Rollover Analysis of Bus Body Structure as Per AIS 031/ECE R66

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Abbreviations: AIS- Automotive Indian standard, ECE- Economic Commission for Europe Regulation.

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Abstract

Bus rollover is one of the most serious types of accident as compared to other modes of bus accidents. Strengthening bus frames to maintain residual space (occupant space) and minimizing occupant injury are necessary.

This paper deals with the study of bus roll over case as per AIS 031/ECE R66 regulation conditions. The AIS 031 is equivalent to ECE R66 regulation but excluding for driver and co-driver. The ultimate aim of this study was to investigate the impact on passenger residual space as per AIS 031 regulation. As a first step, before we go for complete rollover simulation, the critical bus body joints are physically tested same is repeated by simulation approach once we have the correlating results approval is taken from ARAI. As a second step, the complete vehicle rolls over simulation was performed.

FE model of the full vehicle was comprised of first order shell elements, spring elements, mass elements (ADMAS) and Rigid Elements. An average Element edge length of 10 mm is maintained in the critical regions and 30mm in the noncritical regions. The engine, power transmission, suspension and axles were modeled by 1D element. Mass balancing was done using balancing tool in HyperCrash V11 402.

Computer simulation of the joint test was showing low load carrying capacity of joints as compare to test results which means computer simulation was showing higher deformation (lower distance b/w superstructure & residual space) as compare to physical testing. Hence simulation results are conservative compared to test, if bus passes in simulation then we have confidence that it will pass in test with more margin. During roll-over simulation, the minimum distance between superstructure & residual space was found to be 38.0 mm on driver side as per AIS 031.

The Volvo Bus was found to meet the Rollover requirement as per AIS-031.

FE modeling & model setup of the entire bus structure was carried out using HyperMesh and HyperCrash respectively. Finally, simulation was carried out using RADOISS explicit solver.

Introduction

Buses are generally believed to be very safe. A study by Pearce et al. [1] found that bus rollovers caused an average of 25 casualties per accident. Also, a rollover can cause up to five rotations to occur on the road. A “serious rollover” occurs when the vehicle flips more than two times. Lastly, a combined rollover involves two different dangers; for example, a head-on collision that leads to a rollover, or a rollover that ends with the bus in a lake. The most typical collision configurations involving buses and coaches are side, rear, frontal and rollover. Although rollover crashes are not common, the number of seriously injured occupants was high as compared to other crash types [2], however, the research and interest related on its safety seemed relatively low.

In most parts of the world, especially in Europe, safety requirements are continuously visited to improve passenger safety in buses or coaches. Since there are many seriously wounded passengers in traffic accidents of buses, more careful analysis and simulation for impact accidents should be investigated.

Albertsson et al., [3] conducted comprehensive studies on rollover crash injuries in Sweden. They investigated on 128 victims with regard to injury outcomes, mechanisms, and possible injury reduction for occupants when using a safety belt. Other studies found that, when the bus or coach rotates 90º or more, occupants would have high risks of sustaining injuries [4, 5]. In fact, Matolcsy [6] collected the statistics of over 300 rollover accidents, which showed the average casualty rate to be 25 per accident. In case of a rollover, the passengers run the risk for being exposed to ejection, partial ejection, projection, or intrusion, and are thus exposed to a high fatality risk [6, 7]. However, the most dangerous one is intrusion. Due to
large-scale structural deformations, structural parts intrude into the passenger or compress them (lack of strength of the superstructure) [6].

During a bus or coach rollover, the occupant will have a larger distance from the center of rotation as compared to that of a car occupant. For this reason, the Automotive Indian standard, Regulation No. 031 (AIS 031) titled “Resistance of the Superstructure of Oversized Vehicles for Passenger Transportation” has been in force to prevent catastrophic consequences during rollover accidents, thereby ensuring the safety of bus and coach passengers [8].

Instead of the roll-over test on a complete vehicle, at the discretion of the manufacturer, one of the following equivalent approval test methods can be chosen:

- A complete bus rollover test
- A bay section rollover test
- A numerical simulation of rollover

**Test conditions & Requirements (AIS 031/ECE R66 Regulation)**

The superstructure of the vehicle shall be of sufficient strength so that in the event of rollover it doesn’t intrude inside the Residual space. This means, the vehicle including all its structural parts, members and panels and all projecting rigid parts such as luggage racks, on-the-roof ventilation equipment, should not intrude inside the Residual space. However, bulkheads, partitions, rings or other members reinforcing the superstructure of the vehicle and fixed appliances such as bars, kitchenettes or toilets shall be ignored.

