Development of Sub System Sled-Based Lateral Pole Impact Test

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ABSTRACT

During the vehicle development, the full-scale testing is one of the most timing and resources consumption part of the process. A solution has been proposed where full-scale Lateral Pole tests can be simplified to sub system sled tests, requiring less resources in terms of BiW while allowing to reproduce impact tests conditions, where vehicle deceleration and intrusion are applied in a controlled way to reproduce crash kinematics.

This paper explores the development of this sub system setup, which can be applied afterwards for restraint system development. It presents CAE activities, component characterization tests, sub system validation and methodology definition involved in the process.

INTRODUCTION

Side and oblique collisions account for approximately 21% and 51% of all traffic collisions with victims in Spain [1]. Governments around the world have implemented regulations to assure a minimum safety level for vehicles under side-crash scenarios. On the other hand, independent consumer organizations, such as Euro NCAP, have implemented testing protocols to encourage vehicle manufacturers to increase vehicle safety protection level.

The necessity for more flexible and representative subsystem testing techniques is a persistent requirement, to allow vehicle development programs to comprehend as many variables as possible during the safety system integration process.

The project aims to develop a new sub system test setup capable of reproducing lateral pole impact tests, considering vehicle deceleration and door intrusion. The advantage of this system is the significant reduction in sample expenses during development phases where multiple tests are required to develop the side restraint system, full vehicles and/or body in white would be no longer required for early development phases. In this way, a higher number of crash scenarios and specific conditions could be assessed, with a reduced resources condition. This study addresses how accurately a simplified sled-based system can reproduce the complex kinematics of lateral pole impacts.

Currently, sub system sled based lateral impact tests are already available in the industry, such as ASIS [2] and another similar technology where servo hydraulic actuators are integrated into sled systems. The aim of this study is to present an alternative method, using sled test concepts applied to a crash test track and deformable elements instead of servo hydraulic actuators, to simplify the setup and make it feasible for crash test laboratories without sled test equipment.

The development starts with an explanation about the methodology applied to simulate vehicle intrusion in a controlled and repetitive manner, definition of the deformable elements geometry, validation of the methodology through virtual analysis while comparing to full scale crash test simulations, try out for material correlation and a finally a physical test for complete system validation and comparison with either full scale crash tests or another sub system sled-based test technology.

METHODOLOGY

LOAD CASE DEFINITION – The load case chosen for the development of this sub system sled-based test concept is the side oblique pole impact crash test at 32 km/h, applied in several markets as a regulatory test and currently included in the Euro NCAP testing protocol.

Figure 1. Euro NCAP Side Pole Impact crash test [3]

The election of this load case is justified by the fact that the high structural intrusion speed and short energy absorption areas culminate in one of the most challenging and resource demanding load cases for restraint system and occupant protection development. Once the load case is defined, the next phase is to define how to reproduce the crash kinematics in a simplified testing environment.

VEHICLE PULSE AND STRUCTURAL DEFORMATION CONCEPT – The basic test methodology consists in simulate the vehicle conditions through articulated structural elements assembled on a sled platform, that will be then impacted by another sled impactor, which will generate the required inputs for the reproduction of the kinematics conditions observed in a full-scale crash test regarding the near side occupant protection. Before defining the details of each of those elements, a simplification of the system was implemented to properly distribute the required studies for a better understanding of the complete system.

The principle of the crash model simplification and dummy interaction with vehicle interior is based on already known concepts, such as the MDB impact diagram (du Bois et al.,2004):

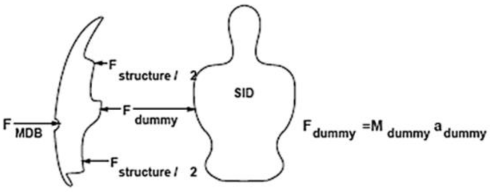

Figure 2. Door and SID "free body" diagrams [4]

However, in this concept study, instead of representing a barrier test and a SID dummy, the system is designed in a way to reproduce the load paths from the pole crash with a WorldSID dummy. The focus of this sub system test is to reproduce with maximum accuracy the occupant injuries of thoracic and pelvic body regions, focusing on the development of side airbag restraint system development. Therefore, 2 independent intrusion regions are considered to correctly address the differences along vehicle architecture:

1. Upper pole intrusion zone: that will simulate mainly the door structure characteristics.

2. Lower pole intrusion zone: that contemplates, besides the door, the sill beam and B-Pillar stiffnesses.

The longitudinal displacement will be transmitted by sliding, which will be controlled to apply desired velocities. A third load path is considered for the global vehicle kinematics, which will generate the secondary impact effect of the dummy against vehicle interior. At the same time, a detailed crash kinematic analysis allows the design of an articulated non-deformable structure, that simulates the vehicle structural elements which supports interior trim elements, that will interact with the occupant, while being able to reproduce the very complex condition of the deformation kinematics in a robust and repetitive way. For this project, the head injury assessment is not considered, therefore the head protection will be performed via a standard absorption element for dummy protection. This concept can be simplified and illustrated as follows:

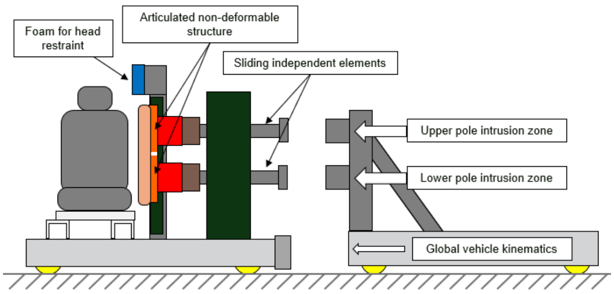

Figure 3. Simplified concept setup

Once the system is simplified, an in-depth CAE study takes where full-scale crash simulations are used to divide and quantify the energy transmitted through the previously categorized load paths. This study allows a better understanding of energy requirements to assure the crash intrusion speed conditions, which are a key factor for a proper restraint system development. This energy is then adjusted to the system via basic inputs, such as impactor mass and speed, and then modulated by deformable elements mounted between impactor and the articulated structure that will simulate the deformation pattern.

These deformable elements are meticulously defined and dimensioned considering the mechanical characteristics of the materials and geometry, changing those parameters allows a better adjustment of the crash intrusion velocities. The simplified model with the energy deformable elements and energy inputs can be detailed as follows:

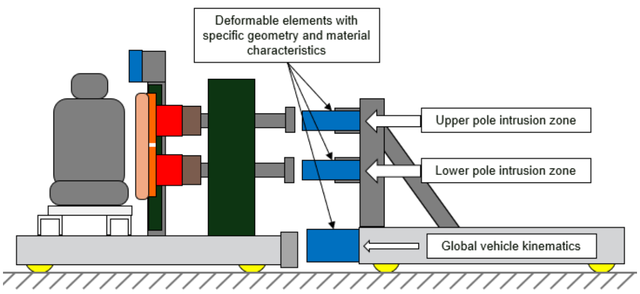

Figure 4. Simplified concept setup with deformable elements

The global vehicle pulse is also modulated using deformable elements, which allow the reproduction of specific velocity characteristics as in a full-scale crash test.

VALIDATION OF THE SYSTEM THROUGH VIRTUAL SIMULATION – After the design of articulated structure and the dimensioning of deformable elements, a complete system virtual simulation is conducted to validate the energy inputs definition and evaluate dummy response over the new concept system, this step is conducted before starting preparations for the physical tests.

A detailed sequence of images illustrates the comparison of structural intrusion and dummy kinematics between the concept and a full vehicle crash simulation, where red lines represent the full-scale crash simulation and the gray colored lines shows current project concept, both conditions are simulated with same conditions of trim components, airbag, and dummy positioning:

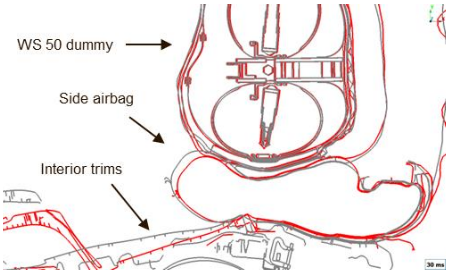

Figure 5. Articulated structural device comparison - 30ms - Z450

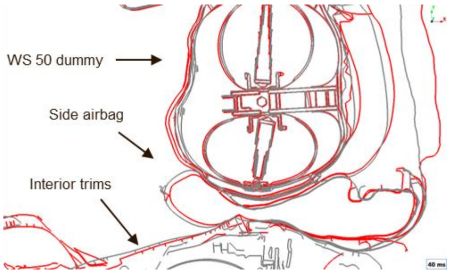

Figure 6. Articulated structural device comparison - 40ms - Z450

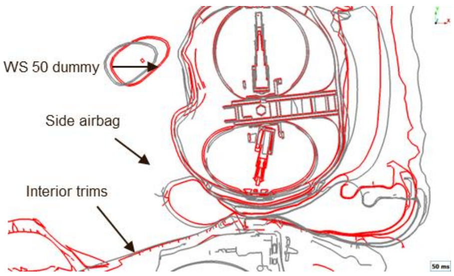

Figure 7. Articulated structural device comparison - 50ms - Z450

Overall dummy biomechanical responses were thoroughly compared, and the final conclusions were that the system is comparable to full scale crash tests in virtual environment. Some of the main biomechanical responses can be also compared in the following image:

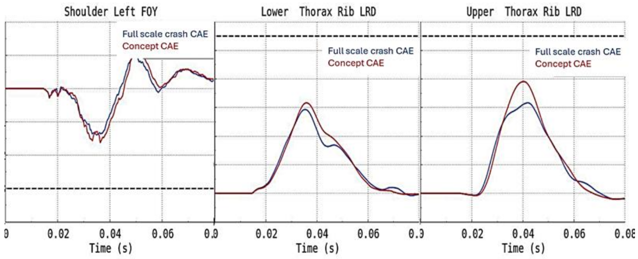

Figure 8. Dummy kinematics comparison between crash CAE and concept CAE simulations

MODEL CORRELATION

SUB SYSTEM TEST FOR MATERIAL CORRELATION – Sub system tests, mostly reduced impact tests, were carried out to improve the material characteristics of the deformable elements used for the intrusion speed control and global pulse definition, consequently improving the correlation of the virtual model as well under dynamic conditions. An example of a subsystem test with deformable elements can be seen in the image below, where the influence of material characteristics of deformable elements was assessed:

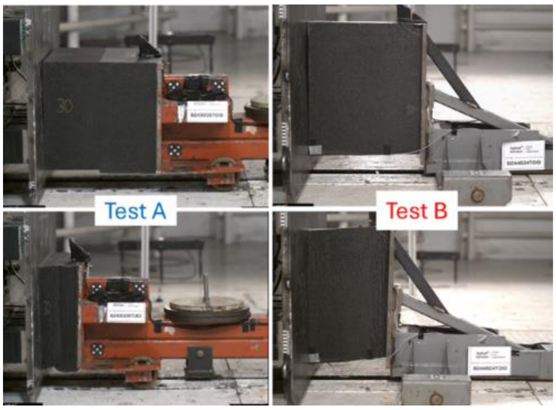

Figure 7. Sub system impact tests for system improvement

The outcomes of these tests were again compared to virtual model for correlation improvement, as an example, the following image illustrates the velocity comparison between the previous tests and CAE simulations under same conditions:

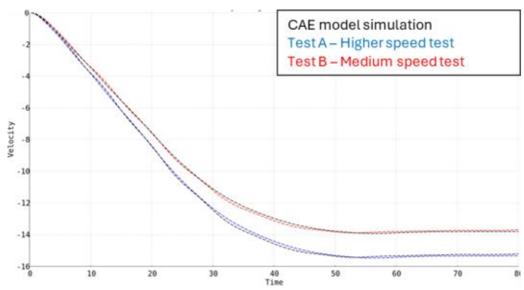

Figure 8. Sub system impact test comparison with CAE simulation

A total of 20 impact tests were performed and the results compared to simulation results, the feedback on the system allowed a more accurate control of the system inputs and to further generate sensibility studies for easier and faster setup parametrization and corrections.

SENSITIVITY STUDY FOR INPUTS VARIABILITY – A The model correlation studies, and sub system impact tests allowed a better understanding of the system and the impact on inputs variability over the final responses. The collected data provided a powerful database for a Design of Experiments (DoE) methodology, which enables a systematic analysis of these sub system test results. The main variables implemented in the tests and analyzed were:

- Deformable elements geometry
- Deformable elements material properties
- Initial impact velocity
- Sled brake force
- Sled mass

By applying the DoE concept, we aim to:

- Identify the most relevant inputs.
- How the variables interact with each other.
- Adjust the system according to specific needs.
- Improve robustness by reducing variability.
- Improve overall system performance.

The objective is to keep testing other variables and increase the statistical data, with more information we will be able to correctly address problems encountered on future tests and improve the system in a more efficient manner.

TESTING AND VALIDATION

TEST SET-UP CONSTRUCTION – A CAD model with detailed construction concepts was created upon the CAE model simplification, respecting the constraints and functional requisites of the validated system setup. The construction was divided into 3 stages:

1. Articulated non-deformable structure that simulates the door intrusion kinematics, with an incorporated sliding system that interacts with the deformable elements from impactor sled.

2. Sled that simulates the simplified vehicle's occupant compartment, for installation of articulated structure, trims, seat, and seat belt.

