Blast Mitigation Seat Simulations Using LS-DYNA®

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1 Abstract

Military vehicles are exposed to mine and explosive loads in operational conditions and the vehicle must have the appropriate protection level to prevent personnel injuries. Blast mitigation seats represent a critical component in ensuring personnel safety. In this study, we conducted mine blast simulations using the non-linear finite element code LS-DYNA® to examine the structural behavior of blast mitigation seats. The blast simulations were carried out in accordance with the requirements of NATO AEP-55 STANAG 4569 VOL-2. We employed the Structured Arbitrary Lagrangian-Eulerian (ALE) method for these simulations. The model encompassed an ALE domain, including soil, air, explosive definitions, and a Lagrange domain for the 4x4 military vehicle. To assess the impact of the explosive charge on the occupant, we utilized the LSTC Hybrid III 50th dummy. We measured force and acceleration outputs from the dummy and compared them with the allowable limits defined in NATO AEP-55 STANAG 4569 VOL-2

***KEYWORDS:** Mine blast simulation, military vehicles, blast mitigation seat, ALE

2 Introduction

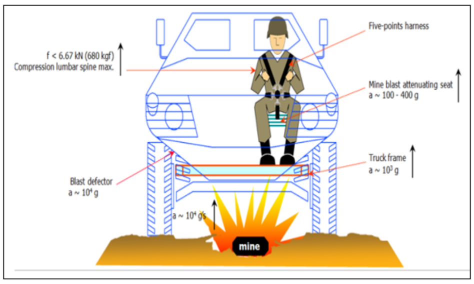
Military vehicles are exposed to mine and explosive loads in operational conditions, and it is essential for these military vehicles to have maximum protection levels to prevent personnel injuries due to mine explosions. The body structures of military vehicles are typically manufactured from steel armor plates or aluminum plates with ballistic properties. When a military vehicle is subjected to a mine explosion in operational conditions, it is desirable that there are no damages such as tearing or ruptures on the vehicle's body under the mine load. Additionally, the pressure loads on the military vehicle should not cause injuries to the personnel inside the vehicle. Mine-protected seats are one of the most crucial systems in military vehicles for preventing personnel injuries.

Fig.1: Military vehicles mine blast tests

In this study, we conducted mine blast simulations using the non-linear finite element code LS-DYNA®. These simulations were performed in accordance with the requirements of NATO AEP-55 STANAG 4569 VOL-2, a NATO standard that outlines protection levels for military vehicles against various ballistic threats, including small arms, artillery, and explosive devices. This standard categorizes protection levels based on the types of threats and ammunition.

Fig.2: Armoured vehicle personnel compartment

As part of this study, a finite element model of a 4x4 military vehicle, including critical equipment and a blast mitigation seat, has been developed. Underbelly blast simulations using 6 kg and 8 kg TNT charges were conducted. To assess the impact of the explosive charge on the occupant, we employed the LSTC Hybrid III 50th dummy. We recorded force and acceleration outputs from the dummy and compared them with the allowable limits specified in NATO AEP-55 STANAG 4569 VOL-2.



Level	Grenade and Blast Mine Threat		
4	4b	Mine Explosion under belly	10 kg (explosive mass) Blast AT Mine
	4a	Mine Explosion pressure activated under any wheel or track location	
3	3b	Mine Explosion under belly	8 kg (explosive mass) Blast AT Mine
	3a	Mine Explosion pressure activated under any wheel or track location	
2	2b	Mine Explosion under belly	6 kg (explosive mass) Blast AT Mine
	2a	Mine Explosion pressure activated under any wheel or track location	
1	Hand grenades, unexploded artillery fragmenting sub-munitions, and other small anti personnel explosive devices detonated anywhere under the vehicle.		

As notification of the protection level is advised to use the first character of the threat type followed by the protection level (e.g. M2b).

Fig.3: Mine explosion levels

During a mine explosion, military vehicles must meet specific protection standards to prevent injuries to personnel inside the vehicle. After the design of military vehicles is completed, physical tests are conducted in real-world conditions to assess the vehicle's resistance to mine explosions. These tests involve placing mannequins inside the vehicle and analyzing the forces acting on them. NATO AEP-55 STANAG 4569 VOL-2 standards define the maximum loads that can affect these mannequins during the tests. It is of utmost importance that the loads generated on the mannequin during mine tests do not exceed the target values specified in the standard.

