CONCEPTS AND MODELS REGARDING THE BEHAVIOR OF ANTISEISMIC DEVICES FOR THE BASE ISOLATION SYSTEM

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ABSTRACT

The paper presents the main antiseismic devices, as component elements of the base isolation systems, in such a manner that the functional and constructive parameters are correlated with the inertial and stiffness characteristics of the dynamic isolated building. Also, each device will be characterized through a rheological model, which conditions the eigenvalues and eigenvectors spectrum, as well as the dynamic response to an exterior excitation of a seismic nature. In this context, antiseismic devices defined and characterized by the European Standard EN 15129 will be presented. Based on the requirements formulated in the norm, the devices can be identified and their laws of evolution established and checked as follows: antiseismic devices with permanent rigid connection; antiseismic devices with rigid connections with respect to the instantaneous displacement and antiseismic devices dependent on the velocity and on the velocity variation in time.

Keywords: rheological models; dampers; laboratory testing

REZUMAT

Lucrarea prezintă dispozitivele antiseismice, ca elemente componente ale sistemelor de izolare a bazei, astfel încât parametrii funcţionali şi constructivi să poată fi corelaţi cu caracteristicile inerţiale şi de rigiditate ale clădirii izolate dinamic. Fiecare dispozitiv va fi caracterizat printr-un model reologic ce condiţionează atât aspectul de valori proprii şi vectori proprii cât şi răspunsul dinamic al excitaţiei exterioare de natură seismică.
In acest context, vor fi prezentate dispozitivele antiseismice definite şi caracterizate de standardul EN 15129, astfel încât, pe baza cerinţelor formulate în acesta să poată fi identificate, stabilite şi verificate legităţile de evoluţie ale dispozitivelor după cum urmează: dispozitive antiseismice cu legătură rigidă permanentă; dispozitive antiseismice cu legătură rigidă şi dependentă în raport cu deplasarea instantanee; dispozitive antiseismice dependente de viteza şi variaţia vitezei în raport cu timpul.

Cuvinte cheie: modele reologice; amortizor; testări în laborator

1. INTRODUCTION

The antiseismic devices with functional role in the base isolation system of buildings that must be protected against earthquakes are: elastomeric isolators and fluidic dampers based on silicone oil (16, 26, 17).

Integrating these devices in the "base isolation system" is a requirement of the new and more modern design concepts. These specialized products must meet certain fundamental demands based on performance functions (23, 5).

Elastomeric devices are designed as viscoelastic isolation elements meant to resist to vertical loading and to lateral deformations with values of the slip angle greater than 45^0. Due to this reason, the structure of the dynamic isolation device on horizontal direction is composed of multiple elastomeric layers alternating with metallic reinforcing, which, through vulcanization, form a multilayer elastomeric ensemble parametrically defined through stiffness, internal-loss and dissipation (25).

The rheological model can be Kelvin-Voigt (23, 36) or hysteretic, depending on the internal dissipation mechanism.

The dampers with viscous oil are devices especially designed in such a manner that the two chambers of the cylinder, separated by the division of the flow piston, are connected for two distinct situations (14):

- the dissipation function through the viscous fluid arc rheological system, modeled as Kelvin-Voigt;
- the dissipation function through the fluid-viscous rheological system, modeled as Maxwell (28).

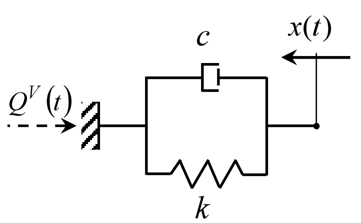
Conceptually, the two functions are fundamentally defined, being represented by the distinct dynamic response at initial shock, with the same energy dissipation (15, 20).

2. THE DYNAMIC RESPONSE OF ELASTOMERIC ISOLATORS TO CALIBRATION LOADINGS

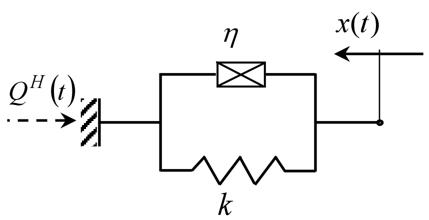
The dynamic schemes from Fig. 1 are specific to the kinematic excitation loading method given by the instantaneous displacement:

$$x = x(t) = A_0 \sin\omega t \qquad (1)$$

where $\omega = 2\pi f$, in which f represents the cycle frequency (19, 7).



a) Voigt-Kelvin model [V]



b) Histeretic model [H]

Fig. 1. Schematization of the order I model for the elastomeric systems test on stand

The elastomeric systems are coupled in parallel at slip loadings under norm conditions, at harmonic cycles as kinematic excitations of the form: $x(t) = A_0 \sin\omega t$ (13, 27).

