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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

NEWS

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METHODOLOGY FOR CONDUCTING VIRTUAL TESTS BY CREATING A FINITE ELEMENT MODEL OF ROAD SAFETY FENCING

Abstract. In this paper, we formulated the concept of the process of hitting a car on a fence as a movement along a curved trajectory with a certain radius of curvature. Special attention was paid to the contact of parts of different stiffness (when modeling the fence, these are ground-stand contacts), since the stiffness of the spring added to the contacting surfaces directly depends on the stiffness of the bodies being contacted. When soft bodies contact, its rigidity may be small, which can lead to instability of the solution. Also, the critical deflection of the fence (the transverse deflection of the fence, equal to twice the value of the console departure), after which the beam is inevitably lowered along with the deviated posts and the vehicles move over the fence.

Keywords: fence, safety, simulation, method, rack, console, beam, strength, test, car, finite element, construction, virtual analysis.

Initially, it was assumed that the retaining capacity of the fence should be provided by the strength of the posts, and the beams should work in elastic deformation with a small deflection.

The first works devoted to the problems of designing road barrier fences appeared in the 1960s. Among foreign studies, the first published works were Moore R. L., Jehu V [8].

In this paper, we formulated the concept of the process of hitting a car on a fence as a movement along a curved trajectory with a certain radius of curvature. V. Giavotto [9] proposed the principle of equality of the kinetic energy of the movement of the car and the work of the deformation of the fence. In Giavotto, as already mentioned above, he proposed a scheme for two-stage work of the fence created by a passenger car (first stage) and a heavy vehicle (second stage). M. Graham [7], analyzing the test results, proved the need to take into account the permissible overloads of passengers when the vehicle hits the fence, which later became one of the main criteria for the safety of the fence.

In Russia, the issues of designing and calculating road fence structures were considered in the works of V. I. Shestikov [10], B. M. Eliseev [11], E. E. Gibshman [3], P. K. Malinin [12], V. A. Karo-Made [13], V. P. Zaluga [14], V. V. Astrov [1].

The proposed methods contained a significant number of assumptions. So, Jehu V. I considered the vehicle as an absolutely rigid point. The methods of V. I. Shestikov [10] contain numerous empirical coefficients, which makes it possible to use the method only for a certain construction of the fence.

The method proposed by V. A. Astrov [2] can be considered the closest to the real situation, according to which the retaining capacity of the fence is determined by the sum of the work of bending its beam, bending the posts and tension of the beam. The main achievements of this technique should be considered:

a) determination of the critical deflection of the fence (the transverse deflection of the fence, equal to twice the value of the console departure), after which the beam is inevitably lowered together with the deflected posts and the vehicle moves over the fence. Thus, in order to prevent lowering of the beam in case of supercritical deflection, it is necessary to separate it from the struts. This idea was the beginning of the development of detachable consoles (CO);

b) the development of criteria for the quality of the fence, which allows:

- simplify the visualization of the fence on the general background of the road;
- make an assessment of the minimum height of the fence, which is a condition for preventing the car wheel from moving over the fence;
- determine the distance between the lower part of the beam and the road surface, preventing the wheel of a passenger car from entering under the beam;
- ensure that the vehicle does not directly interact with the racks.

However, the proposed method does not allow us to determine all the necessary consumer safety characteristics of road barriers (BDO) - the values of the dynamic deflection and the working width of the fence [4, 6],

All the calculation methods discussed above are largely based on empirical and semi-empirical models, which does not allow us to transfer the results and conclusions to other constructions. These methods do not consider joint deformations of the entire system – beams, posts, consoles, soil, road surface structure, friction between the vehicle and the fence, etc. [4].

Numerous developments carried out in a number of countries, primarily in the United States and Canada [9] We have shown that the most acceptable tool for computational analysis for road barriers is the finite element method (FEM), and the possibility of its application to this problem appeared only with the development of powerful computational systems for engineering analysis, such as LS-DYNA, ANSYS, ABAQUS, MSC.Software. A special feature of the calculation problem is the need to consider the collision of a deformable body (TC) with a deformable fence system, and the problem is essentially nonlinear and is associated with the consideration of fast-flowing processes.

