

CRASHWORTHINESS DESIGN OF ANSALDOBREDA LIGHT METRO VEHICLE

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ABSTRACT - The latest revisions of prEN15227 introduced new strong requirements related to the lifting of the axles mounted on the bogies of the impacting vehicles. This work describes the methodology applied by AnsaldoBreda to demonstrate the compliance of its new Light Metro Vehicle to all the prescriptions stated in prEN15227. Starting from the main idea of the train configuration, the passages needed to define the final layout of the adopted energy absorption devices have been illustrated. The whole model has been realized with BETA CAE Systems' ANSA and consists of a FEM description of the vehicle VS vehicle crash scenario, with initial vertical offset. The models of the leading cars, belonging to the two impacting metro units, embody the sacrificial crumple elements, the automatic coupler and the bogies. Due to the fundamental role covered by the bogies, both in the dynamic behaviour of the vehicle and in the analysis of the vertical movements of the axles, a special attention has been dedicated to the development of their models. The whole final model consists of about 1400000 elements, the simulations have been performed with LSTC LS-Dyna X64 solver and the post processing of results has been carried out with LSTC LS-Post and BETA CAE Systems' μETA PostProcessor.

TECHNICAL PAPER -

1. INTRODUCTION

A modern rolling stock must not only fulfil the traditional static load and fatigue requirements, but also the passive safety requirements. These crashworthiness requirements must be considered in the design of the coach structural part of the vehicle.

Sophisticated crashworthiness analysis are today a regular step in the engineering process of developing a new train, AnsaldoBreda has employed the explicit finite element to perform crashworthiness analysis for about ten years.

Vehicle crash is a dynamic phenomenon featuring a complex interaction between structural and inertial behaviour. It is generally recognised that in a typical collision the end structure first experiences the impact and only successively it may undergo some deformation in the impact region itself. The passengers experience later the effect of the impact. The first phenomenon is normally referred to as primary collision and the second type of events, related to the passengers, are normally referred to as secondary collision.

Due to geometrical complexities of rail vehicle structures and to the complicated behaviour of the materials when involved in large plastic deformation, finite element computer programs with elastic-plastic dynamic analysis capabilities have to be used.

The structures in the front end of the first car are located in the impact region thus they should deform so as to dissipate a large amount of crash energy through plastic deformation of its part. The axial load carrying capabilities and force-deflection curves for the end structure parts are also obtained by the use of a finite element code considering both geometrical's and material's non-linearities.

The crashworthiness behaviour in a crash event of the Thessaloniki Automatic Driverless Light Metro has been analysed by means of a Finite Element Model (FEM). This document explains the methodology used to achieve, on the various components of the metro unit, the desired results in terms of forces, energies and deformation patterns, in compliance to the crash safety requirements stated on the Technical Specification of Thessaloniki Metro (1) and on prEN 15227 (2).

Since the front ends of the leading motorcars undergo the very first impact, energy absorption devices have been placed directly on the train's fronts. These structures, which serve as energy absorbers, are the result of many calculations and experiences coming from earlier projects.

The Light Metro unit will have a maximum speed of 80 km/h, it consists of four cars arranged as follows: two end cars with cabin and two intermediate, supported by four motor bogies and one, in central position, trailer bogie.

