Analysis of Highway Safety Barrier as FRP Material

Vishwadeep Sardar [1], Sanket Chemte[1], Krunal Dhaygude[1], Mrunal Singh[1], Prathamesh Takale[1],

Department of Mechanical Engineering, Smt. Indira Gandhi College of Engineering, Ghansoli, Maharashtra, India

---***---

Abstract - *Due to the improvement in today's world, increasing demand has been put forth regarding the safety measures in Highway Barriers along with their efficiency towards Price, Material Strengths Etc. This results in the requirement for changing the Barrier's Material considering its weight ratio. The advent of automobiles that use fewer nonrenewable energy sources, as well as sacrificing the protection of occupants due to the minimized weight of the car, is a key problem for both the vehicle sector and the government. Henceforth, a Car, Mini Bus and Bus is designed with the utilization of Solid Works 2020 software which is a tool for modelling design exploiting FRP material. The car body crash analysis is performed in ANSYS 2022 R2 deploying an ANSYS LS-DYNA module utilizing the FEM approach. We are going to Analysis with Three Vehicles a Car, a Truck and a Heavy Truck which are Specified in Different Weights, Speeds and Angles of Impact on the Barrier. along with that, we are comparing the results of the Material which is used now which is Aluminum Alloy and the FRP Material. Testing is carried out with varying speeds and the analysis of stress generated by crashing; deformation of Safety Barrier is performed.*

Key Words: **Car Crash Analysis, Explicit Dynamics, LS-DYNA, Finite Element Analysis**

1.INTRODUCTION

At present, the type of highway bridge guardrails mainly consists of steel guardrails and concrete guardrails. For concrete guardrails, the stiffness of the concrete is particularly large, and the damage to the vehicle during a collision is substantial. Besides, the weight of the concrete guardrail is excessively large, which cannot be used in large-span bridges. Although the collision performance of the steel guardrail is better than that of concrete guardrail, the service life of steel guardrail is relatively short, lasting approximately 15 years under normal weather conditions. In view of the serious environmental deterioration in recent years, particularly the occurrence of acid rain, salt fog, and other weather conditions, the service life of the steel guardrail used in bridges has become even shorter. Studies show that many steel guardrails have been seriously rusted before they reach the design service life, causing a high cost of maintenance and reinforcement. Therefore, a new type of bridge guardrail composed of new materials is necessary to be developed to innovate bridge guardrails. In recent years, the emergence of fiber-reinforced polymer (FRP) has expanded the strategies for the innovation of bridge guardrail materials. FRP is a continuous fiber composite with a resin matrix and can be divided into carbon fiber-reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP), aramid fiber-reinforced polymer (AFRP), basalt fiber-reinforced polymer (BFRP) and so on. The most significant characteristics of FRP are lightweight, high strength, strong resistance to corrosion and fatigue, and strong elastic deformation ability. At the beginning of the twenty-first century, Professor Bank and Gentry investigated the thermoplastic GFRP guardrail and found that it was superior to the traditional steel guardrail in terms of energy absorption in the bending failure process.

2. PROBLEM DEFINITION

In the current scenario of Highway Crash Barriers, the Government allows the use of Steel Alloys like Aluminum Alloy, Chromium Steel Alloy etc. Here there are two main Possibilities of how Accidents can occur:

- CASE - 1: We know that car's Speed is Nearly 60 to 80 km/h so as the car strikes the barrier will Break and the car can cross the road and strike other cars.
- CASE - 2: In Case 2 the car's Speed can give a strong impact on the barrier, that barrier will not break but the car will get damaged and the Person sitting in that car will be injured or the maximum chance is Death for that person.

3. LITERATURE REVIEW

J. Santhakumar et al. [1] [2020], made "Design and crash analysis of car body using FRP materials adopting FEM", it was published in the International Journal of Innovations in Scientific and Engineering Research (IJISER). This paper is regarding an efficient design and analysis of a car crashing is investigated and a hatchback car designed utilizing solid works 2016 software. The car body crash analysis is performed in ANSYS 16 deploying an explicit dynamic module utilizing the FEM approach. Testing is carried out with varying speeds and the analysis of stress generated by crashing, deformed car body parts as well as strain are performed.

Z. Butans et al. [4] [2016], a study on Road Safety Barriers, the Need and Influence on Road Traffic Accidents. This article views an example of a road traffic accident, which is also modelled by the PC-Crash computer program. The given example reflects a road accident mechanism in case of a car-to-barrier collision and provides information about the typical damage to the car and the barrier. This paper describes the impact of the road safety barrier type and its presence on the road traffic accident mechanism. Implementation and maintenance costs of different barrier types are viewed. This article presents a discussion on the necessity to use road safety barriers, as well as their optimal choice.

Lee, Min-Chul et al. [3] [2011], a study about Performance Analysis of Steel-FRP Composite Safety Barrier by Vehicle Crash Simulation published in the Journal of the Korean Society for Advanced Composite Structures. In this study, the performance of a steel-FRP composite bridge safety barrier was evaluated through vehicle crash simulation. Surface veil, DB and Roving fibers were used for FRP. The MAT58 material model provided by LS-DYNA software was used to model FRP material. The spot weld option was used for modelling contact between steel and FRP beam. The structural strength performance, the passenger protection performance, and the vehicle behavior after the crash were evaluated corresponding to the vehicle crash manual. As the result, A steel-FRP composite safety barrier was satisfied with the required performance.

Ali O. Atahan et al. [1] [2007], a study on Finite Element Simulation of a Strong Post W-Beam Guardrail System. In this study, an explicit three-dimensional nonlinear finite element code, LS-DYNA, is used to demonstrate the capabilities of computer simulations to supplement full-scale crash testing. After a failed crash test on a strong post guardrail system, LS-DYNA is used to simulate the system, determine the potential problems with the design, and develop an improved system that has the potential to satisfy current crash test requirements. After accurately simulating the response behaviour of the full-scale crash test, a second simulation study is performed on the system with improved details. Simulation results indicate that the system performs much better compared to the original design.

4. EXPERIMENTAL SET-UP

ANSYS is a finite element analysis software for simulating and analyzing engineering problems. In ANSYS, the experimental setup refers to the configuration of the simulation environment, including the Geometry, Materials, Meshing, Boundary Conditions, and Solver settings.

To set up an experiment in ANSYS, you typically start by creating or importing a 3D CAD model of the system you want to analyze. You can then assign material properties to each model part, define the loads and boundary conditions, and select the appropriate solver settings.

