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How to Build a Battery Case

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Abstract

Many aspects of electric vehicles carry over from vehicles with conventional propulsion systems. Thus, the previously gained knowledge and established development processes from conventional combustion engine vehicles should be maintained for electric vehicles as well. Indeed, there are several issues where electric vehicles do differ and need revised development processes or even new ones. This paper investigates how the electrochemical energy storage device (battery) of an electric vehicle influences passive safety concepts of conventional propelled vehicles. Therefore, the work in hand focuses onto an exemplary side load case of a pole impact. In order to protect the battery from thermal runaway a suitable housing is needed and has to be integrated into the body in white. The work in hand shows a methodology to optimize the deformation area of a pole impact by structural investigation and load path optimization of a battery case. The investigation includes FEM simulation on full vehicle and component level.

Keywords: Electric Vehicles, Crash Safety, Pole Impact, High Voltage Battery

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1. Motivation

The goal of this paper is to preserve passive safety without compromise in range of the electric vehicle (EV) [2]. There are several properties that influence the range of an EV: driving resistances, degree of efficiency of the power train, energy density of the battery cells and workspace for battery cells. The work in hand approaches this topic from the body in white (BIW) development and focusses on the last enumerated property – increase of workspace for battery cells. Thus, the structural components such as the BIW and the battery case have to be adjusted to synergistically protect the battery cells [1] by reducing pole intrusion. The required structural components have to be designed accordingly to have proper load paths and innovative lightweight solutions. Design rules are desired that facilitate the development and validation of safety of electrical vehicles [2], [3]. The presented methodology approaches design rules for battery cases in terms of load path optimization and intelligent segmentation of the battery workspace.

2. Methodology

The analysis is based on several boundary conditions.

- The battery cells are assembled in modules that are shaped in the form of a rectangular solid
- Several identical modules are assembled within the battery case
- The battery case is integrated with the underfloor of a body in white in between the vehicle sill
- The presented methodology does not modify the body in white for the sake of fair complexity of the work in hand. The body in white effects can be considered by an additional iteration loop at higher level, following the same methodology.
- The analysis is conducted exemplarily on a pole impact of a side load case. This load case is considered to be one of the most critical ones for the battery safety since there is a 100% overlap with the battery workspace and a minimum free crash length.

The work in hand approaches the analysis top down according to Fig. 2.1. The approach basically consist of three steps: A, B and C. The requirements are defined on vehicle level and get broken down to a less complex analysis on component level.

