Validation of Hydraulic Gas Damper Coupler and Crash Simulation of Large Rolling Stock Model in LS-DYNA®

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Abstract

*The hydraulic gas damper coupler (HGDC) is the most important energy absorbing component in rolling stock crash impact. The HGDC can effectively dissipate crash energy and reduce excessive structural loads at all impact speeds. In this paper, the LS-DYNA material *MAT_HYDRAULIC_GAS_DAMPER_DISCRETE_BEAM (*MAT_070) is used to simulate the HGDC coupler. Using this formulation, both static and dynamic characteristics have been replicated. The validated HGDC models have been incorporated into rolling stock frontal impact simulations. A simple mass-beam representation for the carriages and a full scale detailed model – containing 16 carriages and more than 28 million elements – have successively been analysed. This paper also presents the innovative pre-postprocessing and data storage methods developed by CNR and Arup to handle the very large FE models and results files.*

Key Word: Hydraulic Gas Damper Coupler, Rolling Stock, Very Large FE model

Over the past decade, rolling stock traffic has expanded rapidly in Mainland China. Most major cities have underground facilities and High-Speed networks cover most of the East and Middle regions of China. CNR is one of the main Chinese manufacturer of railway vehicles, with a product range covering all rolling stock types. CNR has a track record of international success and has exported his train design to South America, Africa, the Middle-East and South-East Asia. Within CNR, the demand for safety simulation is also increasing. Due to the train model dimensions and the long crash simulation time, CAE teams still face technical bottlenecks: current software and hardware are hard-pushed to handle pre and postprocessing operations on the very large simulation models as well as the amount of data generated. This paper also presents a dedicated approach to the analysis of very large FE crash models in LS-DYNA.

1- Hydraulic Gas Damper Coupler Model

The Hydraulic Gas Damper Coupler (HGDC) is a critical energy absorption component in rail vehicles. By efficiently dissipating crash impact energy, it contributes to passenger safety and damage reduction. Deceleration in the HGDC elements is fairly constant and impact forces applied to the carriage structure kept to manageable levels. HGDC are also mobilized in carriages coupling and towing actions and emergency braking events.

*MAT_HYDRAULIC_GAS_DAMPER_DISCRETE_BEAM (*MAT_070) formulation in LS-DYNA has been specifically developed to model combined hydraulic and gas filled dampers with variable orifice coefficient and has been adopted in this study.

The HGDC is composed of two oil and gas chambers separated by a moving piston. In the oil chamber, the fluid circulates through an orifice partially obstructed by the profiled pin of the piston..

The reaction force in the HGDC has two sources. In the gas chamber, the gas is adiabatically compressed. In the oil chamber, the plunger is forced into the cylinder, displacing the oil which flows through the orifice. As force is applied, the gas volume is first adiabatically compressed before the plunger in forced into the cylinder, displacing the oil that flows through the orifice. As the piston pin is profiled, the free orifice area varies with stroke and so does the oil resistance. The compressed gas provides the recoil force required to re-extend the HGDC after impact.

Reaction force and energy absorbed depend on impact velocity. Figure 1 gives a schematic description of a HGDC element.

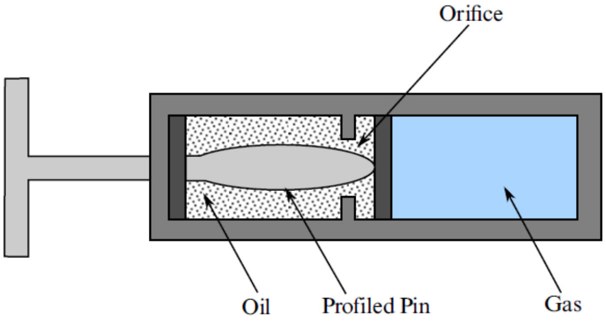


Figure 1 - Hydraulic Gas Damper Coupler

For a discrete beam element using this formulation, the force is computed as follows:

$$F = \mathrm{SCLF} \times \left\{K_h \left(\frac{V}{a_0}\right)^2 + \left[P_0 \left(\frac{C_0}{C_0 - S}\right)^n - P_a\right] A_p\right\} \qquad (1)$$

Where:

S is the element deflection

V is the relative velocity across the element

C_0 is the length of the gas column

a_0 is the area of the orifice

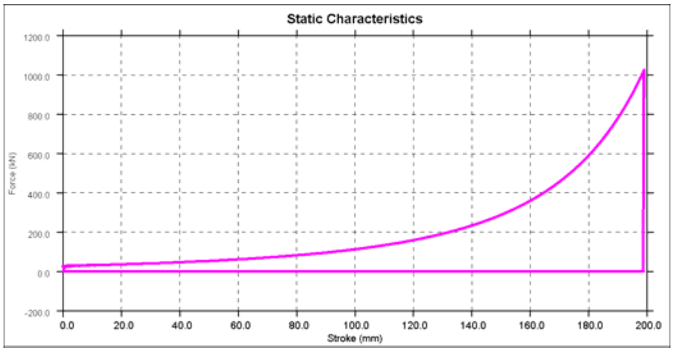
A_p is the piston cross section area

P_a is the atmospheric pressure

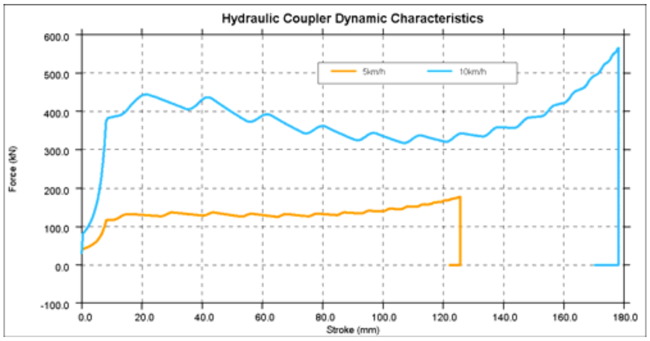
P_0 is the initial gas pressure

The reaction force is proportional to the square of the impact velocity. To assess the dynamic characteristics under different loading regimes, three cases have been tested on a very simple single-beam model: quasi-static loading, and 5m/s and 10m/s impact velocities.

The HGDC element parameters were derived from physical CNR products.



（a）Quasi-Static Characteristics



（b）Dynamic Characteristics

Figure 2 Coupler force-displacement characteristics

In the quasi-static cases, the contribution of the gas chamber compression dominates. The reaction force increases with stroke.

The dynamic cases illustrate the sensitivity to impact speed. The hydraulic force component can be very high and is kept fairly constant through most of the compression action. At the end of the impact, as the velocity drops, the HGDC exhibits ‘quasi-static’ characteristics again, reaction forces increasing again with stroke. The energy dissipated by the HGDC, quantified as the area below the force-displacement curve is also a function of the impact velocity.

These characteristics match well the behavior of HGDC observed in similar physical tests.

2 - Simple Rolling Stock Model

Our HGDC calibrated model has been first used to simulate the coupling and towing actions on two train units following a standard internal design procedure. The train units are simply modeled with series of carriage masses and HGDC discrete beams – the stiffness of the carriages is ignored. Each train unit consists of six carriages. The first train unit is static until it is impacted by the second unit travelling at a coupling speed of 10km/h (2.778m/s). After impact, the two units are connected and travel together. The HGDC should ensure that impact forces remained at acceptable levels and that the trains incur no damage during the coupling event. For this loadcase, the HGDC maximum allowable force is 680kN and stroke is 200mm.

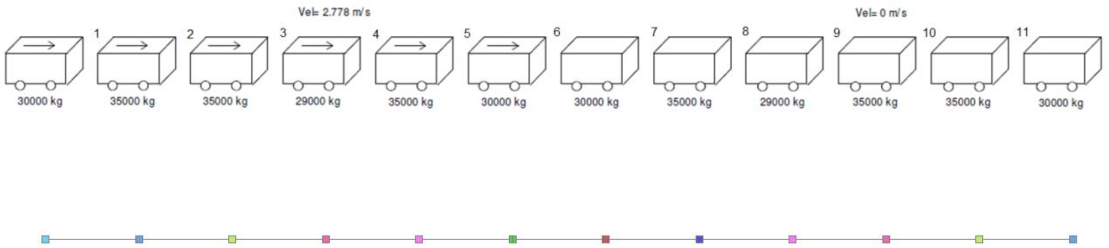


Figure 3 Simplified Rolling Stock Rake Configuration (Up) and FE model (Low)

The complete impact event lasts about 1 second and the final velocity of the coupled units is 1.4m/s. Almost 50% of the initial kinetic energy is dissipated by the 11 inter-carriages HGDC elements.

