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THEORETICAL AND NUMERICAL CONSIDERATIONS ON THE COMPOSITE NEOPRENE USED AT VIBRATION AND SHOCK ISOLATION ISOLATORS

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ABSTRACT

Construction of passive insulation elements in neoprene single microstructure mixture has demonstrated that the isolators can have the necessary elastic characteristics but low internal damping. The reduced scale models have in the structure viscoelastic materials basing on natural rubber symmetrically distributed in respect to geometrical reference system chosen for the isolator. The materials consisting of natural or synthetic rubber are used as filling elements symmetrically located so that globally the isolator can be properly characterized both at compression and shear. This paper presents a study case with two material type modelled as Voigt-Kelvin element and Hooke-Maxwell element and three neoprene bearings modelled with: Voigt-Kelvin elements, Hooke-Maxwell elements and Voigt-Kelvin + Hooke-Maxwell elements.

KEYWORDS: composite neoprene, rheological modelling, vibration and shock isolator

1. INTRODUCTION

Base isolation systems intended for seismic shocks and vibrations consist of rubber or neoprene viscoelastic elements constructed in various technical solutions. The most frequent passive isolation systems are realized basing on neoprene elements in a sandwich construction having intermediary steel shims and the same neoprene mixture for each layer. In this case, the hysteretic dissipation factor of the isolator is equal to that for a single neoprene layer, all the layers being identical from the physical-mechanical and geometric points of view [2].

This study puts into evidence the possibility to realize and model the viscoelastic isolators based on microstructure composite mixture consisting of neoprene smoke black and chemical foam compound or solids with entrapped air (cork poudrette). Also, this approach points out the possibility to realize and model the macrostructure composites by assigning geometric spaces defined inside the isolator geometric space.

The rheological modelling for the neoprene isolator behaviour shows the increase of the internal energy dissipation by increasing the hysteretic factor (damping structure coefficient) [1], [2], [3], [4].

2. THE STRUCTURE OF THE COMPOSITE NEOPRENE

The passive isolation elements for dynamic shocks and vibrations have to comply with the following conditions:

-assuring provision of the bearing capacity by appropriate values of the mechanical resistance;

-assuring provision of the rigidity necessary to attain static deflections under loading conducting to avoid the significant resonance with destroying character;

-optimisation of the requirements concerning relative low rigidity with those for high internal dissipation.

In order to obtain the above mentioned desiderates, a new approach regarding realization and modelling of the composite neoprene isolators is necessary. This approach will introduce an original concept, namely micro and macro structural composite antivibrating viscoelastic materials.

The viscoelastic materials consisting of micro structural composite neoprene by using some appropriate grading of the powder materials – smoke black and air introduction in nanometric spaces by cork poudrette or chemical foam compound; thus, the composite neoprene at the microstructure level may be realized physically and technologically and may be rheologically modelled as follows:

-composite neoprene microstructure having low damping expressed by the hysteretic factor δ_1 and low rigidity by the modulus of elasticity in shear G_1 or rigidity factor k_1;

-composite neoprene microstructure with high damping expressed by the hysteretic factor δ_2 and high rigidity by the modulus of elasticity in shear G_2 or the rigidity factor k_2.

The isolator with composite macrostructure consists of identical neoprene layers separated by steel shims, each layer consisting of macrostructure distinct units having various physical-mechanical characteristics. In this case, the neoprene elements are realized by controlled structure of the materials with δ_j, k_j, $j=\overline{1,n}$, so that after vulcanisation the isolator could be obtained as in fig. 1 and fig. 2 (pos. 1 is from micro composite structure neoprene modelled as Voigt-Kelvin and pos. 2 is from micro composite structure neoprene modelled as Hooke-Maxwell.