The dynamic response $Q(t)$ of the order I system is given by the differential equation for the Kelvin-Voigt model:

$$c\dot{x} + kx = Q(t) \qquad (2)$$

and under the form:

$$\frac{k}{\omega}\eta\dot{x} + kx = Q(t) \qquad (3)$$

for the hysteretic model, in which:

c – viscoelastic force coefficient;
k – stiffness coefficient to shearing;
η – internal loss coefficient;
ω – pulsation of the excitation;
$Q(t)$ – reaction force at applied harmonic excitation.

For the Kelvin-Voigt model the reaction force, $Q_v(x)$, is presented with respect to the instantaneous displacement $x = x(t)$ or with respect to the pulsation of the excitation, ω, meaning $Q_v(\omega)$, as well as the dissipated energy ΔW_v^{cin}, the dissipation power P_v^{cin} and the equivalent critical damping ratio $\zeta_{v,eq}^{eq}$ of a viscoelastic damping or a IInd order system (22, 1). Thus, one obtains:

$$Q_v^{cin}(x) = kx \pm c\omega A_0\sqrt{1 - \frac{x^2}{A_0^2}} \qquad (4)$$

representing a family of ellipses which can be parameterized with ω or A_0 considering the nature and size of the excitation.

$$Q_0^v = A_0\sqrt{k^2 + c^2\omega^2} \qquad (5)$$

is the maximum value of the viscoelatic reaction force of the form:

$$Q(t) = Q_0^v \sin(\omega t - \varphi) \qquad (6)$$

The maximum dissipated energy that corresponds to the area of an ellipse defined through ω and A_0 is:

$$\Delta W_v{}^{cin} = \pi c \omega A_0^2 \qquad (7)$$

The dissipation power of the elastomeric element is given by:

$$P_v{}^{cin} = \frac{1}{2} c \omega^2 A_0^2 \qquad (8)$$

The equivalent critical damping ratio of a complete IInd order system, with the elements *m*, *c, k* is (24, 8):

$$\zeta_{v,eq}{}^{eq} = \frac{1}{2}\frac{c\omega}{k} \qquad (9)$$

For the hysteretic behavior of the elastomeric isolator in concordance with the previous model, one has the following parametric quantities of interest (11, 6):

$$Q_H^{cin}(x) = k\left[x \pm \eta A_0 \sqrt{1 - \frac{x^2}{A_0^2}}\right] \qquad (10)$$

$$Q_0^H = kA_0\sqrt{1+\eta^2} \qquad (11)$$

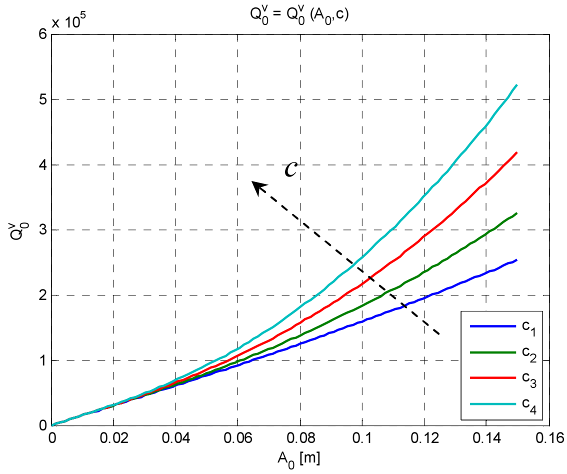
$$\Delta W_H{}^{cin} = \pi k \eta A_0^2 \qquad (12)$$

