Pandur Dynamic Driving Simulator - Analysis of mine blast effects

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Abstract

The work developed in this thesis aims at contributing to the Pandur Dynamic Driving Simulator. This contribution results from the creation a simulation event with the goal of increasing the simulation system capabilities. In order to do that, events related to a mine blast under the vehicle were created with an equivalent mass of TNT regulated by STANAG 4569.

Those events were analysed based on the development of a detailed study on blast explosive charge and the respective influence on the vehicle, when the detonation occurs under the hull. The explosive burst analysis was developed from a review of previous works and a design of numerical simulations using the finite element method, thought the LS-DYNA® software.

The results were then implemented in the simulator according to the architecture developed by ETI for this project.

This investigation allowed to conclude that the obtained results are coherent and enough. However, to make a more precise investigation it would be necessary to evaluate other modelling and simulation methods for mine blasting analysis.

Keywords: Dynamic Driving Simulator,Infantry Combat Vehicle 8x8 Pandur II, Mine Blast, Numerical Simulation, LS-DYNA

1. Introduction

The expenses on military's training and formation have been high. New technology has brought new solutions to this problem, such as virtual reality and simulation systems. These computational means present themselves as solutions because they allow us to reduce purchasing and maintenance's costs. The development of the Pandur II Dynamic Driving Simulator (PDDS), figure 1, rouse the Portuguese Army's interest on this kind of technology, which brought many benefits to National Defence industry. The PDDS, which is being developed by Empordef – Tecnologias e Informação S.A. (ETI), was designed as a set of subsystems that, when integrated into a system of systems, will delivery the vehicle's necessary emulating functions intended for the simulator.

The work developed intends to contribute to project PDDS, in a way that addresses the effects caused by the antitank mine on the vehicle, according to STANAG 4569 [12]. The analysis is made by the modulation physic phenomena and respective implementation in the simulation's package and virtual reality's control on the simulator.
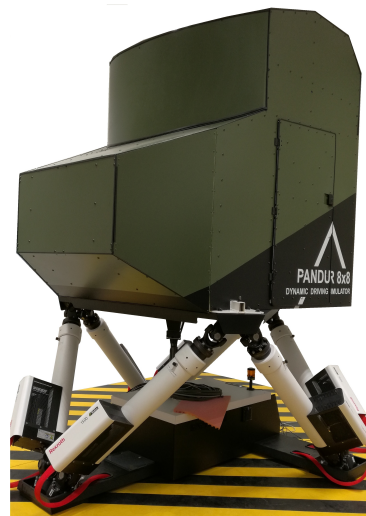

Figure 1: Pandur Dynamic Driving Simulator.

Nowadays it is highly accepted that numerical simulations provide results that are close to reality, while reducing the use of the real system and, at the same time, avoiding extensive costs that would turn the intended investigation much more expensive. The analysis was performed using the LS-DYNA® as computational tool.

2. Background

The technical designation of the vehicle is Wheeled Armoured Personnel Vehicle 8x8 Pandur II, and the PDDS simulator is based on ICV version of the vehicle, figure 2.

Figure 2: VBR 8x8 Pandur II ICV.

2.1. Empiric model of the blast wave propagation

Kingery [8] and the US Department of the Army [1] compiled large sets of data obtained from experimental tests. With this compilation they were able to develop polynomial equations of high order, through interpolation of experimental data, that allows to foresee the parameters of a free field spherical blast and an hemispherical blast on a surface. These equations were accepted as regretion tools by the engineering community and used as models for open air blasts (with no obstacles) or blasts in contact with surfaces. Thanks to this, it was developed a new software named CONWEP [7] that fulfils all numeric calculations of the effects caused by conventional weapons. The TM5-855-1 [1] states that the pressure created by the blast wave decay is approached by a triangular pulse. In the other hand, Remennikov [11] and Lahir [9] state that the CONWEP method uses Friedland's equation to use a more realistic concept to describe the phenomena. Equation (1) translates this concept, which also represented in figure 3.

