Research of Dynamic Process in Water Cistern of Fire Automobile during Its Moving along Rough Woodland

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Abstract. This work is dedicated to the research of the dynamic process in the fire automobile's water cistern with different levels of filling. The work's aim is to obtain data on the fluctuations of the dynamic system's mass center that combines water and its tank during a fire automobile moving through a rough woodland at different speed. Determined data allow to predict the danger of fire automobile overturning under such conditions. During the solution of this task, the geometric configuration of the fire automobile cistern with water was modeled using the universal program complex LS-DYNA for computer modeling of dynamic systems. Time relations of cistern's turn angles were set to recreate the dynamic impact on the fire automobile water cistern from the side of the rough woodland relief. The obtained relations were used as boundary conditions for recreating the dynamic impact of the rough woodland relief. The turning angles for the water cistern were determined depending on the relief bumps. The geometric form and parameters of these bumps were calculated using a pseudorandom number generator. Upon the explicit method and smoothed particles hydrodynamics method realized in LS-DYNA program code, the center mass fluctuating regularity for the water cistern of a fire automobile was determined in dependence of filling level and movement speed. This regularity can be used as a basis for predicting the danger of a fire automobile overturning as it moves through rough woodland.

Keywords: Water Cistern of Fire Automobile, Rough Woodland, Mass Center Fluctuation, Smoothed Particles Hydrodynamics Method, Explicit Method, Danger of Overturning.

Introduction

Statistical analysis of the fires' current state shows that the number and the forest fires' scale tend to increase, due to modern challenges of natural, environmental and man-made nature [1]. The main vehicles that deliver fire extinguishers to fires and extinguish fires are fire trucks, including fire tank trucks with water cistern [2]. When operating a fire tank truck that is not completely filled with water, there is an increased risk of overturning when it crosses rough forested terrain due to fluctuations in its masses center. Therefore, when operating fire tanks, it is recommended for fire departments to avoid traffic on rough forested terrain with an incompletely filled tank, which is equivalent to a ban. Such recommendations have to be violated every time, since a strict ban on the operation of fire tanks is economically and practically unjustified. The main data of the recommendation should be revised taking into account the scientific research results. Considering the foregoing, we can conclude that the fluctuation patterns' study of the fire tank trucks' masses center, caused by the dynamic influence of inequalities when they move over rough forested terrain, is an urgent scientific and technical task.

1 Analysis of literary sources and problem statement

In terms of the danger level associated with the distribution scale, socio-economic losses and environmental consequences, landscape fires are among the most dangerous wildfires[1]. To create the preconditions for successful control of these fires, intensive research is conducted in almost all areas of the industry [1]. The increase in the means' mobility of transporting fire extinguishing agents to fire cells while maintaining safe working conditions for fire departments remains an important aspect in extinguishing landscape fires. Among the main means of extinguishing landscape and forest fires are special fire tank trucks, for which an essential aspect of increasing efficiency is to prevent their overturning. The tipping hazard is especially pronounced when fire trucks are not completely full. As a result, dangerous waves can form there, which can cause large fluctuations in the masses center and, as a result, overturning of the tank. Providing scientifically based recommendations on the parameters of the fire trucks' movement across rough forest terrain would create prerequisites for improving their safe operation and would increase the efficiency of their use. The works [2-4] are devoted to the dynamic processes occurring in the fire trucks' tanks. In these papers, different approaches to predicting the dynamics of these systems are formulated. In [2], an approach that represents the water mass in a tank in the form of a pendulum dynamic system is proposed. This approach allows to determine the fluctuations of the masses center of the dynamic system, however, the disadvantage of this approach is the limitation when taking into account the influence of the internal system of breakwaters and partitions. These articles [3] are dedicated to the study of dynamic processes in tanks using a general theoretical approach based on the use of the Navier-Stokes equation system. This approach quite accurately reproduces the dynamic processes of waves' formation and spreading in tanks with baffles, however, in this case, difficulties arise in determining the masses center's fluctuations of this dynamic system. The smoothed particles hydrodynamics (SPH) method [4, 5] is found to be advantageous for modeling dynamic processes during the fire truck's movement, according to which water in a tank can be simulated using particles, this method allows you to simulate the mutual viscous interaction between particles and the tank fencing. Under such conditions, it is convenient to study the fluctuation of the masses center of the formed dynamical system. Given the complexity of mathematical models, their implementation is possible only with the use of special software. In the work [6] in order to solve scientific and technical problems of fire safety a universal software package LS-DYNA, developed by Livermore Software Technology Corporation (LSTC) for the study of dynamic systems was effectively used. The LS-DYNA computing software code implements the approach to modeling the dynamics of liquids based on the SPH method in combination with the explicit method of integrating differential equations of dynamics with their approximation by the finite element method, which is a prerequisite for its mathematical modeling of dynamic processes in a fire tank truck during its movement through rough forest terrain. Considering the above information, the aim and objectives of the research were set.

