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# New Technologies and Devices to Increase Structures' Safety to Dynamic Actions

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## 1. Introduction

A dynamic action may transfer to a structure a quantity of energy equal or smaller than the excitation energy associated to a vibration cycle, function of the harmonization or de-harmonization of the structure eigen movement with the dynamic action kinetics. The transferred energy may build-up as kinetic and potential energy in the structure, which in point of its dynamic behavior can be over-harmonized, under-harmonized or in resonance with the excitation.

In order to see how to limit the energy built-up in a structure and how to reduce it, the dynamic response of the structure in the time and frequency ranges with an oscillating system with a single degree of freedom subjected to a harmonic dynamic action, should be analyzed (Fig. 1.1.).

The oscillating system of a ' $m$ ' mass, ' $k$ ' stiffness and ' $c$ ' damping is subjected to a transportation oscillating movement  $u_s(t)$  of a harmonic type with period  $T_s$ .

Analyzing the diagram one it results that the reduction of the seismic response of a structure may be obtained by increasing the structure damping capacity. For example, the response of energy built-up in the structure on dynamic actions is reduced by about 4 times if the structure damping is increased from 5% to about 10% and of about 16 times if the structure damping is increased from 5% to 20%.

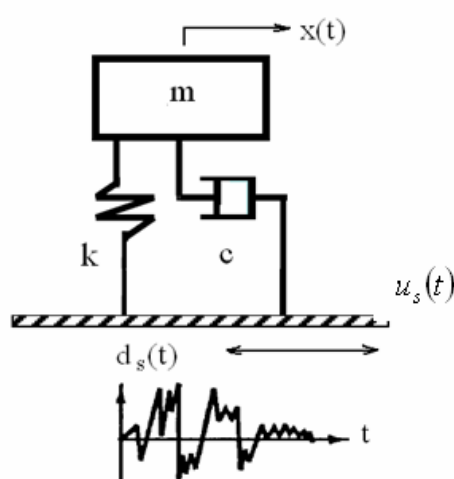


Fig. 1.1. Oscillating system with one degree of freedom driven by excitation  $u_s(t)$

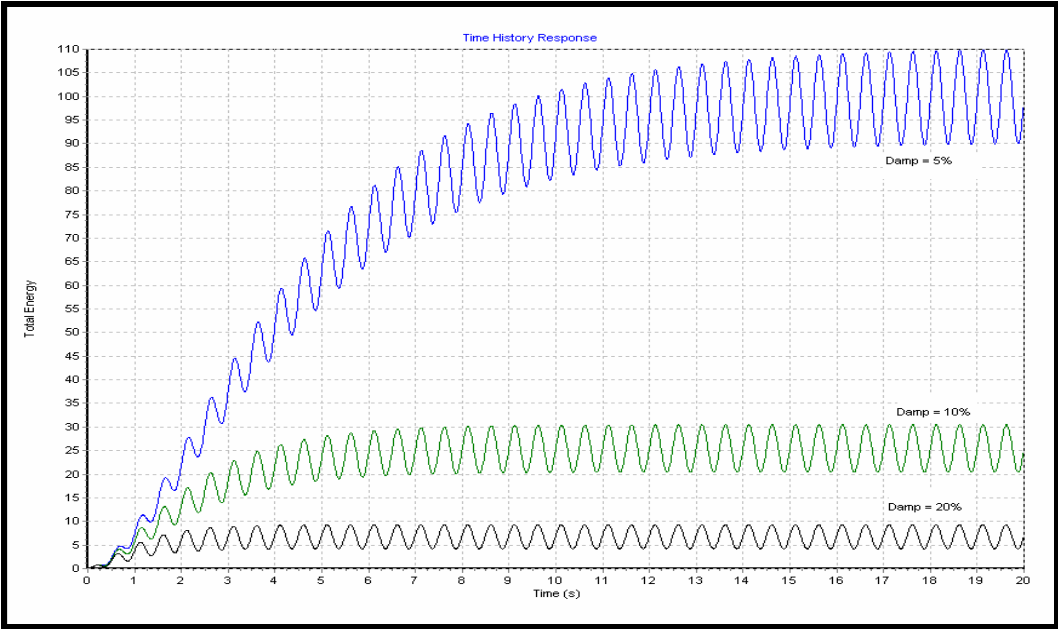


Fig. 1.2. The total energy built-up in the oscillating system in resonance regime with excitation for the relative damping  $\beta=5\%$ ,  $10\%$  and  $20\%$ .

