TRAINSAFE: SAFE VEHICLE STRUCTURES

Workshop 27 – 28 April 2004
The Belfry, West Midlands

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Presenter Profiles

John Roberts

John Roberts Associate Institute of Physics (AInstP), Diploma Management Studies (DMS), Diploma in International Marketing (DipM), Member Chartered Institute of Marketing (MCIM)
Bombardier Transportation for seven years
Present position – Group Engineering Centre of Competence for Crash Safety
Speaker for the Economic Evaluation Group for Conventional Interoperability
Member of the Revision Group for High Speed TSI
Member of CEN WG2
Coordinator of Trainsafe Thematic Network
Manager Crash Test Laboratory at MIRA for six years
Manager Certification for Rolls-Royce and Bentley Motor Cars for 15 years
Crashed 14 Rolls-Royce cars during that period. Two accidentally.

Allan Sutton

No profile available.

Julian Ellis

Julian Ellis is a textile technologist who has worked in research and development for almost all of his career. He is a special lecturer in orthopaedic and Accident Surgery at the University of Nottingham where, following the research projects into the air crash at Kegworth on the M1 motorway in England, he developed a major research programme on lower limb injuries in front seat drivers and passengers in motor vehicles, known as the LLIMP project.

Julian is heavily involved in fibre placement techniques and through-stitching technologies for composite preforms, and his company, Ellis Developments, designs and develops textile surgical implants.

Julian has spent much time in prison over the last 17 years, but believes in the saying “never explain”.

Federic Carl

No profile available.

Didier Leveque

Dider has worked for SNCF for 22 years. He is an expert in field of Passive Safety and biomechanics for 10 years

Relevant Experience:

Worked as manufacturer collaborator and since 4 years as approving design in the field of vehicle structural passive safety concept and also research project manager for occupant protection over the last 10 years.

Experience mainly in the train structural crash test and dummy sled test sector.

Patrick Jumin

Expert of the SNCF in the Passive Safety domain
(3.5 years for the french railway operator and 3 years in the automotive industry / Renault / Mecalog's consultant).

Experience mainly in the passive safety specification, crash tests, and numerical simulations.

Relevant Diploma and Experience:

PhD in Civil Engineering (Laboratory of Solid Mechanic / Ecole Polytechnique - F)
Master OF CAD/CAM/CAE (Cranfield - GB)
8 years in study office on the modelling of soil-structure interaction (military application - nuclear explosion - Airix/Megajoule projects, civil engineering, ...).

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Amar Ainoussa, Mechanical Engineer, Bombardier Transportation Ltd,
Worked in the field of railway rolling stock structures for over 14 years.

Manuel Peirera

No profile available.

AGENDA FOR TUESDAY (27 April 2004) – DAY 1

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EVENT WELCOME	JOHN ROBERTS (BOMBARDIER)
EVENT STYLE	ANDY WILD
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DINNER **Speaker – Julian Ellis**	

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TOPIC OVERVIEWS • **Vehicle Interface Safety (Buffers, Couplers & Anti-climbers)** • **Derailment Protection**	PAPER AUTHORS
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CLOSE	

JOHN ROBERTS

ENERGY ABSORPTION IS PRESCRIPTION CONSTRUCTIVE?

TRAINSAFE – Energy Absorption is prescription constructive?
Subtitle: Safe Vehicle Structures

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Abstract:

There is no such thing as a train without crashworthiness. Even a structure designed before the application of the High Speed Technical Standards for Interoperability (HS TSI) has an inherent level of crashworthiness. However when crashworthiness criteria are defined to a prescriptive level as found in the current and legally imposed HS TSI Directive the achievement of those exacting criteria becomes an unnecessary burden to the manufacturer and does not in reality add to the safety of such a vehicle in the way that was envisaged when the TSI was written. By removing the prescriptive nature from that Directive during its revision and not including that in a new Directive for Conventional traffic the vehicle structures designs can be left open to enable the industry to utilise modern and innovative methods. But is a mean deceleration level of 5g key to saving lives and reducing injury levels?

Introduction

Rail vehicle crashworthiness legislation is produced in order to save the lives or lessen the injuries of the occupants during the prescribed collision scenarios:

- Train to train
- Train to locomotive
- Large obstacles level crossing
- Small obstacles

To reduce the deceleration during these scenarios it is necessary to absorb energy forward of the driver. The use of Energy Absorbing (EA) Units is key to this criterion.

This paper will concentrate on that one aspect of Energy Absorption being the first line of attack during the collision process starting from basic principles with the physical laws of motion. But is this enough to save lives and lessen injuries?

Active v/s Passive Safety

Before considering the energy absorbing mechanism it is firstly necessary to discuss the differences between "Active" and "Passive" safety. This debate has been continuous during the various workshops of Trainsafe and it would be beneficial to put a "Stake in the ground" in defining the difference. Certainly within the directive there is a positive statement to the effect that Passive Safety measures should not be deployed to compensate for a lack of Active Safety.

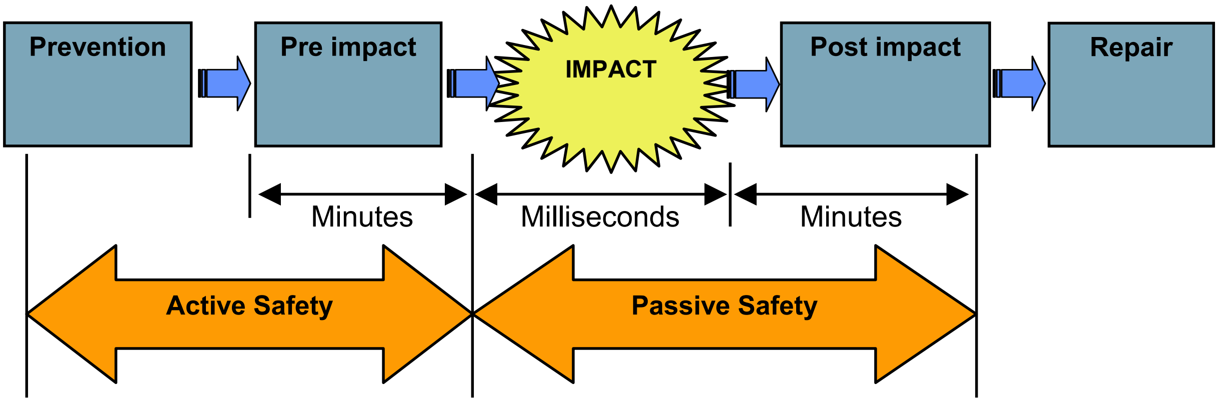


Fig 1 Crash Process Model

Active Safety can be defined as a number of systems:

- Signalling
- Obstacle detection
- ERTMS

Passive Safety is aspects of the vehicle such as:

- Vehicle structure
- Energy absorption
- Protective cells
- Restraint systems
- Vehicle interior layout and design

There is still debate to define in whether the following lie in the Active or Passive area:

- Egress
- Door systems

Laws of Motion

The physical laws of motion are the defining element in determining the first principle design of the energy absorbing elements at the front of the vehicle. In order to achieve the maximum mean deceleration level of 5g prescribed within the HS TSI the following table shows the element length required. For this exercise the like to like impact scenario is considered as the most simplistic for comparison.

Velocity km/h	Velocity m/s	Velocity into Solid wall	Displacement @ 5g	Total Absorber Length (70/30 ratio)	Minimum Total Cab Length (Absorber + Survival Space)
36.00	10.00	5.00	0.25	0.36	1.11
55.00	15.28	7.64	0.59	0.85	1.60
60.00	16.67	8.33	0.71	1.01	1.76
120.00	33.33	16.67	2.83	4.05	4.80

Fig 2 Minimum Cab Length from First Principles

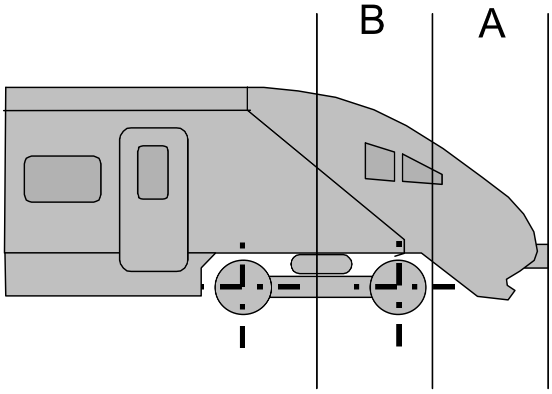
The calculation assumes a 70/30 ratio of length to absorb energy against fully compressed length as can be seen in the collapsed EA unit in figure 3.

However units constructed out of composite material could bring that down to a virtually 100% length utilisation figure. But the validation of the ageing effects of such materials is problematic.

Fig 3 Fully collapsed EA unit

Application

If we then apply those principles to the design of the cab structure it can be clearly seen that the cab would be split into two sections A and B where A is the energy absorbing section which would vary from 0.35m to 1.01m dependant upon whether the HS TSI requirement of 36 km/h like to like impact or UK group standards clause 9.2 speed of 60 km/h is required.



FFFig 4 Cab Layout – First Case

Also assuming the Safetrain recommendation of 55 km/h for this scenario a length of 0.85m would be required.

One example of an operator requirement in the UK put this closing velocity figure up to 120 km/h leading to a 4.05m crush length.

Section B is the 0.75m driver's survival zone.

This may seem at first sight to be a simple design exercise until we consider vehicles such as the class 375 or the type 185 locomotive. Locomotives forming a special case.

Fig 5 Class 375

The short nose is usually defined by other operating considerations and is outside the control of the Crash Safety requirements. So key to the problem would be the need to keep levels of deceleration within the driver's cell down to the prescribed figure of 5g. How was this achieved within the Safetrain project?

Fig 6 Type 185 Loco

Application of EA to the Safetrain Concept

The Safetrain cab concept included the classical bolt-on EA units which formed the main absorbing part of the collapse structure. Following the collapse of these elements the cab structure forward of the cab door formed the next stage of energy absorption with the driver's desk and seat module moving rearwards.

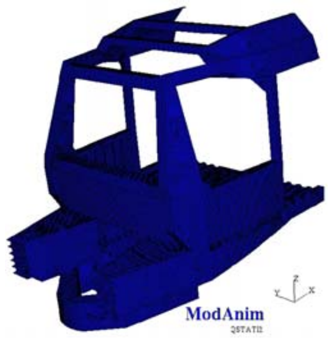


Fig 7 Safetrain Crash Concept pre Crash

The FE analysis diagram and the subsequent crash test show the validation of the Crash Concept for Safetrain however it is clear that the compliance with both the energy absorption and deceleration prescription has been achieved at the expense of excessive length.

The design utilises far more displacement than that required by the simple Laws of Motion.

Fig 8 Safetrain Crash Concept post Crash

This solution, although a solution, is not applicable to the short nose operating conditions defined for the commuter vehicle and locomotive classes.

F

Fig 9 Safetrain Crash Test

Application of EA to Short Nosed Vehicles

It becomes apparent that the application of Safetrain solutions to vehicles which due to operational necessity are short nosed becomes impracticable.

A solution has to be found.

To bring down the deceleration in the drivers zone to 5g and below it is necessary to absorb sufficient energy in the short nose. This is not practicable as already determined. It is therefore necessary to seek derogation against this requirement and introduce an EA zone C rearward of the driver's zone to ensure that the deceleration in the passenger tube is maintained. This would produce a deceleration in the driver's zone in excess of 5g.

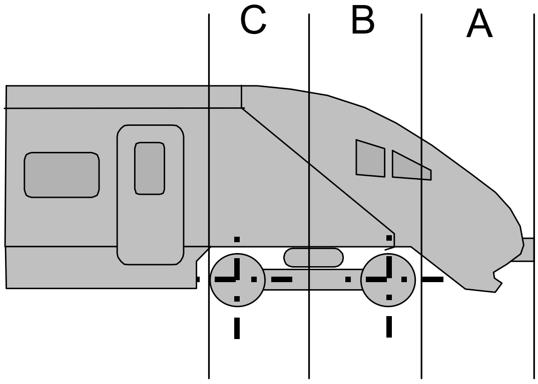


Fig 9 Cab Layout – Second Case

It is therefore necessary to find an alternative passive safety measure to protect the driver. A belt system is not acceptable to many of the driver's trade unions using the argument that a belt would restrict the speed of escape. The only solution would be to employ an air bag system.

Air bag systems applied to the rail driver's seating position have been investigated for some considerable time as may be seen in figure 10 in a picture extracted from an early Rail Crash test.

It should be remembered that an Air Bag system is a secondary means of absorbing the energy of an occupant so preventing injury.

Fig 10 Driver's air bag system

The European Driver's Desk (EUDD) recognised the need to facilitate the provision of an airbag system by providing a dedicated area immediately in front of the driver.

Fig 11 EU Driver's Desk

Conclusions

Energy absorption techniques can produce the prescribed mean deceleration level of 5g for the main occupant or passenger tubes however it is more difficult and in some cases impossible to achieve these levels of deceleration for the driver's zone.

In reality the vehicle crashworthiness is defined to save the lives or lessen the injuries of the occupants during the prescribed collision scenarios:

- Train to train
- Train to locomotive
- Large obstacles level crossing
- Small obstacles

It could therefore be argued that the vehicle structure should be validated by defining the injury levels of the occupants. In this way passive safety systems could be deployed to protect during the impact phase and focus the design of the vehicle interior to this end.

To achieve this it necessary to accept a higher deceleration rate in the Driver's area and provide an alternative means of energy absorption in the form of an air bag system.

However it is still necessary to ask the question is a 5g mean deceleration low enough to afford the occupants the necessary level of Passive Safety without significant redesign of vehicle interiors?

FEDERIC B. CARL

LOCOMOTIVE ENERGY ABSORPTION

TRAINSAFE – Locomotive Energy Absorption
Safe Vehicle Structures

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Name and Qualifications
Dipl.-Ing. Federic B. Carl, graduated in mechanical engineering (design of rail vehicles) at Technical University of Dresden
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Relevant experience
Static and crash analysis in the field of crashworthiness design for locomotives over the last three years.

Abstract:
This paper describes the application of crashworthiness design to locomotives and the energy absorption concept.