4.1 Geometry

4.1.1 W- Beam

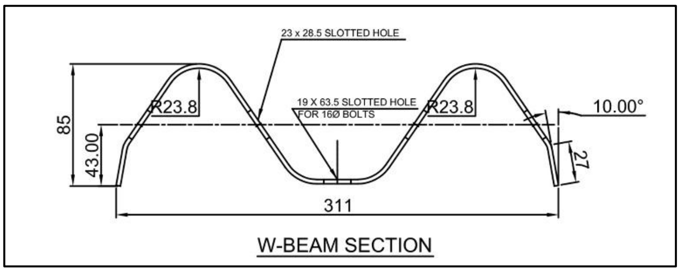

Fig -1: W-Beam Post

4.1.2 Assembly Set-up

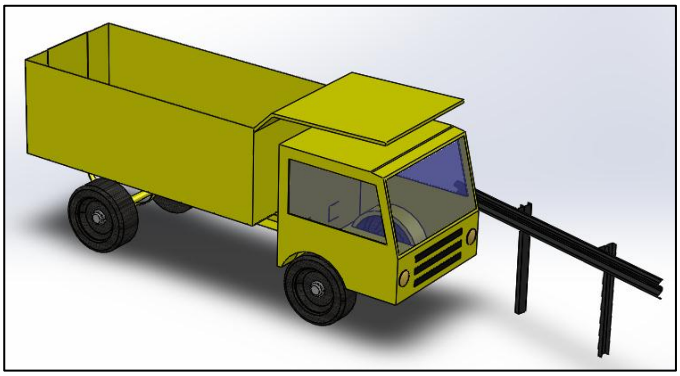

Fig -2: Assembly Set-up

4.2 Material Properties

Fiber Reinforced Plastic (FRP)	
Density (Kg/m^3)	1700
Tensile Strength (Pa)	3.7e+09
Young's Modulus (Pa)	2.5e+11
Poisson's Ratio	0.3

Table 1 – FRP Material Property

Structural Steel	
Density (Kg/m^3)	7850
Tensile Strength (Pa)	4.6e+08
Young's Modulus (Pa)	2e+11
Poisson's Ratio	0.3
Coeff. Of Thermal Expansion (1/°C)	1.2e-05

Table 2 – Structural Steel Material Property

Aluminum Alloy	
Density (Kg/m^3)	2770
Tensile Strength (Pa)	3.1e+08
Young's Modulus (Pa)	7.1e+10
Poisson's Ratio	0.33
Coeff. Of Thermal Expansion (1/°C)	-2.3e-05

Table 3 – Aluminum Alloy Material Property

4.3 Meshing

After assigning material to each and every part, we started with meshing. Meshing is nothing but dividing the given object into multiple smaller parts called elements. The finer the mesh, results will be more accurate. But then the time required for solution will be more. We took element size as 20 mm in our analysis as the mesh is finer which can see in Fig 3,

Overall, meshing is a critical step in ANSYS simulations, and careful consideration must be given to the meshing parameters and methods to obtain accurate and reliable results.

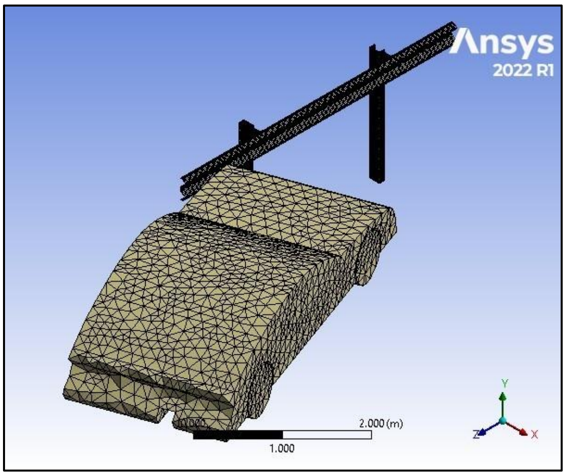

Fig 3- Body Sizing Mesh

4.4 Boundary Condition

4.4.1 Fixed Support

In ANSYS, a fixed support boundary condition is used to restrict the degree of freedom of a node or an edge in a specific direction. This condition is used when a model is fixed at a particular location, preventing it from moving or rotating in a particular direction. We apply fixed support to the Bottom of the C channel as Shown in Fig 4.

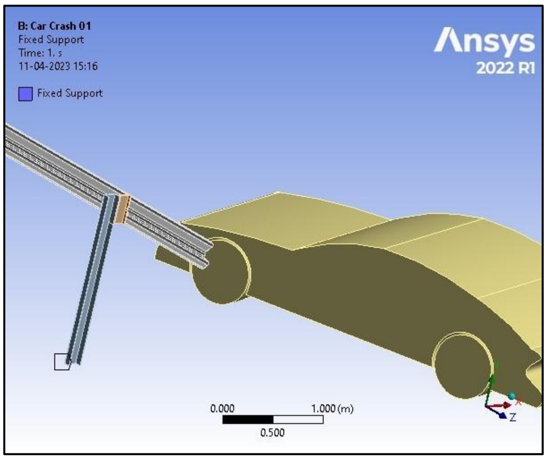

Fig 4 – Fixed Support

4.4.2 Initial Velocity

In the analysis, since it is an assembly, we used different boundary conditions in order to make a proper analysis. The task is performed in ANSYS workbench LS-Dyna module. The first boundary condition used is velocity. As per the design parameters, a velocity of 27.78 m/s is applied in the direction car. As shown in the Fig 5.

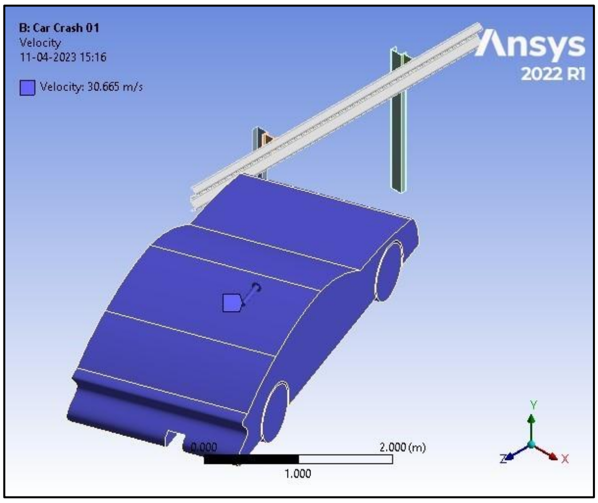

Fig 5 – Initial Velocity

4.4.3 Analysis Setting

In Ansys LS-DYNA, the analysis setting refers to the parameters and options that are defined to control the simulation behaviour and accuracy. These settings are specified through various input files and keywords, and they affect the behaviour of the solver, the accuracy of the results, and the computational performance of the simulation. We have taken the end Time of 1 Sec, Time Safety Factor 0.9 Sec and Maximum Number of Cycles of 5,00000, as shown in Table 4.