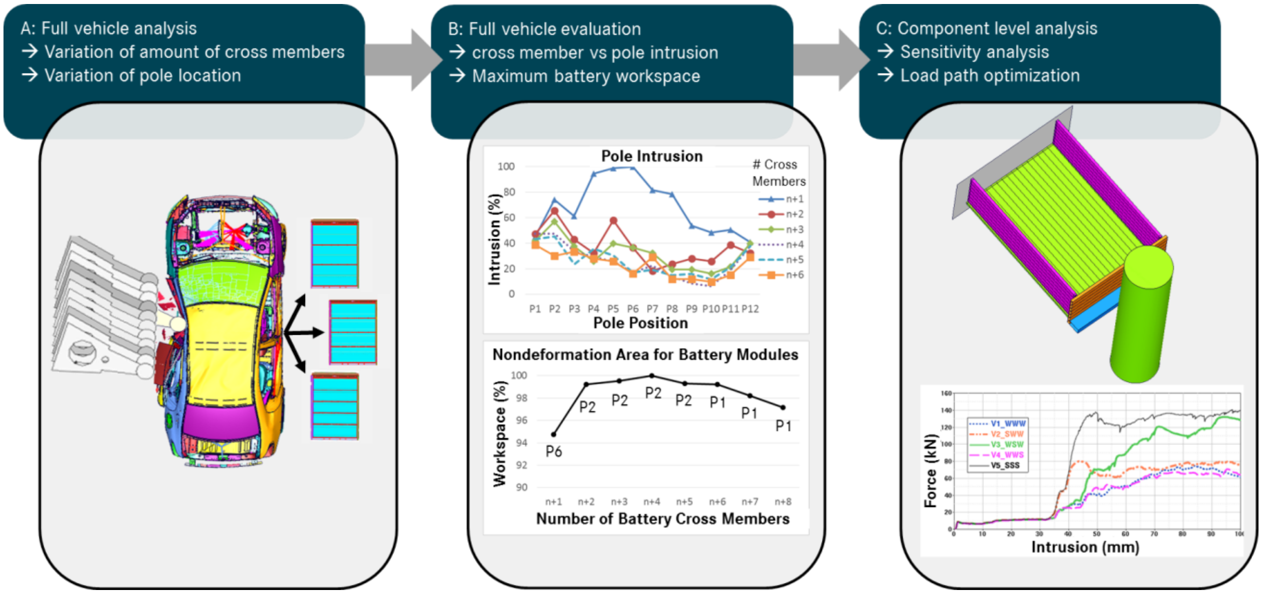


Fig 2.1: Visualization of the presented methodology

A. First, the influence of impact location and number of battery cross members is investigated. Therefore, a full vehicle crash simulation is utilized as illustrated in part A of Fig. 2.1. The impact location is varied in discrete steps along the sill of the vehicle in order to identify the worst case location. The simulation is conducted for a varying number of battery cross members. As a result of step A information about pole intrusions is achieved with respect to impact location and number of battery cross members.

B. Second, based on the results of the previous step the optimum number of battery cross members is derived. The optimum number of cross members is characterized by preserving a maximum non intrusion workspace for the battery modules according to part B of Fig. 2.1. As the number of battery cross members is increased, the pole intrusion is reduced. This effect is nonlinear over the number of battery cross members as presented in Fig. 2.2 (left picture). Thus, it happens that at a certain number of cross members the benefit falls behind the required workspace of the added cross member as illustrated in Fig. 2.2 (right picture). This evaluation considers the maximum intrusion of each cross member variant as shown in Fig. 2.2 (left picture: n+i) since the dimensioning of each variant would focus onto the worst case impact position. As a result of step B the segmentation of the battery workspace into symmetrical module compartments is achieved. These geometrical findings carry over to step C as constraints for the battery section considered.

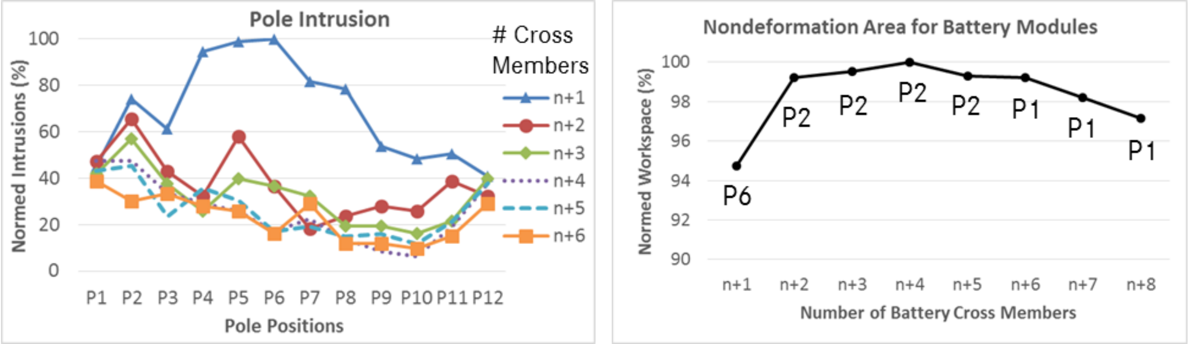


Fig 2.2: Full vehicle battery work space evaluation

C. The third step is focusing onto the distribution of the structural components within a battery case as shown in part C of Fig. 2.1. The worst case position is found to be when the impact is in between the battery cross members. The analysis is based on a crush simulation of the battery case component. The component is reduced to a single module compartment as this can be considered the smallest symmetrical section of a battery case. The geometrical constraints for the battery section are applied as derived in the previous step. The performance of the battery section is evaluated in terms of quasi static force level which is derived from a crush simulation. The optimization is done as a sensitivity analysis by reinforcing single components of the battery case at equal mass. As a result of step C the influence of the single battery case components is ranked and predicts the proper distribution of the structural components for the requested lightweight design.

3. Model Build Up of Battery Component Level Analysis

Most battery cases show symmetries. The proposed methodology suggests to focus on the smallest symmetric section to reduce the computational and modeling effort. A single half chamber section of the battery case is considered in Fig. 3.1. For the analysis of proper load paths the basic design is shown in Fig. 3.2. The considered setup is created to demonstrate the proposed methodology. The used setup is illustrated below:

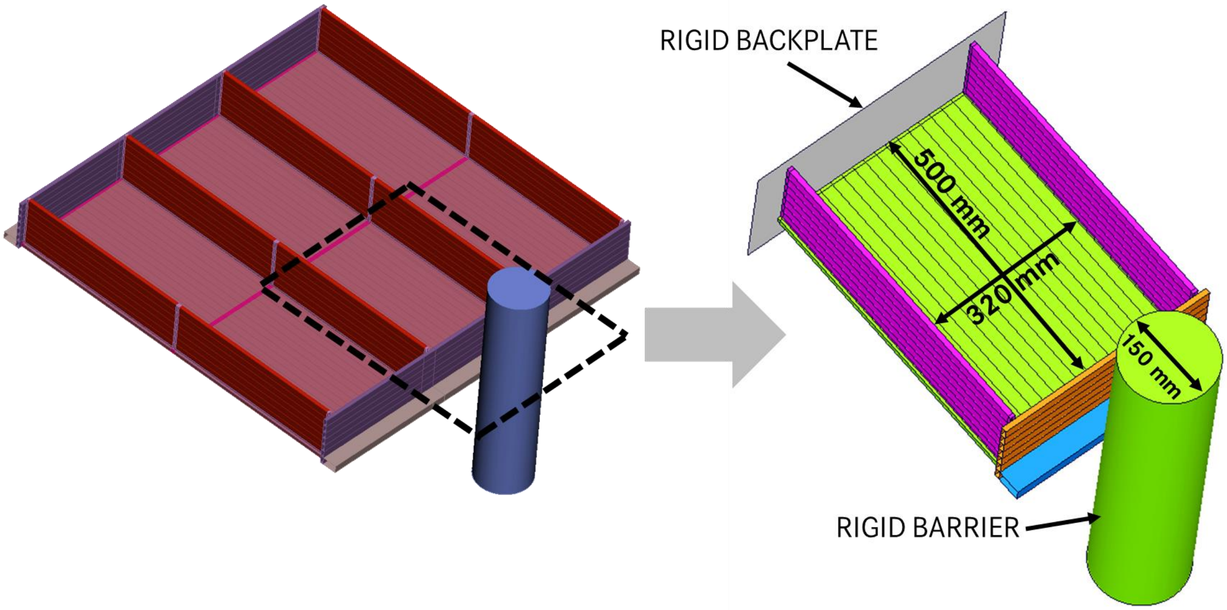


Fig 3.1: Half chamber section from battery case for quasi static analysis

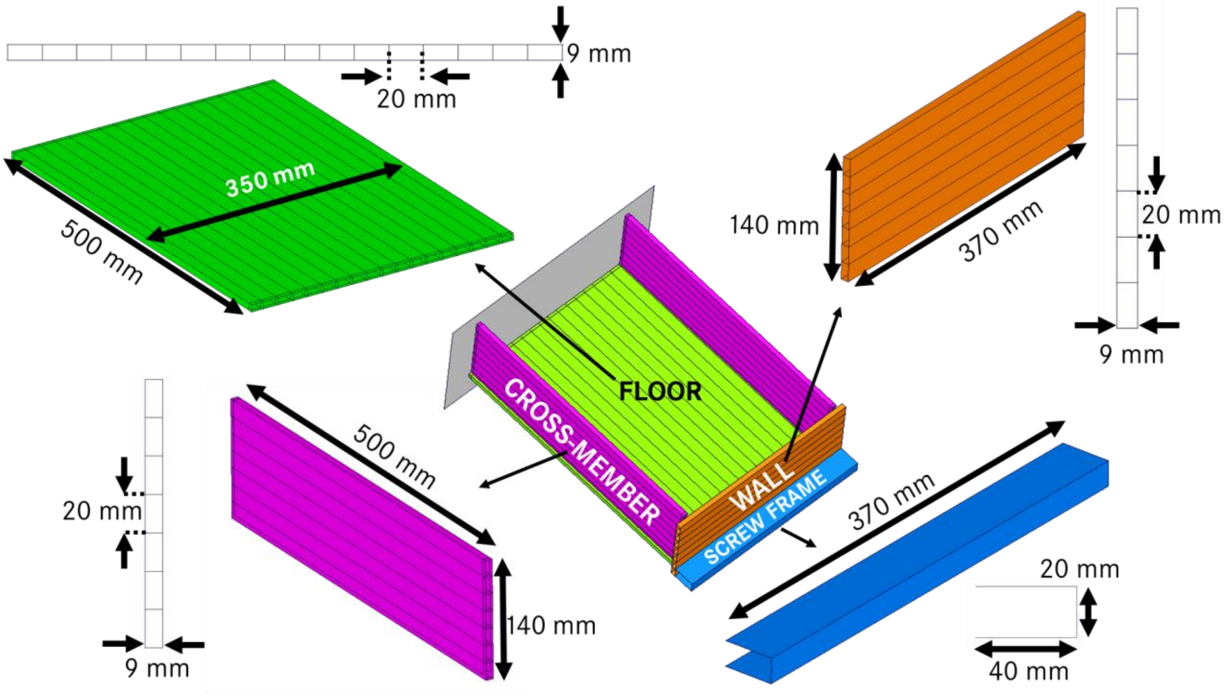


Fig 3.2: Individual parts and dimensions of the considered battery section

3.1 Assumptions

The proposed methodology is capable of being applied to a larger amount of components and to various impact locations. The following assumptions are made to demonstrate the presented methodology.

