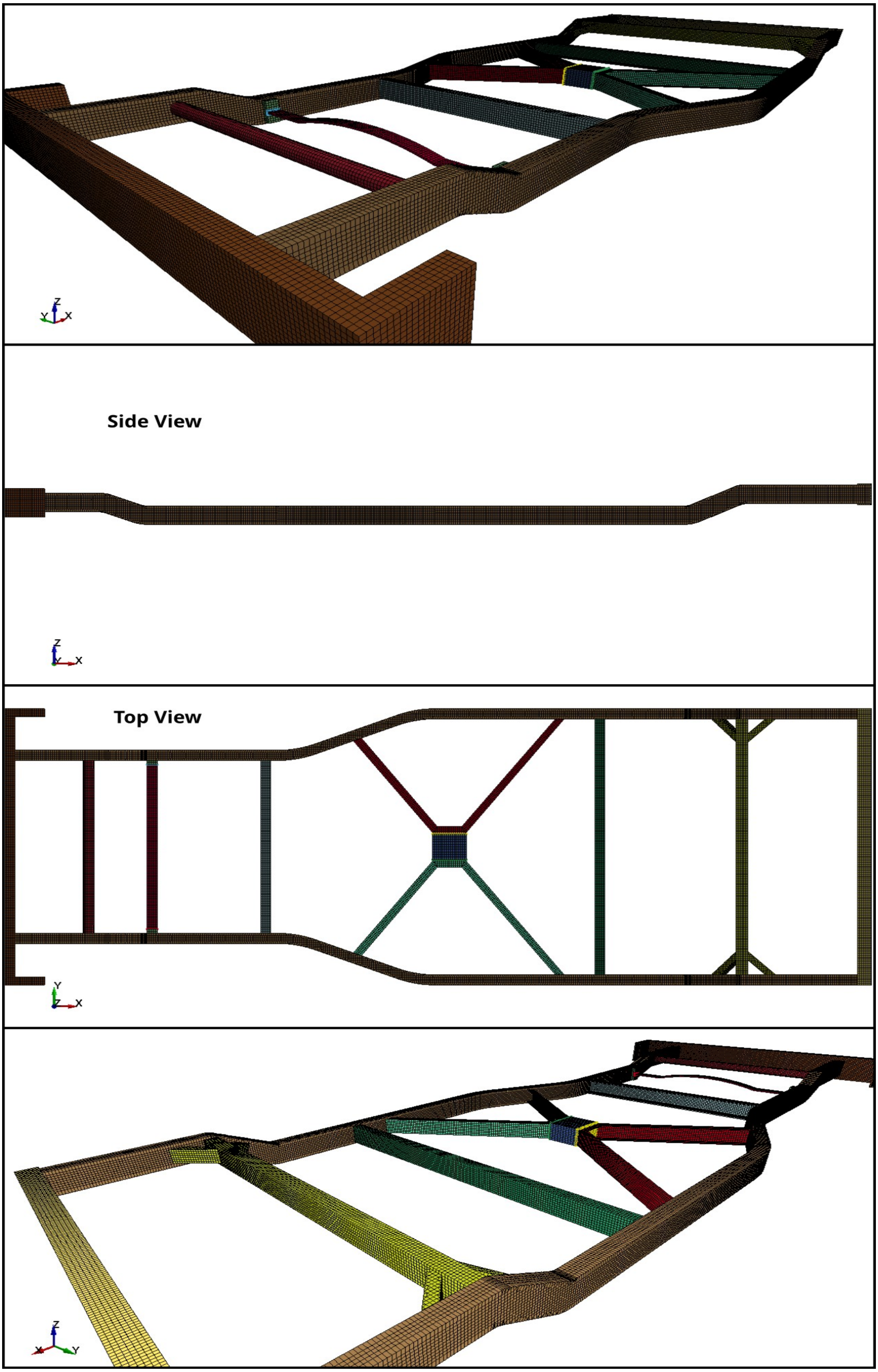
- Total length of the chassis including the bumpers is 4378.10 mm and the width of the widest section of the chassis is 1662 mm.

- The rails have hollow box cross-section with dimensions 100 x 50 x 6. Dimensions are in millimeter. Cross-members were modelled with C-section channels, hollow box and tubular sections with 6mm and 8mm thickness.

- Prepared the mesh from the CAD model in *LS-PrePost.* Only shell elements were used for both the cases in part-I of this project. Some solid elements were used in one of the cross-member as connectors to the rails.

- Defined the material, section, rigid-body constraints, welding, and contact definitions in a *keyword* file in *LS-PrePost*.

Number of shell elements	60250
Number of solid elements	200
Total number of elements	60450
Total number of nodes	61471
Material	Stainless Steel AL-6XN
Material model	Johnson-Cook model


Side View
Top View

Simulation Setup (Part I)

- Created the LS-DYNA input file, specifying the crash scenario (frontal offset) and impact velocity in the negative x-direction (64 kmph and 100 kmph).

