A Comparative Study of Modeling Approaches for External Structures in Mine Blast Simulations of an Armored Military Vehicle

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Abstract

External structures are known to be critical in ensuring the protection of occupants in military vehicles during mine blast events. There are variety of modelling approaches that can be employed to represent external structures in mine blast simulations of armored military vehicles. This study aims to present an accurate configuration considering the modelling efforts and tight project schedules by comparing different modeling techniques applied to external structures, such as add-on armor plates and other external subsystem components. A whole vehicle finite element model is utilized for an on-going research and development project to evaluate the effectiveness of these modeling approaches by comparing simulation results with live fire test data of Hybrid III dummy and plastic deformations of the hull structure. The findings emphasize that the modelling approach of not only primary protective structures but also other external components significantly contributes to better representation of the tests. Configurations featuring accurately modeled external structures demonstrate improved accuracy in occupant safety assessment. The outcomes of the study contribute to enhancing the efficiency and reliability of the conceptual design phase by providing faster and relatively reliable finite element solutions, specifically in terms of representing external structures in the simulations.

1 Introduction

Design for mine blast protection of armored vehicles requires great effort considering the increasing threat levels defined by military standards [1]. Finite element analysis plays an important role considering the time and effort that saves compared to the conventional test campaigns. However, it is important to establish a reliable modelling method to have proper accuracy and feasible solution time. At the conceptual design phase there is limited information about the subsystems of the vehicle. Therefore, simpler models including major components such as hull and floor plate are used to calculate bottom plate displacement and according to the results the floor plate minimum distance is determined. It is also known that total weight of the structure considerably changes the general behavior; thus, some subsystems whose design details are not present are represented with mass elements.

This study represents the evolution of the finite element model of an 8x8 armored military vehicle starting from conceptual design phase to final design. Moreover, this study mainly focuses on the add-on armor plates and the drivetrain structures, which are installed externally to the main hull. Four different analyses are performed and compared in each other in terms of bottom plate displacement, side wall (sponson) displacement and total solution time. Additionally, the results are compared with the live fire test data of lower tibia loads of Hybrid III dummy.

`*ALE_STRUCTURED_MESH` is used to create the ALE domain and the fluid structure interaction is defined with **`*CONSTRAINED_LAGRANGE_IN_SOLID`** keyword [2]. Simulations are run with MPP version of LS-DYNA® R11.0.0 and Intel MPI 4.3.1 using 120 cores.

2 Model Information

In order to represent add on armor plates three different approaches are used as given in Table 1.

Model	Modelling of Add-on Armor Plates
1	**`*ELEMENT_MASS_PART`**
2	**`*CONSTRAINED_INTERPOLATION`** + **`*ELEMENT_INERTIA`**
3	Physical

Table 1: Modelling approaches for the addon armor plates

At the preliminary analysis armor weights are established using ***ELEMENT_MASS_PART** keyword. As the inertia and the mounting details are not determined, this method can be suitable for the conceptual design phase analysis. One of the drawbacks of this method is the lack of inertia of the armor plates and the other one is that the uniform mass of the related throughout the analysis. Consequently, there is no chance to accurately simulate any failure or rupture of the armor plates during the mine blast event.

Second model can be used when the sizing of the armor plates is finalized. Here, the mass and inertia of each armor plate are individually connected to the bolted joint locations using ***CONSTRAINED_INTERPOLATION** keyword. Integrating both mass and the inertia of the armor plates this approach potentially yields more accurate solutions; however, as in Model #1 the failure or rupture of the armor plates cannot be simulated for this modelling technique, too.

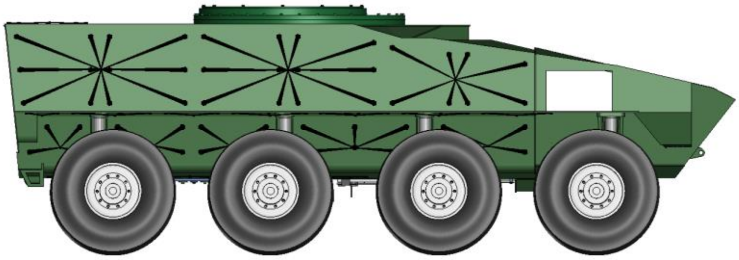

Fig.1: Representation of armor plates with ***CONSTRAINED_INTERPOLATION** *+* ***ELEMENT_INERTIA** *elements*

When the design is completed, it is possible to include both the armor plates and the joints physically into analysis model. It might be time consuming to create the finite element model but more accurate results are expected.

