ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

VEHICLE IMPACT ABSORBTION IN THIN WALLED TUBES WITH VARIABLE SECTION-THEORETICAL APPROACH

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***Abstract*—**The resistance structure of the modern car is designed so that it could absorb the impact energy through controlled deformation. This goal is necessary in order to reduce not only the shock effects on occupants but also the injuries suffered by them in accidents. The deformation manners of the structure, axial compression, bending or combined, determine the amount of energy that can be dissipated by the structural elements. The efforts of car makers consist in obtaining axial compression deformation behavior, which is the maximum mode to absorb the impact energy.

***Keywords*—**thin walled tube, variable section tube, effort, stresses, vehicle crash, trigger geometry.

I. INTRODUCTION

The field of vehicle impact has been also approached under various aspects in [1] - [10], [13] - [17]. Many models have been used and improved along the years to analyze vehicle deformation.

The scope of the paper is to determine the influence of trigger geometry upon the energy absorbed by a thin walled tube submitted to an axial impact, using a theoretical approach.

II. EFFORTS AND STRESSES IN TUBES WITH VARIABLE SECTION

The calculation relations are determined considering the following hypotheses:

- the mass of the hitting body is "m_1";
- the tube mass "m_{11}" is insignificant as compared to mass "m_1";
- during the impact with the mass "m_2" of the rigid barrier, the assembly made up of masses "m_1" and "m_{11}" comes to a stop;
- the movement speed of masses "m_1" and "m_{11}" is "v";
- a shock compression takes place.

The tube of mass "m_{11}" is considered to have a variable section (frustum of a cone) and it is provided with material removal area, as seen in fig 2.

The dynamic force "P", which occurs during the impact, may be determined with the law of conservation of energy: the kinetic energy of the assembly made up of masses "m_1" and "m_{11}" moving with speed "v" is completely turned into potential strain energy (compression of the tube with variable section and mass "m_{11}")

$$E_c = U \quad \Rightarrow \quad \frac{m_1 \cdot v^2}{2} = \int_l \frac{P^2 \cdot dx}{2 \cdot E \cdot A} \qquad (1)$$

The similarity of structures OB2C2 and OBC leads to:

$$A = \frac{x^2}{(a+l)^2} \cdot A_2, \ \ respectively \ \ A_1 = \frac{a^2}{(a+l)^2} \cdot A_2 \qquad (2)$$

where: A, A_1, A_2 stand for the tube cross-sections at distance "x", "a" and "a+l" to point „O".

There results the form of potential strain energy:

$$U = \frac{P^2}{2 \cdot E} \cdot \int_a^{a+l} \frac{dx}{\frac{x^2}{(a+l)^2} \cdot A_2} = \frac{P^2 \cdot l \cdot (a+l)}{2 \cdot E \cdot A_2 \cdot a} \qquad (3)$$

The relation (1) leads to the force during the shock in the tube with mass „m_{11}"

$$P = v \cdot \sqrt{\frac{a}{l \cdot (a+l)} \cdot E \cdot A_2 \cdot m_1} \qquad (4)$$

From (2) and (4) we have the compression stress σ_{co}:

$$\sigma_{co} = \frac{P}{A_1} = v \cdot \sqrt{\frac{E \cdot m_1}{A_2 \cdot l} \cdot \left(1 + \frac{l}{a}\right)^3} \qquad (5)$$

Provided the yield stress is to be reached in the section submitted to the highest stress, "A_1", in case of the diagram from fig. 1, the relation (5) may lead to the determination of the minimum area of the cross section or the speed at which the tube has to move in order to reach the yield stress σ_c.

$$v = \frac{a}{a+l} \cdot \sigma_c \cdot \sqrt{\frac{A_2 \cdot l}{E \cdot m_1} \cdot \frac{a}{a+l}} \tag{6}$$

where "A_2", a and "1" may be constructively adopted parameters.