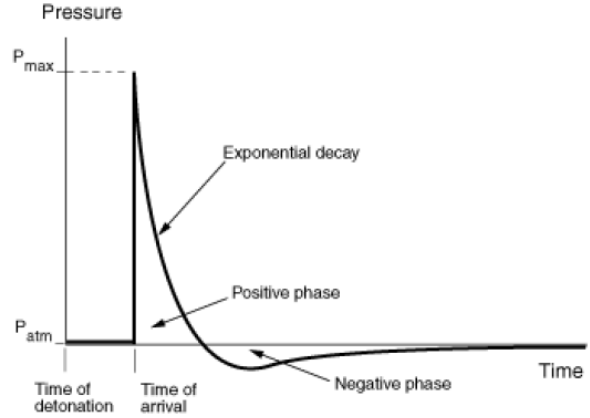$$p(t) = (p_{max} - p_{atm}) \left[1 - \frac{t - t_a}{t_d} \right] e^{-\frac{a(t - t_a)}{t_d}} \quad (1)$$

Figure 3: Pressure variation due to the blast wave [9].

2.2. Previews Works

It is possible to find, in the scientific community several developed works in this area, this is, around the mine blasting modulation under military vehicles' hulls resorting to LS-DYNA® as computation tool. Namely, Brill et al. [5], presents a maximum pressure of 0.1446 [GPa] in the vehicle's hull, relatively to the vehicle's dynamic. We can observe a maximum 0.065 [m] and 2.55×10^3 [m/s^2] of displacement and acceleration respectively. Although the vehicle in analysis (APC M113) presents a different geometric configuration and different moments of inertia from vehicle in analysis (APC Pandur II), both vehicles has a mass around the same magnitude: APC M113, at 12500 [Kg], Pandur II approximately 18000 [Kg]. Some other published works were considered, either the obtained results or the associated concepts of the blast phenomena. As for the additional literature, for a more profound analysis, it can be consulted [10, 2, 3, 4, 13].

3. Implementation

3.1. Pandur Dynamic Driving Simulator

The PDDS has a compartment that simulates the driver's seat through a replica, fixed on a dynamic platform that reproduces the motion and sensation to the driver. The simulation system software is made by several packages, and to each one of them is assigned one specific function. The contribution of this work is given to the package Vehicle. This package contains lamped model of the Pandur II and its systems with the purpose to create a realistic simulation of the vehicle, being responsible of processing all specific functions of the vehicle's features, its user and its dynamics. The blast wave created by the anti-tank mine produces a very high pressure variation in a small space of time. This phenomena induces forces and moments applied to the vehicle's Center og Gravity (CG). The described occurrence and the simulated system's structure makes the phenomena's implementation analysis to be the

calculation of the resultant forces and the moments in the body of the vehicle in each degree of freedom (DOF) (Fx, Fy, Fy, Mx, My, Mz). After this, another package, named Vehicle Dynamic, calculates the vehicle's dynamic response: linear and angular accelerations, for each DOF.
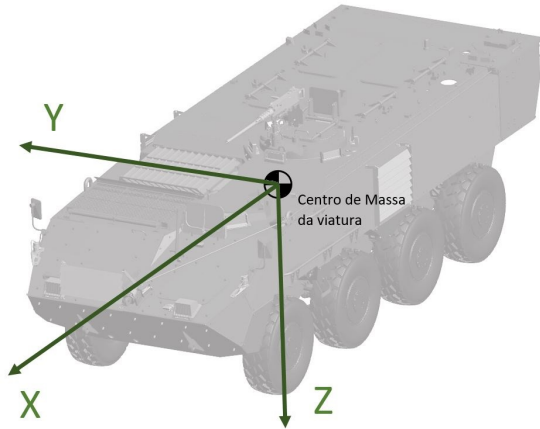

Figure 4: Referential axis used by the simulation system.