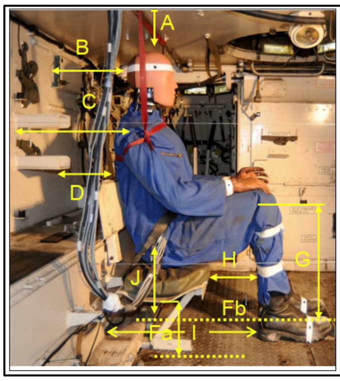


Table E2 Injury Assessment Reference Values for Hybrid III ATD with MIL-Lx

Body region	Criterion	IARV	Pass/fail level
Head	Head Injury Criterion	HIC_{15}	250
Neck	Axial compression force	Fz-	4.0 kN - 0 ms / 1.1 kN > 30 ms *(Figure in appendix E6.3)*
	Axial tension force	Fz+	3.3 kN @ 0 ms / 2.8 kN @ 35 ms / 1.1 kN > 45 ms *(Figure in appendix E6.3)*
	Shear force	Fx+- / Fy+-	3.1 kN @ 0 ms / 1.5kN @ 25-35 ms / 1.1 kN > 45 ms *(Figure in appendix E6.3)*
	Bending moment (flexion)	Moc_y +	190 Nm
	Bending moment (extension)	Moc_y -	77 Nm
Thorax	Thoracic Compression Criterion	$TCC_{frontal}$	30 mm
	Viscous Criterion	$VC_{frontal}$	0.70 m/s
Spine	Dynamic Response Index	DRI_z	17.7
Femur	Axial compression force	Fz-	6.9 kN
Tibia*	Axial compression force	Fz-	2.6 kN (Mil-LX, upper load cell) 5.4 kN (HIII, lower load cell)

*) On decision of the NA the Mil-LX leg or the HIII leg with the corresponding pass/fail values can be used.

Fig.4: AEP-55 STANAG 4569 Allowable dummy loads

3 FE Models and Materials

The simulation model consists of the ALE domain which includes soil, air and explosive definitions and the Lagrange domain for the vehicle and structural parts. The "Structured ALE" method has been used in the simulations.

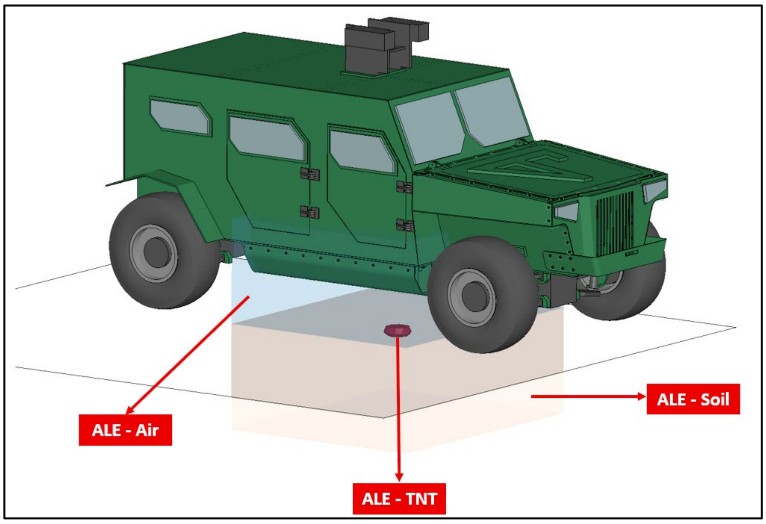


Fig.5: Ale & Lagrange domain - 1

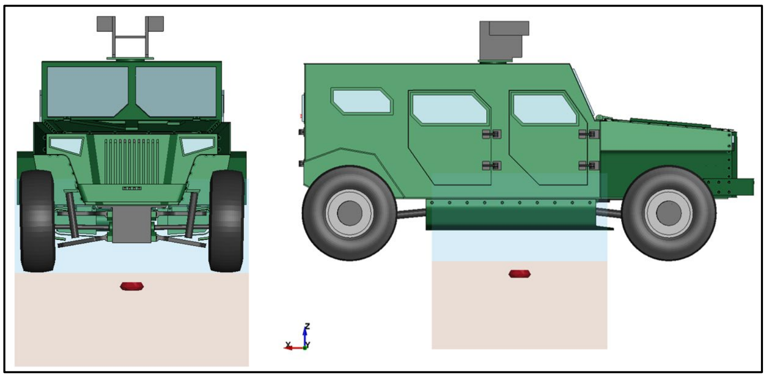


Fig.6: Ale & Lagrange domain - 2

ALE domain consists by air domain, soil and explosive as shown in Figure 5. The air is modelled with ***MAT_NULL** and ***EOS_LINEAR_POLYNOMIAL** keywords. Material parameters are taken from [3]. ***MAT_SOIL_AND_FOAM_FAILURE** is used for soil model and parameters are taken from [4]. The explosive material is modelled with ***MAT_HIGH_EXPLOSIVE_BURN**. ***EOS_JWL** equations of state with the parameters for TNT are taken from [2]. ***INITIAL_VOLUME_FRACTION_GEOMETRY** is used to fill into the ALE domain by soil, air and explosive. The fluid-structure interaction between the target plate and ALE model is carried out with ***CONSTRAINED_LAGRANGE_IN_SOLID** keyword.