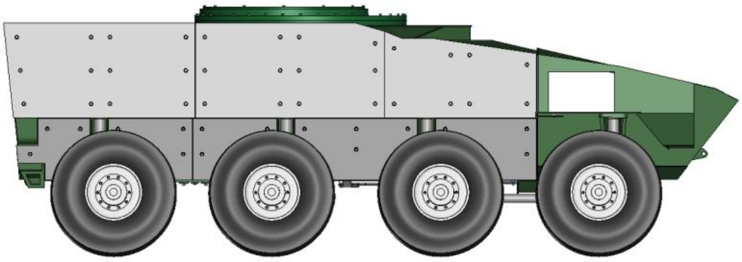

Fig.2: Physically modeled add-on armor plates

Two distinct methodologies are employed to model drivetrain structures within the finite element analysis as given in Table 1.

Model	Modelling of Drivetrain
A	***ELEMENT_MASS**
B	Physical

Table 2: Modelling approaches for the drivetrain

In the first approach, each station is represented with ***ELEMENT_MASS** keyword. This method is suggested for the conceptual design phase considering previously stated drawbacks as it might lead to potentially misleading results due to inaccuracies in simulating critical physical aspects such as failure and inertia.
As a second method, drivetrain structures are involved in the finite element model with only minor simplifications to be accurately represented. This approach aims to provide results which are more realistic as it is possible to observe any failure and inertial effects on the hull structure.

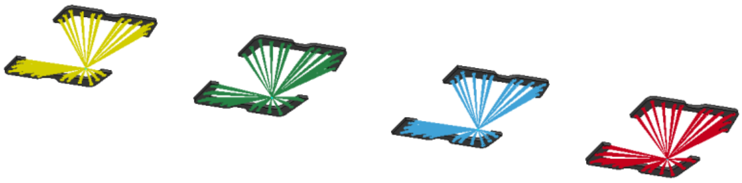

Fig.3: Representation of the drivetrain stations with ****ELEMENT_MASS***

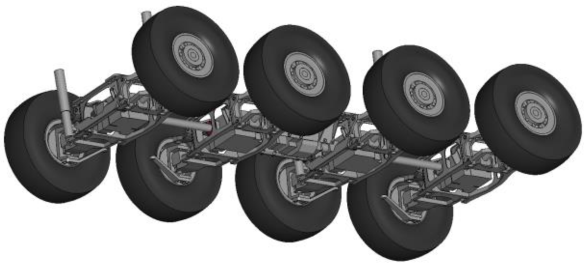

Fig.4: Physically modeled drivetrain.

Four simulations are run for combinations of modelling approaches of add-on armor plates and the drivetrain.

Simulation	Comments
1A	Suitable for conceptual design phase analysis.
1B	Represents the effect of physical drivetrain.
2B	External armors with ***ELEMENT_INERTIA** + ***CONSTRAINED_INTERPOLATION**
3B	Physical drivetrain and armors

Table 3: Simulation models

3 Results

3.1 Comparison of Total Coupling Forces in Vertical Direction

Coupling forces are acquired using the ***DATABASE_FSI** keyword [2]. When the physical drivetrain is used coupling starts earlier attributed to the inclusion of suspension arms and other components. The peak value for the vertical coupling force is less in comparison to the simulation employing ***ELEMENT_MASS**, where a larger area influenced by the blast effect. Due to complexity of the physical representation, chattering is observed for total coupling force.