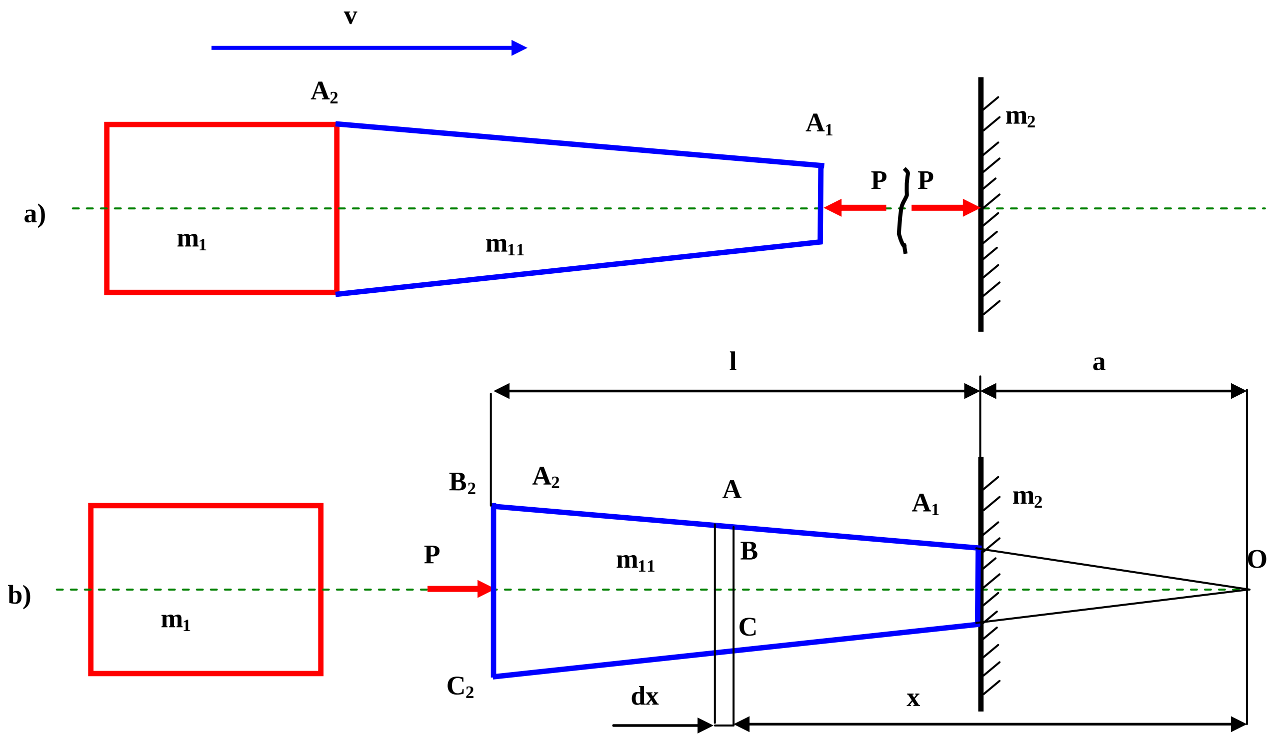

Fig. 1. General sketch of dynamic collision

III. Discussion

a) Provided A_2 = constant, that is a = ∞, there results a tube with constant cross section.

$$\sigma_{co} = v \cdot \sqrt{\frac{E \cdot m_1}{A_2 \cdot l}} \tag{7}$$

The relation (7) is used to calculate the normal stress σ in any cross section of the tube of mass "m_{11}".

b) Provided a → 0, then A_1 → 0, which shows that compression stresses have high values which mathematically tend to infinity.

c) The maximum stress develop in the smallest section area, "A_1", according to fig. 1. Under these circumstances, the deformation triggers may be machined, through material removal, according to fig. 1 and 2, so that cross sections of similar area "A_1"might be obtained, sections where the value of the yield stress should be determined at the same time. Hence, the shock effect upon mass "m1" might be diminished.

The calculations may be also based on the determination of potential strain energy through compression, written in stresses not in efforts. Thus, there results the relation:

$$U = \int_V \frac{\sigma_x^2}{2 \cdot E} \cdot dV, \ where \ \ dV = A_x \cdot dx \tag{8}$$

is the elementary volume.

In a similar way to the above demonstration, there will successively result:

$$U = L_e = \frac{\sigma_1^2 \cdot A_1 \cdot l}{2 \cdot E} \cdot \frac{a}{a+l} \tag{9}$$

$$\sigma_{\max} = \sigma_1 = \sqrt{\frac{2 \cdot E \cdot L_e}{A_1 \cdot l} \cdot \left(1 + \frac{l}{a}\right)} \tag{10}$$

The relation of the effort during the impact may be thus written

$$P = \sigma_1 \cdot A_1 = \sqrt{\frac{2 \cdot E \cdot L_e \cdot A_1}{l} \cdot \left(1 + \frac{l}{a}\right)} \tag{11}$$

Provided mass “m_2” is comparable as measurement parameter to mass “m_1”, this being the case of impact between two vehicles of the same class, an approximate calculation may be used by means of an impact multiplier “Ψ” with super-unity value.

$$\psi = 1 + \sqrt{1 + \frac{v^2}{g \cdot f_{st}} \cdot \alpha} \qquad (12)$$

where:
v – speed of the body of mass „m_1”;
f_{st} – linear deformation due to static action of a conventional force; $F = m_1 \cdot g$;
α – coefficient that takes account of mass „m_2” of the hit body;

$$\alpha = \frac{m_1}{m_1 + m_2} = \frac{1}{1 + \frac{Q}{F}} \qquad (13)$$

Where: $F = m_1 \cdot g$ and $Q = m_2 \cdot g$

there result two relations for determining the impact multiplier

$$\psi = 1 + \sqrt{1 + \frac{2 \cdot h}{f_{st}} \cdot \alpha} \qquad (14)$$

provided mass “m_1” fell from a height “h”. Similarly, (15) may be used in case of the tube horizontal movement

$$\psi = v \cdot \sqrt{\frac{1}{g \cdot f_{st}} \cdot \alpha} \qquad (15)$$

where “v” denotes the horizontal movement speed of mass “m_1”.