3.2. Test description

The model of the events that is intend to be analysed is shown in figure 5. As it is illustrated, it is intended to obtain results for the detonation to a mass of 6 [Kg] of TNT, located after the left wheel in the first axis, this means, under the driver's seat. The choice of the loading charge mass is due to the STANAG 4569 [12], wich states that the blast doesn't cause damage in the vehicles personnel.
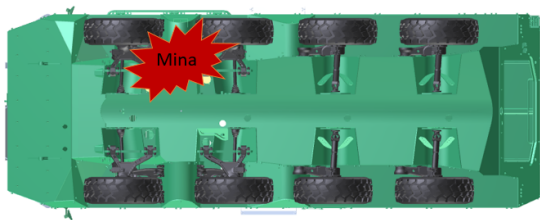

Figure 5: Position of the mine relative to the vehicle.

3.3. Model in LS-DYNA®

Vehicle's body Due to a detailed geometric data of the vehicle and resorting to draw computation's tool SLODWORK®, it was possible design a CAD model of the vehicle. After that, the vehicle's body is discretized in LS-Prepost, figure 3.3. However, there is a need of looking for a compromise between a realistic approach and minimizing the spent time in computation processing. In this way, the design presents only on level of detail necessary and enough to keep the hull's real measuring and configuration.

Vehicle suspension One used technique to create parts (*PART) of spring and damper effect is the creation of discrete elements using the keyword *ELEMENT_DISCRETE, figure 7. To do so, it is defined discrete sections (*SECTION_DISCRETE) between two nodes. The elasticity coefficients to the spring k and the damper c is defined as material, and the keywords are *MAT_SPRING_ELASTIC and *MAT_DAMPER_VISCOUS respectively.

To avoid any compilation errors it is necessary to define the mass that create the suspension. This way there shouldn't exist any nodes without mass when discrete elements are used. Therefore, it is defined 1 [kg] of mass to the node that is part of both vehicle's suspension and vehicle's chassis (a considerably small mass to the vehicle's mass). To the node that stays free and in contact with the ground, it is defined a mass of 200 [kg] in order to recreated the corresponding weight of the vehicle's wheels, 150 [Kg] [6] in addition to its aggregated elements, as the suspension mass itself.

Simulation of the blast load The CONWEP method, chosen for the generation of a blast wave created by the mine blast, it is implemented by the *LOAD_BLAST_ENHANCED card. This keyword allows the data related to the load blast to be entered: equivalent mass of TNT, charge location and activation of calculations associated with both system units, which is intended to be consistent, and also the equations that LS-DYNA® processes during these compilation.
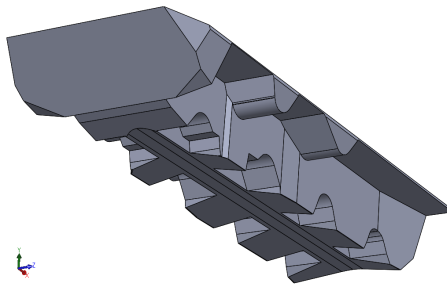
Referential axis To a numeric analysis, the figure fig:coordenadas, illustrates the axis system used and the references to the wheels.
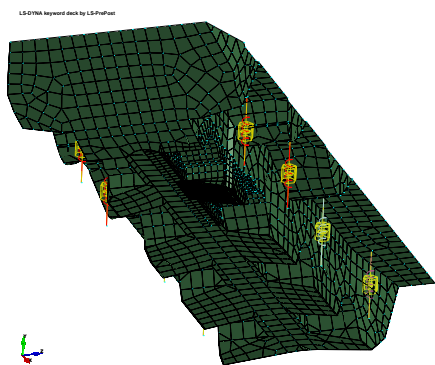
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(a) Complete vehicle
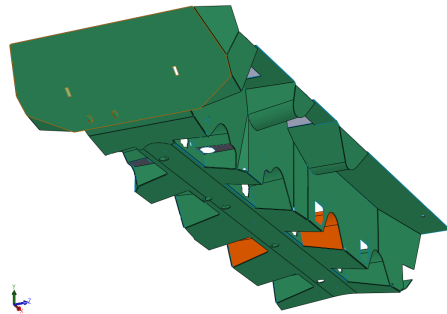
(b) vehicle's hull

