An Open-Source Finite Element Model of a Generic Car Seat: Development and Validation for Low-Severity Rear Impact Evaluations

Jonny Genzel, Anna Carlsson, Astrid Linder, Bengt Pipkorn, Mats Svensson

Abstract A Finite Element model of a generic Laboratory Seat was developed to replicate a physical counterpart used in rear-impact volunteer tests. The Laboratory Seat has a simplified design, developed to facilitate replication in computational models. The seat has a flat rigid base and the seatback consists of four horizontal panels attached to side posts by coil springs. The seat model was validated with results from component tests and sled tests, including the Anthropomorphic Test Device, BioRID II.

An initial test series was carried out to generate data for component validation: the first set of tests to characterise the coil spring properties; and the second set comprising Impactor Tests on Head Restraint Foam to assess the head restraint material properties.

For system level validation, sled tests were conducted both with the empty Laboratory Seat and with the BioRID II. The BioRID II tests were conducted in conjunction with an earlier volunteer test study.

Both the component and the sled tests were reproduced in a virtual environment. Good agreement was achieved between the mechanical tests and the computational simulations.

The seat model is freely available to use: https://openvt.eu/fem/open-access-laboratory-seat-model.

Keywords BioRID, finite element modelling, generic car seat, open source, rear impact.

I. INTRODUCTION

Reference [1] carried out rear-impact volunteer tests comprising eight female volunteers of approximately average size. The volunteer tests were conducted in a specially designed Laboratory Seat in the same seatback design as in previous tests series [2][3]. The seatback was designed to resemble the shape and deflection properties of a Volvo 850 car seat and consisted of four stiff panels covered with 20 mm medium-quality Tempur® foam. The panels were independently mounted to a rigid seatback frame by coil springs to allow easy implementation into a computational model. The seatback angle was adjusted to 24 degrees relative to the vertical plane. The head restraint consisted of a plywood panel covered by firm padding and supported by a rigid steel frame, i.e., it was not coupled to the deflecting parts of the seatback. The head restraint angle was 12 degrees from the vertical plane. The seat-base was rigid, and the flat seat surface was angled 17 degrees from the horizontal plane.

The aim of the present study was to develop and validate a Finite Element (FE) model of the Laboratory Seat and make the model Open Source (OS) [1]. This seat model is intended to be used for validation of FE Human Body Models (HBMs), as well as FE models of Anthropomorphic Test Devices (ATDs), in load cases corresponding to human volunteer tests.

J. Genzel (e-mail: jonny.genzel@vti.se, tel.:+46 13 21 42 92) is an Industrial PhD Student at the Swedish National Road and Transport Research Institute (VTI), Linköping, Sweden. A. Carlsson is a Researcher at Chalmers Industrial Technology and associated to Chalmers University Gothenburg, Sweden. A. Linder is Professor of Traffic Safety at VTI and Adjunct Professor in the Department of Vehicle Safety at Chalmers University, Sweden. B. Pipkorn is Director of Simulation Active Structures at Autoliv Research, Vårgårda, Sweden, and Adjunct Professor at Chalmers University, Sweden. M. Svensson is Professor in the Division of Vehicle Safety at Chalmers University, Sweden.

II. METHODS

Initially, a Computer-Aided Design (CAD) drawing of the Laboratory Seat was created. Thereafter, a FE model was developed by meshing the CAD surfaces with shell, solid and discrete elements, and from this, the Laboratory Seat model was developed. It was validated by means of component, as well as sled tests. The component tests focused on creating validation data for models of the head restraint foam and the seatback panel coil springs. Finally, validation of the Laboratory Seat model at a system level was achieved by reproducing sled tests. The response of the complete Laboratory Seat model was validated with and without the FE-BioRID II model.

CAD Drawing

The Laboratory Seat (Fig. 1) was measured and the geometry of each part was modelled with respect to its cross-section. The generic seat design consists of the following parts: rigid flat surface seat-base, seatback side posts, head restraint with padded polymer foam blocks, and seatback surface consisting of four panels. The four panels (Panels 1–4) were laterally connected to the seatback side posts by means of coil springs of varying stiffness. The seat-base consists of 10 aluminium profiles mounted between the floor and the seat cushion (Fig. 2(a)). The seat cushion consists of a plywood board, 500 mm x 500 mm. The seatback side posts consist of a 670 mm x 515 mm steel profiles to keep the seatback in position. The seatback includes side members and two lateral beams (Fig. 2(b)). The head restraint consists of a stiff steel structure connected via a plywood board measuring 350 mm x 230 mm covered by Polyethylene 220-E foam. The thickness of this foam can be varied to adjust for the head-to-head restraint distance. The four seatback panels are located at the Upper thorax (Panel 1), Lower thorax (Panel 2), Abdomen (Panel 3), and Pelvis (Panel 4) which have been covered in 20 mm Tempur® foam and plush fabric. All of the panels have a height of 120 mm. The width of the Upper thorax panel is 420 mm, while the other panels measure 350 mm. The dimensions of all parts are summarised in Table I and in a schematic drawing in Fig. 3. The seatback angle was adjusted to 24 degrees and the seat-base angle to 17 degrees, relative to the horizontal plane.

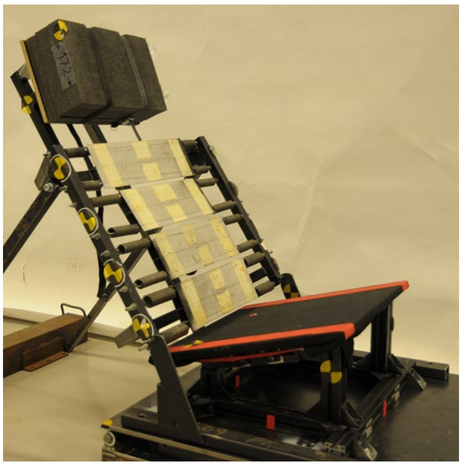
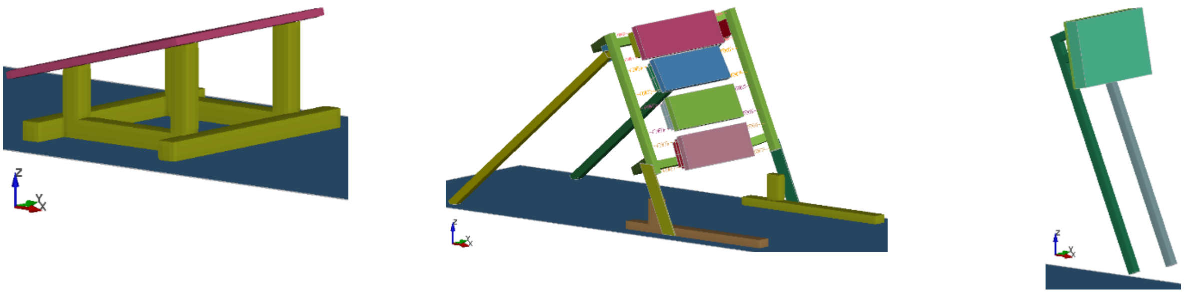


Fig. 1. The Laboratory Seat.