IV. GEOMETRY SUBMITTED TO ANALYSE

In the present study we analyzed thin-walled cylindrical tubes submitted to axial impacts with rigid, flat, steel barrier. On the tube surface deformation triggers were made in the form of cuttings material. The geometric shape of promoters is shown in fig. 2.

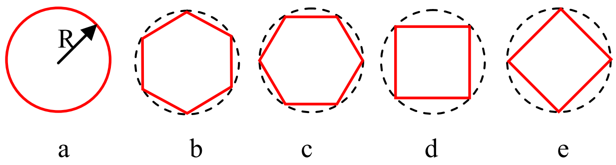

Fig 2. Geometrical shapes of triggers

The triggers were given various geometric shapes such as circle, hexagon inscribed in a circle, square inscribed in a circle and diamond inscribed in a circle, fig. 2. The radius of the circle where these geometric shapes were inscribed is "R".

For the trigger as illustrated in fig. 2 a, b and e, we can use the following relation to determine the tube cross section area.

$$A_{tub} = \left(\frac{\pi \cdot R_2^{\ 2}}{4} - \frac{\pi \cdot R_1^{\ 2}}{4} \right) - 4 \cdot 2 \cdot R \cdot t \qquad (16)$$

The material removals in the tube of mass „m_{11}” take the shape of those illustrated in fig. 3.

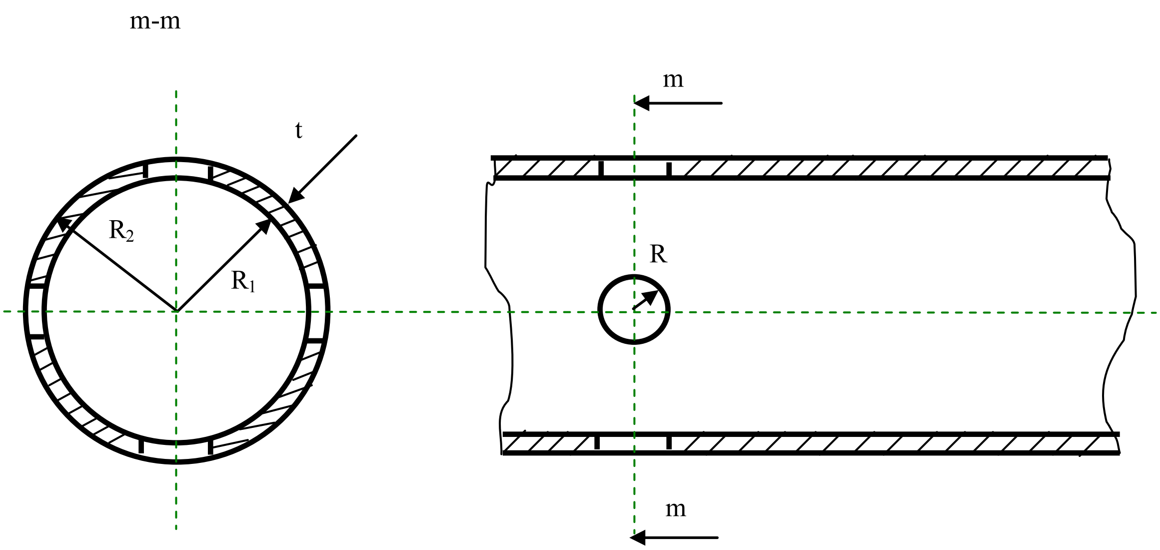

Fig. 3. Diagram used to determine the cross section of tube

Geometrical shapes a, b and e lead to the same area of the cross section. The material removals similar to the ones in fig. 2 c and d lead to an increase in the cross section, noted with „A_{tub}”. The analysis shows that the geometrical shape of the material removed influences the stress and strain state due to the fact that the tube cross section is variable along its length (perpendicular to the shock effect, along the movement of mass “m_1”).

V. CONCLUSIONS

The mechanical processing of deformation promoters, influences in a beneficial way the impact by absorbing it simultaneously in several cross sections whose range value is minimum; thus, they will achieve maximum compression stress higher than yield stress.

The shape of deformation triggers influences the degree of deformation and its dynamics by varying the cross area of the vehicle front structure.

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