(c) Vehicle's 3D CAD model designed in SOLDWORKS®

(d) Discretized model, LS-DYNA®

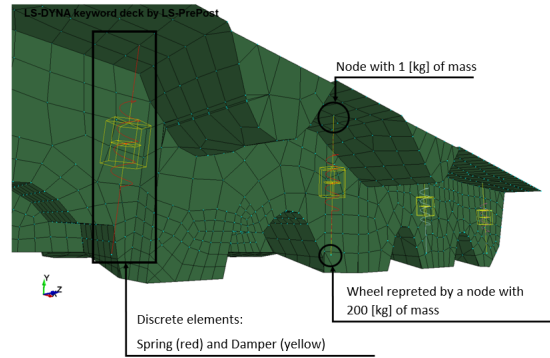Figure 6: Vehicle's 3D CAD Model and discretized plan in 4 steps.

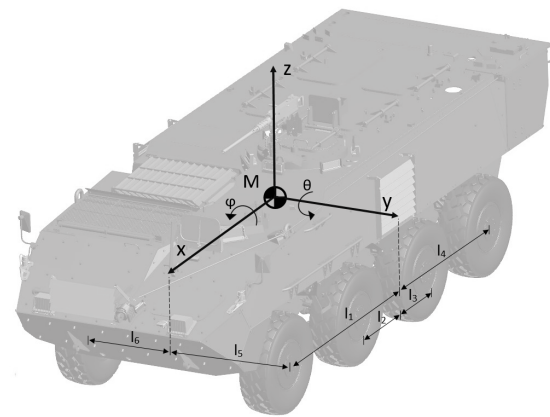Figure 7: Discrete elements of the suspension.

Figure 8: Vehicle body, axis and distnces between wheels and CG.

4. Results

Is shown in figure 9 the propagation of the blast wave around the vehicle's hull. It can be seen the radial propagation of the pressure caused by the blast wave, starting at the point where the load is located. The charge was placed at a distance of 500 [mm] from the vehicle's hull, given that the distance between the hull and the ground is approximately 448 [mm]. it is considered, this way, that the mine is at around a 52 [mm] depth under the ground.
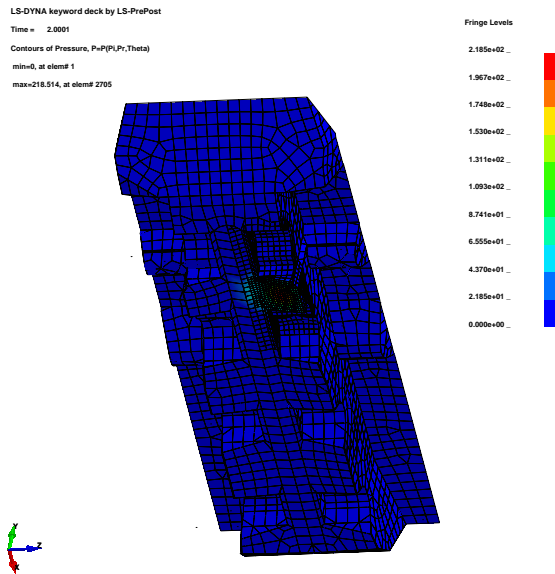
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Figure 9: Load pressure caused in the vehicle's hull at the starting instant

(a) Displacement

(b) Acceleration

Figure 11: Vertical displacement and acceleration the vehicle in rest.

