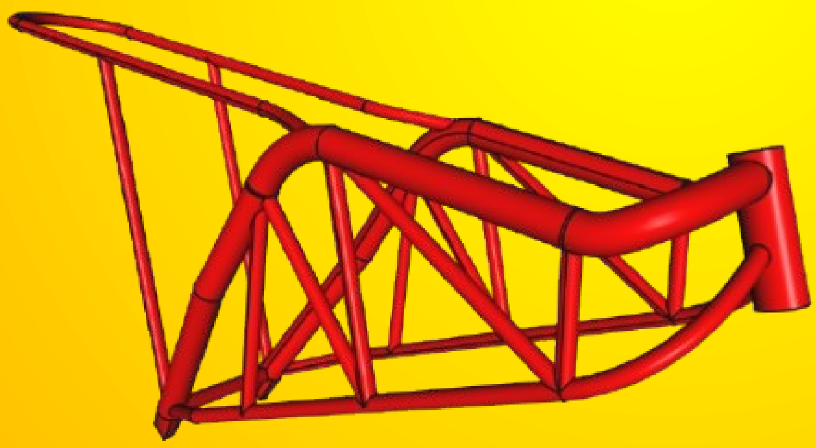
Concept Trellis Frame for a Café Racer Motorcycle

Design, Modelling, and Structural Analysis



By-

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Introduction

Café racers are motorcycles that emphasize a lightweight, high-performance design with a distinctive vintage aesthetic. Traditionally, café racers feature single or double cradle frames. This project aims to innovate by incorporating a trellis frame, known for its modern engineering benefits, into a café racer design. The objective is to create a unique fusion of classic and contemporary elements and to test the frame's structural integrity through simulations.

Objectives

- To design a trellis frame that meets the aesthetic and functional requirements of café racer motorcycles.
- To model the designed frame using open-source FreeCAD software.
- To conduct simulations for drop test and stiffness analysis to evaluate the frame's performance under various conditions.
- To explore the potential of blending traditional café racer design principles with modern trellis frame engineering.

Design: Theory and Requirements

- The motorcycle frame, often referred to as the chassis, is the backbone of a motorcycle's structure, providing the foundation upon which all other components are mounted. A well-designed frame ensures the bike's stability, handling, and overall performance. The trellis frame, characterized by its lattice-like design of interconnected steel tubes, is renowned for its excellent balance of rigidity and flexibility. This design allows for better weight distribution, improved handling, and enhanced structural integrity. In the context of a café racer, the frame not only needs to meet functional requirements but also aligns with the bike's minimalist and vintage aesthetic.

- Ergonomic triangle aka the "rider triangle" refers to the three key points of contact between the rider and the motorcycle: the handlebars, seat, and foot pegs. The geometric arrangement of these points significantly impacts the rider's comfort, posture, and control over the motorcycle. In café racers, the ergonomic triangle is typically designed to create a more aggressive, forward-leaning riding position, with low handlebars, a high seat, and rear-set foot pegs. This configuration not only enhances the bike's sporty aesthetic but also improves aerodynamics and handling at high speeds.

- The geometrical features of a motorcycle frame significantly influence its ride quality and dynamics. Factors such as the frame's rake angle, trail, wheelbase, and overall stiffness play crucial roles in determining how the motorcycle handles and responds to various riding conditions. For example, a steep rake angle and short trail typically result in quicker, more agile handling, ideal for navigating tight corners and urban environments. Conversely, a more relaxed rake angle and longer trail provide greater stability at high speeds, suitable for long-distance cruising. The wheelbase, the distance between the front and rear axles, also affects stability and maneuverability—a shorter wheelbase allows for sharper turns, while a longer wheelbase enhances straight-line stability. The frame's stiffness and structural integrity impact the motorcycle's ability to absorb and dissipate forces from road irregularities, contributing to ride comfort and control.

Design Requirements for a Café Racer Trellis Frame:

1. Classic, Minimalist, and Performance-Oriented Ethos

   - Low, aggressive stance

   - Clip-on or clubman handlebars for a forward-leaning riding position

2. Fuel Tank Design

   - Elongated and sculpted fuel tank for improved aerodynamics

3. Seat Design

   - Single, custom piece seat that complements the bike's sleek lines

4. Foot Pegs

   - Rear-set foot pegs for an aggressive riding posture

5. Frame Geometry

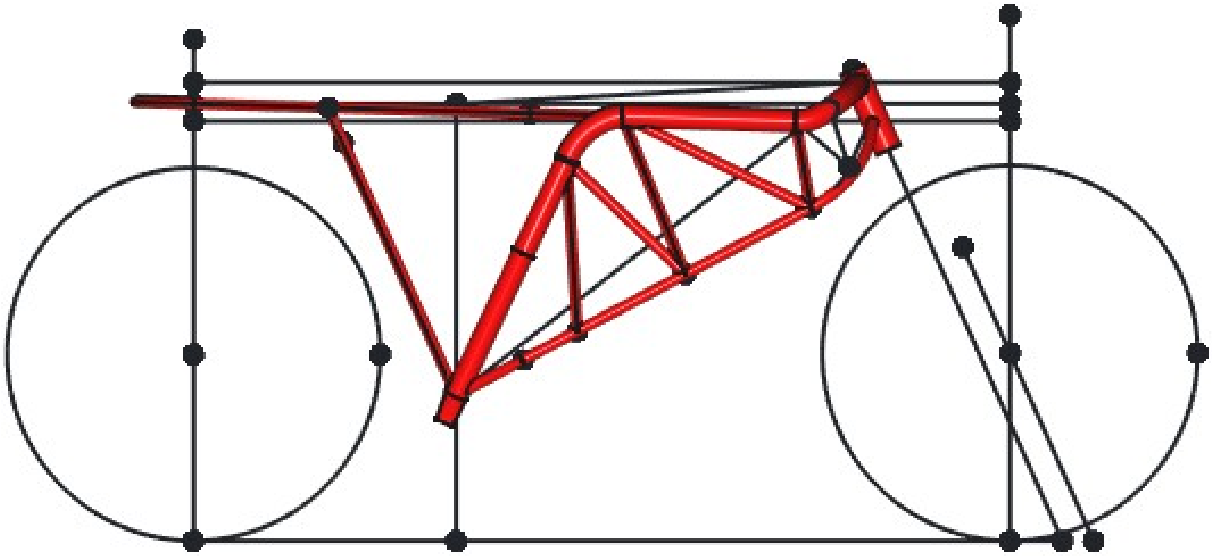
   - Flat line running from the front to the back for a cohesive and streamlined look

