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António Vacas de Carvalho
Research&Development Director of Adtranz Portugal
Coordinator of the Safetrain and Safetram Projects

ADtranz
DaimlerChrysler Rail Systems

Safetrain and Safetram Projects:Results and Objectives

1. Preface

This presentation is divided in three different inter-linked subjects:

- The SAFETRAIN project, linked to the 4th presentation, of DB (Dr. Wolter).

- The SAFETRAIN versus Standardisation (CEN) and Interoperability (STI) and

- The SAFETRAM project, linked with the 3rd presentation of IST (Prof. Pereira) in what concerns the accidents inquiry.

2. The Safetrain Project

SAFETRAIN is a research project on Train Crashworthiness for Europe, funded by the European Commission and sponsored by UIC, having started the 1st August 1997 with the duration of 4 years.

The main objective of SAFETRAIN is to reduce the numbers of fatalities and serious injuries in railway accidents through new improved design of vehicle structures. To improve railway cars passive safety SAFETRAIN has developed technology able to manage the collision energy and designed specific impact structures to crush in a controlled and progressive way. The survival space for occupants is maintained and acceleration levels felt by occupants are kept limited. The SAFETRAIN research serves as basis for the Euro Norm production within the Work Group 2 of the CEN regarding the crashworthiness requirements for rail carbodies Classes I to III.

2.1 The Safetrain Consortium

To carry out the research development a European Consortium was established involving:

Railway Manufacturers, Adtranz Portugal (Project Coordinator), Alstom and Siemens; Railway Operators: DB, and SNCF; Universities: TUD of Dresden, IST and FMH of Lisbon and UVHC of Valencienes; Research Centres: AEA (former BRR), Cranfield Impact Centre, ERRI (representing UIC), Institut für Schienenfahrzeuge of Berlin (Bombardier) and CNTK (former PKP).

2.2 Review of accidents and choice of representative accidents

The Safetrain project benefited from a collision accident inquiry and the further statistical analysis of the data concerning some 500 accidents collected among 12 railway companies in Europe between 1991 and 1995 (ERRI/UIC inquiry).

That study allowed the definition of the most frequently occurring accidents:

1 - Head-on and rear-on collisions (with another railway vehicle)

2 - Collision with a car and with lorry/bus/tractor on the level-crossing

3 - Collision with a buffer- stop

and the principal characteristics of the most frequent accident categories:

Category	1.1	1.2	2.1	2.2	4
Number	31	69	28	80	33
Speed Km/h up to S30	36	11	54	50	2
S50	54	20	72	68	6
(1) S80	91	41	104	102	19
Energy in MJ at: S50	10.2	1.2	0.2	1.8	0.7
(2) S80	32.1	3.2	1.5	5.6	3.4
Mass M_2 at: S50	219T	213T	1.2T	16.5T	∞
Average severity S (3)	374	27	25	28	5

(1) S30, S50, S80 correspond to 30%, 50% and 80% of the total statistic population, as concluded by the statistic analysis

2.3 Analysis of Train sets

A series of optimisation studies through 1D modelling have been carried out by IST (Lisbon) and UVHC (Valenciennes) in order to determine the crashworthiness design parameters or major characteristics for the crush behaviour of vehicle ends. 340 t and 412 t main line trains, 129 t regional trains, multiple units and 50 t motor coach collisions have been analysed in the following selected collision scenarios:

Scenario 1: train vs. train collisions,

Scenario 2: train vs. buffer vehicle collisions,

Scenario 3: train vs. lorry on a level crossing collision.

The optimal force-displacement curves obtained in the optimisation process should result in decelerations in the passenger areas below 5g.

The train C, 129 t regional train, was chosen as the least favourable case regarding the front geometry (it does not allow a “long nose”).

Major conclusions were:

Scenario 1 generates 2.3 MJ to be absorbed at the front and 1.4 MJ at the inter-car. Scenario 3 generates 4.6 MJ to be absorbed at the front and 0.6 MJ at the inter-car.

Therefore, the energy absorption levels required for the front and intermediate ends are 4.6 MJ and 2x0.7 MJ respectively. In fact, the Low energy design absorbs 2x0.7 MJ in the replaceable components and up to 2x1.4 in the end structure.