Object Name	Analysis Setting
State	Fully Defined
Step Controls	
End Time	1s
Time Step Safety Factor	0.9
Maximum Number of Cycles	500000

Table 4 – Analysis Settings

5. RESULT & DISCUSSION

5.1 Crash Test with Car

5.1.1 Barrier Material - FRP

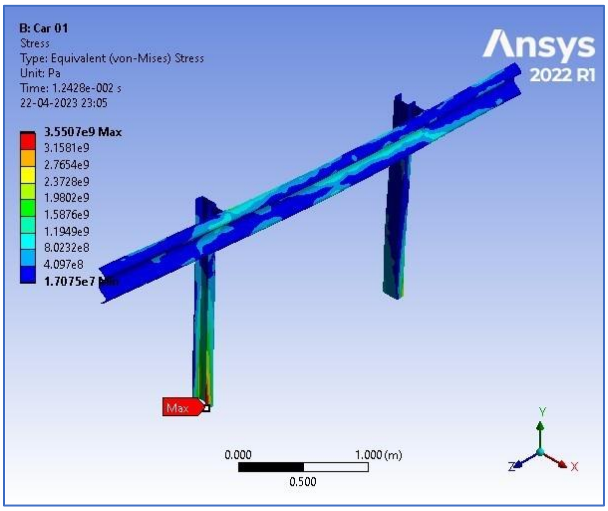

Fig 6 - Equivalent Stress of FRP Barrier

Time [sec]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
0			
1.2428e-002	1.7075e+007	3.5507e+009	4.3803e+008

Table 5 - Equivalent Stress of FRP Barrier

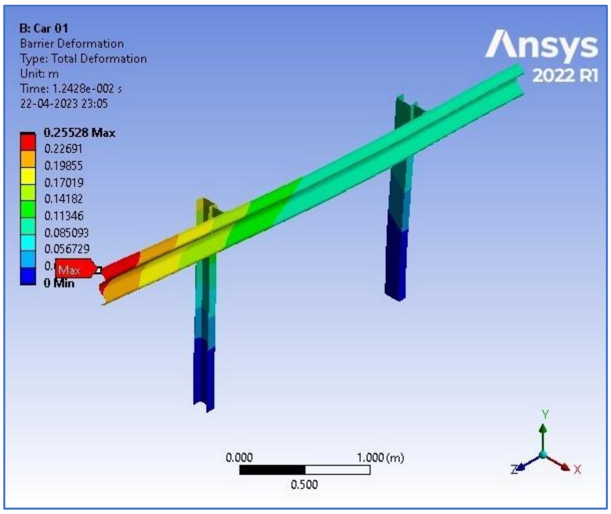

Fig 7 - Total deformation of FRP Barrier

Time [s]	Minimum [m]	Maximum [m]	Average [m]
0			
1.2428e-002	0	0.25528	0.1105

Table 6 - Total Deformation Table of FRP Barrier

5.1.2 Barrier Material - Steel

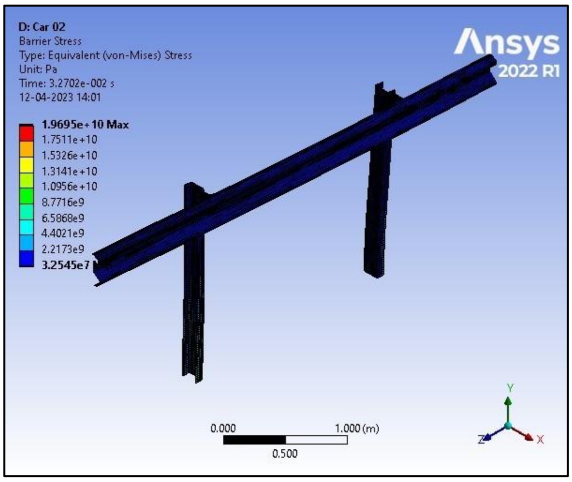

Fig 8 - Equivalent Stress of Steel Barrier

Time[s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
0			
3.2708e-002	3.2545e+007	1.9695e+010	8.4609e+008

Table 7 - Equivalent Stress Table of Steel Barrier

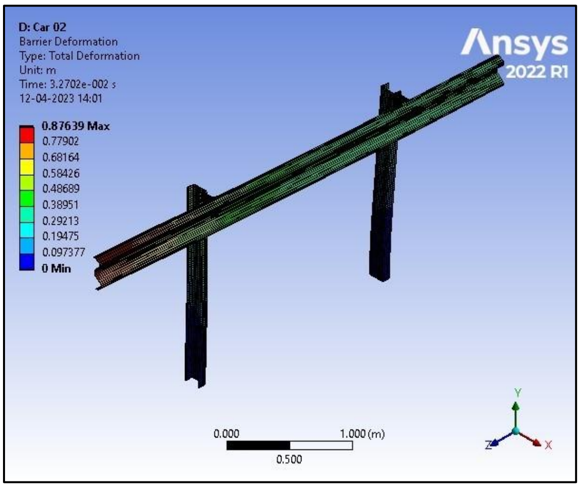

Fig 8 - Total deformation of Steel Barrier

Time[s]	Minimum [m]	Maximum [m]	Average [m]
0			
3.2702e-002	0	0.87639	0.37404

Table 8 - Total Deformation Table of Steel Barrier

5.2 Crash Test with Heavy Truck

5.2.1 Barrier Material - FRP

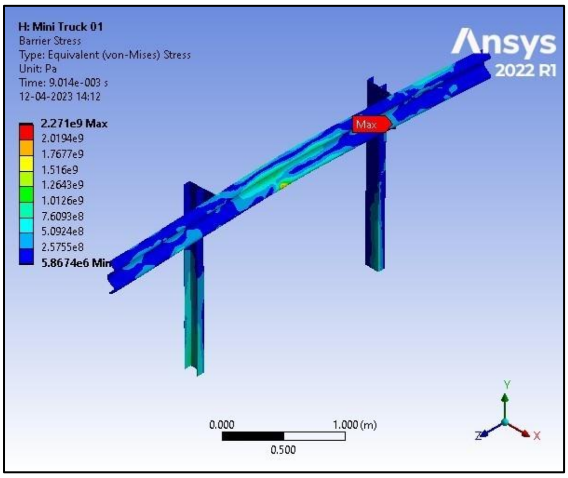

Fig 9 - Equivalent Stress of FRP Barrier

Time[s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
0			
9.014e-003	5.8674e+006	2.271e+009	2.6602e+008