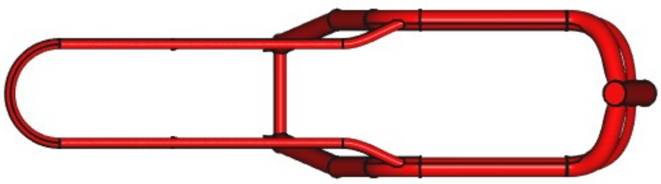
   - Balanced wheelbase for agility and stability

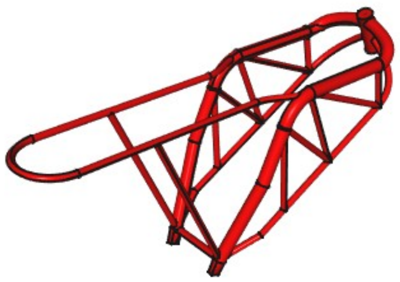
   - Rake and trail configured for responsive handling and precise control

Trellis Frame CAD

In compliance to the geometry requirements, discussed in the previous section, a detailed 3D CAD model of the concept trellis frame was made in FreeCAD.







Pre-Processing and Simulation Setup

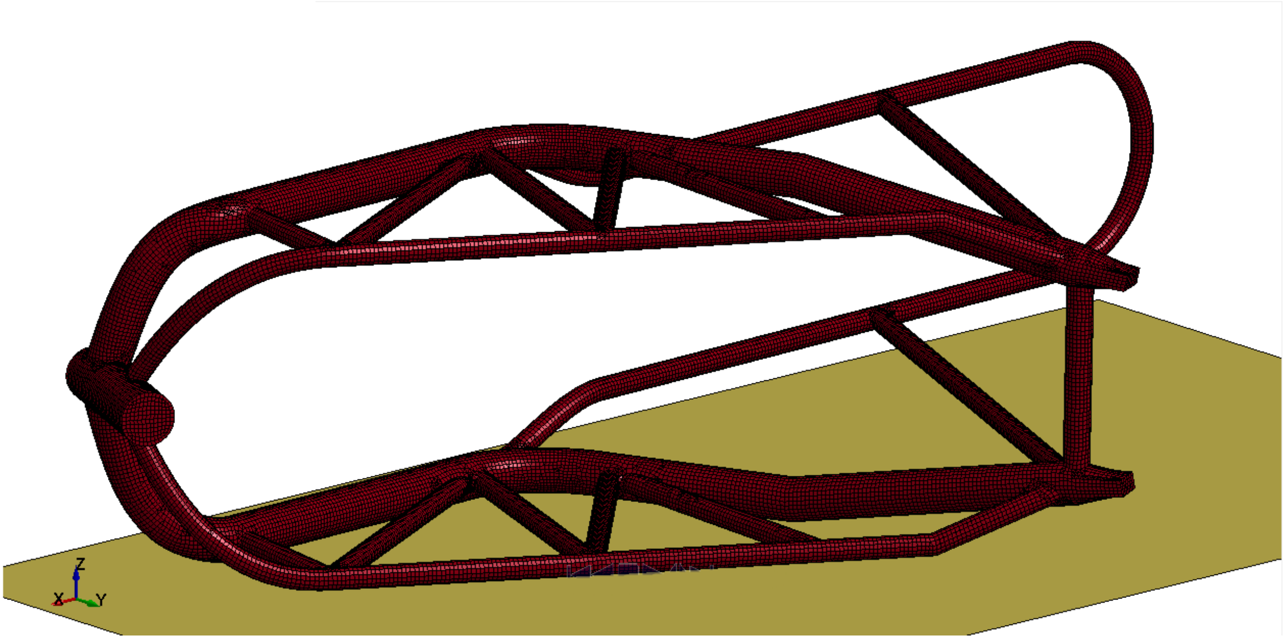


Figure 1: Drop test simulation setup in LS-Prepost

- Prepared the mesh from the CAD model in *Hyperworks.* Only shell elements were used in this project. Additional Bar and RBE2 elements were used in structural simulations to account for the stiffness from cross-members and engine block.

