F.E.M. and experimental studies concerning new devices for seismic damping of buildings subjected to earthquakes

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***Abstract*—** This paper presents the F.E.M. and experimental studies of new Romanian devices for dissipation of seismic energy for buildings affected by Romanian Vrancea earthquakes. These devices were tested by experimental and F.E.M. studies in static cases because their behaviors are the same in dynamic cases. The studies were made in order to determine the stiffness and damping non-linear parameters of these new devices which are necessary to obtain the hysteresis curves. The hysteresis curves obtained within the study can be simulated with Bouc-Wen model of hysteresis and the mathematical relation of this type of hysteresis can be used in order to simulate the new SERB dampers on a building subjected to seism using special simulation software.

***Keywords*—** Ansys, contact elements, FEM, seismic dampers.

I. INTRODUCTION

THE most used method for protecting the building during earthquakes is by using seismic dampers which can be positioned in the foundation or at the supra-structure above the soil. The most common choice is structural passive control systems which have been developed in the past years and they include seismic isolation systems and energy dissipation systems. Among those systems we find friction dampers, metallic dampers, visco-elastic dampers and viscous dampers.

The Romanian earthquakes have some particularities in the Vrancea seismic zone, as it is the velocity, which is smaller (0,3 m/s) then in other countries. A correct approach of the process of designing the damping systems of a building structure, must take into account the particularities of the seismic zone where the building is positioned.

This paper analyze four new types of dampers specifically invented for the romanian earthquakes conditions. These dampers are named SERB. These dampers can be used in any country and any seismic zone not only in Romania.

In order to use them on a finite element model of a building structure equipped with these dampers we must find the hysteresis graphics of these new dampers. They were determined by simple experiments by the Romanian inventor PhD. eng. Viorel Serban [9] but it is necessary to simulate them by F.E.M. with powerful software like Ansys program in order to extend the experimental study.

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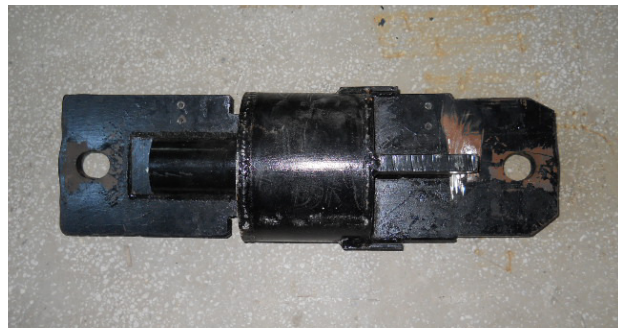

Fig. 1 Type 2 SERB seismic Damper (front view)

Fig. 2 Type 2 SERB seismic Damper (lateral view)

II. PROBLEM FORMULATION

In this section we present the F.E.M. analysis of three new SERB damping devices used for protecting the buildings during earthquakes.

The components of these three new dampers were modeled in Ansys software using 3d finite elements and contact friction finite elements. The load case for these 3d FEM models is the axial force, which is used for elongating then compressing the damper in the same cycle.

The load case for all three models consists of:

- Phase 1 – action of the central resort for tensioning the group of metallic discs.
- Phase 2 – compressing the damper with the axial force increasing from 0 to testing value in 5 seconds.
- Phase 3 - elongating the damper with the axial force increasing from 0 to testing value in 5 seconds.

Between phase 2 and phase 3 we have an intermediate phase which decrease the compressing force to 0 kN in 5 seconds.