After an introduction, covering the achieved improvements on locomotive crashworthiness in the past, the operational conditions influencing the crashworthiness of locomotive-hauled passenger trains and the technical locomotive specific aspects and their impact on the crashworthiness design are described. The distribution of collision energy over the train rake – typically high energy absorption required at the train ends and some further energy absorption at each intermediate interface – implies a train-rake with a consistent level of crashworthiness, including the definition of a suitable crashworthy reference train. The general crashworthiness design problem to find an optimum between the necessary energy absorption capacity, the available deformation length, sufficient strength of structural parts and acceptable values of mean acceleration is aggravated in case of application to locomotives. Moreover, solutions have to be found under strict weight limitations and have to consider the economic efficiency.

A further chapter gives an overview about the crashworthiness design of the new Bombardier TRAXX locomotives, their design conditions, the concept of controlled energy absorption and the different features additionally contributing to the crashworthiness. The design was based on the crashworthiness requirements currently laid down in the TSI Highspeed [3], but also incorporates further means of improved protection for the locomotive driver in case of collision with a heavy obstacle with a high centre of gravity, which is typical for real collisions with lorries at level crossings.

Finally, some current and possible future topics for further investigations regarding the crash-worthiness of conventional rail vehicles are discussed. Improvements on the occupants' safety and a clarification of acceleration effects and resulting loads on equipment attachments are necessary for the further standardisation work. Compatibility between different vehicles of conventional rail (anti-climbers) may be another field for further investigations.

Introduction and state-of-the-art

In the last few years, the subject of "passive safety in rail traffic" - i.e. the alleviation of the conse-quences of accidents and improved protection for the occupants of rail vehicles in accidents involving collisions - has achieved new significance, particularly due to research projects (SAFETRAIN [1], TRAINSAFE [2]) and standardisation work (TSI / CEN) at European level. The knowledge gained and the resultant crashworthiness requirements to be laid down in regulations and standards must be considered in the development and design of future rail vehicles, also including locomotives for conventional rail traffic.

There are no consistent European standards currently available, covering the crashworthiness design of locomotives and conventional rail vehicles. The scope of the TSI-Highspeed [3] is currently limited to fixed formed high-speed trainsets (multiple-units), capable to run with at least 250 km/h at designated high speed lines. The CEN working-group TC 256 WG 2 has addressed this topic since 1998 and is expected to present a first draft of the European standard at the end of this year.

Crashworthiness design has become state of the art for multiple-units and fixed formed train-sets, but has also already been applied to locomotives in the past. The known locomotive crashworthiness solutions generally provide:

- ***External energy absorbers*** (deformation elements) at underframe level in front of the head-stock for heavy shunting impacts and smaller collisions with other rail vehicles, intended to act after complete exhaustion of the reversible buffers
- Comparatively ***stiff cab structure*** in order to protect the driver in case of a collision with a heavy obstacle, e.g. a lorry at a level crossing, possibly added by some additional energy absorbers above the underframe level up to the height of the lower edge of the front window.
- ***Obstacle deflector*** with increased static strength and possibly some controlled energy absorption capability in order to protect the locomotive form the risk of derailment in case of collision with small / low obstacles, e.g. cars.

Crash energy absorption of locomotives on market reaches up to appr. 2,3 MJ per vehicle end up to now [4]. This may be sufficient to cover the scenarios TSI-1 and TSI-2 according to TSI-Highspeed [3] for a locomotive with a mass of appr. 80 … 90 t, depending on the characteristics of the train hauled by the locomotive. Therefore, these solutions achieve significantly better protection for the locomotive occupants under specific design conditions, but at the price of high structural weight. In actual accidents with high proportional collision energies or with certain types of heavy, stiff obstacles with a high centre of gravity, crash behaviour cannot longer be controlled without more extensive measures.

The available state of knowledge was the initial point for the development of an improved, new generation of interoperable crashworthy locomotives TRAXX by Bombardier Transportation.

Crashworthiness of locomotive-hauled passenger trains – Operational conditions [1]

Requirements regarding the design of crashworthy railway vehicles are always a function of active safety. With the help of the SAFETRAIN conclusions and recommendations [1] and on the basis of appropriate regulations, these requirements can be set out in vehicle procurement specifications.

The process is relatively simple in the case of railcars, motor train sets or railway traction vehicles, driving trailers and coaches always used in the same configuration, but it is more

[1] This chapter has kindly been contributed by Mr. Dr. Wilfried Wolter, DB Systemtechnik, Brandenburg / Germany

complex in the case of multi-purpose railway traction vehicles or driving trailers and coaches used in multiple combinations. In view of the fact that, in the case of crashworthy vehicles, the kinetic energy released in a collision has to be converted into controlled deformation of designated vehicle zones and / or components, it is necessary to have the best possible energy distribution throughout each train – not least to be able to develop safer vehicles at affordable prices. In principle, achieving this type of optimisation means that the vehicles at the very front or rear of the train have to absorb a substantially higher proportion of the energy released in a collision than the intermediate vehicles. From a technical and economic standpoint, the effect of this is welcome in the sense that the cost of the majority of vehicles to be purchased per train set – the intermediate coaches – will be far less in terms of crashworthiness than for the railway traction vehicles or the driver's cab section of the driving trailer.

The fact that in a crashworthy train the end vehicles behave differently from the intermediate coaches in terms of absorption of the energy released in a collision leads to a number of conclusions as regards future vehicle procurement:

- The requisite crashworthiness of locomotive-hauled passenger trains can only be achieved if the train is made up of crashworthy railway traction vehicles.
- The necessarily higher energy to be absorbed by the end vehicles in the event of a collision involving crashworthy trains will in future be an additional argument in favour of the use of driving trailers, for it will otherwise be necessary to use end coaches with different design from the other coaches in the train consist or a second crashworthy railway traction vehicle.
- To design railway vehicles that are crashworthy, it is necessary to know the train configurations in which they will be used. This implies the need to define reference train formations in relation to the uses planned to enable railway traction vehicles and driving trailers to be designed to meet crashworthiness criteria.

When procuring multi-purpose railway traction vehicles, it will in future be particularly important for railway operators to think ahead in system terms to ensure the long-term flexibility of their vehicles and meet the criteria for access to neighbouring networks. The railway industry will profit from it as well.

Locomotive specific aspects of crashworthiness

The crashworthiness design principles and requirements investigated in different research projects, as for example the main design collision scenarios or the principle of distributed energy absorption within the train-rake, can basically be adopted for locomotive-hauled passenger trains.

Nevertheless, the crashworthiness design of locomotives is influenced by a number of specific technical and operational aspects, which are partly different from the design of multiple-units or other fixed formed train-sets (as described in section 2). The figure 1 gives an overview about these influencing factors and table 2 contains further detailed information about these specifics and their impact on the design.

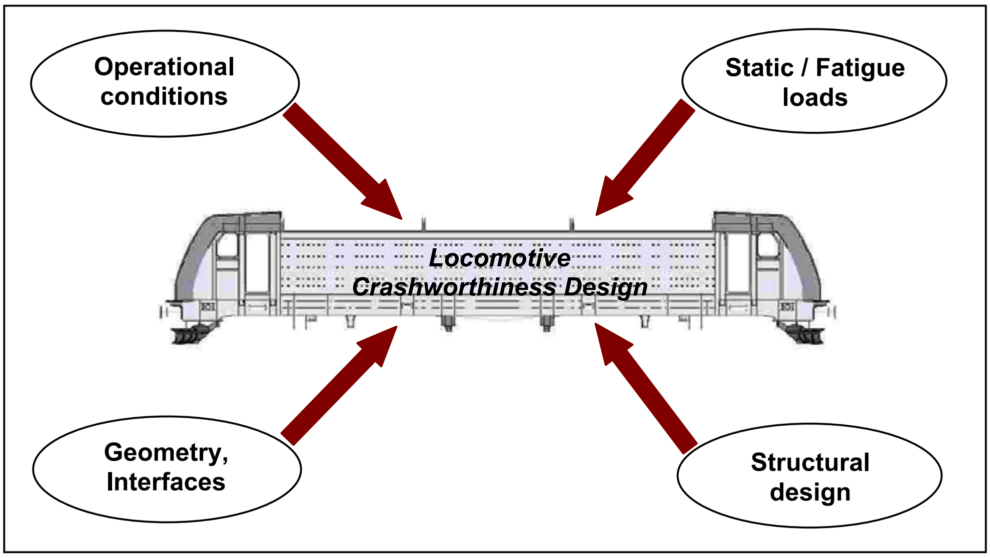

Fig. 1 **Specific aspects with impact on locomotive crashworthiness design**

Characteristic	*Relevance for overall design*	*Impact on crashworthiness design*
1. Operational conditions		
a) No fixed formed train-rake		- Limited possibilities of tuning overall crash behaviour of train-rake - Definition of crashworthy reference train necessary for the design (see section 2)
b) Concentrated power equipment	Higher static and fatigue loads	Additional design condition for structural crashworthiness design
2. Static / Fatigue loads		
a) Normative load requirements	e.g. static buffer load 2000 kN (EN 12663 [5])	Additional design condition for structural crashworthiness design
b) High tractive efforts	Double heading for heavy freight trains	
c) Heavy concentrated masses		dynamic shock behaviour different high loads on attachments
3. Geometry, Interfaces		
a) Symmetry	Locomotive carbody with two identical vehicle ends (cabs)	Same energy absorption on both vehicle ends
b) Compact design (length, mass)	No long aerodynamic nose Small distance between headstock and bogie frame Driver's position near to vehicle end	Available crushing length strictly limited High demands on protection of driver
c) Vehicle overhang	Shall be as short as possible Wheel guiding forces (UIC 518 [6]) Lateral forces at coupling interface	Available crushing length strictly limited
d) Normally equipped with side buffers and screw couplers	Partly different load paths for compressive / draw forces	Clearance for coupler to be maintained ("Berner Raum") Technical solution / compatibility of anti-climbing devices
4. Structural design principles		
a) Monocoque carbody design	Distributed load paths	Structural crushing by local instability → Energy absorption within carbody structure possible
b) Underframe design (non load-bearing superstructure)	Concentrated load paths Comparatively high local stiffness	Collapse by global instability → Energy absorption mainly by add-on elements

Table 2 Locomotive characteristics and their impact on the crashworthiness design

Summarizing table 2, it can be pointed out that the general crashworthiness design problem to find an optimum between the necessary energy absorption capacity, the available deformation length, sufficient strength of structural parts and acceptable values of mean acceleration is aggravated in case of application to locomotives. A number of aspects call for a short deformation length (normal service performance, protection of driver), hence leading to comparatively high deformation forces. Whereas operational and normative load requirements set a lower bound for the deformation force in structural parts, the resulting accelerations lead to high loads on heavy attachments. Moreover, a complying optimum solution always has to be found under strict weight limitations and must consider the economic efficiency.

Crashworthiness design of new Bombardier TRAXX locomotives

Objectives and design conditions

The first application of the new crashworthy carbody of Bombardier TRAXX locomotives is the dual-frequency locomotive class 185.2 for Deutsche Bahn (German Railways - DB Railion) and the multi-system locomotive class Re 484 for Swiss Railways (SBB). Both are 5,6 MW locomotives with a top speed of 140 km/h, a starting tractive effort of 300 kN and a mass in the range of 85 t.

The crashworthiness design has been integrated into existing structures of the carbody as far as practicable in order to minimize additional weight. It increases the protection of the driver in case of collisions (also with heavy obstacles) and reduces the costs for repair after typical low and medium speed collisions with other rail vehicles.

The crashworthiness design of the Bombardier TRAXX locomotives was developed in close cooperation with our main customer, Deutsche Bahn. It is based on the design collision scenarios and specifications according to TSI Highspeed [3], under consideration of a certain reference train. The reference train consists of five crashworthy bi-level coaches with a total mass of 242 t, which is typical for operation in regional traffic on German main lines. Each collision scenario was addressed for the locomotive alone as well as for the locomotive hauling the reference train.

Although both ordered locomotive types are intended mainly for freight service, the carbody design will be used similarly also for other passenger service locomotives of TRAXX, with a top speed of at least 160 km/h. Therefore, a representative crashworthy reference train has been chosen in accordance with the customer, since the crashworthiness requirements can only be applied to a train-rake with a consistent level of crashworthiness.

Energy absorption and crashworthiness design features

The main crashworthiness design features of the new crashworthy carbody of Bombardier TRAXX locomotives are described below and are indicated in figure 3.

The **absorption of energy** is realized in three stages with defined levels of controlled deformation:

1st stage: Buffers with elastomeric spring system **(1)** – more than 0,06 MJ (rev.) per vehicle end

→ *for normal service loads and shunting impacts*

2nd stage: Screw-mounted external deformation elements EST Duplex G1.A1 in front of the head stock (1) – up to 1,7 MJ per vehicle end.

→ *for heavy collisions with other rail vehicles*

3rd stage: Designated crushing zone in the front part of the driver's cab **(2)** - more than 3 MJ, depending on the collision scenario.

→ *Important for heavy collisions, for example with a lorry.*

A high amount of energy absorption is realized through the external deformation elements with high energy absorption capacity, reasonable force levels and low weight. Thanks to this design it is possible to manage the collision energy of the scenarios TSI-1 and TSI-2 without significant structural deformations of the locomotive carbody. Operators benefit from the reduced costs and time efforts for repair due to the modular design with dedicated repair interfaces.

The structural crushing zone was intentionally placed in the front area of the driver's cab in order to take the step to TSI compliant energy absorption at the front end under restrictive locomotive specific design conditions, in order to improve the protection of the train occupants, leaving designated survival zones for the driver. The deformable front area of the driver's cab is designed as a protective cage (4), consisting of sections of strong beams with deformation zones and plastic hinges between them. Hence it is capable to absorb the collision energy with a 15 t lorry acc. to TSI-Highspeed [3] as well as it facilitates the adaptation of contour of the driver's cab front to different heavy obstacles with a high centre of gravity or different geometry and stiffness. It also provides additional energy absorption in case of collisions with other rail vehicles with speeds higher than indicated in the TSI-scenarios.