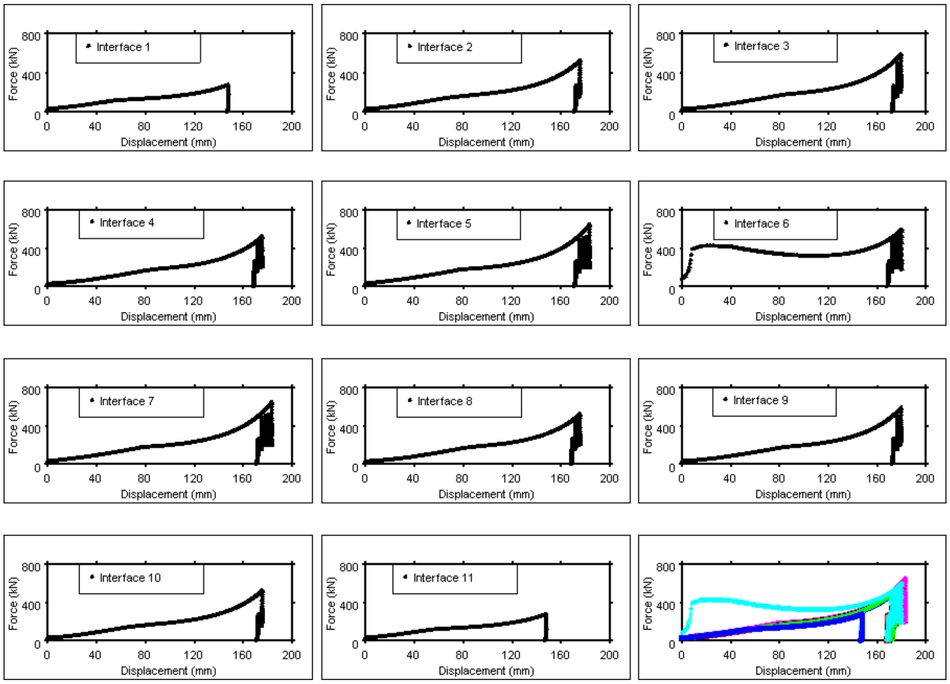


Figure 4 - Force-Stroke Diagrams

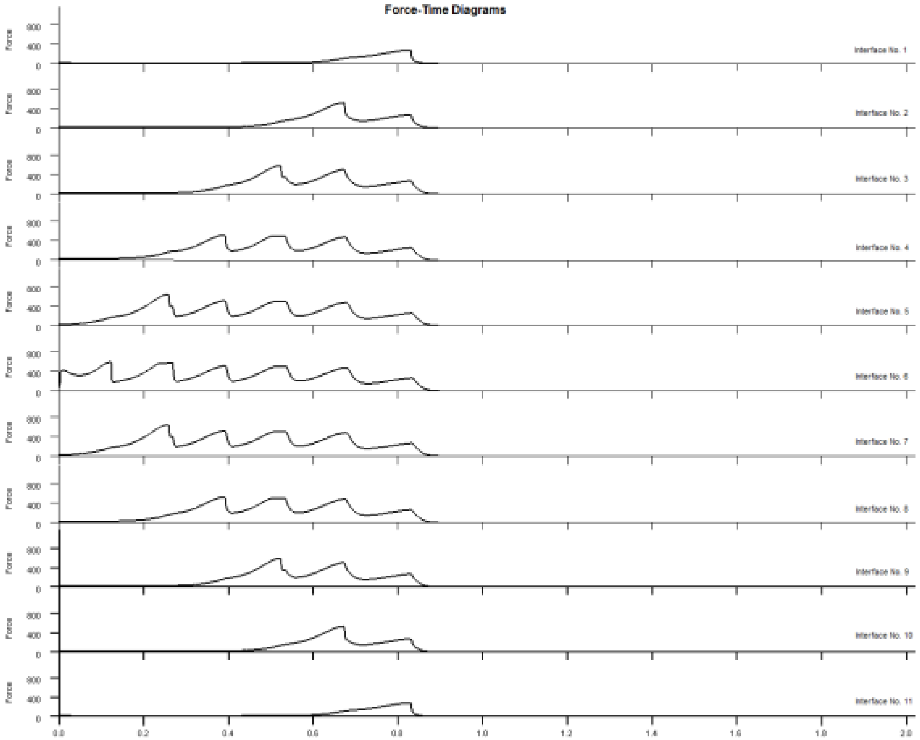


Figure 5 - Force-Time history Diagrams

Maximum force is measured in interface HGDC no.5. At 647kN, it corresponds to levels observed in practice and remains within carriage design capacity. Maximum HGDC stoke does not exceed the 200mm design limit. Interface HGDC no.6, between the two train units shows the typical dynamic characteristics highlighted in the previous section. Using this simple method, the preliminary design of HGDC elements can be validated without costly physical testing. The risk of damage in rolling stock under standard coupling and towing situations can also be quickly assessed.