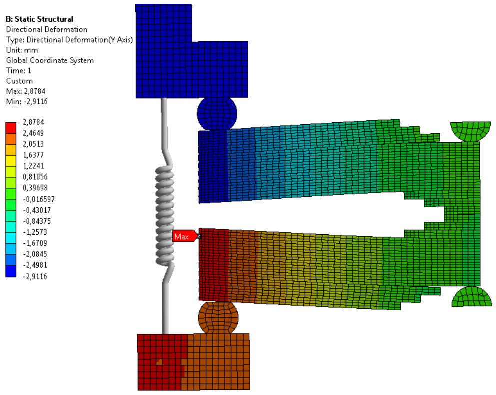

Fig. 3 Oy displacements SERB 1 [mm] (phase 1) – section view

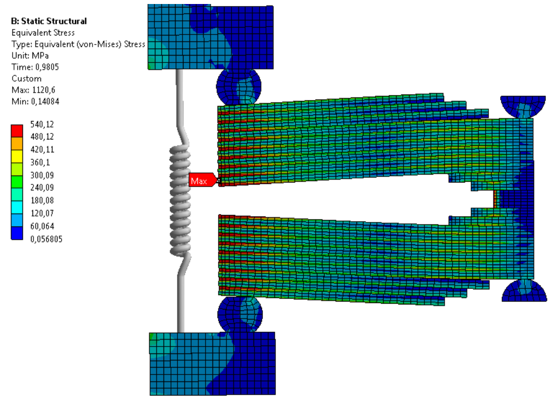

Fig. 7 Von Mises stresses SERB 1 [MPa] (phase 1) – section view

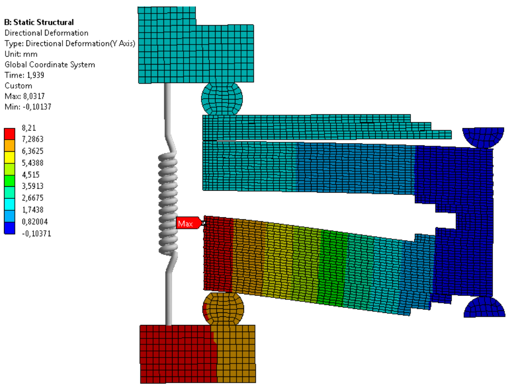

Fig. 4 Oy displacements SERB 1 [mm] (phase 2) – section view

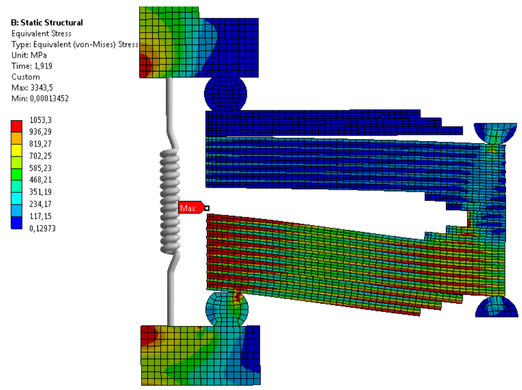

Fig. 8 Von Mises stresses SERB 1 [MPa] (phase 2) – section view

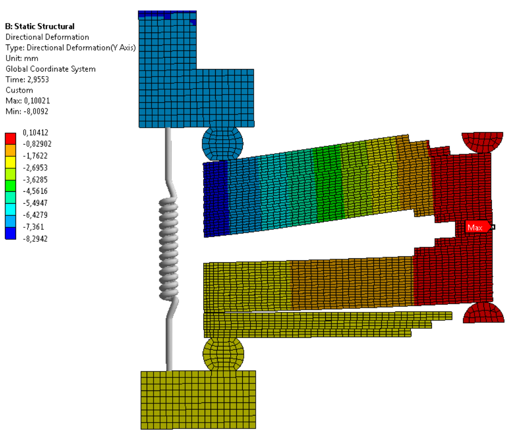

Fig. 5 Oy displacements SERB 1 [mm] (phase 3) – section view

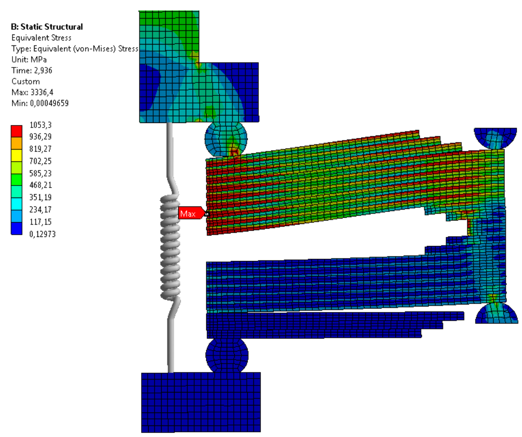

Fig. 9 Von Mises stresses SERB 1 [MPa] (phase 3) – section view

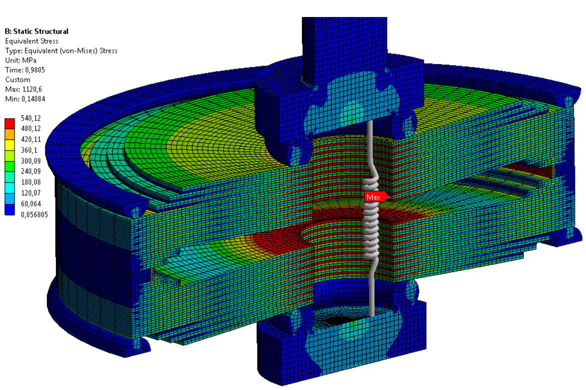

Fig. 6 Von Mises stresses SERB 1 [MPa] - phase 1 - 3D view