2.4 Vehicle Overriding

In parallel to the train set analysis a review of vehicle overriding has been done within Safetrain by AEA (former BRR). In fact, it has been demonstrated that overriding in end-on collisions is the single most serious event that can happen as far as safety of passengers is concerned.

The available information has been reviewed with the principal conclusion that the initial contact between vehicles determines the likelihood of overriding. Surfaces that can easily deform or slide over one another, e.g. buffers, are instrumental in allowing vertical forces to develop and in initiating override. This conclusion is confirmed by the review of past accidents where buffers (with their curved, heavily greased surfaces which allow sliding and the ease with which they can deform locally) have been a feature of almost all overriding collisions.

A number of railway organisations now specify anti-climbers as standard and specify simple vertical loading requirements. Safetrain definitely advise the implementation of anti-climbers and proposes a draft general specification that can be incorporated into the appropriate Euro norm.

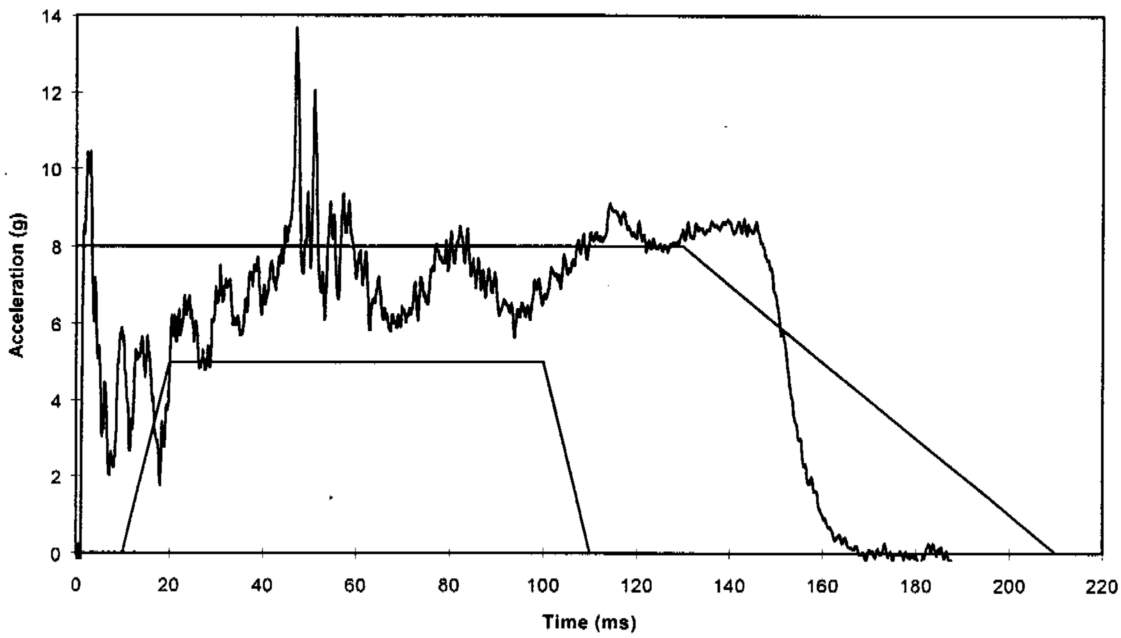
2.5 Passenger mathematical Modeling

Within Safetrain this task was of responsibility of CIC, the Cranfield Impact Centre.

For the analysis of the passenger behaviour, the model of a seat to be used in the passenger simulations was validated against quasi-static and dynamic test data from SNCF. Following further transfers of data from SNCF concerning a dynamic test with a dummy sat on seat during a 5g sled deceleration and a computer simulation of a higher sled deceleration scenario; this data was used as the basis for evaluating the performance of the CIC passenger mathematical model when the deceleration scenarios were represented during computer simulations.

The validation work was carried out for the case (a) seating scenario - uni-directional seating with seat back table in stowed position. There was good correlation between the sled test data and the CIC simulation of the test. There was also good correlation between the SNCF RADIOSS simulation and the CIC DYNA-3D simulation. On this basis it was assumed that the combined seat and passenger model had been validated and could be used for all other seating case scenarios. That is case (b) unidirectional seating and seat back table down, case (c) open bay seating but only one passenger, case (d) open bay seating and facing passengers and case (e) open bay seating with central table and one passenger.

