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Bus Frontal Crash Virtual Approach vs. Experiment

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Abstract: Paper deals with virtual techniques for a bus safety development. The first part briefly introduces a process of bus rollover stiffness increasing using AHSS steels. The second part describes a process of frontal deformation members development with a target to decrease a biomechanical load of passengers on a bus board as well as to safe a bus driver lower body. Finally, a bus full scale frontal crash test with anthropometric dummies HIII 50 % were performed. This test verified results of used virtual techniques with very good agreement comparing to computer simulations.

Keywords: Virtual Approach; FEM Simulation; Bus Rollover; Frontal Crash.

1 Introduction

Traffic in Europe is significantly increasing during last 20 years. This is one of reasons why also a number of traffic accidents is increasing. That is why vehicle designers focus and accent safety of theirs vehicles. Also safety experts are permanently developing new rules, methods and tools for passive and active safety increasing to minimize a number and a level of injuries caused during traffic accidents. One of tools how to force vehicle producers to design safer vehicles is a system of international standards.

Also heavy vehicles for people transportation have to fulfil European ECE and EC and other international standards. One of such standards is a second revision of ECE 66.02 Regulation which increases bus safety requirements comparing to a previous version of this regulation (ECE 66.00). This regulation defines rollover stiffness requirements to minimize plastic deformations of a bus superstructure during rollover traffic accident.

European bus safety experts are systematically and continuously working to up-date and revise actual Regulation versions and also developing and preparing new international standards. One of such standard which is still under development is a Regulation for a bus frontal crash. A target of this new standard will be to minimize a biomechanical load of passengers travelling on a bus board as well as to safe a bus driver lower body and legs during accidents.

An application of some design safety trends into a type line of SOR bus company is a target of this paper.

2 Increasing of a Bus Safety

2.1 Increasing of a Bus Skeleton Rollover Stiffness

The ECE 66.01 (valid from 10/2007) and ECE 66.02 Regulations bring harder loading demands comparing to an original version of the ECE 66.00 from 1986. A main progress is involving a mass of passengers into a total bus mass and also a prolongation of a residual space (a survival space) up to a driver compartment.

Standard buses certified before 10/2007 according to the old ECE 66.00 Regulation have usually week bodies made by an old series technology, see Fig. 1 and 2. These results we reached during a pre-project phase did not fulfil demands of the actual ECE 66.02.

It is clear that stricter loading conditions of the new ECE Regulation are generally not comply with actual world trends to design lighter vehicle bodies to save fuel, reduce a carbon footprint and increase transport capacity.

To design such rollover-proof skeleton of the bus superstructure under tightened conditions with a simultaneously demand of a bus total mass reduction needs to use sophisticated design materials. We solved this task

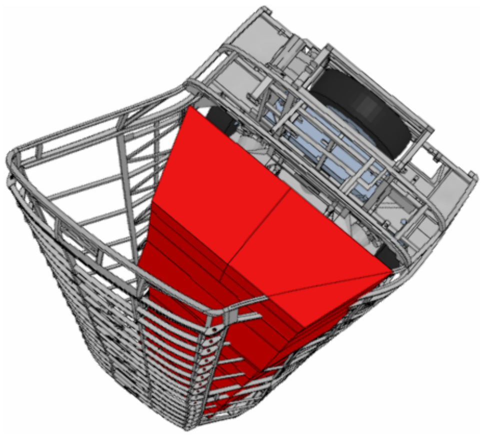

Fig. 1: Bus Structure after Unsuccessful Rollover Test.

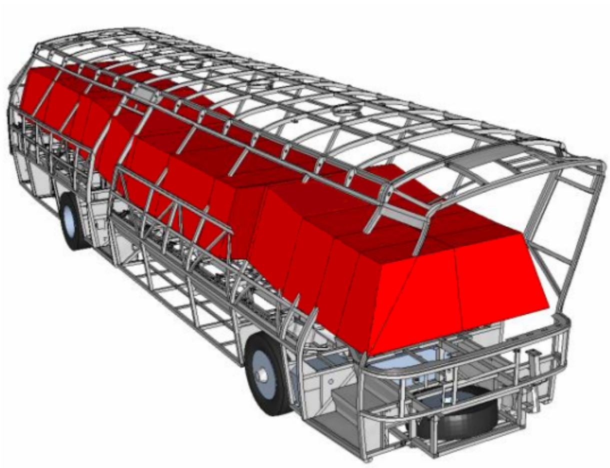

Fig. 2: Residual Space Penetration.

changing standard carbon steels by AHSS steels for critical components of a bus body, see Fig. 4.
So, our final solution introduced a lighter and stiffer AHSS skeleton which fulfils all demands of the ECE 66.01 and ECE 66.02.