In order to point-out the great differences that may occur in the behavior of some structures when such structures are affected by dynamic actions of the same intensity (amplitude) but with different spectral components, an analysis of the structure response in the frequency range is conducted to offer a better qualitative analysis of the amplification phenomena as to the in-time analysis. Such diagrams also allow a substantiation of the innovative solutions to strengthen the structures in order to withstand dynamic actions.

The variation with the eigen period of the kinetic energy,  $E_c$ , and potential energy,  $W_p$  amplitude specific to the oscillating system mass,  $m$ , for the amplitude of the source energy  $E_s$  (a harmonic component, as well) are given in Figs. 1.3. - 1.4., for  $\beta = 5\%$  and  $\beta = 20\%$ , respectively.

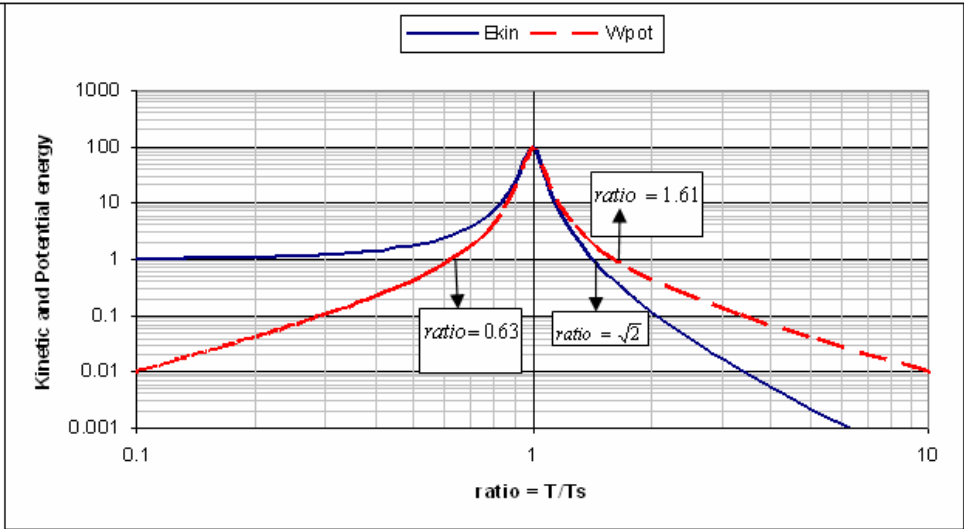


Fig. 1.3. The amplitude of the kinetic and potential energy of the oscillating system as to the excitation amplitude function of  $T/T_s$  for the relative damping  $\beta = 5\%$ .

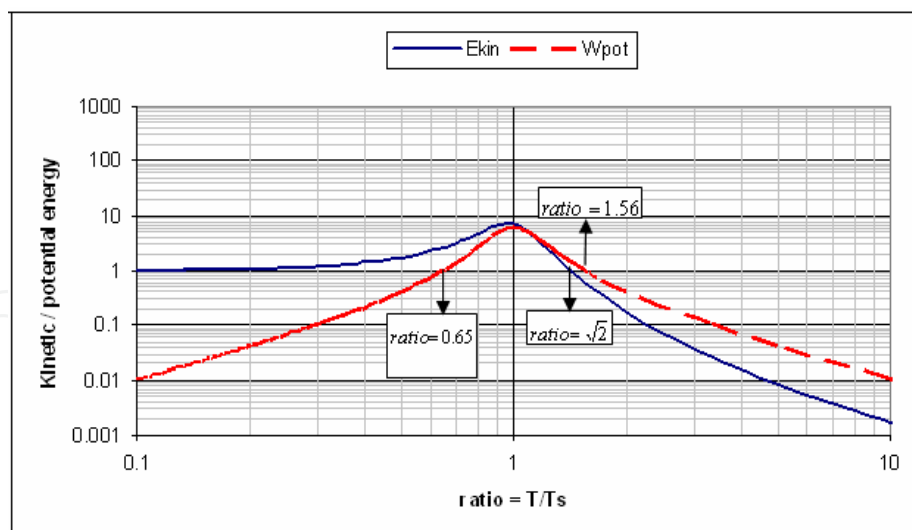


Fig. 1.4. The amplitude of the kinetic and potential energy of the oscillating system as to the excitation amplitude function of  $T/T_s$  for the relative damping  $\beta = 20\%$ .