- Defined the rigid wall representing the barrier at a distance of 10mm from the front bumper.

- Termination time was set at 20ms.

- The unit system chosen is given in the table below:

Mass	Length	Time	Force	Stress	Energy	Temperature
g	mm	ms	N	MPa	N-mm	K

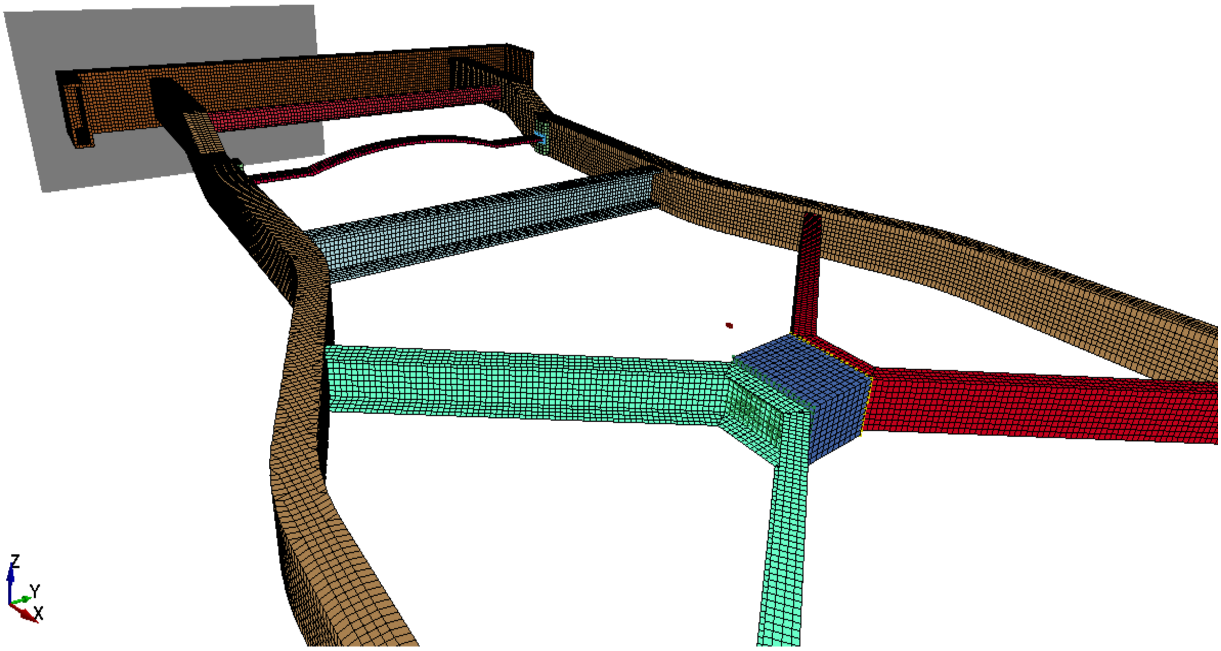
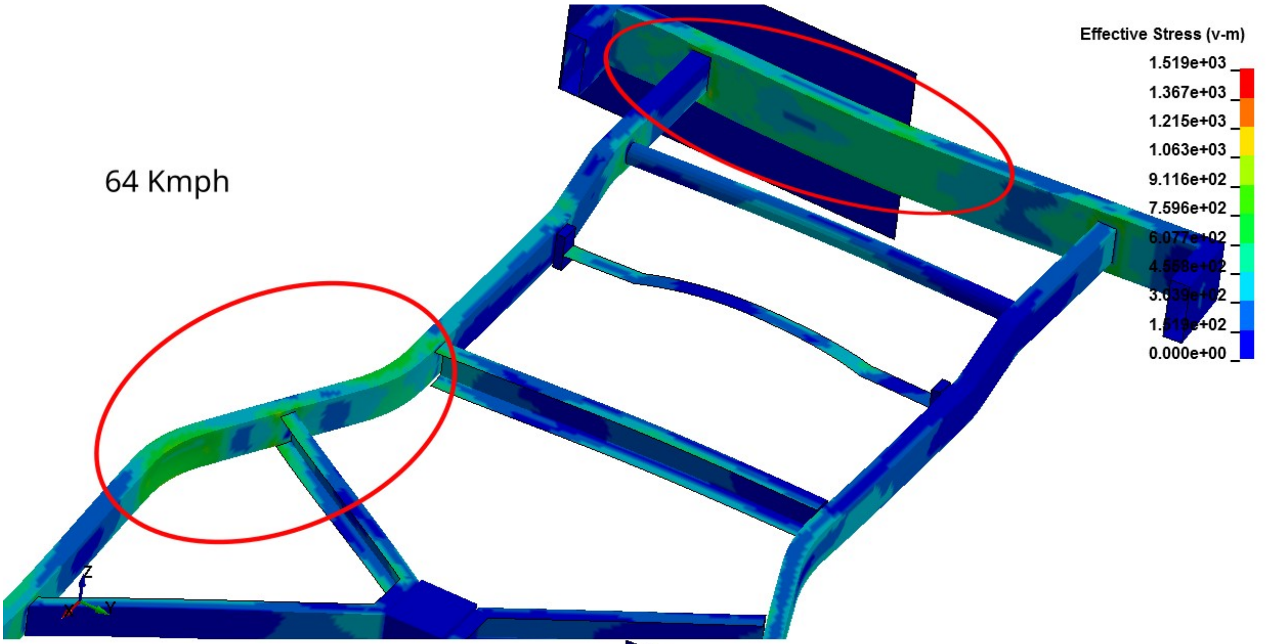
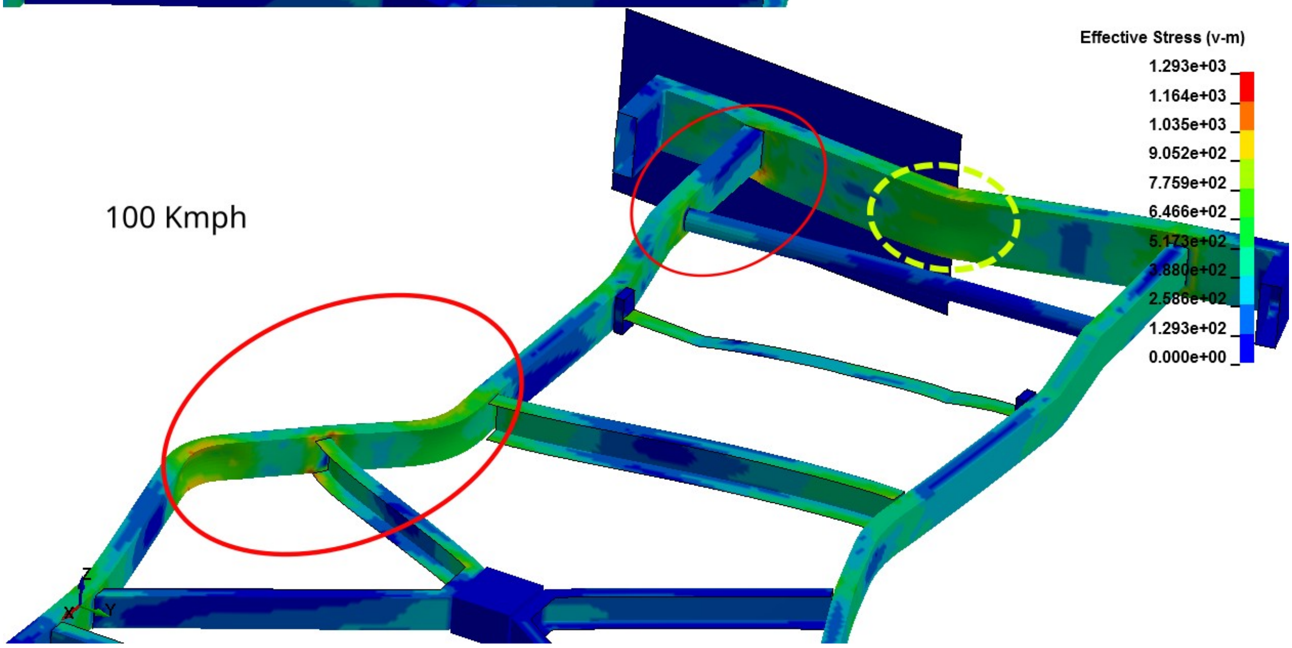