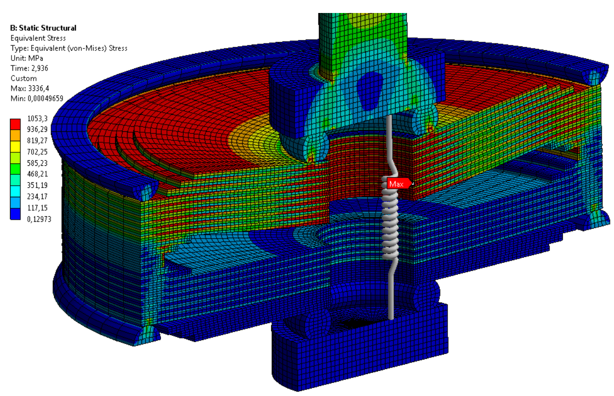

Fig. 10 Von Mises stresses SERB 1 [MPa] -phase 3 - 3D view

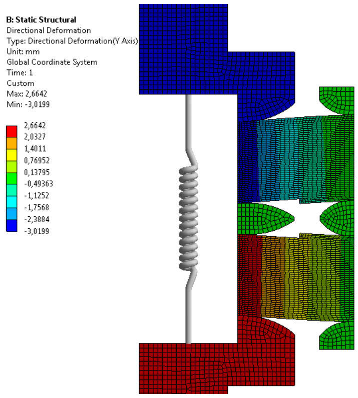

Fig. 11 Oy displacements SERB 2 [mm] (phase 1) – section view

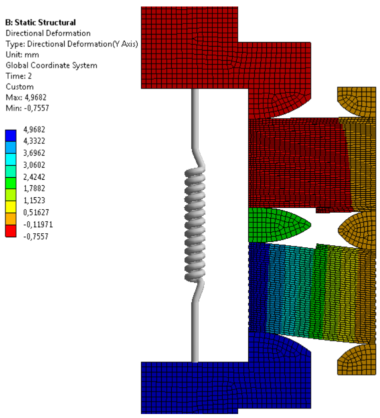

Fig. 12 Oy displacements SERB 2 [mm] (phase 2) – section view

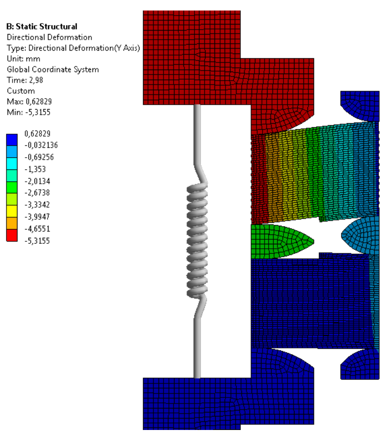

Fig. 13 Oy displacements SERB 2 [mm] (phase 3) – section view

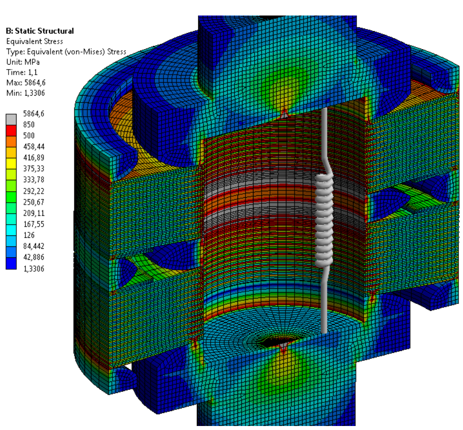

Fig. 14 Von Mises stresses SERB 2 [MPa] - phase 1 - 3D view

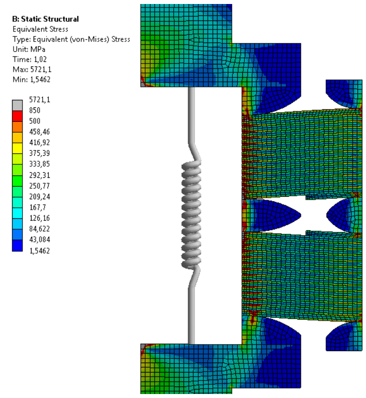

Fig. 15 Von Mises stresses SERB 2 [MPa] (phase 1) – section view

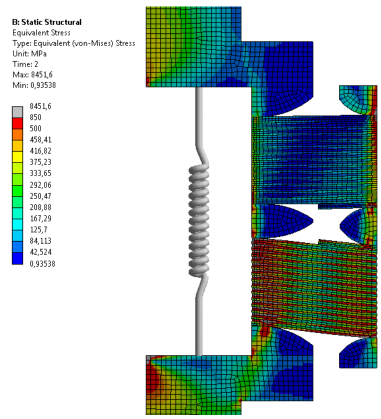

Fig. 16 Von Mises stresses SERB 2 [MPa] (phase 2) – section view