- 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

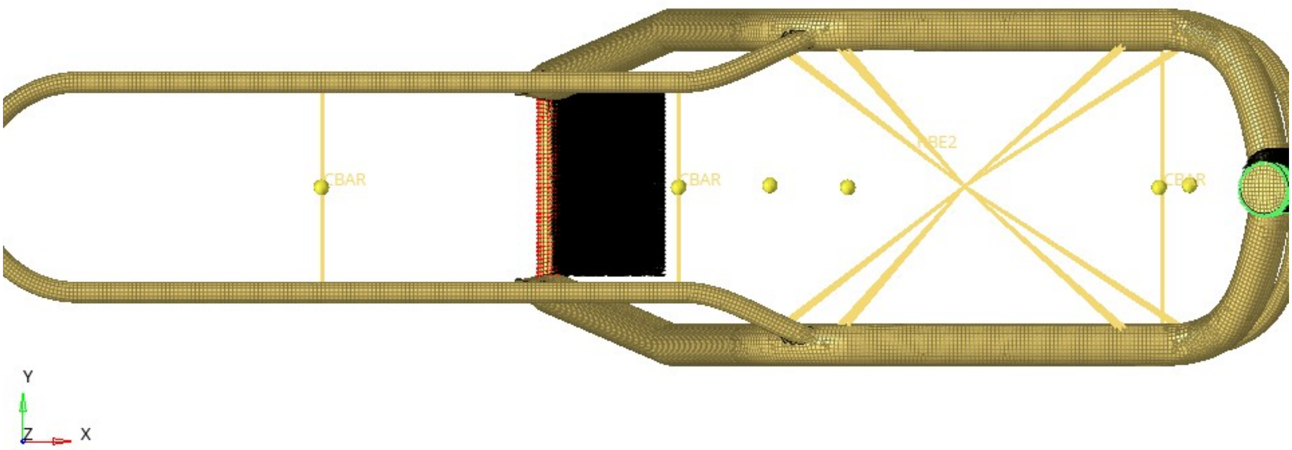


Figure 2: Simulation setup to estimate frame stiffness in Optistruct (top view)

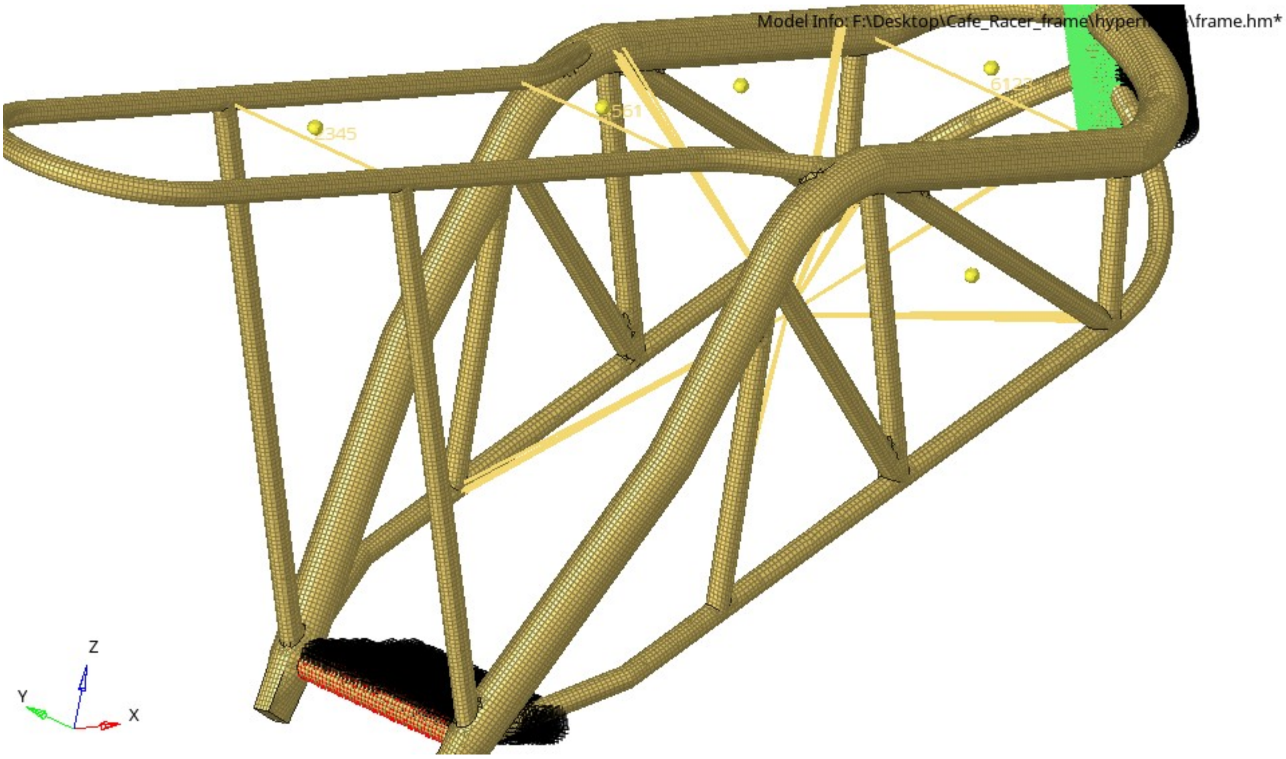


Figure 3: Simulation setup to estimate frame stiffness in Optistruct

Number of shell elements	50707
Total number of nodes	47902
Material	AISI 4130 Chromoly Steel
Material model	Piecewise Linear Plasticity

Drop Test Simulation Setup

- Imported the mesh into LS-Prepost to make the input file for the drop test simulation in LS-Dyna.
- Figure 1 shows the simulation setup. The frame is dropped with its side facing the ground from a height of 2m. So the initial condition was defined as a velocity of $\sqrt{2gh}$ for the falling frame and gravity was applied.
- Defined a rigid wall representing the ground at a distance of 10mm from the frame.
- Termination time was set at 20ms.