Based on these diagrams one may determine the requirement that an oscillating system responds to dynamic loads of smaller or equal amplitudes than with static loads of the same intensity (without amplification). In point of energy, the kinetic and potential energy amplitude built-up in the oscillating system should be smaller or equal to the excitation energy amplitude. The kinetic energy is smaller than the source energy (irrespective of the oscillating system damping) if the eigen period of the oscillating system,  $T$ , is greater by 41% than the dominant repetition period of the excitation,  $T_s$ .

The requirement that the maximum potential energy of the oscillating system be smaller or equal to the maximum energy of the source is dependent on the oscillating system damping and such a thing can be obtained for the oscillating system vibration periods are greater than  $1.41 T_s$ . For  $\beta = 30\%$  the result is  $T > 1.88 T_s$ . So such a requirement is satisfied if the eigen dominant vibration period of the structure  $T$  is 2 times greater than the dominant period of the dynamic action  $T_s$ . Considering the evaluations errors in the computation programs, the presence of several periodic components in the seismic response of structures as well as the errors in the input data or modeling, it is necessary to impose the design requirement  $T > 3 T_s$ , a requirement that is satisfying the design standards related to the seismic isolation design.

Analyzing the diagrams it results that the most efficient solution to reduce the energy built up in a structure is to make a connection having large elasticity and small damping between the structure and foundation so that its eigen period should be greater by at least 3 times the repetition period in the dynamic action.

Figure 1.5 and 1.6 shows the variation of the dissipation power amplitude  $|P_d|$  in the oscillating system and the variation of the total power amplitude  $|P_e|$  transferred from the excitation to the oscillating system, related to the system mass unit and source power  $|P_s|$  function of the ratio between the oscillation system period and the excitation period for a fraction of critical damping of 5% and 20%.

Analyzing the diagrams it results that the amplitude of the total power transferred from the excitation source to the oscillation system and its built up is actually equal with the excitation power amplitude for the oscillation system vibration periods smaller than  $0.4 T_s$ . The amplitude of the power transferred and dissipated is much increased in the vicinity of

resonance and the dissipated power (which usually is smaller than the transferred power) becomes actually equal with the power transferred from the excitation to the oscillating system on a resonance. For periods of the oscillating system greater than the excitation dominant period, the power transferred to the oscillating system is decreasing with the increase of the ratio between the two periods.

The dissipated power is decreasing faster in the vicinity of resonance and, for periods  $T \gg 2T_s$ , the speed in decreasing the dissipated power is getting reduced. For high critical damping (e.g.  $\beta = 30 \%$ ) the power transferred from the excitation is obvious as dissipated power for  $T > T_s$ .