The base case simulations for all the seating scenarios were conducted using a deceleration pulse generated by GEC ALSTOM for the impact between two 45000kg trains with high energy ends colliding at a closing speed of 60km/h. This pulse is generally in good agreement with the collision pulse corridor previously specified.



The base case simulations were evaluated using the occupant injury criteria limits previously specified. In seating cases (a) and (b) none of the injury criteria were exceeded. In case (c) excessive neck bending and femur loads were predicted. In case (d) some injury criteria were exceeded but only by small amounts. In case (e) only the neck bending criteria was exceeded. The results from cases (b) and (e) ignore abdomen load levels since there are no accepted criteria for front loading.

Injury Criteria

- **Head** -HIC of 500
  80g peak resultant head acceleration for < 3ms
- **Neck** a peak flexion bending moment of 190 Nm
  a peak extension bending moment of 57 Nm
- **Thorax** a peak thorax fore/aft compression of 50 mm*
  a peak fore/aft viscous compression (V*C) of 1.0 m/s*
- **Legs** a femur compression force not exceeding 7.58 kN
  - a peak tibia compression force of 8 kN
  - a peak tibia index of 1.0, at either end of the tibia
  - a peak knee sliding joint displacement of 15 mm*

*** not measurable with current dummy model - for thorax acceleration of 60g used**

2.6 Crew Mathematical Modeling

Within Safetrain, this task was of responsibility of AEA (former BRR, UK).

On average, over a hundred passenger and crew fatalities occur each year in rail accidents within the European Union. Cab occupants are particularly at risk since they are positioned at the front end of the train.

Theoretical modelling of the impact between cab occupants and their surroundings has been undertaken using the non-linear finite element package OASYS DYNA 3D, which simulates the Hybrid III rigid crash test dummy currently used extensively by the motor industry. Such models can be used to estimate the level of injury sustained during a collision. Both modern European regional train cabs and high density UK cabs with very limited driver space have been modelled. A total of three collision cases between the driver and the desk console have been investigated: the driver without protection impacting the console, the driver with a seatbelt and the driver impacting the desk console fitted with an airbag and knee bolster. For each of the above, the driver was modelled using 5^{th}, 50^{th} and 90^{th} percentile dummies.

Without protection, serious injury to the occupant's head and femurs is likely. The provision of a seatbelt greatly reduces the risk of head and femur injuries but increases the potential for thoracic injury such as broken ribs. This is especially the case for heavier occupants. The combination of airbag with knee bolster offers the best level of safety for the occupant whatever their size and weight. However, the knee bolster should be adequately designed to allow sufficient knee penetration to avoid damage to the femurs. Moreover, the airbag should be designed in such a way that it inflates fully before contact by the cab occupant.

2.7 Design and manufacture of vehicle ends

The full Safetrain hardware workpackage was coordinated by AEA. Following initial technical specifications drawn by SNCF and DB, two designs have been developed.

The High Energy end design has been carried out by Duewag (Siemens) and included an energy absorption tear-off coupler, an energy absorption obstacle deflector and an arrangement of replaceable energy absorption buffers equipped with rib-type anti-climbers. The driver's cabin structure was designed to progressively absorb further energy of the collision keeping however the driver's vital space in the rear of the cabin.

Furthermore, for the driver's safety, Bombardier designed a driver's desk and seat mounted on a sliding structure only attached to the front of the cabin structure. During the crash, this assembly will slide backwards.

The Low Energy end design has been carried out by Adtranz Portugal and included an arrangement of energy absorption tear-off coupler and the replaceable energy absorption buffers composed of calibrated tubes also presenting a rib-type anti-climber. Due to the curve inscription, geometry constraints have been imposed in the space available for deformation of the replaceable buffers.

The end structure of the car was prepared to absorb further energy of collision.

2.8 Component testing

UK Health and Safety Laboratory (HSL) was subcontracted to undertake the specified impact tests on three full size components from the HE and LE ends. There were tested the low energy absorber; the high-energy buffer and obstacle deflector and the high-energy 2^{nd} phase of crush, the side and centre sill energy absorber.

The test specification required HSL to impact each component at a predetermined impact speed using a moving mass of 10400 kg striking the test component which was mounted on a 17000 kg stationary brake vehicle.