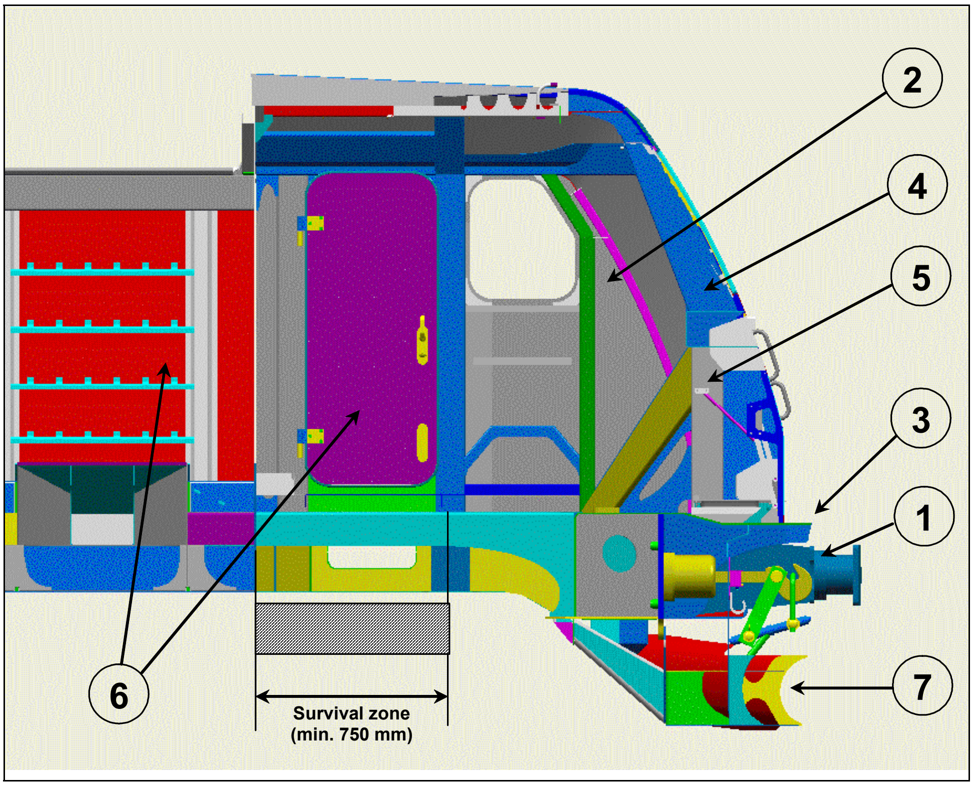

Fig. 3 **Main crashworthiness design features of the TRAXX carbody (for explanation of numbers see text)**

Further features of the TRAXX locomotive carbody contributing to the crashworthiness are:

- **Anti-climbing devices (3)**, capable to work jointly with side buffers of conventional rail vehicles, are provided at each locomotive end and prevent vertical movements and overriding. They are designed to withstand a vertical shear load of 150 kN in accordance with SAFETRAIN recommendations [1].
- A sturdy **front-protection cage (4)** is integrated in the cab structure. It consists of a cross member below the front window (min. static load 700 kN), one cross member above the front window (min. static load 300 kN) and two vertical "collision posts". As indicated above, this protection cage absorbs energy and protects the locomotive driver in case of heavy collisions, e.g. with a lorry and its loading.
- An **anti-penetration wall (5)** closes the gap between the headstock and the cross member below the front window in front of the driver's desk. It is made up from high strength, ductile steel and protects the crew in the cab against the intrusion of aggressively shaped parts.

- The rear area of the cab between the entrance doors (length at least 750 mm) as well as the machine compartment are the **survival zones (6)** for the driver. Additional stiffening in front of the entrance doors prevents global plastic deformations prior to complete usage of the integrated energy absorption of the structure. **Egress and access opportunities** after an accident are maintained even in case of heavy collisions.
- A **combined snow plough and obstacle deflector (7)** at each locomotive end is integrated into the concept of crashworthiness design. The obstacle deflector reduces the risk of a derailment by removing obstacles from the track thanks to its increased static strength. It will deform in a controlled manner under higher loads resulting for example from a collision, thus absorbing energy.

The crashworthiness design of a locomotive carbody like TRAXX requires the application of modern computer design and analysis measures (CAD, FEA – static/crash) with several cycles of optimisation.

Fig. 4 Configuration of the dynamic crash test performed with a mock-up of the Bombardier TRAXX locomotive vehicle end

A dynamic crash test with a speed of 62 km/h and a collision energy of 4,5 MJ to be absorbed by the crashworthy vehicle end has been performed at CNTK (Poland) in order to verify the simulation model and to validate some of the crashworthiness characteristics (fig. 4). The dynamic test was finished successfully, since the collision energy has been absorbed in the designated areas and the survival space remained free from significant plastic deformations. Important parameters regarding the collision behaviour were found to be close to the pre-test simulations.

Potential improvements for future crashworthiness design

Protection of driver in case of collision with heavy obstacle

As indicated in chapter 3, protection of the driver against loss of survival space, intrusion of objects and secondary impact is of special importance for locomotives and other rail vehicles with short overhang. Static design requirements and design collision scenarios TSI-1 and TSI-2 lead to adequate strength and crashworthiness performance on underframe level. But there remains a risk of severe deformations and intrusion into the front of the driver's cab in case of real collisions above the underframe level, since this situation is not addressed by the TSI-3 obstacle (rigid wall) up to now.

Therefore, manufacturers of rail vehicles will currently try to find an economic solution incorporating both:

1. Compliance with existing normative requirements (as minimum demands)
2. Additional measures for different types of heavy obstacles with high centre of gravity

The problem can be approached by an increased static strength of the front of the driver's cab in order to distribute more of the collision energy to the lorry (see chapter 1), but the effectiveness depends on the type and stiffness of the lorry and its loading.

The choice of a more adequate obstacle for scenario TSI-3 than the currently used rigid wall may lead to better solutions. It shall

- be representative for different types of lorries
- have a more realistic behaviour in terms of generated deformations and inertial properties
- and shall be simple for normative description and crash analysis.

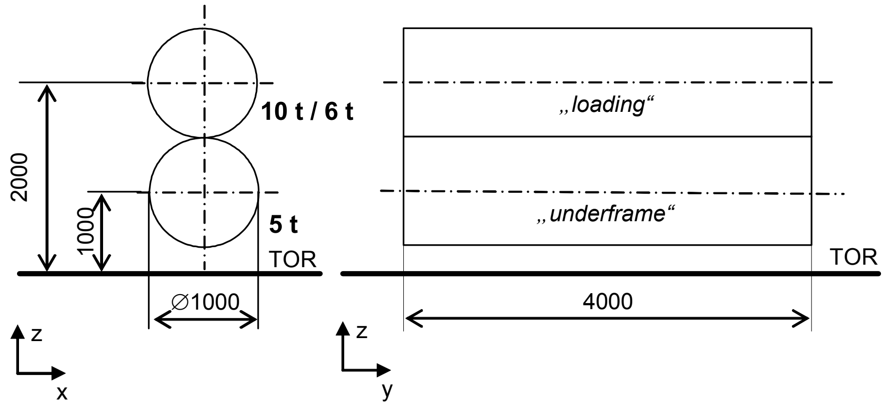

Fig. 5 Example for a rigid two-cylinder obstacle (ADtranz Sweden [7])

One approach, initially applied by ADtranz Sweden for X2000 multiple-units, was a rigid two-cylinder obstacle ([7], see fig. 5). Unless this obstacle gives a more realistic collision behaviour than the rigid wall and favours a design with a high protection for the driver, the uncoupled upper cylinder without any deformability may lead to severe intrusions in case of light rail vehicles, therefore possibly implying unacceptable design restrictions.

French Railways SNCF have performed a number of investigations of collisions with real lorry obstacles. These gave a high accuracy of the real collision behaviour, but each limited to one specific type of lorry (therefore not representative) and too complicate for general application in a standard (description, analysis resources – number of elements due to detailed, asymmetric full-models).

Currently, a new simplified deformable obstacle model, proposed by SNCF [8], is under investigation within CEN/TC 256 WG 2 in order to check if it is generally suitable for application for design collision scenario 3 within CEN and TSI.

Setting sensible specifications regarding the allowable deformations and the maximum mean acceleration in the future standards has to take into account the characteristics of the new obstacle model.

Loads during energy absorption

The crashworthiness design and the optimisation with overall design aspects and structural strength may lead to different mean deformation force levels, depending on the type of vehicle and the specific design conditions, while fulfilling the specified values for mean acceleration, due to different vehicle masses.

May this lead to undesired behaviour in actual collisions between different types of vehicles ?

It can be assumed that this is not a problem, because light rail vehicles to share common tracks with heavier trains (e.g. locomotives or freight cars) will also be designed to meet a collision with a 80 t freight car equipped with side buffers. Since this obstacle is considered as undeformable (only the buffers can contribute to the energy absorption), these vehicles will normally be able to manage the resulting collision energy themselves. Specification of maximum allowable deformation forces in specifications would be an additional design condition probably hardly to comply with in the general optimisation of crashworthiness design.

A different aspect are the methods of averaging the accelerations acting on the carbody structure and the correlation with the static design requirements, e.g. for attachments of equipment. It is the aim that these attachments are capable to withstand the collision shock loads without failure, whereas they are designed for exceptional static acceleration loads against yield (EN 12663 [5]).

This leads to a number of relating questions, which are well known but still unsolved:

- *What are the load characteristics at the attachments (of bogies, racks etc.), which are generated under collision shock loads ?*
- *What is a significant time of a load in terms of attachment's strength ? What is an adequate time span for averaging of acceleration signals ?*
- *How can these be specified in a general manner in future standards, independent from specific design solutions ?*

Anti-climber solutions for rail-vehicles with side buffers

Different principles of anti-climbers for rail vehicles with centre couplers are known and investigated, for example within the SAFETRAIN research project [1], [2]. Ribbed plates are usually positioned at the location of the side buffers and are able to engage with similar anti-climbers as well as with side buffers of conventional rail vehicles. But these solutions are not applicable to vehicles equipped with side buffers.

The typical free circulation of vehicles in conventional rail (no fixed formed train consists) calls for solutions compatible with standard vehicle design (e.g. buffers), since locomotives will be used in combination with different types of coaches or freight cars, or can collide with such vehicles. Solutions engaging the buffers are known and applicable (e.g. [9]), but compatibility between different conventional rail vehicles with different interface geometry may be another topic for further investigations in the context of TSI conventional.

Conclusions

Although there are some specific operational and technical design conditions, crashworthiness design with adequate collision energy absorption is also reasonably applicable to locomotives. The new generation of crashworthy locomotives TRAXX of Bombardier Transportation has been designed according to the crashworthiness requirements of TSI Highspeed [3] and is additionally capable to manage collisions with heavy obstacles with high centre of gravity ahead of current standards.

Improvements on the occupants' safety and a clarification of acceleration effects and resulting loads on equipment attachments are necessary for the further standardisation work.

Compatibility between different vehicles of conventional rail (anti-climbers) may be another field for further investigations.

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DIDIER LEVEQUE & PATRICK JUMIN

SURVIVAL SPACE INTEGRITY

TRAINSAFE - Passive Safety

Subtitle: An example of the experiences return: the equivalent deformable obstacle

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Abstract: The SNCF specifies in passive safety since more than 15 years, in the specification documents linked to its rolling stocks. These requirements resulted from a first state concerning the necessity to protect occupants of the trains in case of collisions, after the accidents as those of the Lyon's train station (1988) and of Voiron (1987).

Considering the return of experiences, from the years which have followed the creation of these specifications, as well as of the analyses of accidents achieved at the national (SNCF) and European (ERRI) levels, requirements have evolved toward a more effective specification in passive safety. So that the design of the rolling stocks permits their good behaviour during the different types of reference collisions, it is imperative to refocus some aspects. The evolution of the heavy obstacle at the level crossing enters in this frame, since the definition of a plane rigid obstacle toward a representative deformable obstacle of the real obstacle behaviour.

After the Port-Saint-Foy (1997) and Neuillé-Pont-Pierre (1999) accidents, the numerical simulation progress have permitted to achieve modelling of these collisions. An orientation has followed toward the specification of a real obstacle in the SNCF's documents of functional specifications. The expected behaviour for these real obstacles have been well targeted. Then we have tried to define a simplified equivalent numerical obstacle at the European level. This obstacle must be integrated to the method of validation of the rolling stocks in passive safety, for the collision against an heavy obstacle at level crossing.

Introduction

The goal of the passive safety is to cover a sufficient number of representative collisions of the most important accidents in gravity and occurrence, once the active safety can not master these dreaded events. The SNCF tries to apply it since more than 15 years, specifying functionalities from which the rolling stocks must answer in order to be ratified in passive safety.

The recent progress at the level of the numeric simulations of accidents, as well as the return of experience on the new rolling stocks, have permitted to refocus and to make evolve these specifications, as well as the method of validation in passive safety.

Therefore, the equivalent rigid obstacle that is applied in order to represent a heavy obstacle during the collisions at the level crossing, is appeared as not representative of this collision type. Therefore, it was necessary to evolve toward an equivalent deformable obstacle more adapted for a coherent design of rolling stocks according to this type of dreaded collision. This new obstacle must be introduced in the new European specifications.

Recall of the passive safety

Refocus the ideas

To absorb a maximum of mega joules of the collision energy, it is well. To have a homogeneous and resistant structure for the zones that are occupied by the passengers, the driver and the crew, while limiting: the overriding, the derailment, decelerations, the intrusion in frontal part and the ruptures of equipment fixings, it is well better. In general, outside of the resistance and the good design of the occupied zone, the minimization of the imponderable effects is obtained with:

- The use of the energy absorption devices at the extremities, crushed in a progressive and controlled manner for efforts much inferior than those necessary in order to crush the protected zones, interchangeable at the maximum, fitted with anti-climbing devices functioning with a vertical offset and a real kinematics of the vehicles.
- The use of an obstacle deflector that must resist and evacuate the low obstacles, without embedding beneath the underframe.
- The use of a frontal window with resistant support on the structure of the driver's cabin.
- The respect of the criterion for the structure and the fixings according to the EN12663.

In the same way, the reference collision scenarios must result from a risk analysis linked to the operating condition. Outside of all specific investigation, it is necessary to apply a representative risk analysis at the European or national level (as for the TSI high speed trains, Safetrain, Safetram,…). These scenarios cannot be seen like equivalent from an energy absorption point of view, but they answer each to a specific configuration of shock (low, high, symmetrical, shift, …). A vehicle designed for only one scenario will never be designed for the other cases of reference (different levels of compatibility). A good structure design is the one that covers the maximum of percentage of case for all types of referenced collisions.