- The single chamber is assumed to be composed of Aluminum extrusion profiles of which dimensions are as seen in the Fig. 3.2.
- The battery case lid is not considered for this analysis as its design is based on several other design disciplines such as electromagnetic compatibility, maintenance etc.. Due to the wide range of requirements the lid is neglected for the structural optimization conducted in the paper in hand.
- The screw frame is not considers for this analysis as its design is mainly constrained by the installation to the body in white and the maintenance.
- Focus for this paper is put on the optimization of the weakest area for the considered side load case. The center of the side wall, as seen in Fig. 3.1, has turned out to be the weakest impact position.

3.2 List of Considered Variants

An additional common mass of 1kg will be added to each part. The additional material is realized by increasing the wall thickness. The wall thickness and mass information is as listed in the Table 3.1. The weight of 2 cross members is considered since the considered battery section consists of 2 of these parts.

Table 3.1: Reinforcement of individual parts of the battery case

Part	Weak (W)		Strong (S)		
	Thickness (mm)	Mass (kg)	Thickness (mm)	Mass (kg)	Delta Mass Δ (kg)
Wall	1	0.3	3.8	1.3	+1
Floor	1	1.1	1.8	2.1	+1
Cross Member	1	0.9 (2 numbers)	2.0	1.9 (2 numbers)	+1
Screw Frame	1	0.2	1	0.2	0

The variants to be simulated and their description is as per the Table 3.2 below:

Table 3.2: List of variants

Variant	V1	V2	V3	V4	V5
Wall	Weak	Strong	Weak	Weak	Strong
Floor	Weak	Weak	Strong	Weak	Strong
Cross Member	Weak	Weak	Weak	Strong	Strong
Mass (kg)	2.5	3.5	3.5	3.5	5.5

3.3 Simulation – CAE Setup

- The simulation is calculated using LS-dyna
- Barrier is given a boundary prescribed motion of 1 mm/ms in positive Y-Direction. Simulation run time of 100 ms, to enable the barrier a 100 mm displacement. This specified run time is considered sufficient to create contact with the battery module which is not in scope of the present work.
- Barrier force is measured with force transducer type contact on barrier. Barrier movement is measured by database history node on barrier as seen in Fig. 3.3
- Tied contacts are defined as seen in Fig. 3.4. An additional automatic single surface contact is defined between barrier and battery case parts.
- The components are modelled according to Table 3.3:

Table 3.3: Finite element simulation details

PART	TYPE	MATERIAL	BOUNDARY CONDITION
All Battery Components	SHELL-ELFORM 16, 5mm global mesh size	Extruded Aluminum - MAT24 GISSMO	FREE in all directions
Impactor	SHELL-ELFORM 2, 5 mm global mesh size	Steel-MAT 20 RIGID	Constrained to move only in Y translational Boundary prescribed motion at 1mm/ms
Backplate	SHELL-ELFORM 16, 5 mm global mesh size	Steel-MAT 20 RIGID	Constrained in all directions