Table 9 - Equivalent Stress Table of FRP Barrier

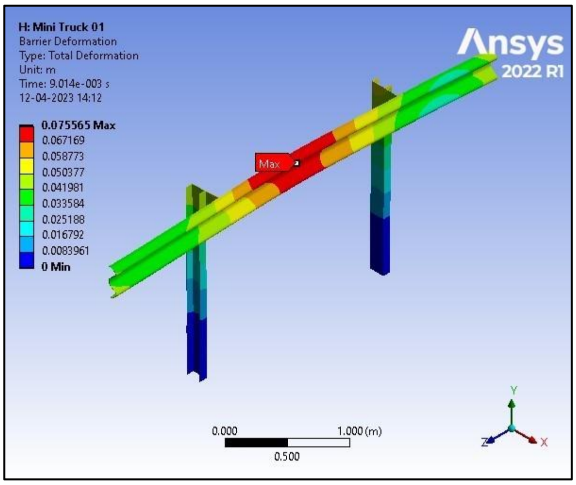

Fig 10 - Total deformation of FRP Barrier

Time[s]	Minimum[m]	Maximum [m]	Average [m]
0			
9.014e-003	0	7.5565e-002	4.1739e-002

Table 10 - Total Deformation Table of Steel Barrier

5.2.2 Barrier Material - Steel

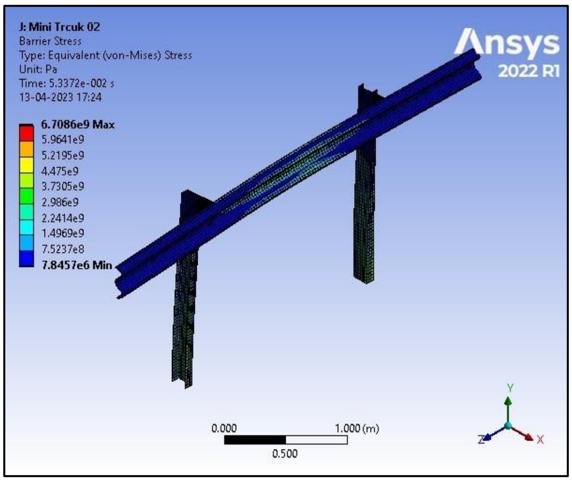

Fig 11 - Equivalent Stress of Steel Barrier

Time[s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
0			
5.e-002	37737	8.0131e+009	3.392e+008
5.3372e-002	57182	6.7086e+009	3.5074e+008

Table 11 - Equivalent Stress Table of Steel Barrier

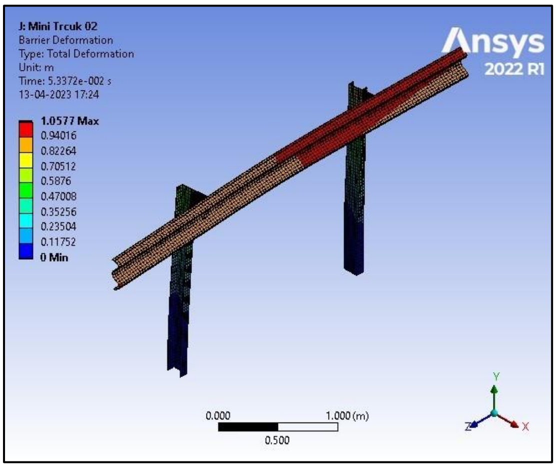

Fig 12 - Total deformation of Steel Barrier

Time[s]	Minimum[m]	Maximum[m]	Average [m]
		0	
5.e-002	0	0.98485	0.6747
5.3372e-002	0	1.0577	0.72101

Table 12 - Total Deformation Table of Steel Barrier

5.3 Crash Test with Truck

5.3.1 Barrier Material – FRP

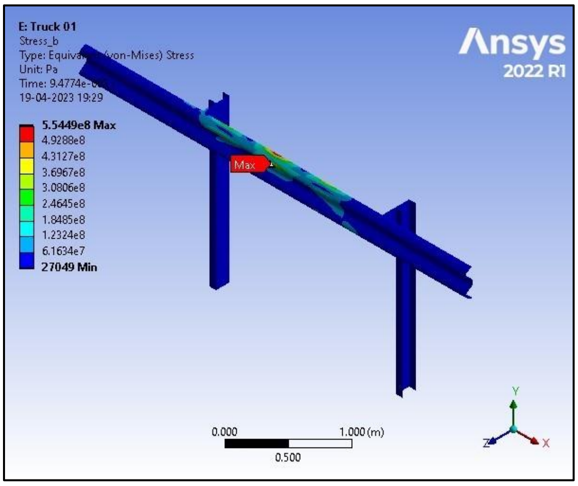

Fig 13 - Equivalent Stress of FRP Barrier

Time[s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
		0	
9.4774e-003	27049	5.5449e+008	2.8601e+007

Table 13 - Equivalent Stress Table of FRP Barrier

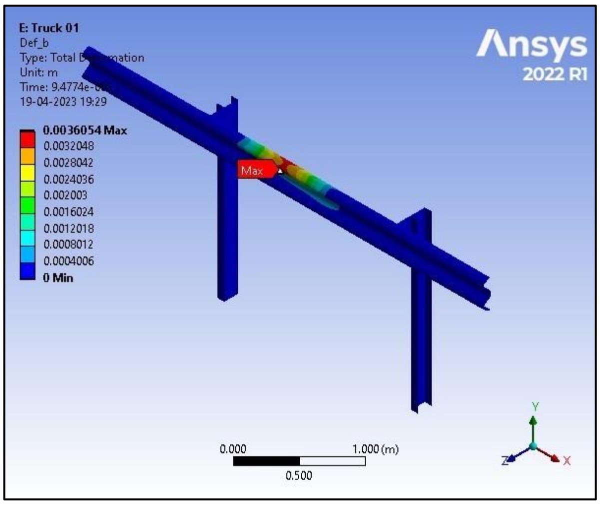

Fig 14 - Total deformation of FRP Barrier

Time[s]	Minimum [m]	Maximum [m]	Average [m]
		0	
9.4774e-003	0	3.6054e-003	1.984e-004