The pressure distribution along the vehicle's hull is represented in the figure 10, in which the curves corresponds to the elements that presents the highest pressure in each moment established in 0.1, 0.5, 0.7, 2.1 and 3.8 [ms] respectively. The analysis of this diagram allows to observe a peak of pressure of 219 [MPa] in the closest element to the load.
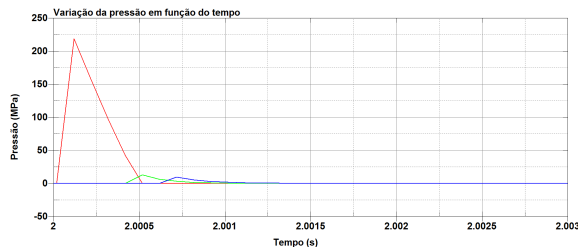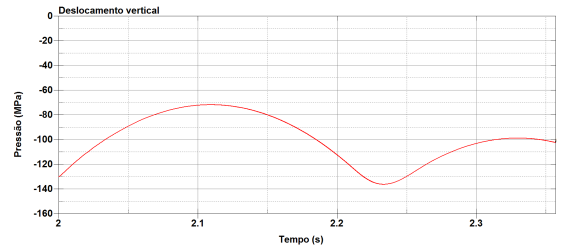

Figure 10: Pressure distribution along the vehicle's hull due to mine blast.

Relatively to the vehicle's mass' centre displacement and acceleration, It can be seen in figure 11 and its respective variations over time.
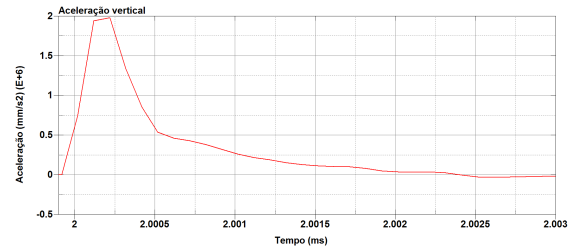
A maximum displacement 58 [mm] and a maximum acceleration of 1.98×10^3 [m/s^2] can be observed, figure 11.

4.1. Simulator - Vehicle dynamic

In figure 12, its illustrated the vertical linear accelerations for both implementations, this is, for the original data and for when the resultant of forces applied in the CG are multiply by a 1.5. factor.
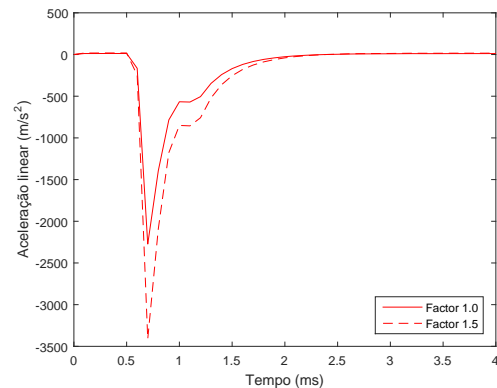

Figure 12: Linear vertical acceleration for implemented models.

Note that the axis system of the PDDS, figure 4, is not the same used by the numerical simulations, figure 8. About the vertical axis zz, it can be observed a maximum 2275 [m/s2] acceleration in negative direction of the zz, which means, in the opposite direction of the ground.

The vehicle should have a visually better behaviour if the results of the applied forces in the CG were multiplied by a 1.5 factor. It can be, in fact, verified a maximum 3412 [m/s2] acceleration. It is a close factor to the one proposed by Bill et al. [5] for the CONWEP method.

To the angular accelerations verified by the simulator's dynamic are shown in figure 13.
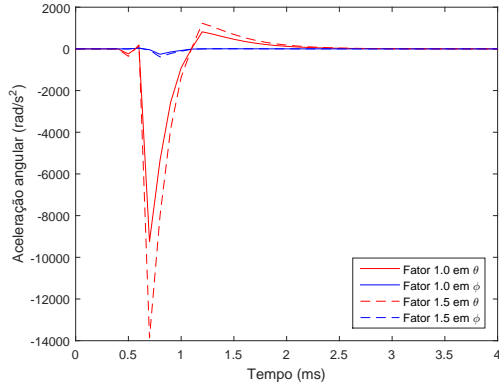
Figure 13: Angular Acceleration for the implemented models.