The protection of the occupants of a rolling stock means the one of the passengers, but also of the crew and the driver. It will never be suited that in case of collision, the driver on his seat (important % of collisions cases) is crushed by his desk, for the reference collision scenarios. The driver must be the first actor having to assure the control of the train and the evacuation of the passengers after the accident. It is illusive to want in the same time investigate different types of protection for the driver (Airbag, belt…), and to develop systems of energy absorption that limit the free space in front of the driver's seat. For the rolling stocks as the tram-trains for whom a compression of the cabin is necessary in order to answer to the criterion of visibility in urban traffic, in the same time it is obligatory to think about a solution permitting the move back of the seat (link to the driver's desk, fusible screw with sliding device,…). The protection of the rolling stocks with reversible devices or inter-changeable is not a luxury when the consideration of the maintenance is necessary.

Principles of specifications in passive safety

For the design of the rolling stocks structure the two complementary requirements concern the design in exploitation and in passive safety of the trains.

- In exploitation, the goal is to protect the rolling stock for the current events (traction, compression, lifting,…), that provide the conventional loadings. One assures classically the respect of the yield stress and one design the structure in the domain of the fatigue.

The European EN12663 Standard of July 2001 provides the prescriptions for the structure design of the railway vehicle in exploitation.

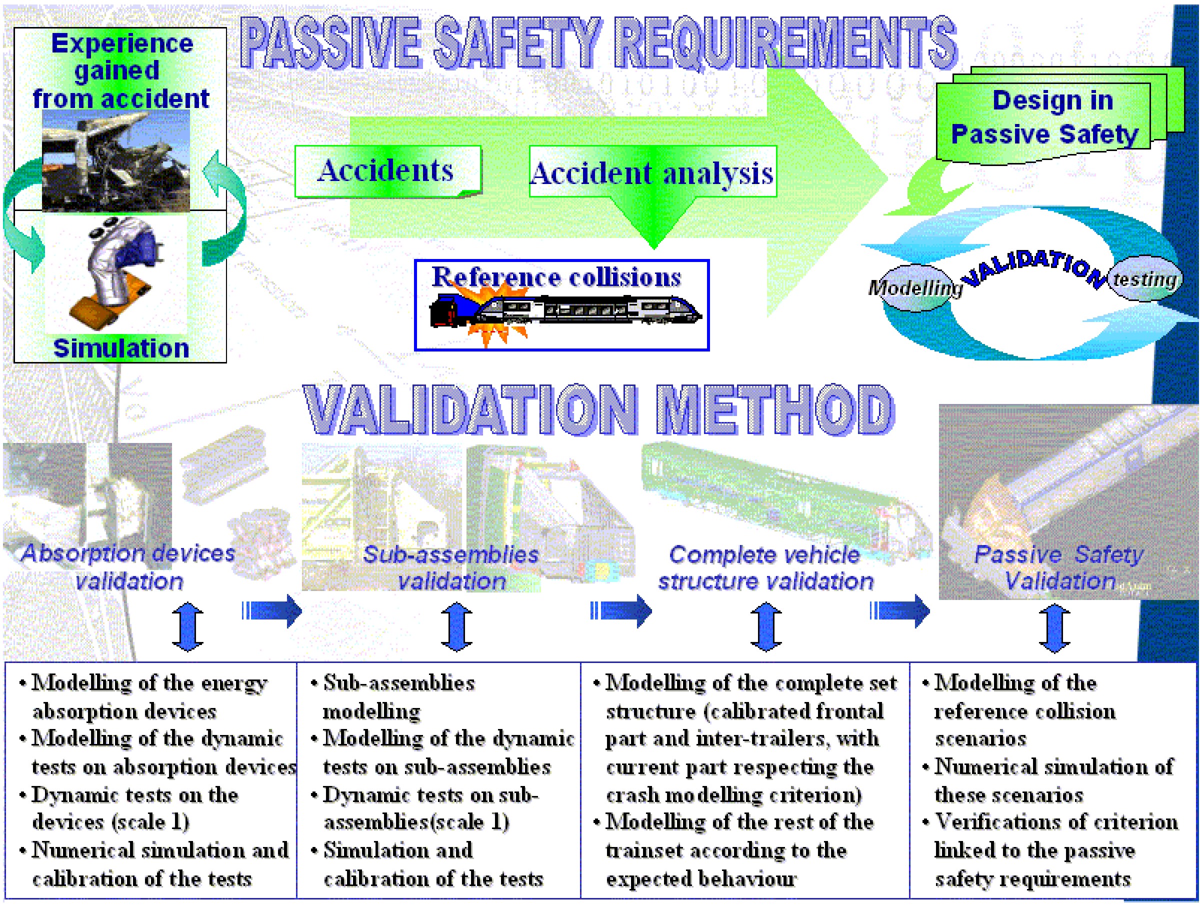

Fig 1 : Rolling stock certification in passive safety

- In passive safety, the goal is to limit consequences of accidents for the trains occupants. The reference collision scenarios are defined for whom the faculty of the rolling stock to resist, to absorb the energy, to limit decelerations, the overriding, the derailment and the intrusion, must be proved. Then, criterion must permit to verify this faculty for all the previous functions. A future European standard under writing must provide prescriptions for the structure design of the railway vehicles in passive safety. It is necessary to note that the recommended method of validation permits to use the numerical models calibrated with the crash tests, to simulate the reference accidents and to verify the criterion.

Collision against an heavy obstacle on level crossing

The analyses of accidents at the European level, as at the French level, show that the most frequent accidents with casualties are the accidents against the heavy obstacles (trucks, bus, tractors), generally on level crossing. If one associates the frequency and the gravity, this collision remains one of the main risks. These accidents, with those against the low obstacles, are those that the active safety has the more of difficulty to master. Besides, it seems that the number of accidents of this type is increasing in France, with the evolution of the road traffic.

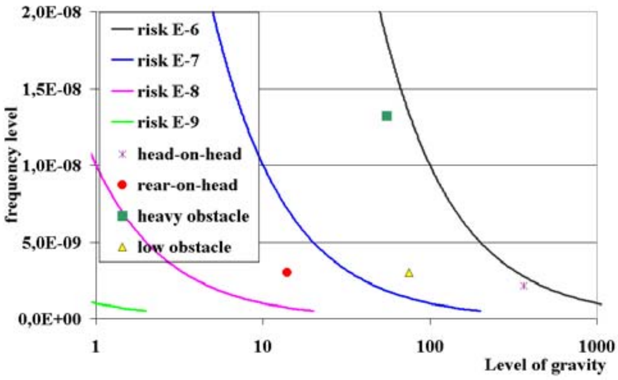

Fig 2 : Mean risk of every dreaded event in France

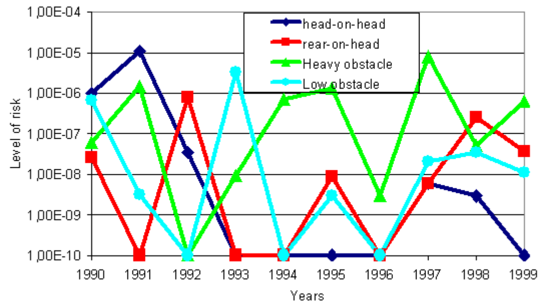

Fig 3: Yearly evolution in France (logarithmic scale)

The B205-1 investigation of the ERRI has permitted to define this risk at the European level, as one of those to take in account for the safety of the occupants of the railway vehicles. Parameters were the following:

Category	2.2	The energy is calculated from $E = \frac{1}{2}\frac{M_1 M_2}{M_1 + M_2}V^2$ where M_1 : Total Mass of the train M_2 : Total Mass of the obstacle V : Relative speed of the collision
Number	80	
Relative S30 **Speed S50** **in km/h S80**	50 68 102	
Energy S50 in MJ **S80**	1.8 5.6	
Mean Mass M_1	126T	
Mean Mass M_2	16.5T	
Mean level of gravity G	28	

For this survey:

- These accidents must define the energy absorption devices in the front of the train.
- This script is the more important in energy to absorb to cover 80% of collisions.
- The mean mass of 16.5 t is supposed rigid.
- This mass is decreased to 15 t as the speed is increased to 110 km/h in order to cover 80% of collisions.

It has resulted on the application of a scenario of a trainset against a plane rigid obstacle of 15 tons at 110 km/h.

Real obstacle

The return of experiences and the numerical simulation of the different accidents against the heavy obstacles in France have permitted to highlight the specific behavior of the railway vehicles submitted to these collisions:

- The impact above the vehicle underframe (without activation of the devices situated at the level of the underframe);

• Distribution of the collision energy between the obstacle and the train (80% of the cases cover an energy absorbed between 1.5 and 2,5 MJ by the train);

• Tipping of the obstacle and its loading over the frontal part of the train (with risk of fall of the frontal window);

• Level of deceleration generally lower to 5g on the duration of the shock.

On no account, the plane rigid obstacle of 15 tons permit to verify these elements. Vehicles designed with this obstacle can present some weakness of structures or over-design that should not be representative of an optimal behavior to cover 80% of collisions against heavy obstacles on level crossing.

Numerical models of heavy obstacles of trailer type (accident of Neuillé-Pont-Pierre) and fuel tank (accident of Port-Sainte-Foy) have been calibrated by the SNCF and proposed in the functional specifications documents, for the new rolling stocks acquisition.

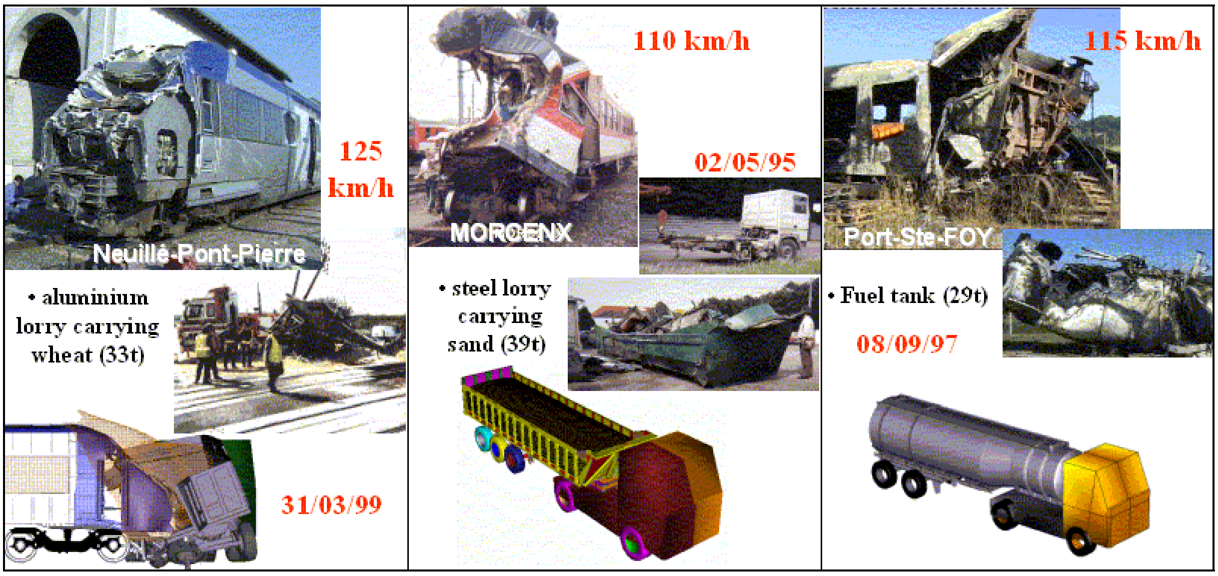

Fig 4 : Development of real obstacle models according to the return of experience

Equivalent deformable obstacle

This last stage of the heavy obstacle definition used in the collision on level crossing, is achieved to definitely replace the maladjusted rigid obstacle of 15 t, but also to simplify greatly the modelling of real trucks.

Therefore, this deformable simplified obstacle must verify the following points:

- verification of the general kinematics and contacts of the real obstacles (with the verification of the holding of the frontal window),
- mass of 15 tons to keep in adequacy with the analysis of risk,
- simple, not costly in calculations and that can be validated on all the softwares.

It is necessary to note that the realization of an equivalent prototype, in order to test it, is not more of actuality. Indeed, the mixed method of the passive safety validation of the rolling stocks doesn't impose the tests of the reference collisions. But it recommends to do the corresponding numerical simulations on calibrated models of trains. The manufacturers are free to buy a truck, to load it with a loading of 15 tons and to launch their vehicle at 110 km/h against this truck.

This last point simplified a lot the development of the equivalent obstacle, with currently a numerical model in phase of acceptance, corresponding to a volume simulating a honeycomb, surrounded by an envelope of steel shells and supported by simple beams.

This model is simple, with a realistic kinematics, not very stiff but sufficiently in order to verify that the rolling stock will be efficiently designed to cover 80% of this collision type.

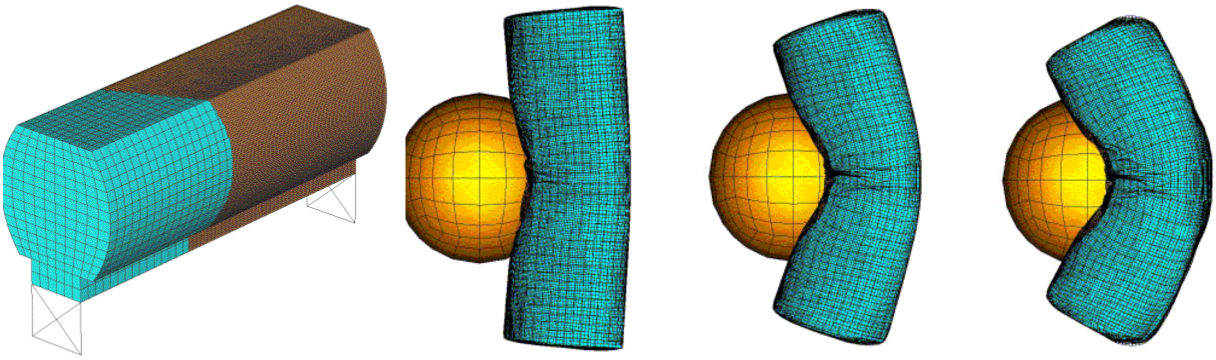

Fig 5 : Equivalent deformable obstacle (Honeycomb Volumes with a steel envelope)

Conclusion

With the wording of the European Standard in passive safety, the new version of the TSI for the high-speed trains, one should have a strong basis in order to design in the best way a railway vehicle in passive safety.