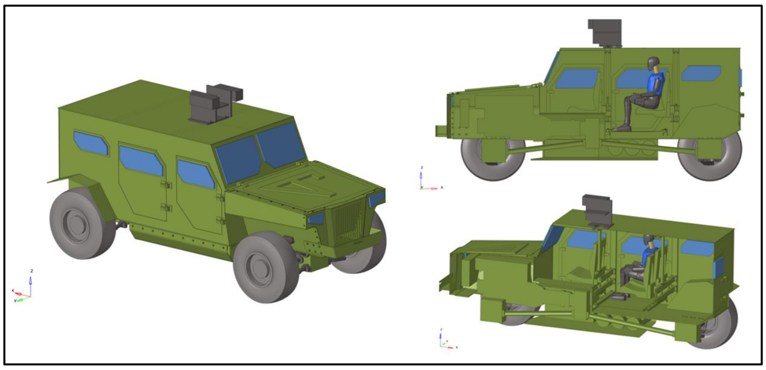


Fig.7: 4x4 military vehicle

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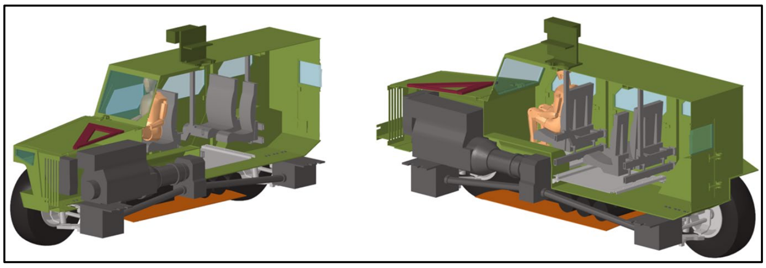

Fig.8: 4x4 military vehicle section view

In the blast simulation, ***AUTOMATIC_SINGLE_SURFACE** contact definition has been employed for defining contacts between parts. Structural parts such as the vehicle body, seats and critical equipment have been modeled using solid elements with element sizes of approximately 15 - 20 mm which have been preferred for areas exposed to mine loads. To capture important geometric details, the element size has been regionally decreased to values of 2-5 mm. The "structured mesh" feature has been used to create the ALE domain, with a mesh size of 20 mm. "Elform -2" element formulation has been used for "Lagrange" hexahedral solid elements, and "ELFORM 16" has been used for shell elements. For ALE elements, "Elform 11" has been used, which is a single integration point formulation allowing multiple material definitions (multi-material).

A detailed seat model has been created using solid elements. In the welding regions, the ***TIED_SURFACE_TO_SURFACE_OFFSET** contact definition has been employed.

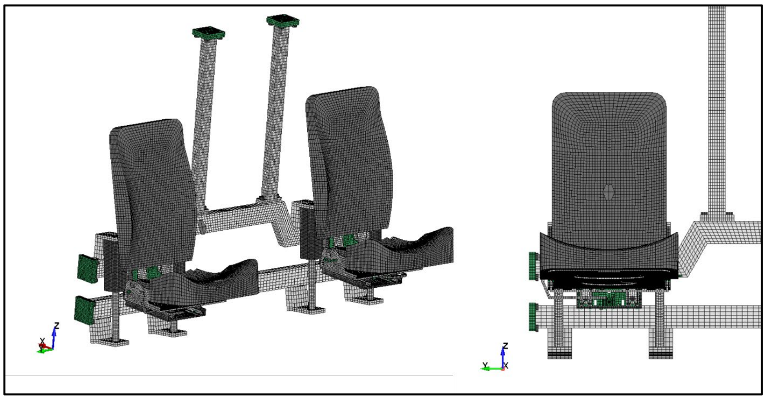

Fig.9: Seat Model - 1

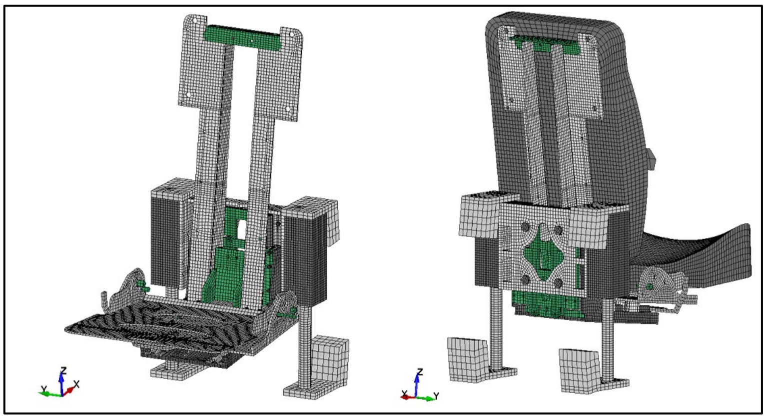

Fig.10: Seat Model - 2

In the analyses, the LSTC.H3.103008-v1.0 rigid dummy model has been utilized. The dummy model has been positioned within the vehicle using the "***Dummy Positioning***" tool found in LS Prepost software. 2D seatbelt definitions have been carried out using the "***Seatbelt Fitting***" tool in Ls Prepost.