$$\zeta_{H,eq}{}^{cin} = \frac{1}{2}\eta \qquad (13)$$

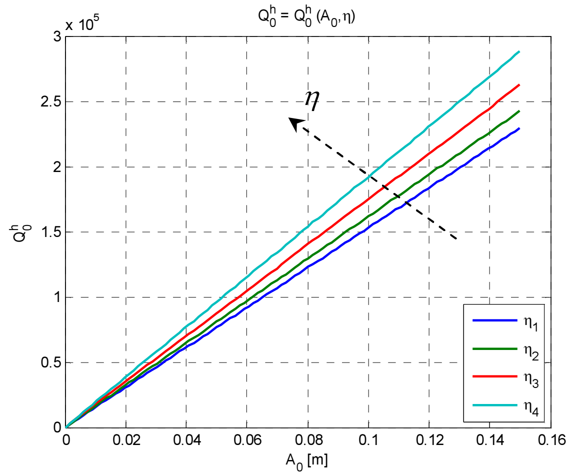
The interest parameters for an elastomeric element are $A_0 = 0.16$m, $f = [0;..;5,0]$Hz and the viscoelastic or hysteretic characteristics are

$c = [0,25;..;1,00] \cdot 10^5$Ns/m,
$\eta = [0,2;...;0,8]$,
$k = 1,5 \cdot 10^6$N/m.

In Figures 2 to 8, the resulted graphs for the interest parameters, considering $\omega = 2\pi f$, are presented.