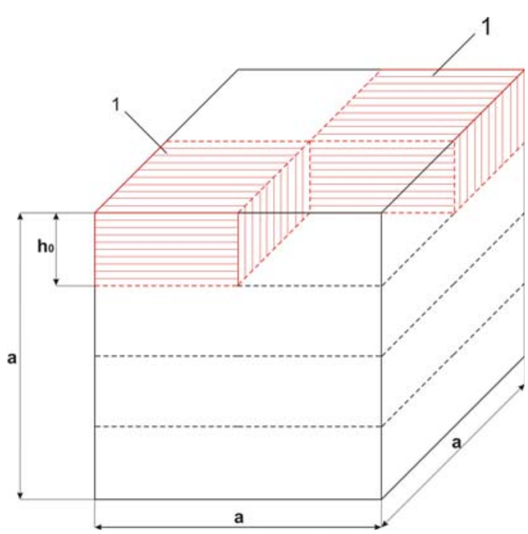

Figure 1 Isolator obtained after vulcanisation (1 - Voigt-Kelvin model unit)

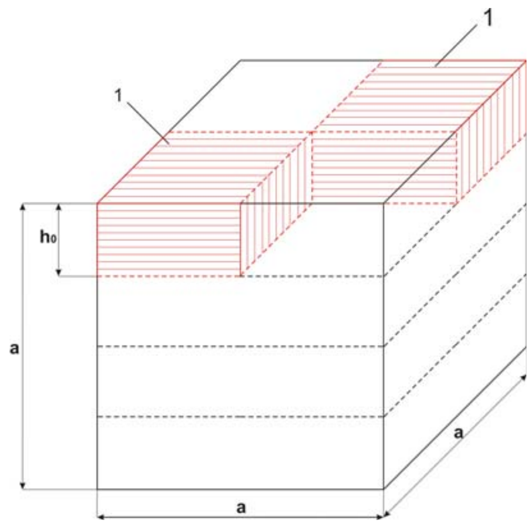

Figure 2 Isolator obtained after vulcanisation (2 - Hooke-Maxwell model unit)

3. THE PARAMETERS OF THE COMPOSITE NEOPRENE LAYERS

The Voigt-Kelvin model illustrated in fig. 3 is characterized by elastic coefficient (modulus) k and the structure dissipation coefficient (modulus) or hysteretic modulus δ.

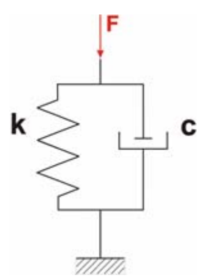

Figure 3 The Voigt-Kelvin model

The complex dynamic rigidity is expressed under the form

$$\tilde{K}(\omega) = k + ic\omega = k\left[1 + i\frac{c\omega}{k}\right] = k(1 + i\delta) \ , \quad (1)$$

where:

k is the rigidity coefficient [N/m]

$\delta = \frac{c\omega}{k}$ - hysteretic factor

c – viscous damping coefficient [Ns/m]

ω – the pulsation of the exciting force **F** (circular frequency) [rad/s]

$i = \sqrt{-1}$ - imaginary unit.

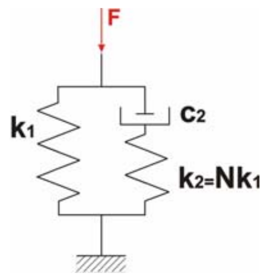

Figure 4 Hooke-Maxwell model

The Hooke-Maxwell model represented in fig. 4 is characterized by complex dynamic rigidity given by relation [5]

$$\tilde{K}(\omega) = K_1(\omega) + iK_2(\omega) \ , \tag{2}$$

where

$K_1(\omega)$ is the dynamic elastic modulus

$K_2(\omega)$ - energy internal loss modulus.

The two above modulus can be calculated with the next relations:

$$K_1(\omega) = \frac{k_1 k_2^2 + (k_1 + k_2)c^2\omega^2}{k_2^2 + c^2\omega^2} \tag{3}$$

$$K_2(\omega) = \frac{k_2^2 c\omega}{k_2^2 + c^2\omega^2} \tag{4}$$

The internal dissipation coefficient or the hysteretic factor of the Hooke-Maxwell model is defined under the form [6]:

$$\Delta(\omega) = \frac{K_2(\omega)}{K_1(\omega)} = \frac{ck_2^2\omega}{k_1 k_2^2 + (k_1 + k_2)c^2\omega^2} \tag{5}$$