The definition of the equivalent deformable obstacle under verification at the European level must permit, with its integration in these documents, to present an improvement of the passive safety of the rolling stocks.

However, it remains to define clearly the different criterion, permitting to ratify a rolling stock that is equipped in passive safety. It will be necessary to correct the incoherencies and to complete all the existing lacks. It must be made at the level of the Europe, even though the national investigations are useful to act as a basis and for new axis of research in order to improve the specifications in passive safety.

ANDREW BRIGHT

VEHICLE INTERFACE SAFETY
(BUFFERS, COUPLERS AND ANTI-CLIMBERS)

TRAINSAFE
Vehicle Interface Safety (Buffers, Couplers and Anti-Climbers)

Subtitle: Safe Vehicle Structures

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Abstract: This paper is written with the aim of provoking discussion and debate on the topic of rail vehicle interface safety. The designs of existing vehicle interface systems i.e. buffer, couplers and anti-climbers are discussed and recommendations are made.

In passive safety terms vehicle interface systems are of primary importance. If appropriately designed they can help to control the dynamics of any collision or derailment thus enabling other passive safety features e.g. vehicle end energy absorption, to play their role. Successful rail passive safety design requires an integrated holistic approach. The conclusions drawn and questions raised at the end of this paper must not be taken in isolation but must be considered in conjunction with other output of the papers covering the other aspects of safe vehicle structures.

Introduction

This paper is written with the aim of provoking discussion and debate on the topic of rail vehicle interface safety.

Rail vehicle crashworthiness designers aim to ensure that rakes remain upright, connected, in-line and on the ground for as long as possible during a collision or derailment. Firstly, this paper derives desirable passive safety characteristics from this philosophy. Essentially this is a list of the passive safety features needed by a vehicle interface system in addition to the required operational features. Secondly, the designs of existing vehicle interface systems (buffers, couplers and anti-climbers) are compared against the derived passive safety characteristics. Where shortfalls are identified, design modifications to existing vehicles interface systems are considered.

Passive Safety Characteristics

This section of the report discusses the passive safety characteristics relating to rail vehicle interface safety that may be derived from the crashworthiness design philosophy.

Vehicles Should Remain Upright

The belief that vehicles should remain upright leads to the passive safety characteristic that vehicle interface systems should provide rotational restraints between vehicles. Thus if an overturning moment is applied to one vehicle in a rake the moment maybe resisted by the mass and inertia of the other vehicles in the rake.

Clearly if the overturning moment is large enough there is a risk that the whole rake will overturn. This risk is dependent upon the number of vehicles in the rake so it is necessary to consider whether this design requirement should apply to short rakes of two or three vehicles.

This characteristic is also related to bogie retention; rail vehicles are considerably more likely to remain upright if their bogies remain attached.

Vehicles Should Remain Connected

The belief that vehicles should remain connected leads to the passive safety characteristic that vehicle interface systems should be strong in both tension and compression since during a collision or derailment both types of forces can develop at vehicle interfaces. The compressive proof strength of the vehicle interface system is required to be a little less than that of the crush strength of the vehicle ends. This is to ensure that damage is sustained by the vehicles interface system in preference to the vehicle body.

The tensile strength requires more careful consideration. One could argue that the requirement should be as great as practicable to ensure connectivity between vehicles. Of course, it is again necessary to take into consideration the strength of the vehicle body since it is clearly more preferable to have the vehicle interface fail rather than the bodyshell. However, there is also an alternative argument that states that in some instances the tensile failure of an interface is inevitable. On these occasions it may be argued that it is preferable for the interface to fail sooner rather than later. For example, during the Potters Bar, UK derailment the fourth trailing vehicle became detached from the leading three vehicles. This coupler failure probably occurred when the fourth vehicle impacted a bridge parapet. Because of the coupler failure the leading three vehicles were able to continue on the rails until they came to rest some 500m later, as a result no injuries were sustained in these vehicles. Had the coupler failed at a significantly higher load then it is likely that the leading three vehicles would have also been derailed. This may have led to all four vehicles being significantly damaged, [1].

Vehicles Should Remain In-Line

The belief that vehicles should remain in-line leads to the requirement that the vehicle interface system should resist jack-knifing. Most couplers do utilise side control units which limit the lateral rotation of the coupling system and hence the relative rotation between adjoining vehicles. But further work is required in order to determine the magnitude of the force that may be applied to these side control units during a collision or derailment. It may prove impractical to rely solely on the coupler system during high speed events. Other independent methods of transmitting the required moment may be devised.

Vehicles Should Remain on the Ground

The belief that vehicles should remain on the ground during a collision or derailment leads first to the requirement that the vehicle interface system should prevent overriding and secondly to the requirement that the vehicle interface system should help prevent vehicles from becoming temporarily air borne. The dangers of vehicles becoming temporarily air borne were highlighted during the Great Heck, UK accident; significant loss of survival space and fatalities resulted from air borne vehicles landing on top of the other vehicles, [2]. One of the causes of the vehicle interfaces becoming air borne is believed to be the compression wave that travels down a rake following a head-on collision. The compression wave is analogous to the wave that can be made to travel down a rope when one end of the rope is moved rapidly.

Past research has tended to focus primarily on the prevention of override thus a lot less is currently known about the mechanism which cause vehicles to become temporarily air borne. Thus it is not known whether any existing vehicle interface system is particularly successful at preventing vehicles from becoming air borne during high speed collisions.

Component Design for Inter Vehicle Safety

In this section the designs of existing vehicle interface systems (buffers, couplers and anti-climbers) are compared against the derived passive safety characteristics. Where shortfalls are identified design modifications to existing vehicles interface systems are considered.

Buffers

Side buffers are now rarely fitted to new rolling stock but many are still in use on older rolling stock in countries throughout Europe. Side buffers primarily fulfil operational role. They transmit compressive forces between vehicles. They are used on vehciles where the coupling system does not have the ability to transmit compressive loads and they are used during depot shunting operations. Side buffers typically consist of a large oval, curved buffing plate connected to a short piston. The short piston does however enable a small degree of energy absorption that is beneficial in very low speed impacts (heavy shunts).

The problem with buffers is that they tend to increase the propensity of vehicles to override. During a collision the piston has a tendency to deform plastically close to its connection with the buffing plate. This allows both buffing plates to rotate. The lower buffing plate thus forms a ramp over which the upper buffing plate is able to slide. The curved shape of the plates means that only a very small initial vertical offset is required. In this manner one vehicle underframe is able to climb on top of the other, [3].

Buffers have been shown to be capable of inducing override even at relatively low speeds. For example, in 1962 at Coppenhall Junction, UK a diesel locomotive impacted the rear of a rake of electrically hauled Mark 1 (all steel) passenger vehicles. The collision speed was believed to be only 10 km/h (6 mph). Due to the impact the two rear Mark 1 vehicles overrode one other killing 18 passengers and seriously injuring 34, [4].

Figure 1: Overriding at Coppenhall Junction, UK, 1962

Side buffers are not the only concern; research has shown that certain types of vestibule buffers can also increase the propensity of vehicles to override, [3].

In my opinion there is a need both to prohibit the use of side buffers on new vehicles and to review all instances where side buffers are still in use. It may be possible to simply remove some of buffers because operationally they are no longer really required. Certainly in all instances the risk should be appropriately evaluated.

The presence of side buffers also prevents serrated box style anti-climbers from being fitted. However perhaps it is possible to turn this apparent design conflict into a design opportunity. Many side buffers are only used for shunting operations in the depot or for vehicle recovery. It therefore ought to be possible to design a novel system that combined the two functions.

Many freight wagons still use draw hook and side buffers. The cost and benefit of replacing these with a more modern type of central coupler should be investigated. Of course at freight wagon intermediate interfaces there is no risk to passegers due to overriding. In fact one might imagine some cargo's to be efficient energy absorbers. This is OK if the freight wagon is carrying a hopper full of coal but not acceptable if the freight wagon is carrying a flammable liquid or a nuclear waste flask.

Couplers

Operational Requirements

The primary role of the coupler is an operational one. Central couplers provide a mechanical connection between two adjacent rail vehicles. Their primary function is to transmit tensile and compressive forces between vehicles. Central couplers also prevent the two vehicle bodies from coming into contact during normal operations.

Couplers also utilise a reversible energy absorption system that limits the peak dynamic loads transmitted between vehicles during normal operations, in particular during heavy shunts. This is achieved by the use of gas-hydraulic or elastomeric elements. Modern couplers also provide pneumatic and electrical connectivity.

Central couplers are now commonly found on all types of rail vehicle from tram to diesel locomotive. On most new vehicles they are used as an alternative to the draw-hook and side buffer arrangement.

Collision and Derailment Requirements

In the majority of head-on collisions the central coupler is the first component to be impacted. Further, at intermediate interfaces, the coupler is the only permanent structural connection between vehicles. For these reasons the central coupler has an important role during the early stages of collisions and derailments.

Many modern couplers contain capsules which are able to absorb energy in an irreversible manner. The use of these capsules has several benefits:

- Firstly in a light collision they may be able to absorb all the kinetic energy of the collision thus preventing costly bodyshell damage.
- Secondly the capsules reduce the initial peak of the deceleration pulse transmitted through the rake.
- Thirdly as the capsule absorbs energy the length of the coupler decreases this brings the two vehicle ends closer together thus allowing other safety features, for example, serrated box style anti-climbers to contact one other and play their role.

The energy absorption capacity of many coupler capsules used in Europe is around 100kJ. Given that the length of most couplers is around 500mm and their collapse force should be at least 2MN. I consider it ought to be possible to design a coupler with energy absorption capacity of at least 500kJ (assuming a stroke efficiency of 50%).

Since the coupler is the only permanent structural connection between vehicles the job of providing roll over restraint naturally falls to the coupler. Thus the torsional moment carrying capacity of the coupling system, including its connection to the vehicle body should be greater than the moment required to roll a vehicle. Alternatively, it may be possible to develop other methods of transmitting torsional loads between vehicles.

It is worth noting that the locking mechanism for coupler heads should be robust. It should be ensured that couplers do not un-lock if vehicles do overturn or become air borne. For example, the locking mechanism should not rely on gravity.

Anti-Climbers

Anti-climber is the term given to a device or system that allows vertical forces to be transmitted between adjacent vehicles during a collision or derailment. Current UK Standards, [5], require anti-climb devices and their supporting structure to be capable of transmitting 100kN. This requirement was derived from the study of relatively low speed impacts, i.e. less than 30mph, (48kph). However, further research is needed to determine the vertical forces that are likely to be developed between vehicles during a higher speed impact. Initial research using two-dimensional mass & spring modelling has indicated that the vertical forces developed can rise as high as 1MN, for short durations, [6].

Serrated Front Plate Anti-Climbers

Serrated front plate anti-climbers are a common form of anti-climber. Typically for each vehicle end they consist of two horizontally ridged square plates. The plates are connected to the headstock at approximately the location where you would expect to find the buffers on older stock.

Modern rolling stock uses this type of anti-climber at the leading ends and occasionally at the intermediate interfaces. There are several concerns with this type of anti-climber:

- Firstly, there are no standards controlling the precise height and transverse location of anti-climbers. Thus if two different vehicles types are involved in a head-on collision it is unlikely that either of their anti-climbers will be effective. Further there are no standards controlling either the pitch or the shape of the serrations.

- Secondly, because the serrations run in a horizontal direction they cannot control any lateral forces that develop during an incident. Engaged anti-climbers are free to slide over one another laterally. Thus this type of anti-climber is not capable of maintaining lateral alignment. In addition if there is a vertical offset present between the engaging anti-climbers this offset will remain constant.

Cup & Cone

A cup and cone style of anti-climber can correct and then control the level of vertical and lateral misalignment between colliding vehicles. When each cup and cone is fully engaged the two vehicle underframes will be perfectly aligned. This issue is important since the underframe usually contains most of the energy absorption capacity of the vehicle end. With the underframes aligned the collapse will be axial and more energy should be absorbed.

A disadvantage of the cup & cone style anti-climbers is that unlike serrated front plate style anti-climbers they cannot easily be designed to include energy absorption.

Anti-climb through the Coupler

Many modern vehicles use the coupler to provide anti-climb restraint at intermediate vehicle ends. Vertical anti-climb forces are transmitted from the coupler interface through the coupler and into the vehicle end. This option usually requires local strengthening of the headstock coupler aperture (letterbox).

This method benefits from the fact that during a collision or derailment no pre-requisites are required before it can begin to work, i.e. the method does not rely on the coupler system reducing in length and the vehicle ends coming together unhindered. The method does however allow some relative vertical movement between vehicles; this is required for normal operation.

Median or Spanning Bogies

The French TGV utilises median bogies each of which supports the ends of two adjacent vehicles. This type of vehicle interface removes the need for buffers, couplers and anti-climbers. The connection between the two adjacent vehicles is able to articulate (i.e. rotate about the vertical axis) but all other degrees of freedom are restrained. Because adjacent vehicles are connected by a bogie and not by a coupler the connection is naturally strong in both tension and compression. The system also counteracts the rotation of the bodyshell around the trainset axis, thereby significantly reducing the likelihood of any vehicle rolling. In addition the system is resistant to jack-knifing. Thus the rake is much more likely to stay upright, connected and in-line during a collision or derailment.

The main disadvantage of this system is that energy absorption capacity can only be located at the leading ends rake. No energy absorption will occur at the intermediate ends.

Conclusions

This paper began with the following philosophy: rail vehicle crashworthiness designers aim to ensure that rakes remain upright, connected, in-line and on the ground for as long as possible during a collision or derailment.

From this philosophy a list of desirable passive safety characteristics for vehicle interface systems was derived:

- Vehicle interface systems should provide rotational restraint between adjacent vehicles to help prevent vehicle overturn.
- Vehicle interface systems should be strong in both tension and compression.
- Vehicle interface systems should provide rotational restraint to help prevent jack-knifing.
- Vehicle interface systems should help prevent overriding.
- Vehicle interface systems should help prevent vehicles from becoming air borne.