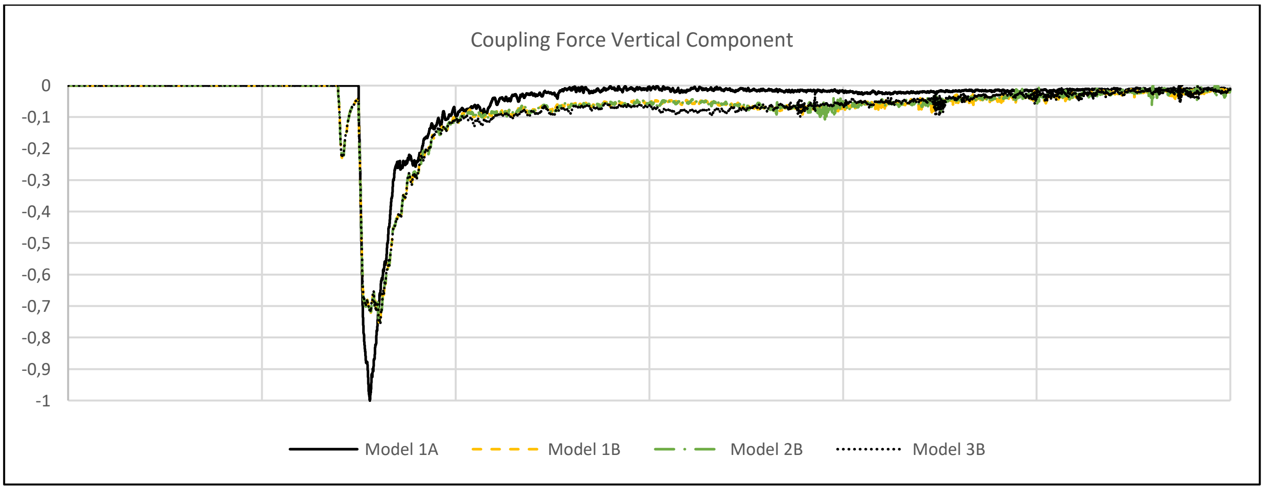

Fig.5: Normalized total coupling forces in vertical direction

3.2 Comparison of Bottom Plate Displacements

Comparing the relative bottom plate displacement results, it is observed that the representation of armor plates does not have a significant effect. However, representing the drivetrain geometries with **`*ELEMENT_MASS`** drastically changes the results and may cause misleading design decisions regarding the floorplate distance from the hull bottom plate as the displacement is very low compared to physically represented drivetrain model even though the total vertical coupling force is very high. In the context of the blast event, the failure of bolts and consequent loss of mass and inertia from the main structure results in better representation of the general behavior of the bottom plate structure.

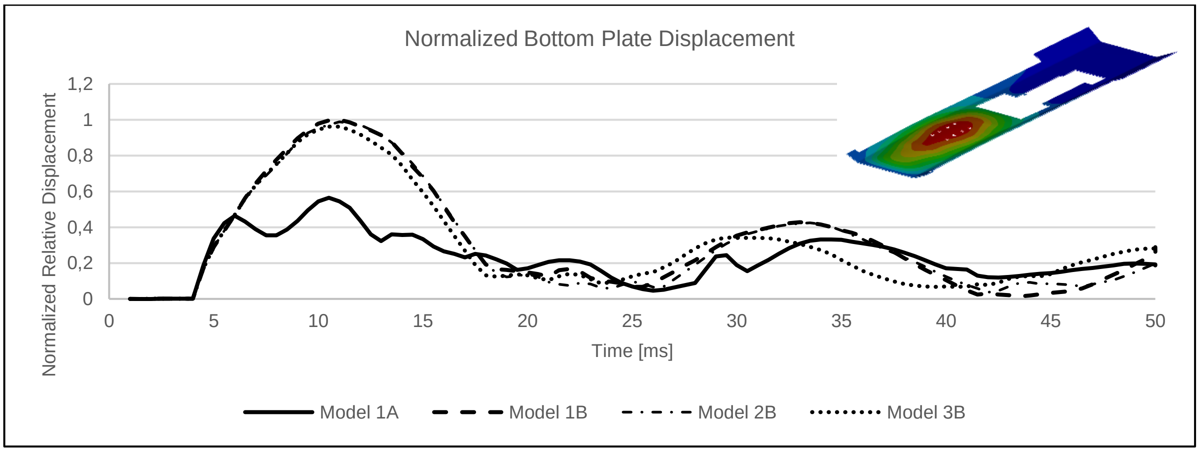

Fig.6: Normalized relative bottom plate displacement

3.3 Comparison of Side Wall Displacements

Side wall displacements plays an important role as there is possibility of failure of the structures installed on it. The findings from Model 1A results show that the side wall displacement is affected by the drivetrain model and very low displacements are observed compared to the ones that represents the drivetrain physically. Maximum displacement is lower for Model 3B compared to Model 1B and 2B. This is not expected as the inertia and mass of the failed armors are lost for Model 3B during the simulation.