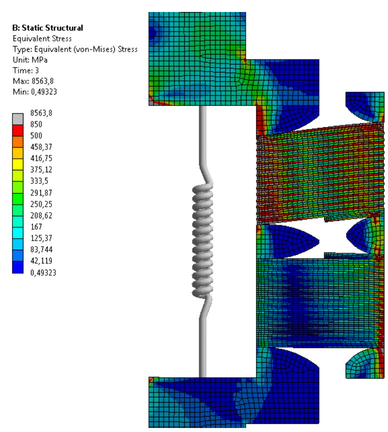

Fig. 17 Von Mises stresses SERB 2 [MPa] (phase 3) – section view

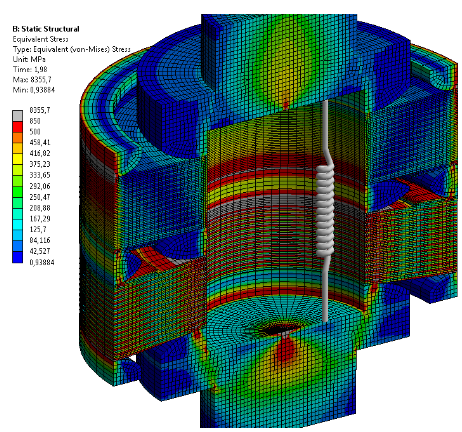

Fig. 18 Von Mises stresses SERB 2 [MPa] -phase 3 - 3D view

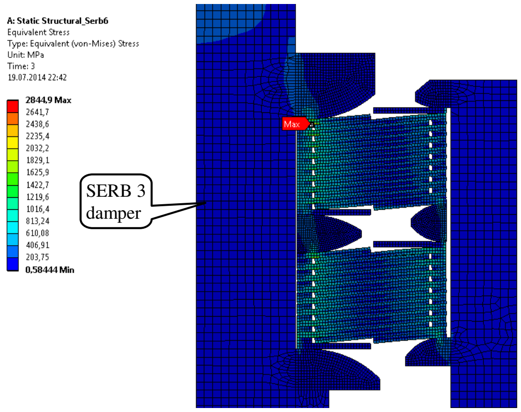

Fig. 19 Von Mises stresses [MPa] compression F= 1000kN (section)

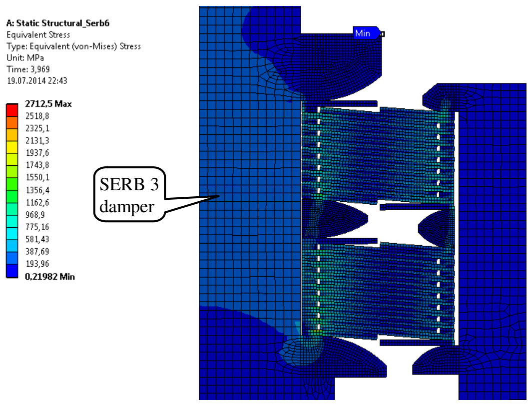

Fig. 20 Von Mises stresses [MPa] elongation F=1000 kN

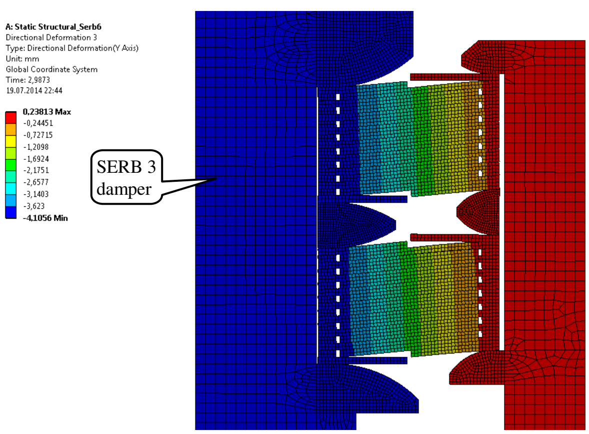

Fig. 21 Oy displacements [mm] compression F=1000kN (section)

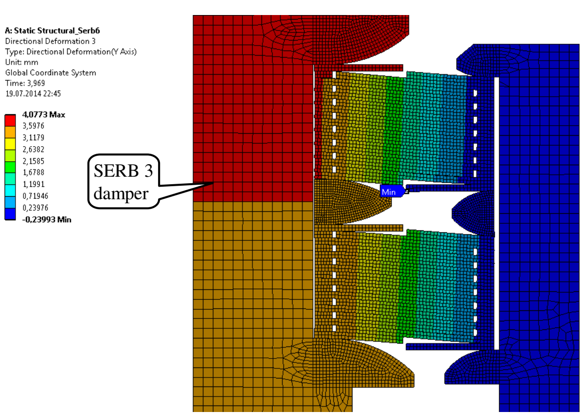

Fig. 22 Oy displacements [mm] - elongation F=1000 kN (section)

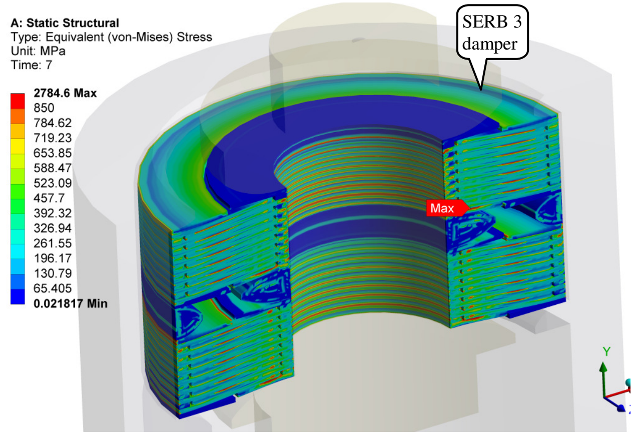

Fig. 23 Von Mises stresses [MPa] elongation F= 500kN (3D view)

