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Theoretical and Numerical Analysis for the Design of a Safety Barrier as Road Restraint System

The paper deals with a theoretical background and with numerical studies achieved on an N2 safety barrier, with normal protection. In order to determine the impact force, a model at a reduced scale was proposed. For the calculus of the dynamic load due to the impact, the corresponding maximum deflection was determined. In the same time, the equivalent stress distribution was plotted for the examined case.

Keywords: *safety barrier, numerical analysis, car crash*

1. Introduction

The safety barriers are situated on dangerous road regions from the point of view of traffic safety, in order to protect the vehicles against the unexpected exits from the road platform on one side as their optical guidance on the other side.

In the present paper the authors intended to propose an adequate model for the designing of a N2 safety barrier and, in the same time, a presentation of the testing device destined for the impact testing of this model. In parallel, the experimental model was analyzed using the finite element method.

2. Geometric characteristics of the safety barrier

The authors considered a deformable N2 safety barrier, in conformity to the EU standard SREN 1317-2, with normal protection as one can see in Fig.1.

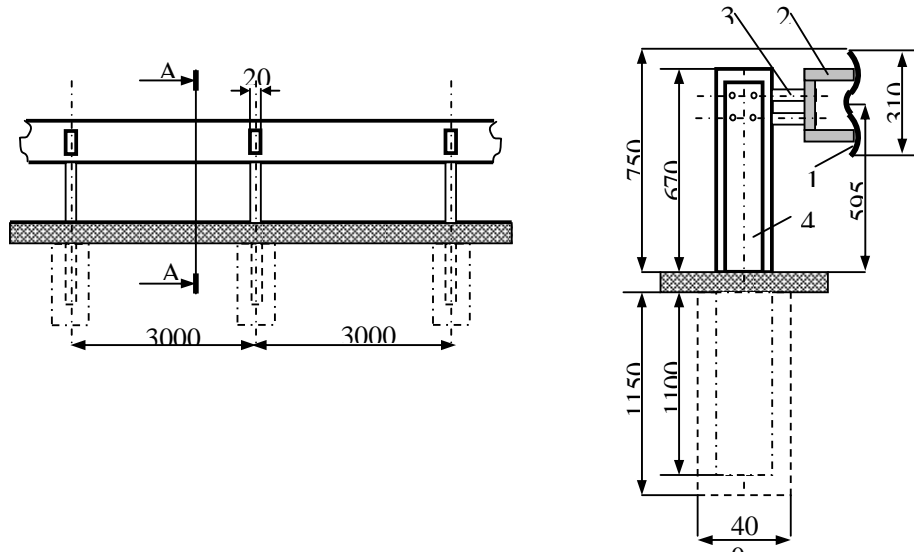


Figure 1. Deformable N2 safety barrier

The main components of a such safety barrier are:

- 1 – Sheet piling profile;
- 2 – Stirrup made from cupping metallic profile;
- 3 – Impact damper;
- 4 – IE10 metallic post.

These types of barriers are subjected to impact, in conformity to impact tests TB11 and TB32. The TB11 and TB32 standards foreseen the following criteria:

Standard	Impact speed [km/h]	Impact angle α [°]	Total mass M [kg]	Vehicle type
TB11	100	20	900	car
TB32	110	20	1500	car

The protection capacity of N2 barriers, in conformity to the SR EN1317-1 standard are:

- the kinetic energy $E_c = 81,9$ kJ;
- the deformation of the barrier side exposed to the car traffic and the corresponding mean force are respectively:

Kinetic energy [kJ]	Deformation of the side exposed to the traffic [m]					
	0,1	0,4	0,8	1,2	1,6	2
81,9						
\bar{F} [kN]	112	79,4	57,2	44,7	36,7	31,1

Related to Fig.2, the distance S_n transited by the center of gravity is calculated with the formula:

$$S_n = c \cdot \sin \alpha + b \cdot (\cos \alpha - 1) + S_b \quad (1)$$

where S_b is the dynamic displacement of the safety barrier side exposed to the traffic.