Figure 1: Crash Simulation Setup

Stress Contours (von-Mises Stress) (Part I)

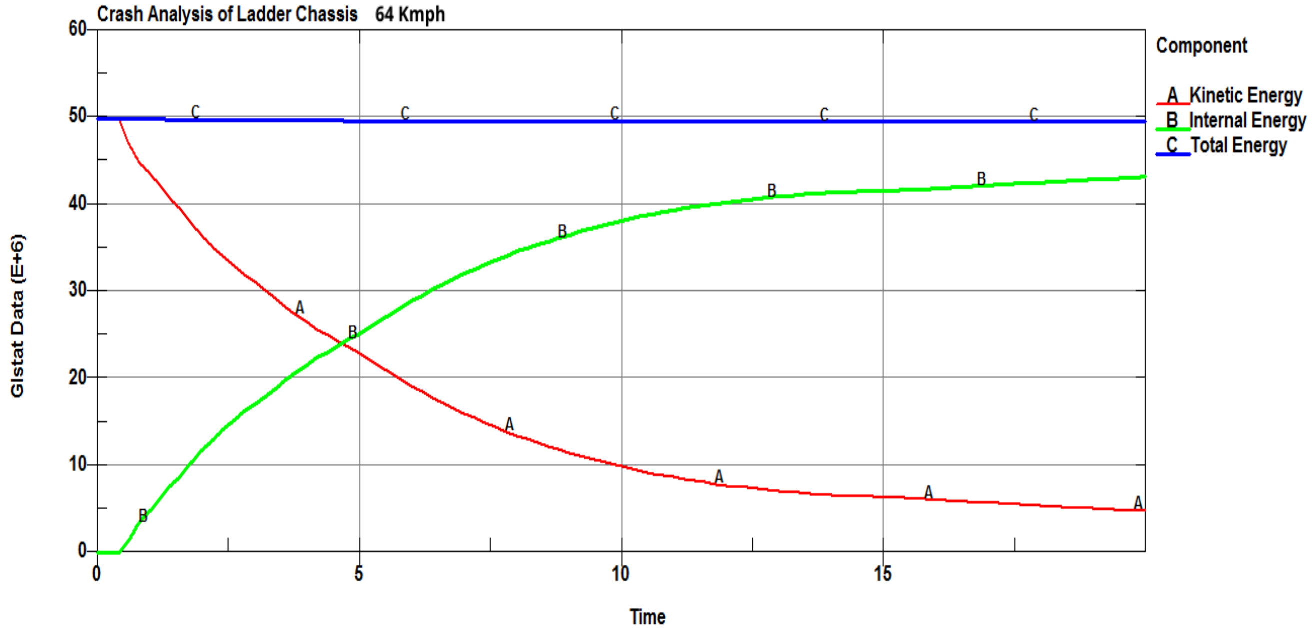
- Post-processing was done using LS-PrePost.
- Stress contours were generated and regions of stress concentration were identified. The regions are marked with red circles in the below image.
- For the 100kmph case, the red circles show the regions of stress concentration just after the impact. As time passes, the stress concentration increases significantly in an additional area marked with yellow dotted circle. (Note- The image shows the two cases at different states, so stress values should not be compared in the image).

