PNEUMATIC AIR OBJECT APPLICATION IN DESIGN OF WATER CROSSING

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Abstract

The results of numerical analysis of the decomposing process of a single pneumatic cassette pontoon bridge as a temporary roadway are presented in the paper. The cassette pontoon bridge is an innovative solution designed for quick assembly of the construction on water. The repeatability of a single module, facility of transportation and operation mean that it can be used in many applications: crossings for military vehicles (e.g. tanks or wheeled vehicles lightarmoured), replacement crossing for trucks (e.g. delivering materials for the construction of the permanent bridge), ribbons replacing flooded roads and footbridges on suddenly increased watercourses. The main problem in our consideration is single cassette pontoon stability at the moment of filling the pontoon. The numerical investigations presented in the present paper aimed at testing the influence of the load on the process of filling the single cassette pontoon. To perform the analyses, LS-DYNA software, in which the dynamic equations of motion are solved using an explicit time integration method, was used. The paper presents initial verification of the initial conditions influence on the process of filling the single cassette pontoon. An important factor considered in the work is a strong influence of an unbalanced load distribution on the surface of the cassette capacity on the process of filling the pontoon.

Keywords: *cassette pontoon bridge, numerical analysis, transport infrastructure, air pollution, pneumatic airbag*

1. Introduction

The water crossings are a very important element in both military and civil logistics. Ease of transport, unloading and assembling is a particularly important parameter of unfolded water crossings. The cassette pontoon bridge discussed in the paper is devoid of undesirable design features such as high transport volume and high mass.

The suitability of such type of water crossing solutions, in civil application, is especially noticeable in the face of natural disasters, such as floods in the last years. In many regions, the local flooding or flooding of road sections occur causing population centres of various sizes being cut off from the world. In such case, protection of supplies would be possible owing to the use of a pontoon cassette bridge or only a certain number of its modules to ensure the free passage through the inaccessible areas. Another advantage of this solution is adjusted load of a single cassette adapted according to the needs [1].

The article describes a numerical model based on the revised final version of the pneumatic cassette pontoon. The demonstrator is shown in Fig. 1.

A load-bearing element of the structure is an air cushion, which is already used mainly by emergency services in order to lift and extend heavy constructions [2]. Such an air cushion, also known as a pneumatic air object, has a small volume in the ground state and can be used in the case of lack of access or limited access to the object of the operation. Its advantages, high strength and height of lifting, used in the construction of a repeatable module of the cassette bridge, causes the possibility of using the module in any conditions and its transport and preparation for use a simple operation without the need of special equipment. They are important features because

Fig. 1. A single pneumatic cassette pontoon at the time of launching

of the relatively large dead weight of the cassette, which results from the applied amount of metal required to ensure the carrying capacity of a single module.

The article presents the results of numerical analysis of a cassette pontoon bridge in the context of the influence of load-bearing elements distribution on the symmetry of unfolding of the structure.

2. Principle of operation

A cassette pontoon bridge is combined of single floating modules of repeatable geometry. The essential parts of a single module are cassette and elastic–air cushion. In the folded position (Fig. 2a), the air cushion is closed inside the cassette, which is also the upper part of the running surface for vehicles moving on it. The cassette also performs a protective function for an air cushion and conduits for its filling. Owe to this solution, the transport of a set of five modules does not require a special vehicle and can be run on public roads without meeting of distinct formal conditions.

The volume of the air cushion, which is divided into at least three chambers, provides buoyancy, which is equal to the sum of dead weight of the module and the object moving on it. The division into chambers ensures retaining its functions even in the case of an air cushion material damage. The principle of operation of the module is shown in Fig. 2.