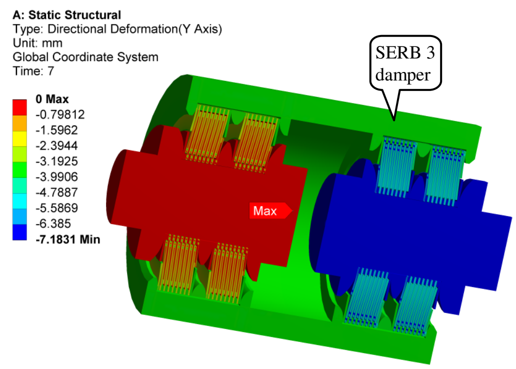

Fig. 24 Oy displacements [mm] elongation F= 500kN (3D view)

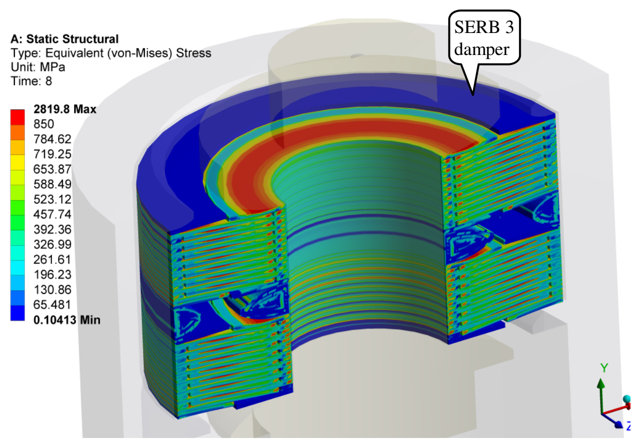

Fig. 25 Von Mises stresses [MPa] compression F= 750kN (3D view)

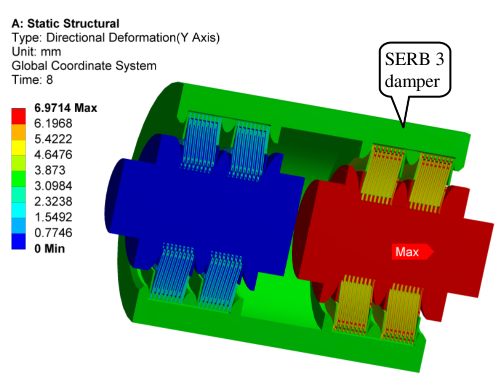

Fig. 26 Oy displacements [mm compression F= 750kN (3D view)

All three SERB dampers F.E.M. models are 3D models which have several loading cases.

For the metallic friction parts of the dampers we have used special steel features. The friction between parts was simulated using contact elements surface to surface with friction coefficient μ=0.3 for friction without lubrification.

For SERB 1 damper model it was used only one cycle with three phases with F=350 kN.

For SERB 2 damper model we have used only one cycle with three phases with F=550 kN.

For the phase 1 of the loading cycle we have used a force for the resort which implies a displacement of 5 mm. This initial stress is necessary for SERB 1 and SERB 2 dampers in order to work with friction phenomenon. The value of initial stress is controlling the damping force.

For SERB 3 damper model we have used four cycles with two phases (compression and elongation). This four cycles were realised with four forces: F_1=250 kN, F_2=500 kN, F_3=750 kN and F_4=1000 kN.

For SERB 3 damper it was not necessary phase 1 on the cycle because this damper works without initial stress.

The hysteresis curves for all three dampers models were determined by Ansys results and they are presented in fig. 27, fig. 28 and fig. 29.