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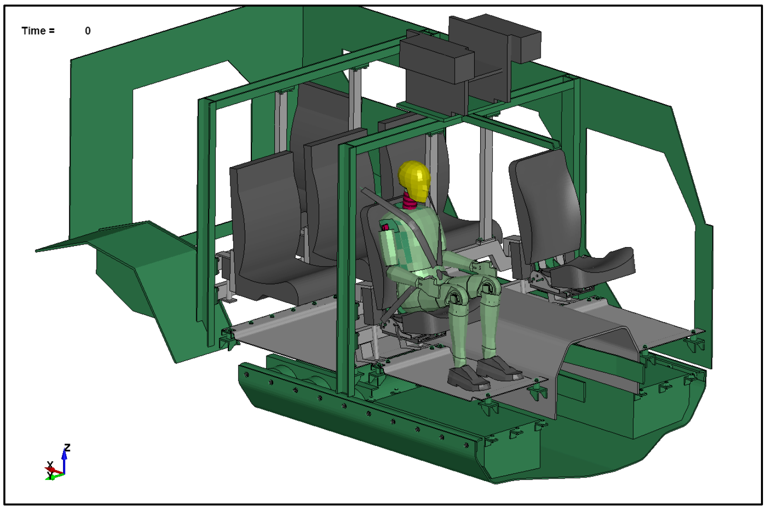

Fig.11: Occupant position inside the vehicle - 1

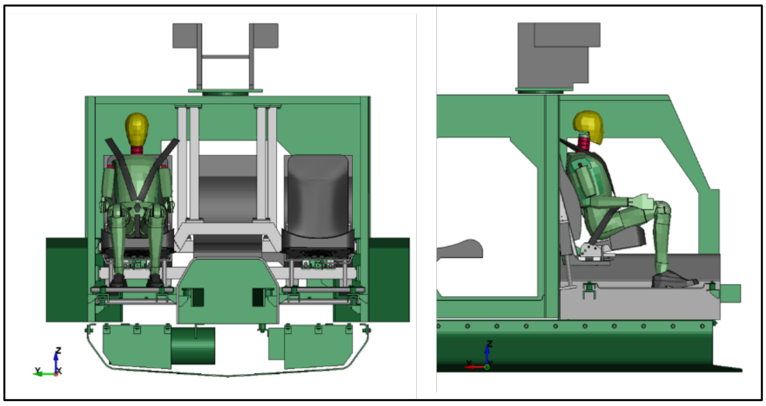

Fig.12: Occupant position inside the vehicle - 2

Bolt models have been established using the 'beam' element formulations. Within the hole regions, 'beam' element definitions have been implemented between the 'rigid' elements. Bolt modeling was carried out using the ***MAT_SPOTWELD** material model and the ***SECTION_BEAM** keyword with ELFORM 9 (spotweld beam). For each bolt type, the ***NRR***, ***NRS***, and ***NRT*** parameters within the material model for spot welds have been specified. The spot welds' failure behavior is modeled when the shear and tensile loads applied to the beam elements reach these predefined values.

In the analysis model, ***MAT_SIMPLIFIED_JOHNSON_COOK** material model has been used for metallic materials. The material parameters for S355, Aluminum, and Armox have been obtained from [5], [6], [7] and [8].

Johnson and Cook express the flow stress as

$$\sigma_y = \left(A + B\bar{\varepsilon}^{p^n}\right)(1 + C\ln\dot{\varepsilon}^*)$$

where

$$\begin{aligned} A, B, C &= \text{input constants} \\ \bar{\varepsilon}^p &= \text{effective plastic strain} \\ \dot{\varepsilon}^* &= \frac{\dot{\bar{\varepsilon}}}{\text{EPS0}} \\ &= \text{normalized effective strain rate} \end{aligned}$$

The maximum stress is limited by SIGMAX and SIGSAT by:

$$\sigma_y = \min\left\{\min\left[A + B\bar{\varepsilon}^{p^n}, \text{SIGMAX}\right](1 + c\ln\dot{\varepsilon}^*), \text{SIGSAT}\right\}$$

Failure occurs when the effective plastic strain exceeds PSFAIL.

Fig.13: Simplified JC model

4 Simulation Results

All simulations were conducted using 8 cores and performed in two steps. Initially, the simulations were solved for 15 ms using the full model, which includes the ALE domain and all structures. Based on the simulation results up to 15 ms, it was determined that the forces from the fluid domain were nearly negligible. In the subsequent step, the ALE domain and the fluid-structure interaction components were removed, and the simulations were run up to 50 ms.

The analyses have been conducted using 6 kg and 8 kg TNT explosives. Figure 14 shows the pressure history which is observed on the bottom plate. It appears that after the 6 kg TNT explosion, there is 4 MPa of pressure on the base plate, and after the 8 kg TNT explosion, there is 4.2 MPa of pressure on the base plate.