3 Full scale detailed crash model

A detailed crash simulation, following EN15227-2008 regulation has been considered, where one stationary train unit is hit by a second one travelling at a speed of 36km/h.

A detailed FE model of a CRH380 high speed train has been built. Both train units are composed of eight carriages including two motor cars, one restaurant carriage and five passenger trailer carriages. All interfaces between carriages and the buffer zones in front of the motor cars are fitted with the HGDC elements described previously.

The aluminum body of the carriage has been explicitly meshed. The primary and secondary suspension elements have been accurately represented with spring and damper elements. Detailed geometry and mass properties of the axles, wheels and bogies have also been considered. Figures 6 and 7 below show the level of modeling complexity.

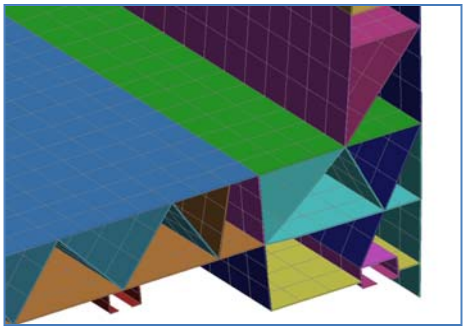


Figure 6 - Aluminum body mesh details

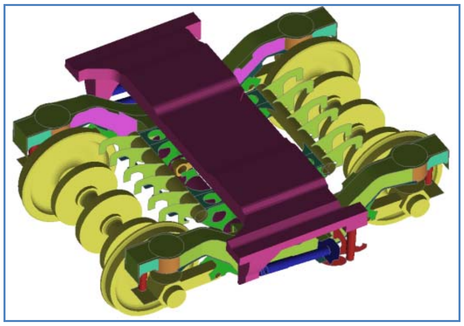


Figure 7 – Typical suspension model

Figure 8 illustrates the three different types of carriages forming a typical CRH380 train unit.

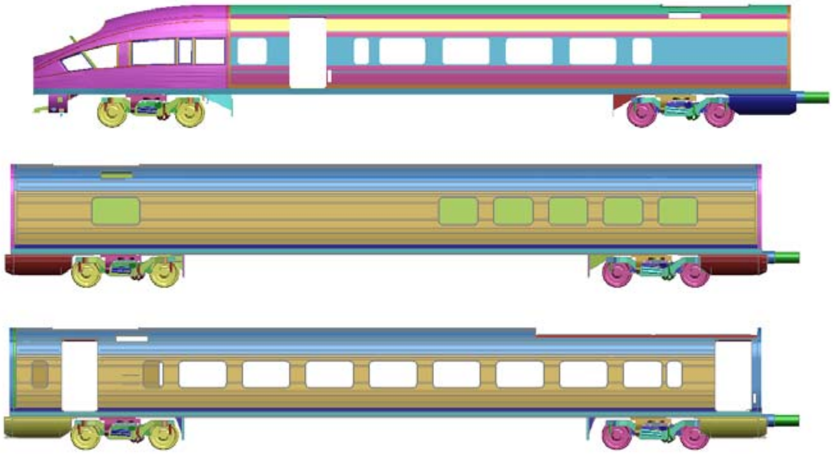


Figure 8 - Carriage models - From top to bottom: Motor, Restaurant and Passenger cars)

The complete simulation model contains about 28.7m elements. Several commercial pre-postprocessing packages have been benchmarked. Oasys®/Primer has proved to be the more robust and fast option to build-up and handle such large LS-DYNA models.

