Problems of modeling the impact of a car on a road barrier by the finite element method

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Abstract. Drivers safety is a high-priority task for engineers. One way to ensure this is to increase vehicles passive safety. Another way to improve road safety is to improve road fences design. This article is concerned with the issues of finite element (FE) modeling a vehicle collision with road fences using the LS-DYNA software package. The article presents a number of problems for modeling a vehicle with an oblique impact in a road fence, in particular, the friction issues between the vehicle tires and the road, the car friction elements and the road fence, problems of describing large deformations and fracture of parts with large FEM meshes and interactions with elements in a small overlap area.

1. Introduction

Saving the lives of drivers and passengers in road traffic accidents (RTA) is extremely pressing problems worldwide. In Russia, this problem has been formulated in the national project named “Safe and high-quality roads”, which sets the goal of reducing road deaths by 3.5 times by 2024. A significant reduction in the RTA severity may be achieved in two ways: by improving the vehicle body design or by improving the road fences design. In design work, an effective analysis tool is a virtual car crashing simulation with a road fence using a nonlinear dynamics apparatus based on the FEM [1]. This article discusses the problems of a vehicle (VH) finite element (FE) modeling in virtual models of the VH interaction with road fences.

2. The specifics of the vehicles and road fences interaction

The interaction process of a vehicle with a fence can be conditionally divided into three stages. First, a vehicle moves towards the fence at an angle with a certain speed, then there is a contact between the vehicle body surface and the fence, turning into a clash, after which the vehicle comes out of contact with the fence and moves along a free path (figure 1).
Each stage of interaction differs significantly from the vehicle's crash test conditions according to Euro NCAP. The main difference is large friction losses due to vehicle body surfaces and the road fences relative displacement during their interaction. The great difficulty in determining contact areas arises in the contact problem due to an oblique impact. Also, the large dimension of the fence model (simulated fence minimum length is about 60 meters) imposes restrictions on the size of the FE mesh, which complicates the solution of fracture mechanics problems. Therefore, approaches to modeling vehicles during crash tests according to Euro NCAP may not always be applicable to describe the vehicles and a road fence interaction.

The collision process is fast-moving and non-linear [2], and to solve this problem it is necessary to use computer technologies in order to reduce economic and time costs. In this study, we used the finite element (FEM) licensed LS-DYNA engineering analysis complex, which allows to solve nonlinear dynamics problems.

3. Difficulties in solving problems of vehicle oblique impact in a road fence

FE modeling is one method for solving engineering and research problems. The finite element model (FEM) used in the virtual test consists of a vehicle moving on a hard surface and a road fence being clashed with the vehicle (figure 2). The initial speed of the vehicle is 90 km/h, weight – 1200 kg, the angle of impact – 20°.

Figure 2. Vehicle and the road fence finite element model.

The difficulties of solving the contact problem in the case of this test lie in determining the friction coefficient between the vehicle tires and the road surface, the vehicle and the road fence. Friction coefficient value in the LS-DYNA software package code is determined by the following formula (1):
where:
\( \mu_s \) – static friction coefficient,
\( \mu_d \) – dynamic friction coefficient,
\( v \) – relative speed between points defining contact of surfaces.

In the case of vehicle tires friction with the road, the static friction coefficient is used. The technical literature contains values of the static friction coefficients, however, the problem lies in its choice, since the tests are carried out year-round under various weather conditions, which determine this factor. The tests are carried out at the research test site with asphalt pavement, but even in clear weather at a temperature of 20°C, the static friction coefficient may vary due to pavement contamination caused by the fence installation. When testing the barrier and bridge fencing, the friction coefficient is also different, since the bridge fence is installed on a pavement with asphalt, and the barrier can be installed on a soil [3] surface.

To assess the effect of the friction coefficient between the vehicle tires and the seating surface, virtual tests were carried out with various options for the static friction coefficient. The test results are presented in figure 3, the results analysis has showed a significant difference in the vehicle trajectory during the test, depending on the selected static friction coefficient.

![Figure 3](image)

**Figure 3.** Vehicle heading angle versus the rolling friction coefficient with contact surface.

When a vehicle and a road fence are struck, friction occurs due to the vehicle body relative slippage along the side guardrail beam, thus there is a continuous contact surface with the change in speed. In this case, to determine the friction coefficient, it is necessary to consider both static and dynamic coefficients. Calculations with changed static and dynamic friction coefficients (figure 4, a and b) have been performed to determine the friction effect on the vehicle movement when it hits a barrier guardrail. As shown by the calculation results with the friction coefficients adopted in the 1st case, the car is hooked to the fence post and its turn. In the 2nd case, the car after hitting the fence leaves out from the contact.

![Figure 4](image)

**Figure 4.** Calculation options with different accepted friction coefficients between the vehicle and the fence: (a) - \( \mu_s=0.74, \mu_d=0.57 \), (b) - \( \mu_s=0.20, \mu_d=0.01 \).

Currently, various fences types are installed on the roads - barrier metal, cable and parapet (concrete). The vehicle model behavior mechanics while hitting a cable system differ significantly
from the vehicle interaction with a barrier fence mechanics. When hitting a cable fence, contact occurs in the local area which is along the cable, and there is a large contact force in the nodes of the body parts open faces [4]. This leads to deformation occurring in the elements in the body model, leading to the numerical errors accumulation, which affect the calculation results. This problem is partially solved by creating a vehicle body closed surface without open edges [5]. In domestic road practice, cable rails are mainly installed on a narrow dividing strip, the racks structure is strengthened, so the cables work together with the racks, not breaking away from them. When in contact with the rack of such a cable system, an impact occurs with less than 25% overlap, unlike an impact during vehicles crash tests where this overlap value is minimal. As a result of such a collision, most of the energy is concentrated in the vehicle and the cable system primary contact area, which when hitting a rack, destroys parts and components located in the impact zone. This leads to wings, bumpers and wheels separation (figure 5).

Figure 5. Vehicle after the collision: (a) cable fence, side-member is not hitted, (b) cable fence, side-member is hitted, (c) crash test with an overlap of 25%.

In this regard, there arises not only a contact problem, but also a problem of parts and assemblies destruction, where it is obligatory to determine the destruction criteria. This is also true when a vehicle wheel [6] hits a guardrail post, at which it breaks off or turns the vehicle over. Therefore, the solution [5] is not suitable for this task, since the model with a body closed surface does not account for the destruction.

In the field of road barriers crash tests modeling, there is a number of features that do not allow the FEM vehicles use, which were created by automakers. Such FEM contain several million elements and are aimed at identifying damage to vehicles after impact. The impact time during a car crash test takes about 0.3 s, while the vehicle and fence interaction can exceed this value several times, therefore, the use of such FEM is disadvantageous, including due to the calculation time. This problem is solved by simplifying the FEM by removing parts that do not affect the test results, replacing it with simpler structures, increasing the grid pitch and changing the elements type. Such changes affect the operation of the variable design; therefore, it is necessary to determine what can be simplified in the considered FE model.

With an increase in the dimension of the mesh of the vehicles front suspension parts that are most susceptible to destruction upon impact due to large deformations, a problem arises in applying the fracture criterion, which well describes the destruction on small grids.

4. Conclusions
The problems considered in this article regarding the choice of contact parameters, friction, and vehicle destruction when it hits a road fence are still relevant today. Further development of these studies is planned.

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