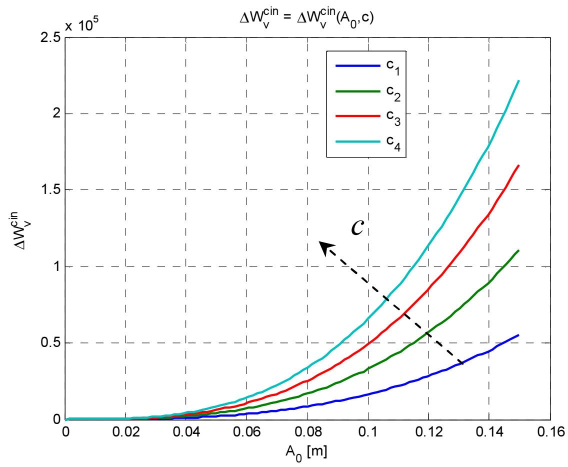


a) $Q_0^v = Q_0^v(A_0, c)$

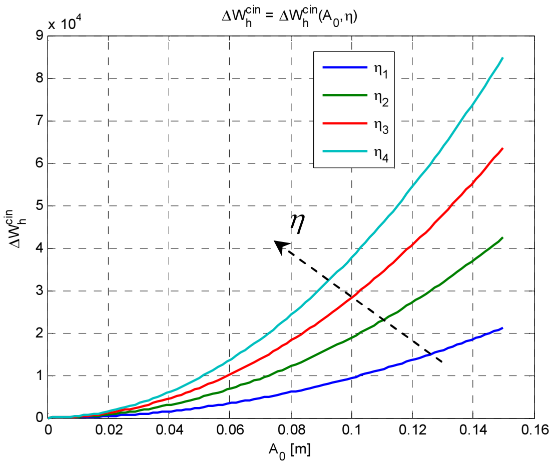


b) $Q_0^h = Q_0^h(A_0, \eta)$

Fig. 2. Reaction force

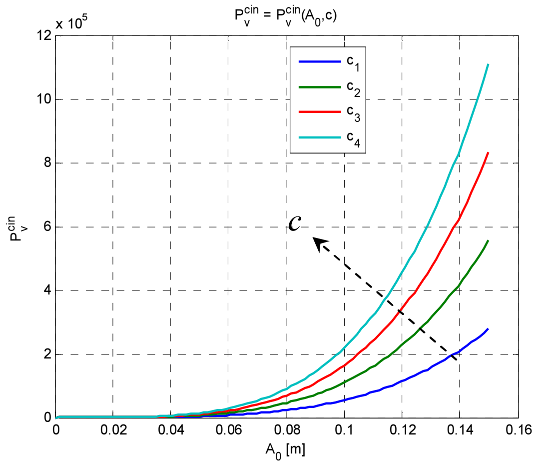


a) $\Delta W_v{}^{cin} = \Delta W_v{}^{cin}(A_0, c)$

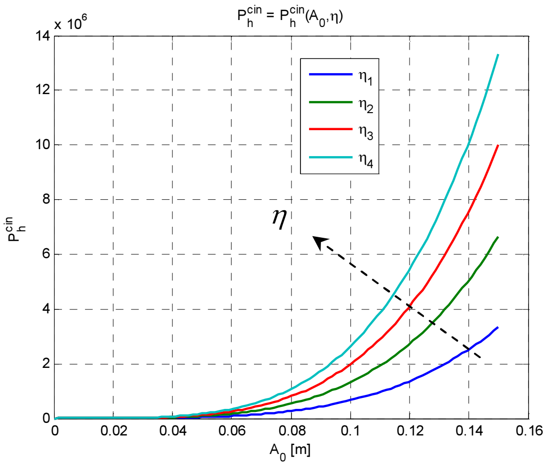


b) $\Delta W_h^{cin} = \Delta W_h^{cin}(A_0, \eta)$

Fig. 3. Dissipated energy

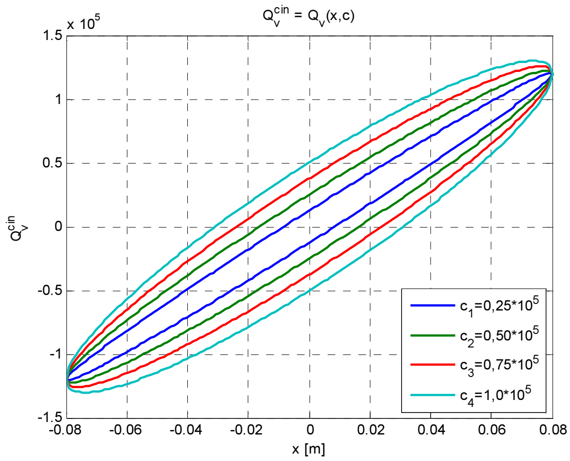


a) $P_v^{cin} = P_v^{cin}(A_0, c)$

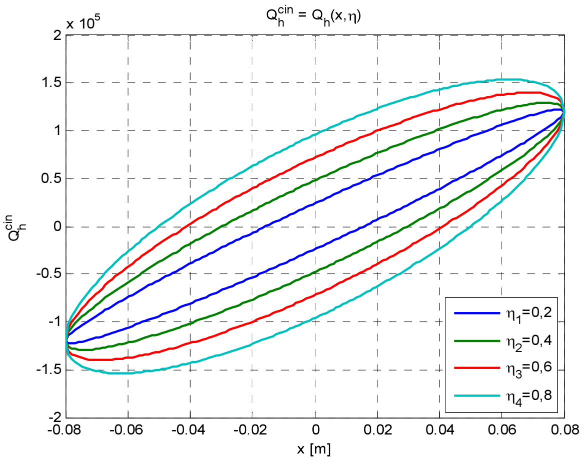


b) $P_h^{cin} = P_h^{cin}(A_0, \eta)$

Fig. 4. Dissipated power