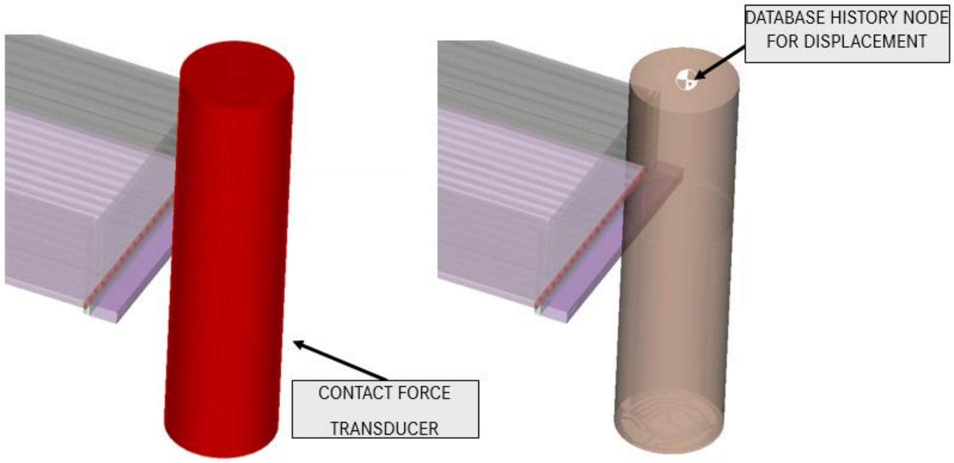


Fig 3.3: Barrier force transducer and history nodes

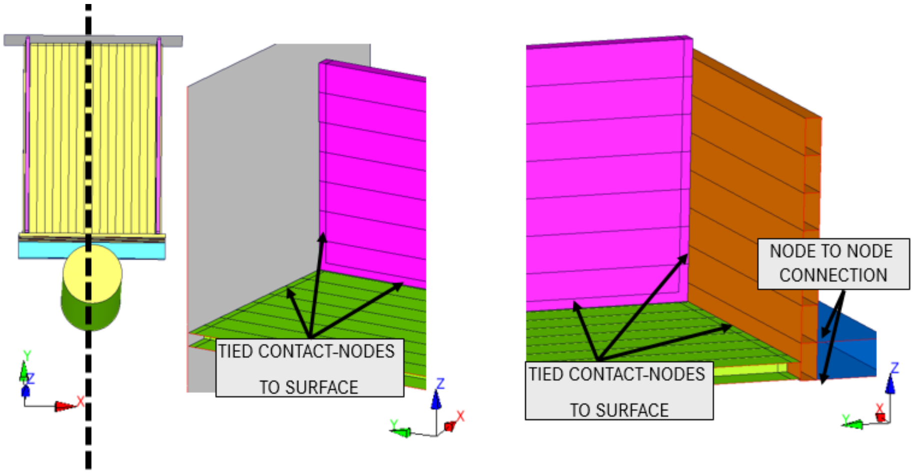


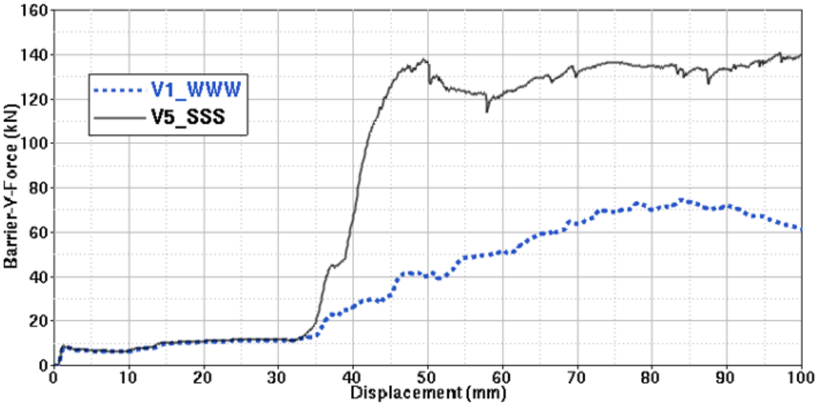
Fig 3.4: Contacts defined between wall, floor, cross member and screw frame

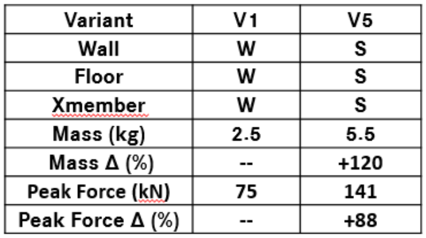
4. Results of Sensitivity Analysis

This section presents the results of the conducted sensitivity analysis. The introduced variants are presented step by step to point out the influence of the separately reinforced components of the battery case.

4.1 Comparison of Weakest and Strongest Variants

To give orientation for the discussed variants the lower and upper bound is presented first. Fig. 4.1 compares the static force curve of the weakest (V1) and strongest (V5) variant considered. The strongest considered variant has a 120% increase in mass over the weakest variant. This reinforcement is brought about by strengthening each part of the battery case by adding 1 kg of material, as described in subsection 3.2. This reinforcement results in an 88% increase in force level. The remaining variants will be in the spread range between the two curves of Fig. 4.1.





Variant	V1	V5
Wall	W	S
Floor	W	S
Xmember	W	S
Mass (kg)	2.5	5.5
Mass Δ (%)	--	+120
Peak Force (kN)	75	141
Peak Force Δ (%)	--	+88

Fig 4.1: Force vs displacement – lower and upper bound

The deformation pattern for this system is similar for all considered variants and is characterized by the points below and Fig. 4.2:

- The force level between 0-32 mm is defined by the weakest component that lies in the load path of the impactor. In our case the screw frame represents the weakest component. The force level is about 10 kN. The screw frame is getting crushed within the first 36 mm of the impactor motion. It has to be stated, that the force level for the first 36 mm can be tuned by the design of the screw frame. The maximum possible force level of the screw frame is limited by the remaining share of the battery case since the crushing of the screw frame can only be realized if sufficient support is provided.
- Beyond 36 mm of impactor displacement the section of the screw frame is fully crushed and the stack of material pushes onto the remaining components of the battery case. The design of the wall and the floor determines the force levels between 40-55 mm of impactor displacement. The deformation behavior also determines the intrusion into the battery module workspace and might cause contact with it. This force rise stops as soon as the unit of battery wall and floor buckles.
- The force level after 55 mm is caused by the floor and wall bending resistance. An axial crushing of the floor would be preferred for this load case but is difficult to be realized due to geometrical design constraints of the floor when compared to an ideal crushing honey comb structure.