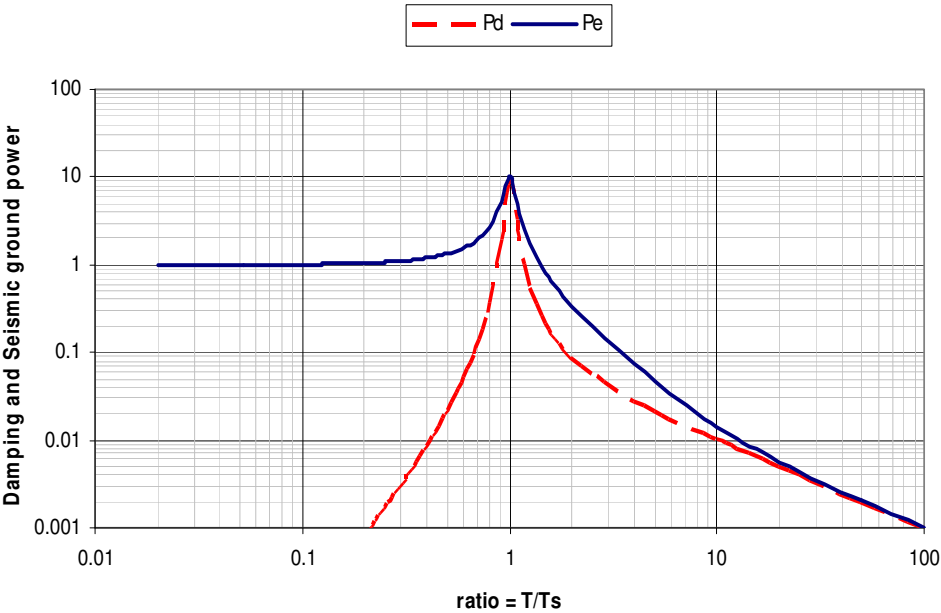


Fig. 1.5. Amplitude of power transferred from the excitation to the oscillating system and the power dissipated in the system, function of  $T/T_s$  and relative damping  $\beta = 5 \%$

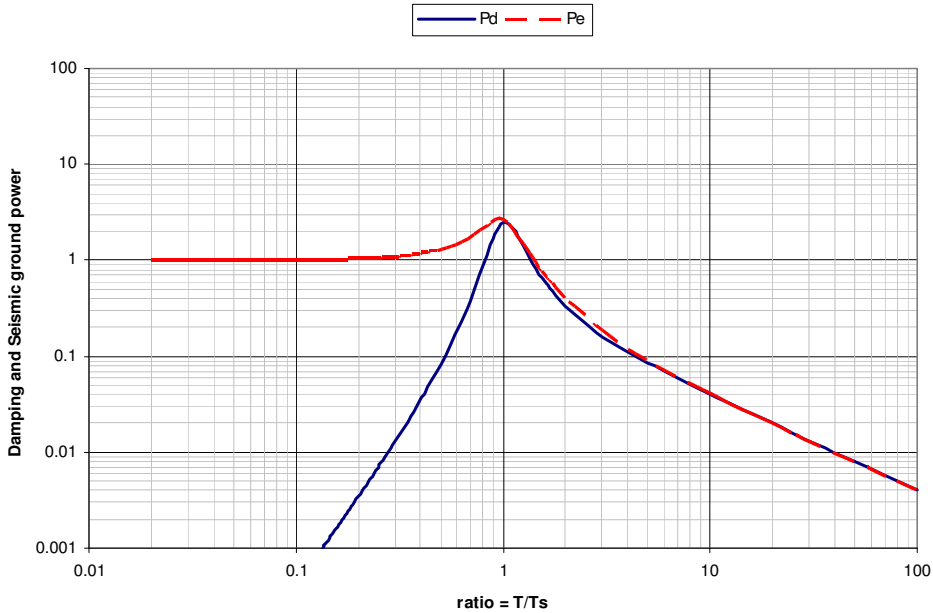


Fig. 1.6. Amplitude of power transferred from the excitation to the oscillating system and the power dissipated in the system, function of  $T/T_s$  and relative damping  $\beta = 20 \%$ .

Analyzing the diagrams in Figs. 1.5.-1.6. it results that the increase of the structure damping capacity with flexible systems evidences positive effects in case of resonance and negative effects in case of the structure isolation because the power transferred to structure is accomplished by damping forces.

For that reason, the structure damping is limited to 30% of the critical damping in the design codes (Romanian Seismic Design Code 2006). For isolation system it is recommendable that the damping should be smallest possible. With this case, the damping shows a positive effect only for the relative displacements between the isolated supra-structure and foundation.

## **2. Reduction of structure dynamic response employing SERB-SITON method**

Considering the large diversity of structures, the analysis of solutions to reduce dynamic response at different excitations is conducted separately for buildings, equipment and pipe-network. In function of the type of structure and/or the kinetic characteristics of the dynamic action, the reduction of the dynamic response may be obtained in several ways.