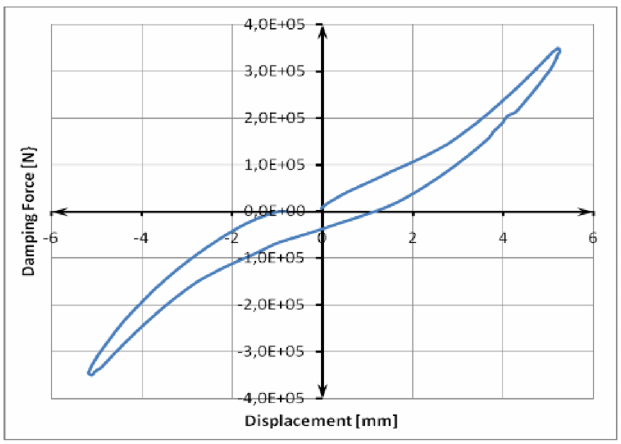

Fig. 27 Ansys hysteresis curve for SERB 1

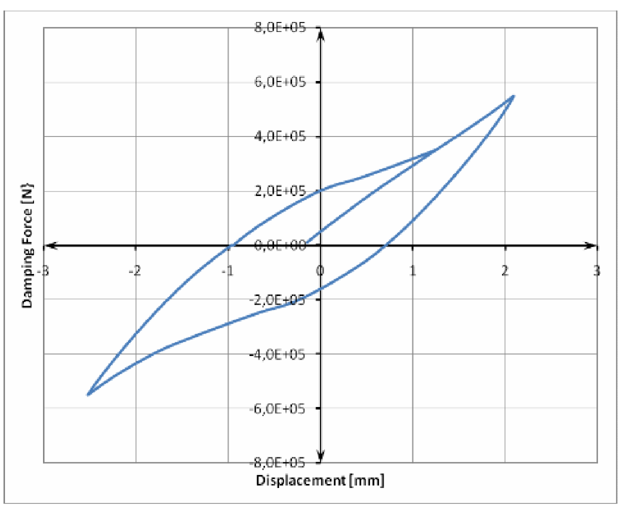

Fig. 28 Ansys hysteresis curve for SERB 2

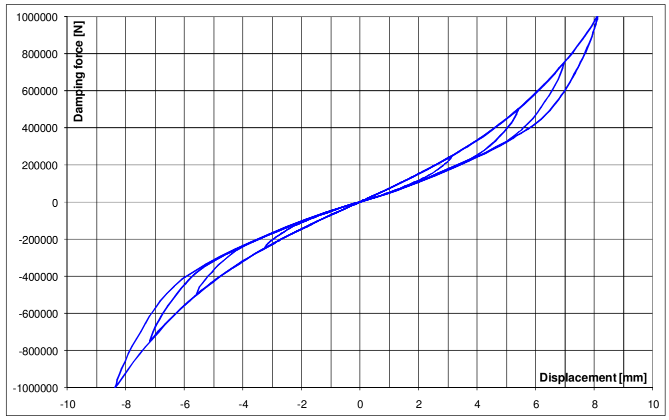

Fig. 29 Ansys hysteresis curve for SERB 3

We can observe that all three dampers hysteresis have special shapes which cannot be simulated with usual damping models: Maxwell, Kelvin-Voigt, Zener, etc.

These shapes are very useful for drift limitation because the damping force is increasing fast with displacements.

For these types of dampers it is recommended to use Bouc-Wen damping model in order to obtain the mathematical relation for the hysteresis graphics.

In order to validate the results of these F.E.M. studies we have done several experimental studies on SERB dampers which are presented in the next section.

III. Experimental Studies

The experimental studies were realized at IMSAR Bucharest and ICECON Bucharest, two important research laboratories in Romania.

The first tested damper, SERB 3, it was invented for equipping the building supra-structure in order to reduce the relative displacement between stories and to dissipate the seismic energy through the friction phenomenon between his metallic components.

This damper was tested at ICECON Bucharest using the SANS testing machine in a stationary regime.

During earthquake the damper is charged with forces in a dynamic transient regime. Because the friction between the metallic components of the damper is without lubrication, the friction force is depending only on the quality of the surfaces in contact and the normal force which act on the friction surfaces. In this case the friction force is not depending on the velocity between the contact surfaces.

That is the reason why the results obtained by experimental studies on SERB dampers using applying loads in static regime, are the same with the results for the case of using dynamic loads.

Because F.E.M. models of all three SERB dampers have similar component parts and they are using the same finite element types with similar boundary condition, we have choosing to test by experiments only SERB 3 damper, assuming that F.E.M. models for SERB 1 and SERB 2 dampers will be validated based on SERB 3 validation process.

Fig. 30 Testing the SERB 3 damper on SANS testing machine at ICECON laboratory

The testing of SERB 3 damper consists in compressing the damper with forces of 300 KN to 1000 KN in cycles with low velocity and to stop the action of compressing force in order to allow the damper to come back at the initial state before another cycle of increasing the force to the next level of compression.

During these cycles the laboratory equipment had store the data in files in order to process them. After processing the data files we have obtained the hysteresis curve for compression.

Due to the construction of the damper it is not necessary to test the damper with elongation forces because the hysteresis is anti-symmetrical.

The hysteresis curve of SERB 3 damper obtained by this experiment is presented in fig.31.

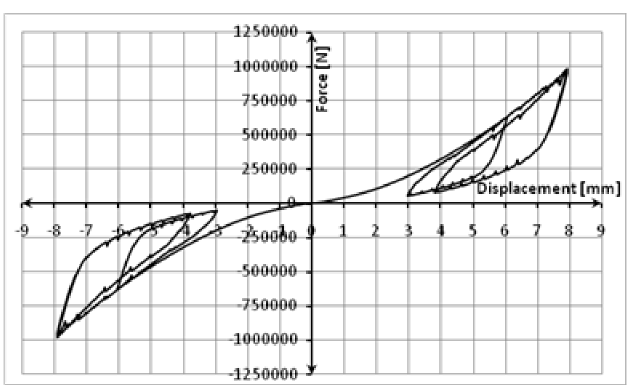

Fig.31 The experimental hysteresis curve for SERB 3 damper

The second damper SERB 4 it was invented for equipping the building at the foundation in order to work in parallel with the base isolation system during earthquakes.