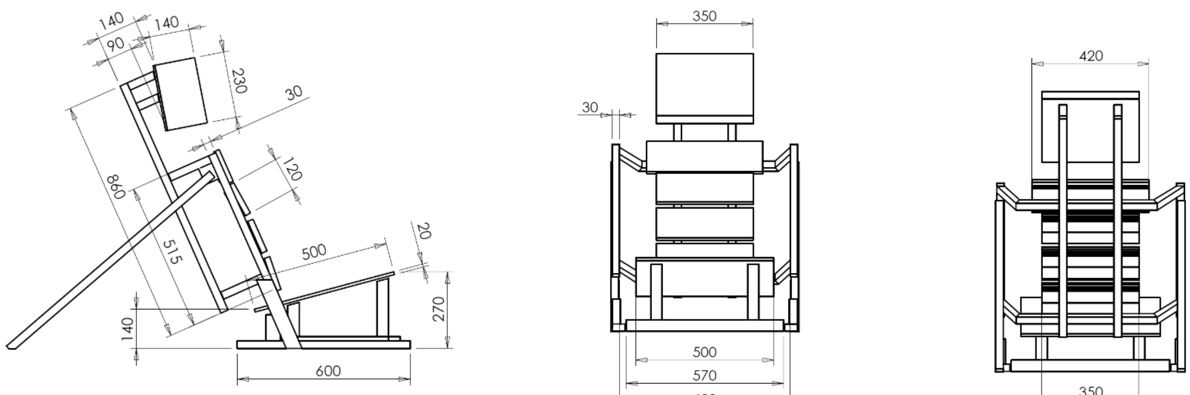


(a) (b) (c)

Fig. 2. The main parts of the Laboratory Seat model: (a) seat-base and seat cushion, (b) seatback side posts and seatback panels, and (c) head restraint structure and head restraint panel.

TABLE I
MATERIAL, MASS AND DIMENSIONS OF THE LABORATORY SEAT

Part				Dimensions (mm)		
No.	Parameter	Material	Mass (g)	Width	Height	Thickness
1	Seat-base	Aluminium	5331	570x600	270	5.0
2	Seat cushion	Plywood	2601	500	500	20.0
3	Seatback side posts	Steel	4542	680	515	2.0
4	Head restraint structure	Steel	3461	860	130	2.0
5	Head restraint panel	Plywood	665	350	230	12.0
6	Upper thorax seatback panel	Aluminium	609	420	120	1.5
7	Lower thorax seatback panel	Aluminium	507	350	120	1.5
8	Abdomen seatback panel	Aluminium	507	350	120	1.5
9	Pelvis seatback panel	Aluminium	507	350	120	1.5
10	Upper thorax foam	Foam	104	420	120	20.0
11	Lower thorax, Abdomen and Pelvis foam	Foam	87	350	120	20.0
12	Head restraint foam	Foam	379	370	230	130.0
13	Upper thorax springs	Carbon steel	102	194	25	3.5
14	Lower thorax and Abdomen springs	Carbon steel	157	260	25	3.5
15	Pelvis springs	Carbon steel	209	244	32	4.5



(a) (b) (c)

Fig. 3. Schematic drawing of the Laboratory Seat: (a) side-view to the right, (b) front view, and (c) back view.

Component Testing: Spring Stiffnesses

Each seatback panel was kept in position by four individual springs to mimic the stiffness of a mechanical car seatback. The springs are numbered R1 to R8 on the right side, and L1 to L8 on the left side (Fig. 4(a)).

The characteristics of the springs were measured using a set-up consisting of a force transducer, a wire strain gauge and a ratchet strap (Fig. 4(b) and (c)). The spring load was increased stepwise by the ratchet strap up to six steps, from unloaded to 700 N. The force was obtained with the force transducer. A string potentiometer was positioned parallel, measuring the deflection.

The pretension of the springs was measured by comparing the deflection of the springs before and after they were positioned in the seat frame.

(a) (b) (c)

Fig. 4. (a) The positions and numbering of each spring element. The testbench to determine the spring stiffnesses of (b) spring and the ratchet strap, and (c) force transducer and the wire strain gauge.

Component Testing: Impactor Tests on Head Restraint Foam

The properties of the head restraint foam were assessed through impact tests using a head form in a drop tower with two different foam thicknesses (40 mm and 130 mm) and with three different drop heights (100 mm, 300 mm and 500 mm). The different drop heights made it possible to distinguish deformation rate-dependent characteristics in the material. Each test was repeated three times to ensure equivalent results, resulting in a total of 18 tests executed (Table II). The test set-up is shown in Fig. 5. At the top of the installation is a distance sensor measuring the distance to the head form with a laser. The force when the head form impacts the foam was calculated by an accelerometer and has been mounted on top of the head form. The radius of the head form is 64 mm, and the weight is 2.8 kg, which is in the right magnitude compared to the shape and weight of a female head. Reference [4] summarised average female size and mass data reporting a head height of 203 mm and a head mass of 3.58 kg.

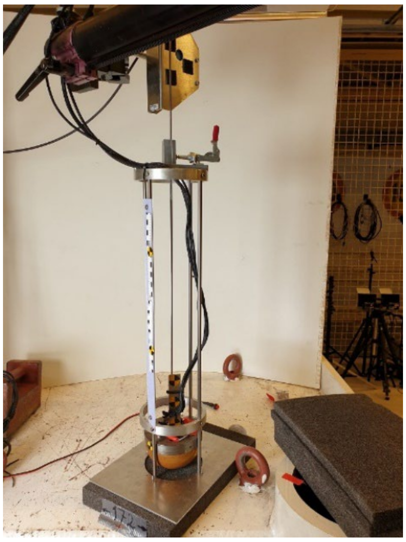


Fig. 5. Drop tower with head form for Impactor Tests.

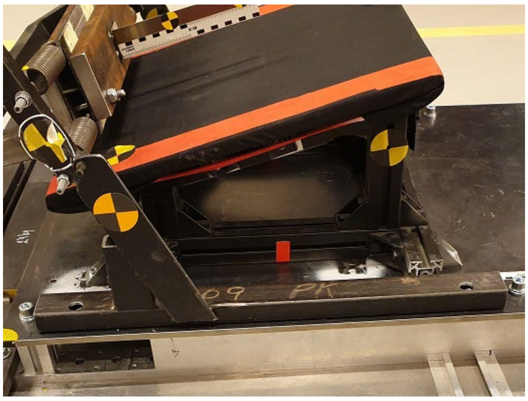
TABLE II

TEST PLAN FOR IMPACTOR TESTS OF HEAD RESTRAINT FOAM

Pulse No.	Foam thickness (mm)	Height (mm)	Description
1-3	40	100	Thin layer and low height
4-6	40	300	Thin layer and medium height
7-9	40	500	Thin layer and high height
10-12	130	100	Thick layer and low height
13-15	130	300	Thick layer and medium height
16-18	130	500	Thick layer and high height

Validation Testing: Empty Seat Tests

To generate data for validation of the complete Laboratory Seat model, sled tests were performed with the empty Laboratory Seat. The Laboratory Seat was mounted on the sled with four anchor points for the seat cushion, two bolts on each side bar and two bolts for the seatback (Fig. 6(a)). The angle of the seatback was mounted at 24 degrees. Four aluminium wings with video tracking targets were mounted on the panels. Two video tracking targets were placed on each wing, separated by 100 mm, to record the displacement during impact with a high-speed camera. Fig. 6(b) shows the panels with additional weights, which were used to increase the displacement during the impact.



