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Numerical Analysis of the Ability of a Floating Vehicle to Overcome a Water Obstacle

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Abstract:

The paper presents the results of simulation tests of the entry of a floating transporter to a water obstacle. The simulation tests were performed with the use of LS Dyna program, based on the finite element method (FEM). The computational model was developed and used in the simulation of the manoeuvre of entering the water obstacle for the extreme conditions, which are described by NATO standards. For a model, as an example vehicle, the floating transporter PTS-M was used. The results of the application of the elaborated model confirmed the possibility to utilise the method to verify the behaviour of a vehicle in a very important and difficult problem from the point of view of vehicle safety conditions.

Keywords:

floating vehicle, entering a water obstacle, finite element method, Arbitrary Lagrangian-Eulerian

1 Introduction

Many factors limit the ability of floating vehicles to overcome water obstacles. The shape of the shore is one of the most important factors apart from the type of ground and the depth of the water. The angle of inclination of the ground in the waterside and underwater part determines the ability to the safe operation of entering water.

Floating transporters (called amphibians) are a typical example of a floating vehicle, mainly used in the armed forces and other specialised services and formations. They are used by Fire Service in actions to save people and property, e.g. during floods and other natural disasters. Floating transporters have, among other things, the ability to transport cargo both on land and in water. Such use of floating transporters means that the places of the water crossing are different each time. It is then necessary

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to enter the water from the mainland and then to leave it safely. There are transitional states in which gradually part of the moving part of a vehicle rests on the ground, and the water already lifts the rest. Then, a significant longitudinal inclination of the vehicle occurs, which may result in water pouring into its interior and, consequently, sinking. Also, dynamic entry to water by a floating vehicle results in the turbulence of the water and generation of a wave, which increases the risk of water pouring into its interior. The mentioned threats were the reason why the manoeuvre of entering a water obstacle was treated as a critical condition, having a significant impact on the safety of a vehicle.

2 Analysis of the Phenomenon of Entering a Water Obstacle by a Floating Transporter

The floating transporter is immersed evenly along its entire length, and the position of the waterline is almost parallel to the horizontal plane of the deck. This prevents water from getting inside. When entering the water, the vehicle is tilted towards the ground. The size of the initial longitudinal inclination results from the inclination angle of the edge of the water obstacle, the deflection of the suspension and the depression of the running gear in the ground. When the transporter enters a water obstacle, its gradual levelling takes place. When the bow of the floating transporter begins to sink into the water, the buoyant force gradually increases. When the angle of a longitudinal inclination of the floating transporter is too high, and the buoyant force is not able to lift it, then the upper part of the bow is flooded, which may lead to sinking, which is a critical condition affecting its safety. This dangerous flooding mechanism is described in detail in the report of Marine Investigation [1]. The authors of the article also conducted research on this phenomenon. PTS-M transporter which was tested during water entry tests is shown in Fig. 1. The Douglass water state was up to 1 (wave state was between calm-glassy and calm-rippled and wave high up to 0.1 m). Moreover the water current was 0 m/s.

Fig. 1 PTS-M transporter which was tested during water entry tests (own elaboration)

The manoeuvre of the transporter's entering a water obstacle can be performed in various ways. You can enter a water obstacle, e.g. very slowly, using the braking system, then there is the smallest risk of flooding the upper part of the bow. However, a very slow entry of a vehicle to water takes a relatively long time, which is not desirable during military or rescue operations. Increased speed of the entry can lead to flooding of the upper part of the bow. If the speed is too high, water may overflow through the upper part of the bow and flood the floating transporter as a consequence. Therefore, a question arises what the permissible speed of entry of a floating transporter to a water obstacle for different ground slopes is.

The vehicle ability to overcome water obstacles depends on the speed of swimming and the stability of entering and exiting from the water. The experience of drivers confirms that the stability of vehicle movement during the entry depends both on the operating parameters of the propellers (screws) and the moment of their engagement, as well as on the shape of the hull. Often, even small changes in the shape of the hull or speed can significantly change the water drag and improve or worsen the dynamics of entering and swimming. Because the behaviour of the vehicle in the initial phase of the water entry depends on the speed and hydrodynamics resulting from the properties of the vehicle shape, the construction of a new floating transporter requires practical tests to determine the boundary parameters of the vehicle entering the water.