The following key issues were derived from studying existing vehicle interface systems:

- Side buffers are known to promote override. There is thus a need to properly evaluate the risk for all vehicles which currently have side buffers fitted.
- The minimum and maximum tensile and compressive strengths of the coupler system should be carefully defined.
- The torsional moment carrying capacity of the coupler system should be greater than the moment required to roll a vehicle. Alternatively, it may be possible to develop other methods of transmitting torsional loads between vehicles.
- It should be ensured that coupler heads do not un-lock if vehicles overturn or become air borne.
- Standards should control the location, size and shape of serrated front plate style anti-climbers.
- Anti-climbers that provide better control of lateral and vertical misalignment should be considered.
- Further research is needed to determine the mechanisms by which vehicles can become temporarily air borne during high speed accidents.

- TGV style median (spanning) bogies remove the need for buffers, couplers and anti-climbers. The resultant passive safety interface has several positive passive safety attributes.

This paper thus serves as an introduction to the following questions:

- Are there any additional desirable vehicle interface system characteristics?
- How well do existing vehicle interface systems meet these derived characteristics?
- How well do existing standards control these characteristics?
- What are the business benefits in ensuring that vehicle interface systems exhibit the passive safety characteristics identified?
- What are the priorities for future research activity?

References

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[2] ***BRIGHT, AP***: *'Selby Incident Crashworthiness Investigation'. Atkins Report BK0636/R001, Issue 01, July 2001.*

[3] ***BELL, HK***: *'Mark 1 Crashworthiness: 'Investigation into Relative Contribution of Modifications'. Atkins Report BK0507/R001, Issue 01, November 2001.*

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AMAR AÏNOUSSA

A DISCUSSION OF THE LEVEL CROSSING COLLISION AND TRAIN TO TRAIN COLLISION SCENARIOS

TRAINSAFE – A discussion of the level crossing collision and train to train collision scenarios

Subtitle: Safe Vehicle Structures

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Abstract: The limitations of the 15T rigid wall level crossing collision scenario are exposed and a case for more realistic deformable obstacles is made. A re-assessment of the train to train collision reference speed is suggested based on the *recommendations* of the Safetrain project.

Introduction

Today in Europe, most new trains have some form of passive crashworthiness capabilities built-in. Dedicated National standards and code of practices born out of experiences and improving practical state of the art design capabilities and tools have been in used for many years. A European Technical Specification for Interoperability (TSI) addressing among other things the crashworthiness requirements of High Speed rolling stock [Ref. 1] has been issued while a dedicated crashworthiness European standard complementing the strength requirements detailed in 'Euronorm EN 12663' [Ref. 2] is being drafted as we speak. This European standard is being developed to bring some further harmonisation within the European interoperability framework.

A collision is a sequence of events and effects:

Train to train collision scenario
Large obstacles level crossing collision scenario
Small obstacles level crossing collision scenario
Collapse initiation → peak forces and duration
Structural collapse (controlled)
Deceleration levels
Anti-climbing
Escape routes (driver route obstruction – burst through door)
Derailment
Passenger and crew containment
Roll over
Equipment retention
Crew and passenger injury levels
Fire
Smoke
Etc…

The following discussion will concentrate on the passive safety aspect of the collision and more specifically on the base criteria associated with the level crossing crash scenario and the train to train crash scenario. The perceived shortfalls of the present arrangements and criteria are discussed.

2 Large obstacles level crossing collision scenario: *A case for deformable obstacles*

Opening

A debate has been going on for quite sometime with regard to the suitability and interpretation of the High Speed TSI 3rd collision scenario requirement. This collision scenario is intended to represent the collision at a level crossing between a train and a large obstacle such as a high sided lorry. Presently the standard prescribed a collision with a 15T rigid flat surface. This load case can be illustrated using the cab developed during the Safetrain project [Ref. 3], as follows:

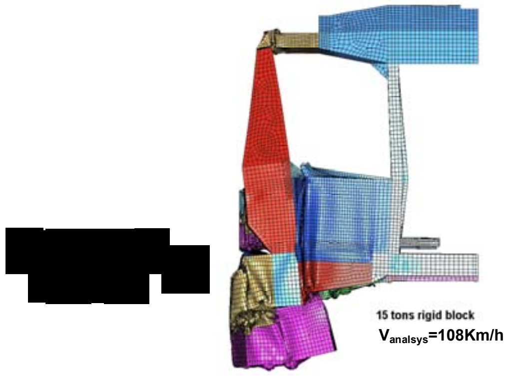

Fig. 1 Train safe cab against a rigid wall collision simulation

The energy absorption prediction is unreasonably high and all the deformations are confined to the areas where the cab and the rigid wall have first contacted i.e. predominantly on the leading end of the underframe. Very limited deformations are recorded in the upper part of the cab. This is in contrast to documented real collisions events as pictured below, where it can be asserted that the underframe (□) does very little in reacting the obstacle while the cab (O) above floor takes the brunt of the impact. This is linked to the 'roll-in' effect of the obstacle when struck by the colliding train.

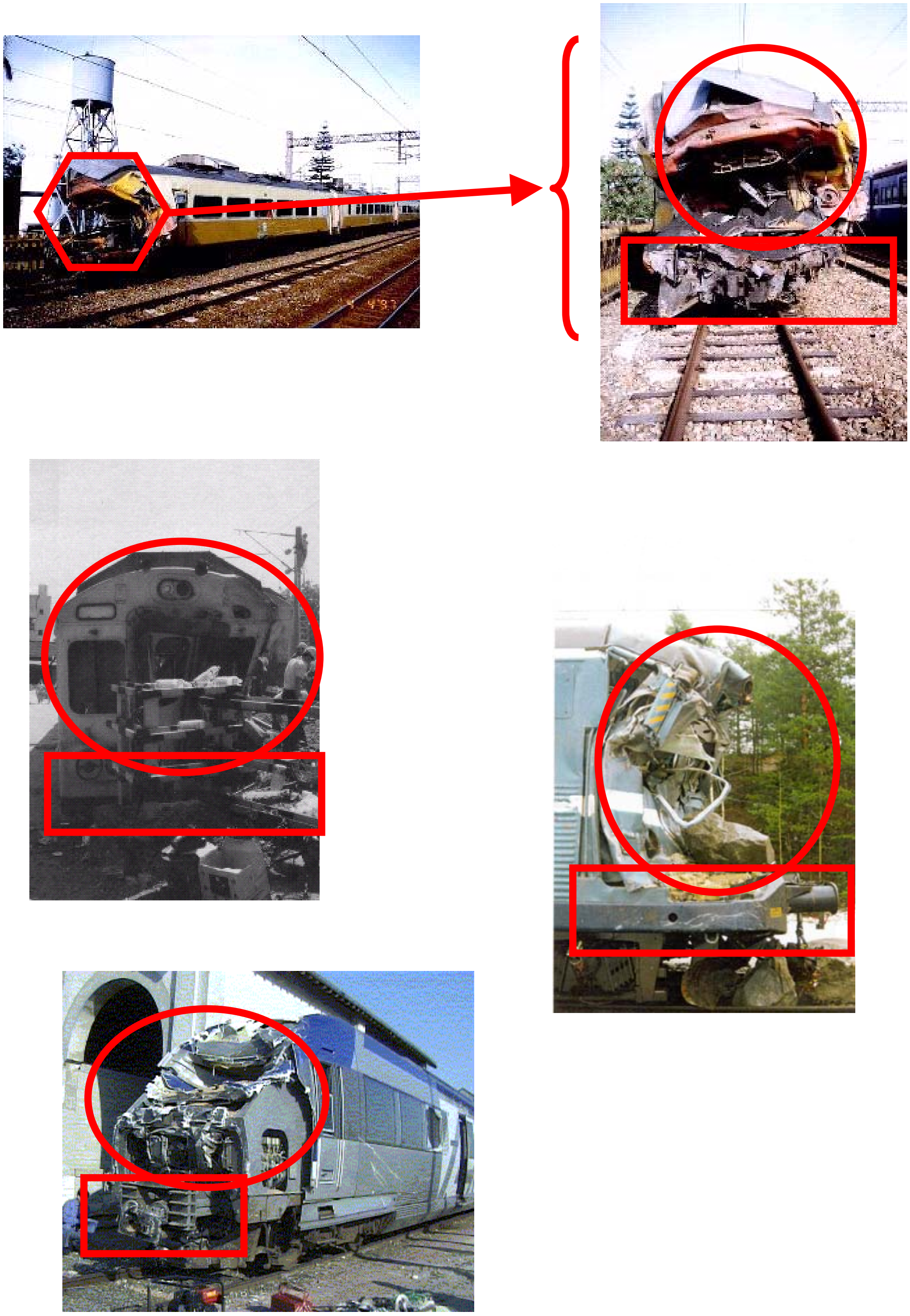

Fig. 2 Typical high sided obstacle collisions at level crossings

Discussion

In 1998, with reference to the 15T rigid wall obstacle, the European Rail Research Institute (ERRI) had already stated the need of a rigid-mass substitution model corresponding to the energy absorption characteristics of a road vehicle [Ref. 4]. SNCF has made several 'numerical' models of high sided lorry available:

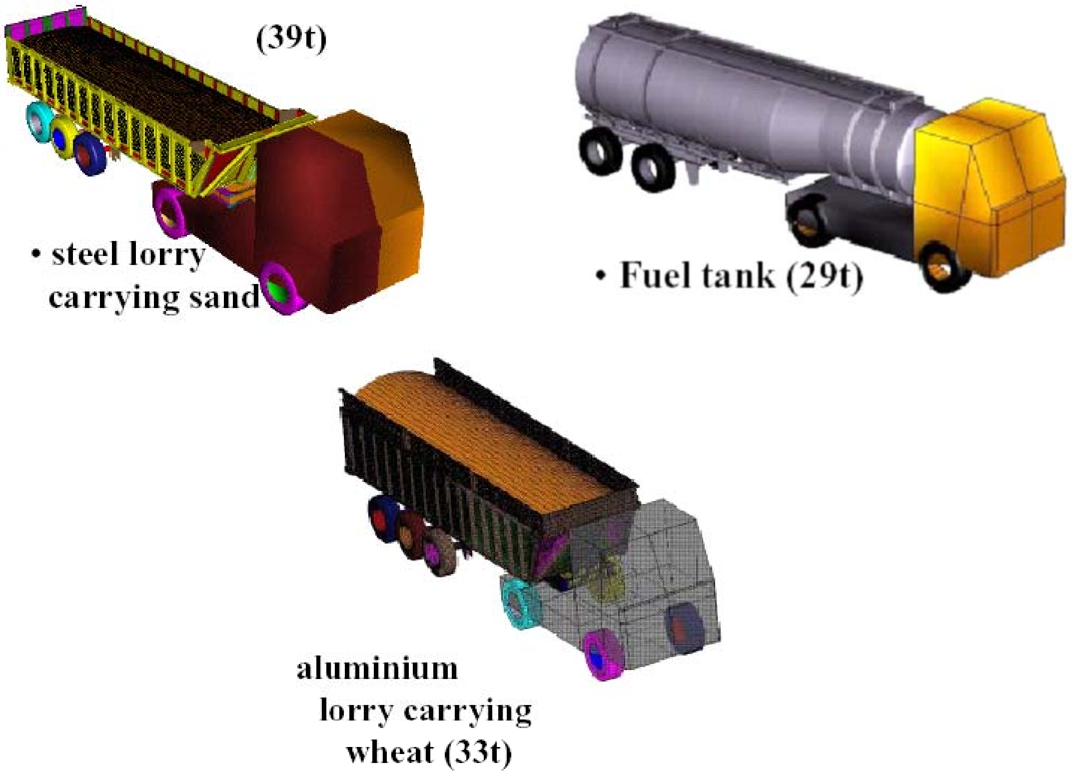

Fig. 3 Examples of available lorry models

For example, in the Safetrain cab with the tanker collision case at 136Km/h, the following deformed cab is obtained:

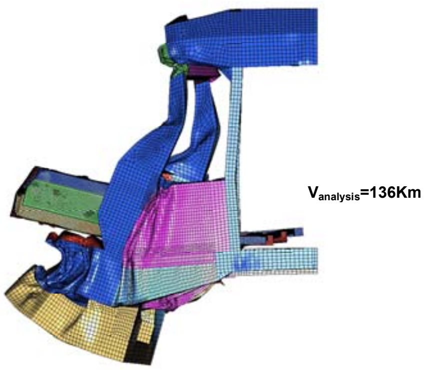

Fig. 4 Safetrain cab model against tanker model collision

In this instance, the predicted deformations of the cab cell are comparable to those recorded in real accidents. Unlike the rigid wall scenario, a realistic level of 'structural' intrusions of the cab space has been captured highlighting potential weaknesses of the cab structure. Furthermore, the predicted energy level absorbed by the cab is much higher under the rigid wall load case than the 'real' deformable obstacle as in the rigid wall load case scenario the obstacle energy absorption and deformation capabilities are simply ignored (Fig. 5). Over the past years, SNCF has carried extensive work on this subject, fuelling an on-going constructive debate.

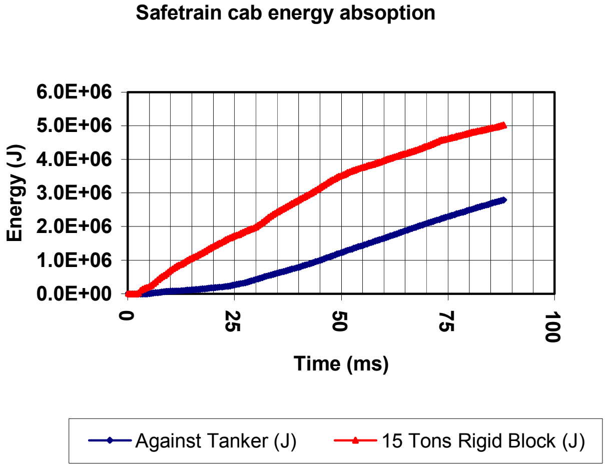

Fig. 5 Energy absorption comparison between the rigid wall and a deformable obstacle collision scenario

The 'real' models (Fig. 3) while more realistic are however complex and difficult to condition. They are however useful and necessary for the calibration of simpler and easier to condition models. Such simplified obstacle models are being developed with success. For example Bombardier Transportation has developed such a preliminary 'simplified' model (Fig. 6) to evaluate the feasibility and merits of such an approach [Ref. 5].