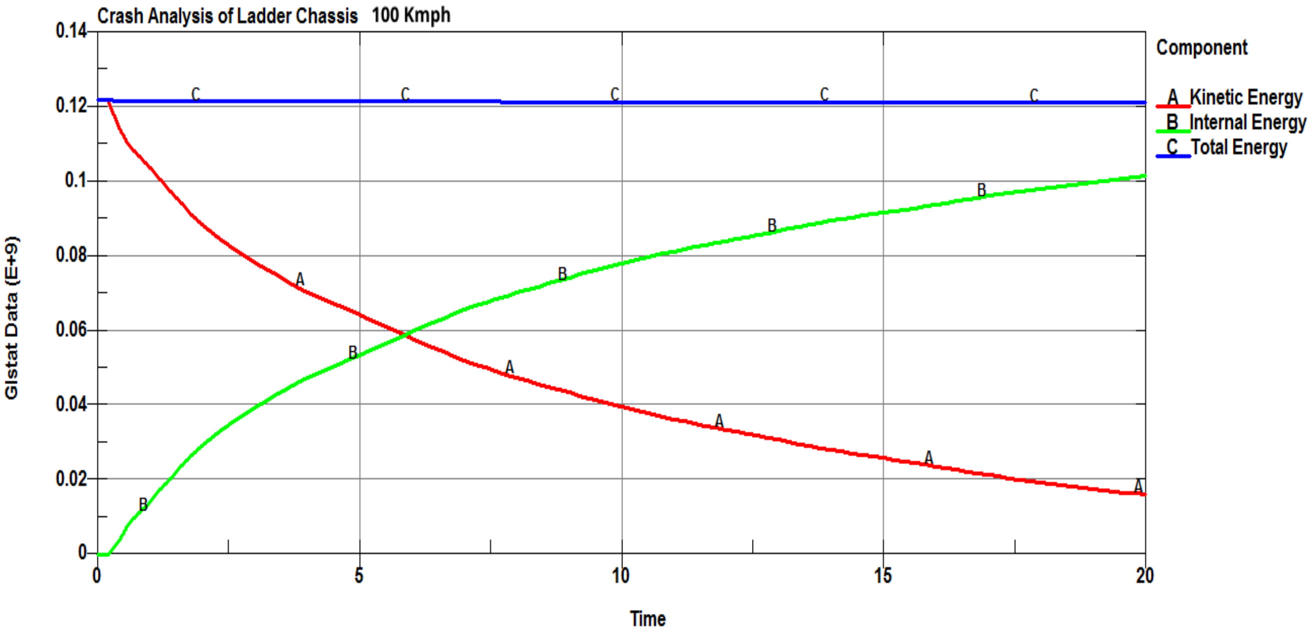




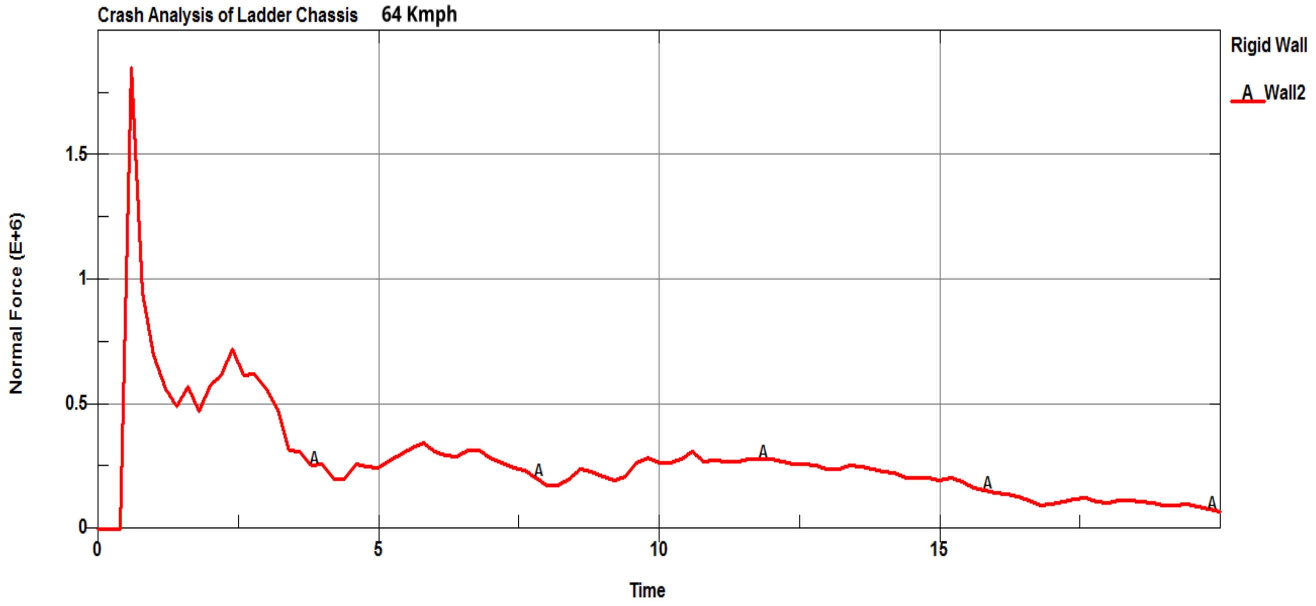
System Energy Plots (Part I)

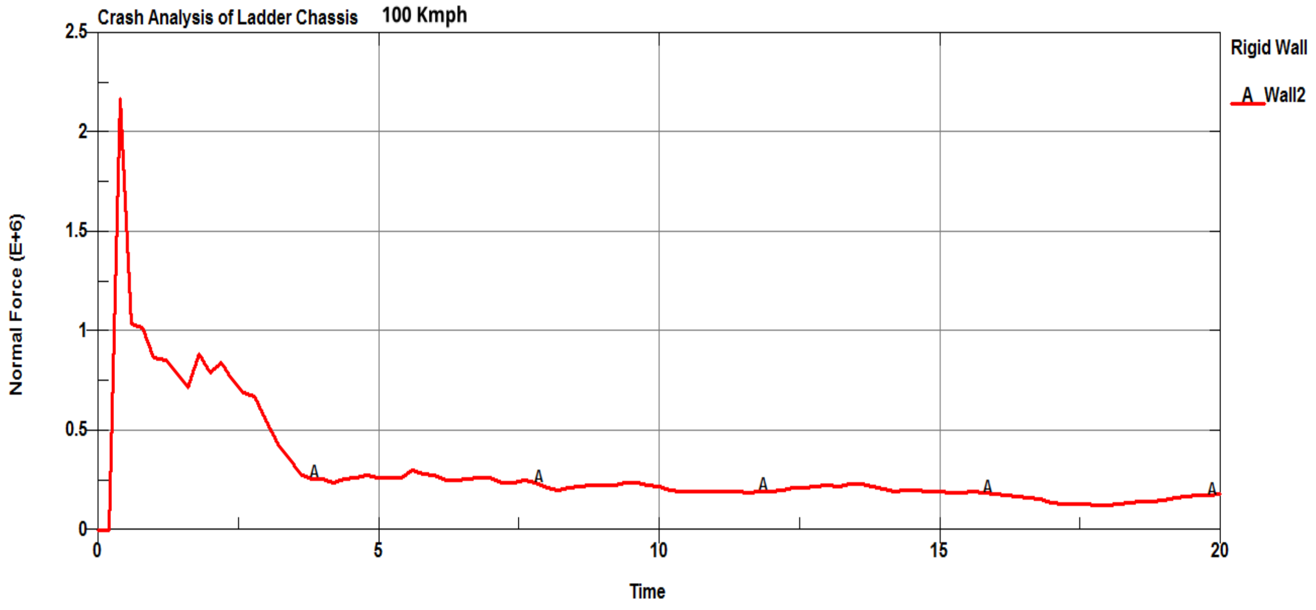
The plots for both the cases show that total energy of the system (chassis) is conserved. This verifies the simulation setup.