Table 14 - Total Deformation Table of FRP Barrier

5.3.2 Truck with Steel Barrier

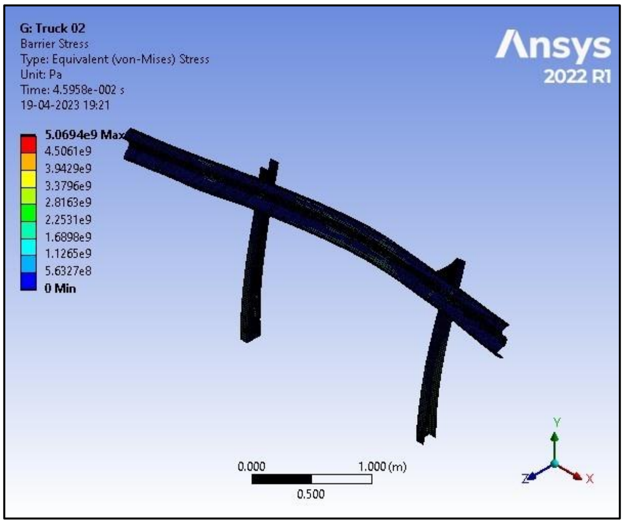

Fig 15 - Equivalent Stress of Steel Barrier

Time[s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
		0	
4.5958e-002	1.1331e+007	5.0694e+009	4.7008e+008