The results of these tests (derived force-displacement curves) were further used for adjustment to the HE and LE ends design.

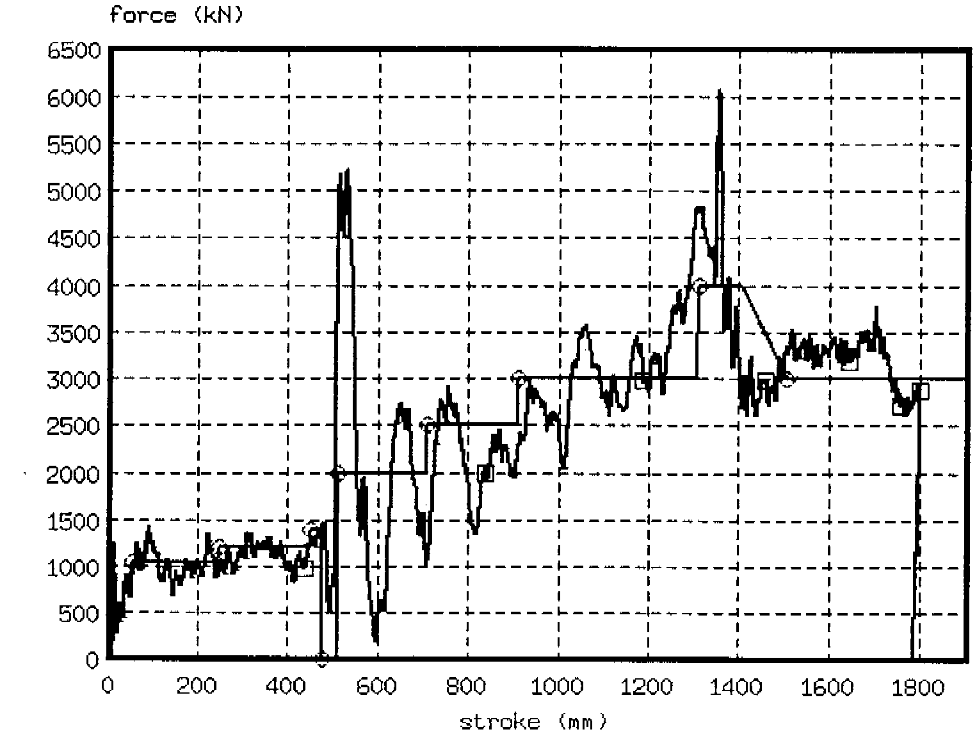
2.9 Modeling

Alstom (Valencienne and DDF Reichshoffen) has carried out the modelling of both HE and LE structures. The modelling was done along the design, validating and pointing out the difficulties.

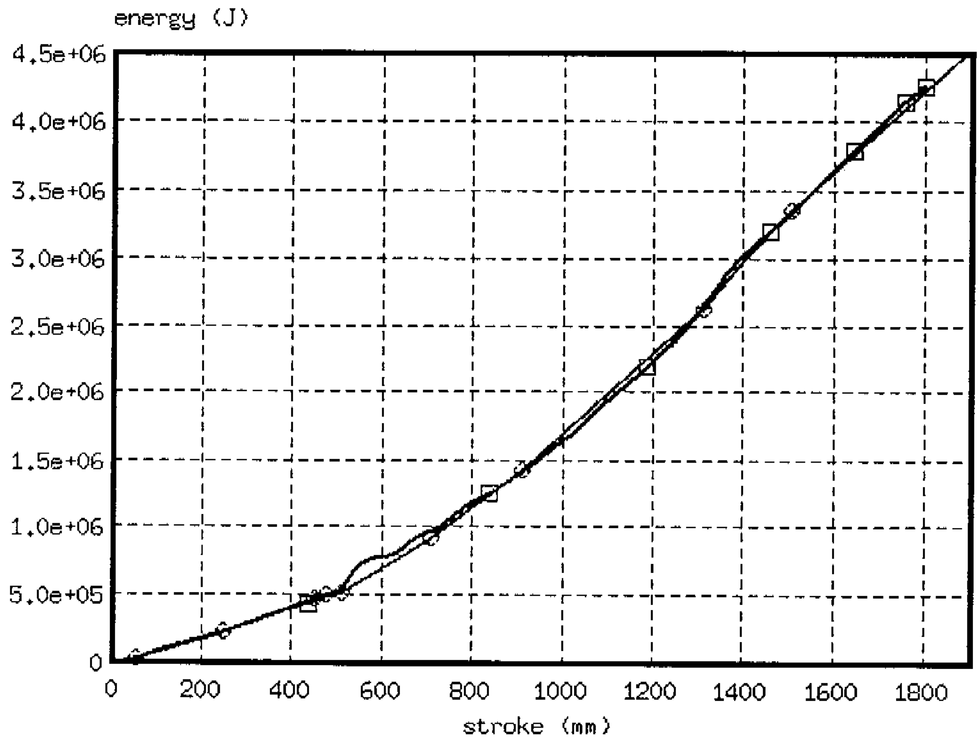
Forces, displacements and energy levels were foreseen through this analysis. The existing software does not take into account material damages. For example, cracks in welds, which can only be envisaged through the stress levels.