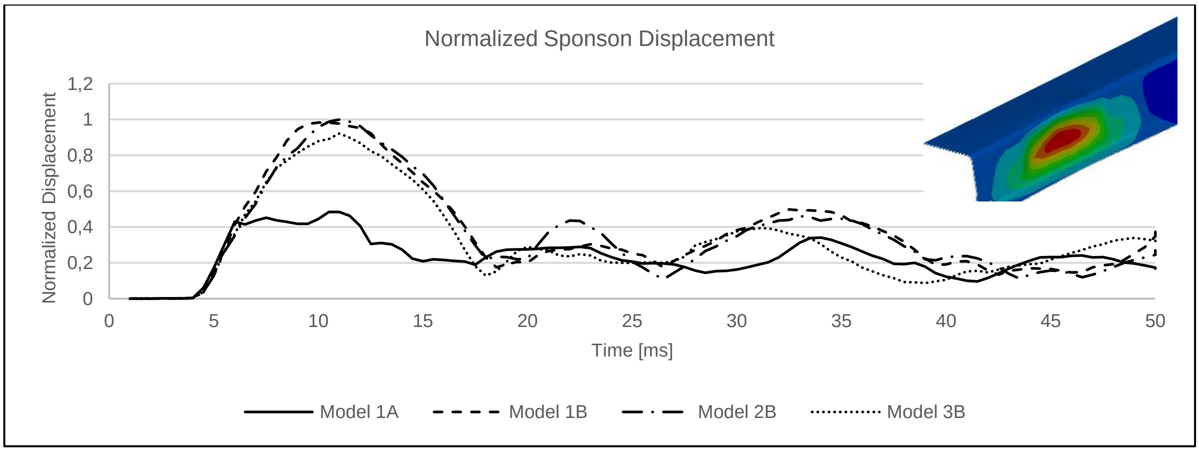

Fig.7: Normalized sponson displacement

3.4 Lower Tibia Loads

Lower tibia loads are compared with the experimental data. For both left and right feet, the loading starts later than the experiment but with a sharp increase the peak values coincide for all the modelling configurations. Notably, Model 1A and 1B underestimates the loads with a deviation of nearly 20% and 15% respectively. Utilizing a physical drivetrain model without a correct representation of the armors would create a risk. In Model 2B, the peak lower tibia loads for both left and right feet are almost exactly the same compared to the experiment. But a conservative approach might be preferred as in Model 3B, for which loads are around 15% higher than the actual test. Moreover, a smooth curve is acquired as in the test on the contrary to the other models.