Structural Simulation Setup

In conducting the structural simulation for the motorcycle frame, three critical stiffness tests were employed as outlined in Vittore Cossalter's "Motorcycle Dynamics" (Cossalter, 2006):

1. Longitudinal Stiffness Test: Evaluated the frame's ability to resist deformation under longitudinal forces, ensuring stability and performance during acceleration and braking.
2. Lateral Stiffness Test: Assessed the frame's resistance to lateral forces, crucial for maintaining balance and handling during cornering.
3. Torsional Stiffness Test: Measured the frame's resistance to twisting forces, essential for preserving the integrity and safety of the motorcycle during dynamic maneuvers.

The simulations were conducted using Optistruct solver. The solver input deck was prepared in Hyperworks itself.

- Figure 2 and 3 shows the simulation setup with appropriate applied loads and constraints in accordance to the stiffness test method.
- Rigid body constraint (RBE2) element and 1D Bar elements were also defined so as to account for the engine-block stiffness and cross-member stiffness in the total frame stiffness.
- Non-linear (geometric and material) static method was used for simulations.

Results

1. Drop Test Simulation

- Post-processing was done using LS-PrePost.
- Stress contour was generated and regions of stress concentration were identified.

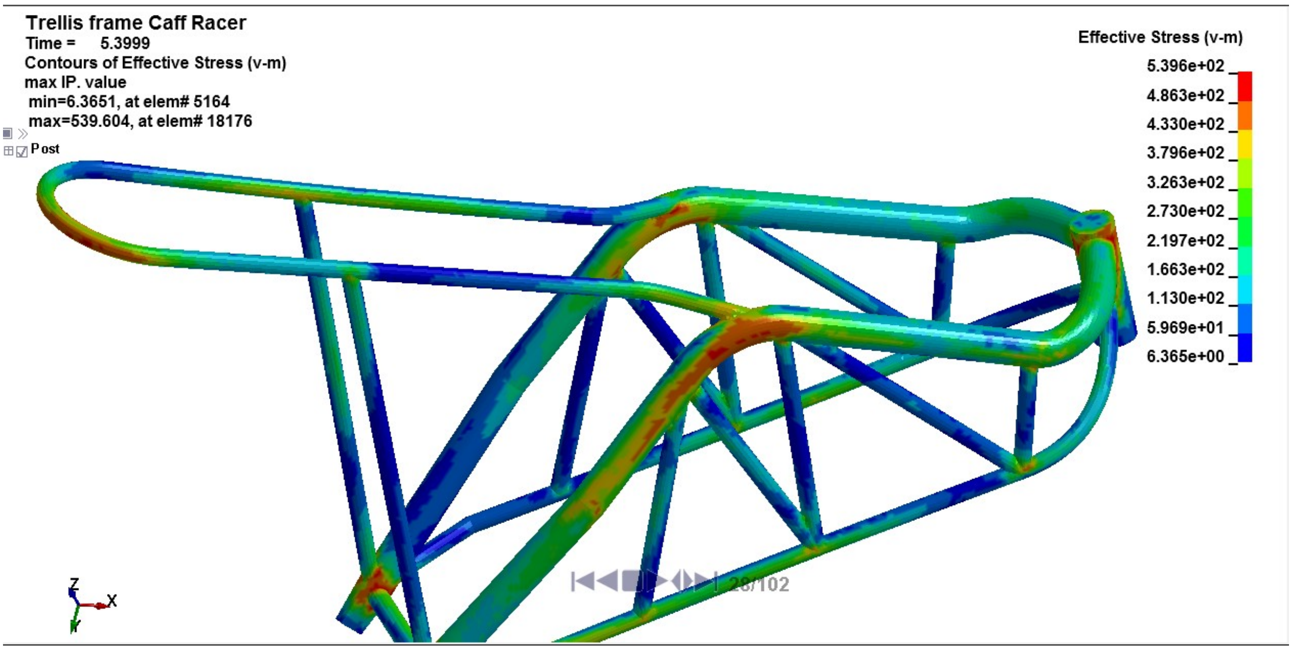


Figure 4: Stress contours as viewed from below the ground (rigidwall)

Figure 5 shows the areas in the frame with plastic strain.