3. Impactor sled with specific weight distribution conditions and 3 dedicated impacting areas where deformable elements were inserted.

Figure 11. Construction of the sled and articulated structures

Once all elements were built, the articulated structure was then integrated with the vehicle's compartment sled and the complete setup was moved to the test track. A crash test facility was used to carry out the physical validation tests, the traction system was responsible for the traction of the impactor sled while the vehicle compartment sled was kept in static condition. Several instrumentation techniques were used to monitor all test data, such as: accelerometers, load cells, string displacement sensors, 3D tracking photogrammetry and high-speed video recording.

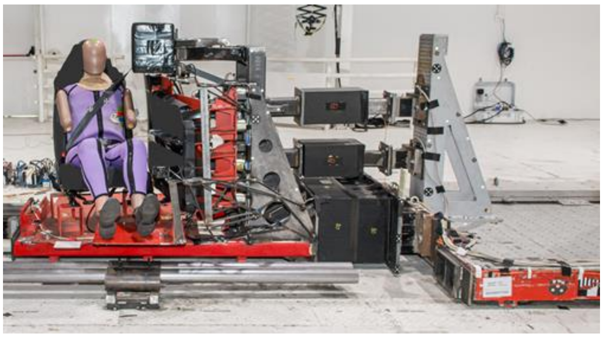

Figure 12. Sub system lateral Pole Sled test setup

TEST RESULTS – In overall, the results from the conceptual test showed good correlation with simulation results. Analyzing the dummy's biomechanical response, major differences can be found in the shoulder and pubic lateral forces:

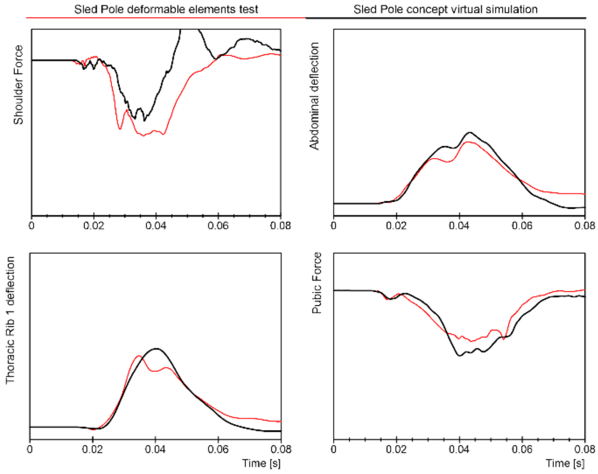

Figure 13. Dummy biomechanical values comparison between physical and simulation results

These differences can be also observed when evaluating the vehicle kinematics, more specifically on vehicle pulse and door intrusion velocities. It is possible to see in the graphics below that the physical test (red curve) has a slightly higher pulse when compared to the simulation results (black curve). However, the most significant differences are observed on the upper- and lower-cylinder displacement curves, the faster displacement in the upper cylinder indicates a higher intrusion velocity in the upper door area, which creates a faster interaction with restraint system and dummy, this effect is clearly seen on shoulder lateral force curve.

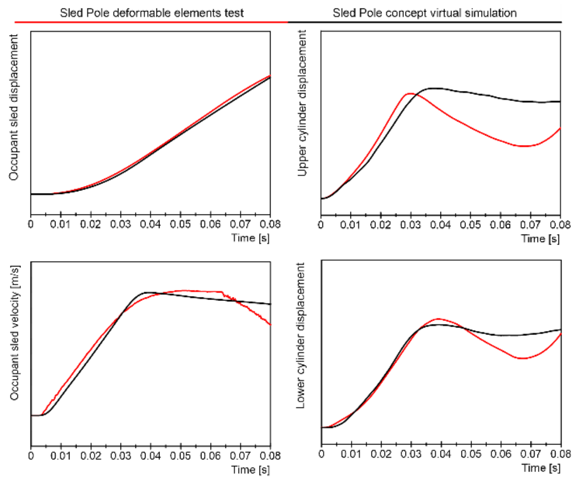

Figure 14. Sled kinematics comparison between physical and simulation results

Besides the maximum displacement values are comparable in terms of amplitude, the faster interaction with the dummy generates an inertia momentum that will increase the shoulder force value. This effect is attenuated in the thoracic ribs, as the side airbag covers the dummy's torso and avoiding direct contact with door trim. Torso, abdominal and pelvic values are very comparable to simulation results, most differences are observed in terms of amplitude, which is mostly caused by the rebound of the sled cylinders intrusion, it is possible to observe in the displacement curves that the cylinders push back instead to hold on position, as the simulation curves do. Dummy kinematics behavior is comparable and airbag deployment and positioning was correct and according to the predictions.