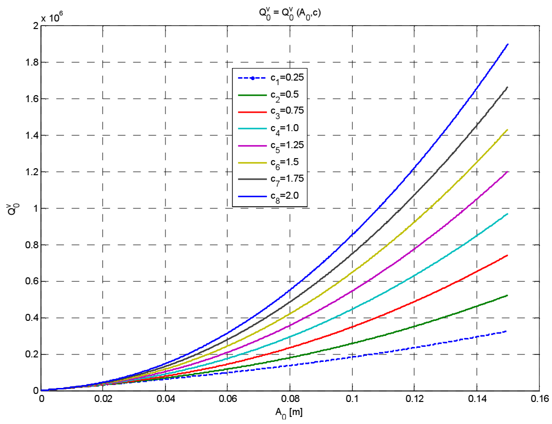


a) $Q_v^{cin} = Q_v(x, c)$

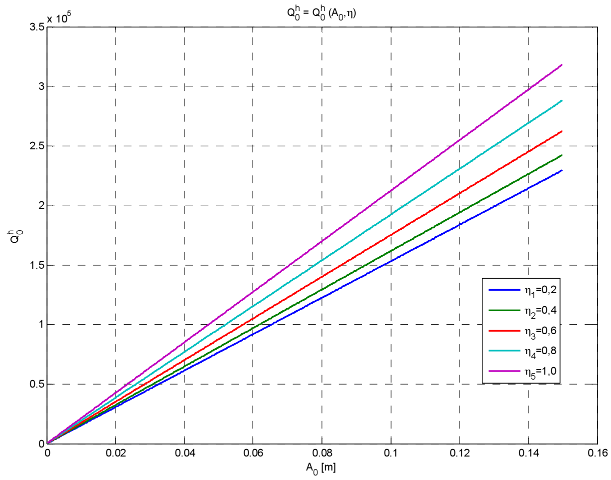


b) $Q_h^{cin} = Q_h(x, \eta)$

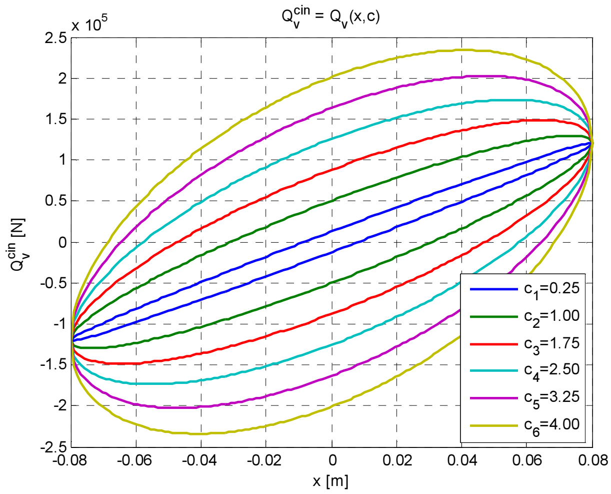
Fig. 5. Hysteresis curve



a) $Q_0^v = Q_0^v(A_0, c)$; $A_0 \in [0{,}01 \ldots 0{,}15]m$

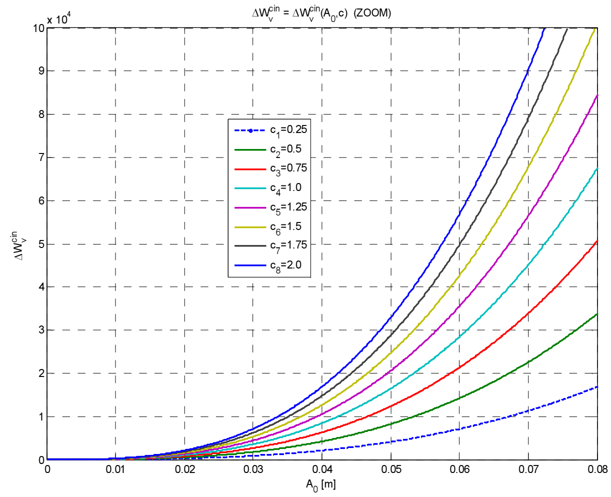


b) $Q_0^h = Q_0^h(A_0, \eta)$ $A_0 \in [0{,}01 \ldots 0{,}15]m$

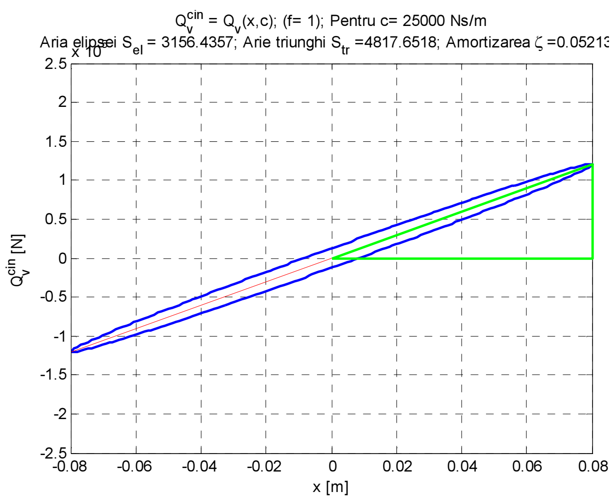


a) Hysteretic curve for $f = 1$ Hz

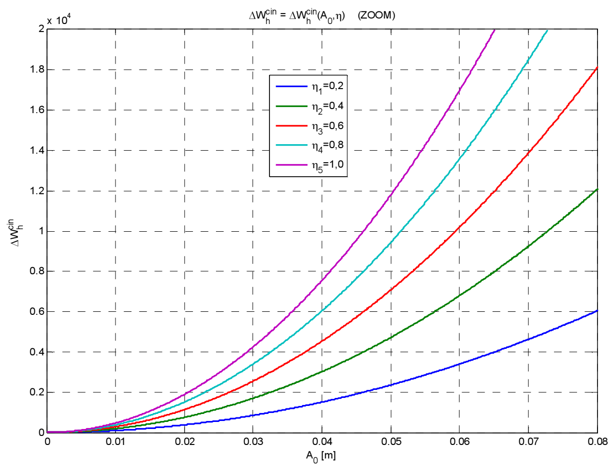
Fig. 6. Family of curves for the reaction forces for [V] and [H] models