The dynamic test was also analysed including the wagon modelling based upon characteristics provided by CNTK, to support the tests.

FORCE AND ENERGY/DEFLECTION CURVES FOR SAFETRAIN HEE MODELING



1 □ S49 simulation results
2 ○ S49 theoretical curve



1 □ S49 simulation results
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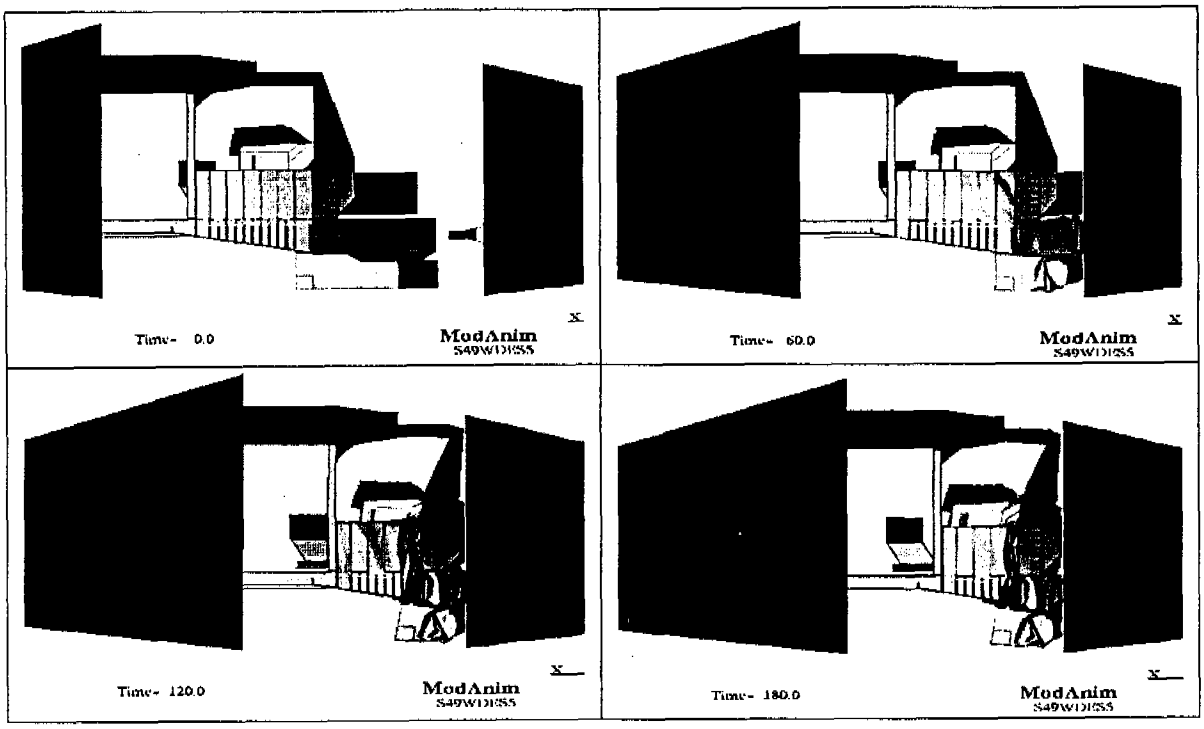


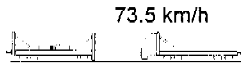
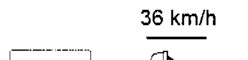
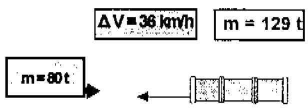
2.10 Quasi-static crush test on HE model

AEA Technology Rail was contracted to undertake a single full face quasi static crush test on a prototype of HE end. The purpose of this test was to provide the force, deformation and energy absorption information that could be compared with the similar data from both the theoretical modelling studies and the dynamic tests.