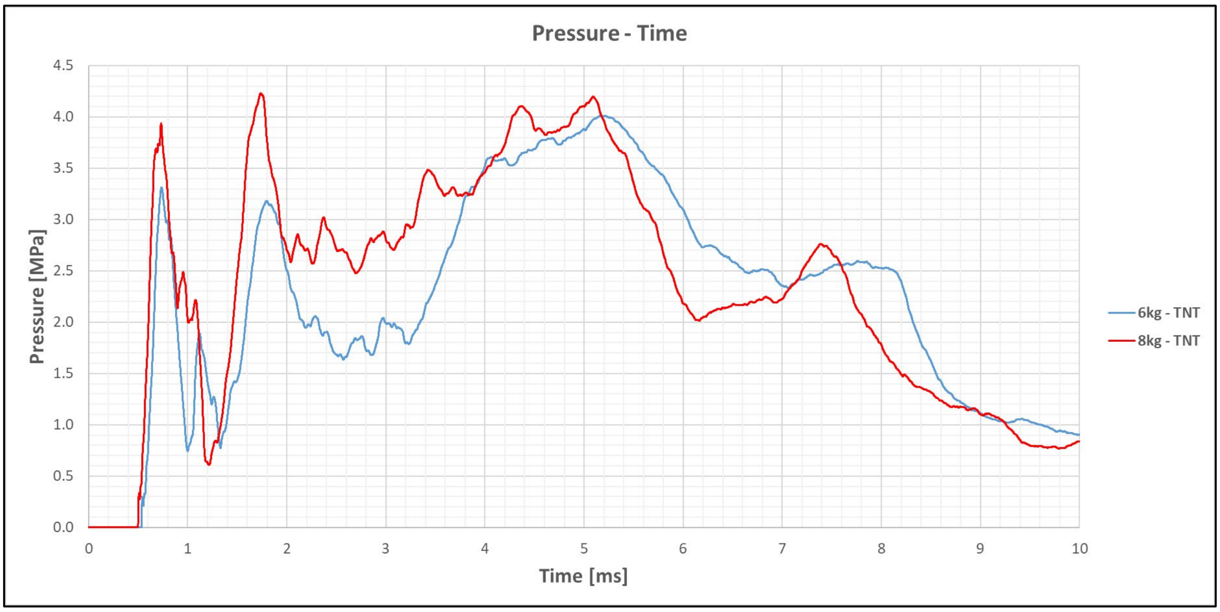

Fig.14: Pressure history

Figure 15 shows the acceleration history outputs which were observed on the bottom plate of the vehicle. As shown in the figure below, the maximum acceleration is calculated as 447 g after 8kg TNT explosion and 247g is observed after 6kg TNT explosion.

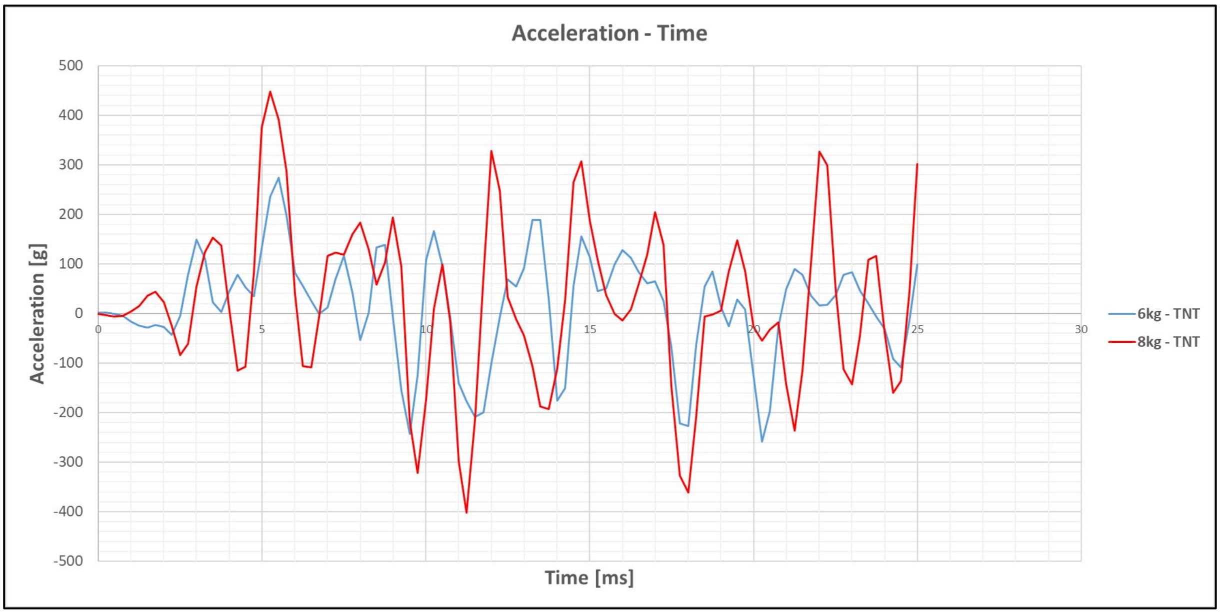

Fig.15: Acceleration history

Figure 16 illustrates the simulation stages up to 30 ms.