The main parameter is the permissible angle for a ground slope and the permissible entry speed at a given angle of a slope of the ground. In practice, the tests of entering to water obstacle begin with a small entry inclination and a low entry speed. If the vehicle enters a water obstacle without flooding, in the following tests, the vehicle entry speed is increased until the maximum safe speed is reached. The procedure is repeated for higher entry inclination angle. After the permissible entry angle and the entry speed are reached, the tests are completed, and the parameters are recorded in the technical documentation of the vehicle. Similar attempts are made for climbing out of the water [2]. There is a NATO standard for it [3, 4] according which a vehicle entry into the water should be performed at the entry inclination angle of 20° (40 %) and the exit inclination angle of 17° (30 %). The analysed process of entering a water obstacle by transporter is an issue relatively rarely presented in the available specialist literature.

The main reason for this is the inconvenience of a laboratory experiment. Such an experiment requires the use of a real object and the possession of wharves with different or adjustable inclination angle. So, these are dangerous, time-consuming and expensive tests. Therefore, simulation tests are more useful at an early stage of the research. The methods based on the similarity theory are most often used in them, allowing the study of model behaviour without the need to use large-scale research objects. The application of the similarity theory includes the appropriate selection of physical parameters of the laboratory model that meets the similarity criteria. The theory is based on three laws: Newton, Federman-Bughingorn and Kirpiczew-Guchaman [5]. The research on the floating transporter was carried out by, among others, the team of prof. Walentynowicz from the Military University of Technology [6]. The use of the simulation model enables relatively quick and straightforward modifications of the structure, e.g. changes in the shape of the bow and observation of the influence of changes on the permissible speed of entering a water obstacle. Currently, the most advanced simulations are carried out using numerical methods. For this purpose, the finite element method is used most often [7-9].

3 Model Description

The practical purpose of the simulation described in this paper was to check the compliance with the quoted NATO standardisation requirements [3, 4] by the floating transporter in terms of entering the water at the maximum angle of ground slope. The object of research was the PTS-M floating transporter, widely used in the world [10] and the simulation results were to allow for the formulation of conclusions regarding the modernisation of its shape and proposals for the entry technique. The entry of the transporter (1) along a rigid ramp inclined at an angle of 22° (2), into a tank with dimensions of (20 × 10 × 5) m (3), filled with standing water was simulated (Fig. 2).

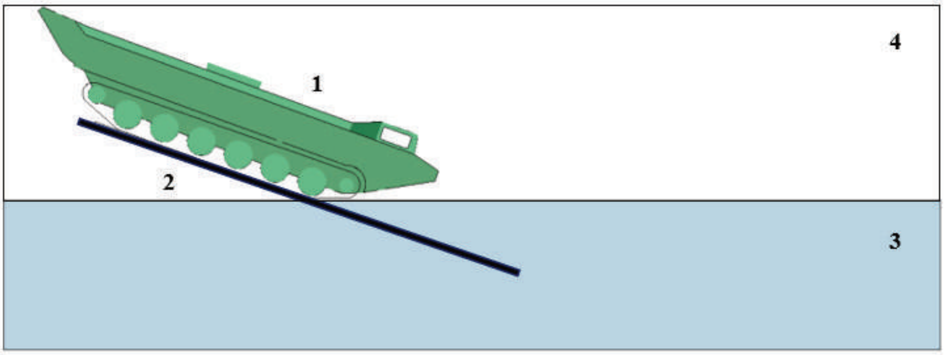

Fig. 2 Initial positions of the floating transporter on the ramp before entering the water: 1 – transporter, 2 – entry ramp, 3 – water, 4 – air domain

When vehicle entries the water, the forces acting on the vehicle are gravity acting on the centre of gravity, ground reaction, buoyancy acting on the floating part, propeller thrust, air resistance, water resistance. The model did not consider the influence of mass variability, impact of water waves, variability of possible vehicle weight, the effect of breakwater and other factors.

The simulation tests were performed with the use of LS Dyna program, based on the finite element method (FEM). It is a software package for the analysis of fast-changing phenomena using the explicit finite element method to calculate engineering. For this purpose, the structure model (vehicle and ramp) was modelled with HEXA elements in Lagrange space. The defined materials for structure were of rigid type (MAT_RIGID). The extra weight of the engine, equipment, and crew was distributed as ELEMENT_MASS keywords on the selected nodes of the transporter. Due to the necessity to take into account the hydrodynamic phenomena occurring in the liquid and gaseous medium, air and water were modelled in the Euler space. The MAT_NULL model of the material was assumed for air and water. For all elements with MAT_NULL, polynomial equations of state (EOS) were used. To connect both areas, authors used the Arbitrary Lagrangian-Eulerian (ALE) description, according to the fluid-structure interaction (FSI) algorithm [11], which allows the transfer of pressures between elements of fluid and solid-state mechanics. A mechanism of mutual interaction between both centres was introduced (by defining the CONSTRAINED-LAGRANGE-IN-SOLID constraints). The material properties were given to the finite elements (respectively: steel, air, and water).