(a)

(b)

Fig. 6. (a) Attachment of Laboratory Seat on sled, and (b) seatback panels with additional weights and wings.

A test plan was designed to measure the displacement of each panel when the Laboratory Seat was subjected to a rear-impact. Table III shows the first four tests (Pulse No. 1-4) run only with the own weight of the panels and wing. While the last four tests (Pulse No. 5-8) were executed with additional 9.5 kg weights on each panel. A total weight of 38 kg on the entire backrest was considered to be similar to the load from the Upper body of a human. Reference [4] reported an average female torso and pelvis mass of 35.4 kg. The desired speed and acceleration started at 6 km/h and 3 g for the first pulse, which is close to the pulse used in the volunteer tests [1]. The severity was then gradually increased up to 16 km/h and 5 g, which is close to the pulse used in Euro NCAP low-severity rear-impact [5]. The same pulses were executed for the test set-up with additional weights. All acceleration pulses for the Empty Seat tests are visualised in Fig. A.1 (Appendix A).

TABLE III

TEST PLAN OF PLANNED SLED TESTS

Pulse No.	Weight (kg)	Mean speed (km/h)	Max acc. (g)	Description
1	0.5	6	3	Low weight and volunteer-speed impact
2	0.5	9	4	Low weight and low-speed impact
3	0.5	12	4	Low weight and medium-speed impact
4	0.5	16	5	Low weight and high-speed impact
5	10.0	6	3	High weight and volunteer-speed impact
6	10.0	9	4	High weight and low-speed impact
7	10.0	12	4	High weight and medium-speed impact
8	10.0	16	5	High weight and high-speed impact

Sled Testing and Simulation: BioRID II

In conjunction with the volunteer tests of [1], as part of the EU funded ADSEAT project, four additional Sled Tests were carried out using a mechanical BioRID II ATD in the same Laboratory Seat and under the same test conditions. These four tests were conducted with varying head restraint gaps, as per to Table IV. The simulation of the FE-BioRID II model was run in the same test configuration as the mechanical BioRID II test (Fig. 7).

To position the FE-BioRID II model in the same position as the sled tests with mechanical BioRID II, a 300 ms pre-simulation sequence was run involving three settling steps. During the first 100 ms, the pelvis movement of the FE-BioRID II model was prescribed to touch Panel 4 (Pelvis) of the Laboratory Seat model. The second 100 ms, the 4th thoracic vertebrae were prescribed to move 13 mm into the seatback to create a small pretension to the upper seatback panels. The last 100 ms, the pre-simulation was ended by applying 1g of gravitational load and reaching the equilibrium state between the FE-BioRID II model and the Laboratory Seat model. These three settling steps replicate the positioning procedure of the mechanical BioRID II in the Laboratory Seat.

The horizontal head-to-head restraint gap for the FE-BioRID II model and for the mechanical BioRID II is presented in Table IV. The average gap was 136 mm for the two sequences with the same foam thickness (Pulse No. 43-10 and 44-10).

TABLE IV
HEAD-TO-HEAD RESTRAINT DISTANCE IN THE X DIRECTION

Model	Pulse No.	Distance in x direction (mm)	Foam thickness (mm)
Mechanical BioRID II	43-10	133	140
Mechanical BioRID II	44-10	139	140
Mechanical BioRID II	45-10	180	90
Mechanical BioRID II	46-10	No head restraint	No head restraint
FE-BioRID II	NA	120	140

(a) (b)

Fig. 7. (a) The mechanical BioRID II Sled Test set-up, and (b) the corresponding FE-BioRID II model set-up.

The acceleration pulse used in the simulation of the FE-BioRID II model (FAT BioRID-2 v4.0) had been created in accordance with a mean approximation of the mechanical BioRID II Sled Tests [1] shown in Fig. A.2 (Appendix A). The mechanical BioRID II data include four tests (43-10, 44-10, 45-10 and 46-10) at a rearward impact of 6.7 km/h. The mean approximation of the sled response resulted in a mean acceleration of 1.9 g and a maximum acceleration of 3.0 g.

The Laboratory Seat Model

The Laboratory Seat model was created using the tool ANSA (v20.1.1, BETA CAE Systems, Epanomi, Greece), while the simulations were evaluated by the LS-DYNA (LSTC, Canonsburg, USA) solver version (Massively Parallel Processing, double precision, release 10, Linux distribution). Post-processing was made with data exported with LS-PrePost (v4.6 64 bit, LSTC, Canonsburg, USA) and imported to MATLAB (R2021b, Mathworks, Kista, Sweden) for visualisation.

The FE model of the Laboratory Seat was created by meshing the CAD surfaces. All parts of the Laboratory Seat model were modelled by means of shell elements, except the foam material and spring elements. The foam material was modelled as solid elements while the spring elements were modelled by means of 1-dimensional discrete elements. The spring elements were connected between the seatback side posts and seatback panels. The Laboratory Seat model was developed using an element size of 10 mm, unit system: “mm/kg/ms” and the time step of the simulations was executed with 1 µs.

The correlation quality was assessed using an available objective rating tool called CORA plus (CORrelation and Analysis, v4.0.5, Partnership for Dummy Technology and Biomechanics, Gaimersheim, Germany) [6]. The CORA score was calculated by comparing the phase and amplitude of two curves over a given time window. The crash test results provide the reference curve to which the simulation output curve has been compared to. A CORA score of 100% is considered almost perfect and a score above 70% is assumed good.

TEMA Automotive (v.4.1, Image Systems, Linköping, Sweden) was used for video analyses of the sled tests.

Signals of Interest

The measured signals of interest for analysing the Laboratory Seat model are shown in Table V.

TABLE V
ANALYSED SIGNALS FOR THE LABORATORY SEAT MODEL

No.	Parameter	Filter	Function	Model node id
1	Acceleration (g) for Upper thorax panel	SAE CFC 60	x_ acceleration	40231-Panel_1_U_Thorax
2	Acceleration (g) for Lower thorax panel	SAE CFC 60	x_ acceleration	39209-Panel_2_L_Thorax
3	Acceleration (g) for Abdomen panel	SAE CFC 60	x_ acceleration	38181-Panel_3_Abdomen
4	Acceleration (g) for Pelvis panel	SAE CFC 60	x_ acceleration	37451-Panel_4_Pelvis
5	Target sled (g) in x direction	SAE CFC 60	acceleration	Sled (44879)

III. RESULTS

The results of the four different set-ups are presented in the following sections. They consist of: Spring Stiffnesses, Head Restraint Foam Model, Empty Seat Tests, and Sled Tests with Laboratory Seat. For the Spring Stiffnesses, the resulting implementation of spring force vs. deflection curve is shown. The material properties of the foam on the head restraint were determined by Impactor Tests on Head Restraint Foam. Finally, the spring elements and head restraint foam implementation were included in the Laboratory Seat model. The Laboratory Seat model was evaluated in sled test simulations reproducing both set-ups, with and without the FE-BioRID II model.