The use of methods of numerical nonlinear analysis of the dynamics of the processes of collision of deformable bodies allows us to conduct studies that take into account all the features of the materials and structures of the fences themselves, their location on the road and the design of the road surface. Now it is possible to simulate full-scale tests and, together with the data from these tests, to be able to effectively solve the problems of selecting and installing fences [16, 18]. Currently, foreign publications contain a significant amount of data on such virtual analysis, they study the collisions of various vehicles, various fence designs, the behavior of fence installation elements in the ground and on the road surface, and conduct research on the choice of the optimal location of the fence on the roadside and on the dividing strip [17]. However, the application of this approach for domestic BDO structures required the development of simulation techniques, taking into account the specifics of materials and structures, and, most importantly, determining the scope of virtual tests in the road fence certification system, developing appropriate regulatory requirements and implementing these techniques in the domestic practice of designing barrier road fences.

The main structural elements of road safety fencing (BDO) are racks, consoles and beams. A three-dimensional 3D model of the BDO structure is shown in figure 1. A geometric model can be created in any CAD system. The considered structural elements of BDO are thin-walled profiles, the thickness of which is much smaller than other sizes, so it is advisable to model them with shell elements. The shell from the 3D model is most easily obtained by selecting the median surface.

The next step is to create a finite element grid (KES) The success of the calculation is mainly determined by the quality of the grid. When creating the CES, regular grids were used, which better reflect the shape loss during deformation, and also significantly reduce the calculation time compared to irregular grids (figure 2) [17].

The smaller the grid, the more accurate the calculation results will be, but it must be taken into account that for the stability of the solution in explicit methods, the time step must be less than the time of the perturbation wave passing through the element, and this time directly depends on its size. Therefore, reducing the size of the element leads to a significant increase in the duration of the process (without changing other parameters). On the other hand, a rough grid may not show the correct shape of the part's deformation or a sharp change in stress in the area under consideration. Numerous calculations have shown that for the main structural elements, the optimal KES is 20x20 mm [16].

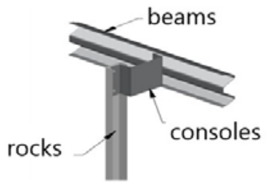
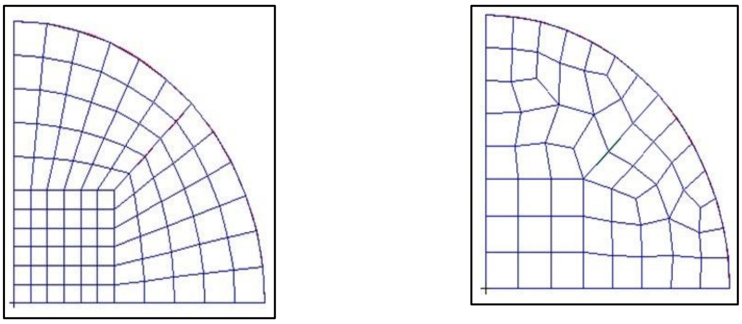


Figure 1 – BDO design



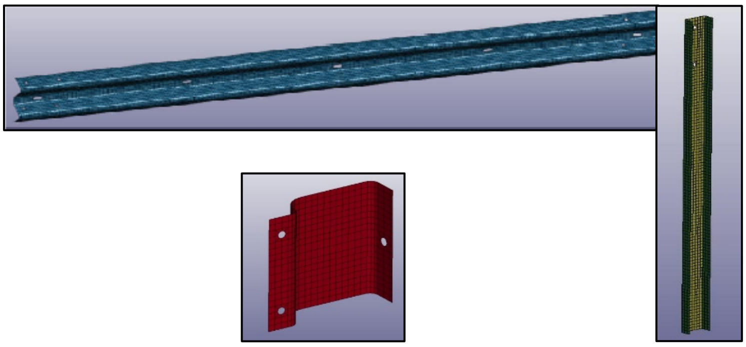
a *b*

Figure 2 – Grid types: *a* – regular, *b* – irregular

The construction of the KES console-shock absorber and rack fully corresponds to the construction of the beam stack. CE models of the main structural elements of the fence are shown in figure 3.

In the process of collision with the vehicle, the fence elements experience plastic deformations. In the LS-DYNA CE complex, there are a large number of different material models (more than 200). For BDO, the most optimal material is MAT_024 [22], its formulation will be discussed in more detail below.

a *b*



c

Figure 3 – CE-models of structural elements of the barrier fence:
a – beam; *b* – console shock absorber; *c* – rack

Model implements the Prandtl-Reiss material model [18], which describes the behavior of metals in the case of a complex stress state under elastic-plastic deformations. The deformation curve is approximated piecewise-linearly: the deformations are divided into segments and it is assumed that the plastic modulus is constant on each of these segments. Hardening in the MAT_024 material occurs only due to the rate of deformation. The MAT_024 model allows the use of isotropic or kinematic hardening, but in this work they were not taken into account due to the small cycle of the processes. Let's consider the basic equations describing the work of the material.