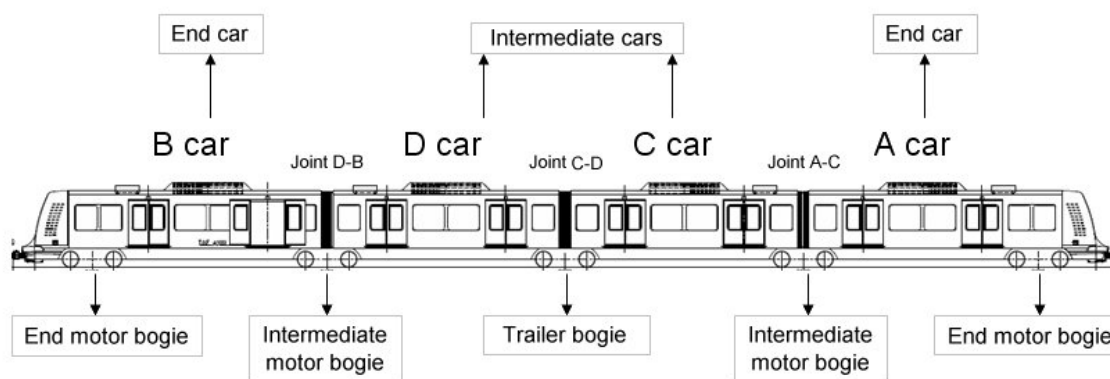


Figure 1 - Metro unit's layout

For the simulation the entire A motorcar has been modelled as deformable 1D, 2D and 3D elements, while the remaining cars have been simulated by means of lumped masses connected by springs of suitable stiffness; the connection between cars is obtained by the use of a rigid spherical joint whose upper and lower sides are mounted on the adjacent cars' ending beam.

The main conditions that shall be applied for the crash scenario object of this study are as follows:

- Frontal collision with initial vertical offset, between the two units, of 40 mm
- Straight track
- Relative speed of 25 km/h
- Two identical metro units impacting
- Considering the contribution, in term of masses, supplied by all seated passengers

Undergoing all the conditions written above, the cabin and the carbody of the cars belonging to the impacting metro units shall not be deformed.

1.1 DESCRIPTION OF THE MODEL

The FEM models have been prepared using the ANSA pre-processor by BETA CAE Systems, starting from the 3D CAD drawings. The whole model consists of about 1400000 elements of which more than 1,000,000 are deformable. To run such an analysis the LS-Dyna explicit code by LSTC has been used. This solves the dynamic equations of motion with a suitable numerical integration procedure and is able to perform a stress/strain analysis by taking into account the strain rate effects and the materials' failures and non-linearities. The analysis results provide information about force-time contact curves, decelerations, energies' levels. Moreover they give a qualitative evaluation of the collapse path of the sacrificial structures and of the dynamic and cinematic behaviour of the whole vehicle.

Considering the accuracy of the model, the articulated bogies which are not symmetrical and the expected not fully symmetrical and/or synchronized deformations between the left and right sides of the vehicles, it was impossible, to reduce calculation times, to perform the simulation using the symmetry along the entire vehicles. The size of the mesh has been chosen in agreement with the small or large deformations expected on the various elements. This means that the areas undergoing large deformations have a finer mesh than those ones where small or negligible deformations are expected. The deformable shell elements' side lengths are in the range between 5 and 30 mm.

The numerical model of the entire metro unit is composed by a certain number of subsets, of which the main are: the coupler, the energy absorbers, the bogies, the cabin and the carbody. FEM model is composed of:

- The leading's car carbodies
- The leading's car cabins
- The absorbers mounted on leading cars
- The automatic couplers mounted on leading cars
- The motor bogies
- The rail
- A series of beam elements with appropriate stiffness that play the role of the remaining train rake of each unit

The carbodies are light structures made of welded aluminium alloy's extrusions. The intermediate cars are symmetrical, while the ending cars have a front end designed to allow the mounting and the fastening of the cabin.

The cabin is a complex frame of high resistance steel tubes and plates. The cabin, in the chain of the transmission of the impacting loads, is the first structure that should not deform, due to that a lot of time was spent for its design and its optimization.

The automatic coupler can absorb energy thanks both to a regenerative device and to a not-regenerative device. Usually the regenerative device absorbs energy depending on the impacting speed: the more its characteristic curve becomes rigid the more the impacted speed grows. Consequently it is preferable not to take into account that element in the simulations of crash, because in real conditions, its contribution is very small in comparison to the levels of energy absorption.

The front couplers' heads are made of shell elements, that schematization was needed in order to simulate the contact one against the other. The draft gears, instead, have been simulated with beam elements, whose characteristic curves "stroke vs. force" are such that, after the absorption stroke related to the nominal compression force, there is a peak of force working as shear out and then a free stroke related to a zero value of force. That way of modelling the coupler, with its different phases of work, allows to describe in detailed way the cinematic and dynamic behaviours of the impacting vehicles.