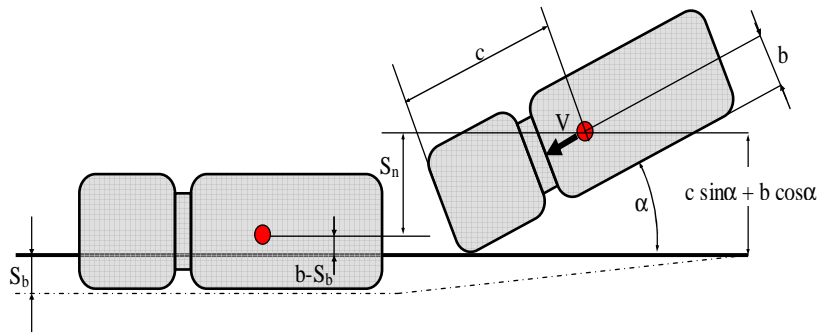


Figure 2. Displacement of the center of gravity in case of a lateral impact ($\alpha = 20^\circ$)

3. Design of the model

The model proposed by the authors, keep the same characteristics of the material. In this context two different scales have been chosen for the lengths ($\lambda=15$) as well as for the masses ($K_m = 300$). The output values are the force scale:

$$K_f = \lambda \cdot K_m = 15 \cdot 300 = 4,5 \cdot 10^3, \quad (1)$$

respectively the kinetic energy scale,

$$K_E = K_m \cdot \lambda^2 = 300 \cdot 15^2 = 67,5 \cdot 10^3. \quad (2)$$

The model of the post a circular section has been chosen, due to the fact that an **I** shape is difficult to be manufactured.

In order to determine the dimensions of the post, a limit case corresponding to a limit moment M_L calculated taking into account the Prandtl schematization (Fig.3).

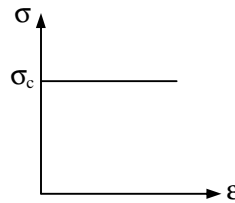


Figure 3. Prandtl schematization

$$M_L = \sigma_c \cdot S_p \quad (3)$$

where, σ_c represents the yield limit and S_p the statically moment of the plastic zone.

By equalizing the limit moment corresponding to the "**I**" shape post with the circular corresponding one it results effectively an equalization of the statically moments S_p :

$$S_{p1} = S_{p2} \Rightarrow \frac{\pi d^3}{6} = 19,9 \cdot 10^3 \Rightarrow d \approx 62 \text{ mm.} \quad (4)$$

The diameter of the post model will be in this case:

$$d_m = \frac{d}{\lambda} = \frac{62}{15} = 4,14 \text{ mm} \quad (5)$$

The dimensions of the sheet pilling profile, using the corresponding length scale $\lambda = 15$, are given in Fig. 4.

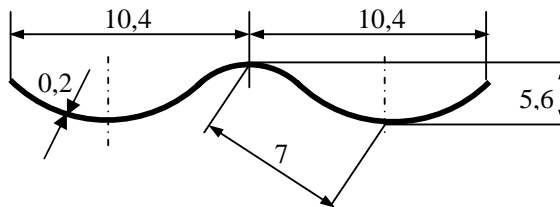


Figure 4. Geometry of the sheet pilling profile

Starting from the previous model, a new metal foil with a thickness of 0,5 mm will be used leading to a modification of all dimensions (Fig.5). In order to determine these dimensions the static moment S_p'' of the prototype will be calculated with the relationship:

$$S_p'' = \frac{S_p'}{\lambda^3}, \quad (6)$$

$$\text{where: } S_p' = 4 \cdot \left(\frac{38,4 \cdot 3 \cdot 28,3}{2} + \frac{77 \cdot 3 \cdot 56,7}{2} \right) = 32716 \text{ mm}^3 \quad (7)$$

The static model will be therefore $S_p'' = \frac{32716}{15^3} = 9,7 \text{ mm}^3$

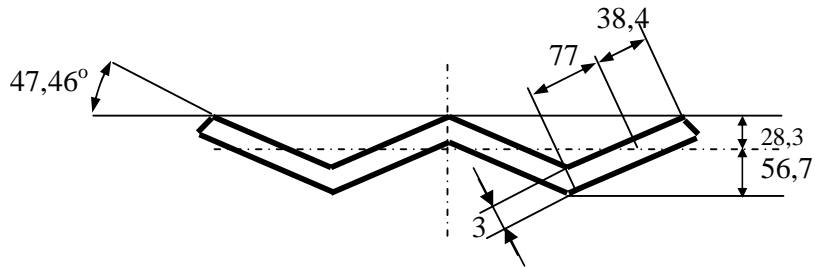


Figure 5. Approximation of the pilling profile geometry

Considering the corresponding height of the model, h_m and by an equalization of the static moments, a value $h_m = 3,6 \text{ mm}$ will be obtained.

