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DESIGN OPTIMIZATION OF 1-D CHASSIS FRAME USING DIFFERENT BEAM CROSS SECTIONS IN ANSYS

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Abstract

Chassis design plays a critical role in the performance, safety, and dynamic stability of Formula Student race cars. Since vehicle performance is inversely proportional to mass, optimization of the chassis structure is essential to achieve high stiffness with minimal weight. This study presents a finite element-based structural and modal analysis of a 1-D space frame chassis using different beam cross sections: circular, rectangular, and I-profile sections. Two configurations (single frame and double frame) were evaluated using Structural Steel and Titanium Alloy materials.

Keywords: Chassis optimization, Finite Element Method, Space frame, Structural steel, Titanium alloy, Modal analysis, ANSYS.

1. Introduction

The chassis is the primary load-bearing structure of a race vehicle. It supports:

- Suspension loads
- Impact forces
- Powertrain loads
- Driver safety systems

Performance requirements include:

- High torsional stiffness
- Low bending deformation
- Impact resistance
- Minimum weight

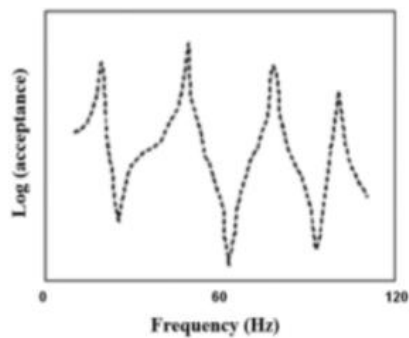
For Formula Student vehicles, chassis stiffness significantly influences:

- Handling
- Ride quality
- Suspension performance
- Driver safety

This study focuses on structural optimization of a 1-D beam-based chassis using different cross-sectional geometries.

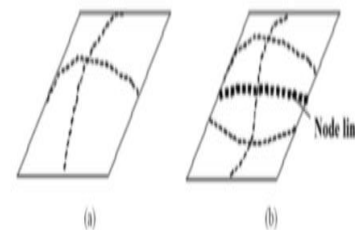
VEHICLE INTERIOR:

The body structures of typical passenger cars are usually formed by welding multiple stamped steel plates of thickness of 0.7 to 1 mm shows a typical frequency response function of vehicle body steel panel. The ratio



of vibration speed V to excitation force F is usually defined as the acceptance response transfer function of the panel. The acceptance response transfer function is a function of frequency and is a complex quantity.

In the acceptance response transfer function of a typical plate, the peaks on the curve indicate several low-order natural modes. The first- and second-order modes shapes of a rectangular plate are illustrated. The first-order shape exhibits in-phase vibration of the entire area without node and node line. The second-order shape exhibits out-of-phase vibrations at two areas with one node line in between.



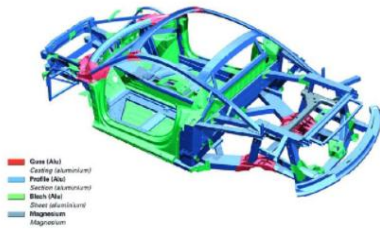
The real boundary condition of the plate on the vehicle body is neither simply supported nor fixed. The actual first-order natural frequency of the plate on the vehicle body is usually between the estimated values from the simply supported case and fixed case, respectively.

2. Chassis Design Concepts

Common chassis configurations include:

- Ladder Frame
- Space Frame

- Backbone Chassis



- Monocoque
- Carbon Fiber Monocoque

The present study uses a **space frame configuration**, due to:

- Ease of fabrication
- Cost efficiency
- Good strength-to-weight ratio
- Compatibility with tubular members

Monocoque

A monocoque is similar to that of a skinned space frame but without any underlying support through the monocoque area.

Carbon Fiber Monocoque

Carbon fiber monocoques are similar to angular monocoques but have very little compressive strength but high tensile strength.