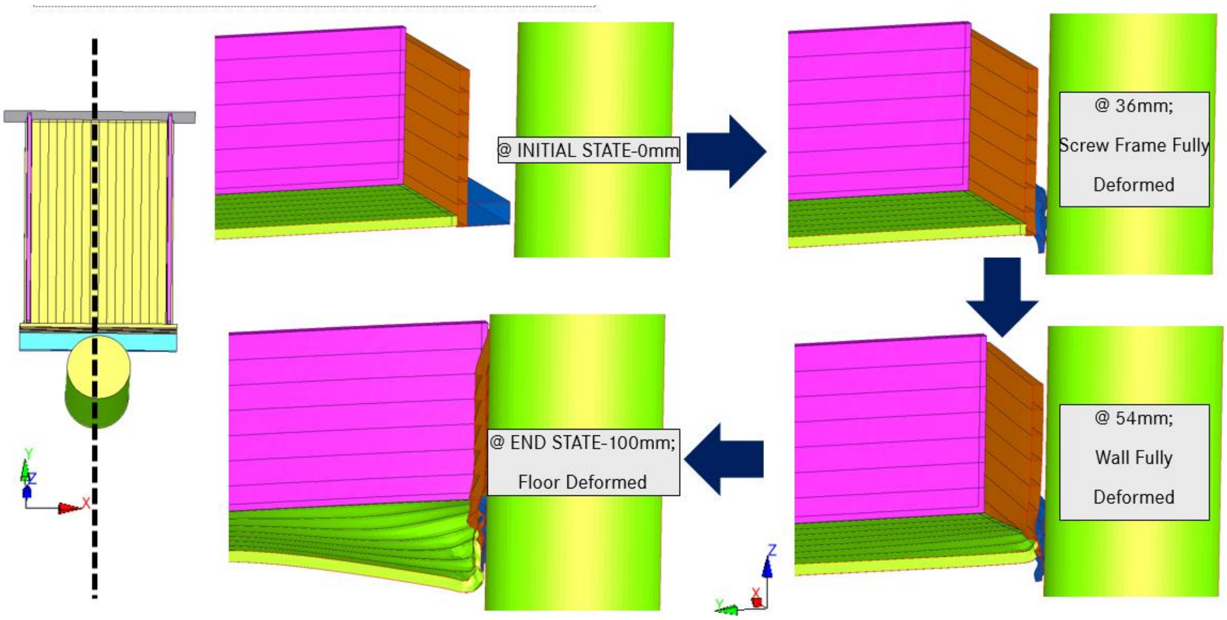
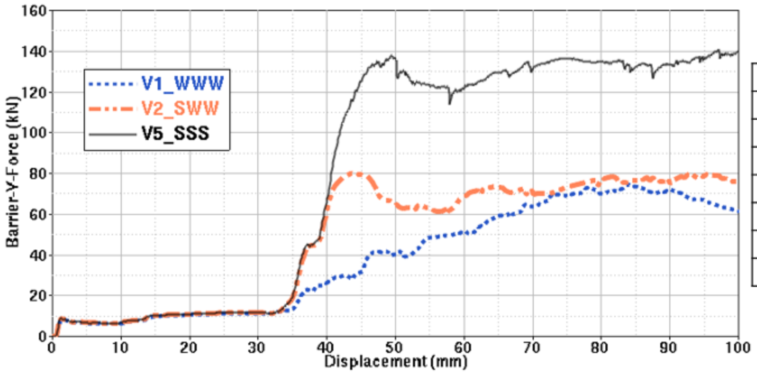


Fig 4.2: Deformation pattern of analyzed battery case

4.2: Reinforcement of the Wall:

This subsection shows the performance gain when reinforcing only the battery wall. Therefore the battery wall is modified according to subsection 3.2 by 1 kg. The force curve is compared to the upper and lower bound in Fig. 4.3. The variant with the reinforced wall (V2) has a 40% increase in mass over the weakest variant (V1). Reinforcement of the wall shows an early onset of force level between 35 and 45 mm. When compared to the fully reinforced variant (V5) it becomes obvious that the wall itself does not come close to the overall peak force reached in the fully reinforced variant. For the wall reinforcement of variant V2 a maximum gain is seen between 40 and 70 mm impactor displacement. However, beyond 70 mm the benefit is gone and the forces level is similar to the lighter, un-reinforced variant (V1). Thus, reinforcing the battery wall does not yield the total benefit of the fully reinforced variant in terms of maximum peak force.