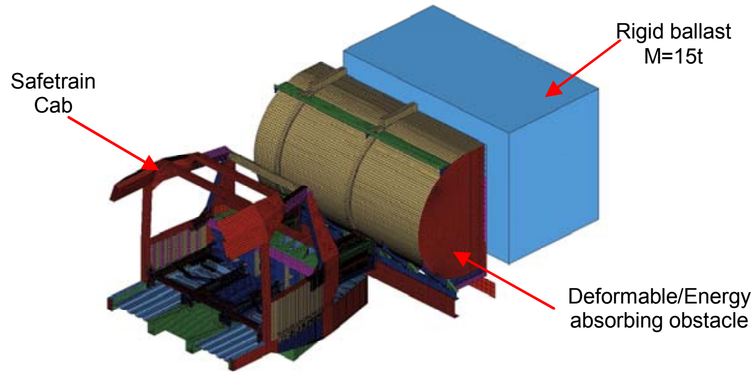

Fig. 6 Simplified deformable obstacle

The 'simple' calibrated model was tested against the Safetrain cab and yielded the following deformed structure:

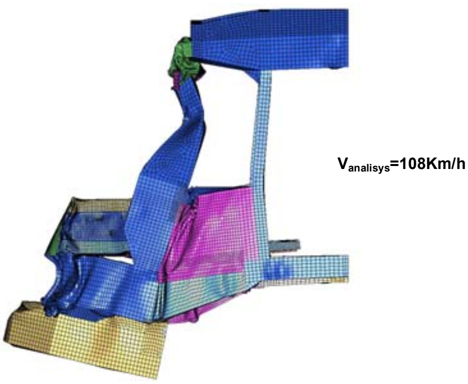

Fig. 7 Resulting deformed Safetrain cab

The proposed deformable 'simple' obstacle model has captured the cab space 'invasion' associated with the roll effect of the obstacle inherent to such collisions [Fig. 9]. Compared to the rigid wall load case, a deformable energy absorbing obstacle produces realistic deformations.

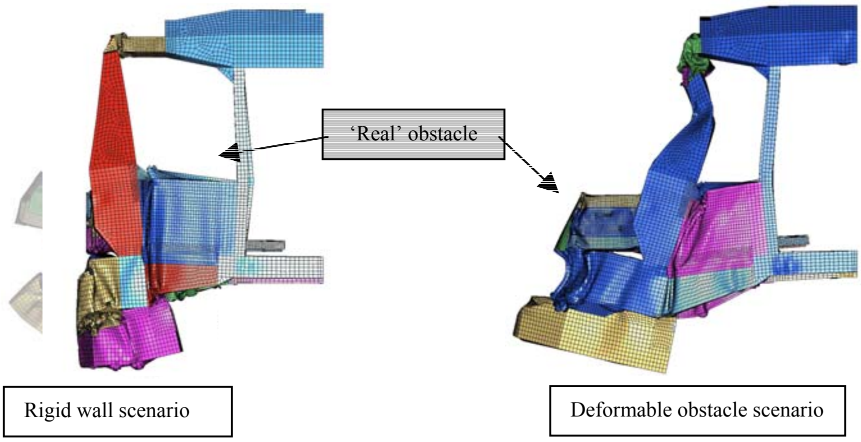

Fig. 8 Deformed Safetrain cab

Furthermore, the predicted energy level [Fig. 9] absorbed by the cab during a simulated collision with early *iterations* of the 'simple' deformable obstacle configuration, unlike the rigid wall, is close to that associated with the reference 'real' obstacle.

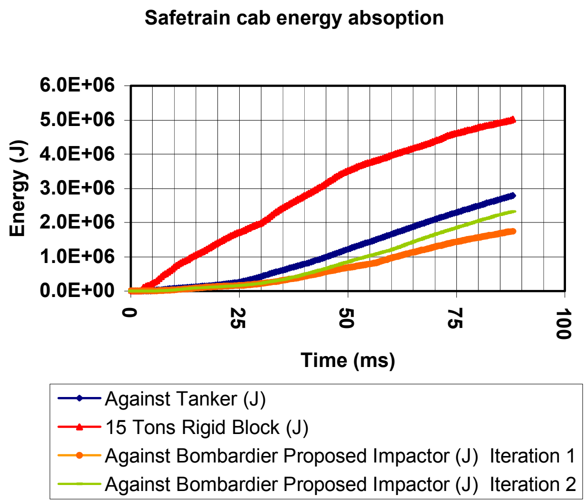

Fig. 9 Energy absorption comparison

Closure

During a collision between a train and a heavy high sided obstacle, the obstacle impacts the leading end of the underframe of the train and then tends to roll into the path of the train interacting with and 'crushing' the upper structure of the cab while being pushed. The deformable obstacle duplicates closely the mechanism observed in real level crossing collision accidents. This is not achieved with the 15T rigid wall scenario. 'Fully' deformable realistic obstacles are available enabling the calibration of simpler deformable obstacle models. Two parts 'rigid/deformable' reduced mass obstacles, similar to the two cylinders type arrangement for example, are also being investigated with promising results.

The CEN/TC 256 WG2 working group charged with drafting a crashworthiness European standard to bolster and complement the strength requirements detailed in EN 12663 [Ref. 2], is presently addressing and discussing this specific issue.

3 Train to train collision scenario: *What reference collision speed?*

Opening

The reference collision speed between two *'identical'* trains is, according to *the 1st collision scenario* of the 'High Speed TSI', 36Km/h.

Discussion

The European Union Safetrain project has concluded that its most representative reference train to train collision scenario should be carried out at 55Km/h [Ref. 3]. This speed value was the result of a statistical analysis of the accidents having occurred in Europe between 1991 and 1995. This work sponsored by the UIC Passenger Commission was carried out by ERRI [Ref. 4]. Meanwhile, the British Group Standard GM/RT2100 specifies a collision speed of 60Km/h [Ref. 6].

The 36Km/h collision speed has now also found its way into the draft being developed by the CEN/TC 256 WG2 working group on the basis that *it is used in the TSI High Speed standard*. Yet, as mentioned above, the comprehensive work undertaken within the Safetrain project advocates a higher speed of 55Km/h.

Closure

A number of questions therefore arise:

- Is the 36Km/h reference collision speed statically supported?
- How was this speed limit substantiated?
- Were the Safetrain findings to conservative?
- Were the results of the ERRI statistical analysis misinterpreted?
- Is the 36Km/h collision scenario assumption valid?
- Is the 36Km/h collision scenario assumption sufficient for a safe design?
- Should the train to train collision speed be raised to 55Km/h?

Conclusion

The heavy obstacle level crossing collision scenario and its shortfalls are being considered and debated by the CEN/TC 256 WG2. It is obvious that the original 15T rigid wall load case scenario is not representative and ought to be regarded as a preliminary sizing tool only. The cab cell is exposed to structural intrusions and therefore survival space reduction not captured by the rigid wall obstacle. An economical and representative numerical reference obstacle (or a set of) with deformable characteristics and able to duplicate the rolling-in motion can be and have been developed. Such representative obstacles are achievable as shown by Bombardier Transportation and the extensive work carried out on the subject by SNCF.

With regards, to the train to train collision scenario, the reference collision speed ought to be re-assessed taking into account the ERRI findings and the recommendations made by the Safetrain project. Beside the questions raised in the discussion here above, the database of accidents used by ERRI could be extended to cover a wider period and the statistical analysis re-assessed accordingly.

The Trainsafe project gives the railway rolling stock industry the opportunity to question, reflect on and clarify the issues herewith raised for safer trains.

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2. ***BS EN 12663:** Railway applications – Structural requirements of railway vehicle bodies, 2000*
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4. ***ERRI B 205.1/RP 1:** ANALYSIS OF COLLISION ACCIDENTS – Statistical analysis of accident database. Definition of reference accident scenarios. April 1998*
5. ***BOMBARDIER TRANSPORTATION Ltd,** Collection of internal development work, Derby, UK, 2003*
6. ***Railway Group Standard GM/RT 2100 Issue 03**: Structural Requirements for Railway Vehicles*

APPENDIX

A ENERGY ABSORPTION

B LOCOMOTIVE ENERGY ABSORPTION

C SURVIVAL SPACE INTEGRITY

D VEHICLE INTERFACE SAFETY

E DERAILMENT

Energy Absorption
Is prescription constructive?

Safe Vehicles Structures Workshop
28 April 2004
The Belfry – UK Midlands

BOMBARDIER TRANSPORTATION

Introduction

- No such thing as a train without crashworthiness
- Or Energy Absorbing capability
- All structures have an inherent level of crashworthiness
- How do we manage and design it into the structure
- Where does the definition of Energy Absorption end

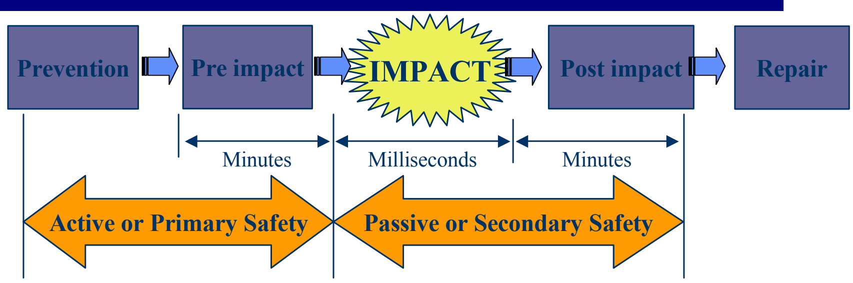
BOMBARDIER TRANSPORTATION

The Legislation

- Rail vehicle crashworthiness legislation is produced in order to save the lives or lessen the injuries of the occupants during the prescribed collision scenarios:
  - Train to train
  - Train to locomotive
  - Large obstacles level crossing
  - Small obstacles
- To reduce the deceleration during these scenarios it is necessary to absorb energy forward of the driver.
- The use of Energy Absorbing Units is key to this criterion.

BOMBARDIER TRANSPORTATION

Active & Passive Safety



Active Safety:-

- Signalling
- Obstacle detection
- ERTMS

Passive Safety:-

- Restraint Systems
- Protection Systems
- Vehicle Interior Layout

BOMBARDIER TRANSPORTATION

Laws of Motion

Velocity km/h	Velocity m/s	Velocity into Solid Wall m/s	Displacement @ 5g m	Total Absorber Length m (70/30 ratio)	Minimum Total Cab Length m (Absorber + Survival Space)
36.00	10.00	5.00	0.25	0.36	1.11
55.00	15.28	7.64	0.59	0.85	1.60
60.00	16.67	8.33	0.71	1.01	1.76
120.00	33.33	16.67	2.83	4.05	4.80

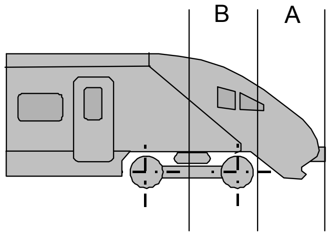
BOMBARDIER TRANSPORTATION

Compression Ratio

- The calculation assumes a 70/30 ratio of length to absorb energy against fully compressed length

BOMBARDIER TRANSPORTATION

Cab Layout 1



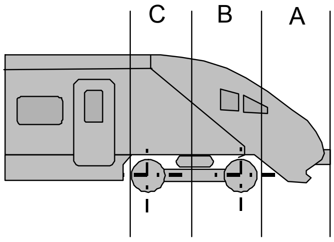
- Split into two sections
- A is the energy absorbing section
- B is the 0.75m driver's survival zone

BOMBARDIER TRANSPORTATION

Short-nosed vehicles

BOMBARDIER TRANSPORTATION

Cab Layout 2



- Split into three sections
- A is the energy absorbing section
- B is the 0.75m driver's survival zone
- C is the secondary energy absorbing zone

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Alternative Energy Absorption

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Conclusions

- Energy absorption can produce mean deceleration level of 5g in main occupant or passenger tubes
- Difficult for the driver’s zone.
- Vehicle Crashworthiness legislation is defined to save the lives or lessen the injuries
- Vehicle structure validation should use occupant injury levels
- Passive safety systems could be deployed to protect in the impact phase
- Necessary to accept a higher deceleration rate in the Driver’s area
- Provide an alternative means of energy absorption - air bag system
- Is 5g mean deceleration low enough to afford the occupants the necessary level of Passive Safety without significant redesign of vehicle interiors?

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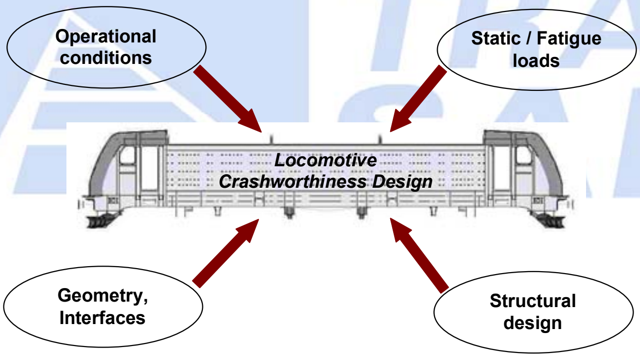
Safe Vehicle Structures - Locomotive Energy Absorption (1)

- **State of the art of locomotive crashworthiness**
  - External energy absorbers
  - Stiff cab structure
  - Obstacle deflector
- **Locomotive specific aspects of crashworthiness**



Design objective:

Optimal overall solution under strict weight limitations !