Utilizing aluminum correctly can lead to similar stiffness and strength compared to a steel chassis but at significant weight savings. It is however easy to jump to the conclusion that Aluminum will always yield a lighter frame for the weight but in simulation later it will be proved to be only minimally. Since the R8 is formed of many different types of parts it is expensive to assemble.

All have been used in production cars. Almost all are rear wheel drive and front engine allowing the backbone to double as a transmission and drive shaft tunnel.



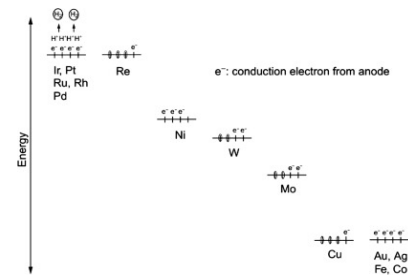
Lotus was the first to utilize the “Tub” approach to build a chassis for the Eliseen.

3. Materials

3.1 Structural Steel

- Yield strength \approx 240–450 MPa
- High stiffness
- Good weldability
- Economical

Likewise, titanium alloys are immune to MIC due to the stability of the TiO_2 passive film. However, the absorption of hydrogen (e.g., produced in general corrosion or when used with active metals) can cause the fragility of the material.



3.2 Titanium Alloy

- Yield strength up to 1400 MPa
- Excellent strength-to-weight ratio
- High corrosion resistance
- Expensive

Material selection affects:

- Mass
- Deformation
- Stress distribution
- Manufacturing cost

4. Finite Element Method (FEM)

The finite element method (FEM) is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

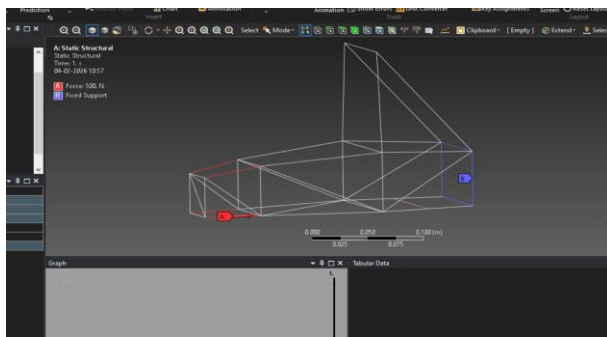
Finite Element Analysis (FEA) was conducted in ANSYS.

Analysis Types:

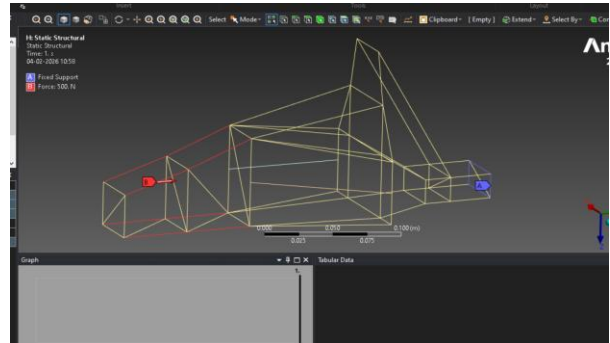
- Static Structural Analysis
- Modal Analysis

Objectives:

- Evaluate total deformation
- Evaluate stress distribution
- Compare stiffness
- Identify natural frequencies



Single structure frame



Double structure frame

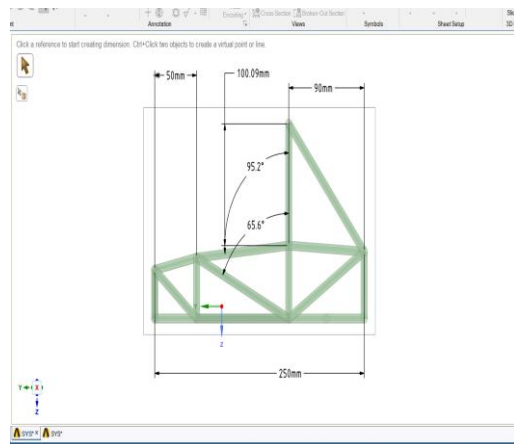
5. Geometry and Cross-Section Profiles

Three beam cross sections were analyzed:

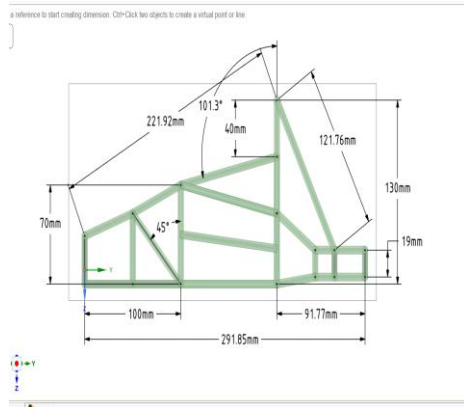
1. Circular profile
2. Rectangular profile
3. I-profile

Two configurations:

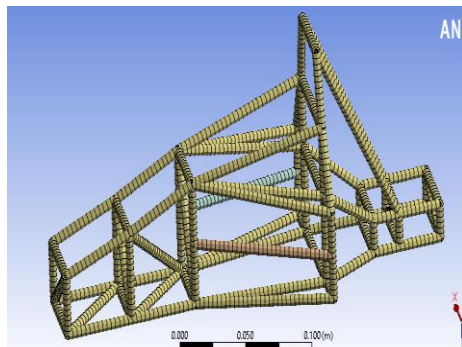
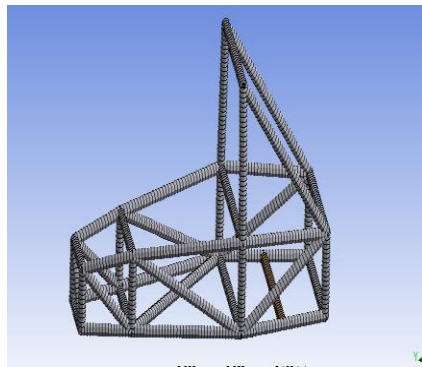
- Single frame chassis
- Double frame chassis



Geometry description

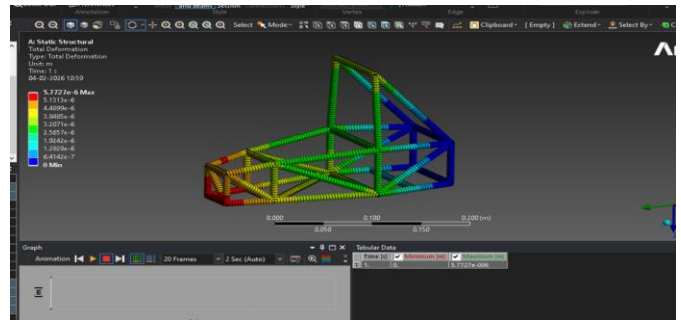


Double structure frame

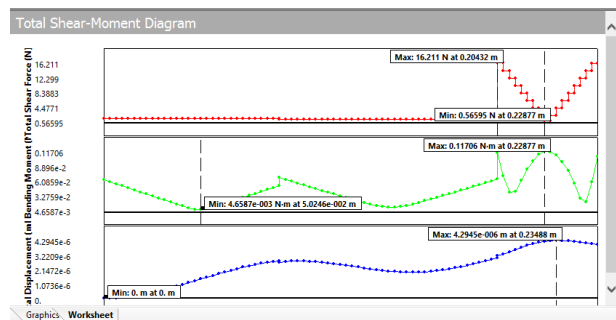


Material	Total Deformation (m)	Max Stress (Pa)
Structural Steel	5.7E-6	1.6E6
Titanium Alloy	1.2E-5	1.5E6

Steel shows lower deformation due to higher stiffness.