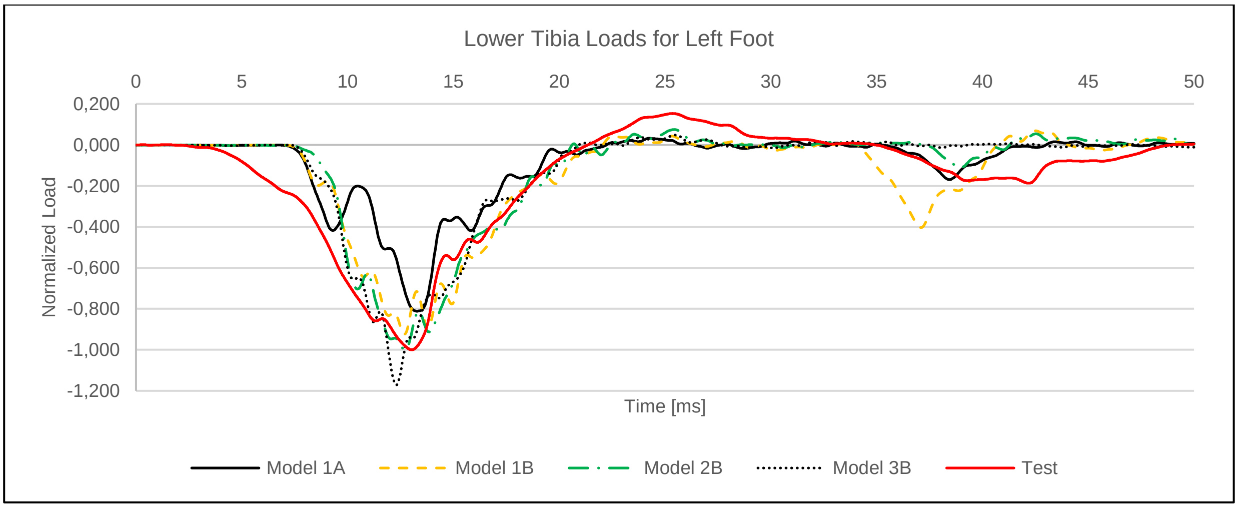

Fig.8: Normalized lower tibia load for left foot

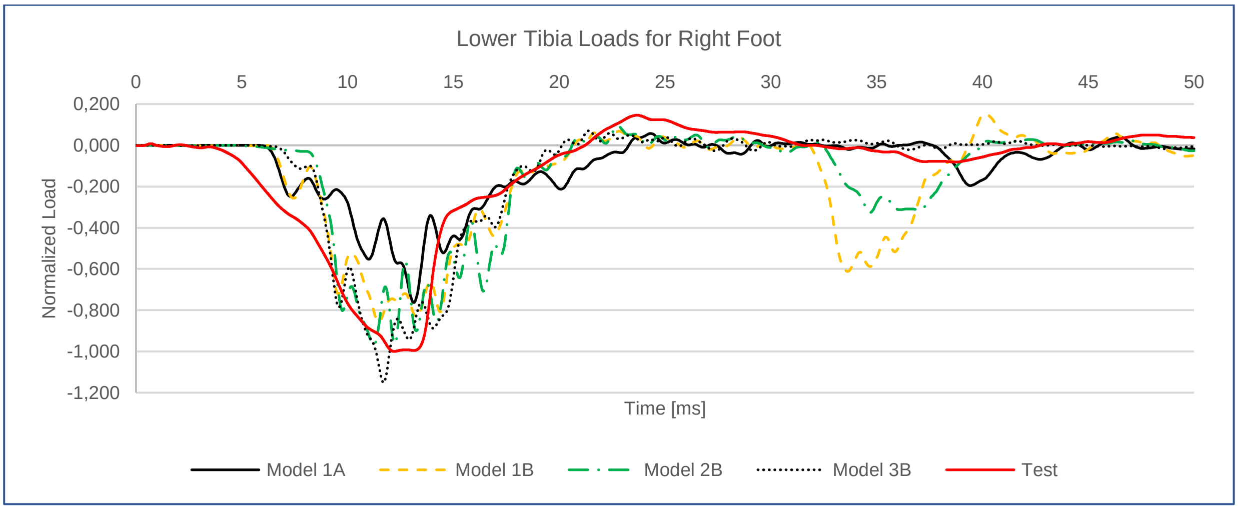

Fig.9: Normalized lower tibia load for right foot

3.5 Comparison of Solution Time

The total elapsed time increases with higher complexity of the simulation model. Among these models, Model 1A is the most basic one and it saves a significant amount of time. However, in pursuit of accuracy, the integration of drivetrain geometry within the model is vital. Including drivetrain results in ~25% increase in solution time. Further increasing the complexity with the usage of **`*ELEMENT_INERTIA`** along with **`*CONSTRAINED_INTERPOLATION`** keyword results in an additional 10% extension of the solution time. Including physical armor plates adds another 5% to the solution time. Considering the lower tibia forces and to be on the conservative side use of Model 3B is recommended.

Model	Solution Time [s]
1A	70360
1B	88527
2B	98076
3B	103232

Table 4: Solution time for models.

4 Summary

In this study, modeling approaches for external structures, particularly add-on armor plates and drivetrain components are investigated for mine blast simulations of an 8x8 armored military vehicle. Three different modelling approaches for armor plates are implemented and drivetrain structures are

represented with two modelling techniques. Structural responses are compared in between and lower tibia loads are compared with the test data.
Regarding drivetrain modeling, use of ***ELEMENT_MASS** causes inaccuracies in terms of physical response and occupant safety results; thus, this methodology should be preferred only for initial design phases in benchmark studies. The physically modelled drivetrain provided a more consistent representation of general system behavior and the occupant safety results. Furthermore, the inclusion of accurately represented drivetrain structures contributes to a more logical understanding of the vehicle's response, aiding the design decisions. The drawback for this approach is the high complexity of the structures and long modelling time.

On the other hand, accurate modeling of add-on armor plates plays an important role to correctly simulate the real-world mine blast events. It is clear that simplified approach with ***ELEMENT_MASS_PART** keyword is suitable for the conceptual design phase. While suitable for preliminary analyses, these models lack the capacity to represent armor plate failure or accurately predict their effect on the whole structure and occupant safety results. Besides, representing mass and inertia of each armor plate with mounting details through ***CONSTRAINED_INTERPOLATION** and ***ELEMENT_INERTIA** keywords and physically involving them yielded better results, particularly in terms of predicting the lower tibia loads compared to the test data. Physically representing the armor plates might be time consuming but one may prefer this approach if a conservative result is desired. While physical modeling introduces increased solution times, its benefits in terms of accuracy and reliability are significant.

5 References

[1] AEP-55 Procedures for Evaluating the Protection Level of Armored Vehicles, Volume 2, November 2010
[2] LS_DYNA® Keywords User’s Manual, Volume I, R11, Livermore Software Technology Corporation, 2018