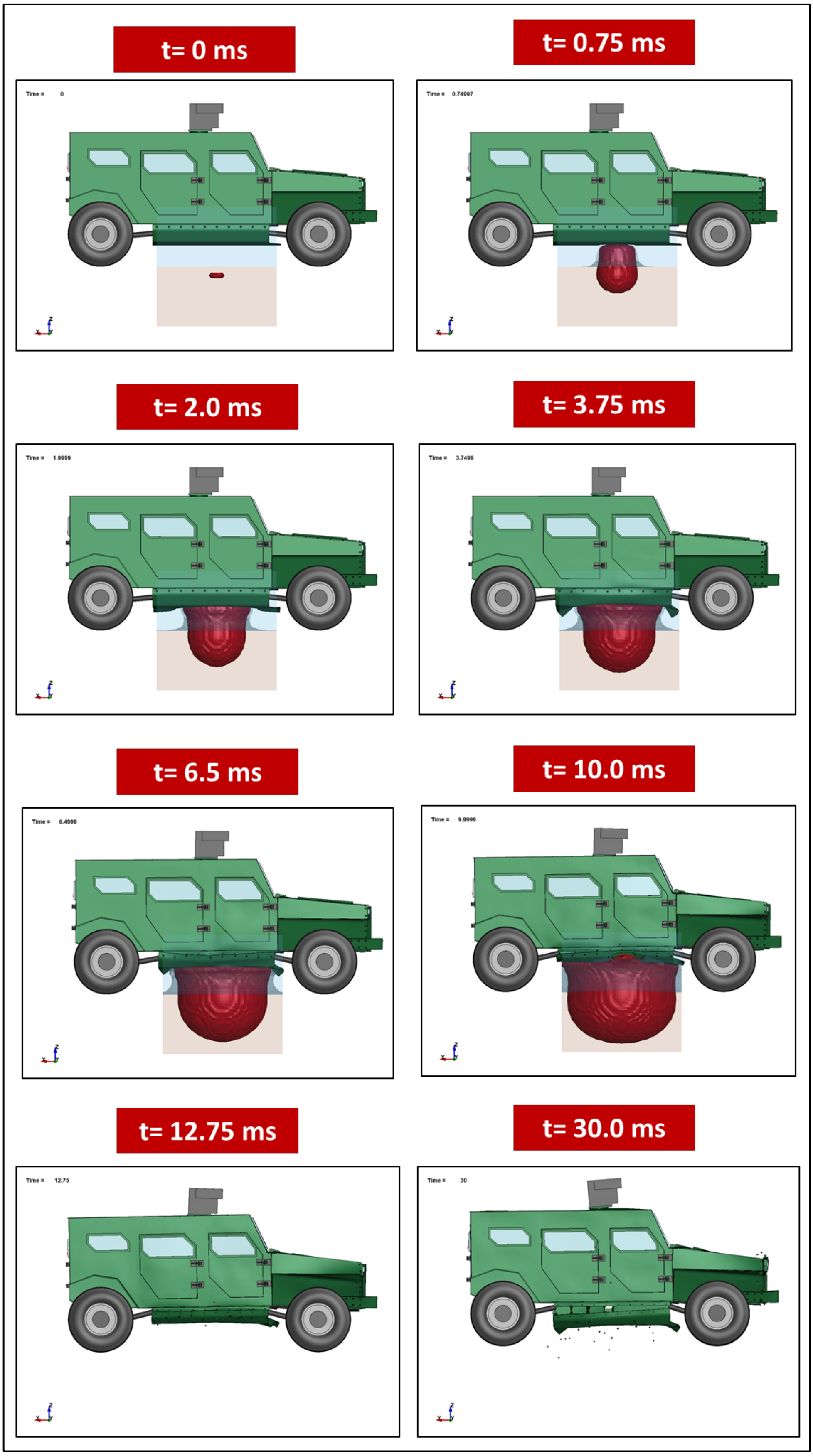

Fig.16: Simulation stages – 1

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Figure 17 shows the dummy motion inside the vehicle up to 30 ms.