The module absorbed 4.6 MJ in a total of 1800 mm displacement.

The static test force/displacement can be found in the DB paper (4^{th} of this workshop).

2.11 Dynamic tests

Test	Representative scenarios	Test Objectives	Test parameters
Test 1 2^{nd} August 2000  Test of Front End	Train vs. lorry at a level crossing. 	Covers 80% of accid. ents from statistic B205 (regional train 129 t vs. lorry 16.5 t, speed 100 km/h). Validation of STI scenario.	Impact mass 45 t. Impacted mass 45. Collision speed 73.5 km/h. Energy absorbed: 4.6MJ.
Test 2 4^{th} August 2000  Test of Front End	Train vs. buffer stops or heavy rail vehicle in maneuvers. 	Covers 80% of accid. from statistics B205 for train vs. buffer stops. Assessment of front collision vs. buffer's heavy vehicle. Validation of STI scenario.	Impact mass 45 t. Impacted mass wagon 80 t. Collision speed 36 km/h. Energy absorbed: 1.44MJ.
Test 3 19^{th} September 2000  Test of Inter-trailer Ends	Train vs. train, head-on or rear-on collisions (inter-trailer behaviour). 	Together with test1, covers 50% head-on collision and 80% rear-on collisions from accident statistics B205 (regional trains 129 t, speed 55 km/h). Validation of STI scenario.	Impact mass 70 t. Impacted masses 30 t and 59.5 t. Collision speed 54 km/h. Energy absorbed: 1.4MJ.

DB, CNTK (PKP) and Bombardier (former IFS) were responsible within Safetrain of the full scale dynamic tests. The two first full-scale dynamic crash tests have been carried out the 2^{nd} and 4^{rd} August at the CNTK Test Site in Zmigród -Poland. A 3^{rd} test is foreseen to 29^{th} this month November 2000.

The 1^{st} and 2^{nd} tests registered data is now being processed.

The Safetrain tests will be completed in the end of this month as the 3^{rd} test will be held in Poland, Zmigród Ring, the 29^{th} November.

The last tasks of the project will be coordinated by SNCF: they are the Analysis of all tests' results and the Project Overview and Recommendation for Standards.

4. The SAFETRAIN versus Standardization (CEN) and Interoperability (STI)

4.1 Safetrain versus CEN Standards

The Consortium Safetrain agreed in 1998 to deliver its research results to the standard production within WG 2 of CEN. The WG2 decided that the crashworthiness requirements should be a Part II of the standard prEN 12663 – Structural Requirements of railway vehicle bodies.

Since then, Safetrain and the WG2 have been working in straight relationship. In fact, some of the Safetrain representatives are also permanent members of the WG2. The 6th WG2 meeting was held 27th and 28th September in Krefeld and a draft of the Standard is in an advanced phase.

Several Annexes are to be worked out by the WG2 members:

A - Methods for determining the limiting collision impact speeds (also the collision scenarios): B – Energy absorption levels required ; C – Distribution of energy at vehicle interfaces; D – Large object model; E – Obstacle deflector characteristics; F – Validation methods for passive safety levels.

The Safetrain project has almost finished all the tests and it is starting the final analysis of the tests' results and the project overview (Safetrain will end the 31st July 2001). It is expected that the CEN Standard shall benefit from the conclusions and can produce the final draft up to the end of the Safetrain project, as planned.

4.2 Safetrain versus Interoperability

The European Commission Council Directive 96/48/EC of 23rd July 1996 created in its Article 21 a Regulation Committee chaired by the CE representative (from DG Tren) and composed by the Member States representatives.

This Committee has been composing a Commission Recommendation (initially a Commission Decision) on the basic parameters of the trans-European high-speed rail system referred to in Article 5 of Directive 96/48/EC- version dated 2000.10.05.