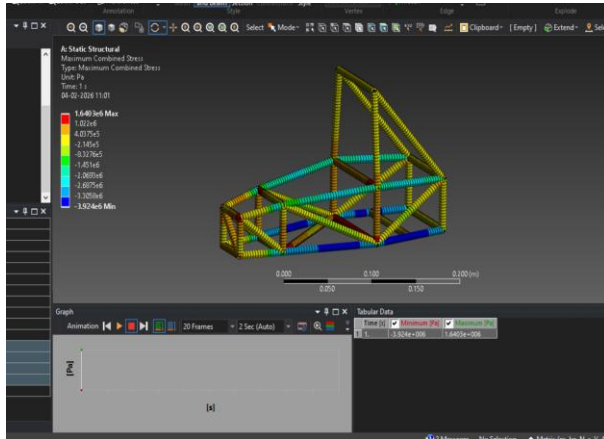


Deformation of circle profile

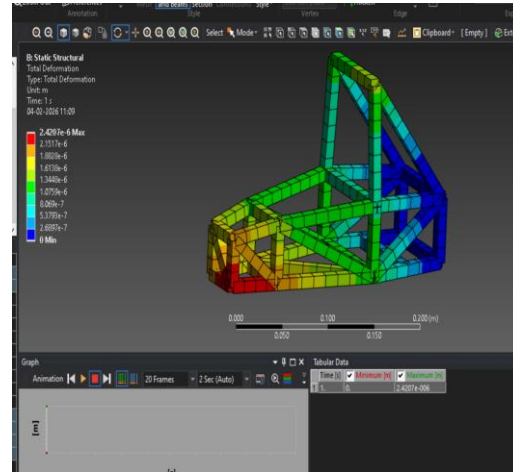


6. Static Structural Analysis Results

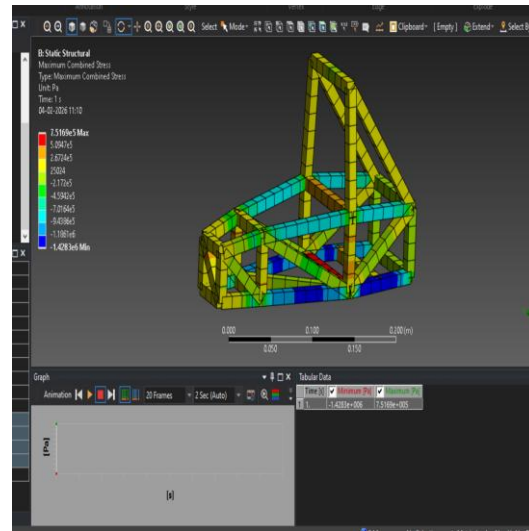
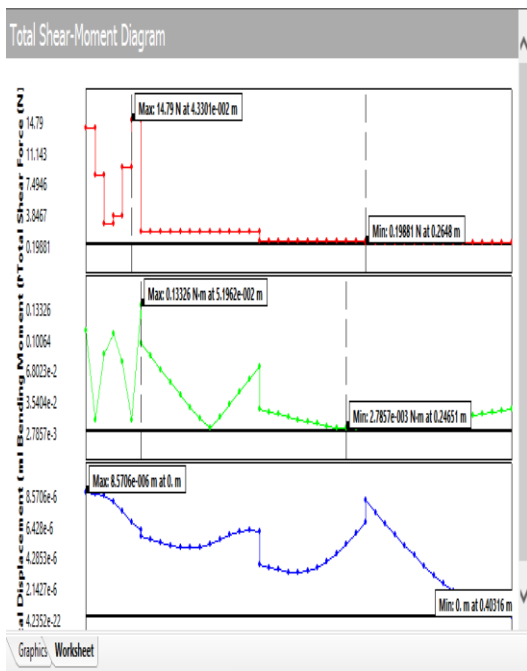
6.1 Single Frame – Circular Profile