The main assumption adopted for the construction of the physical model was that the vehicle enters the water freely – under the influence of the forces generated by the caterpillars. Then, after the caterpillars detach from the ramp, the vehicle is driven by the reaction forces generated by the propellers. At this moment, the main drive is turned off, and the water propellers are turned on. The described mechanism produced a driving force of 14 kN and allowed the transporter to move at an average speed of up to 5 km/h. During the entry, the rotating wheels of the transporter interact with the water, disturbing the laminar flow of water around the vehicle. Due to the small influence of these disturbances, these phenomena were not included in the model.

4 Results of the Simulation

The analysis of the vehicle entry process into the water included, among others, the study of the time course of the trim (defined as the difference between the forward draft and the aft draft). The trim equals zero when the vehicle is in the horizontal position and it rises when the front of the vehicle is submerged. Due to its small values, in accordance with engineering practice, the amount of trim was expressed not in degrees, but in units of length as the difference between the draft at the bow (point A) and the stern (point B).

In order to calibrate the graph, the values of the instantaneous trim were increased by the difference in the height of both points of Δ = 0.366 m, measured in the horizontal position of the transporter (Fig. 3). Finally, the following equation was used for the trimmer (1):

$$T = h_B - h_A - \Delta \quad (1)$$

where h_B – the temporary height of the point B relative to the bottom, h_A – the temporary height of the point A relative to the bottom, Δ – the difference in the height of points A and B when the transporter is stationary on a horizontal surface (Fig. 3)

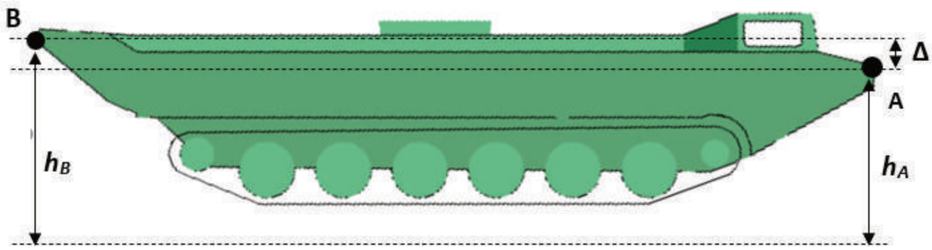

Fig. 3 Trim measurement: A – measurement point corresponding to the bow, B –measurement point at the stern

The graph of the momentary location of points A and B obtained from numerical calculations, from Eq. (1), is shown in Fig. 4.

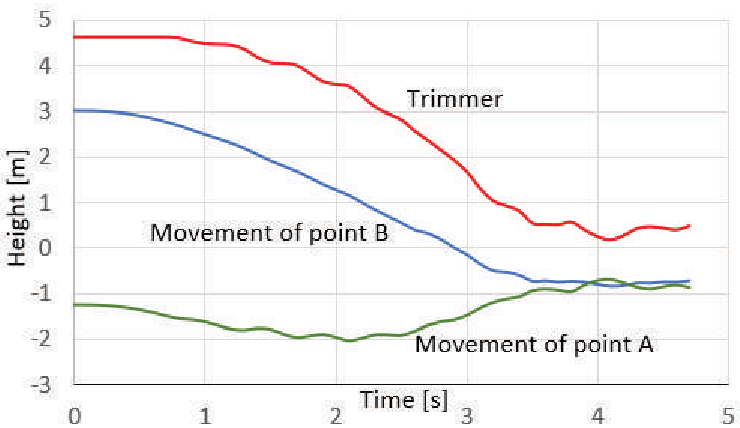

Fig. 4 Trim [m] *as a function of time* [s]*, calculated by the formula (1): top line – trimmer, bottom line – the movement of point A, middle line – the movement of point B*

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Moreover, as a result of numerical calculations, we obtained the visualisation of the transporter's entry process to the water obstacle. Selected successive sequences of the transporter entering the water are shown in Fig. 5.

