Rollover analysis of complete bus super structure as per AIS031 using steel and composite material with advanced finite element method

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Abstract **-Nowadays, highway traffic safety is a very important issue over the world. Everyday a noticeable number of vehicles are facing different types of accidents. Rollover is one of the severe types of accidents. Accidents due to rollover are very frequent over the world. Rollover fatalities have become a major safety issue. Most rollover crashes occur when a vehicle runs off the road or rotate sidewise on the road by a ditch, curb, soft soil, or other objects. Besides, the forward speed as well as the sideways speed of a vehicle causes rollover that greatly increases the extent of damage to the vehicle and its occupants during rollover. Rollover accidents are also very common and frequent in India. In most of the rollover accidents of buses, its roof faces strong impact with the surface of road. However, this impact leads to collapse of bus roof causing severe injury to the occupants and extreme damage to the frame of bus. It is difficult to capture and analyze bus superstructure against these rollover experimentally. Finite Element Analysis (FEA) is an imperative tool in automotive world for virtual validation of designs during early stages of development cycle. A robust approach in numerical simulation is required to achieve the desired results as rollover performance of complete vehicle is complex in nature and depends on many parameters of design. In present study, a finite element model of complete bus was developed using established method. Survival space templates for each passenger seat as described in AIS031 regulation also incorporated in the model. Analysis setup done for rollover event with every detail given in the regulatory test procedure. Angular rotational speed of the bus & kinetic energy just before the impact were calculated through basic principles of mechanics. Similar case was simulated using composite material of bus member and compared with the baseline case. Significant improvement and weight saving was achieved in case of composite material of bus super structure.**

Index terms: **-FEA, Rollover, Bus, Safety**

I. INTRODUCTION

A passenger bus can undergo in different types of impacts at the time of accident i.e. frontal impact, lateral impact, rollover etc., out of these rollover characterizes a big threat for the passengers. Rollover is occurred when the bus, falls alongside, causing large distortions to the structure, because all the vehicle weight forces the bus members in its inner direction, causing several harms to the passengers. Therefore, the adequate structural strength of buses is extremely important.

In order to ensure the passenger safety of transit buses, AIS-031 [1] regulation is being implemented in India from October 2008, which is equivalent to ECE-R66, specifying requirement of strength of superstructure of buses during rollover. In India AIS031 is mandatory regulation for protection of passenger bus occupants in case of rollover accidents. This safety regulation imposes stringent requirements of bus body super structure strength during rollover events. Therefore, it is necessary to evaluate bus structure cage strength accurately during initial phase of design itself using numerical simulation techniques.

Based on different seating arrangements and applications, Buses usually are built in a number of variants as per customer needs. It is always difficult and expensive to test every bus variants with rollover loadings, hence advanced simulation tools like FEA (Finite Element Analysis) can be used to simplify the rollover test.

FEA is also widely used to simulate composite materials. M. P. Bendsoeet al [2] focuses on, An Analytical Model to Predict Optimal Material Properties in the Context of Optimal Structural Design. They dealt with simultaneous optimization of material and structure for minimum compliance. Linear elastic continuum material properties were used in their study. They derived different types of analytical forms for different material properties. The examination for optimization of the material leads to an abridged structural optimization problem, for which the existence of solutions can be shown and for which effective methods for computational solution can be devised.
Shao-Yun Fuet al [3] focuses on, Effects of Fiber Length and Fiber Orientation Distributions on the Tensile Strength of Short-Ffiber-Reinforced Polymers. They derived the strength of SFRP as a function of fiber length and fiber orientation distribution taking into account the dependences of the ultimate fiber strength and the critical fiber length on the inclination angle and the effect of inclination angle on the bridging stress of oblique fibers. Then they studied the effects of the mean fiber length, the most probable length (mode length), the critical fiber length, the mean fiber orientation, the most probable fiber orientation and the fiber orientation

coefficient on the tensile strength of SFRP in detail. This study helped to determine the fiber length distribution and fiber orientation distribution. A comparative study based upon the present theory and the existing experimental results proved the satisfactory findings.

This study covers the rollover detailed FE simulation and test as per AIS031. Initially detailed FE model of bus superstructure was developed with non-linear material properties of steel. A composite bus model rollover test was also performed to compare the simulation results of complete bus behavior. LS-Dyna solver was used to simulate the joint stiffness test.