The aim of the study. The aim of this study was to identify patterns of fluctuations in the masses center of fire trucks caused by the dynamic impact of irregularities in their movement through rough forest terrain as a scientific basis for recommendations to fire departments in the operation of fire tank trucks to improve their efficiency and safety.

Main research objectives. To achieve the aim set, the following main objectives were formulated:

- to develop a geometric and water tank's mathematical model of one of the most common fire trucks using the LS-DYNA software package capabilities;
- to develop a mathematical model of the rough forest terrain for its reproduction of its influence when applying boundary conditions to the dynamic system of the fire truck's water tank when it moves through rough woodland;
- using the developed mathematical model of the tank to investigate the dynamic processes in the water tank and to identify fluctuations' patterns of the masses center of fire trucks caused by the dynamic influence of irregularities in their movement through forest cross-country terrain;
- to provide recommendations on the proportions between the level of water filling the tank of the fire truck and its speed movement through rugged forest areas on the basis of the identified patterns.

2 Mathematical modeling of the surface relief influence on dynamic processes in the tank of a fire truck during its movement through rough forest terrain

2.1 Design features of the fire truck's tank

To study the impact of surface relief on the dynamic processes occurring in the tank of a fire truck during its movement through forest terrain, one of the most common options was considered, fire truck AC-4,5-60 (TGM 12.240) -364, which can be used for extinguishing landscape fires with water and air-mechanical foam. The appearance of the truck together with the located water tank is shown in Fig. 1. The internal structure of the truck's tank is given here:

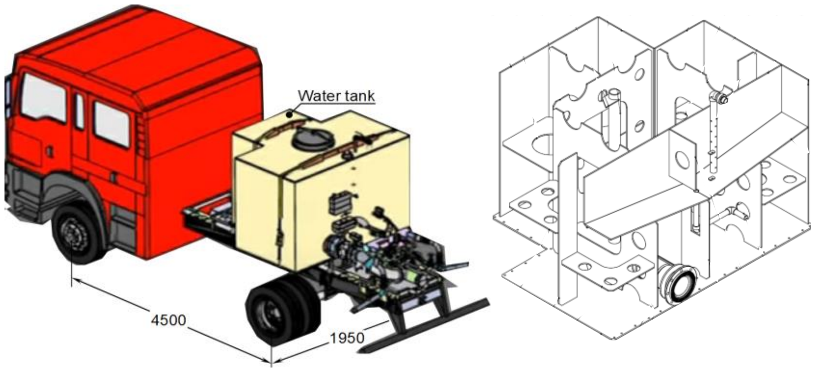

Fig. 1. Location of the water tank in the fire truck.

2.2 Mathematical model of the influence of the surface relief

The main parameters that determine the movement of the tank when overcoming the forest cross-country terrain, taking into account the influence of local relief are rotations around horizontal axes and vertical movement, as shown in the diagram shown in Fig. 2.

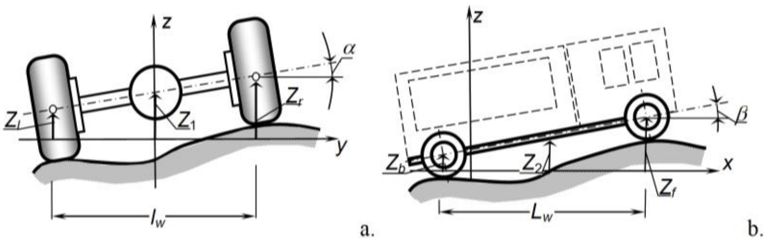

Fig. 2. Calculation schemes for determining the tilt (a) and the yaw (b) of a fire truck.