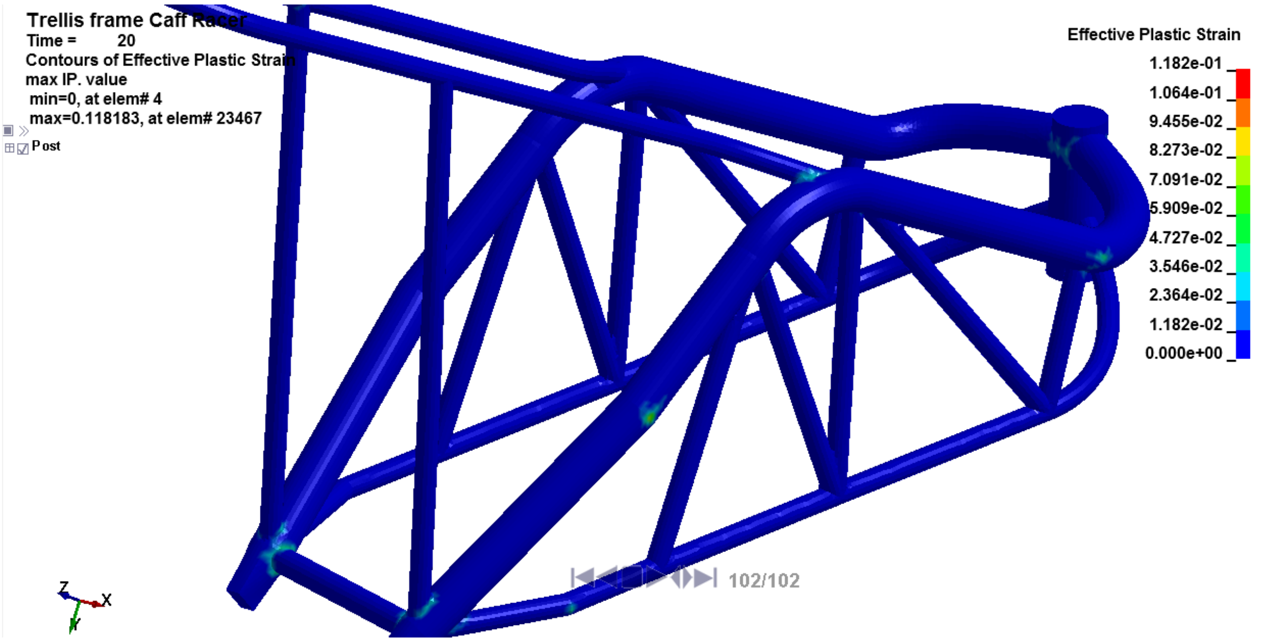
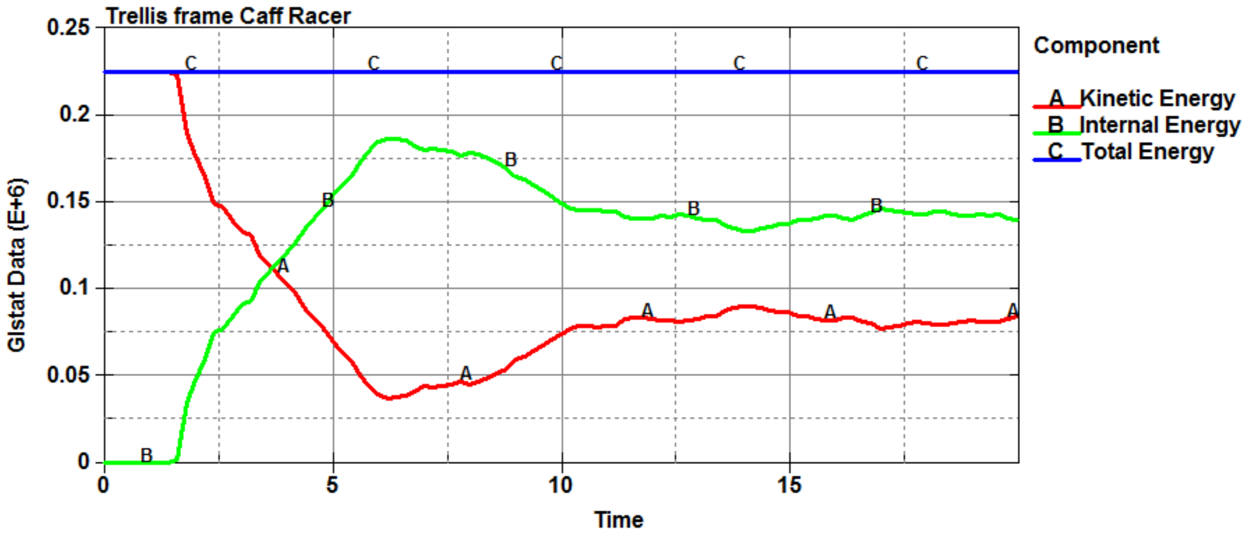
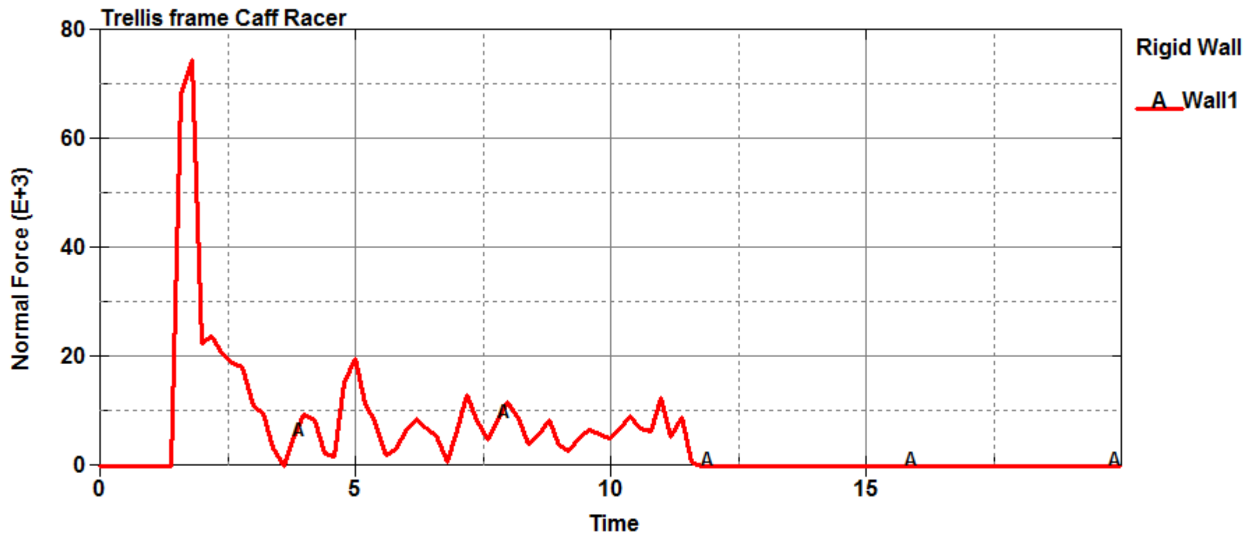


Figure 5: Plastic strain in the frame

- <u>System Energy Plot:</u> The energy plot below show that the total energy of the system (frame) is conserved. This verifies the simulation setup.