Several modeling practices are applied and specific Primer features exploited to reduce modeling time, minimize errors and streamline the analysis process:

a- Organised model labeling: each carriage is assigned fixed label ranges for nodes, elements, parts, etc.

b- Systematic use of INCLUDE files: The train models are split into a database of input files representing the vehicle subsystems, carriage body, suspensions, bogies, boundary conditions, contacts and so on. The various loadcases can then be assembled from the database by selecting the appropriate include files using loadcase templates. The team can be sure that they are always using the latest version and the correct data. The system allows easy creation of sub models as each include file can be handled on its own. This saves time when performing design modifications.

Oasys software has several tools specifically developed to make working with include files easy, including:

- a- The ability to set numbering ranges for include files and automatically renumber to within these ranges when reading files in
- b- Version control
- c- Interactive renumbering by include file
- d- Tool for quick creation of 'rigid patches' for connection
- e- The ability to select which include file to work in using 'layers'. This means that even though the whole model may be read in, new entities will be created in whichever include file is the current 'layer'
- f- The ability to create a database from a directory of include files
- g- Ability to select which include files in a model to read in or write out
- h- The part tree in Primer enables components to be 'dragged and dropped' into different include files to speed up organisation of the model
- i- Automatically build, check and write out several loadcases in one go using multiple templates
- j- Control and manipulate models in Oasys pre and post-processing software by include files
- k- Automatic reporting based on analysis templates

Figure 9 below shows the complete FE analysis model.

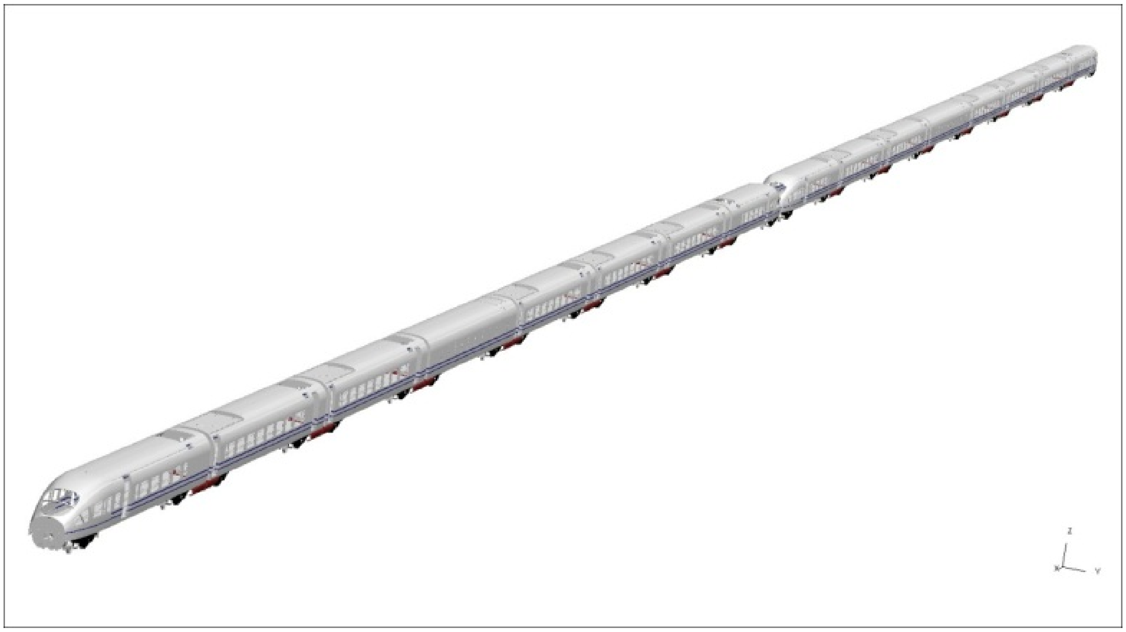


Figure 9 – Detailed CRH380 Model for LS-DYNA crash simulation

Not only the analysis model is very large, but also the impact simulation duration of 1.6s is unusually long. CNR mobilize 420 cores on its calculation cluster to run this type of analyses.

Total CPU time is about 63 hours. Typically about 1.4Tb of graphical plot files and 13Gb of time history data are generated during each impact run for detailed assessment of the design performance.

All postprocessing is performed with Oasys/D3plot and T/HIS.

Figures 10 and 11show some of the analysis results.