In its point 11- Boundary Mechanical Characteristics of rolling stock, the Recommendation defines the passive safety requirements and retakes the well-known initial TSI scenarios and conditions.

On the other end, the European Association for Railway Interoperability (AEIF) was appointed as the joint representative body in accordance with Article 6 of the Directive, and also AEIF is already drafting a different text on STI's on passive safety.

This document is the draft of TSI 4.1.7. Mechanical Boundary Characteristics for Rolling Stock [BP15] - 96/48-ST05EN04 – version dated 2000.10.23.

So being, there exist presently four entities linked to the EC and working out passive safety documents on a European basis: the Safetrain project, linked to DG XII, the CEN, the Regulation Committee and the AEIF both linked to DG TREN.

There is no collaboration between the Safetrain project/CEN and this Regulation Committee and AEIF. These two are keeping their documents confidential till its final approval that will happen till 15th December 2000. In this situation is more likely that conflicts will exist between the Interoperability and the future European standard. And the risk exists that the interoperability regulations could overcome the technical-based CEN standard.

In particular, a requirement on both documents on a static condition for the carbody in the occupant's areas can have inconvenient consequences for the future carbody. It is the following requirement of the draft on the Commission Recommendation, point 11. Boundary mechanical characteristics of rolling stock, 11.2 Characteristics to be respected:

"There must be an enhanced resistance for passenger compartments in the front car and for the driver's survival space. The sections limiting these spaces must be designed with static resistance of at least 1500 kN over the average crash train* of the fusible areas for all three test collisions."

* the lapse is in the original.

and the following requirement of the draft of TSI 4.1.7. Mechanical Boundary Characteristics for Rolling Stock [BP15] - 96/48-ST05EN04:

"Greater crashworthiness in passenger areas located in the front vehicle and in the driver's survival cell. The sections of structure covering these areas shall be designed with a static load limit of at least 1500 kN above the mean crush force of the crumple zones during the 3 collision scenarios considered."

If adopted, this requirement will lead to a major increase of the carbodies weight with a negative impact on manufacturer costs and on the energy consumption (not only for high-speed trains but also for a number of the conventional trains).

It is strongly advised this requirement be replaced, with the focus on the crashworthiness major objective that is to assure the vital space for the occupants in case of a collision accident, such as:
"There must be an enhanced resistance for passenger compartments in the front car and for the driver's survival space. The sections of the structure covering these areas shall not collapse during the 3 collision scenarios considered."

Even if the Commission Recommendation and the TSI draft are only for the high-speed rail system, the Scenario 3 refers to a collision at a speed of 110 km/h on a level crossing with a road vehicle of 15 t.

This Scenario is for a high-speed train but operating in a conventional line with level crossings. It is the more energetic scenario and represents a collision of a 160 km/h running train, braking down to 110 km/h and colliding with an obstacle on a level crossing.

The energy to be absorbed in such collision can be about 6 MJ. This value corresponds to the minimum energy absorption required in both documents, 75% of it to be absorbed in the front of the first car in the train set, or 4.5 MJ- resulting e.g. from a mean crush force of 2500 kN and a 1.8 m crush stroke.

If 1500 kN over the average crash force of the fusible areas is requested, this example leads to a static strength of 4000 kN in the occupant areas (only to comparison, the present European standard for carbodies requires a static value of 1500 kN at floor level).

This Scenario 3 is valid not only for high-speed trains but for every train with maximum speed of 160 km/h operating in a line with level crossings, so for all conventional trains operating in these conditions.

From a legal point of view, conventional train occupants must not be at a greater risk than high speed train occupants under the same collision accident conditions. If such a recommendation is to be an EC future regulation, the same requirements must also be applied to the conventional trains.

The conventional rail car's fronts do not have the "long noses" which can allow for bigger crush strokes. Conventional trains can only afford for a limited crush stroke: to absorb 4.5 MJ higher crush forces will be needed. If a 1500 kN surplus is requested for the static resistance of the occupants compartments that will lead to unacceptable heavier carbodies.

Furthermore, the requirement
"The sections limiting these spaces must be designed with static resistance of at least 1500 kN over the average crash train of the fusible areas for all three test collisions."
is a static condition on a dynamic phenomenon, and presents other inconvenient.