II. LITERATURE REVIEW

Despite the fact that intensive investigations are carried out on this subject, due to commercial competition and consequent secrecy, few papers are available. Abe et al [4] simulated the three-dimensional behaviour of two vehicles at collision using dynamic models numerically and compared the calculated results with real vehicles' collision test data in their study. Takubo and Mizuno [5] analyzed sport utility vessel (SUV) accidents using statistics and the case study method accessing a national accident database and detailed accident investigative data. Among the case studies, one rollover accident was analyzed. The study of Parenteau et al [6] was to estimate the distribution of rollover accidents occurring in the field and to compare the vehicle kinematics in the predominant field crash modes with available laboratory tests. For this purpose, the authors analyzed US accident data to identify types and circumstances of accidents for vehicle rollovers. Eger and Kiencke [7] investigated the influence of various parameters and their variations on rollover accidents in their study in order to show that even simple models could deliver important properties of vehicle rollover. Dias and et al in [8] present a new method for predicting the rollover limit of buses, based on a theoretical model and dynamics test. These tests performed on the road under real conditions and the developed mathematical model should be able to predict a reliable rollover limit of a bus. Castejon and et al [9] exhibit a developed simulation technique for the rollover test of buses, which is applied to a new concept of lightweight bus wholly made of composites. After the rollover simulations based on this developed technique are applied to the composite bus, a prototype of the bus was built and tested.

III. METHODOLOGY:

Bus super structure made up of tubes of uniform thickness. Therefore tubes are modeled using shell elements in their middle plane. An average element length of 8mm is maintained. The chassis consists of axles, tires and suspension systems, therefore it is required to capture the mass of all subsystems on chassis accurately. The chassis controls the dynamics of during the total bus rollover. Appropriate geometrical properties and material properties assigned to the shell elements. It was ensured that modeling process for tubes and weld joints is consistent with the established joint modeling method.

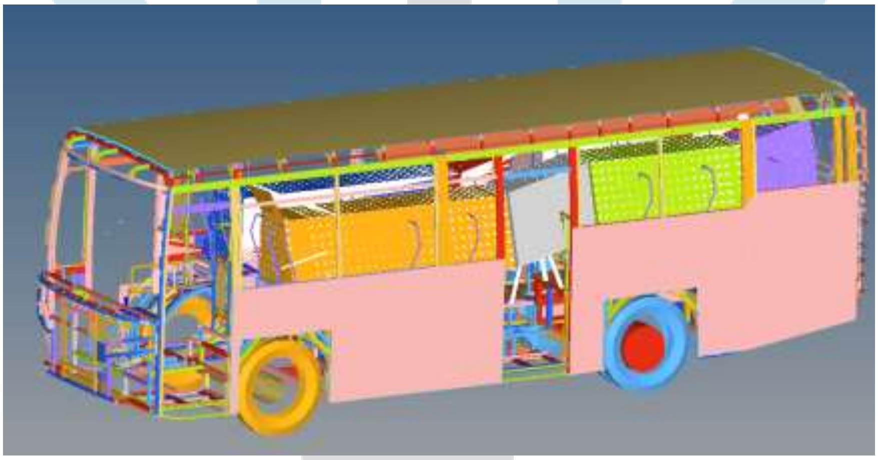


Figure 1: FE Model of complete bus structure

Figure 2 shows a Bus rollover experimental test proposed by standard AIS031 [1]. The vehicle should be elevated by a platform that rotates it with angular velocity (it should not exceed 5 degrees per second) until it rolls due to gravitational effects.

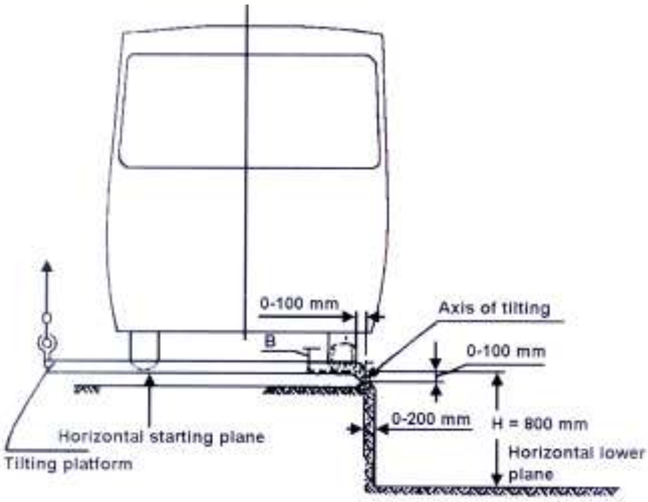


Figure 2. AIS031 standard axis of tilting

Passenger survival space requirement as defined in AIS031 standard is modeled in the bus FE model. This template has standard size and position with respect to passenger seats. Figure 6 shows relative position of survival space template surfaces with respect to seat and bus structure.