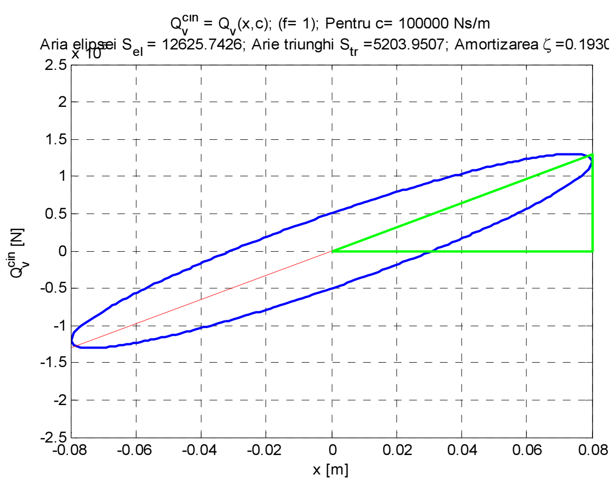
a) $\Delta W_v^{cin} = \Delta W_v^{cin}(A_0, c)$



b)

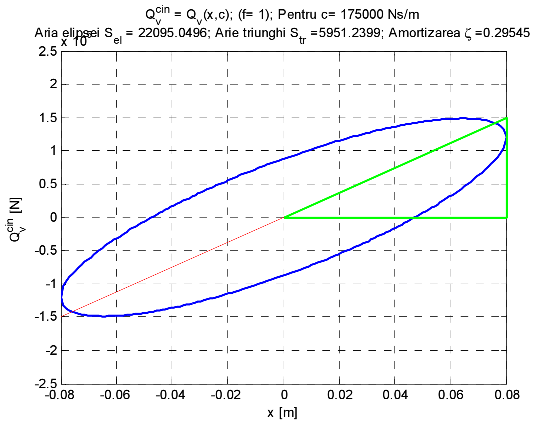


b) $\Delta W_h^{cin} = \Delta W_h^{cin}(A_0, \eta)$

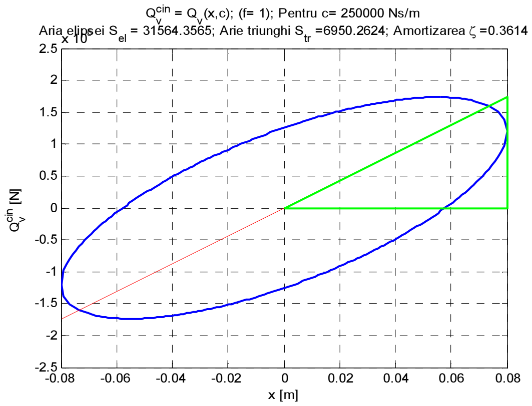


c)

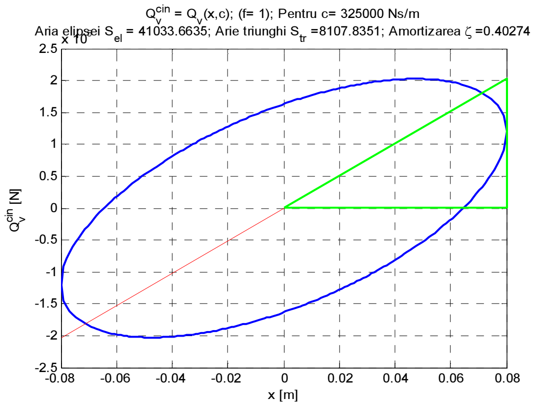
Fig. 7. Family of curves for the dissipated energy for [V] and [H] models



