Crashworthiness Analysis of Metro Cars  
(As per International Railway Standard EN 15227) 

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Abstract: 

BEML Limited is a premier rolling stock supplier of metro cars in the country and has supplied metro cars for DMRC, BMRCL and Jaipur Metro Corporation. Safety of the passengers is of prime importance and very stringent guidelines have been put up by the various international standards like EN, UIC.

Structural integrity has to be ensured up to certain speeds and beyond those speeds, the extent of deformation allowed is also specified in the standards. For the simulation of crashworthiness analysis of train sets, EN 15227 stipulates mainly two load cases, viz, 1) Head on collision of trains 2) Override condition of cars in train formation.

Energy absorbing device is one of the key safety devices provided on the vehicle. In case of collision, the energy absorber in the Buffer/Couplers absorbs desired amount of energy and protects the passenger area from further crushing.

The FE model of complete train set was built & analyzed for the load cases as per the standards. **HyperWorks 9.0 was used for modeling and LS-Dyna software was used to carry out the analysis.** **MATL68-Nonlinear plastic discrete beam, MATL70 was used for the modeling of energy absorbing device.** Energy balance curve, reaction force displacement were extracted to study the complete behavior of train set on collision. All the load cases were post processed using **Altair HyperView.**

The analysis helped BEML to verify the design for crashworthiness of the car body structure.

1. Introduction 

Metro trains have brought a phase change in public transportation in India. There have been a lot of developments among metro rail systems, since DMRC launched its metro service way back in 2002. Metro rail network is increasing with good pace in cities like Bangalore, Hyderabad, Mumbai, Jaipur etc. Millions of new commuters are getting added to this community every day and the important aspect will be the safety of commuters. Metro vehicles should be designed to ensure the safety of commuters.

Metro car designers and builders have greater responsibility to build the rail cars, which ensures safety in all types of accidents. Collision of vehicles is one such accident or mishap, which can take place anywhere/anytime and will result in lot of causalities and property loss/damage etc. In order to address these issues, international rail communities have put up very stringent guidelines through many railway standards.

2. Crashworthiness Standards for Rail-Vehicles 

Standards, which define the guideline, are EN15227 & GM/RT2100. The latest issue of GM/RT2100 refers back to again EN-15227 in its latest issue “GM/RT2100 December 2010”, under **Clause no 3.3.1 Structural crashworthiness**
Simulate to Innovate

and prevention of overriding. Therefore EN 15227 becomes master document for guidelines crashworthiness simulations/Testing for rail vehicles Therefore all the discussion brought out here are based on EN 15227.

EN-15227 classifies all rail vehicles into 4 categories. All metro vehicles are categorized based on type of vehicle, railway, interference of road traffic etc. Metro rail cars fall under category II. Load cases in this category are as below:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Simulation/Test Description as per EN15227</th>
<th>Applicability to Metro Vehicles</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>A front end impact between two identical train units</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>A front end impact with a different type of railway vehicle</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>Train unit front end impact with a large road vehicle on a level crossing</td>
<td>No</td>
<td>Dedicated infrastructure</td>
</tr>
<tr>
<td>04</td>
<td>Train unit impact into low obstacle (e.g. car on a level crossing, animal, rubbish)</td>
<td>No</td>
<td>Dedicated infrastructure</td>
</tr>
</tbody>
</table>

Table No. 1  Load cases as per EN 15227

Discussion in this technical paper is limited only to metro vehicles, i.e. collision energy, reaction force and deformation of car body. Other aspects of collision scenarios are not considered in this technical paper. EN standard stipulates for the following measures, which should be employed to provide protection of occupants in the event of collision.

i. Reduce the risk of overriding.

ii. Absorb collision energy in a controlled manner.

iii. Maintain survival space and structural integrity of the occupied areas.

iv. Limit the deceleration.

v. Reduce the risk of derailment and limit the consequences of hitting a track obstruction.

3. Active and Passive Safety systems of a Rail Car

In any rail car, two types of safety measures are adopted.

a) Active safety: The equipment, which prevent the collision occurring

   Ex: Brakes, Signaling.

b) Passive safety: Equipments which reduces the consequences of a collision

   Ex: Automatic Couplers, buffers

Following are some of the passive safety features found generally on the rail cars.

i) Anticlimber: Anticlimber, a teeth shaped bracket mounted on underframe. During collision event, the teeth gets interlocked with the teeth of another car and avoid the climbing of cars, one over another.
i) Automatic Coupler: Automatic coupler is a device which absorbs desired amount of impact energy and protects the occupant chamber.

**Working Principle of Coupler**

Both draft and buff loads are transmitted along the force flow line. The regenerative buffer converts impact energy into compressive and friction energy. It contains preloaded gaseous and hydraulic media. The preload force ensures a defined response of the buffer.