F.B.Carl, 28 April 2004

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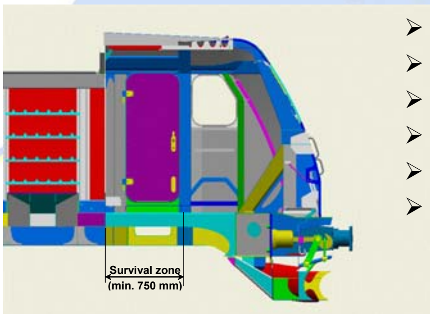
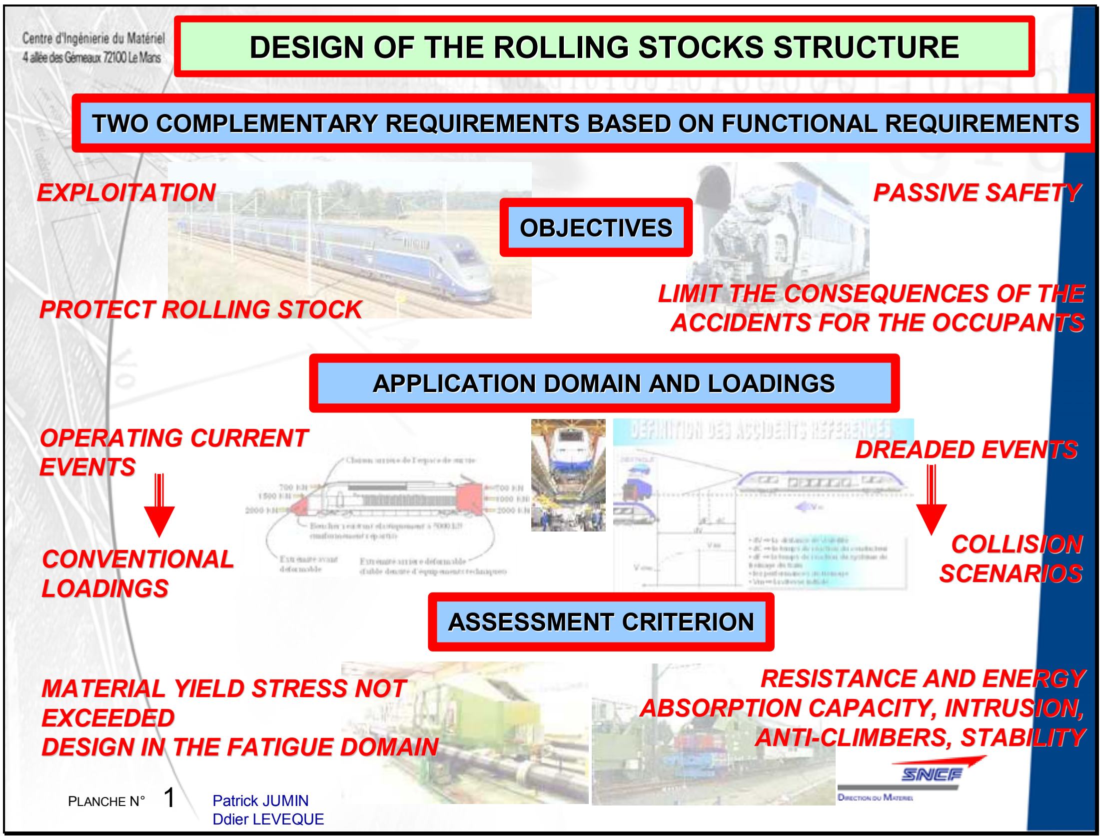
Safe Vehicle Structures - Locomotive Energy Absorption (2)

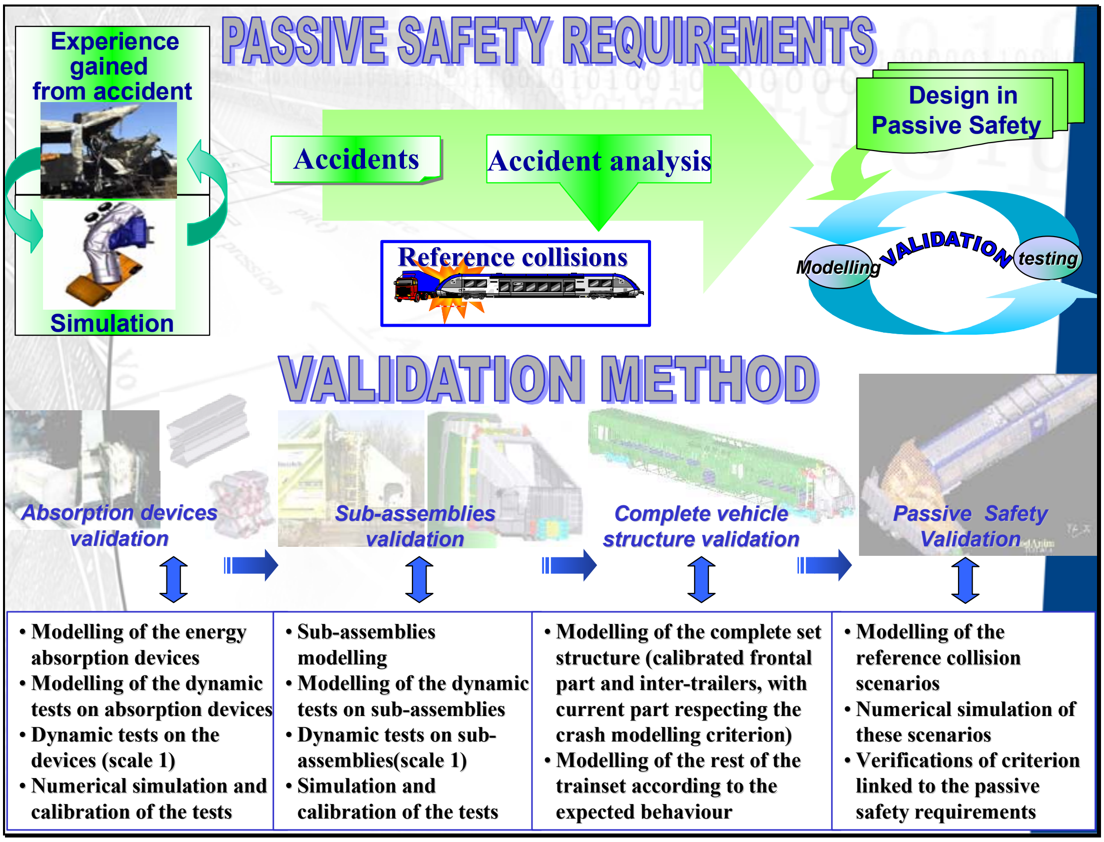
- **Crashworthiness design of new Bombardier TRAXX locomotives**

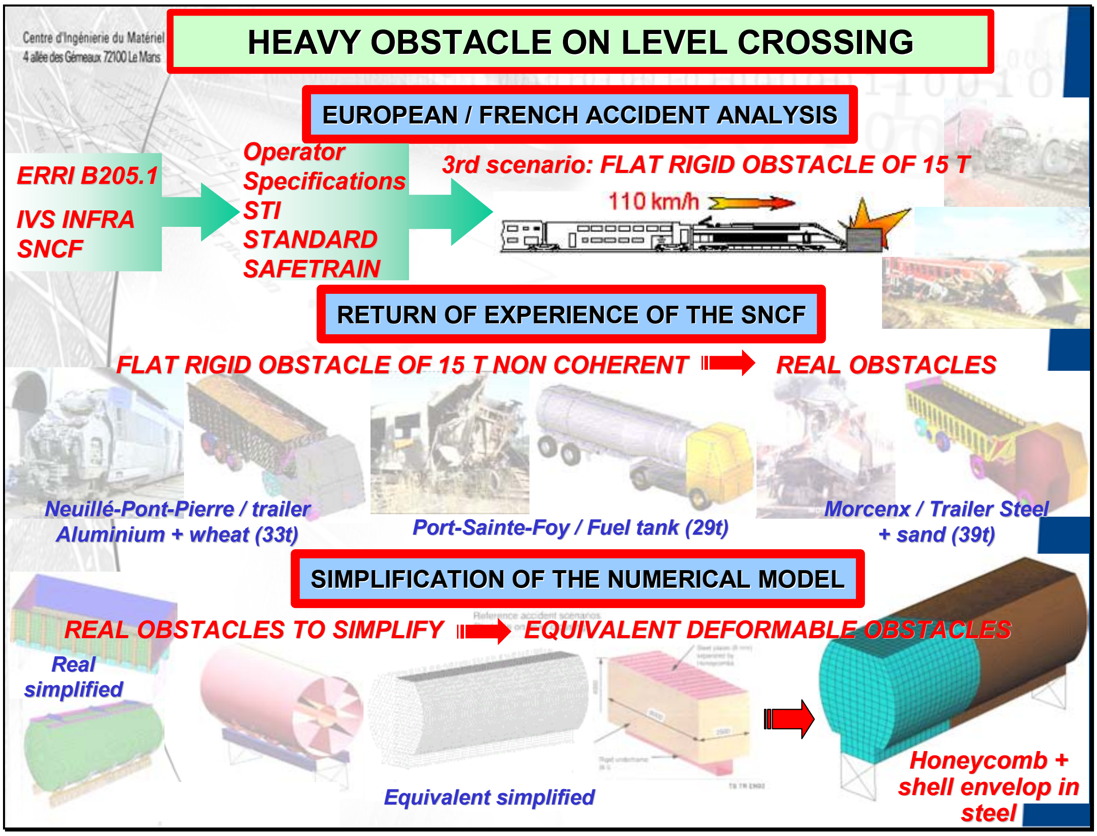


  - Crashworthiness design based on TSI-HS (2002)
  - Crashworthy reference train considered
  - High external energy absorption (TSI-1, TSI-2)
  - Improved protection for the driver (heavy obstacle)
  - Survival zones in driver's cab and machine comp.
  - SAFETRAIN compliant anti-climber
- **Fields for further research work**
  - Protection of driver in case of collision with heavy obstacle
  - Equipment attachments: Collision shock loads vs. static design against yield
  - Compatible solutions for anti-climbers of rail-vehicles with side buffers

F.B.Carl, 28 April 2004


Centre d'Ingénierie du Matériel
4 allée des Gémeaux 72100 Le Mans
DESIGN OF THE ROLLING STOCKS STRUCTURE
TWO COMPLEMENTARY REQUIREMENTS BASED ON FUNCTIONAL REQUIREMENTS
EXPLOITATION
OBJECTIVES
PASSIVE SAFETY
PROTECT ROLLING STOCK
LIMIT THE CONSEQUENCES OF THE ACCIDENTS FOR THE OCCUPANTS
APPLICATION DOMAIN AND LOADINGS
OPERATING CURRENT EVENTS
CONVENTIONAL LOADINGS
DREADED EVENTS
COLLISION SCENARIOS
ASSESSMENT CRITERION
MATERIAL YIELD STRESS NOT EXCEEDED
DESIGN IN THE FATIGUE DOMAIN
RESISTANCE AND ENERGY ABSORPTION CAPACITY, INTRUSION, ANTI-CLIMBERS, STABILITY
SNCF
PLANCHE N° 1
Patrick JUMIN
Ddier LEVEQUE


PASSIVE SAFETY REQUIREMENTS
Experience gained from accident
Simulation
Accidents
Accident analysis
Reference collisions
Design in Passive Safety
Modelling
VALIDATION
testing
VALIDATION METHOD
Absorption devices validation
Sub-assemblies validation
Complete vehicle structure validation
Passive Safety Validation
• Modelling of the energy absorption devices
• Modelling of the dynamic tests on absorption devices
• Dynamic tests on the devices (scale 1)
• Numerical simulation and calibration of the tests
• Sub-assemblies modelling
• Modelling of the dynamic tests on sub-assemblies
• Dynamic tests on sub-assemblies(scale 1)
• Simulation and calibration of the tests
• Modelling of the complete set structure (calibrated frontal part and inter-trailers, with current part respecting the crash modelling criterion)
• Modelling of the rest of the trainset according to the expected behaviour
• Modelling of the reference collision scenarios
• Numerical simulation of these scenarios
• Verifications of criterion linked to the passive safety requirements


Centre d'Ingénierie du Matériel
4 allée des Gémeaux 72100 Le Mans
HEAVY OBSTACLE ON LEVEL CROSSING
EUROPEAN / FRENCH ACCIDENT ANALYSIS
ERRI B205.1
IVS INFRA
SNCF
Operator Specifications
STI
STANDARD
SAFETRAIN
3rd scenario: FLAT RIGID OBSTACLE OF 15 T
110 km/h
RETURN OF EXPERIENCE OF THE SNCF
FLAT RIGID OBSTACLE OF 15 T NON COHERENT
REAL OBSTACLES
Neuillé-Pont-Pierre / trailer Aluminium + wheat (33t)
Port-Sainte-Foy / Fuel tank (29t)
Morcenx / Trailer Steel + sand (39t)
SIMPLIFICATION OF THE NUMERICAL MODEL
REAL OBSTACLES TO SIMPLIFY
EQUIVALENT DEFORMABLE OBSTACLES
Real simplified
Equivalent simplified
Honeycomb + shell envelop in steel

ATKINS

TRAIN SAFE

Safe Vehicle Structures

Vehicle Interface Safety (Buffers, Couplers and Anti-Climbers)

- Philosophy
  - *'Rail vehicle crashworthiness designers aim to ensure that rakes remain upright, connected, in-line and on the ground for as long as possible during a collision or derailment'.*
- Passive Safety Characteristics
  - Torsional rotational restraints between vehicles
  - Strong in both tension and compression
  - Resistant to jack-knifing
  - Resistant to overriding
  - Resistant to vehicle becoming temporarily air borne
- Questions
  - Are there any additional desirable vehicle interface safety characteristics?
  - How well do existing vehicle interface systems meet these characteristics?
  - How well do existing standards control these characteristics?
  - What are the business benefits?

ATKINS

TRAIN SAFE

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- Key Issues
  - Side buffers are known to promote override. There is a need to evaluate current risks
  - The coupling system should not 'un-lock' if vehicles overturn or become airborne
  - Standards should control the location, size and shape of serrated front plate anti-climbers
  - Anti-climbers that provide better control of lateral and vertical mis-alignment should be considered
  - Research is needed to determine the mechanisms by which vehicles can become temporarily air borne during high speed accidents
  - TGV style median (spanning) bogies remove the need for buffers, couplers and anti-climbers
- Question
  - What are the priorities for future research activity?

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Experience the Extraordinary

A discussion of the level crossing and train to train collision scenarios

- **Level crossing scenario:**
  - A more realistic obstacle
  - A more realistic crash scenario
  - A more representative obstacle
  - A more representative state of deformation
  - An energy absorbing obstacle
  - A deformable obstacle

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Experience the Extraordinary

A discussion of the level crossing and train to train collision scenarios

- **Train to train collision scenario:**
  - TSI high speed → 36Km/h
  - Euronorm (draft) → 36Km/h
    - *With reference to TSI ???*
  - SAFETRAIN /ERRI → 55Km/h

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TRAIN SAFE

A discussion of the level crossing and train to train collision scenarios

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