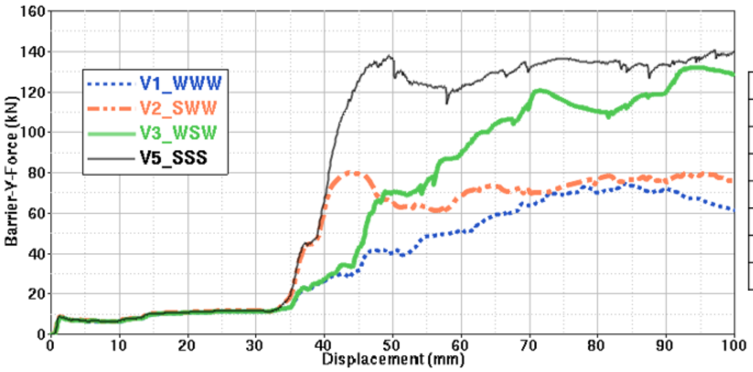


Variant	V1	V2	V5
Wall	W	S	S
Floor	W	W	S
Xmember	W	W	S
Mass	2.5	3.5	5.5
Mass Δ (%)	--	+40	+120
Peak Force (kN)	75	81	141
Peak Force Δ (%)	--	+8	+88

Fig 4.3: Force vs displacement – reinforcement of wall

4.3 Reinforcement of the Floor:

This subsection shows the performance gain when reinforcing only the battery floor. Therefore the battery floor is modified by 1 kg as described in subsection 3.2. Thus, the variant with the reinforced floor (V3) has a 40% increase in mass over the weakest variant (V1) and is equally heavy as Variant V2 with the reinforced battery wall. As presented in Fig. 4.4, reinforcement of the floor (V3) shows a higher rise in force level compared to the equally heavy variant with the reinforced battery wall. Where the previously investigated influence of the battery wall caused a force increase between 35 and 45 mm the effect of the battery floor influences force levels at a later stage, beyond 45 mm of impactor displacement. It has to be stated that the reinforced floor reaches almost the peak force of the heavier fully reinforced variant (V5). At the end, the peak force is missed by less than 12%.

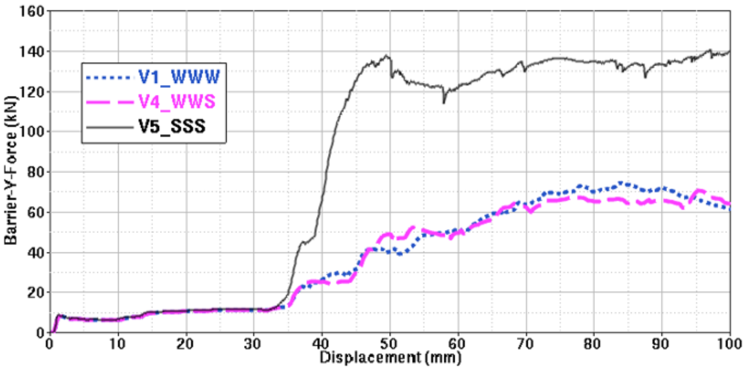


Variant	V1	V2	V3	V5
Wall	W	S	W	S
Floor	W	W	S	S
Xmember	W	W	W	S
Mass	2.5	3.5	3.5	5.5
Mass Δ (%)	--	+40	+40	+120
Peak Force (kN)	75	81	132	141
Peak Force Δ (%)	--	+8	+76	+88

Fig 4.4: Force vs displacement – reinforcement of floor

4.4 Reinforcement of the Cross Member

This subsection shows the performance gain when reinforcing only the battery cross member. Therefore the cross members are modified by 1 kg as described in subsection 3.2. Thus, the variant with the reinforced cross member (V4) has a 40% increase in mass over the weakest variant (V1). Reinforcement of the cross members results in no benefit in terms of force levels as seen in the curves in Fig. 4.5. At the considered worst case impact location the effect of cross members is negligible. Due to the chamber size the battery wall does not work like an ideal force distributor and cannot transmit the forces to the cross members without bending significantly about the impact position.