All automatic couplers will work as per force/stroke diagram. As the buffer region squeezes/compressed a certain amount of energy is absorbed. This energy absorbing phenomena continues till the max capacity of energy absorption. Once it exceeds its max limit, the overload protection device fails and the coupler unit slides into the underframe. Typical force/stroke diagram of an automatic coupler is shown in fig no. 5.

In the event of a heavy impact, the impact energy is reduced and partially stored by over flowing and compressing the media. The friction spring converts energy into friction energy through a package of spring washers arranged alternately and pre-stressed with a defined force. The pre-load force ensures a defined response of the friction spring. In case of high loads, the spring washers slide into each other. The wedge shaped edges of the rings
produce very high friction energy. Due to the friction energy the impact energy is reduced and energy is stored due
to the deformation of the spring washers. After the impact, the spring washer return to their initial position due to the
stored spring energy and the coupler shank is ready to operate again.

iii) Collision Post: Collision post is structural members of end-structure assembly of rail vehicle. These helps in
avoiding the tubing/telescoping of the cars one into another. Collision post extends from underframe to roof.

These elements of safety contribute a greater safety for the passengers/commuters and helps in efficient crash
energy management i.e. controlled dissipation of energy during a collision and to protect the passenger area.

4. Carbody Structure:
Carbody structure is a monocoque shell with major assemblies like. Underfame, Sidewall, Roof, Endwall /Cab
structure. Different steel variants and carbon steels are used to fabricate the structure. Typical 4-car unit has been
considered in this study.

5. FEM Simulation
Finite element model of DT-Car (Driving Trailer) and M-car (Motor car) are shown below.
The crash simulation of the metro car train set (4 car units) has been carried out using explicit FEA technique. The FE model is built using shell, solid, beam and mass elements. Each car is connected to other car using coupler. Connections have been modeled using appropriate 1D element. Total train set model consists of around 1.68 million elements. Model consists of 4 cars (2 DT cars, 2 Motor Cars).

Coupler is modeled using beam elements. A strict quality criterion was followed to develop the model. The coupler with draftgear works according to force-stroke diagram as provided by the supplier. As the Carbody is symmetrical, half model is considered for the analysis. Material properties of stainless steel of different grades and carbon steels have been used.

The FE model is built using HyperMesh and LS-Dyna is used as solver. HyperMesh interface for LS-Dyna has almost all features to build good FE model for LS-Dyna. Sanity runs were carried out to ensure the quality of the model. The total Kinetic energy of half train is 0.5 MJ. Crash energy management equipments (CEM) help to dissipate this energy in a controlled way.

6. **Load cases and Boundary Conditions:**

The vehicle speed recommended for crash analysis as per EN 15227 is 25 kmph.

<table>
<thead>
<tr>
<th>Design Collision scenario</th>
<th>Collision obstacle</th>
<th>operational characteristics of requirements</th>
<th>Collision speed-km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>C-I</td>
</tr>
<tr>
<td>1</td>
<td>Identical train unit</td>
<td>All systems</td>
<td>36</td>
</tr>
</tbody>
</table>

Table No. 2- Excerpt from EN 15227-Velocity Details

The following load cases were considered based on EN standard 15227.

6.1. **Head on collision with identical unit with an approaching speed of 25 kmph.**

In this load case, train is made to collide with a rigid wall at an approaching speed of 25 kmph. Since the rigid wall does not absorb any energy, it results in a condition of head-on collision of 2 trains. This satisfies the first condition as per EN 15227.
6.2. Override protection with an approaching speed of 25kmph.

This particular load case is about colliding 2 identical units with a vertical offset of any one vehicle. This offset value is 40 mm as per EN15227. In this case, one vehicle is stationery and other is moving with a speed of 25 kmph. Anti climber provided at the extremities of train unit resists the overriding of the vehicle by interlocking. Rigid wall is placed 40mm above the level of stationery train unit and this arrangement meets requirement for simulation of overriding condition as per EN standard.
7. **Train operator safety:**

EN standard 15227 requires train operator seat clearance as shown below.

It is observed from the analysis that a clearance of more than 300 mm exists after the collision of carbody at speed of 25 kmph (approaching speed).

8. **Conclusion:**

Crashworthiness analysis revealed that the carbody structure has deformed in a progressive manner and energy absorption is also in a controlled way. Both cases, Head on collision and overriding collision are carried out successfully as per EN standard 15227.

In this study FEA technique is used effectively to assess the crashworthiness of metro car as the physical test of crashworthiness is highly expensive. FEA has been used to instill the confidence in the design process of metro carbody structures.

**References:**


[4] Development of crashworthy railway passenger cars, RITES Limited, Gurgaon, India

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