Component Test Results: Spring Stiffnesses

Fig. 8 shows the mean values of the measurement results for the four springs on each panel. The measurement of the R5 spring at the Abdomen Panel was discarded due to a data acquisition error. The force vs. deflection graph was adjusted leftwards to adjust for the pretension of the springs when installed into the seatback side posts, hence stiffness at 0 deflection of the Upper Thorax was 146N, Lower Thorax/ Abdomen was 118N, and Pelvis was 350N. The difference in curve inclination in the graph are due to the different spring characteristics selected to reproduce the stiffness and dynamic properties of the original Volvo 850 seatback reported by [2].

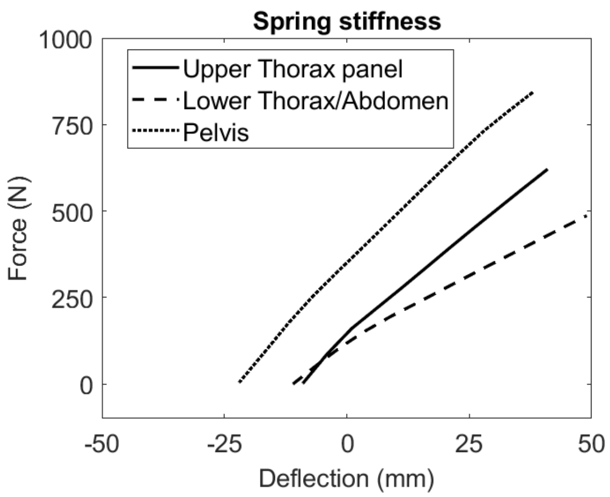


Fig. 8. The mean values for the spring stiffnesses on the Upper Thorax (R1, R2, L1 and L2), Lower Thorax (R3, R4, L3 and L4), Abdomen (R6, L5 and L6) and the Pelvis (R7, R8, L7 and L8) panels.

Component Test Results: Head Restraint Foam Model

The material model of the head restraint foam was manually tuned to match the simulations and Impactor Tests on Head Restraint Foam. The material model was made in a Soft Density Foam (MAT_57) with parameters for Hysteresic Unloading (HU): 0.5, Damping coefficient (DAMP): 0.5, Shape control: 7, and Scale Factor Ordinate (SFO): 0.009. The measured density of the foam material is 34.62 kg/m^3.

The results from the Impactor Tests on Head Restraint Foam and simulations are displayed in Fig. 9 (40 mm and 130 mm foam thickness). The blue arrows in Fig. 9 show the loading phase of the foam in a compressed state, while the red arrows show the unloading phase as the foam recovers. In some cases, only two of the three test repetitions of the head form on Impactor Tests on Head Restraint Foam were used, depending on whether any measurements were removed due to data acquisition issues. The middle drop height (300 mm) gave the highest CORA score of 95.4% for the maximum deflection (Fig. 9(b)), while the lower drop height (100 mm) gave the highest CORA score of 98.6% for the maximum force (Fig. 9(d)). All CORA scores are summarised in Table VI.

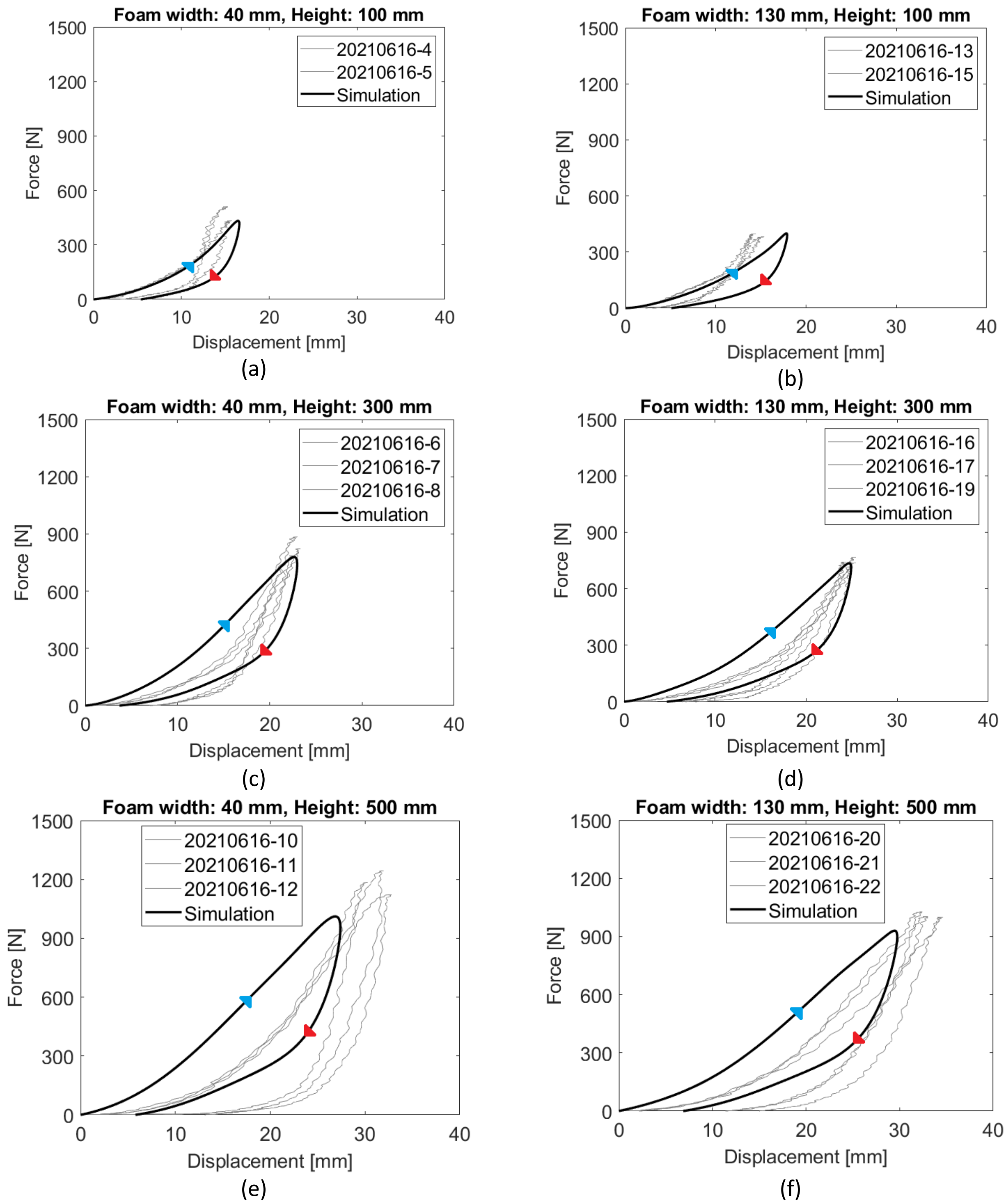


Fig. 9. The head foam test and simulation of material test for 40 mm foam at different heights: (a) 100 mm, (c) 300 mm, and (e) 500 mm. Head foam test and simulation of material test for 130 mm foam at different heights: (b) 100 mm, (d) 300 mm, and (f) 500 mm. The blue arrows show the loading phase, while the red arrows show the unloading phase.