- <u>Rigidwall Normal Force Plot</u>



2. Structural (Stiffness) Simulations

- Lateral Stiffness (K_1): it is defined as the ratio of the lateral force (along the swingarm pivot axis) to the deformation in that direction. In this project, the steering head is completely constrained and a load of 5kN is applied on the swingarm pivot axle. Typical values lateral stiffness lies in the range of 1-3kN/mm for sport-bike.

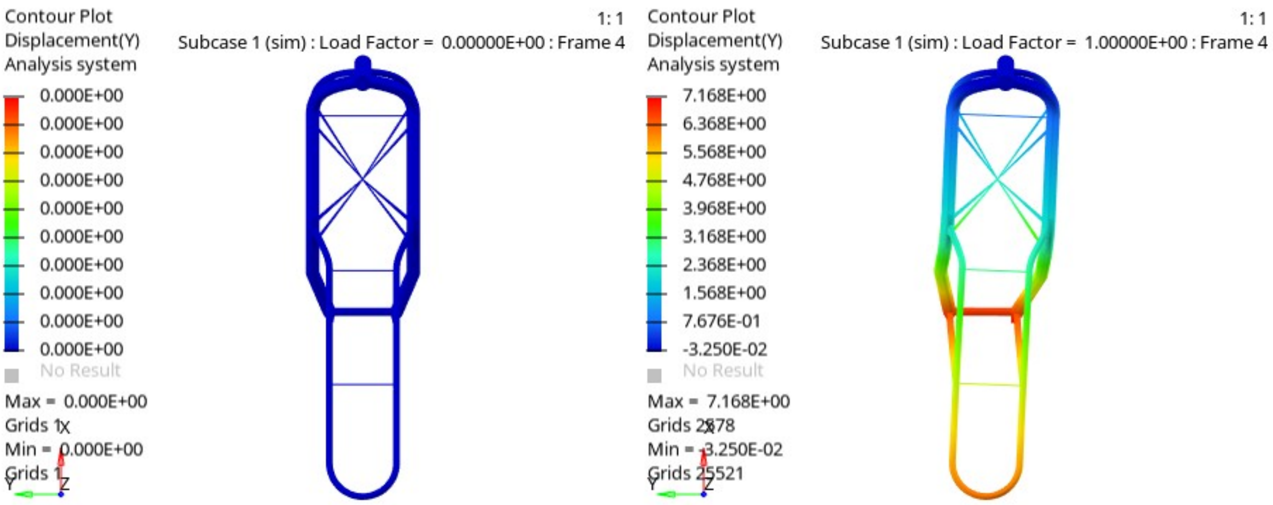


Figure 6: Deformation in the frame; (Left) unloaded and (Right) loaded. [Visual representation is scaled by a factor of 10, to see the deformations.]

The value of K_1 comes to 0.7kN/mm for the given load. This is less than the prescribed values of lateral stiffness for sport-bikes. This means that this frame will handle poorly during high-speed cornering. Given the fact that this is the very first design of the frame, it is still not bad. There is a need to carry out the design changes and optimization to improve lateral stiffness. Figure 7 shows stress concentration in the frame. The highest value of the stress generated in the frame is slightly above the yield stress value of 435MPa.

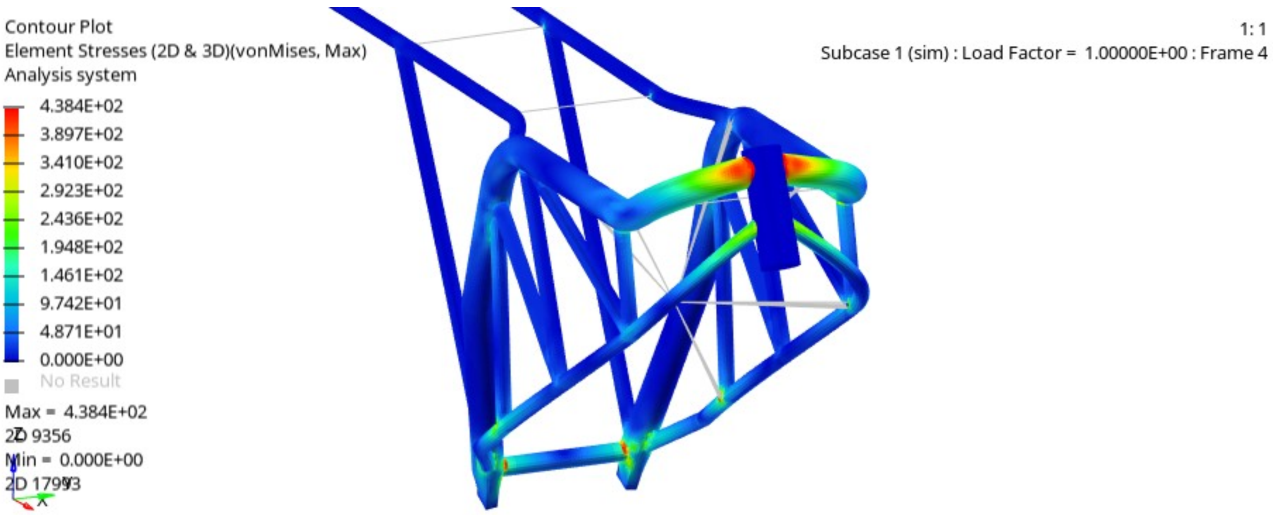


Figure 7: Stress contour plot for the lateral loading.