The absorbers are sacrificial elements that are designed selecting the best compromise between shape and weight, in order to make them to deform in a controlled manner converting kinetic energy in deformation energy with high levels of efficacy and efficiency. The new requirements imposed by the latest draft of prEN15227 (2) are the reasons why a new generation of absorbers has been developed, to permit them to keep their stability not only under axial compression loads generated during an impact with vertical offset.

In the metro unit being studied there are two kinds of bogies: the motor bogie and the trailer bogie. Since it has been fully modelled only the leading A cars, were needed to study accurately only the motor bogie on which the A carbody is rested. Moreover, being the bogies very heavy and away from the impact point, they are very important for the calculation and above all for the cinematic and dynamic behaviour. Starting from these considerations, the bogies' FEM models are made up by a group of rigid parts with their right masses and inertial properties. Each part of the bogie is free to move with respect to the others, as it actually happens by the interposition of elastic and/or viscous elements.

Each bogie is composed of:

- Bolster beam simulated with rigid body
- Bogie frames simulated with rigid body
- Wheelset simulated with rigid body
- Traction Rod simulated with solid elements
- Motors and gearboxes simulated with rigid body
- Resilient wheels simulated with both rigid body and elastic spring
- Shock absorbers, primary suspension, secondary suspension, elastic elements between traction rods and chassis, gearbox's and motor's elastic supports, everyone simulated with elastic spring.

Since the latest versions of prEN15227's new requirements focused on the overriding risk linked to the lifting of the wheelsets during the impact, the anticlimbers and the bogies, have been simulate very carefully. A specific requirement in fact, imposes that: "the vertical displacement above the rail, of at least one wheelset on each bogie, shall be no more than 75% of the nominal flange height".

Main equipment contribute, in term of mass, has been spread on the vehicle structure, while the passenger's mass has been simulated with lumped masses placed on the frame of the car. Lumped masses have been also used to simulate the B, C, D cars and the remaining three bogies of each metro unit.

1.2 UNITS OF MEASUREMENT AND REFERENCE SYSTEMS

The units of measurement applied are:

| | |
|---------|-------------------|
| Mass: | kilogram (kg) |
| Length: | meter (m,mm); |
| Time: | second (sec,msec) |
| Force: | Newton (N,KN) |
| Energy: | Joule (J,KJ,MJ) |

Reference systems:

- Global Cartesian orthogonal for nodes;
- Local Cartesian orthogonal for elements.

1.3 CRASH SCENARIO

As required in the Technical Specification Thessaloniki Metro (1) the analysis are based on the assumption that a AW1-loaded Metro unit impacts against another one in standing conditions, with a relative speed of 25 Km/h (AW1 represents the sum of the vehicle's tare mass and of the all seated passengers' mass). The crash happens in a straight section of the track and, in order to respect the 40 mm of initial vertical offset as stated in prEN15227 (2), (due i.e. to different wheels' level of worn and/or dynamic effects), the standing unit have been placed 40 mm under the nominal height condition. The initialization of the velocity field of the impacting unit has also taken into account the rotational velocities of the wheelsets.

2. CHARACTERISTIC OF MATERIALS

The carbody structure is constituted of aluminum alloy, while the cabin and the absorbers are made of high resistance steel. For all structural material it has been used the “*MAT_PIECEWISE_LINEAR_PLASTICITY” from LSDYNA library. For the materials interested by large deformations, basically the sacrificial elements, the major accuracy is presented. That material has been characterized with the Cowper-Symonds parameters obtained by last AnsaldoBreda's test series.