Rigidwall Normal Force Plots (Part I)





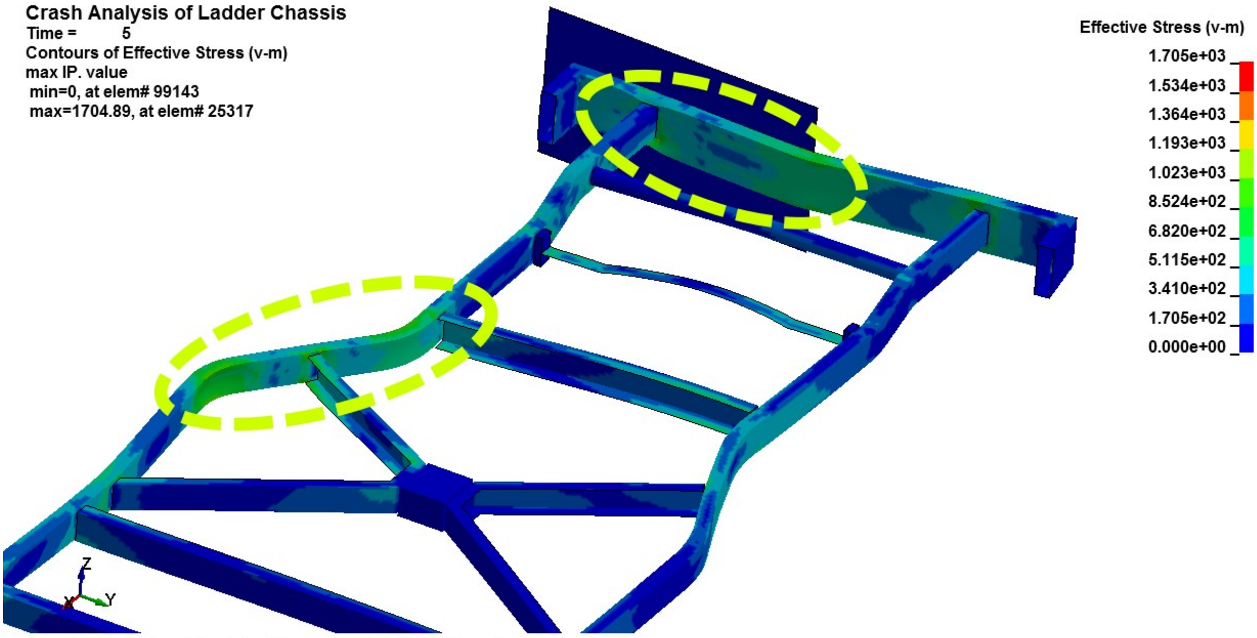
Pre-Processing and Simulation Setup (Part II)