The definition of residual space is mentioned in the ECE R66/AIS 031 regulation considering SR points of front most and rearmost seats, floor and side pillar geometry Fig 1. The cross section of the residual space, perpendicular to the length is a trapezoid and it runs through the length.

![Figure 1: Residual space](image)

**Process Methodology**

Below option was selected for approval and agreed with test agency.

**Option:** Full Vehicle CAE simulation of the bus model will be carried out by Volvo and results will be reviewed by test agency. Simulation results will be supported by physical determination of C.G of the bus and testing of critical bus body joints and subsequent approval.
Geometric Model

All geometrical details were obtained from reference drawings. Geometric modeling of the bus was carried out using CATIA software. The mid-surfaces of these CAD model were extracted, since most geometrical features of the bus have been defined with thickness, to proceed for shell-meshing. Most components of the structure were ERW steel tubes of square, rectangular and hat cross-sections Fig 2.

Upon completion of the mesh generation of the complete body structure Fig 3. Masses were imposed according to a structured methodology. Firstly, a list of vehicle masses was prepared. The engine, power transmission and suspension were modeled by 1D element. The axles were modeled using rigid truss elements and the mass and inertia are imposed using the same method. The fixed masses were imposed by using mass elements. The distributed masses were imposed by changing the density of the related region.

Finite Element Modeling

FE model of the full vehicle was comprised of 1646623 first order shell elements, 7308 spring elements and 44 mass elements (ADMAS) and 481 Rigid Elements. An average Element length of 10 mm is maintained in the critical regions and for the regions under the floor (lower structure-chassis) element length up to 30 mm was used. The roof structure is meshed with 10mm fine mesh to accurately capture deformation. For all the super structure parts, QEPH formulation with 5 point integration was assigned. The model contains less than 5% Triads. The mass of Engine, power transmission and seats were added in its COG using beam & rigid elements, the mass of A/C unit, AC duct, Luggage rack, tool & battery box, side & roof hatches, doors, plywood, compressor, side mirrors, radiator were distributed close to its COG. FRP and glass are included in the model which is an important component for structural integrity. Finally after the FE model generation, mass balancing was done to bring the global COG as close as possible to the physically calculated COG. Residual space is connected to the high stiffness region on the axle which does not affect the structural strength in any manner. The axle is rigid and mass is added at appropriate locations.
Material Properties

All metallic material are Non linear and LAW36 is used for the same

Loads & Boundary condition

The model was set for both RH and LH side rollover Fig 4. Ditch is modeled as fixed rigid wall. Platform was modeled by shell elements and defined as rigid using RBODY. Platform RBODY was constrained in all degrees of freedom. $E^* = 0.75 \text{ Mgh (Nm)}$ was applied to the structure by a rotational velocity to all the parts of the vehicle. \( h \) is the vertical distance between the vehicle COG at free fall position, and the vehicle COG which is kinematically rotated up to the ground contact position.

**Formula used to calculate angular velocity:**

1. $I_{xx} (\text{offset}) = I_{xx} + mr^2$
2. $mgA\theta = \frac{1}{2}(I_{xx} (\text{offset}) \omega^2)$

Where:
- $m$ = vehicle kern mass (kg)
- $I_{xx}$ = Moment of inertia (kg mm²)
- $A\theta$ = height of the COG from unstable state to fully tilt state (mm)
- $r$ = height of the COG from unstable state to the point of rotation (mm)
- $\omega$ = Angular velocity (rad/ms²)
Results & Discussions

To check the accuracy of simulation results, it was verified whether the total energy remained constant during the simulation time period. A graph showing the various energy distributions from the rollover simulation of bus structure Fig. 5. The figure shows that energy distribution did remain constant, indicating that analysis results were accurate. It could be observed that the kinetic energy drops and transforms into internal energy (strain energy + sliding energy) over time.

![Energy Plot](image)

**Figure 5:** Energy Balance graph – LHS rollover

![Deformation states](image)

**Figure 6:** Deformation states: LHS rollover
Figure 7: Deformation states: RHS rollover

- Roll over at RH side
- Residual space after impact

Figure 8: Result summary

- Roll over at LH side
- Residual space after impact
References