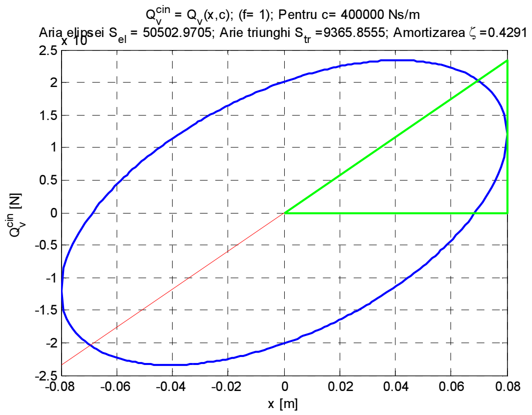
d)



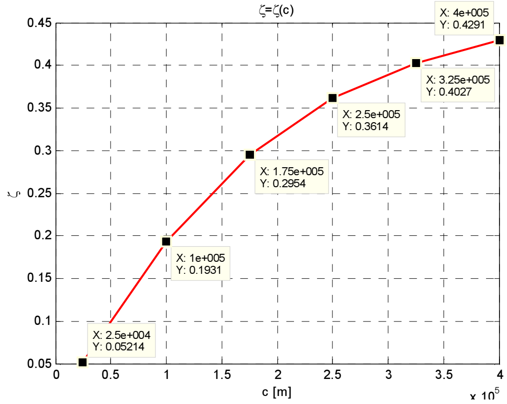
e)



f)



g)



h)

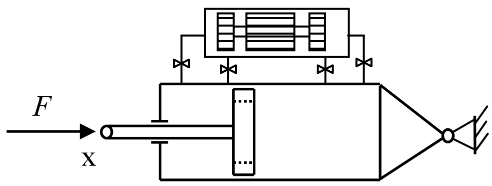
Fig. 8. Evolution for the hysteretic curves

3. THE DYNAMIC RESPONSE OF THE HYDRAULIC DAMPER AT A SHOCK IMPULSE

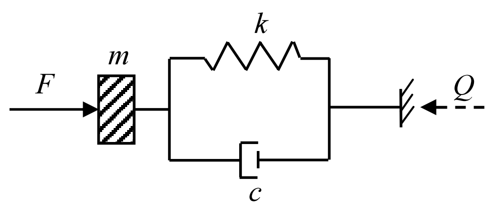
Figure 9 presents the principle scheme of a hydraulic cylinder with two separated chambers by a piston with adjustable orifices in terms of cross-section. At the exterior, a control/adjustment and command unit is located, which communicates with the two vehicular chambers of the silicon oil.

Function of the adjustment model, the damper can be designed as Kelvin-Voigt, also called viscous arc, for which the stiffness of the oil is significant for its sudden compression.

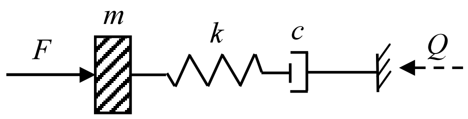
The Maxwell model is characterized through a significant viscous damping given by the forced flow of the oil without a high elastic compression (12).



a) General layout



b) Kelvin-Voight model



c) Maxwell model

Fig. 9. The Hydraulic Damper Scheme

The transmissibility of the force *F(t)* to the fixed point is estimated through the transmitted force *Q(t)*. Thus, one has (10, 21):

$$T_{v-k} = \frac{Q_0}{F_0} = \sqrt{\frac{1+\delta^2}{(1-\delta^2)^2+\delta^2}} \qquad (14)$$

$$T_M = \frac{Q_0}{F_0} = \sqrt{\frac{\delta^2}{\Omega^4+\delta^2(1-\Omega^2)}} \qquad (15)$$

$$\delta = \frac{c\omega}{k} \qquad (16)$$

For both rheological models, at pulsations of the initial shock of $\omega = [2..60]$rad/s and eigenpulsations of minimum 300 rad/s, meaning $\Omega = \frac{1}{150} \dots \frac{1}{5}$, with $\Omega^2 \cong 0$, the transmissibility $T = \frac{Q_0}{F_0} = 1$ for maximum displacements will be given differently, as dynamic rheological response (2, 9). Thus, for the Kelvin-Voigt model one has A_1^{V-K} and for the Maxwell one A_2^M, with the ratio $\Delta = \frac{A_2^M}{A_1^{V-K}}$. In this case, the next relationships may be written (3,4):

$$A_1^{V-K} = \frac{F_0}{k}\frac{1}{\sqrt{1+\frac{c^2\omega^2}{k^2}}} \qquad (17)$$

$$A_2^M = \frac{F_0}{k}\frac{\sqrt{1+\frac{c^2\omega^2}{k^2}}}{\frac{c\omega}{k}} \qquad (18)$$