According to the technical characteristics of fire trucks and according to the recommendations [7], the maximum angular displacements and geometric characteristics of the reference track were adopted. When determining the rotation angles of the local relief, a separate sequence of surface irregularities is set for the right and left wheels of the rear axle using a pseudo-random number generator. To reproduce the possible options, three cases of tank movement with speeds of 6 km/h, 4 km/h and 2 km/h are considered. Thus, 3 sets of displacement laws for a fire truck tank were obtained. Fig. 3, as an example, represents the laws of tank truck's movement for a speed of 6 km/h.

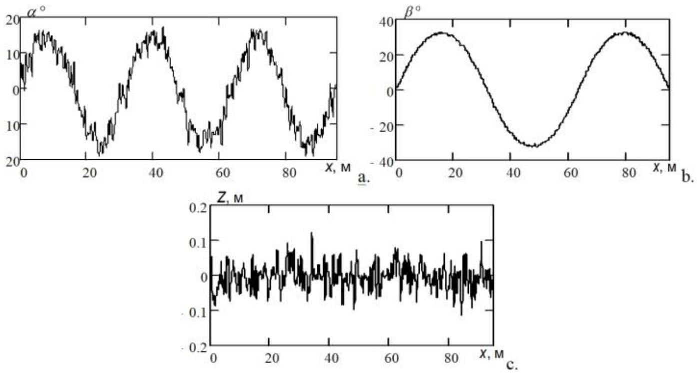

Fig. 3. Laws of tank movements when a fire truck moves through forest terrain at a speed of 6 km/h: a - tilt angle; b - yaw angle; in - vertical movement.

2.3 Mathematical model of the tank

Using the accepted assumptions about the tank of the fire truck, the finite-element scheme presented in Fig. 4.

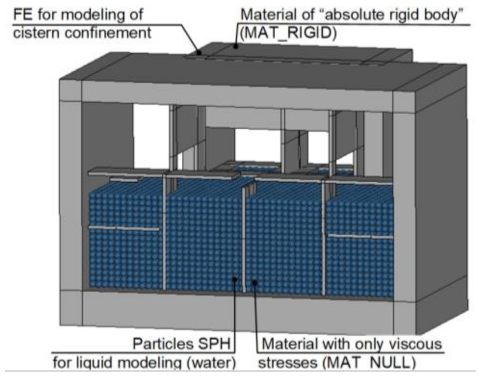

Fig. 4. Finite element scheme of the fire truck's tank.

The main components of the mathematical model of dynamic processes in the fire truck's tank during its movement through the rough forest terrain are given in Table. 1.

Table 1. The main components of the mathematical model and methods of its implementation.

Component (method)	Way of implementation	Source
Basic system of equations	System of differential equations based on conservation laws	[5]
Mathematical model of a liquid	Smoothed particles hydrodynamics method	[4, 5]

Numerical implementation method	Explicit method with finite element method approximation	[5]
Computing tool	Software complex LS-DYNA	[5]
Contact interaction	Penalty Method	[5]

3 The results obtained during the research

The position of the water tank with the level of filling with 25% for different moments of time during its movement at a speed of 6 km/h by the reference track of rough forest terrain is shown in Fig. 5.

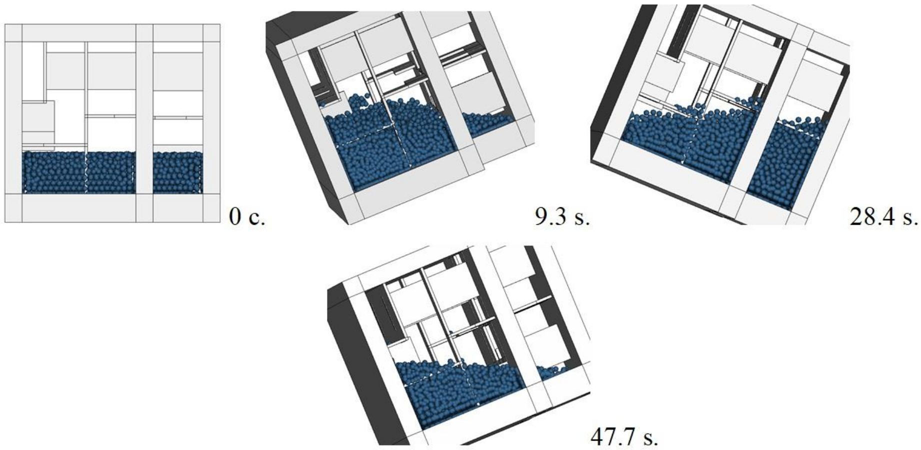

Fig. 5. Position of the tank with 25% level of water filling of the fire truck's tank for different moments of time at its movement at a speed of 6 km/h rough forest area.