Deformations in the material are divided into elastic, which are removed after the load, and plastic - irreversible. Therefore, the total increment of deformations can be represented as:

$$d\epsilon_{ij} = d\epsilon_{ij}^{e} + d\epsilon_{ij}^{p}\,, \tag{1}$$

where $d\epsilon_{ij}{}^{e}$ – elastic deformations; $d\epsilon_{ij}{}^{p}$ – plastic deformations.

The increment of elastic deformations is found from Hooke's law. To formulate the general system of equations, we use the form of Hooke's law in terms of the first stress invariant I1 and the stress deviators_{ij}:

$$\epsilon_{ij}^{e} = \frac{1}{9k} I_1 \delta_{ij} + \frac{1}{2G} S_{ij}\,, \tag{2}$$

where K is the volume modulus of elasticity; G is the shear modulus; δ_{ij} – Kronecker delta.

This form of Hooke's law is convenient from the point of view of numerical methods, since in most modern programs the hydroscopic and deviatory parts of the stress are calculated separately.

If the stresses fall on the surface of the material's flowability, then in addition to elastic deformations, plastic deformations begin to accumulate.

The yield surface of the material * MAT_24 is determined by the Mises equation:

$$f(J_2) = J_2 - k^2 = \frac{1}{2}S_{ij}S_{ij} - k^2 = 0\,, \tag{3}$$

where $J_2 = 0.5 * s_{ij} * s_{ij}$ – the second invariant of the stress deviator, k, is the material constant associated with the yield strength.

According to the Prandtl-Reuss theory, the direction of the increments of plastic deformations is perpendicular to the yield surface (figure 4).

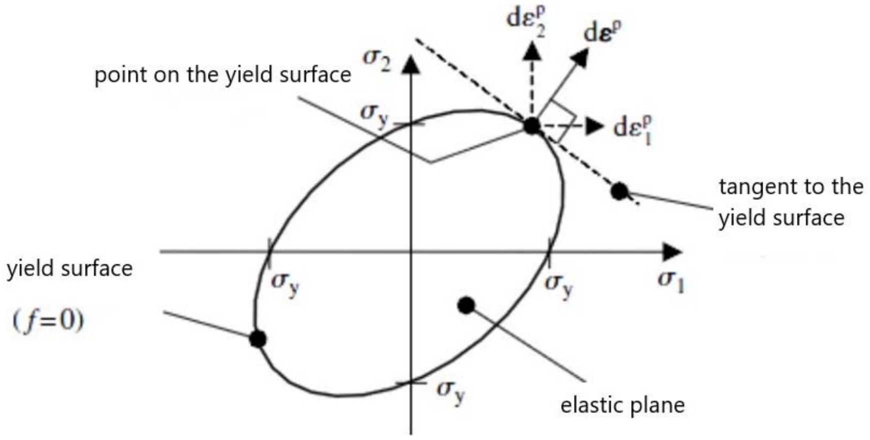


Figure 4 – Increment of plastic deformations in the flat case

The values of the increments of plastic deformations are derived from the associated flow law, and it is assumed that the yield surface coincides with the function of the plastic potential. Therefore, given the Mises flow surface, the flow surface takes the following form:

$$d\epsilon_{ij}^{p} = d\lambda \frac{\partial f}{\partial \sigma_{ij}} = d\lambda * S_{ij}\,. \tag{4}$$

where $d\lambda$ – scale factor, s_{ij}- the maximum deviator stress.

The scale factor $d\lambda$ is found from the rate of plastic deformation:

$$d\lambda = \frac{dW_p}{2k^2} = \frac{S_{mn} * de_{mn}}{2k^2}\,, \tag{5}$$

where de_{mn} – deviator of the strain tensor.

To get the incremental ratios *MAT_24, we substituteequations (2), (4), (5) in equation (1). The general relation takes the form:

$$d\epsilon_{ij} = \frac{ds_{ij}}{2G} + \frac{dI_1}{9K}\delta_{ij} + \frac{s_{mn} * de_{mn}}{2k^2} * S_{ij} \tag{6}$$

Equation (6) relates the increment of deformations to the stresses at each step for the MAT_024 material. The first step of the program is using the above equations and knowing the current value of the hydrostatic pressure I1=3p and the stress deviatorss_{ij}, allows you to find the total increment of deformations $d\epsilon_{ij}$. In the second step, using finite-difference schemes, we obtain the deformed state at time t+1. At the third step, knowing the deformations, the position of the medium at time t+1 is determined, after which the stress state is recalculated, and the process is repeated from step 1.