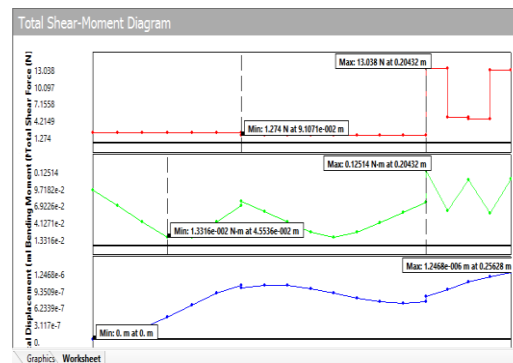
Stress of circle profile

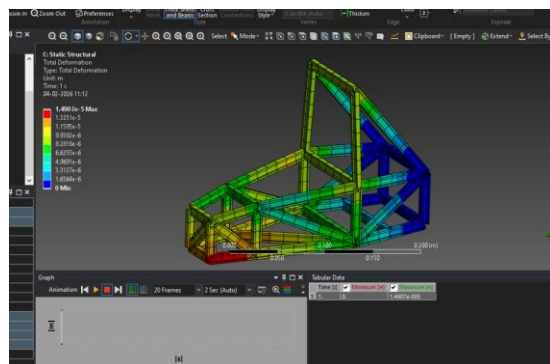


Deformation of rectangular profile

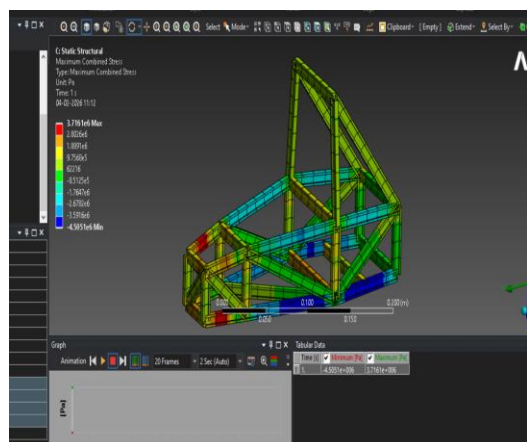
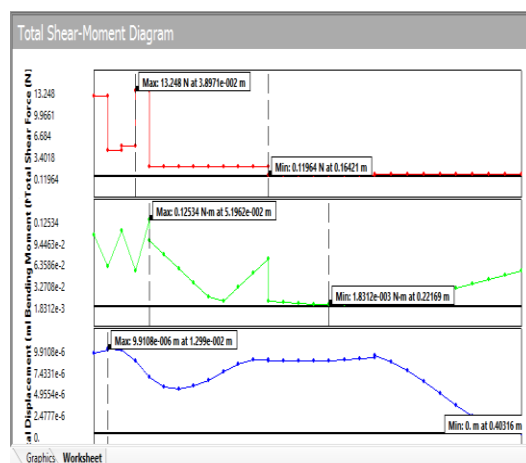