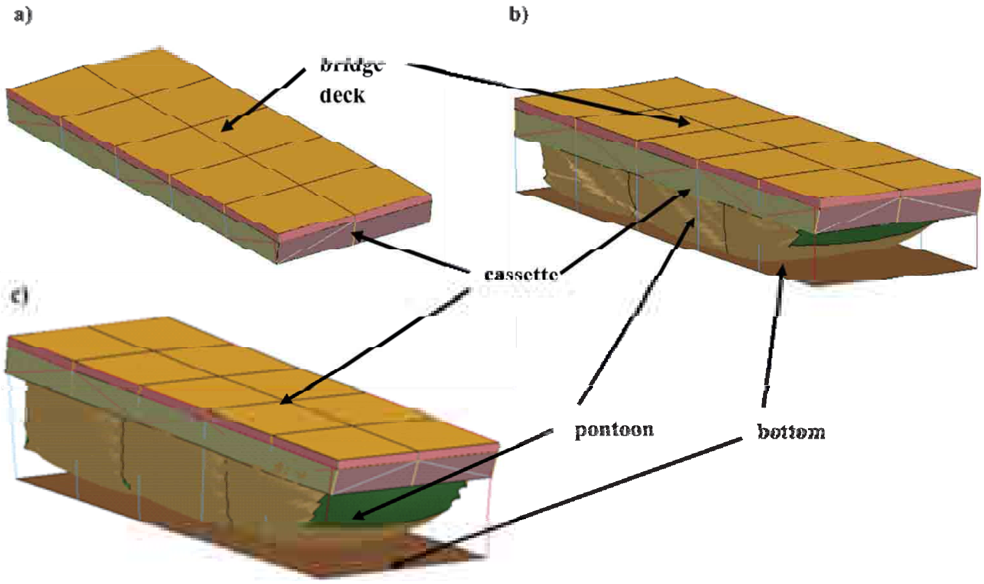

Fig. 2. The principle of operation of the module: a) ground state, b) intermediate state, c) full state

The principle of operation of a single module of the cassette pontoon bridge is based on the Archimedes principle, which states that the buoyancy force F_w acting on a body immersed in fluid is equal to the weight of fluid displaced by the body and is written with the formula [2] indicating whether it is an equtation number or a reference to literature:

$$F_w = \rho \cdot g \cdot V \, , \tag{1}$$

where ρ is the density of fluid or gas in which the body is immersed, g is the gavitational acceleration, and V is the volume of the body which is immersed.

To make the body float on the water's surface, its weight is required to be balanced by the buoyancy force. The module can be loaded with additional mass of a passaged object at low dead weigth of module m_m and high buoyancy of an elastic air cushion. M_d value of this mass can be estimated using the following formula:

$$m_d = \rho \cdot V + m_m \, . \tag{2}$$

Functionality of the presented solution is ensured by minimizing the weight of the module associated with displacement of the device, what allows crossings of large mass objects (e.g., trucks).

From the user's safety point of view, buoyancy is as important as stability of the construction in the sense of the ship theory. The concept of stability of a vessel is defined as its ability to return to equilibrium disturbed by internal forces such as waves or uneven weight distribution. The basic quantity determining initial stability of the ship is metacentric height of the vessel determined by the following formula:

$$m = \frac{J}{V_z} - a \, , \tag{3}$$

where m is the metacentric height, J is the moment of inertia of the axis of inclination, V_z is the solid displacement volume, and a is the distance of the centre of gravity of the body from the centre of buoyancy in the position of floating.

Figure 3 shows designations used in equation (3).

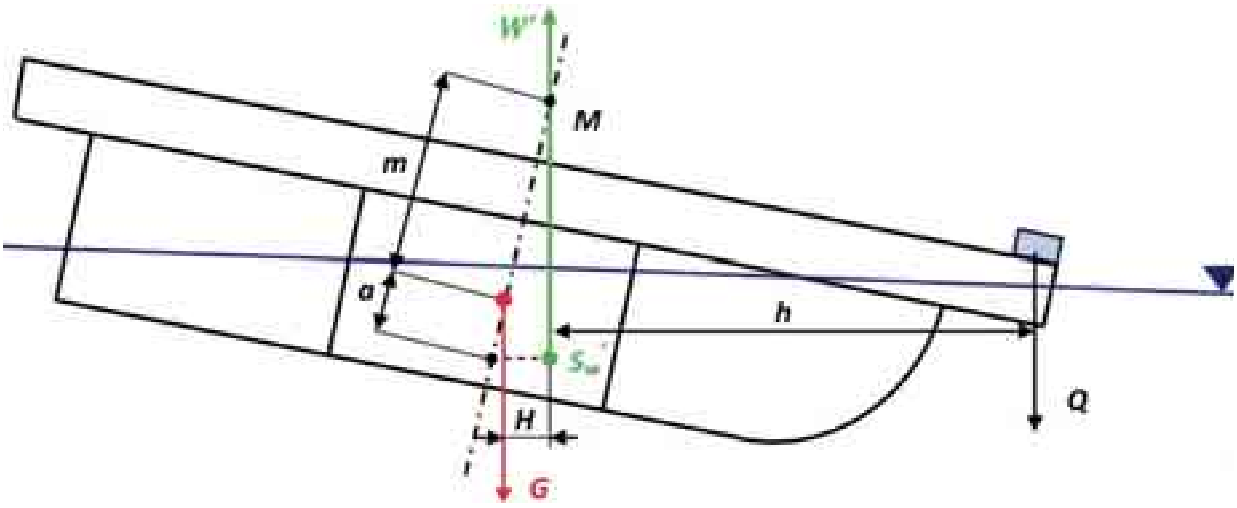

Fig. 3. Diagram for calculation of analytical stabilities

In the case of a pneumatic air object, the volume of the buoyancy force is variable since it depends on the mass flow rate of flowing gas and on time. In the case of the cassette pontoon bridge module, the analytical calculation of the current value of metacentric height m requires knowledge of the current value of the cushion filled with gas as presented in Fig. 2. Weight Q corresponds to uneven weight distribution of a metal cassette.