The yield surface is modified depending on the rate of plastic deformations by changing the material constant *k*. In * MAT_24, the Cooper-Symonds hardening model is adopted as a function of the strain rate $\dot{\epsilon_{ij}}$:

$$\beta = 1 + \left(\frac{\epsilon_{ij}}{C}\right)^{\frac{1}{p}}, \tag{7}$$

where p, C – experimental hardening constants.

Taking into account the law of strengthening, the von Mises yield surface-formula (3) takes the form:

$$f(J_2) = J_2 - \beta k^2. \quad (8)$$

The possibility of destruction was set in the model. Destruction in the material occurred when equivalent plastic deformations occurred$\bar{\epsilon}$achieved fracture deformations ϵ_f:

$$\bar{\epsilon} = \epsilon_f.$$

The fracture deformations were determined experimentally. If the equivalent deformations in the element reach the fracture deformations, then the element is removed.

The map of the MAT_24 material model and the deformation diagram are shown in figure 5.

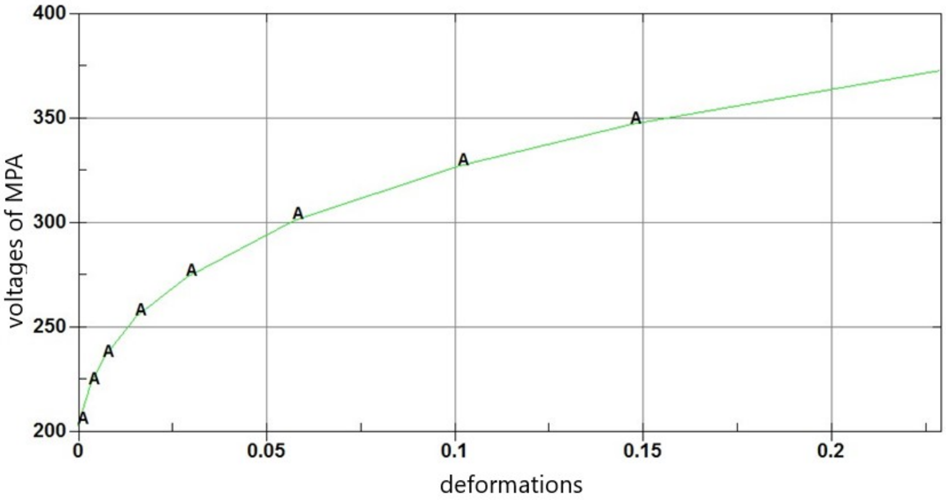


Figure 5 – St 3 material deformation diagram for MAT_024

The soil is a loose medium, the particles of which rub against each other. When the material is hydrostatically compressed, it becomes more difficult for the soil particles to move relative to each other, and the overall strength of the soil increases. Therefore, when describing the behavior of the soil, it is necessary to take into account the first stress invariant, which characterizes the hydrostatic compression of the material. In this case, the material *MAT_005, described by Craig [17], was used to model the soil.

$$f(I_1, J_2) = J_2 - [a_0 + a_1 p + a_2 p^2] = 0, \quad (9)$$

where p – hydrostatic pressure; a_0, a_1, a_2 – constants of the material.

To obtain incremental relations that relate stresses and deformations, we use the same approach that was used to derive the relations for * MAT_24. The main prerequisites will be the division of the total stress tensor into elastic and plastic components. Using formulas (1), (2), and (4), we obtain:

$$d\epsilon_{ij} = d\epsilon_{ij}^{e} + d\epsilon_{ij}^{p} = \frac{dI_1}{9k}\delta_{ij} + \frac{ds_{ij}}{2G} + d\lambda\frac{\partial g}{\partial\lambda_{ij}}, \quad (10)$$

To obtain an incremental model, it is necessary to find the flow surface g and the scale factor $d\lambda$.