To comply with that requirement the structure must be analysed with a dynamic code, the average crush force be derived to be used in the static analysis of the occupant's compartments.

In both documents it is not explained how that force shall be applied to the occupants compartments analysis. If a force uniformly applied on the cross-section is to be used, that will be far from real conditions, as the reactions on the rear of the crumple zones will depend on the geometry and on the structure crush behaviour.

Presently, carbody structures are designed and analysed with dynamic codes like DYNA 3D, PAMCRASH, RADIOSS, etc. More than likely these codes will be applied assuring the correct design where the crush will smoothly progress from the front to the cabin rear with the desired crush force and energy levels.

At the same time, during this process, the non-collapsibility of the occupant's areas can be checked and assured not only for the average crush forces but also for the significant pic-forces.

The value 1500 kN is arbitrary and stands only as a provision for a design uncertainty on the crumple zone, i.e., a safety factor. It gives no freedom to the designer future improvement and accuracy, and does not take into account the more than likely big advances in the future structure analysis..

5. The SAFETRAM Project – Passive Safety of Tramways

5.1 The Safetram objectives

Safetram is a EC funded project within the EC Programme Competitive and Sustainable Growth and addresses the problem of tramway passive safety, which includes all structural and interior design rules that contribute to a safe environment for occupants during crash events.

Passive safety has been applied currently and successfully in the automotive industry and, more recently, it is being implemented in trains.

Addressing an entirely new European problem, Safetram proposes to develop the correspondent rules for tramways, a passenger guided transport system operating in a complex environment of mixed traffic.

One main objective of the Safetram is to devise guidelines for tramway construction that, in due course, will lead to a measurable decrease of the overall injury rate in accidents.

Two types of vehicles will be studied:

The city trams, circulating inside one town,

The periurban trams, or tram-trains, taking passengers from suburban areas to the city centre sharing the railway tracks.

Safetram proposes to develop, validate and demonstrate improvements in structural and interior crashworthiness, thus increasing the occupant safety of these vehicles.

The standing passenger case will be analysed through the modelling of an innovative numerical dummy which will be fully validated by sled tests and applied on a research of interior collision scenarios.

An agreement was settled with UITP: Safetram will benefit from their knowledge and experience during the research. Safetram will also serve as basis for the Euro Norm production, regarding the crashworthiness requirements for Classes IV and V, "Light Duty Metro and Heavy Duty Tramway" and "Tramway Vehicles".

5.2 The Safetram Consortium

To carry out the research development a European Consortium was established involving: Railway Manufacturers: Adtranz Portugal (Project Coordinator), Breda Ferroviaire, Adtranz Nuremberg, Alstom and Alusuisse; Railway and Tramway Operators: BVG, DB, RATP and SNCF; Universities and Research Centres: CNTK (former PKP), IST (Lisbon), MIRA (Motor Association – UK) and TUB.

5.3 The Safetram workplan

The following work is to be performed for a research project with 3 years duration:

· Identification of representative collision scenarios and their associated parameters based on a statistical study of accidents in Europe.

> Safetram will depart from a accident inquiry near tramway operators where about 58000 accidents were reported. In this workshop, the 2nd presentation that inquiry will be presented.

· Optimisation studies, with the aim to find the suitable characteristics of structural zones assuring adequate behaviour for the specified collision scenarios.

· Definition of design specifications for city and periurban trams (their requirements are very different in terms of energy absorption capacity due to the obstacles each vehicle can come across).

· General construction rules concerning major features of the tramway structures: energy absorption zones, type of coupler, non-structural energy absorbers, obstacle deflector, passenger compartment, driver location, etc.

· Dynamic tests specification to define test conditions such as collision speeds and masses. Identification of measurable parameters, data acquisition methods and test control systems.

· Detailed design and manufacture of two prototypes to be subsequently validated by the dynamic testing. During the design phase, complex detailed non-linear dynamic models are analysed to validate the proposed solutions.

· Development and validation through tests of a hybrid 3 50% numerical dummy and its use on the assessment of the standing passengers' dynamic behaviour.

· Sled testing of key scenarios and correspondent passive safety solutions to reduce the potential hazards in vehicle interiors for passengers. Study of driver particular environment.

· Analysis of modelling and test results from the passive safety standpoint. Issue of guidelines towards the crashworthiness requirements of the Euro Norm.