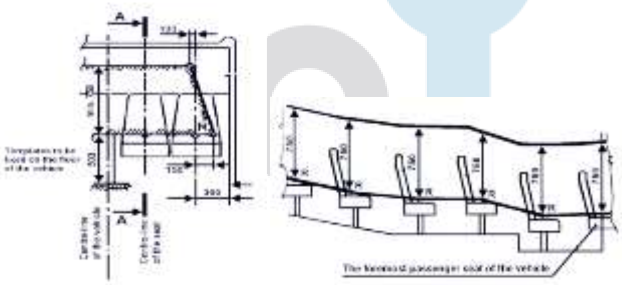


Figure 3. Survival space template

Physical bus rollover test as per AIS031 conducted by rotating complete bus through a rotating platform till it reaches up to the point where it rotates and falls by its own. This position is called angle of repose. Angular velocity can be calculated by applying law of conservation of energy.

Potential Energy at equilibrium = Kinetic energy at impact

$$Mg\,\Delta h = \frac{1}{2} I\omega^2 \qquad (1)$$

Where,

M = kreb Mass of the bus, kg

g = Gravitational constant, mm/sec2

Δh = Drop of centre of gravity from highest point till impact position

I = Moment of Inertia of bus, kg-mm4

ω = Angular velocity, rad/sec

Figure 8 shows the kinetic energy at the impact is 49 kJ.

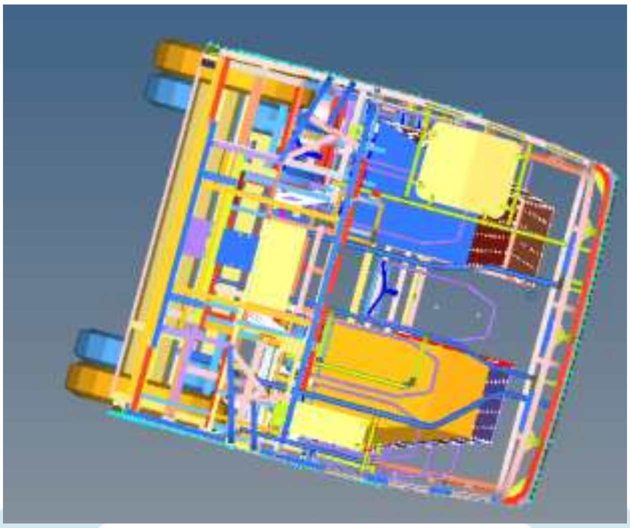


Figure4. Initial impact position of the Bus rollover model.

Hyperlaminate is an easy to use module on HyperMesh to create, review and edit material data and plies for composite laminate. In this study we will use HyperLaminate module to create orthotropic material data. When setting up composite analyses the material orientation on the elements has to be checked and where necessary to be adapted, to be able to effectively compute the desired orientation of anisotropic materials.

2D > composites > material orientation

3.1.6 Ply generation

In this step we can define the fiber assignment (angle) and the thickness for each ply of you Laminate. Further and create one by one in the model browser referring to the chart below.

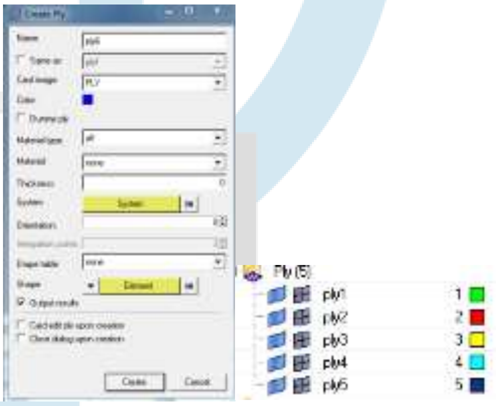


Figure5: Material card for composite plyFigure 6Fiber Reinforced Different Orientation

The created plies are stacked to form a laminate. Multiple laminates can be used based on requirement. Thin structures made of composite laminates are increasingly used in the manufacture of structural components. The enhanced strength to weight ratio makes composites especially attractive for aerospace applications. There is always demand to maximize the payload. All the problems posed in this context are constrained approximation problems with constraints on maximum transverse deflection, buckling load, failure load, natural frequency etc. It is imperative to estimate the constraint quantities accurately for an acceptable optimal design. Onset of laminate failure is an important aspect for a designer. Onset of failure in composite laminated plates requires the local stress state to be known in the structure, particularly near structural details; at interlamina interface and in the individual lamina. Accurate prediction of the local stress state becomes important for a reliable estimate of the failure load, which may be crucial for a safe design of the component.