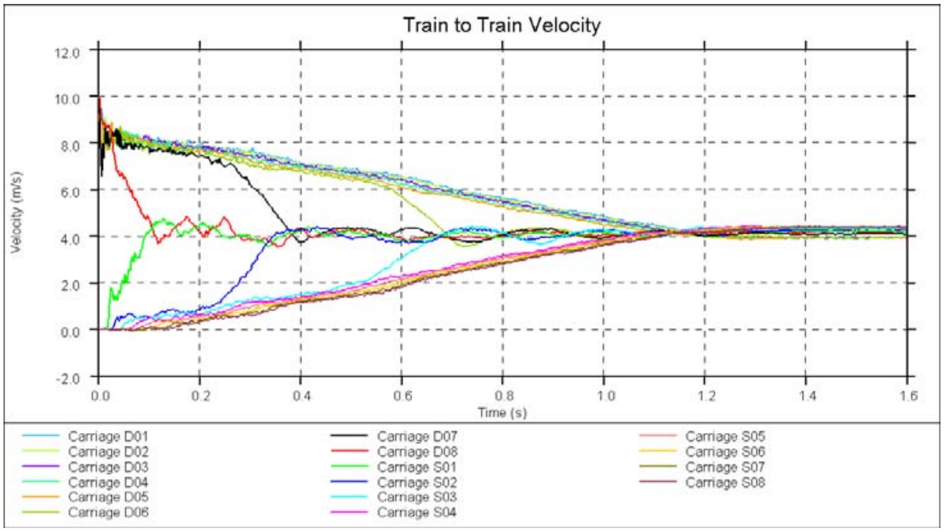
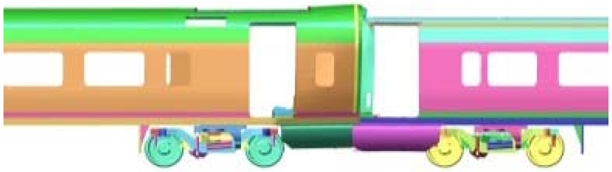


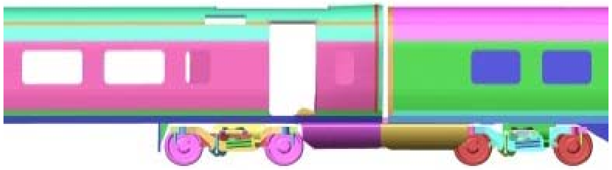
Figure 10 - Carriage velocity time history results

(a) Interface between two power cars

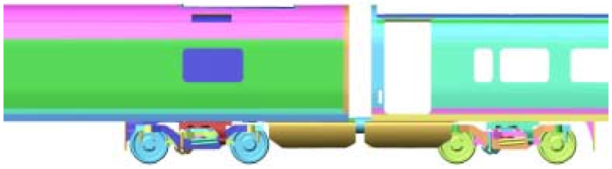
(b) Interface between back of power car and first passenger carriage



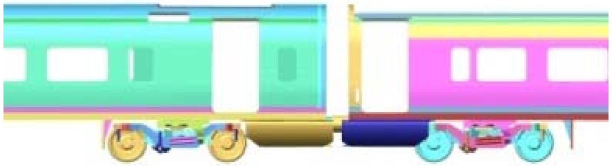
(c) Interface between first and second passenger cars



(d) Interface between second passenger car and restaurant car



(e) Interface between restaurant cab and third passenger car



(f) Interface between third and fourth passenger cars

Figure 11 - Carriage Final Deformations

The first 3 carriages on each train unit, suffer moderate structural damage and passenger/driver survival space is not compromised. Contacts between body structures are prevented for all other carriages as the HGDC elements dissipate about 10% of the impact energy and effectively limit damage propagation.

4 - Conclusions

CNR has performed benchmark test on LS-DYNA *MAT_070 formulation to simulate combined hydraulic gas damper elements. The component dynamic behavior has been compared to physical test results and validated. The HGDC model has been used in train crash simulations.

A simple train-to-train coupling and towing simulation model is used in-house to assess the design of HGDC elements with different carriage configurations and mass distributions. Costly full scale physical tests can be limited to final verification phases.

The requirements for full scale detailed rolling stock simulation are increasing. Crash simulations of two CRH380 train units, including HGDC elements have been carried out.

Advanced modeling techniques and model management processes have been developed to meet the stringent turnaround needs of the CNR CAE teams. 30M-element models can be constructed and handled efficiently and 1.5s real time impacts can be analysed and postprocessed within 3 days by using the right combination of high performance hardware and Oasys software.

References

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