With the notation from relation (5), the expression of the complex dynamic rigidity becomes:

$$\tilde{K}(\omega) = K_1(\omega)[1 + i\Delta(\omega)] \tag{6}$$

If we consider the rigidity ratio

$$\alpha = \frac{k_1 + k_2}{k_1} = 1 + N \ , \tag{7}$$

where $N = \frac{k_2}{k_1}$, the hysteretic factor can be written as follows:

$$\Delta(\omega) = \frac{ck_2\omega(\alpha - 1)}{k_2^2 + \alpha c^2\omega^2} \tag{8}$$

The hysteretic factor $\Delta(\omega)$ achieves the maximum value at the pulsation:

$$\omega = \omega_M = \frac{k_2}{c\sqrt{\alpha}} \tag{9}$$

The maximum value of the hysteretic factor can be calculated with the relation:

$$\Delta_{max} = \Delta(\omega_M) = \frac{\alpha - 1}{2\sqrt{\alpha}} \tag{10}$$

Considering the relative exciting pulsation (the pulsation ratio)

$$\Omega = \frac{\omega}{\omega_M} = \frac{2\omega\sqrt{\alpha}}{\alpha - 1} \ , \tag{11}$$

the expression of the complex dynamic rigidity becomes

$$\tilde{K}(\Omega) = K_1(\Omega)[1 + i\Delta(\Omega)] \tag{12}$$

where the significant parametric relations for the Hooke-Maxwell model are:

$$K_1(\Omega) = \alpha k_1 \frac{1 + \Omega^2}{\alpha + \Omega^2} \tag{13}$$

$$\Delta(\Omega) = 2\Delta_{max}\frac{\Omega}{1 + \Omega^2} = \frac{\alpha - 1}{\sqrt{\alpha}}\frac{\Omega}{1 + \Omega^2} \tag{14}$$

Figure 5 shows the diagram of the adimensional dynamic elastic modulus $K_1 / k_1(\Omega)$ and fig. 6 shows the diagram of the energy internal loss modulus $\Delta(\Omega)$ for different values of the α.