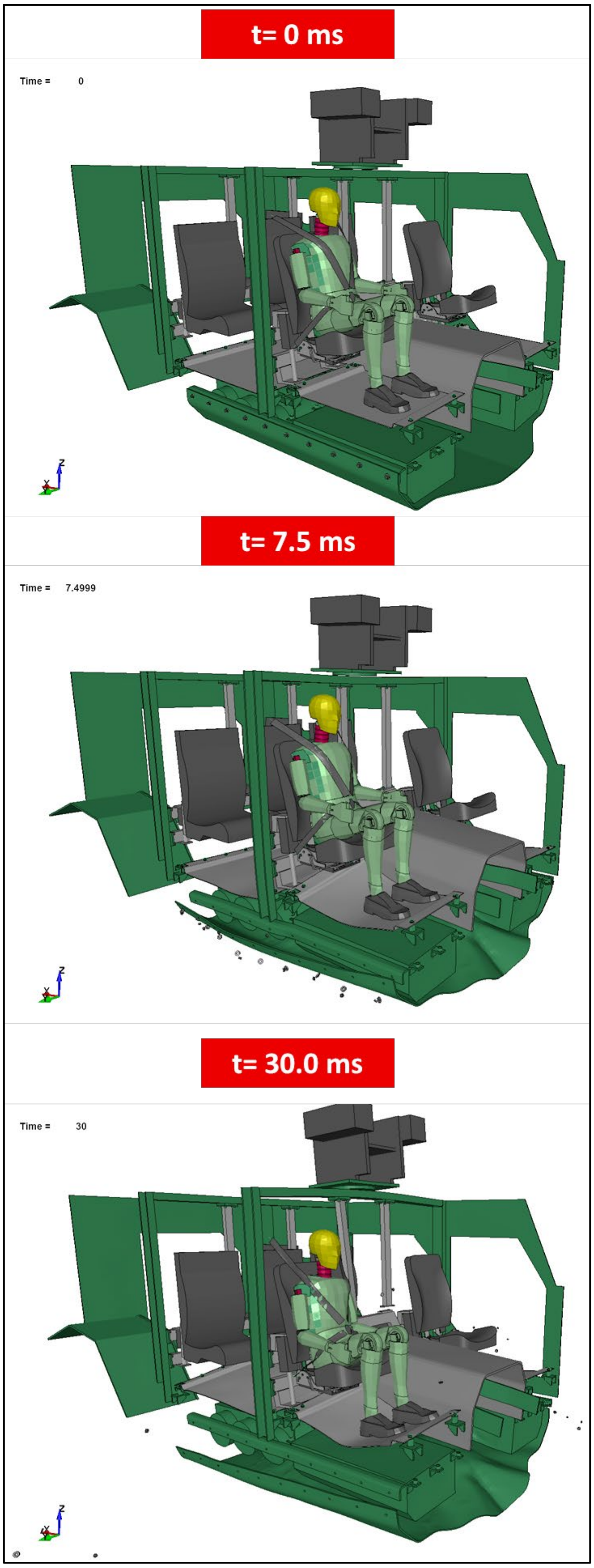

Fig.17: Simulation stages - 1

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Figure 18 shows the tibia forces which are obtained from the LSTC H3 dummy. As shown in the graph, the maximum tibia force is calculated as 5.4 kN after 8kg TNT explosion and 4.5 kN is obtained after 6kg explosion. Both levels are in the acceptable range.

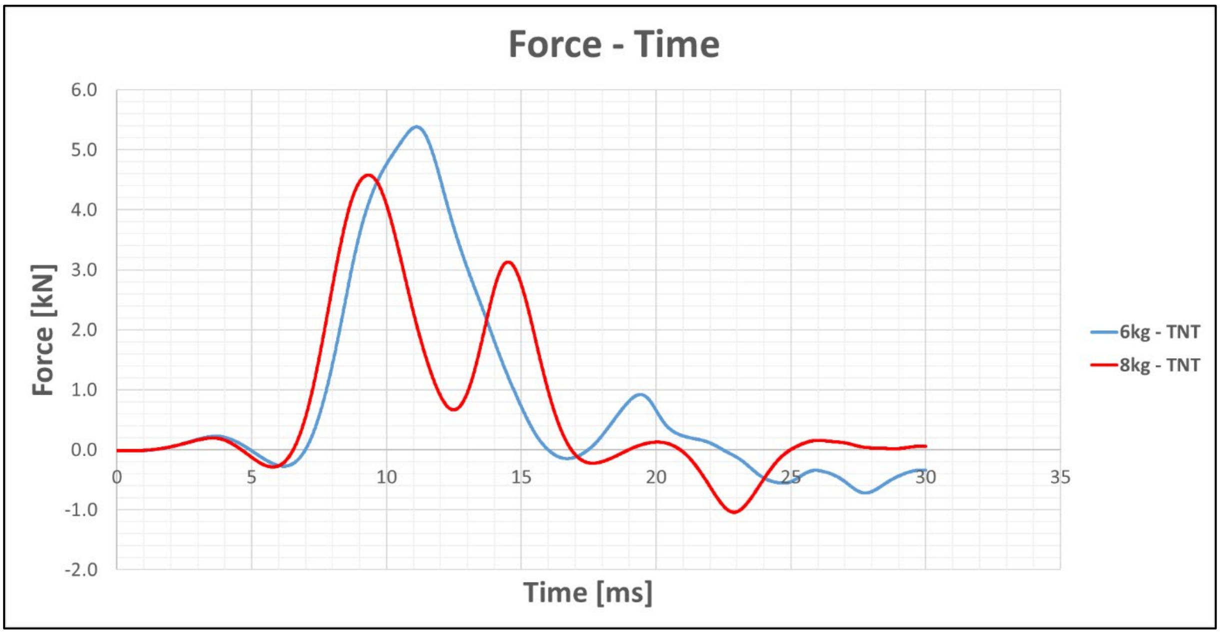

Fig.18: Tibia force history

Figure 19 illustrates the pelvic acceleration history, the maximum pelvic Z acceleration is calculated as 135 g after 8kg TNT explosion and 118 g is obtained after 6kg explosion.