TABLE VI
CORA SCORE FOR IMPACTOR TESTS

Pulse No.	Displacement score (%)	Acceleration score (%)	Total score (%)
1-3	94.2	86.0	90.1
4-6	90.1	97.5	93.8
7-9	73.4	79.6	76.5
10-12	95.4	75.2	85.3
13-15	78.8	98.6	88.7
16-18	72.9	86.8	79.8

Validation Results: Empty Seat Tests

The Empty Seat Tests were conducted on the Laboratory Seat in accordance with the test plan in Table III, with the acceleration pulses shown in Fig. A.1 (Appendix A). The deflection in the x direction of each individual panel was measured for four different sled speeds, from 6 km/h to 16 km/h. Fig. 10 shows the difference in deflection between the simulation and sled tests for each panel for Pulse No. 8. A similar comparison was also performed for the seven other validation cases.

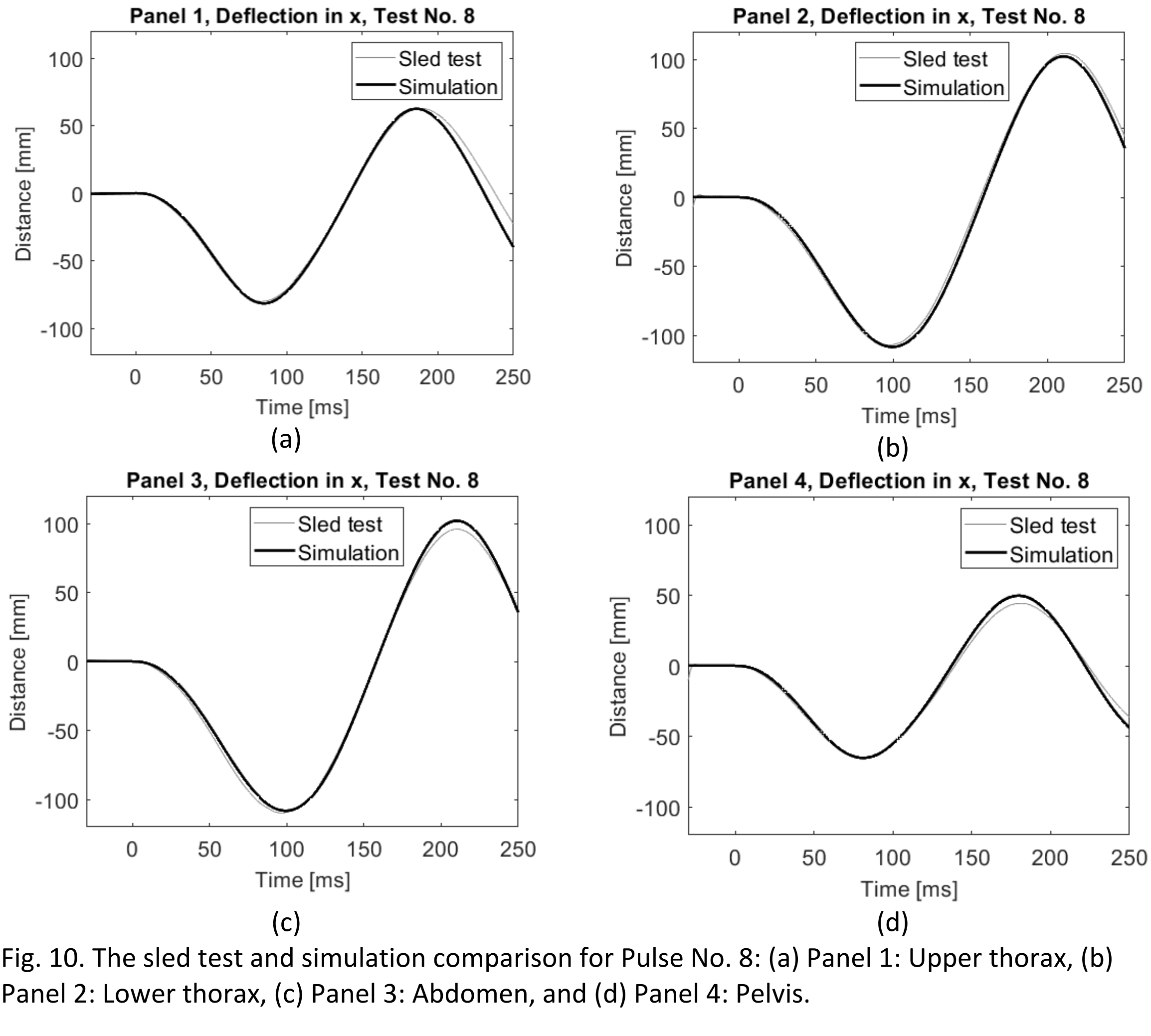


Fig. 10. The sled test and simulation comparison for Pulse No. 8: (a) Panel 1: Upper thorax, (b) Panel 2: Lower thorax, (c) Panel 3: Abdomen, and (d) Panel 4: Pelvis.

The results from the sled tests made without weights, for Pulse No. 1-4, are displayed in Fig. A.3 (Appendix A), and the sled tests with weights on the panels for Pulse No. 4-8 are displayed in Fig. A.4 (Appendix A).

The simulation results of Pulse No. 1-4 are shown in Fig. A.3 (Appendix A), and Pulse No. 5-8 are shown in Fig. A.4 (Appendix A). The results from the validation tests include a comparison of the panel displacement between the sled tests and the simulations.

The most severe pulse (Pulse No. 8) gave the highest CORA scores: 96.2% for Panel 1 (Upper thorax panel), 99.7% for Panel 2 (Lower thorax panel), 99.5% for Panel 3 (Abdomen panel), and 97.3% for Panel 4 (Pelvis panel).

All CORA scores are summarised in Table VII for Panel 1, Panel 2, Panel 3 and Panel 4.