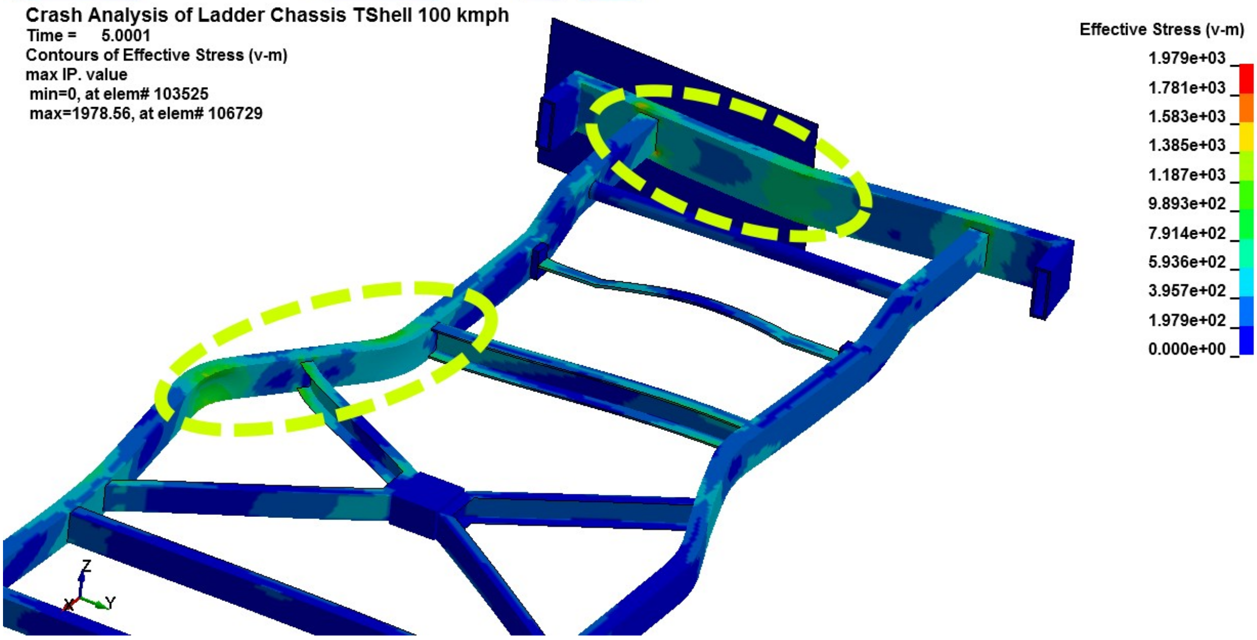
- The second part of this project focuses on the performance difference between shell and tshell elements.
- A third FEM model (we will call it tshell model) was made in *LS-PrePost*, wherein shell elements were replaced by thick-shell elements (tshell) in the mesh. Two cross-member parts were kept as shell elements to avoid mesh penetration between them and the rails.
- The initial velocity of 100kmph was given in negative x-direction to contrast this model with the one (we will call it shell model) from part-I of the project.
- Termination time was kept at 5ms, to keep the computational time reasonable.
- Rest everything was modelled the same as that in the shell model of part-I for the 100kmph case.

Number of shell elements	11655
Number of tshell elements	48779
Number of solid elements	200
Total number of elements	60634
Total number of nodes	110928
Material	Stainless Steel AL-6XN
Material model	Johnson-Cook model

Stress Contours (von-Mises Stress) (Part II)

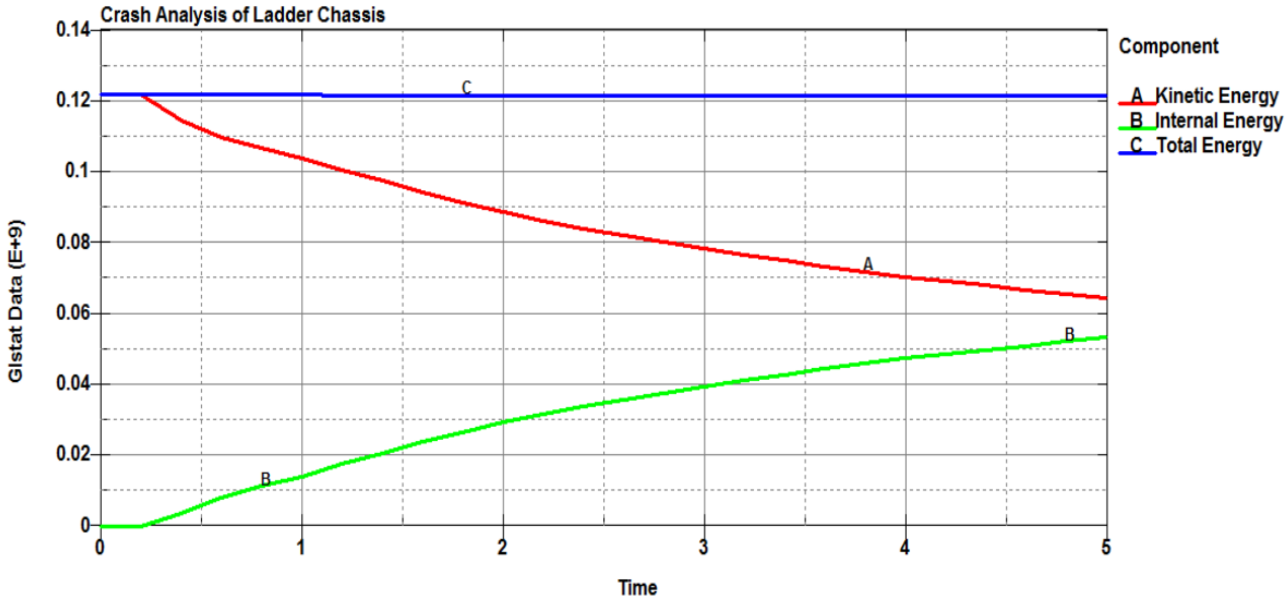
- Stress contours are plotted for the shell and tshell model at the final state i.e at 5ms.
- Regions of stress concentration are marked with yellow dotted circles in the image below.
- Stress appears continuously distributed over larger areas in the shell model whereas it appears more concentrated in specific areas in the tshell model.