4.2. Discussion

In this work it is intended to achieve the final goal, implement the numerical results in the PDDS. Table 1 allows to validate the vehicle's model's physical properties, namely, the mass and the vehicle's CG main moments of inertia.

Table 1: Mass and the vehicle's CG principal moments of inertia

	Mass (ton)	Attitude	Moments of Inertia (ton.mm$^2 \times 10^7$)
Numerical Model	18.034	Roll	1.38
		Pitch	7.42
		Yaw	8.41
Real	18.000	Roll	1.04
		Pitch	3.5
		Yaw	3.78

To make a discussion about the obtained results, the table 2 presents the peaks of pressure, acceleration and vertical displacement obtained for each numerical model. The table's line corresponding to the simulator allows a results' discussion about the way the implementation is made. This last model has the purpose to validate the implemented numerical model.

Table 2: Comparation between results to each fase.

Modelo		Pressão (MPa)	Aceleração (m/s^2)	Deslocamento (mm)
Numerical Analysis		219	1980	58
Simulator	1.0	-	2275	-
	1.5	-	3412	-
APC M113	Brill et al. [5]	144.6	2550	65

After analysing table 2, it can be seen in a general way that, for each parameter evaluated, they found themselves in the same order of magnitude, in each parameter evaluated, the variation that is seen in each approach or method are

Relatively to the final goal, it can be seen that when it comes to vertical acceleration, the values obtained by the simulation system (package vehicle dynamic), are consistent and close to the ones predicted by the numeric simulations. Namely the acceleration obtained for the detailed geometry model, 1980 [m/s2], and the acceleration obtained by the PDDS, 2275 [m/s2].

The data collected in the bibliographic revision, help validate the numeric models. In the vehicle VBL M113 model's case presented by Brill et al [5], it can be seen a diference of 570 [mm/s2] of vertical acceleration and a diference between pressures of 74,4 [Mpa], related to the geometry detailed model. As it was expected, the Pandur II shows a minor acceleration, due to the fact that the VBL M113's mass is lower.

5. Conclusions

This work presents a methodology of a numerical analysis based on bibliography and previous investigation. The objective was to develop virtual simulations of mine blasting under the hull of VBR Pandur II close to reality. After analysing the obtained results, it was possible to verify that this data is consistent and properly validated compared to previous works.

In view of an application of the intended results for the reality simulation in the PDDS, we can verify its utility and positive implementation.

The numerical analysis was made in a progressive way, increasing the detail level of each model. In each step of the project we can verify:

- The blast phenomena occurs in a short period of time;

- The amount of pressure caused on an obstacle is considerably influenced by the distance that the obstacle is from the blasting mind

This work turns out to be a propose of methodology in the mine blast under the Pandur II's investigation, as well. This contribution also needs improvement in numeric simulations. This means:

- It would be necessary to test more methods (ALE and coupled methods) in order to verify if the results would be better, more precise or strict;

- Not just use the LS-DYNA® in the discretization step, but also resort to other programmes, in order to look for the potential and advantages that each software presents. This way, it possible to use each advantage to bridge the

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gaps and disadvantages of the others. The LS-DYNA® presents a considerable potential to be part of the process and calculations, the keywords basis is intuitive and efficient in the application of specific models. Is less user friendly in geometric creation and respective mesh, making it necessary another software to bridge this gap.

- Making experimental tests would help to validate the developed work, in order to make another kind of analysis, for example to verify if a vehicle fulfils, in reality, what's stated by STANAG 4569.

After introducing the numeric model in the PDDS, it was concluded that, due to the fact that the sample time was too high and because the blast was also quick, it would be necessary to low the speed of the simulator itself, however due to facts like the level of hardware or even the platform were not implemented in a detailed form. However, to the implemented model in the virtual simulation in PDDS, was verified a use and a positive implementation.

Acknowledgements

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