3. DESCRIPTION OF THE CONTACTS

The types of contacts used in the analysis are:

- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE between the wheelsets and the rail
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE between the couplers' heads
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE between the two couples of absorbers
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE between the interfacing plates cabins/carbodies
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE secondary suspension's vertical stop
- *CONTACT_AUTOMATIC_SINGLE_SURFACE between the shell elements of the absorbers
- *CONTACT_AUTOMATIC_TIED_SURFACE between the solid modelled anticlimber plate and the shell modelled absorber

4. ANALYSIS RESULTS

The first absorption stage is provided by the automatic couplers' buffers, they absorb about 390 kJ; at the end of the not-regenerative stroke the force increases and when it is over the limit value of the shear out device it detaches from its plate. After the automatic coupler's extrusion the anticlimbers of the absorbers engage and the lateral crumple elements start their compression. The crumple elements work in series, it means that after an initial trigger the second one start to crush only when the first one reaches the total compression stroke. At the end of the crash phenomenon there is the elastic rebound of the involved structures and the anticlimbers disengage.

When the absorbers engage the vertical offset between their teeth is grown from the initial 40 mm (when there is the impact between coupler heads). This is due to the pitching movements of the leading cars originated by the forces acting on the coupler mounting plate in the first phase of absorbing.

4.1 ENERGY BALANCE

The initial kinetic energy has been transformed as shown:

$$E_{kin0} = E_{int} + E_{kin1} + E_{sd} + E_{sl} + E_h$$

where:

E_{kin0} = Initial Kinetic Energy (of the moving vehicle)

E_{int} = Internal Energy

E_{kin1} = Residual Kinetic Energy (of the two vehicles)

E_{sd} = Spring and damper energy

E_{sl} = Sliding energy

E_h = Hourglass energy

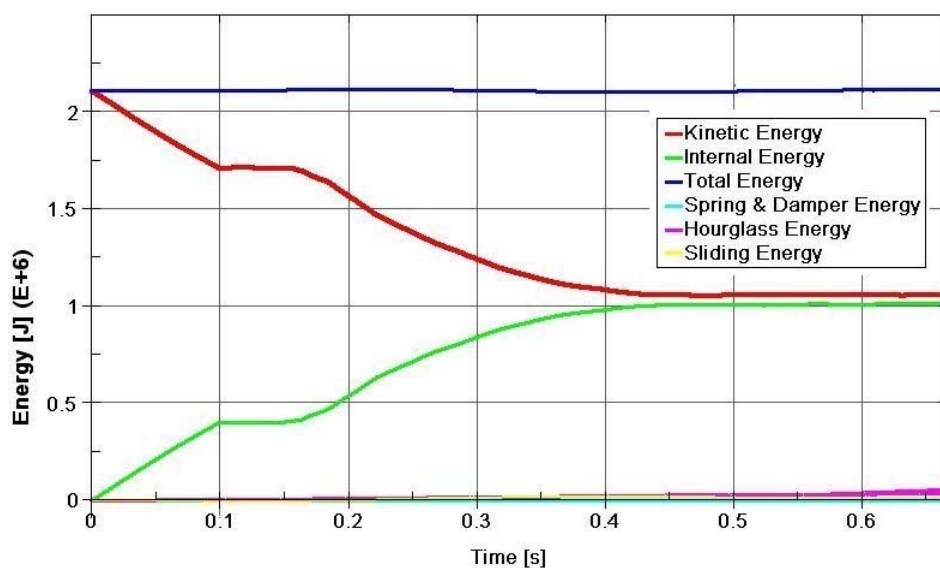


Figure 2 - Net accelerations

Here are reported the values of the energies.

We can consider that the crash phenomena regarding the front parts of the leading cars are ended after 500 ms.

| | | |
|-------------------------|----------|--------------|
| $E_{kin0} \approx$ | 2.13 MJ | $t = 0$ ms |
| $E_{couplers} \approx$ | 388 KJ | $t = 500$ ms |
| $E_{absorbers} \approx$ | 566 KJ | $t = 500$ ms |
| $E_{kin1} \approx$ | 1.065 MJ | $t = 500$ ms |

4.2 ACCELERATIONS

A fundamental parameter in crash analysis is the magnitude of the accelerations undergone by the vehicles (and their occupants) during the impact. Accordingly to prEN15227 (2) the method of determining the mean deceleration for the vehicle shall correspond to the time since when the net contact force on the vehicles exceeds zero, until when it falls again to zero. Notice that the net contact force shall be calculated as the algebraic sum of the longitudinal forces acting on opposite ends of the vehicle. The accelerations curves have been obtained as stated in (2) for the two leading cars (that are the ones experiencing the highest levels of acceleration), while for the 1D modelled remaining cars the accelerations on the joints' node have been plotted.