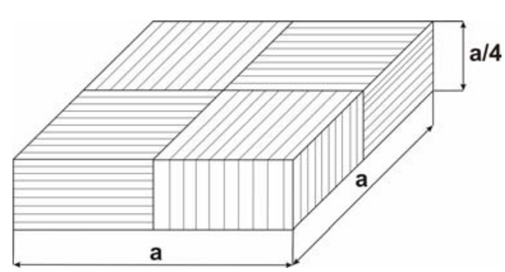

Figure 7 The composite viscous elastic layer

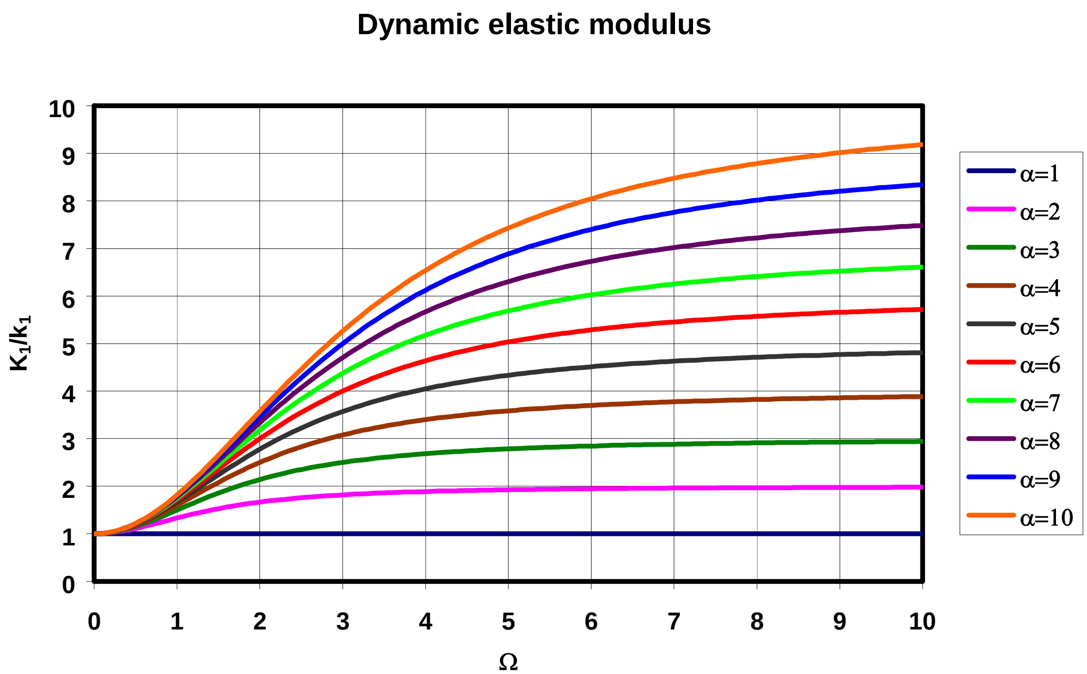

Figure 5 The diagram of the adimensional dynamic elastic modulus $K_1 / k_1(\Omega)$

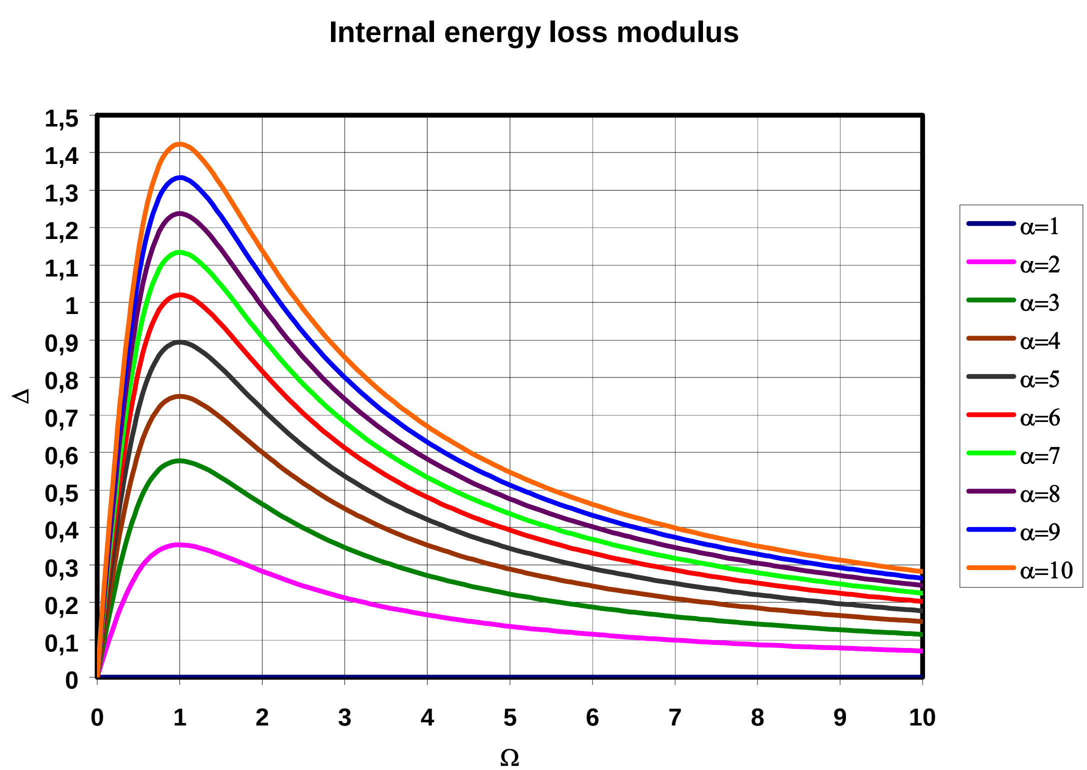

Figure 6 The diagram of the energy internal loss modulus $\Delta(\Omega)$

In order to establish the elastic and the dissipation parameters for one layer of macro structural composite neoprene, we consider the example of the structure from fig. 7. Each layer consists of two V-K units and two H-M units connected in parallel.