To successfully design such superstructure respecting mentioned standards needs using a hi-tech software equipment which can solve non-linear dynamic task for relatively huge FE structures (over 1 million elements). Our project was solved with sw PAM-Crash. To tune well implemented material models, 3-level material testing is usually applied. Between the first two testing levels became dynamic coupon tensile tests to evaluate dynamic strength of used materials and also their strain rate influence which cases material hardening during a higher loading speed. The second testing level is a dynamic component test, usually a dynamic 3 point bending test made on chosen components as window pillar profiles or welded crosses of these profiles with longitudinal window profiles. There is important tuning of material properties on the base of these performed laboratory tests. Tuned material properties are usually highly dependent also on the used size of FE mesh.

A final stage of testing is usually a bay section rollover test used just for verification purposes, see Fig. 3.

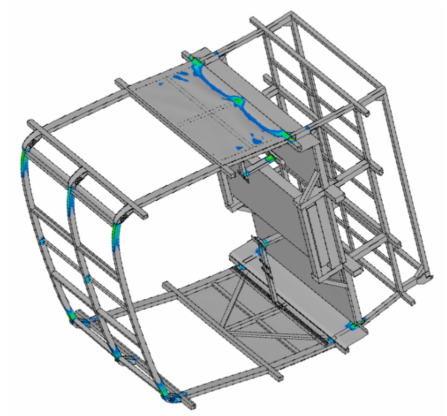

Fig. 3: Bay Section Rollover.

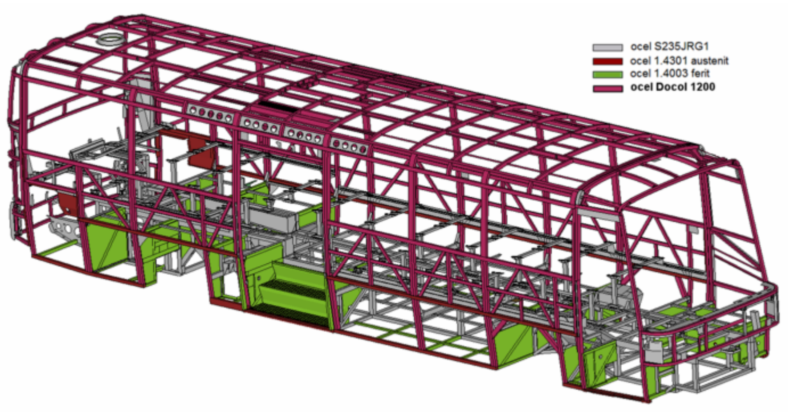

Fig. 4: Bus Superstructure.

2.2 Bus Frontal Crash with Crash Absorbers

A second task of the project was to design an absorber avoiding or decreasing mainly a biomechanical load of occupants on a bus board during a bus frontal crash.

First, we analyzed a number of various traffic situations during this stage of the project – frontal crashes with a several types of rigid barriers as a barrier 4 m high, 50 % left off-sets, 50 % right off-sets, wide barrier 1 m high, ... etc. and next a pendulum tests according to the ECE 29 and several types of so called Swedish tests well known from an alternative vehicle category of lorries and trucks, see Fig. 5 and 6.

As a conclusion of these computer simulations, we recognized a huge potential for development of bus frontal deformation zones. A next important point for a vehicle passive safety was to increase also a driver safety. We engaged in several design variant of a frontal steel absorber solution, see Fig. 7 to 9. Very interesting solution is using a bonded corrugated plate box made from carbon thermoplastic sheets built-in into the bumper see Fig. 10. This solution can be successfully combine with steel absorbers which modify a bus chassis.

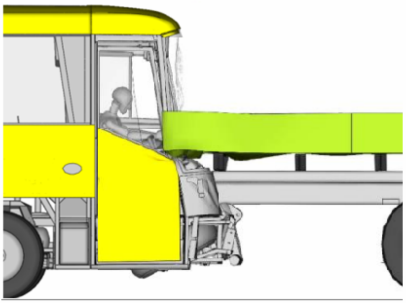

Fig. 5: Frontal Crash between Bus and Track Platform, $\Delta v = 30$ kph.