TABLE VII
CORA SCORE FOR PANEL 1, PANEL 2, PANEL 3 AND PANEL 4

Pulse No.	Panel 1 (%)	Panel 2 (%)	Panel 3 (%)	Panel 4 (%)	Total score (%)
1	71.4	45.6	65.6	57.8	60.1
2	59.6	48.1	72.0	72.6	63.1
3	61.7	54.1	72.0	87.8	68.9
4	60.5	45.0	51.8	73.1	57.6
5	88.8	99.3	92.5	92.9	93.4
6	90.8	99.1	96.4	96.6	95.7
7	94.3	98.7	98.1	97.1	97.1
8	96.2	99.7	99.5	97.3	98.2

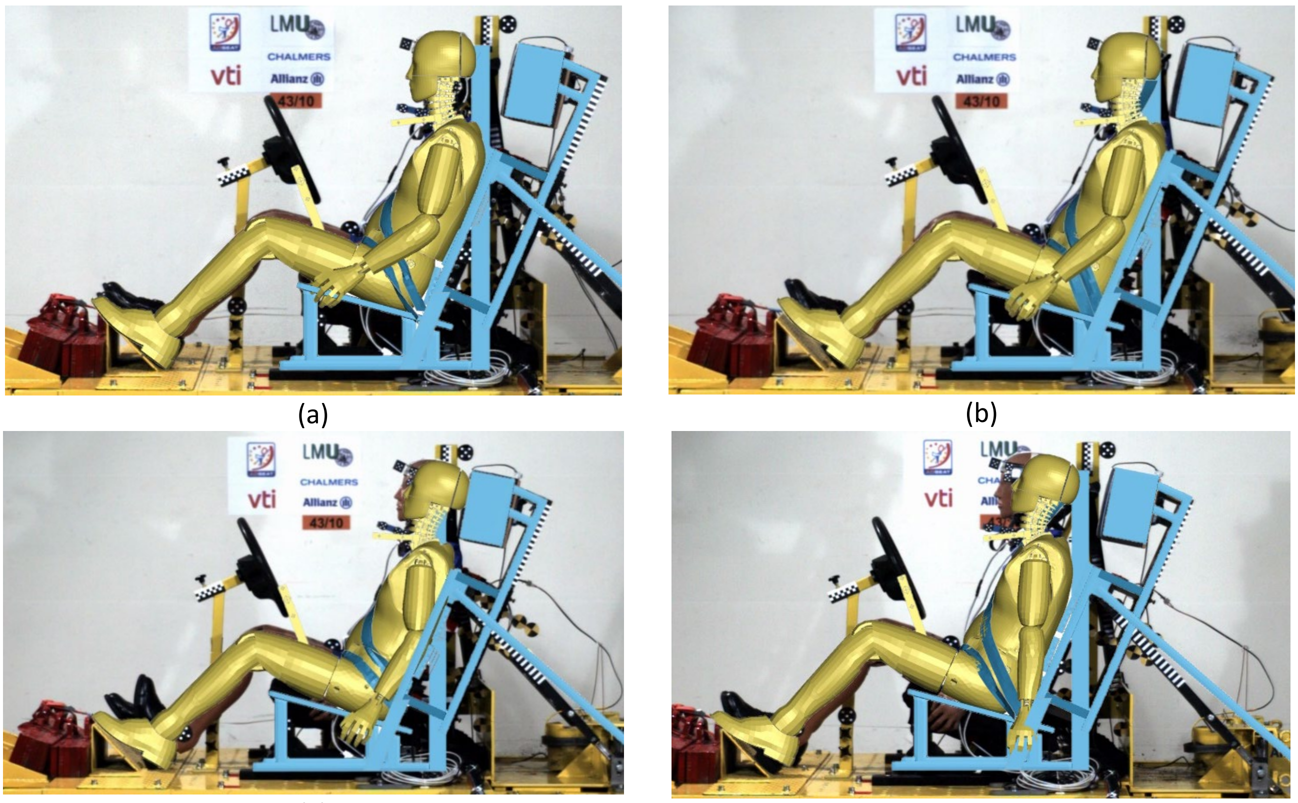
Validation Results: Sled Tests with Laboratory Seat and BioRID II

An average acceleration pulse for the mechanical BioRID II (Fig. A.2, Appendix A) was used to accelerate the sled with the Laboratory Seat model with the FE-BioRID II model seated on it. A video comparison between the mechanical tests and simulations is shown in Fig. 11.

The sled test data describe the displacement of the panels captured via video analyses of the Laboratory Seat in the mechanical BioRID II tests. The results of the comparison between the simulated and mechanical tests are presented in Fig. 12. The CORA scores varied between 99.5% and 88.6%. All values for all panels are presented in Table VIII.

TABLE VIII
CORA SCORE OF SLED TEST AND SIMULATION RESULTS

	Panel 1	Panel 2	Panel 3	Panel 4	Total
CORA score (%)	99.5	97.3	91.7	88.6	94.3



(a) (b) (c) (d)

Fig. 11. A video comparison between the mechanical tests and the simulations: (a) 0 ms, (b) 80 ms, (c) 160 ms and (d) 240 ms.

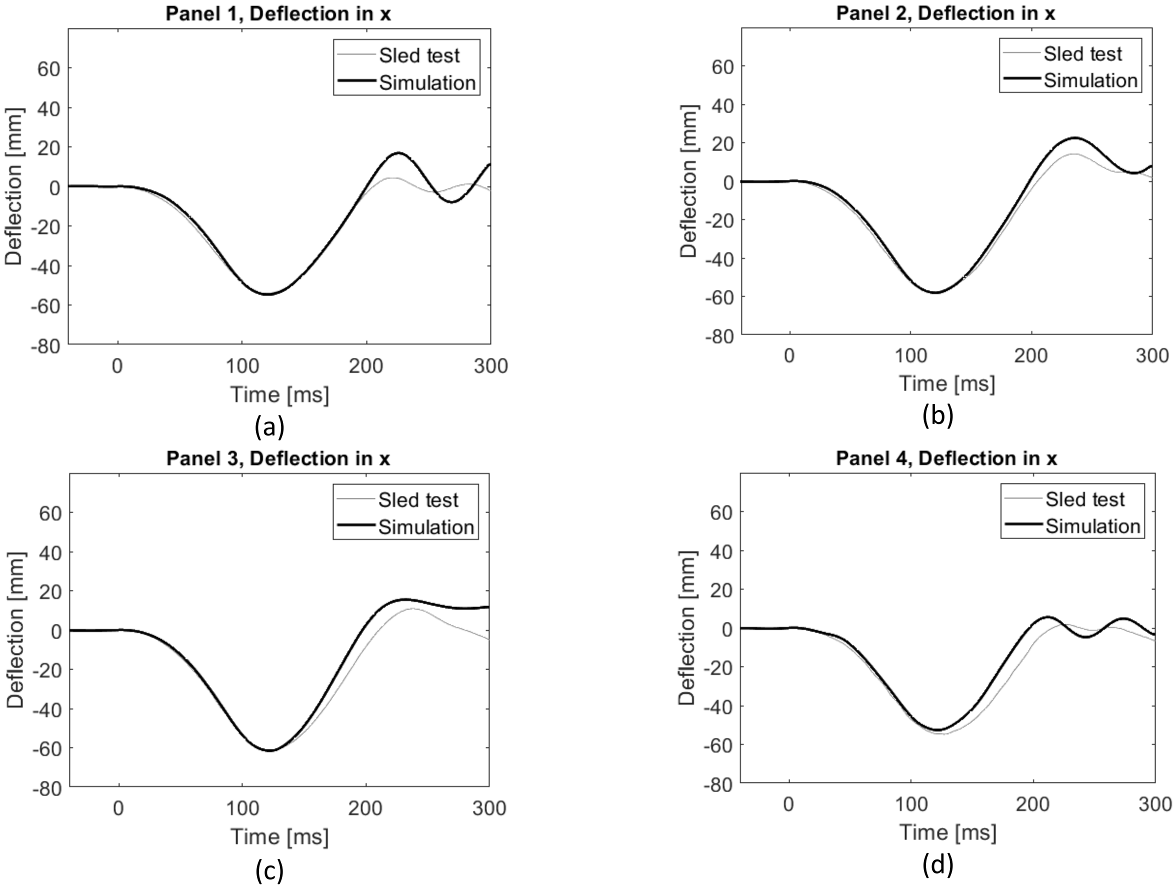


Fig. 12. A comparison for the panel displacement between mechanical tests and the simulations: (a) Panel 1: Upper Thorax, (b) Panel 2: Lower Thorax, (c) Panel 3: Abdomen, and (d) Panel 4: Pelvis.