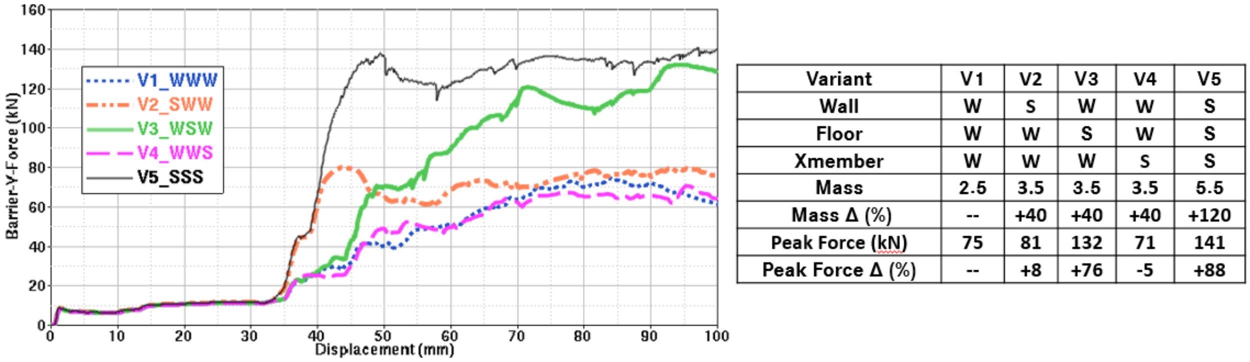


Variant	V1	V4	V5
Wall	W	W	S
Floor	W	W	S
Xmember	W	S	S
Mass	2.5	3.5	5.5
Mass Δ (%)	--	+40	+120
Peak Force (kN)	75	71	141
Peak Force Δ (%)	--	-5	+88

Fig 4.5: Force vs displacement – reinforcement of cross members

4.5 Summary of Results:

Reinforcing the floor has a higher influence on the peak force level compared to the reinforced battery wall or cross member. From Fig. 4.6 it can be seen that adding 40% mass to the floor brings about 85 % gain in force level whereas reinforcing the battery wall gains only 14% and the cross member none at all. Thus, of all considered components the floor contributes highest to the force level as illustrated in Fig. 4.6.



Variant	V1	V2	V3	V4	V5
Wall	W	S	W	W	S
Floor	W	W	S	W	S
Xmember	W	W	W	S	S
Mass	2.5	3.5	3.5	3.5	5.5
Mass Δ (%)	--	+40	+40	+40	+120
Peak Force (kN)	75	81	132	71	141
Peak Force Δ (%)	--	+8	+76	-5	+88

Fig 4.6: Force vs displacement – summary of results

5. Conclusion

The presented methodology utilizes crash simulations on full vehicle level to determine the worst case position and the influence of the amount of battery cross members reveal the maximum battery module workspace. Based on the derived geometrical constraints the sensitivity analysis of a symmetric battery section ranks in order of performance the effect of the single battery case components. The presented methodology helps to draw up a concept in the advanced engineering that corresponds to physics and light weight designs with proper load paths. As a result of the conducted methodology the following design rules are formulated for the considered side load case of a pole impact:

- The number of battery cross members should be increased until the point where lateral intrusion reduction does not overrule the lost workspace (leads to compromise in range) of the additional cross members.
- The presented deformation patterns have to be considered when aiming for force gain at specific impactor displacements: Screw frame (0-36 mm), battery wall (36-70 mm), battery floor (>45 mm)
- The floor takes up the highest force and should be treated especially due to the best force gain to added weight ratio.
- The cross members do not have any influence at the considered worst case impact location.
- The battery protection is not only an issue of static force levels. Additional aspects like module penetration, battery case breaking and water penetration etc. have to be treated additionally to ensure a comprehensive passive safety of an electric vehicle.

References

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Prof. Dr. Christian Glöggler is manager for the CAE- Enviroment of hybrid-components in electric vehicles at Daimler. After his studies in mechanical engineering with a focus on technical design and management, he absolved his Dr.-Ing. degree at the University Stuttgart in 2002. His dissertation treated the stress optimization in cylindical pressed shaft-hub-connections under torsion loads. Since 2002, he is working in Daimler Group and worked in various departments in different work locations. His career start was in the Group Research in Daimler Ulm (Formerly DaimlerChrysler). From 2009 to 2012 he was the head of the department for MBC and VAN – CAD at Mercedes Benz Research and Development in India, Bangalore. Since 2012 he is responsible for the CAE analysis of specific components in E-Drive architectures, supporting with his team,the structural development phase of future electric drive concepts. Additionally, Christian Glöggler works at the University of Applied Sciences in Ulm as honoris professor for Technical Design since 2010.

Prof. Dr. Rodolfo Schöneburg has been working for Daimler AG in Sindelfingen as a director in the Mercedes-Benz cars division since 1999. His responsibility includes safety, durability, and corrosion protection. Prof. Rodolfo Schöneburg is today one of the world’s leading experts in the field of ground vehicle and traffic safety. He holds a professorship for innovative safety systems from the University of Applied Sciences in Dresden. For his numerous contributions in improving occupant safety and for his work in protecting the lives of road users, he has received many international awards for his extraordinary work in the area of vehicle safety.