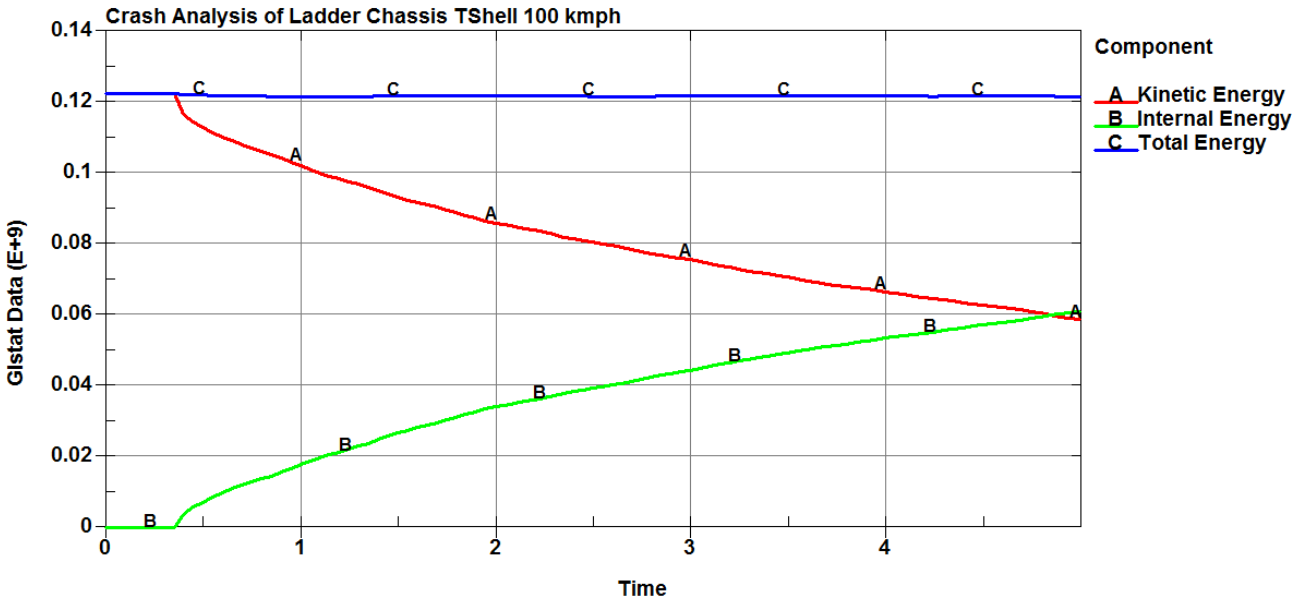




System Energy Plots (Part II)

The plots for both the cases show that total energy of the system (chassis) is conserved. This verifies the simulation setup. Notice the difference between the two. Kinetic energy reduces relatively faster in the tshell model.





Conclusion

- The simulation revealed critical areas of deformation and stress concentration in the chassis during the frontal offset crash.

- The model's behaviour at different impact speeds (64 kmph and 100 kmph) was compared in part-I.

- The table below shows the findings in part-II:

	Shell Model (100kmph)	Tshell Model (100kmph)	%age difference
No. of nodes	61471	110928	80.46
No. of elements	60450	60634	0.3
Max. Stress	1872.60	2534.20	35.33
Computational time	~0.25hr	~2.13hr	752

The shell model is taken as the reference to calculate the percentage differences. The maximum stress occurs at 2ms state in the shell model while at 1.8ms in the tshell model. The maximum stress in tshell model is 35% higher than the shell model. The tshell model requires 752% more computational time than the shell model for almost same number of mesh elements. This can be attributed to the fact that tshell elements are 3D elements with 8 nodes and accounts for out-of-plane stress. On the other hand, shell elements are 2D elements with 3 or 4 nodes and doesn't incorporate out-of-plane stress.

Disclaimer – In the project, mesh dependency study was not conducted due to limited resources. So the results and outcomes in this project are qualitative and demonstrative in nature.

References

1. Muthyala, Monica. “Design and Crash Analysis of Ladder Chassis.” (2019).

2. Soltani, Mehrtash, Ameen Topa, Mohamed Rehan Karim, and N.H. Ramli Sulong. “Crashworthiness of G4(2W) Guardrail System: A Finite Element Parametric Study.” International Journal of Crashworthiness 22, no. 2 (2017): 169–89. doi:10.1080/13588265.2016.1243636.

3. https://www.researchgate.net/publication/361569186_Investigation_of_Honeycomb_Sandwich_Panel_Structure_using_Aluminum_Alloy_AL6XN_Material_under_Blast_Loading

4. https://www.researchgate.net/publication/342353302_How_to_perform_crash_simulation_with_LS-DYNA

5. LS DYNA Tutorial | Crash analysis procedure | Step By Step |

6. Setting up a crash simulation in LS-Dyna

7. Combined Analysis of LS-DYNA Crash-Simulations and Crash-Test Scans