IV. DISCUSSION

The aim of this study was to develop and validate a Laboratory Seat model and make the model available to the public through an OS license. The intention was to provide a tool that could be used by researchers to evaluate low-speed rear-impacts studies, product development, reconstructions, ATD development, and volunteer tests. The Laboratory Seat model was validated both at a component and a system level.

The process of developing a robust and validated model of the Laboratory Seat involved two different test set-ups at component level, from a test bench to determine the stiffness of springs in the seatback, to identifying the properties of the foam material model of the head restraint. The loading was static in the component tests of the spring stiffnesses, although the springs were loaded dynamically during rear-impact. The difference between the static and dynamic behaviour of the springs has in this case been disregarded because the Laboratory Seat tests were performed at low speeds and coil springs are primarily known to have elastic properties.

The varying phase shifts in Panels 2 and 3 for Pulse No. 1-4 in Fig. A.3 (Appendix A) after the initial cycle are likely dependent on deviation between the physical components (panels, springs and spring attachments) and how they are represented in the seat model. It becomes clear that the influence of these deviations once the panels are loaded with the 9.5 kg weights is insignificant. Pulse No. 5-8 in Fig. A.4 are far more representative of the load range in the tests with FE-BioRID II model, so these latter tests provide the most essential comparison among the Empty Seat Tests. Pulse No. 5-8 also only include the first panel deflection cycle, up until about 150 ms, the only one that is representative of the phase when the dummy or volunteer is in contact with the seatback.

The ambition in the present study was to reproduce the test set-up of [1]. In the empty seat sled-tests it would have been possible to also include accelerometers on the seatback panels to create more validation data. The close fit between test and simulation in the onloading phase in Fig. 10 does however indicate that the accelerations would match well between tests and simulations.

Additional mechanical validation tests together with recreated simulations would strengthen the model's reliability, such that a better validated material model of the foam on the seatback panels remains to be made.

The mechanical BioRID II tests were used in the validation of the whole seatback of the seat model. Although extended video analysis of the mechanical BioRID II head movement would be possible, due to as the FE model of the BioRID II lacking good biofidelity in the T1 angular response and thus in the head and neck region [7], the comparison would be deceptive. In addition, the mechanical BioRID II sled tests used a head band to attach accelerometers to the head, corresponding to volunteer tests. The head band fitted in between the head and the head restraint, which was not reproducible in the FE-BioRID II model simulations. We therefore restricted our validation of the head restraint to the Impactor Tests on Head Restraint Foam.

The VIRTUAL project [8] is producing various seat models, one of which is the Laboratory Seat model outlined in this article. One benefit of using virtual models is the ability to perform parameter studies, for example, evaluating how the stiffness or geometry of the seatback affects human body dynamics. However, to ensure reasonably valid results of such virtual parameter studies, it is essential that the seat model is validated against mechanical tests of a similar load case.

In future studies, the Laboratory Seat, in combination with volunteer test results [1], can be used to evaluate the kinematic response of an average female HBM.

The simplified construction of the physical Laboratory Seat facilitates the development of a robust and valid Laboratory Seat model. The relatively simple and reproducible Laboratory Seat design will offer the option of using HBMs in parameter studies to investigate seat and head restraint design principles, and how they influence head and neck dynamics and internal loading. These parameter variations could include different spring stiffnesses in the seatback, distance to the head restraint, seatback angles and more. With virtual testing these seat design parameters could be investigated with HBMs that represent both female and male occupants of varying sizes in varying seated postures. This would hopefully ensure that manufacturers can design robust seat designs with good neck protection over a wide variability range.

The Laboratory Seat model is freely available as OS and stored in GIT: https://openvt.eu/fem/open-access-laboratory-seat-model.

V. CONCLUSIONS

An FE model of a Laboratory Seat of a generic design was developed and validated from component to system level. The validated tool is suitable for evaluation of HBMs and computational ATD models in low-speed rear-impact test conditions.

The simple construction of the Laboratory Seat enables different types of parameter studies, such as different spring stiffnesses in the seatback, distance to the head restraint, and angles of the seatback.

A prerequisite for trusting virtual testing results is traceability to mechanical tests. A defined Laboratory Seat model would also allow for comparison of different models of ATDs and HBMs relative to human volunteer responses.

The Laboratory Seat model and all results are available OS for further analyses and verification. In the future, the reliability of the Laboratory Seat model may be further enhanced if the number of researchers reviewing the results and executing additional evaluations increase. Any suggestions for further development and findings can easily be uploaded to the OS platform.

VI. ACKNOWLEDGEMENTS

This study was funded by the European VIRTUAL project with funding from the European Union Horizon 2020 Research and Innovation Programme under Grant Agreement Nr. 768960. The simulations were performed at Chalmers Centre for Computational Science and Engineering (C3SE) in Gothenburg, Sweden. The mechanical BioRID II tests for validation data were received from the EU funded FP7 project Adaptive Seat to Reduce Neck Injuries for Female and Male Occupants (ADSEAT), under Grant Agreement Nr. 233904. The video analyses of sled tests for validation were performed by Philip Sorri (VTI, Linköping, Sweden).

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VIII. APPENDIX A: ACCELERATION PULSE AND SLED TEST RESULTS

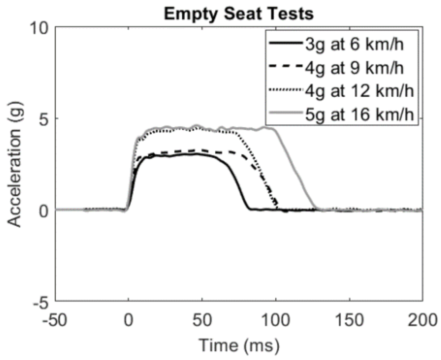

Fig. A.1. The acceleration pulses of the Empty Seat Tests.