- Longitudinal Stiffness (K_2): it is defined as the ratio of the force applied perpendicular to the steering-head axis to the deformation in the frame. Here, the swingarm pivot axle is fully constrained and a load of 5kN is applied on the steering-head perpendicular to its axis. Typical values of longitudinal stiffness lies in the range of 5-10kN/mm for sports bike.

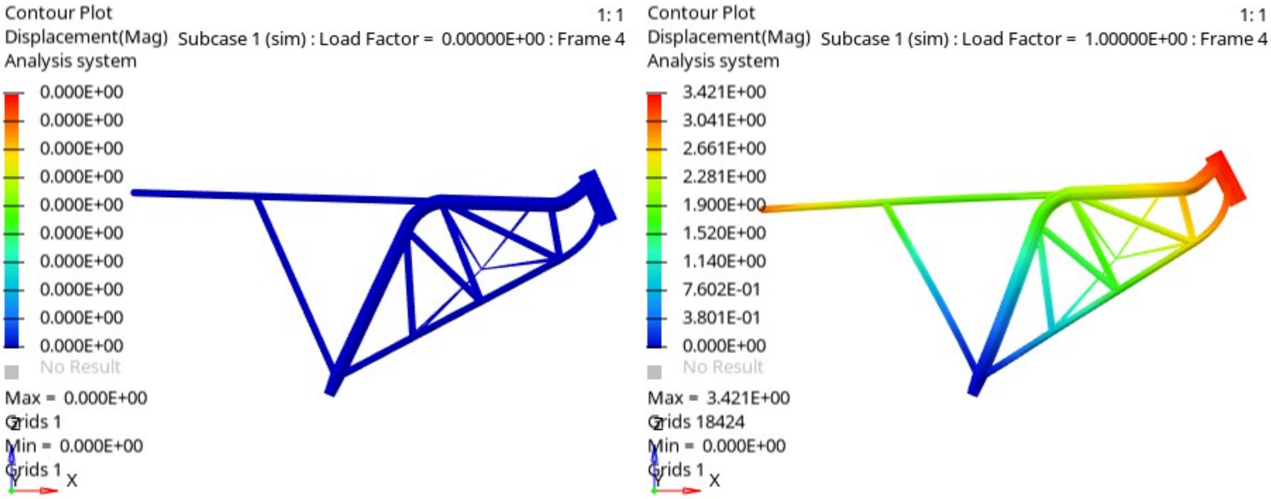


Figure 8: Deformation in the frame; (Left) unloaded and (Right) loaded. [Visual representation is scaled by a factor of 20, to see the deformations.]

The value of K_2 comes to 1.46kN/mm for the given load. This is again lower than the prescribed range of longitudinal stiffness for sports bike. Figure 9 shows stress concentration in the frame. In this case, the maximum stress value is below yield stress. Such low stiffness will compromise the ride stability and will cause discomfort to rider during acceleration and braking. Design optimization is required by analysing the stress concentration in the frame.

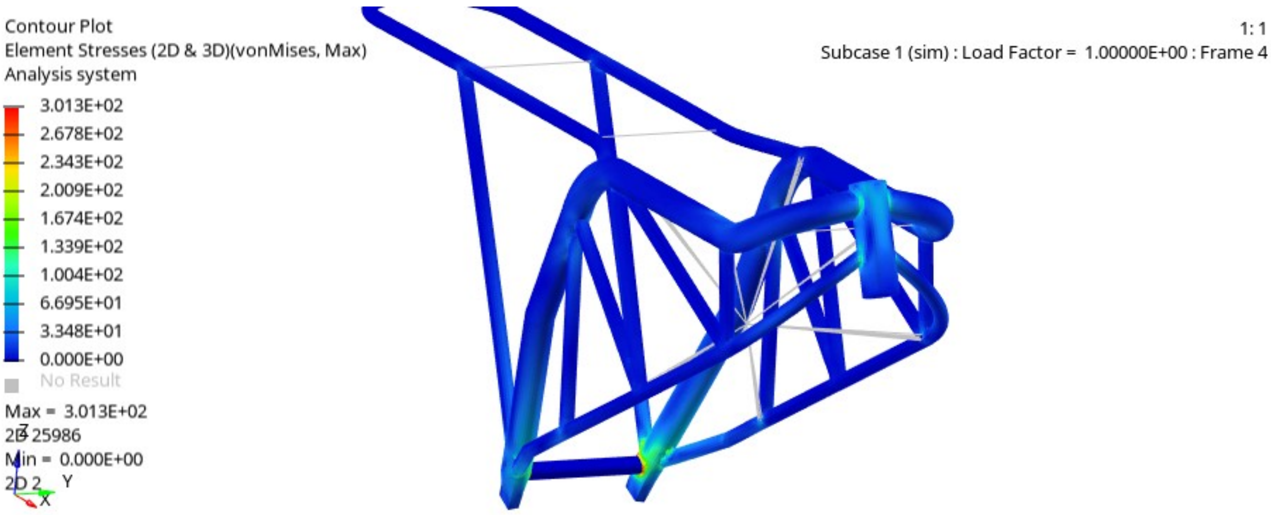


Figure 9: Stress contour plot for the longitudinal loading.

- Torsional Stiffness (K_3): it is calculated for the moment about an axis that is perpendicular to the steering-head axis and passes through the swingarm pivot axis. In this project, the steering-head is fully constrained and a moment of 3.4kNm was applied on the swingarm pivot axle along the axis perpendicular to the steering-head axis. Suitable values for a sport-bike lies in the range of 3-7kNm/°.