In order to trace the position of the tank's masses center with different levels of its filling with water during the movement of the fire truck a trajectory of its movement at a speed of 6 km/h was built. Fig. 6 presents the curves that reproduce these trajectories.

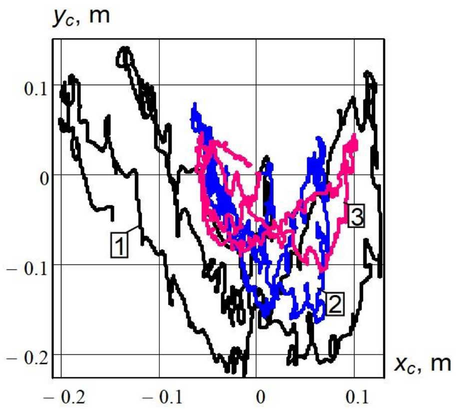

Fig. 6. The trajectories of the masses center position of the tank at a speed of the fire truck 6 km/h through rough forest terrain with different levels of water filling: 1 - 25%; 2 - 50%; 3 - 75%.

To identify the fluctuations' regularities of the masses center of the fire truck, a regression dependence was made by the method of full factorial experiment in accordance with [8]. The resulting regression looks like this:

$$y = 192.75 + 1.23 \cdot V - 21.625 \cdot v - 0.105 \cdot V \cdot v \quad (1)$$

where V is the level of filling the fire truck's tank (%), ν is the speed of movement (km/h).

Assessing the influence of the inertia transverse force, the corresponding calculations of the difference between the moments of the resulting forces in the vertical and transverse directions were made according to the scheme in Fig. 7.

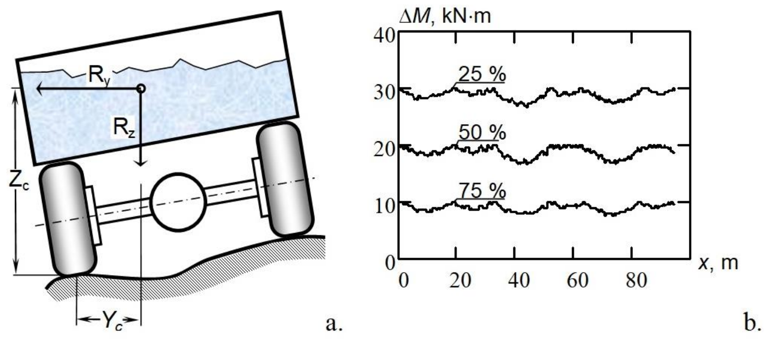

Fig. 7. Diagram for determining the moments' difference of equivalent forces in a fire truck (a) and moments' curves of fire truck's equivalent forces depending on time for different levels of the tank's filling (b).

The curves (look Fig. 7 (b)) of equivalent forces' moments in the tank depending on time show that the forces of inertia acting in the transverse direction do not significantly affect the possibility of overturning, as the difference between the vertical and horizontal components of the equivalent force have only positive values that are large enough. This can be explained by the effect of extinguishing large splashes and waves with the existing breakwaters, which are part of the tank design.

4 Conclusions

The conducted research allows to draw the following conclusions:

- the mathematical model on research of fluctuations of the tank's masses center with water depending on speed of the fire tank truck at its movement through rough forest terrain was created and the corresponding calculations were made;
- it was found that the fluctuations of the masses center of the fire truck's tank are most affected when it moves through rough forest terrain at a speed of 6 km/h when filling the tank with water by 25%;
- revealed fluctuations' regularities of the fire truck's masses center, on which the dependence's mathematical model of the maximum displacement of the masses center of the tank with water depending on speed and tank's filling level in the form of regression was obtained;
- it was proven that the inertia forces in the transverse direction do not significantly affect the possibility of overturning.

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