If we consider that a macro composite layer is made from n units (V-K or/and H-M) with $\left(K_j, \Delta_j\right)$ $j=\overline{1,n}$, the complex rigidity is:

$$\tilde{K}=\sum_{j=1}^{n} K_j + i\sum_{j=1}^{n} K_j\Delta_j \tag{15}$$

The relation (15) can be written as follows

$$\tilde{K}=K_p\left(1+i\Delta_p\right) \tag{16}$$

where: K_p is the total dynamic rigidity

Δ_p - total hysteretic factor for the layer.

The above parameters can be calculated with the next formulae:

$$K_p=\sum_{j=1}^{n} K_j \tag{17}$$

$$\Delta_p=\frac{\sum_j K_j\Delta_j}{\sum_j K_j}=\omega\frac{\sum_j c_j}{\sum_j K_j} \tag{18}$$

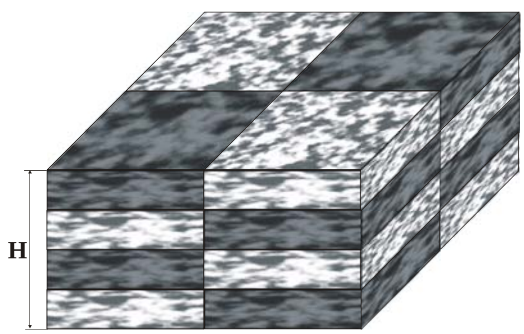

Figure 8 The composite viscous elastic layer

In case of an isolator consisting of m serial connected layers, identical from the physical and geometrical point of view and separated by steel shims (fig. 8 shows an isolator with four identical layers), we have:

$$\tilde{K}_{isol}=\frac{1}{m}\sum_{j=1}^{n} K_j + i\frac{1}{m}\sum_{j=1}^{n} K_j\Delta_j \tag{19}$$

$$\tilde{K}_{isol}=\frac{1}{m}\sum_{j=1}^{n} K_j\left[1+i\frac{\sum_{j=1}^{n} K_j\Delta_j}{\sum_{j=1}^{n} K_j}\right] \tag{20}$$

Relation (20) can be written

$$\tilde{K}_{isol}=K_{isol}\left(1+i\Delta_{isol}\right), \tag{21}$$

where the parameters of the isolator can be calculated as follows:

$$K_{isol}=\frac{1}{m}\sum_{j=1}^{n} K_j \tag{22}$$

$$\Delta_{isol}=\frac{\sum_{j=1}^{n} K_j\Delta_j}{\sum_{j=1}^{n} K_j} \tag{23}$$

Taking into account that the hysteretic factor can be written function of critical damping $\Delta_j=2\zeta_j$, we have:

$$\Delta_{isol}=2\frac{\sum \zeta_j K_j}{\sum K_j} \tag{24}$$

4. NUMERICAL SIMULATION

The goal of the numerical simulation is to calculate the elastic and damping parameters of an isolator made from composite neoprene with micro and macrostructure. We consider a rectangular isolator with composite structure made from four neoprene layers like in fig. 8. The sizes of the isolator are $a=b=H=1m$ and the viscous elastic units are made from neoprene with micro composite structure and mechanical characteristics like in Table 1.

Table 1. Mechanical and geometrical characteristics of the neoprene units

Neoprene type	SAB 31	SAB 4a
E [kN/m^2]	4300	7000
G [kN/m^2]	800	1160
Hardness [^{0}ShA]	55	65
Δ	0.170	0.250
ζ	0.085	0.125
Shape coefficient Φ	0.5	0.5

For each viscoelastic unit with the dimensions $0.5 \times 0.5 \times 0.25m$, the elastic coefficients has the values acc. to Table 2.