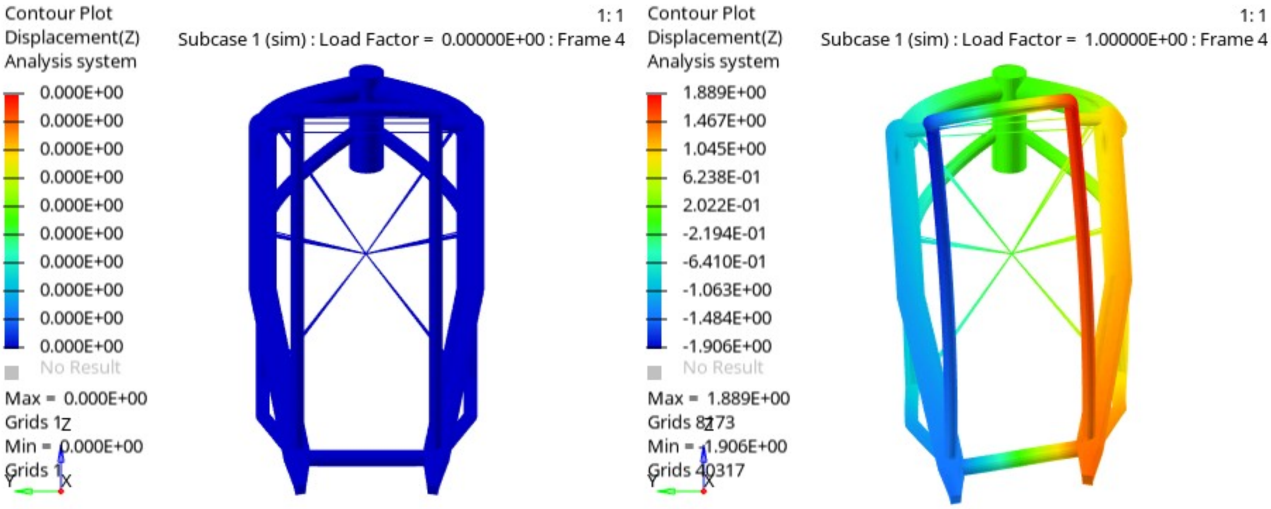


Figure 10: Torsional deformation in the frame; (Left) unloaded and (Right) loaded. [Visual representation is scaled by a factor of 10, to see the deformations.]

The value of K_3 comes to 3.65kNm/° for the given load. The torsional stiffness of the frame lies within the stipulated range for sports bike. However, as seen in figure 11, the maximum stress value generated in the frame is higher than the yield stress value of 435MPa. Stress is concentrated in the swingarm pivot axle and the region where it connects to the frame.

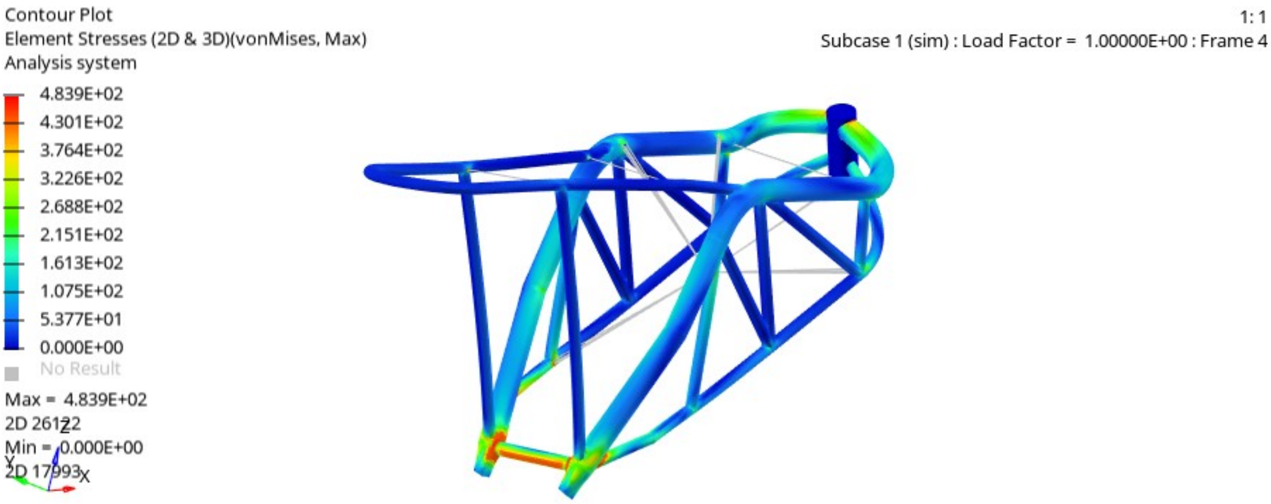


Figure 11: Stress contour plot for torsional loading.

Conclusion

- A motorcycle geometry was made which incorporates sport-bike dynamics and cafe racer design aesthetics. A concept trellis frame was designed and modelled based on this geometry.

- Structural simulations were done on this frame to estimate its stiffness according to three tests namely, lateral, longitudinal, and torsional stiffness tests. Except for the torsional stiffness test, the frame doesn't meet the passing criteria for modern sports bike.

- Being the first design, the frame performed decently. Design modification/ optimization based on stress distribution and deformation results, is the future scope of this project. Following could be the possible approaches:
  1. Mesh convergence study to further improve the results.
  2. Improving cross-bracing to stiffen the swingarm pivot and headstock area.
  3. Modifying pipe diameter and thickness.

- The drop test simulation revealed critical areas of deformation and stress concentration in the frame.

- No significant plastic strain was seen in the current frame design for the drop test, even without cross-bracing.

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

References

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