Stress of rectangular profile

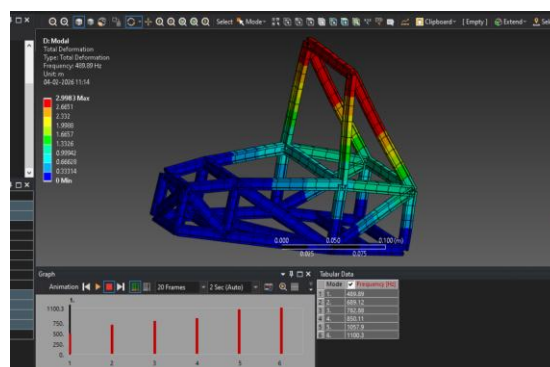




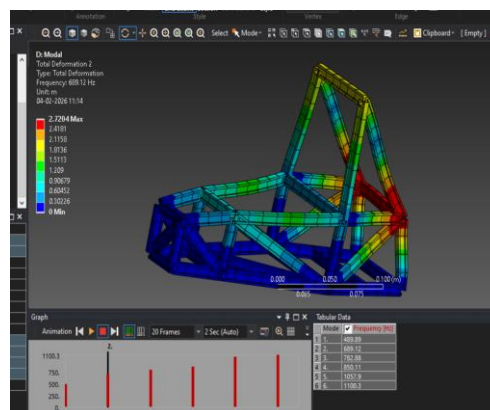
Deformation of I profile



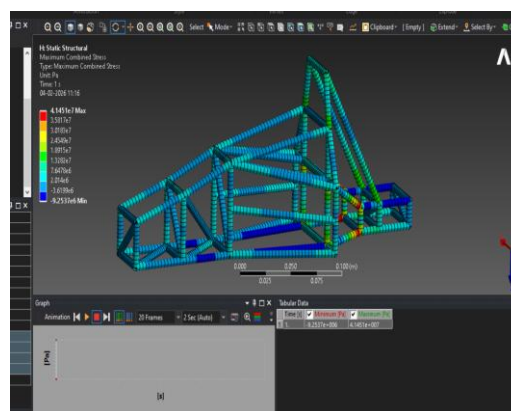
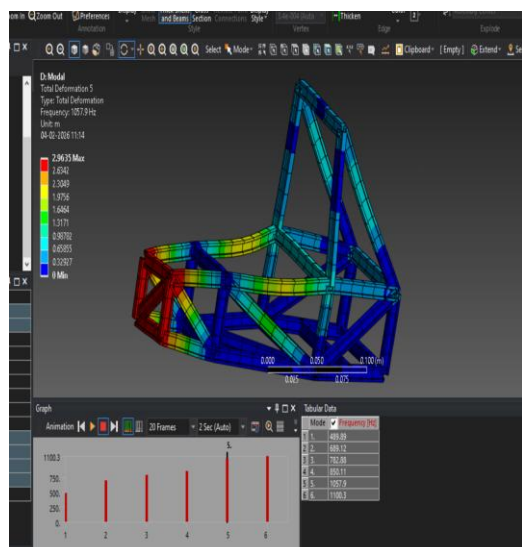
Stress of I profile