Table 15 - Equivalent Stress Table of Steel Barrier

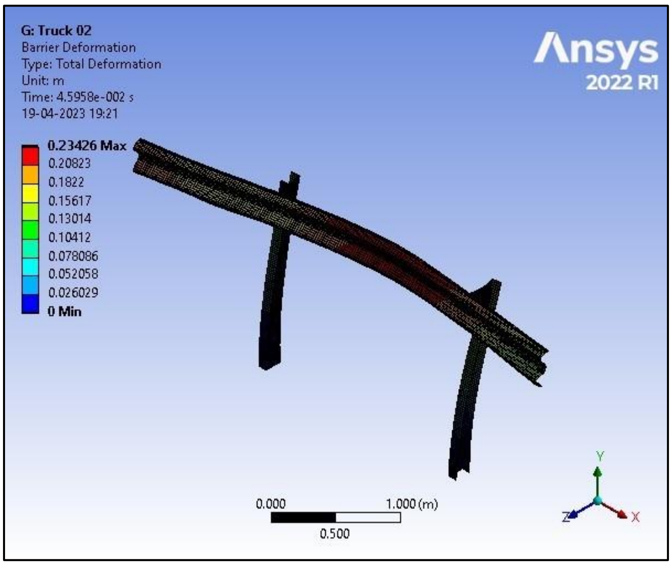

Fig 16 - Total deformation of Steel Barrier

Time[s]	Minimum [m]	Maximum [m]	Average [m]
	0		
4.5958e-002	0	0.23426	0.15324

Table 16 - Total Deformation Table of Steel Barrier

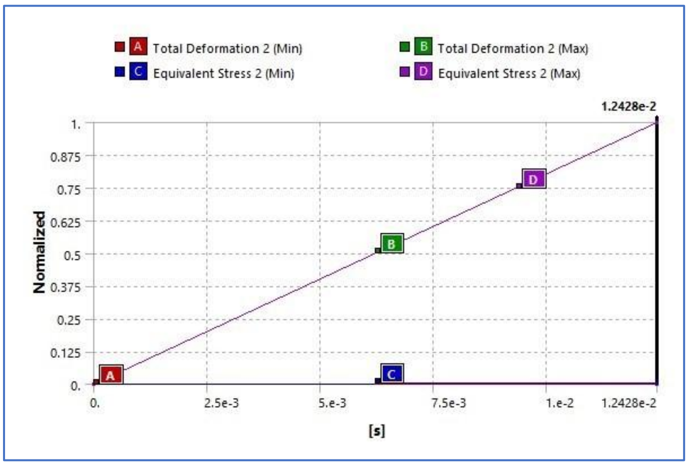

Fig 17 - Car with FRP

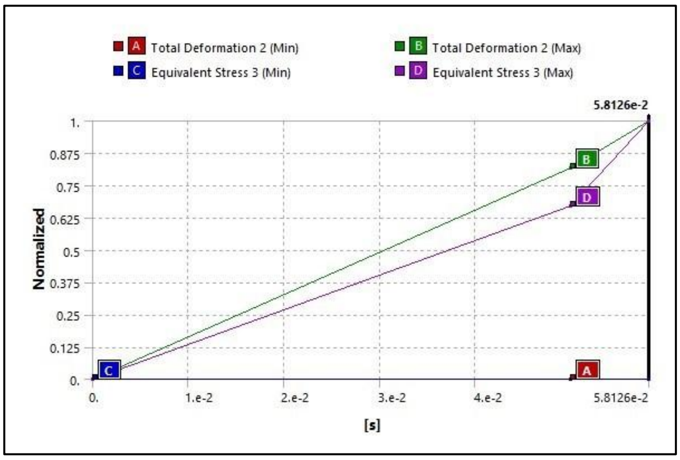

Fig 18 - Heavy Truck with Steel

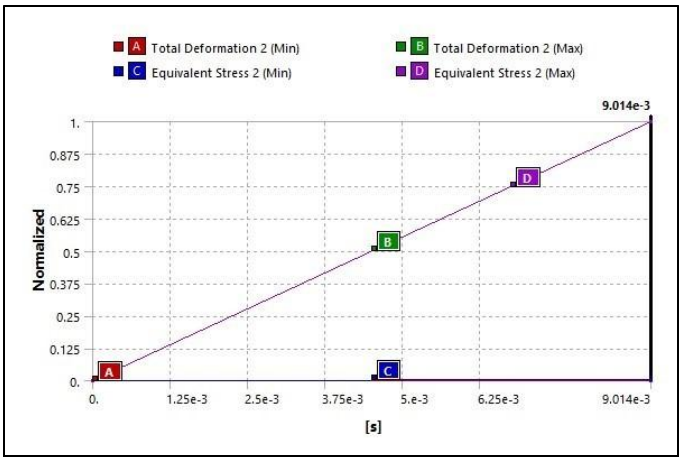

Fig 19 – Truck with FRP

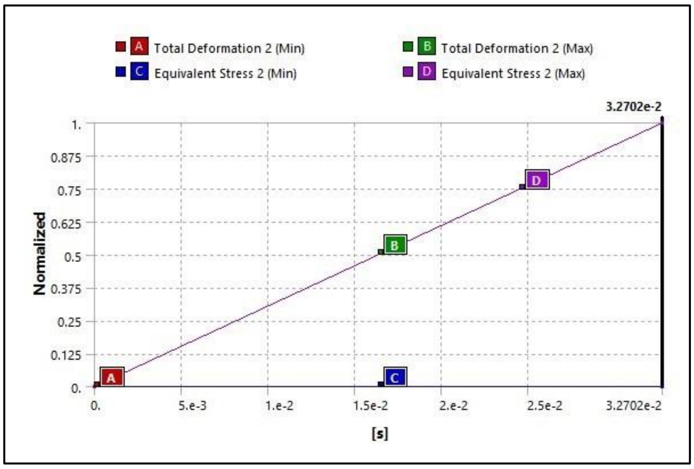

Fig 20 – Car with Steel

Fig 21 – Heavy Truck with FRP

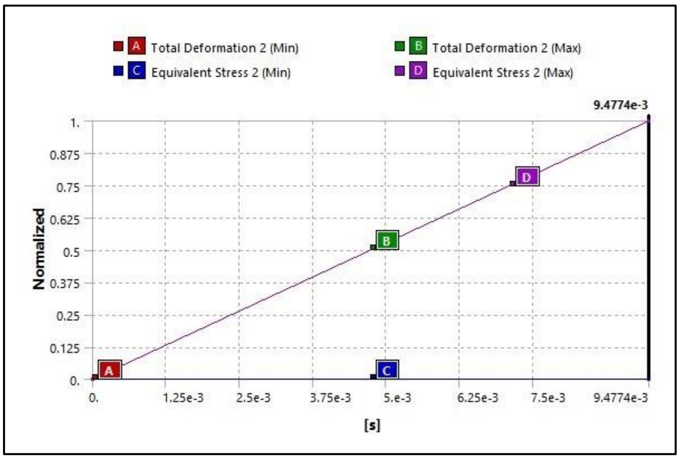

Fig 22 – Truck with Steel

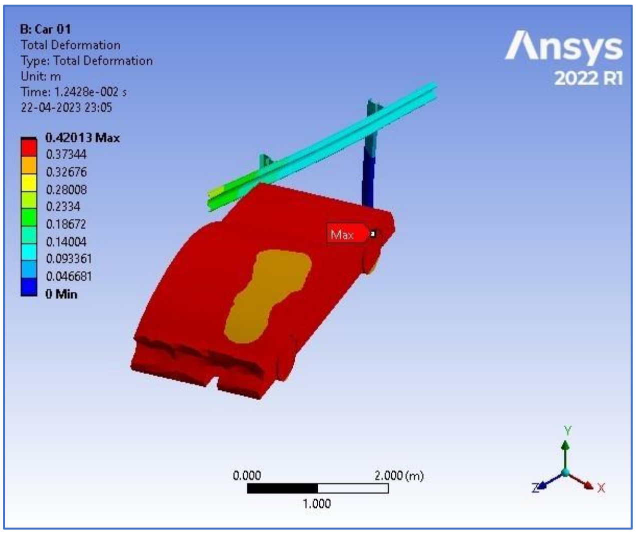

Fig 23 – Deformation of Car with FRP

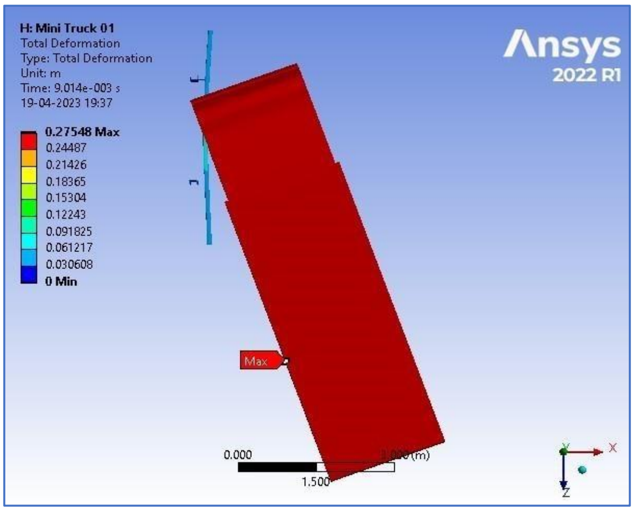

Fig 24 – Deformation of Heavy Truck with FRP

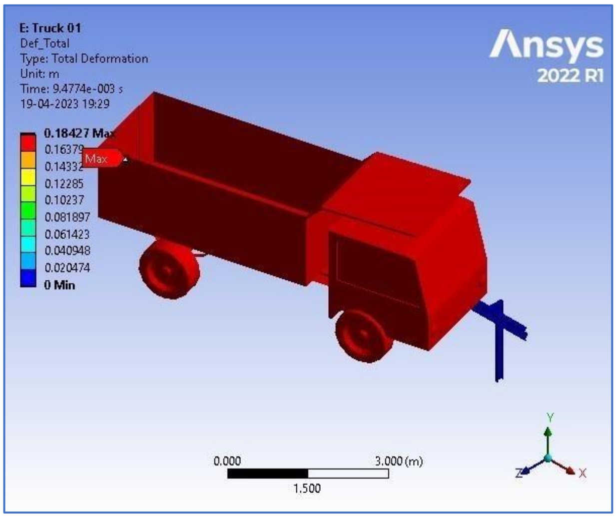

Fig 25 – Deformation of Truck with FRP

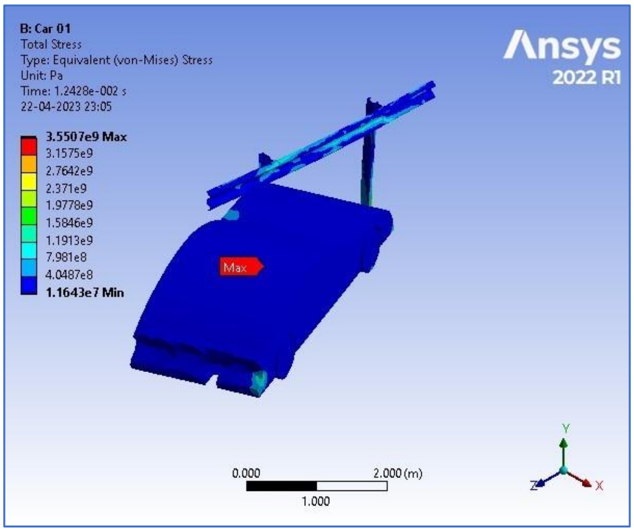

Fig 26 – Stress of Car with FRP

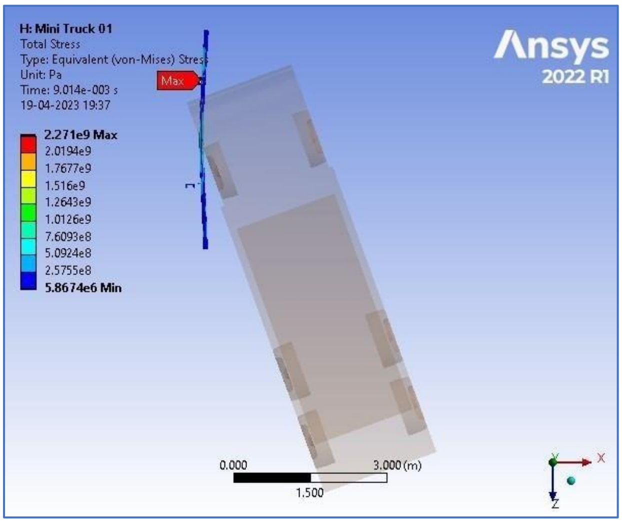

Fig 27 – Stress of Heavy Truck with FRP

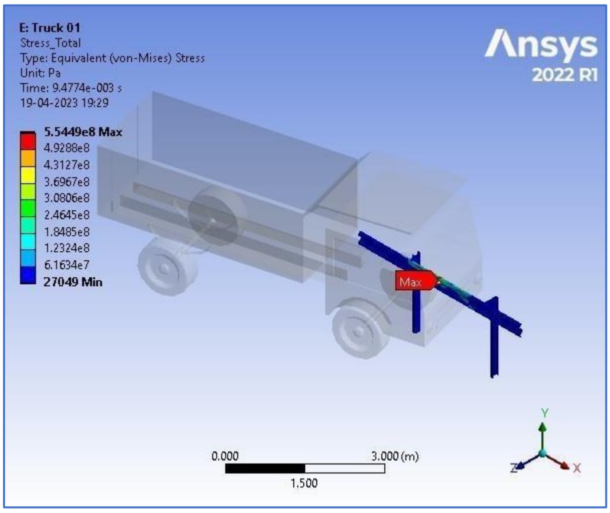

Fig 28 – Stress of Truck with FRP

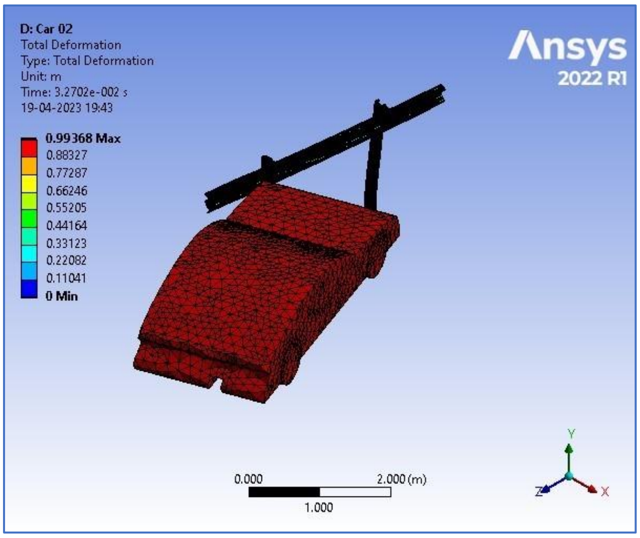

Fig 29 – Deformation of Car with Steel

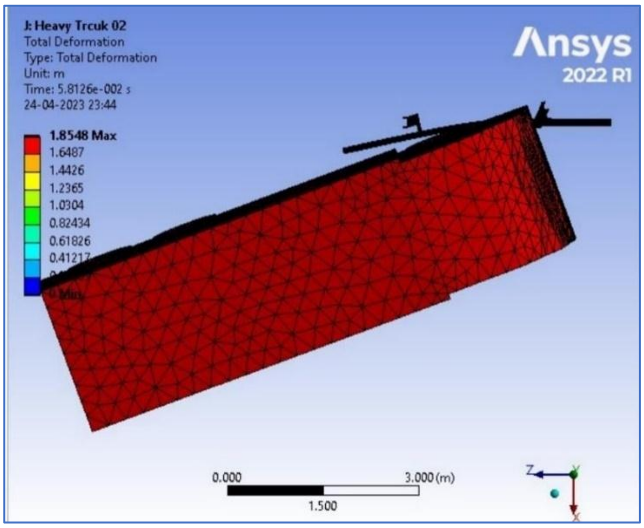

Fig 30 – Deformation of Heavy Truck with Steel

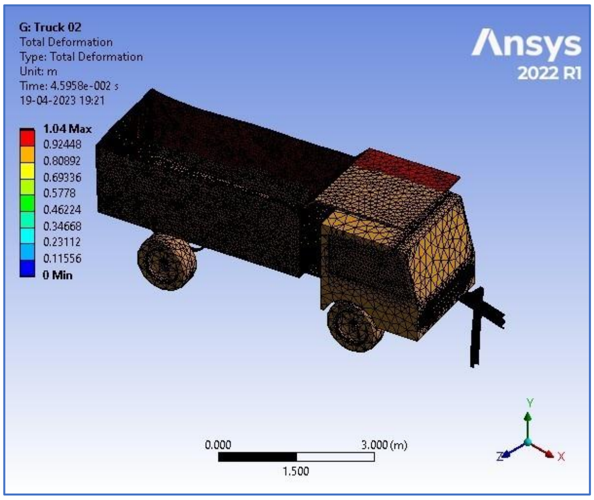

Fig 31 – Deformation of Truck with Steel

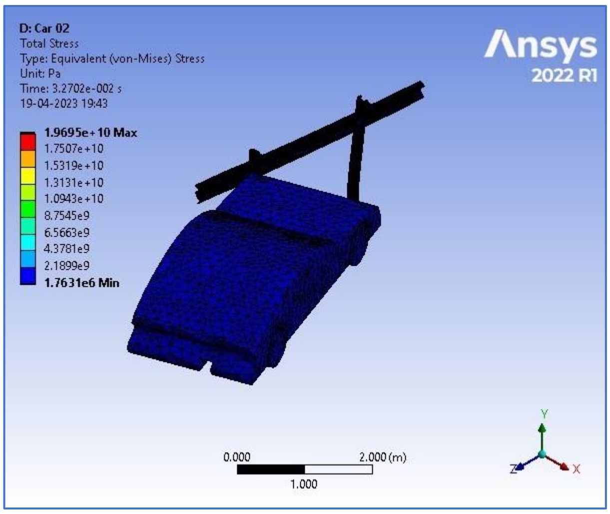

Fig 32 – Stress of Car with Steel

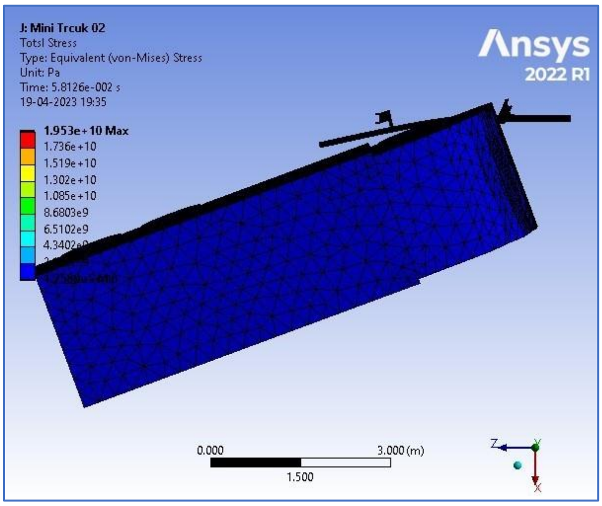

Fig 33 – Stress of Heavy Truck with Steel

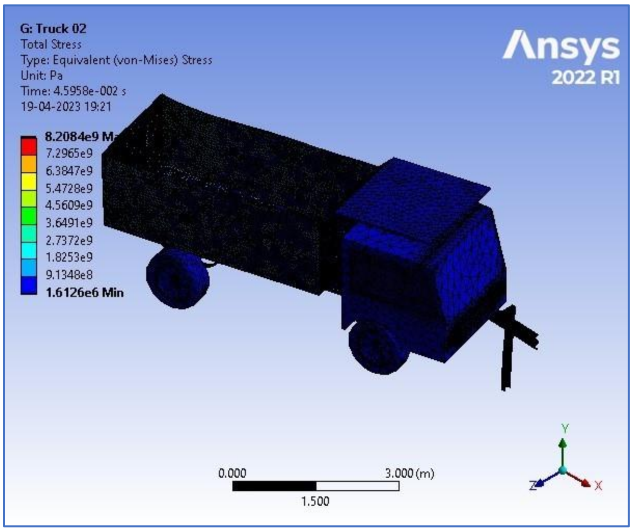

Fig 34 – Stress of Truck with Steel

5.4 Result Comparison

We are Comparing the Results of Different vehicles with Different Materials. A comparison is shown below in tabular format,

Vehicle	FRP Barrier	Steel Barrier
Car	3.5507e+009	1.9695e+010
Heavy Truck	2.271e+009	6.7086e+009
Truck	5.5449e+008	5.0694e+009