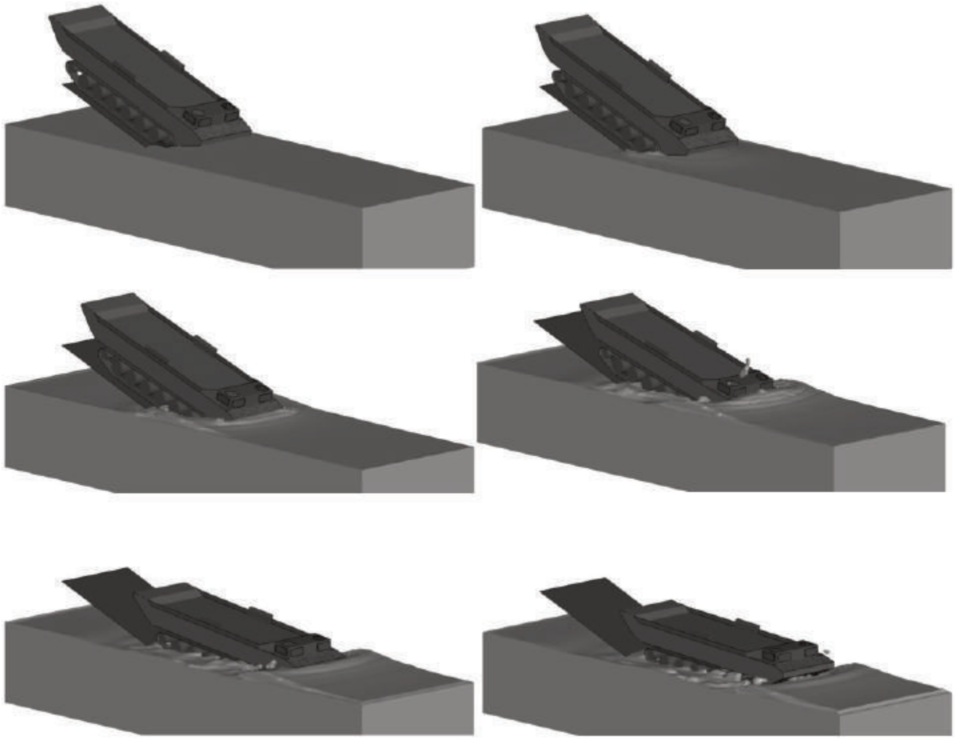

Fig. 5 Successive phases of the transporter entering the water (image recorded every 0.7 s*)*

Because the main objective of the simulation was to check whether the tested transporter can enter the water at a big inclination angle of the ramp (22°), the fulfilment of two conditions was essential:

- the transporter should regain lift after maximum trim and flooding the bow (first condition),
- no water penetrating the cargo part of the transporter (second condition).

The problem with meeting the first condition may occur when the nose of the transporter is at the lowest position in relation to the water level (Fig. 6). In this position it is subjected to a very high hydrodynamic pressure, generating a large torque. In case the buoyancy does not balance the transporter, it may lead to its sinking. This moment appears when point A is below the water surface.

The analysis of the movement of point A shows that this point moves towards the water surface and then goes up (Fig. 7). Thus, in the analysed case of the PTS-M transporter, the flooding effect was not observed (Fig. 7). It can be assumed that the effect could occur with an increase in the total vehicle weight to the maximum (18 t) and the vehicle speed well above 5 km/h.

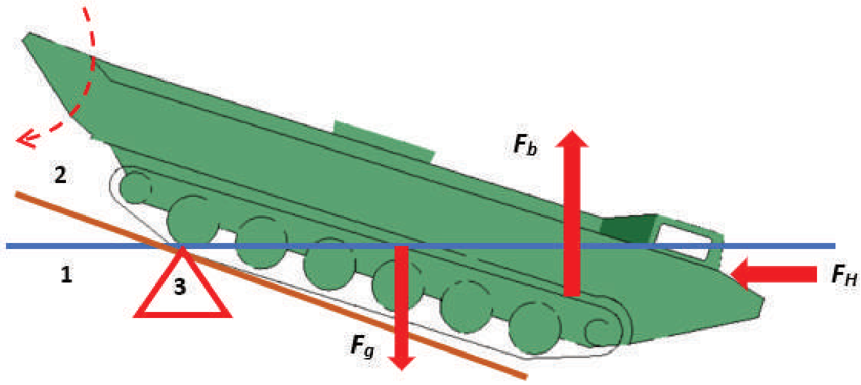

Fig. 6 The mechanism of appearance of the moment of forces causing the sink of the transporter: 1 – water line, 2 – ramp, 3 – the momentary centre of rotation, 4 – FH – hydrodynamic pressure force, F_g – gravity force, F_b – buoyancy force