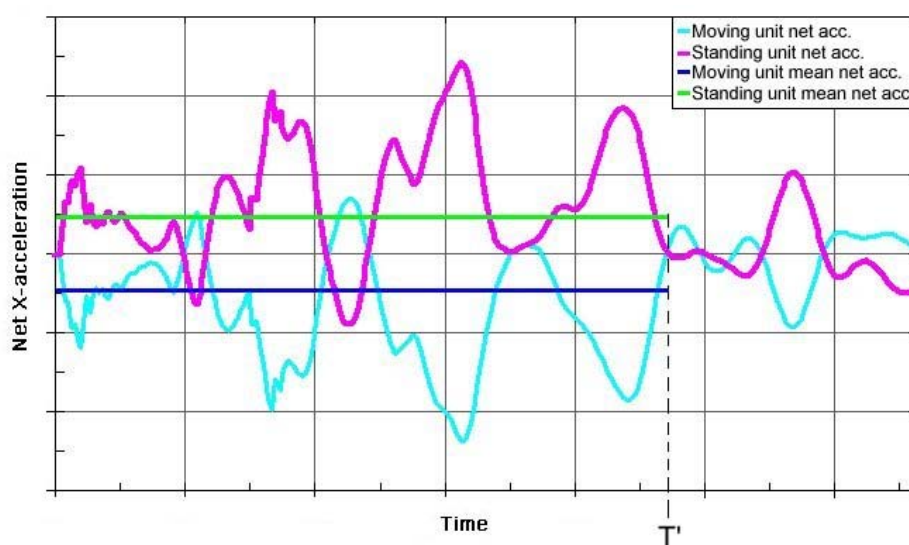


Figure 3 - Net accelerations

The accelerations undergone by the leading cars have been evaluated scaling the net contact forces with the masses of the respective cars. The masses considered are the sum of leading cars and of the first two bogies, because those are the elements that undergo the net force.

4.3 BOGIES

First the connection between bolster beam and chassis (provided by the traction rods) and the supports of bogies's equipments was investigated. The level of accelerations and forces prove that not failure or excessive deformations are reached.

The second goal to achieve was to demonstrate the compliance of the vehicle to the overriding requirements. Due to the design of the bogies, which have an articulated chassis, first the vertical displacement of each wheel had to be investigated. Then accordingly to (2), where only the complete wheelset is taken in to account, a mean value between the two wheels mounted on each axle of the bogies has been calculated. The vertical displacements, estimated as above, demonstrate that the wheelsets (and also the single wheels) undergo negligible liftings. The absence of large vertical displacement ensures that there are not derailment risks.