3. Subject area

Using modern computer techniques for modelling and numerical analyzing enabled simulation of unfolding a single cassette of the pontoon bridge without the need of expensive experimental tests.

Despite the fact that a discrete model of the cassette was built of beam elements on which the mesh of four-node coat elements was spread, the analyses comprise material nonlinearities and contact phenomena with friction. It possible owe to ascribing an elastic-plastic material model to all the finite elements mapping the shape of the cassette.

The conducted analyses resulted in observation of numerous constructional factors considerably influencing the process of filling the pontoon, what is directly connected with stability of the cassette during its filling. The analyses helped the constructors with elimination of unfavourable effects occurring during filling resulting from conditionings of the construction. Numerical analyses helped to notice insignificant, apparently negligible, geometric asymmetries of the model and showed their great influence on cassette stability. Owe to using finite element analysis it was possible to detect unfavourable effects occurring in the process of filling the pontoon even at the stage of its design.

4. FEM numerical calculations

The numerical modelling and analyses process requires the most possible simplification of the researched object both in the aspect of geometry and environmental conditions in which the analysis is to be carried out. LS-DYNA software was applied to the analyses. The code's origins lie in highly nonlinear, transient dynamic finite element analysis using explicit time integration [2].

The process of filling the pontoon was rendered owe to using the SIMPLE_AIRBAG_MODEL option which enables modelling of thermo-dynamic filling of a container such as a pontoon using the approach of control area. It allows for determining the dependencies between the rigid movement of unfolding walls of the pontoon and its volume.

The gamma law equation of state used to determine the pressure in the airbag:

$$p = (\gamma - 1) \cdot \rho \cdot e \,, \tag{4}$$

where p is the pressure, ρ is the density, e is the specific internal energy of the gas, γ is the ratio of the specific heats:

$$\gamma = C_p / C_v \,, \tag{5}$$

where C_p and C_v are the heat capacity at constant pressure and constant volume, respectively.

From conservation of mass, the time rate of change of mass flowing into the bag is given as:

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \frac{\mathrm{d}M_{in}}{\mathrm{d}t} - \frac{\mathrm{d}M_{out}}{\mathrm{d}t} \,, \tag{6}$$

where M_{in} is the flowing mass, and M_{out} is the gas flowing out mass.

4.1. FEM analysis

In order to verify the symmetry its lack in the process of filling the pontoon, the analysis was carried out for a cassette with a fixed bottom. Telescopic-spring mechanisms were modelled as spring elements with stiffness determined from analytical calculations. Asymmetrical load was realized through extended stiffness of corner spring element as in the case presented in Fig. 4.

Extension of pontoon cassettes, presented in Fig. 2, is caused by introducing air whose mass flow rate in the function of time is presented in Fig. 5.

A pontoon discrete model, in which the cassettes were characterized by different volume, was used in the conducted analyses.

The numerical analyses resulted in obtaining the image of asymmetrically unfolded cassette (Fig. 6–8). Application of LS-DYNA software enables following the process in any, moment of time, both the unfolding process of the cassette and monitoring such values as stresses, deformations and displacements of individual elements of the construction growth. The process of filling in the selected time moments is presented in Fig. 8.

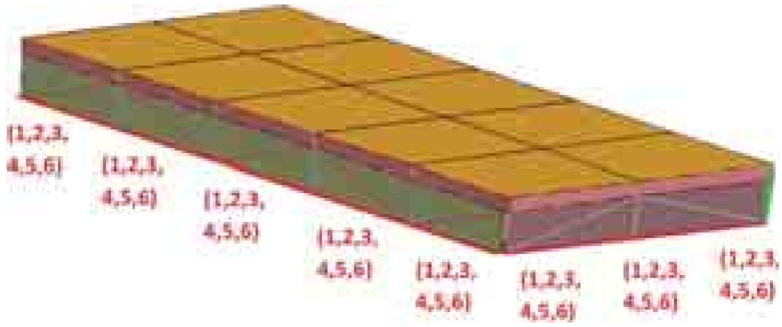

Fig. 4. The way of fixing the cassette in the considered case. All deprived translation degrees of freedom of the cassette bottom; 1, 2, 3 – subsequent deprived translation degrees of freedom; 4, 5, 6 – subsequent deprived rotational degrees of freedom