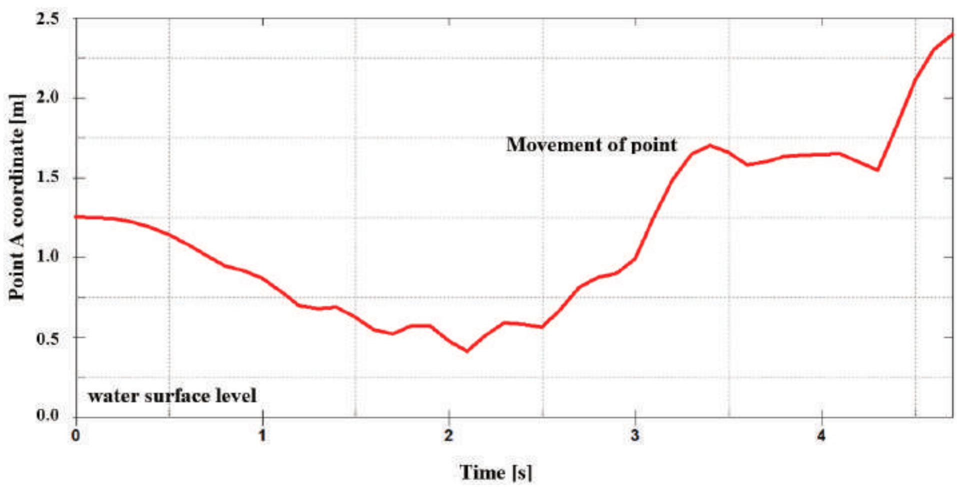

Fig. 7 The movement of point A *in relation to the water surface* y_A (*t*)*:*
point A *coordinate* [m]

The fulfilment of the second condition was assessed by observing the amount of water flowing through the cabin to the loading part of the transporter.

During the simulated entry of the transporter to the water, no water was overflowing into the load compartment. The most significant height of the water column hitting the cabin did not exceed its size and reached 400 mm (Fig. 8).

The numerical model was validated by comparing the results of the numerical calculations with the observations of the wave height generated during the test of the transporter recorded by a television camera (Fig. 9). The measured greatest wave heights did not exceed 350 mm and were slightly lower than the values resulting from the numerical calculations. This difference may have been due to the inaccuracy of the wave height measurement.

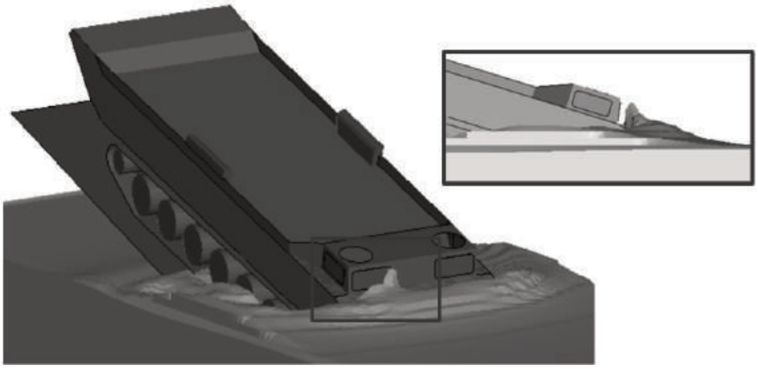

Fig. 8 The highest amplitude of the water wave recorded at t = 1.7 s

Fig. 9 Measuring the height of waves against transporter after manoeuvre to enter the water

5 Conclusion

The results of the computational model described in the paper were verified by comparison of the simulation with a practical attempt to enter a floating transporter PTS-M into a water obstacle. The simulation of the entry of the floating transporter to a simulated water obstacle showed that:

- the model presented in the paper is an efficient tool for designing the shape of a floating vehicle and gives a fast and reliable impact of these changes on vehicle behaviour, especially a water obstacle entering,
- the computational model can be used to design and analyse the construction of floating vehicles, especially the entering water obstacle by the vehicle and to significantly contribute to increase the safety of the manoeuvre,
- the use of this calculation model will significantly reduce the time and cost of developing new vehicle constructions.

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