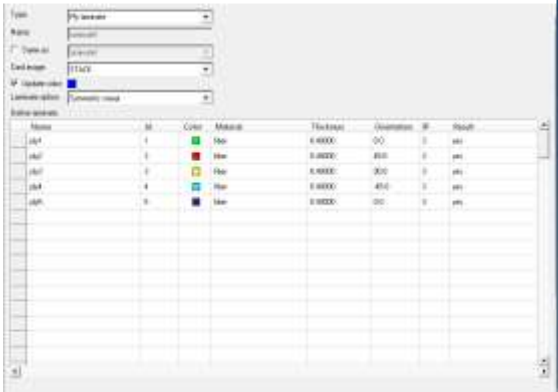



Figure 7: LaminatesFigure 8: Property creation

There are several types of properties that can be used to model a laminate. In HyperMesh we can choose between a PCOMP card (zone based, with HyperLaminate), PCOMPG card (global zone based, with HyperLaminate) and PLY/STACK/PCOMPP card (ply based, in the model browser). The main difference of the PCOMPP card in contrast to the other ones is the external information relationship. That implies that the ply definition; the stacking order; the assignment and the thickness are defined separately in other cards (PLY, STACK, and LAMINATE). So the PCOMPP card is used to create composite properties through the ply-based definition. Compared with the PCOMPP card you can define all things directly within the PCOMP/G card. A zone based laminate is divided in several parts (zones) which anon consist of several plies (one stack of plies per part). Zones are typically defined to simplify the design interpretation process and improve manufacturability but the design freedom is less extended.

A ply based composite modeling allows the user to simply focus on the physical buildup of the composite structure. Moreover it eliminates the burden associated with identifying patches (PCOMPs) of unique lay-ups, which can be especially complicated for a free-sizing generated design. Generate a new property called 'CFK prop' in the model browser by right clicking in it. Choose card image 'PCOMPP' and assign the created Carbon material.

Material Properties used

Table 1: Material properties

Mechanical properties of material used for Analysis:

GI Tube Properties

Material	Density (kg/m^3)	Young's Modulus (MPa)	Poisson Ratio	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
IS 4923	7890	210000	0.29	240	410	15

Material details:

Material	Density (g/cm^3)	Young's Modulus (MPa)	Poisson Ratio	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
MSC/LA-102-1	1.7189	9767.647	0.3	313.74	313.74	4.75
MSC/LA-102-2	1.7922	10982.949	0.3	316.15	316.15	4.54
MSC/LA-102-3	1.7455	11087.016	0.3	314.7	314.7	4.6

IV. ANALYSIS

Deformation of bus structure in case of steel tubes is showing in figure below**.** The survival space is intruding significantly in case of steel tubes. As per AIS031 the model is considered to be failed. Figure shows the deformation of bus in case of composite material. The bus is showing adequate survival space in case of composite material. Figure 11 shows the energy balance curves.