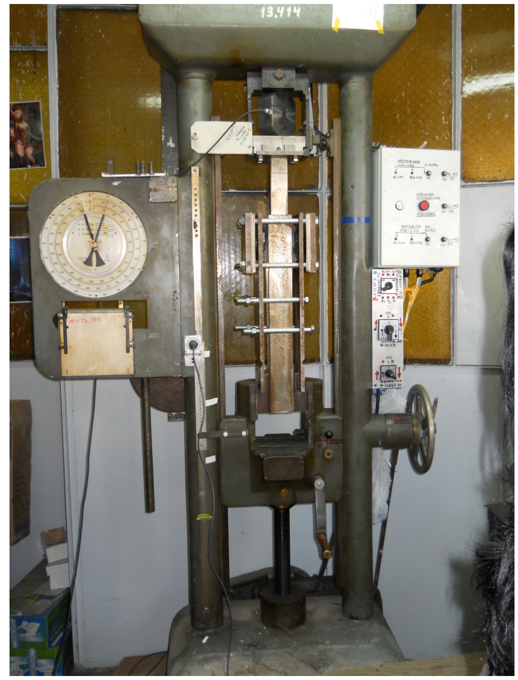

Fig. 32 Testing the SERB 4 damper on special testing machine at IMSAR Bucharest laboratory

This damper has metallic components in contact and the friction phenomenon during earthquakes is without lubrication. That is the reason why we have tested this damper with static compression and elongation forces, although this damper is subjected to dynamic forces during earthquakes. The results are the same in static and dynamic cases.

The testing was realized at IMSAR Bucharest laboratory on a special testing machine which acts on the damper with cycles of compression and elongation forces with low velocity (static regime).

This damper has the possibility to increase the friction force by acting on a system with screws and springs.

This testing was creating for spring force corresponding to the distance of 203 mm between the screws heads.

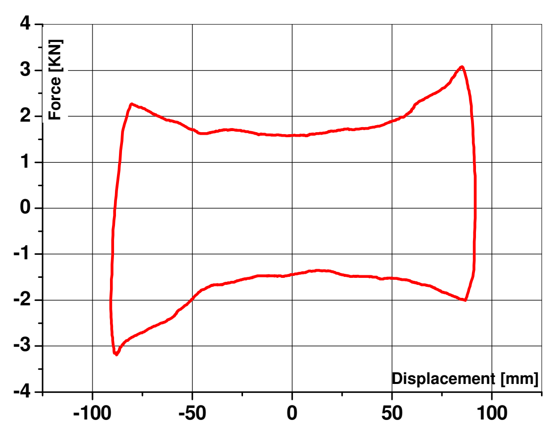

Fig. 33 The experimental hysteresis curve for SERB 4 damper

The hysteresis curve has a special shape which can be modeled with modified Bouc-Wen model of hysteresis.

IV. Theoretical Model

In order to use the hysteresis curve of the SERB dampers we must find mathematical relations which describes those curves.

All the program software which simulates the behavior buildings equipped with dampers during earthquakes, have the possibility to simulate the dampers with usual hysteresis curve. But, because the SERB damper have unusual hysteresis curve, they can not be modeled with usual mathematical model for damper hysteresis as Maxwell, Kelvin-Voigt or Zener.

That is the reason why we use the Bouc-Wen model to find the mathematical relations for this type of hysteresis.

The general model of Bouc-Wen hysteresis is:

$$\frac{dz}{A-|z|^n[\beta+\gamma\cdot \mathrm{sgn}(\xi'\cdot z)]}=d\xi \qquad (1)$$

where: A, β, γ, n are the parameters which controls the magnitude and shape of hysteresis curve, $z(\xi)$ where z is the damping force and ξ is the damper displacement.

Using $\alpha = \beta + \gamma$ and $n = 1$ we find the following parameters to approximate the first experimental hysteresis curve: $A = 0.1$, $\beta = -3.5$, $\gamma = 1.6$.

The first theoretical hysteresis curves for SERB 3 damper is presented in fig. 34 and fig. 35.

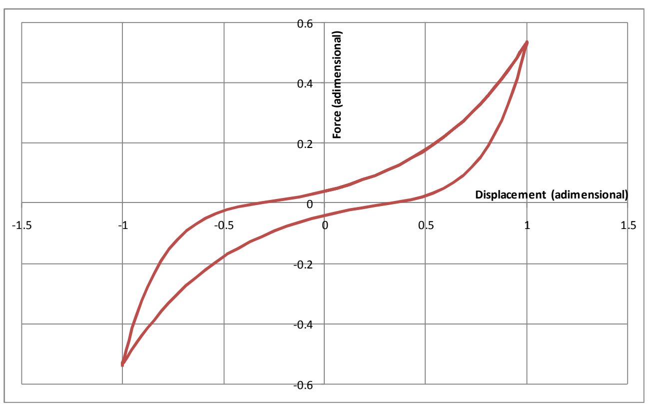

Fig. 34 First theoretical hysteresis curve for SERB 3 damper

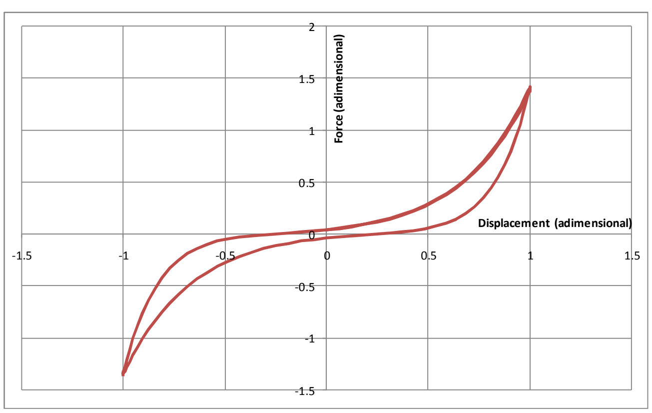

Fig. 35 Second theoretical hysteresis curve for SERB C-194 damper

Using $\alpha = \beta + \gamma$ and $n = 1$ we find for the second theoretical hysteresis the following parameters to approximate the experimental hysteresis curve: $A = 0.097$, $\beta = -4.5$, $\gamma = 1.5$.