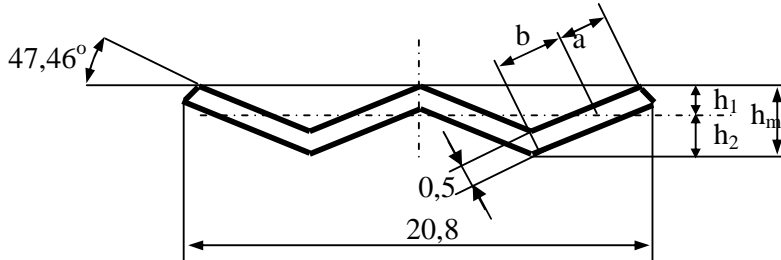


Figure 6. Determination of the real height of the prototype

For the previous model (Fig.6), the values of a , b and S_p'' will be respectively:

$$a = \frac{h_1}{\sin \alpha} = \frac{2h_m}{3 \sin 47,46} ; b = \frac{h_2}{\sin \alpha} = \frac{h_m}{3 \sin 47,46} ; S_p = 20 \cdot \frac{0,5h_m^2}{18 \sin 47,46} = 0,754h_m^2 \Rightarrow h_m = 3,6 \text{ mm}.$$

The final model is presented in Fig.7.

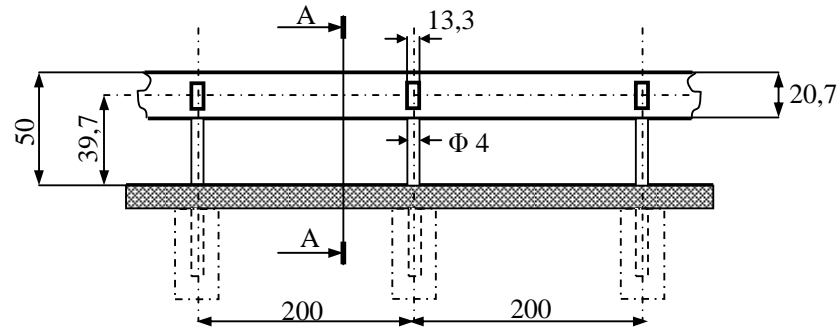


Figure 7. Presentation of the final model geometry of the safety barrier

4. Design of the device destined to the model testing

The model will be fixed on a stiff plate at an angle of 70° . A great care will be taken into consideration so that every movement of the model will be inhibited (Fig.7). On this model a body having a mass $m = 5$ kg falls from the height h_m .

The body mass m will be calculated with the relation: $m = \frac{M}{k_m}$, where $k_m = 300$ is

the mass scale and M , the mass of the real car ($M = 1500$ kg).

The height h of the dropping mass m is determined equalizing the kinetic energy E_c of the car with the strain energy E_p of its mass. Considering the deformation of the traffic side $S_b = 0,8$ m (accordingly to the Standard SR EN1317-1), one could express:

$$S_n = c \sin \alpha + b(\cos \alpha - 1) + S_b = 1,431 \text{ m} . \quad (9)$$

The value $0,631$ m has been obtained taking into account an energy value of $81,9$ kJ, a force $F = 112$ kN and the deformation of the traffic side $S_b = 0,1$ m, using the mean force:

$$\bar{F} = \frac{M(v \sin \alpha)^2}{2[c \sin \alpha + b(\cos \alpha - 1) + S_b]} \quad (10)$$

where $v = 110$ km/h and $\alpha = 20^\circ$. The mass will drop from a height

$$h_m = \frac{h}{\lambda} = \frac{2g}{\lambda} = \frac{47,63}{15} \approx 3,17 \text{ m}$$

The design of the device destined for the model testing is presented in Fig.8.

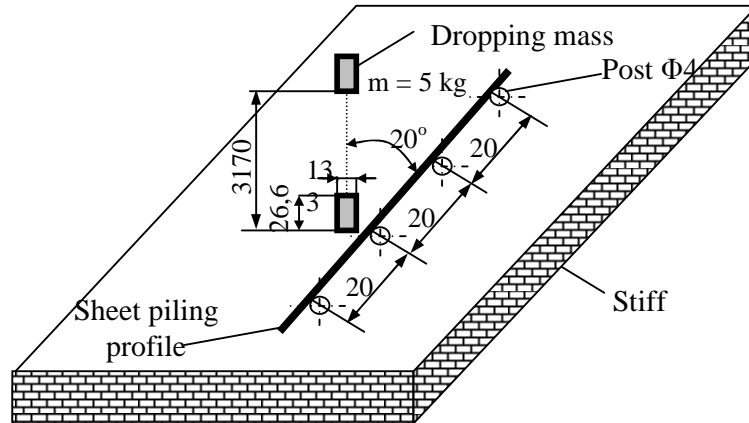


Figure 8. Design of the device destined for the model testing

5. Numerical results

The model was meshed using a SHELL93 element as one can see in Fig.9. This element is particularly well suited to model curved shells. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes (UX, UY, UZ, ROTX, ROTY, ROTZ). The deformation shapes are quadratic in both in-plane directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The element is characterized by plasticity, stress stiffening and large deflections.