Table 2. Elastic coefficients of the neoprene units

Neoprene type	SAB 31	SAB 4a
Compress. coeff. K_z [kN/m]	5800	9400
Shearing coeff. K_x [kN/m]	800	1160

Taking into consideration the physical model from fig. 8 and the values of the two units types from Table 1 and Table 2, we can calculate the elastic and the damping parameters of the isolator function of the rheological model as follows:

a)Voigt – Kelvin model (V-K)

-neoprene units: 2 × SAB 31 + 2 × SAB 4a

-mathematical model: fig. 9

-calculus relations:

$$K_{layer}^{z} = 2(K_{1z} + K_{2z}) \quad (26)$$

$$K_{layer}^{x} = 2(K_{1x} + K_{2x}) \quad (27)$$

$$\Delta_{layer}^{V-K} = 2\frac{K_1\zeta_1 + K_2\zeta_2}{K_1 + K_2} \quad (28)$$

$$K_{isol}^{z} = \frac{1}{4}K_{layer}^{z} \quad (29)$$

$$K_{isol}^{x} = \frac{1}{4}K_{layer}^{x} \quad (30)$$

$$\Delta_{isol}^{V-K} = \Delta_{layer}^{V-K} \quad (31)$$

-elastic and damping parameters: Table 3

Table 3. Elastic and damping parameters of the neoprene isolator (V-K model)

Parameter	Layer	Isolator
Compress. coeff. K_z [kN/m]	30400	7600
Shearing coeff. K_x [kN/m]	3920	980
Hysteretic dissipation factor Δ	0.218	0.218

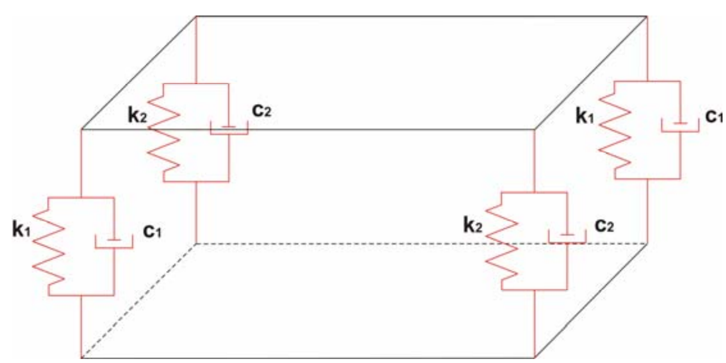

Figure 9 Voigt – Kelvin mathematical model (V-K)

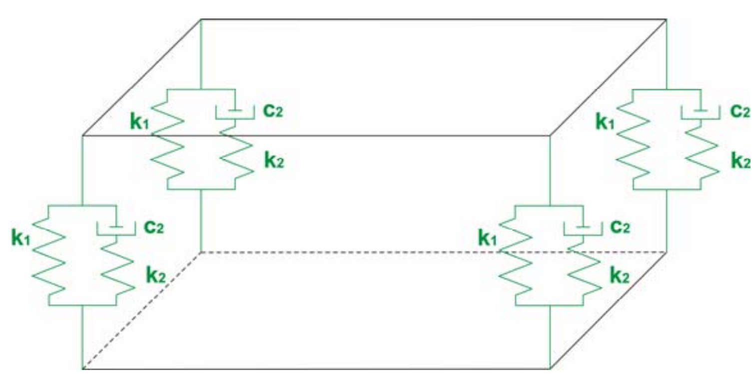

Figure 10 Hooke-Maxwell mathematical model (V-K)

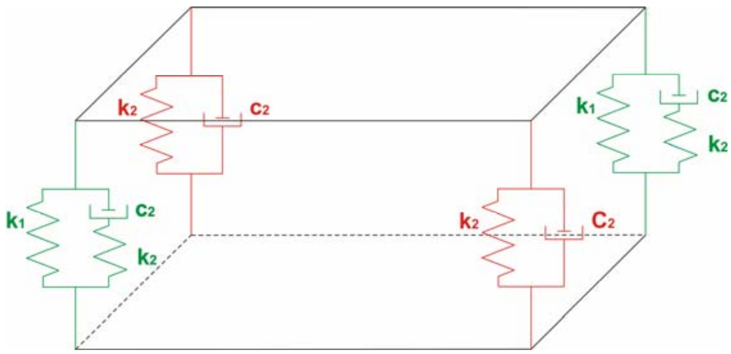

Figure 11 Composite mathematical model (V–K + H-M)

b)Hooke-Maxwell model (H-M)

-neoprene units: SAB 31 + SAB 4a (composite microstructure)