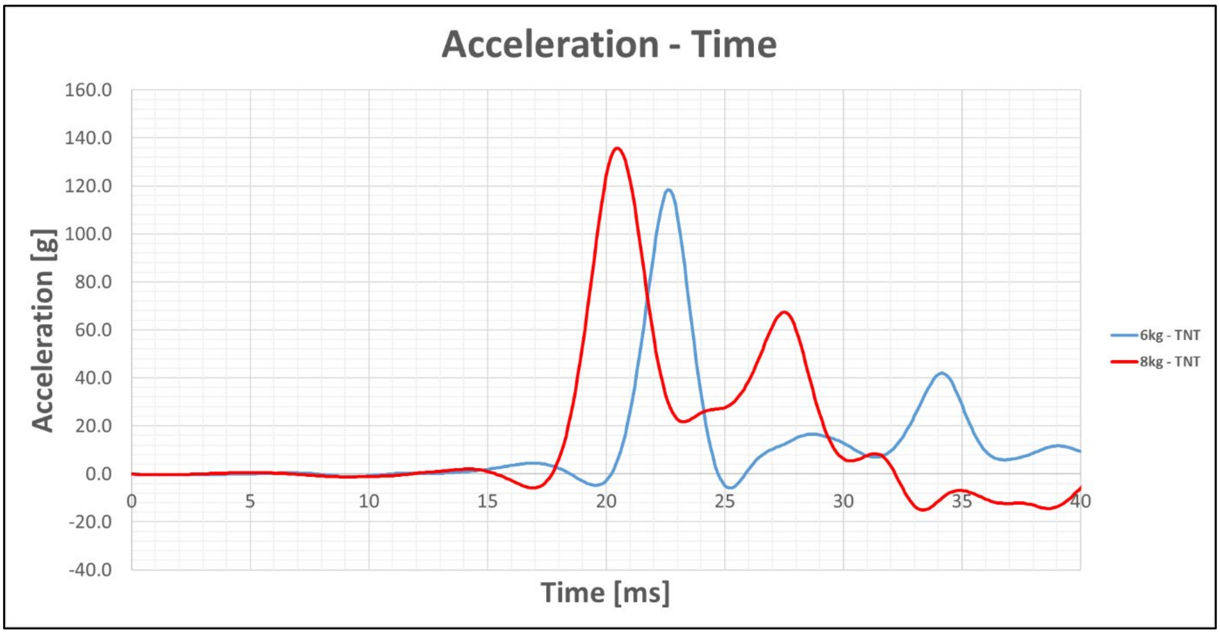

Fig.19: Pelvic acceleration history

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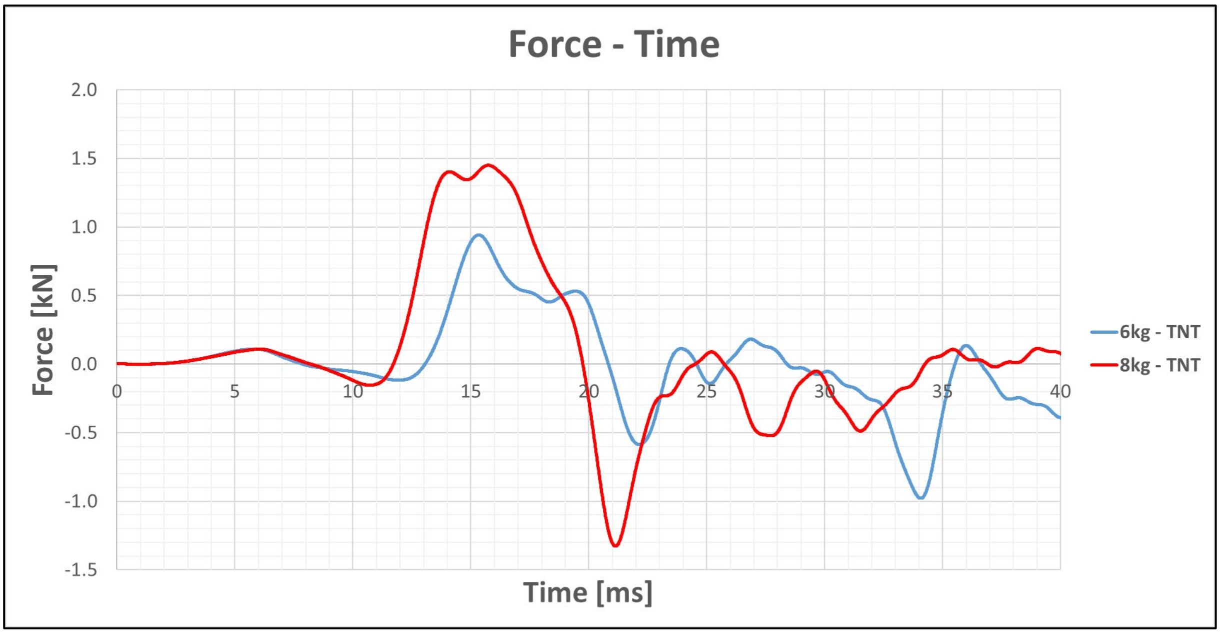

Fig.20: Femur force history

As shown in the Figure 20, the maximum femur force is calculated as 1.45 kN after 8kg TNT explosion and 0.94 kN is obtained after 6kg explosion.

5 Summary

In the scope of this study, detailed finite element models of the 4x4 military vehicle and the critical mission equipment inside it were first created, followed by simulations of 6 kg and 8 kg TNT explosions.

The LSTC H3 50th dummy model was used in the analysis. After the explosion analysis, comparisons were made between the loads on the dummy model and the pressure and acceleration values on the vehicle. According to STANAG 4569 standards, eleven parameters on the dummy need to be checked after a mine explosion. In this study, for illustrative purposes, tibia and femur forces are presented. When examining the analysis results, it is observed that there is a 60% increase in the acceleration value on the vehicle after the 8 kg TNT explosion. The loads on the dummy model used in the analysis show an average increase of 30% after the 8 kg TNT explosion.

This study was conducted as an example of mine explosion simulations on a 4x4 military vehicle. As a result of the analysis, it is crucial that the vehicle's finite element model is properly created, material models are accurate, seat and damping models are precise, and the accuracy of the dummy model is critical for accurately simulating the loads on the dummy model.

6 Literature

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