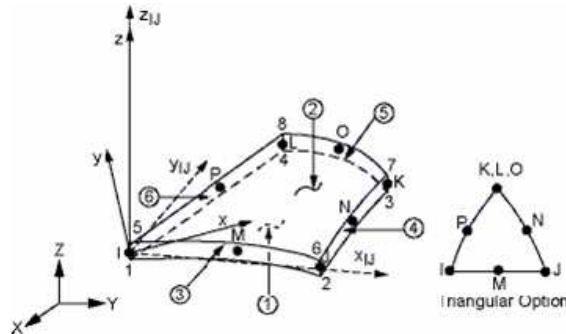


Figure 9. SHELL93 element

Only a part of the sheet piling profile situated between two adjacent posts has been analyzed. An initial loading corresponding to a static force of 50 N (equivalent

to a mass of 5 kg) was applied in the midspan of the barrier. In order to calculate the dynamic load due to the impact, the corresponding maximum deflection was determined. In Fig. 10 the deformed shape of the piling profile is presented. As one can see, the maximum deflection for the corresponding force was $\delta=8,944$ m.

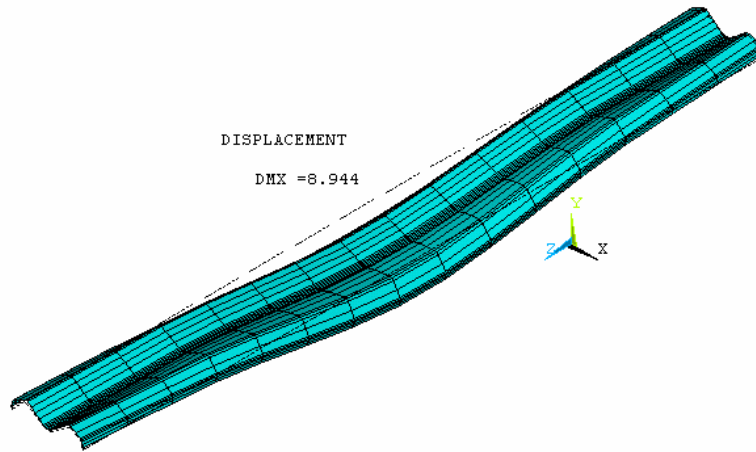


Figure 10. Deformed shape

The equivalent stress distribution, calculated for an impact force $F' = 34,9$ kN is presented in Fig.11.

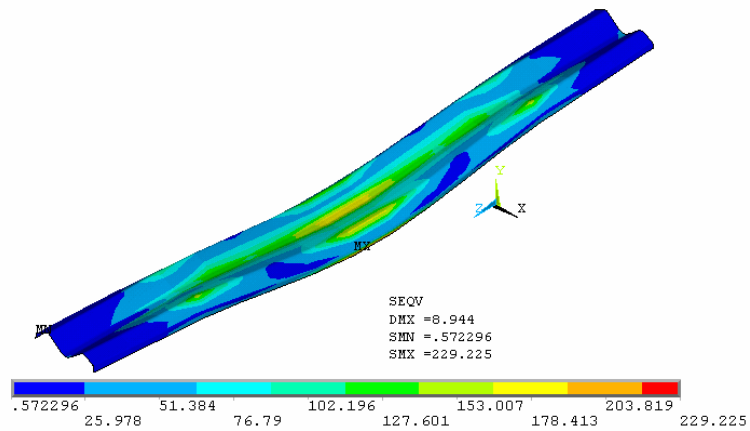


Figure 11. Von-Mises stress distribution for the analyzed model

6. Conclusions

The proposed model presented in this paper could be successfully applied for all the types of safety barriers (light, heavy and very heavy) and for all values of the traffic side deformation. The mean force \bar{F} offers information on the interaction between the vehicle and the barrier during the impact. It is a useful measure for a first evaluation of the total force which acts on the anchorage devices of the barrier and of the vehicle in collision.

References

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