Mode shape 1

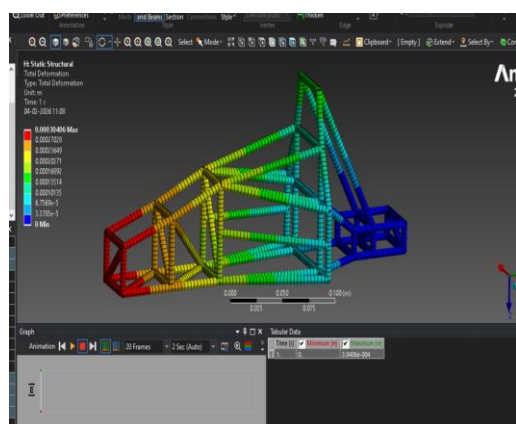


Mode shape 2

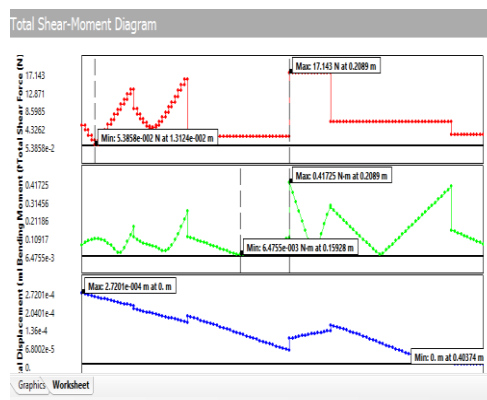


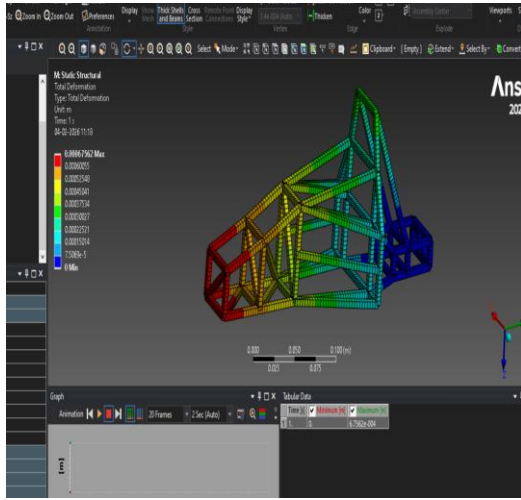
Stress of circular section

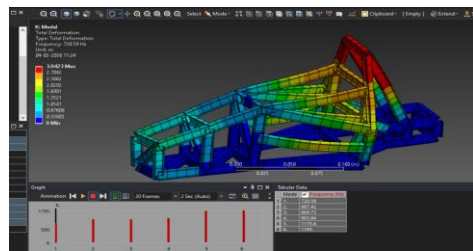
DOUBLE FRAME:



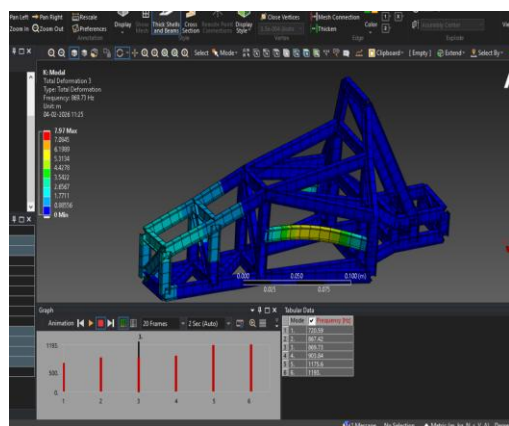
Double frame deformation



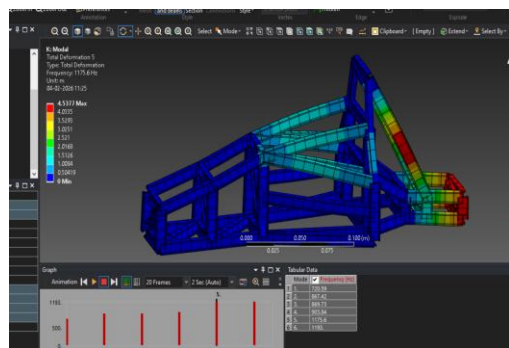




Mode shape 1



Mode shape deformation 2



Mode shape deformation 3

6.2 Single Frame – Rectangular Profile

Material	Total Deformation (m)	Max Stress (Pa)
Structural Steel	2.4E-6	7.5E5
Titanium Alloy	5E-6	7.8E5

Rectangular section shows improved stiffness compared to circular.

6.3 Single Frame – I-Profile

Material	Total Deformation (m)	Max Stress (Pa)
Structural Steel	1.5E-5	3.7E6
Titanium Alloy	3.1E-5	3.5E6

I-profile exhibits higher stress concentration in single frame.

7. Double Frame Chassis Results

7.1 Circular Profile

Material	Total (m)	Def Max (Pa)	Stress
Structural Steel	0.0003	4.1E7	
Titanium Alloy	0.0006	4.1E7	

7.2 Rectangular Profile



Material	Total (m)	Def Max (Pa)	Stress
Structural Steel	0.0003	4E7	
Titanium Alloy	0.00067	4E7	

- Worst performance: I-section (Titanium)

Double Frame Performance:

- Best stiffness: I-section (Steel)
- Lowest stress: I-section configuration

Material Comparison:

- Structural steel shows lower deformation.
- Titanium reduces weight but increases deformation.

7.3 I-Profile

Material	Total (m)	Def Max (Pa)	Stress
Structural Steel	0.0001	1.8E7	
Titanium Alloy	0.0003	1.88E7	

10. Optimization Insights

- Cross-sectional geometry significantly affects stiffness.
- I-section effective for torsion resistance.
- Rectangular section effective for bending.
- Double frame configuration enhances rigidity.
- Steel remains most practical solution.
- Titanium advantageous when weight reduction is critical.