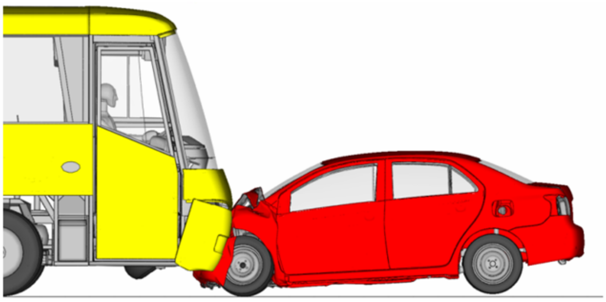

Fig. 6: Frontal Crash between Bus and Passenger Car.

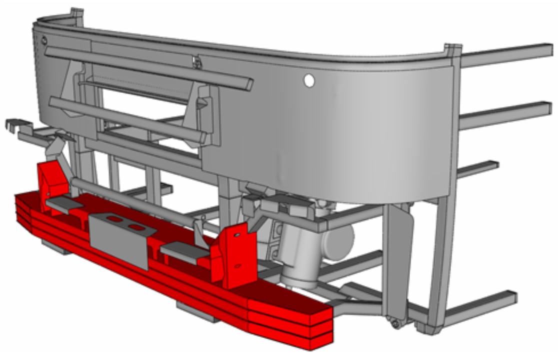

Fig. 7: First design variant.

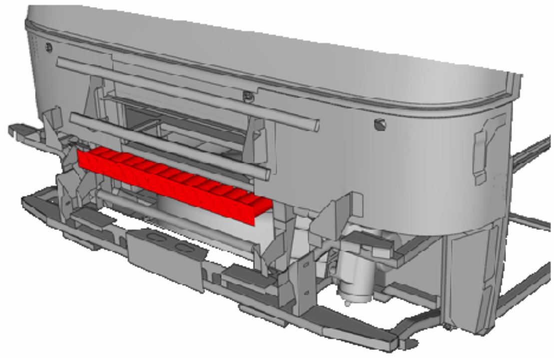

Fig. 8: Second design variant.

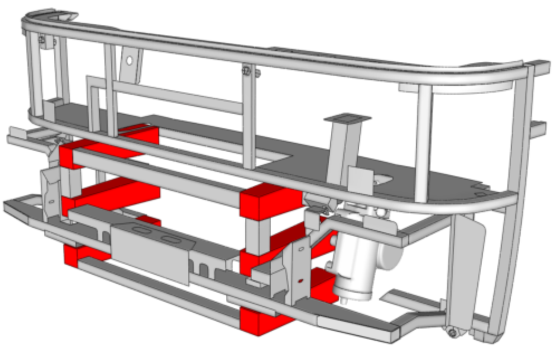

Fig. 9: Third design variant.

Fig. 10: Composite design variant.

We were not fully satisfied with almost all tested variants of frontal absorbers above (Fig. 7, 8, 9) from different reasons. A last variant we chose finally was very simple and smart solution. It modifies only main longitudinal beams at a forward area which are not originally straight but folded, see Fig. 11. Additionally folded beams create rigid hinges which can absorb a huge amount of kinetic energy during a frontal crash in case of traffic accident. Such absorbers can decrease a biomechanical load on the bus board from 15 g up to less than 10 g, see Fig. 12. Another advantage of this solution is that such absorbers do not increase bus mass.

The frontal absorbers designed according to the Fig. 11 were applied to a standard bus chassis, see Fig. 15. Then we performed a full-scale frontal crash test of such modified bus into the rigid barrier in 25 kph, Fig. 14. Before and also after the crash tests we performed 3D scanning of the whole bus body structure using the Faro Laser Scanner Focus 3D. A precision of this measurement was 2 mm. So, all full-scale displacements were very easily identified using this technique. A final comparison with results of computer simulation stated very good agreement between the full-scale test and computer simulation, see Fig. 15, 16, 17 and 18.

Also a driver movement and its biomechanical load was carefully analyzed during the whole project, Fig. 13. To minimize a driver lower legs injury, a special rigid frame with a whole driver compartment was developed and applied to the bus chassis. Such frame is moving back during the frontal crash respecting and safe mainly both driver legs.

To determine and verify a set of biomechanical criteria as HIC, neck flexion and extension, pelvis acceleration … etc., we used and instrumented 3 pcs. of HIII/50 % dummies during the full-scale test. We also applied a set of strain gauges on the absorbers at the frontal bus chassis to compare real stresses with simulation results. Dewetron SIRIUS and DEWE 43 with 32 channels were used as a data acquisition equipment.