For the second damper it is recommended to use the modified Bouc-Wen model [8] (papillon model). In this case the mathematical relation used for SERB 4 hysteresis curve is:

$$\frac{dz}{A-\beta\cdot z}=\mathrm{sgn}(\xi)d\xi \qquad (2)$$

For the first fitting of experimental hysteresis curve of SERB 4 we have found the parameters $A = -0.1$, $\beta = -2$. In this case the first theoretical hysteresis is presented in fig. 36, for positive values of forces and displacements.

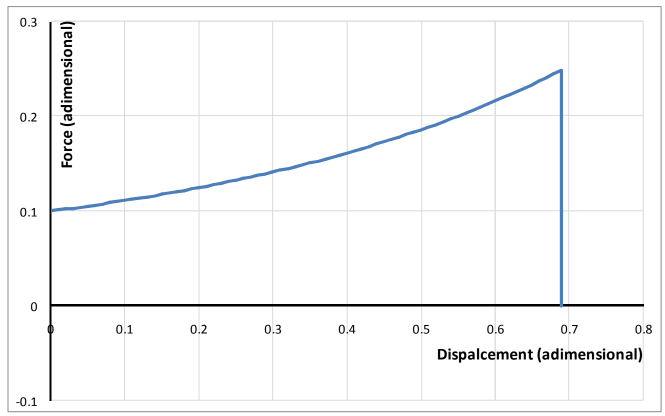

Fig. 36 The theoretical hysteresis curve fo SERB 4 damper

For the second fitting of experimental hysteresis curve of SERB 4 we have found the parameters $A = -0.48$, $\beta = -5$. In this case the second theoretical hysteresis is presented in fig. 37, for positive values of forces and displacements.

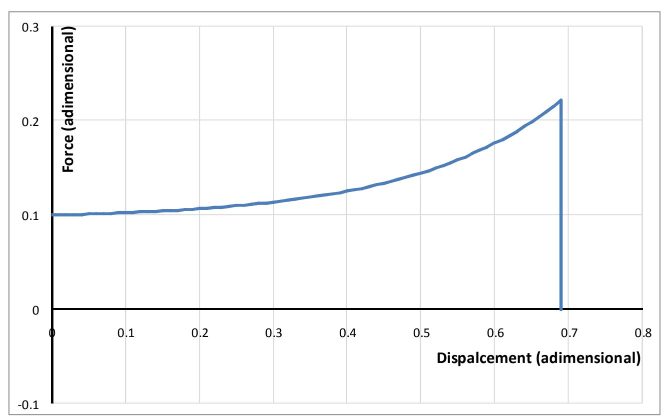

Fig. 37 The theoretical hysteresis curve fo SERB 4 damper

Because the usual programs software like ETABS, SAP 2000, SCIA, ANSYS, do not permit the Bouc-Wen hysteresis model for the dampers used, we have used the program GenEcAm (made by the author) in order to obtain influence of SERB 3 and SERB 4 dampers on buildings behavior during earthquakes.

V. Conclusions

The Romanian SERB dampers used for equipping the buildings are efficient devices for protection during earthquakes but they can not be analyzed using the usual program software like ETABS and SAP 2000 because they have unusual shape of hysteresis curve.

SERB dampers can be positioned at the supra-structure of the buildings (SERB 1, SERB 2, SERB 3) or at the foundation (SERB 4).

The hysteresis curve of SERB dampers can be modeled with Bouc-Wen model of hysteresis in order to be used by the usual programs software for buildings seism simulation, and the parameters of this model are presented in this paper.

SERB dampers were tested by experiments but our F.E.M. simulation extends the study by using different load cases then the experiments. The numerical results are similar with the experimental results and they complete each other in order to observe the differences in the hysteresis curves for different types of load cases.

These hysteresis curves are useful in F.E.M. simulation of buildings equipped with these new dampers for which the F.E.M. software does not have specific damping elements in their finite elements library.

These shapes of hysteresis are very useful for drift limitation because the damping force is increasing fast with displacements.

A great advantage of using SERB devices is the cost of the damping system which is five times smaller then the same damping system which use Taylor devices.

SERB devices can be optimized in order to assure an optimized shape of hysteresis curve for each type of buildings. The optimization consists in modifying the dimensions of the metallic components which contribute to the friction and elastic phenomenon. This optimization process can be done with dampers F.E.M. models presented in this paper, which have been validated with the experimental results.

By using SERB devices we can reduce the drifts by 20% to 30% in order to protect the building during earthquakes [3].

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