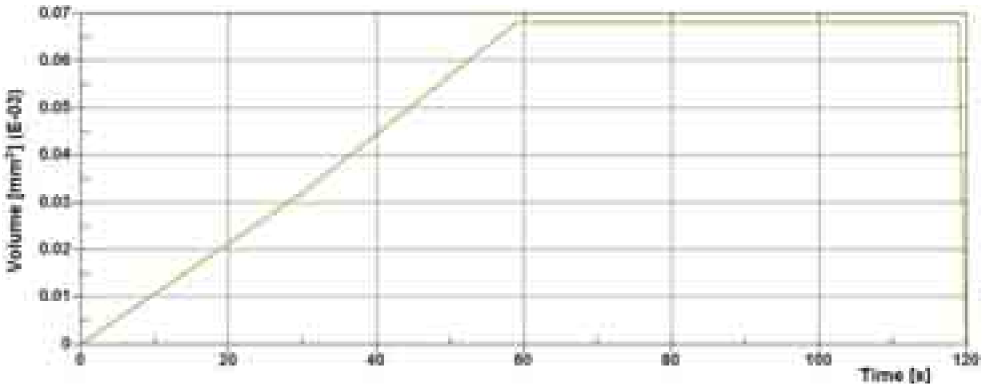

Fig. 5. Mass flow rate in the function of time

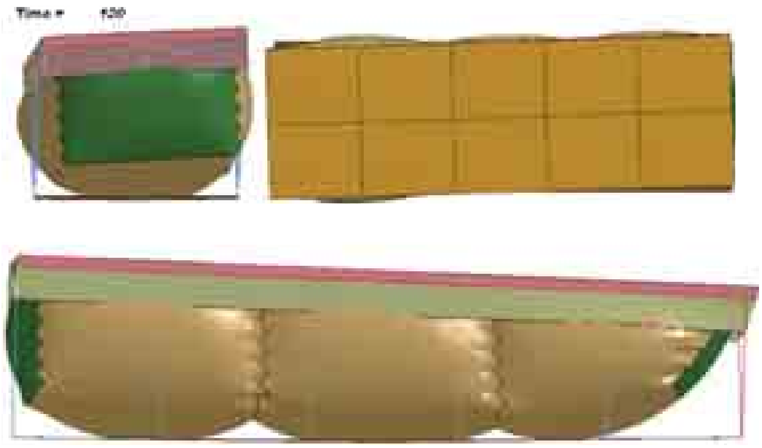

Fig. 6. Lack of symmetry of the cassette with the filled pontoon presented in different perspectives

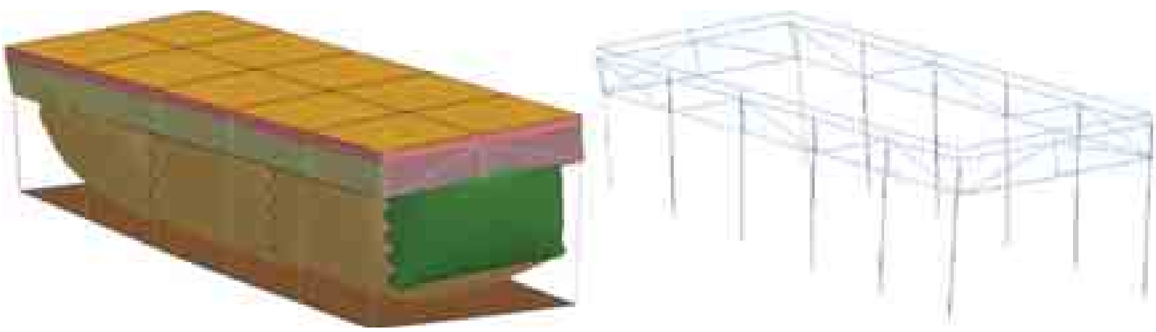

Fig. 7. Distribution of strengthening in the form of beam elements (blue colour) and springs localization (red and yellow colours)