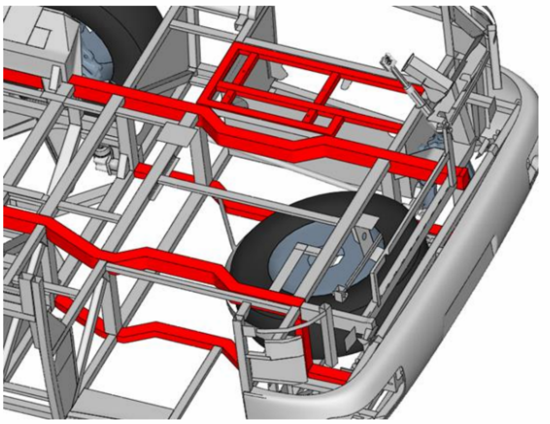

Fig. 11: Final design variant.

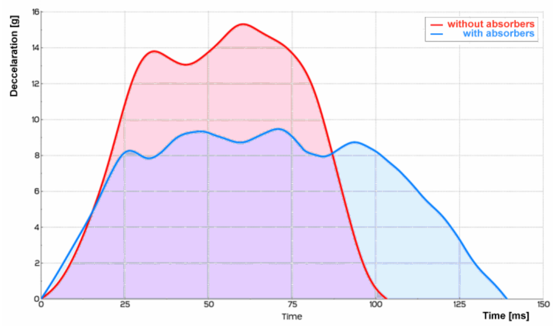

Fig. 12: Bus Board Decceleration, 30 kph.

Fig. 13: Driver Compartment.

Fig. 14: Full-Scale Frontal Crash Test.

3 Conclusion

Various kinds of material laboratory tests, component tests and also full-scale physical tests are important stages for verifying results reached by virtual simulation techniques. Our paper demonstrates a virtual approach in development techniques for heavy vehicle passive safety increasing and a high agreement of results between our virtual simulations and the real full-scale test.

Fig. 15: Vehicle after Frontal Crash.

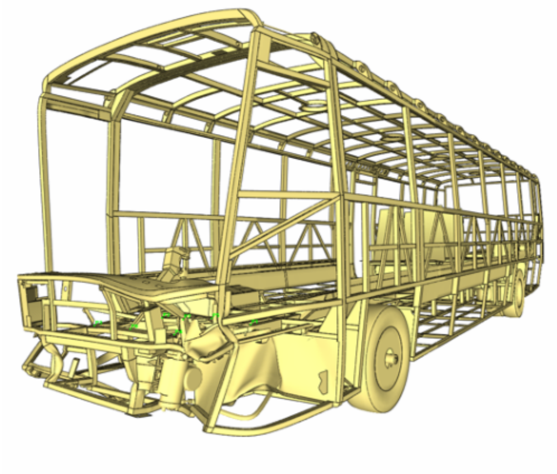

Fig. 16: Result of Simulation.

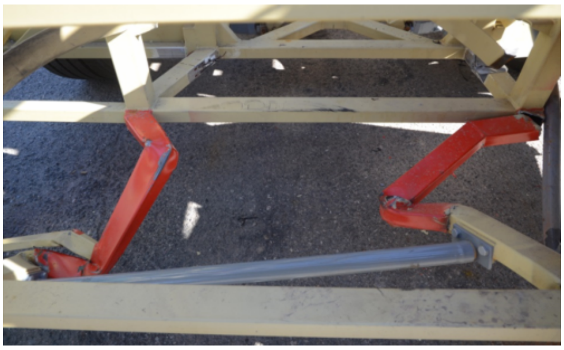

Fig. 17: Chassis Deformed after the Crash.

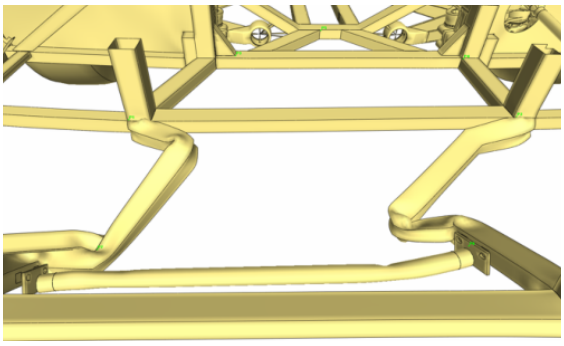

Fig. 18: Deformed structure, Simulation.

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