The ratio $\Delta(\omega)$ may be written as:

$$\Delta(\omega) = \frac{A_2^M}{A_1^{V-K}} = \frac{k^2+c^2\omega^2}{kc\omega} \qquad (19)$$

For a damper with $k = 185 \cdot 10^6$N/m, $c_{j+1} = (0.5 \cdot 10^6)2^j$Ns/m, where j=0, 1, 2, ..., 10.

In Figures 10, 11 and 12, the variations of Δ with respect to the specific parameters Ω and *c*, *c* and *k*, *k* and Ω are presented under the form of families of curves, for $\omega = 2\pi f$, in which $f = [0{,}01, \dots, 10]$Hz.

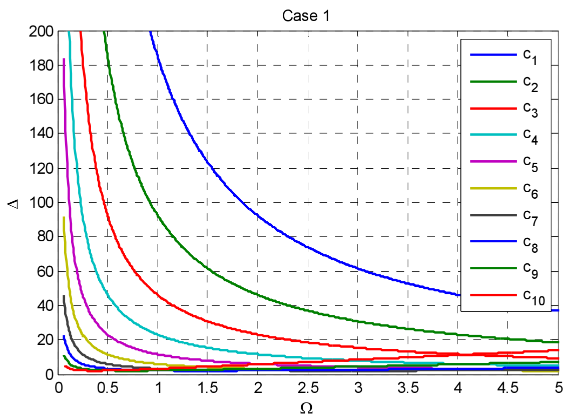


Fig. 10. Variation with respect to c

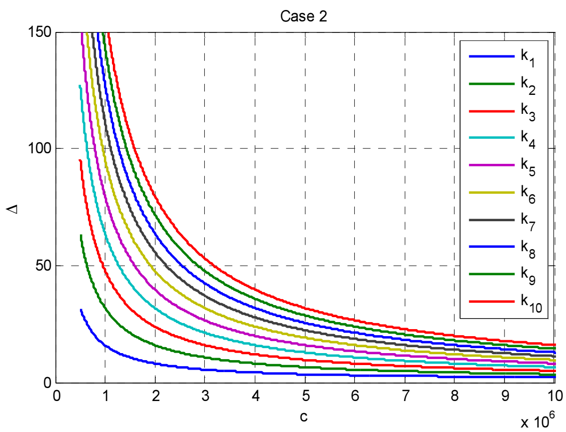


Fig. 11. Variation with respect to k

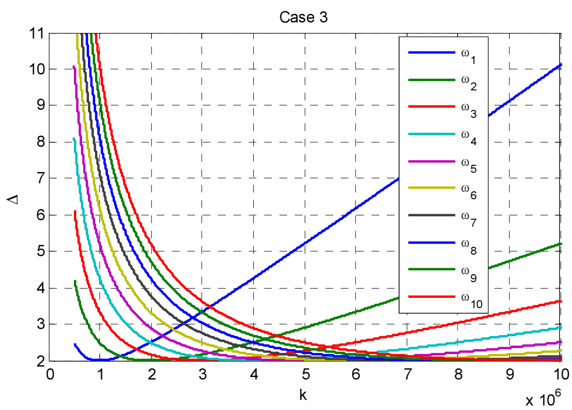


Fig. 12. Variation with respect to ω

4. CONCLUSIONS

The characteristics of the antiseismic dampers are determined in laboratory testing regime, at harmonic cycles generated by given laws.

For the elastomeric elements given kinematic excitations are applied. The hysteretic loops are drawn and, based on them, the elastic and dissipation parameters are determined.

For the hydraulic dampers the dynamic shock regime is established. The significant harmonic force is determined leading to the dynamic action represented by the significant force $F = F_0 sin\omega t$.

Based on real time pressure and flow measurements as well as instantaneous displacements, c, k and Ω are determined.

Function of the adjustment and geometrical, position and shape configurations of the calibration orifices, the damper can be modeled as either Kelvin-Voigt or Maxwell.

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