-mathematical model: fig. 10

-calculus relations: (2) to (14) and

$$\alpha = 1 + 2\Delta_{max}^2 + 2\Delta_{max}\sqrt{1+\Delta_{max}^2} \qquad (32)$$

$$K_2 = (\alpha - 1)K_1 \qquad (33)$$

$$K_{1z_{layer}}^{H-M} = 4K_{1_z} \qquad (34)$$

$$K_{1x_{layer}}^{H-M} = 4K_{1_x} \qquad (35)$$

$$\Delta_{isol}^{H-M} = \Delta_{layer}^{H-M} = \Delta_{unit}^{H-M} \qquad (36)$$

$$K_{1z_{isol}}^{H-M} = \frac{1}{4}K_{1z_{layer}}^{H-M} \qquad (37)$$

$$K_{1x_{isol}}^{H-M} = \frac{1}{4}K_{1x_{layer}}^{H-M} \qquad (38)$$

-elastic and damping parameters: Table 4

-input data:

$\Delta_{max} = 0{,}5 \Rightarrow \alpha = 2.61$

$f = 5Hz \Rightarrow \omega_M = 31.415s^{-1}$

-elastic and damping parameters: Table 4

c)Composite Voigt-Kelvin + Hooke-Maxwell model (V–K + H-M)

-neoprene units: 2 × V-K + 2 × H-M

-mathematical model: fig. 11

-calculus relations: (2) to (14) and

$$\tilde{K}_{layer}^{comp} = 2\tilde{K}^{V-K} + 2\tilde{K}^{H-M} \qquad (39)$$

$$K_{1_{layer}}^{comp} = 2\left(K_1^{V-K} + K_1^{H-M}\right) \qquad (40)$$

$$\Delta_{1_{layer}}^{comp} = 2\left(\Delta_1^{V-K} + \Delta_1^{H-M}\right) \qquad (41)$$

$$\Delta_{isol}^{comp} = \Delta_{layer}^{comp} \qquad (42)$$

$$K_{1z_{isol}}^{comp} = \frac{1}{4}K_{1z_{layer}}^{comp} \qquad (42)$$

$$K_{1x_{isol}}^{comp} = \frac{1}{4}K_{1x_{layer}}^{comp} \qquad (43)$$

-elastic and damping parameters: Table 5

Table 4. Elastic and damping parameters of the neoprene isolator (H-M model)

Parameter	Unit	Layer	Isolator
α	2.61	-	-
Compression coeff. K_z [kN/m]	8380	33520	8380
Shearing coeff. K_x [kN/m]	1150	4600	1150
Hysteretic dissipation factor Δ	0.500	0.500	0.500

Table 5. Elastic and damping parameters of the neoprene isolator (V-K + H-M model)

Parameter	Layer	Isolator
Compress. coeff. K_z [kN/m]	28360	7900
Shearing coeff. K_x [kN/m]	3900	975
Hysteretic dissipation factor Δ	0.380	0.380

5. CONCLUSIONS

By rheological modelling of the micro and macro structural dissipative isolators in composite neoprene, high performances as global elasticity as well as internal dissipation can be attained.

Thus, we conclude as follows:

- the isolator rigidity in case of compression for the first two models remains almost the same meaning that $K_z^{V-K} = 7600 kN/m$, $K_x^{V-K} = 980 kN/m$ for the Voigt-Kelvin model and $K_z^{H-M} = 8380 kN/m$, $K_x^{H-M} = 1150 kN/m$ for the Hooke-Maxwell model;
- the internal dissipation expressed by the hysteretic factor is much higher for the neoprene composite Hooke-Maxwell modelled as compared with Voigt-Kelvin model, meaning $\Delta_{isol}^{H-M} = 0.500$ and $\Delta_{isol}^{V-K} = 0.218$;
- the rigidity coefficients in case of composite neoprene isolator with Voigt-Kelvin and Hooke-Maxwell elements have lower values than the Hooke-Maxwell model and the hysteretic damping $\Delta_{isol}^{comp} = 0.380$.

Based on the case studies, optimum and efficient solution for base isolation systems consisting of micro and macro structural composites could be found.

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