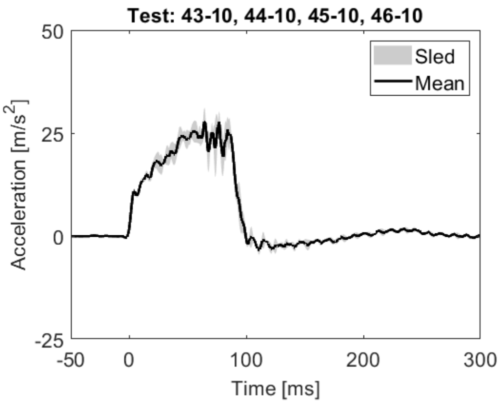

Fig. A.2. The acceleration pulse of the BioRID II corridor.

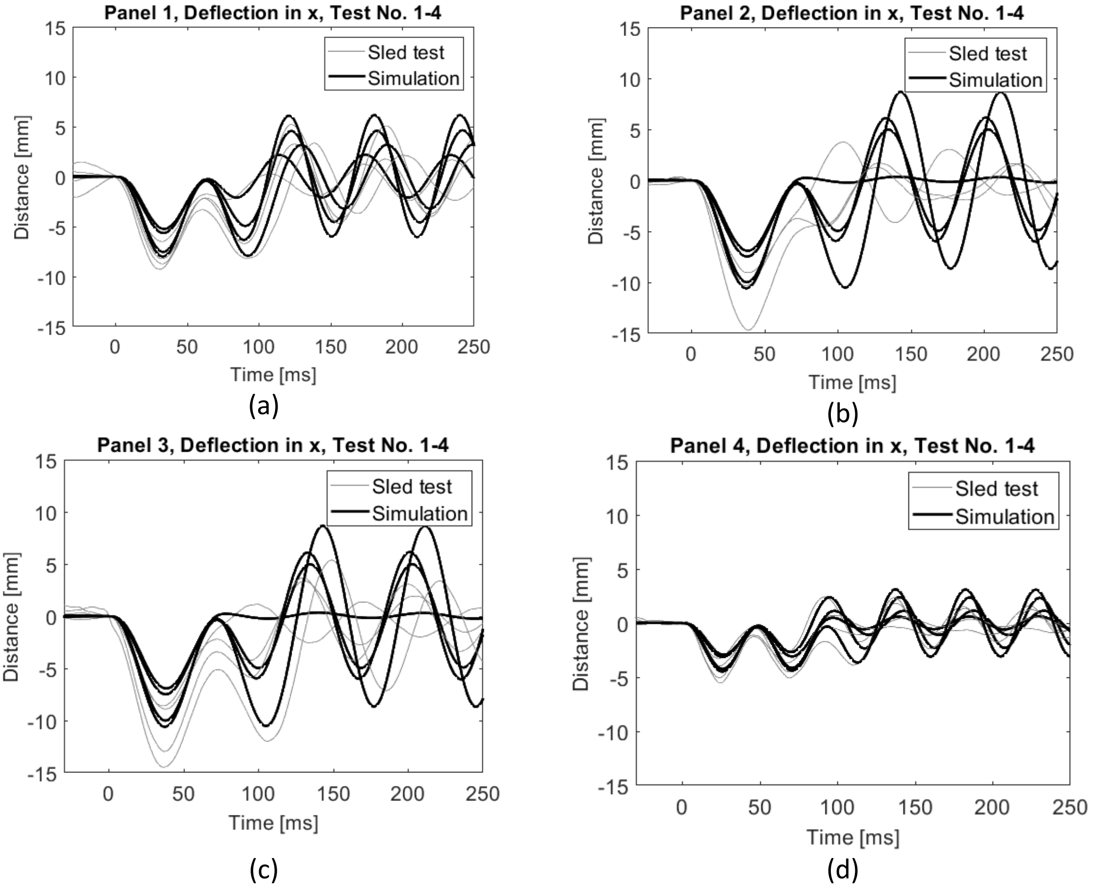

Fig. A.3. Sled Test and simulation results for Pulse No. 1-4: (a) Panel 1, Upper Thorax, (b) Panel 2, Lower Thorax, (c) Panel 3, Abdomen, and (d) Panel 4, Pelvis.

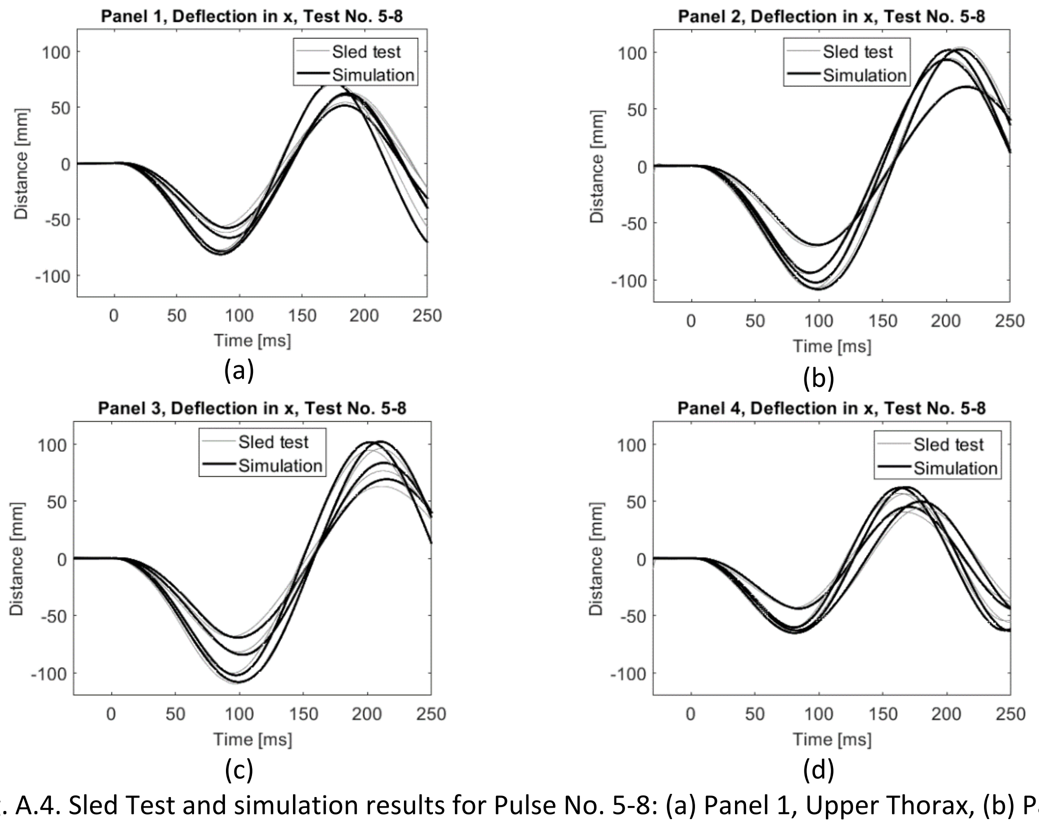

Fig. A.4. Sled Test and simulation results for Pulse No. 5-8: (a) Panel 1, Upper Thorax, (b) Panel 2, Lower Thorax, (c) Panel 3, Abdomen, and (d) Panel 4, Pelvis.