Table 17 - Comparison of Equivalent Stress [Pa]

Vehicle	FRP Barrier	Steel Barrier
Car	0.25528	0.87639
Heavy Truck	7.5565e-002	1.0577
Truck	3.6054e-003	0.23426

Table 18 - Comparison of Total Deformation [m]

6. CONCLUSION

In this project, the comparison is made of the deformation and stress generated in highway safety barriers when a car crashes into it to deduce which material is better to construct the barrier. A car, a truck, a Truck and a barrier are made in Solidworks software. The crash analysis is done in Ansys- Ls Dyna where barriers with 2 materials Fiber Reinforced Plastic (FRP) and Structural Steel are taken. All 3 models of cars are analyzed with the same velocity when the material of the barrier is FRP and steel.

1. When we use Car and apply **FRP Material** to the Barrier it is observed that at Velocity 27.78 m/s Maximum **Equivalent Stress** Developed in the Barrier is **3.5507e+009 Pa** and Maximum **Total Deformation** Developed in the Barrier is **0.25528 m.**

   When we use Car and apply **Steel Material** to the Barrier it is observed that at Velocity 27.78 m/s Maximum **Equivalent Stress** Developed in the Barrier is **1.9695e+010 Pa** and Maximum **Total Deformation** Developed in the Barrier is **0.87639 m.**

2. When we use Heavy Truck and apply **FRP Material** to the Barrier it is observed that at Velocity 30.56 m/s Maximum **Equivalent Stress** Developed in the Barrier is **2.271e+009 Pa** and Maximum **Total Deformation** Developed in the Barrier is **7.5565e-002 m.**

   When we use Heavy Truck and apply **Steel Material** to the Barrier it is observed that at Velocity 30.56 m/s Maximum **Equivalent Stress** Developed in the Barrier is **6.7086e+009** ***Pa*** and Maximum **Total Deformation** Developed in the Barrier is **1.0577 m.**