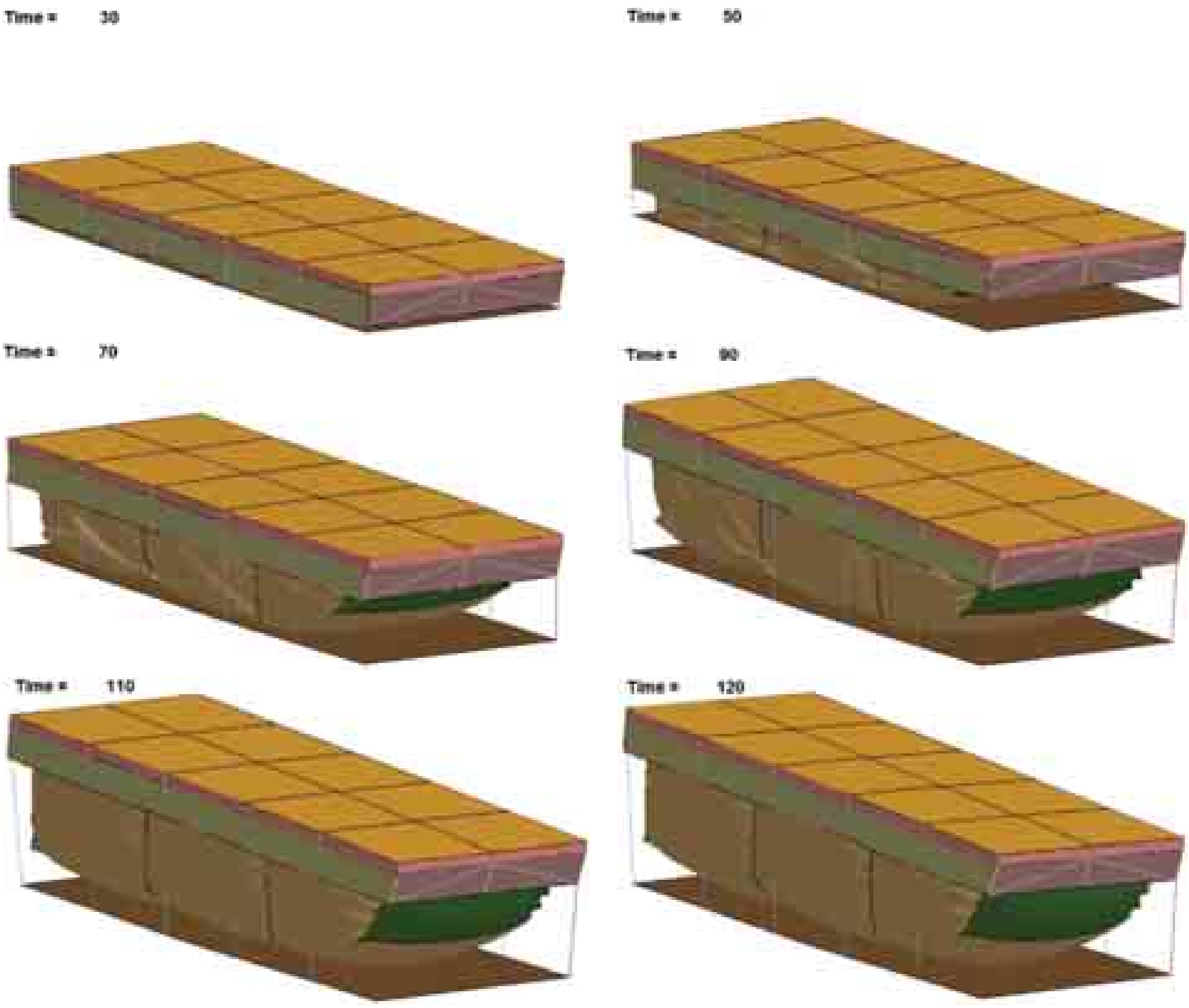

Fig. 8. Process of unfolding the pontoon with the fixed bottom for selected moments of time – measured in seconds

The lack of symmetry observed in the last stage of filling results from intentionally changed stiffness of the cassette constructional elements. The purpose of this operation was to study the influence of uneven distribution of construction mass on the final shape of the cassette (Fig. 7).

Such asymmetrical image of the unfolded cassette results from:

– pontoon geometry – uneven volume of individual cassettes
– the way of modelling the beam construction – beam elements applied for strengthening and spring elements of different stiffness

5. Conclusions

A pontoon cassette bridge is a structure broadly applied for both civil and military purposes. Its design using computer methods of mechanics requires connection of problems from different fields. From the mechanics point of view, the most important thing is to determine dependencies between rigid movement of unfolding walls of the pontoon and thermo-dynamical problem of filling the container of different volume. Application of an approach of control area for modelling of the process of filling the pontoon allows for conducting the simulation of unfolding the walls of the air cushion for the construction whose dimensions extend 1000 times thickness of material from which the air cushion is made.

The numerical analysis allowed also for determining the influence of asymmetry on behaviour of whole the construction in time of changing the volume of the pontoon that is, for example, estimating stability of the module for each volume of the pontoon.

The studies on modifications of the bridge construction are continued.

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