Figure 15. Dummy kinematics in physical test

Apart from the comparison with the reference simulation model, an additional study was conducted comparing the proposed system results with another 2 different test methodologies:

- Full scale crash test
- Sled-based side pole impact with servo hydraulic actuators.

All tests were conducted with the same test conditions and components, the only variable was the test methodology.

Again, the overall dummy results showed a good correlation level in terms of injury values, especially in the torso area, which is the most affected body region in side crashes due to occupant interaction with vehicle interior [5]. Shoulder lateral force and upper thoracic rib displacement presented, respectively, a response of 120% and 97% of the crash test values.

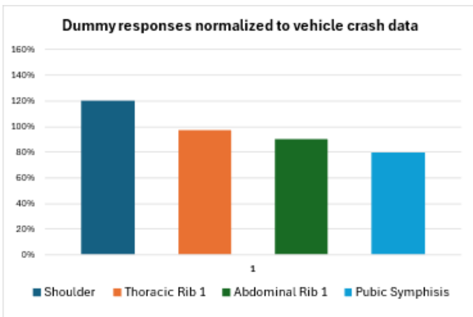

Figure 16. Dummy responses normalized to crash test

When deeply analyzing the kinematics behavior, the similarities are still there, but the same tendency is observed as the previous comparison with CAE simulation results. The upper extremities response, shoulder, and upper rib showed an earlier loading behavior because of the higher intrusion displacement of the upper cylinder. Likewise, all values after 40ms tend to be lower in the current methodology due to the push back effect of the upper and lower cylinders.

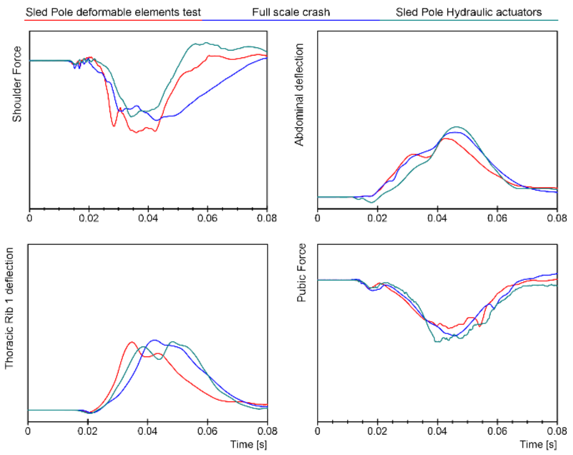

Figure 17. Dummy biomechanical comparison between different test methodologies - 1

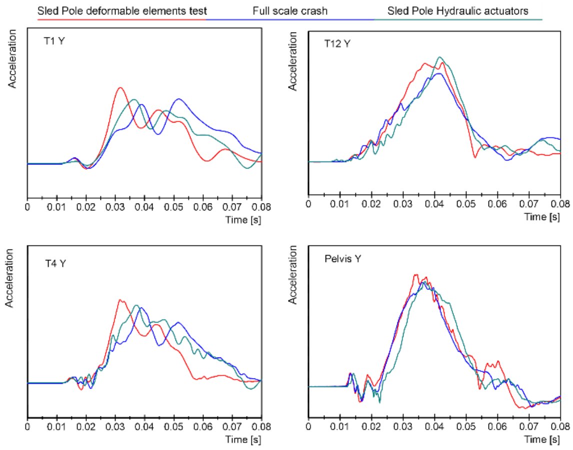

Figure 18. Dummy biomechanical comparison between different test methodologies - 2

CONCLUSION

This study has demonstrated that the proposed subsystem test methodology can effectively reproduce biomechanical responses comparable to full-scale crash tests.

Additional reworks and set-up improvements are required to improve previously mentioned differences and to make the system feasible for a long series of testing phases, some examples of these modifications are:

- Vertically constrained sled system to avoid pitching effect during the test.
- Blocking system to sliding cylinders, to avoid push back effect.

Besides these physical modifications on the setup, additional activities will be conducted in terms of CAE modeling. The DoE database shall be improved with the aid of advanced material correlation techniques, such as coupon level tests and additional sub system material correlation tests. This will allow for much more effective, robust and reliable test conditions.

Considering the results similarities with alternative test methods and with full scale crash test, it can be assumed that the proposed methodology can fulfill the requirements for a sub system test technique as it offers a representative crash severity condition and, therefore, can be applied for side restraint system development projects, providing cost-effective alternatives during early development stages while maintaining adequate fidelity for restraint system optimization.

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