3. When we use Truck and apply **FRP Material** to the Barrier it is observed that at Velocity 19.44 m/s Maximum **Equivalent Stress** Developed in the Barrier is **5.5449e+008 Pa** and Maximum **Total Deformation** Developed in the Barrier is 3**.6054e-003 m.**

When we use Truck and apply **Steel Material** to the Barrier it is observed that at Velocity 19.44 m/s Maximum **Equivalent Stress** Developed in the Barrier is **5.0694e+009 Pa** and Maximum **Total Deformation** Developed in the Barrier is **0.23426 m**.

From the results, it is observed that the deformation and stress in the safety barrier when it is constructed with steel is more than when it is with FRP. Barriers to redirecting out of-control vehicles on the road are undergoing several improvements. So, more lives can be saved when a car crashes into barriers. FRP material is stronger and more flexible than the regular steel with which the barrier is usually constructed. Therefore, FRP material is a better pick for constructing highway safety barriers.

7. REFERENCES

- AK Steel (formerly Armco) genericized trademark
- "Guardrail". Oxford Dictionary. Archived from the original on September 7, 2014. Retrieved 7 September 2014.
- "crash barrier". Oxford Dictionaries Online. Archived from the original on December 13, 2013. Retrieved 6 September 2015.
- "Barrier Need". TxDOT RDM. 2010-05-01. Retrieved 2011-01-11.
- Roadside Design Guide. American Association of State Highway Transportation Officials. 2002. pp. 1–3.
- "Barrier Need". TxDOT RDM. 2010-05-01. Retrieved 2011-01-11.
- Roadside Design Guide. American Association of State Highway Transportation Officials. 2002. pp. 1–3.
- "Cross Sectional Elements". TxDOT RDM. 2010-05-01. Retrieved 2011-01-11.

- **Online References**
  - https://forum.ansys.com/forums/topic/ansys-ls-dyna-student-faqs/
  - https://shorturl.at/eqsxP
  - https://chat.openai.com/
  - https://www.youtube.com/watch?v=0TBjPp3zko4t=612s
  - https://shorturl.at/efiy6