I-section shows best stiffness performance in double frame configuration.

8. Modal Analysis

Modal analysis identifies natural frequencies and vibration modes.

Observations:

- Higher stiffness → Higher natural frequency
- Double frame configuration shows improved dynamic stability
- I-section improves torsional rigidity

9. Comparative Discussion

Single Frame Performance:

- Best deformation performance: Rectangular section (Steel)

11. Conclusion

The study demonstrates that:

1. Rectangular sections provide best stiffness in single frame.
2. I-sections perform best in double frame configuration.



- 3. Structural steel exhibits lower deformation than titanium alloy.
- 4. Double frame improves torsional rigidity.

- 5. Optimized design reduces weight while maintaining structural integrity.

For Formula Student applications, a double-frame rectangular or I-section steel chassis provides optimal stiffness-to-weight balance.

SINGLE FRAME CHASSIS

CIRCULAR PROFILE

MATERIAL	TOTAL DEF(m)	MIN.STRESS(pa)	MAX.STRESS(pa)
STRUCTURAL STEEL	5.7E-6	1.2E6	1.6E6
TITANIUM ALLOY	1.2E-5	1.2E6	1.5E6

RECTANGULAR PROFILE

MATERIAL	TOTAL DEF(m)	MIN.STRESS(pa)	MAX.STRESS(pa)
STRUCTURAL STEEL	0.0000024	5E5	7.5E5
TITANIUM ALLOY	0.000005	5E5	7.8E5

I – PROFILE

MATERIAL	TOTAL DEF(m)	MIN.STRESS(pa)	MAX.STRESS(pa)
STRUCTURAL STEEL	1.5E-5	1.3E6	3.7E6
TITANIUM ALLOY	3.1E-5	1.3E6	3.5E6

DOUBLE FRAME CHASSIS

CIRCULAR PROFILE

MATERIAL	TOTAL DEF.	MIN.STRESS	MAX.STRESS
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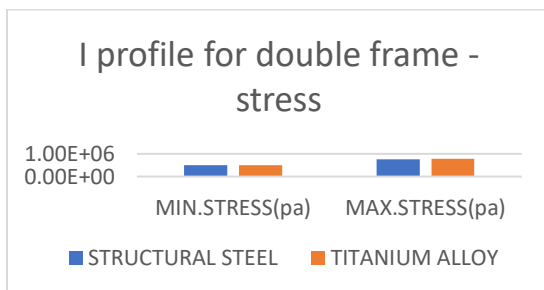
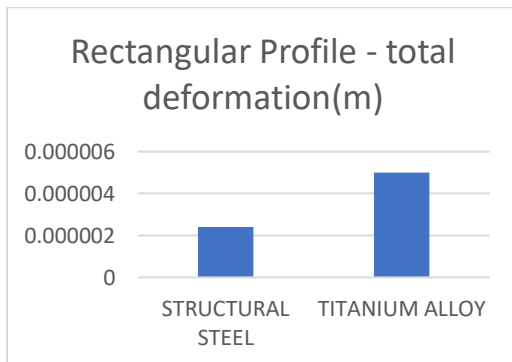
STRUCTURAL STEEL	0.0003	1.8E6	4.1E7
TITANIUM ALLOY	0.0006	1.8E6	4.1E7

RECTANGULAR PROFILE

MATERIAL	TOTAL DEF.	MIN.STRESS	MAX.STRESS
STRUCTURAL STEEL	0.0003	1.5E6	4E7
TITANIUM ALLOY	0.00067	1.5E6	4E7

I – PROFILE

MATERIAL	TOTAL DEF.	MIN.STRESS	MAX.STRESS
STRUCTURAL STEEL	0.0001	2E6	1.8E7
TITANIUM ALLOY	0.0003	2E6	1.88E7



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