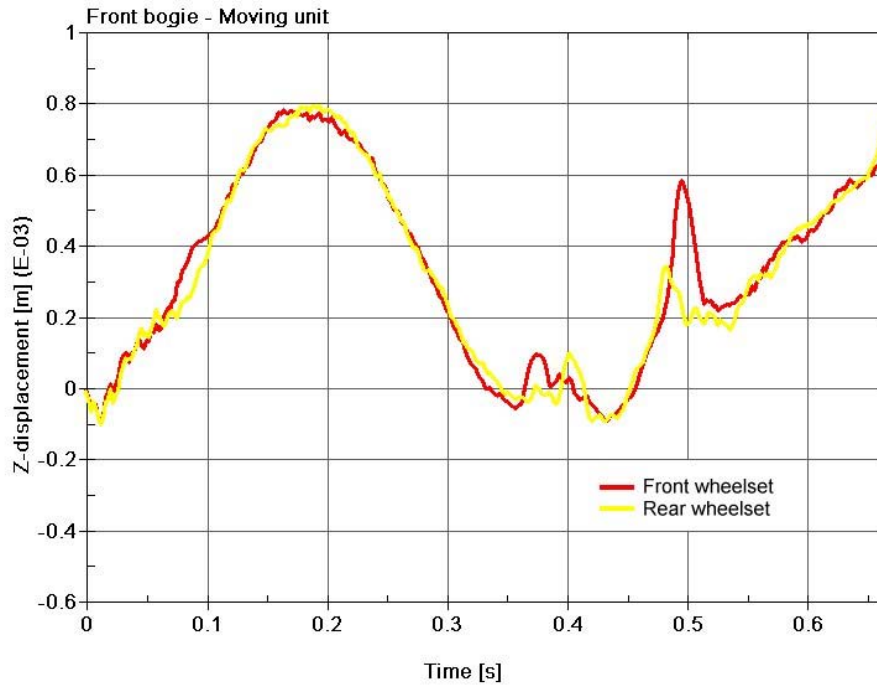


Figure 4 - Front bogie of moving unit

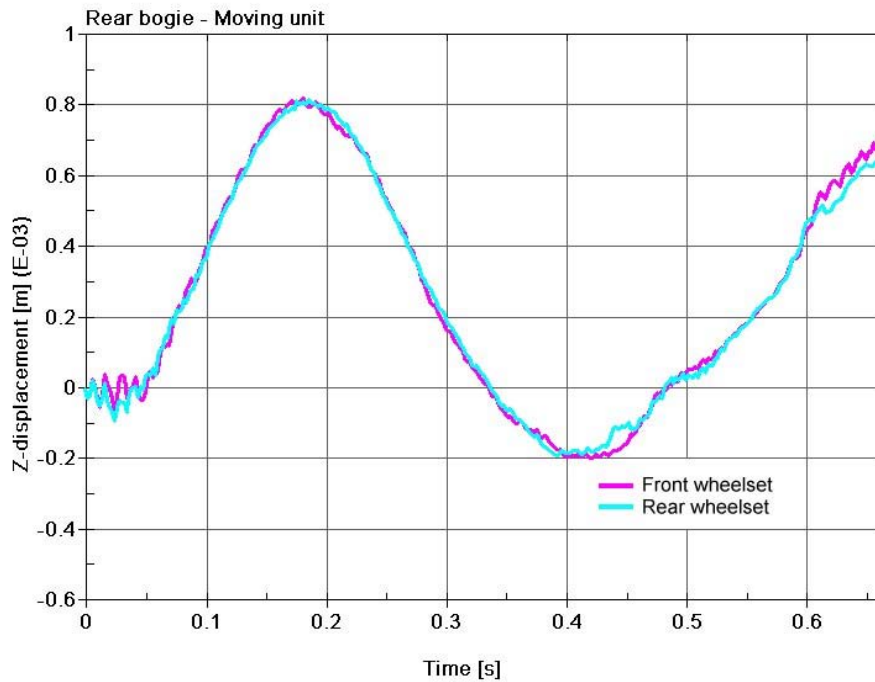


Figure 5 - Rear bogie of moving unit

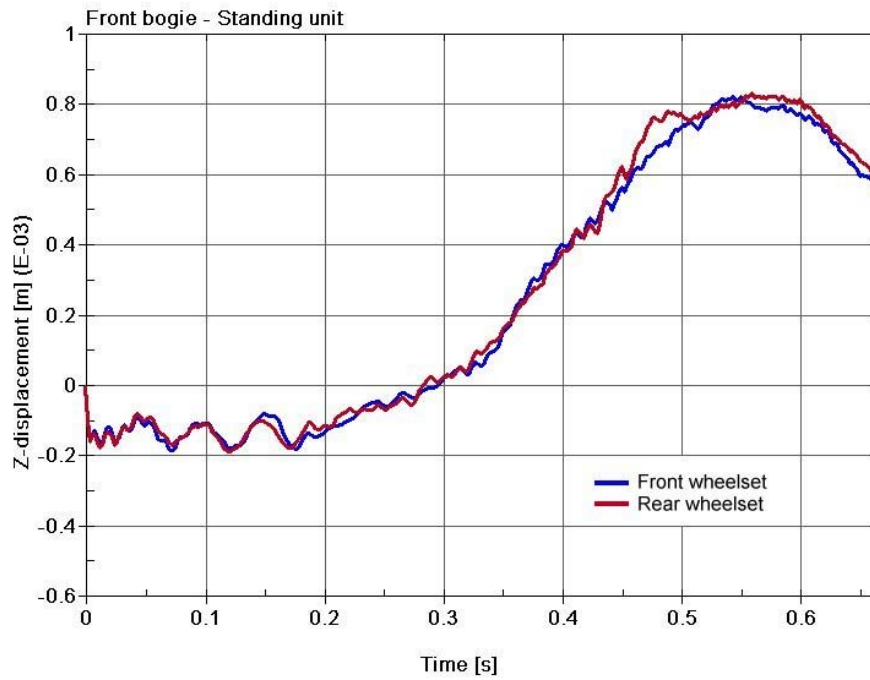


Figure 6 - Front bogie of standing unit

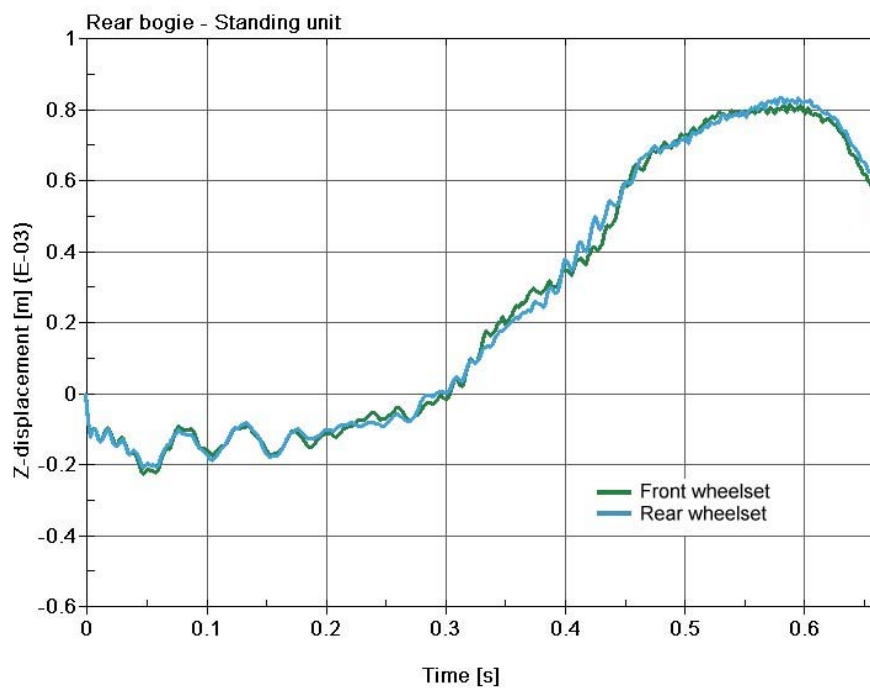


Figure 7 - Rear bogie of standing unit

5. CONCLUSIONS

The architecture of the front end results able to absorb the total amount of energy related to the crash scenario, without overloads on the cabin and on the carbody.

The cabin, the carbody and so the passengers involved in the collision undergo accelerations far minor than the maximum acceptable, while the structures of cars are affected by negligible deformations.

The anticlimbers devices placed on the absorbers first of all avoid the risks of overriding between cars, on the other hand they allow the remarkable fact that wheels keep in contact with the rail during all the event of crash.

Due to what is written above, the vehicle results compliant to the Technical Specification of Thessaloniki Metro (1) and the prEN 15227 (2).

REFERENCES

- (1) ATTIKO METPO A.E., "Technical specification Thessaloniki Metro", December 2004
- (2) European Standard - prEN 15227 - "Railway applications - Crashworthiness requirements for railway vehicle bodies" - Draft January 2007.