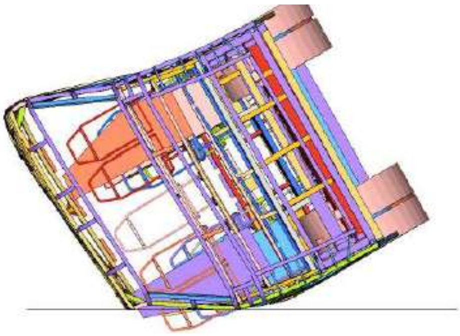


Figure9: With steel tubes

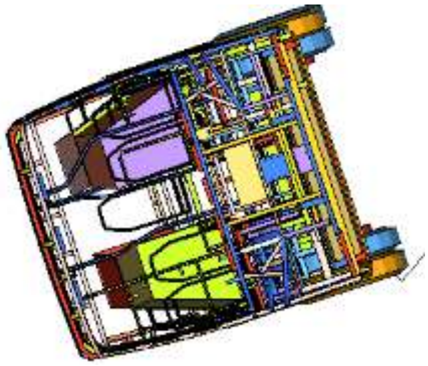


Figure10: With Composite

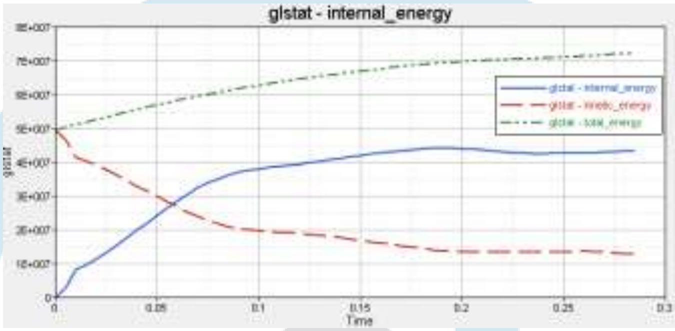
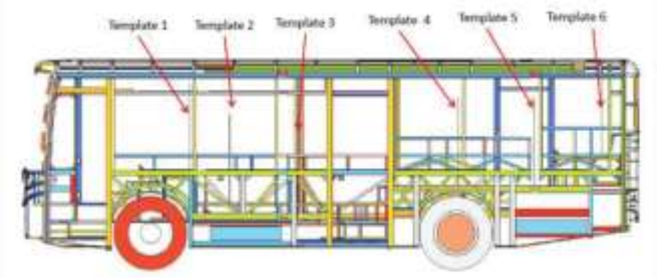


Figure 11. Energy balance graph of Co-driver side rollover.

Figure 12 shows the template locations. It also shows the survival space in case of composite material.



Template No	Clearance between superstructure & Residual Space
TEMPLATE 6	[illegible]
TEMPLATE 5	39.4
TEMPLATE 4	18.3
TEMPLATE 3	45.1
TEMPLATE 2	36.7
TEMPLATE 1	9.7

Figure 12: Template locations in bus

VRESULTS &CONCLUSION

The Overview of simulation results is clearly observed at each time steps during the analysis progress. The bus first comes into contact with the ground when the roof corner touches and hits the ground. Bus structure starts deformation and hence starts absorbing the kinetic energy by its elastic-plastic behavior. As the deformation progresses the bus main vertical tubes starts bending and thereby absorbing the major part of kinetic energy. Cant rail also plays a major role in this energy absorption process. When the waist rail touches the ground the deformation stops and the bus starts sliding as the bus completely left the tilting platform.

The deformation stops when the kinetic energy of the model is completely absorbed and converted into internal energy. The template starts bouncing in between the simulation. The composite structure behavior of structure showed more structure strength as compared to steel.

REFERENCES

[1] Automotive Industry Standard AIS031 – Automotive Vehicles – The Strength of Super Structure of Large Passenger Vehicles

[2] Bendsoe M. P., Guedes J. M., Haber R. B., Pedersen P., Taylor J. E., An Analytical Model to Predict Optimal Material Properties in the Context of Optimal Structural Design, Journal of Applied Mechanics, Volume 61, Issue 4, 1 December 1994, pp93-93.

[3] Fu S. Y., Lauke B., Effects of Fiber Length and Fiber Orientation Distributions on the Tensile Strength of Short-Ffiber-Reinforced Polymers, Composites Science and Technology, Vollume 56, Issue 10, October 1996, pp1179-1190.

[4] Abe, M., Morisawa, M., Sato, T.B., Kobayashi, K.,Three-dimensional behaviour simulation ofvehicle-to-vehicle collision by dynamic model", JSAE Review, 20:101-108 (1999).

[5] Takubo, N., Mizuno, K.,"Accident analysis ofsports utility vehicles: human factors fromstatistical analysis and case studies", JSAE Review, 21:103-108 (2000).

[6] Parenteau, C.S., Viano, D.C., Shah, M., Gopal, M.,Davies, J., Nichols, D., Broden, J., "Fieldrelevance of a suite of rollover tests to real-world crashes and injuries", Accident Analysis and Prevention, 25:103-110 (2003).

[7] Eger, R., Kiencke, U., "Modeling of rolloversequences", Control Engineering Practice,11:209-216 (2003).

[8] Diaz, V., Fernandez, M.G., Roman, J.L.S.,Ramirez, M., Garcia, A., "A new methology forpredicting the rollover limit of buses", Int. J. ofVehicle Design, 34(4):340-353 (2004).

[9] Castejon, L., Miravete, A., Cuartero, J.,"Composite bus rollover simulation and testing",Int. J. of Heavy Vehicle Systems,13(4):281–297(2006).