The material model * MAT_005 is based on the associated flow model, so the flow surface f coincides with the flow surface g. We find the derivative of the yield surface with respect to plastic deformations, the first invariant of the stress tensor, and the second invariant of the stress deviator:

$$\frac{\partial f}{\partial\sigma_{ij}} = \left(S_{ij} - \frac{1}{3}a_1\delta_{ij} - \frac{2}{3}a_2 p\delta_{ij}\right),$$

$$\frac{\partial f}{\partial I_1} = -\frac{1}{3a_1} - \frac{2}{9}I_1 a_2\,;$$

$$\frac{\partial f}{\sqrt{\partial j_2}} = 0. \quad (11)$$

To find the scale factor$d\lambda$, we use the general formula [29] for isotropic materials:

$$d\lambda = \frac{3K * d\epsilon_{kk}\left(\frac{\partial f}{\partial I_1}\right) + \left(\frac{G}{\sqrt{J_2}}\right) * \left(\frac{\partial f}{\partial \sqrt{J_2}}\right) * s_{mn} * de_{mn}}{9K * \left(\frac{\partial f}{\partial I_1}\right)^2 + G\left(\frac{\partial f}{\partial \sqrt{J_2}}\right)^2}. \quad (12)$$

To find the scale factor, we substitute equations (11) into equation (12). After substituting the result into formula (10), we get the general incremental relations for the MAT_005 material.

The contacts between the elements were set by automatic single surface contact [17]. Special attention was paid to the contact details of different stiffness (in the simulation fencing is groundstone contacts), since the spring stiffness to be added to the contact surfaces, depends on the stiffness of the contacting bodies. When soft bodies contact, its rigidity may be small, which can lead to instability of the solution. To solve this problem, contact shells from MAT_009 are added on top of the contact body. When modeling the BDO of the bridge group, the reinforced concrete base was modeled with solid-state elements without the possibility of destruction. These assumptions were introduced after analyzing the protocols of field tests of BDO, according to which the reinforced concrete base does not collapse, the separation of the struts occurs when the anchor pins break.

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ВИРТУАЛДЫ СЫНАҚТАРДЫ ЖҮРГІЗУ ӘДІСТЕМЕСІ ЖОЛ ҚОРШАУЛАРЫНЫҢ ҚАУІПСІЗДІК МОДЕЛІНІҢ СОҢҒЫ ЭЛЕМЕНТТЕРІН ЖАСАУ ӘДІСІ

Аннотация. Жұмыста автомобильдің қоршауға соқтығысу процесі қисықтықтың белгілі бір радиусы мен қисық сызықты траектория бойымен қозғалу туралы идеялар тұжырымдалды. Әртүрлі қаттылықтағы бөлшектердің байланысына ерекше назар аударылды (қоршауды модельдеу кезінде – бұл топырақ-тірек түйіспесі), өйткені түйісу беттерге қосылған серіппенің қаттылығы түйісу денелердің қаттылығына тікелей байланысты. Жұмсақ денелермен байланыста болған кезде оның қаттылығы аз болуы мүмкін, бұл шешімнің тұрақсыздығына әкелуі мүмкін. Сондай-ақ, біліктер қоршаудың критикалық ауытқуын анықтады (консольдің шығарылуының екі есе мөлшеріне тең қоршаудың көлденең ауытқуы), содан кейін қисайған ауытқыдан тіректермен бірге түсуі және көлік құралдарының қоршау арқылы асып өтуі сөзсіз.

Түйін сөздер: қоршау, қауіпсіздік, модельдеу, әдіс, тірек, консоль, беріктік, сынақ, автомобиль, соңғы элементтер, құрылыс, виртуалды талдау.

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МЕТОДИКА ПРОВЕДЕНИЯ ВИРТУАЛЬНЫХ ИСПЫТАНИЙ МЕТОДОМ СОЗДАНИЯ КОНЕЧНЫХ ЭЛЕМЕНТОВ МОДЕЛИ БЕЗОПАСНОСТИ ДОРОЖНЫХ ОГРАЖДЕНИЙ

Аннотация. В работе были сформулированы представления о процессе наезда автомобиля на ограждение как о движении по криволинейной траектории с определенным радиусом кривизны. Особое внимание было уделено контакту деталей разной жесткости (при моделировании ограждения – это контакты грунт-стойка), так как жесткость пружины, добавляемой к контактирующим поверхностям, напрямую зависит от жесткости контактируемых тел. При контакте мягких тел ее жесткость может быть мала, что может привести к неустойчивости решения. Также были определены критический прогиб ограждения (поперечный прогиб ограждения, равный удвоенной величине вылета консоли), после которого неизбежны опускание балки вместе с отклонившимися стойками и переезд транспортных средств через ограждение.

Ключевые слова: ограждение, безопасность, моделирование, метод, стойка, консоль, балка, прочность, испытание, автомобиль, конечных элементов, конструкция, виртуальный анализ.

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