Bearing in mind that the most important dynamic action that may affect a building is the seismic action, the alternatives to accomplish a small seismic response are presented below.

### **2.1 Solutions to reduce the seismic response of buildings**

#### **2.1.1 Alternative 1**

Increase of building damping capacity while also limiting the relative distortions in the linear range of behavior

The solution consists in the control, limitation and damping of level relative distortions by the installation of elastic devices with damping called "telescopic devices", in the structure and/or between the structure segments (Figs. 2.1. - 2.3.).

The telescopic devices are usually installed at the building lower levels in central or excentral braces or around the nodes that make up a symmetrical network of braced panels at each level of the building and which are continued vertically with possible reductions symmetrically arranged.

SERB-SITON telescopic devices are capable of overtaking forces ranging between 1000÷5000kN and to limit the level relative distortions to values usually ranging between  $\pm 10$  mm to  $\pm 20$  mm or other values imposed by the building, (Serban, 2005).

The devices can be fabricated in a large variety of typo-dimensions, Figs. 2.4.-2.5.

The force-distortion characteristic of the devices is nonlinear type, with strengthening in order to limit the structure distortion and their damping may be accomplished for preset values ranging between 30% and 80% of the elastic energy associated to one cycle.

Force-deformation characteristics may actually be accomplished as per any desired shape, Figs. 2.6. - 2.7.

For building rehabilitation the columns, beams or nodes of the braced panels are strengthened by lining with metal profiles tightened to the reinforced concrete structure and the braces by means of SERB-SITON telescopic devices are arranged as per 1 of the 3 alternatives presented in Figs. 2.1.-2.3.

This alternative may be applied to the construction of new buildings or to the rehabilitation of buildings in a nuclear or classic unit without interrupting the operation.

In case of building strengthening, 5% and 10% of the useful surfaces on a building level is affected by the strengthening solution for a period of 30 and 45 days, the rest of the building being useful without restrictions.

By the application of this alternative the important advantages, compared with the classic strengthening solutions are: necessary materials:  $1/10\div 1/20$ ; resulted wasted:  $1/10\div 1/20$ ; strengthening duration:  $1/2\div 1/4$ ; surfaces of site temporary organization:  $1/10\div 1/50$  of the surface required employing the classic strengthening solution; price:  $0.7\div 0.9$ . Buildings constructed or strengthened by use of SERB SITON method provide a behavior of the building structure in the elastic range during an earthquake. The control, limitation and damping of the building seismic response is provided by the telescopic devices inserted in the building structure rather than the building damaged structure with plastic hinges as the case with classic solutions.

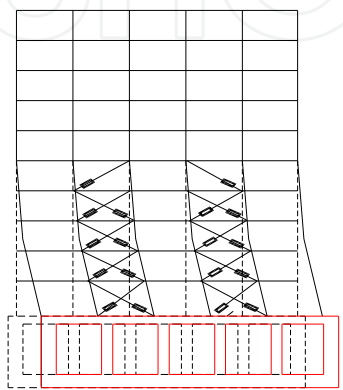


Fig. 2.1. Alternative 1 – central braces

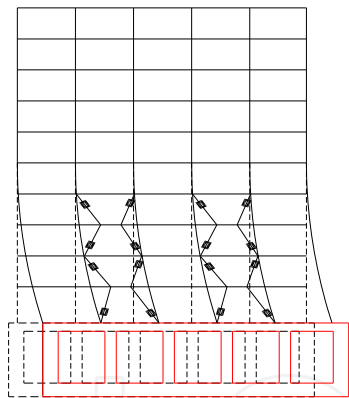


Fig. 2.2. Alternative – eccentric braces

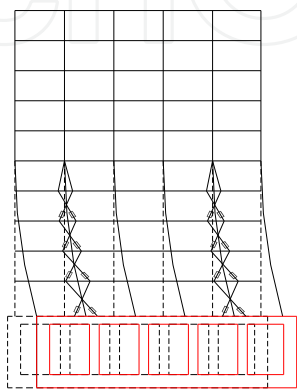


Fig. 2.3. Alternative 2 – strengthening around the nodes





Fig. 2.4. SERB SITON V1 telescopic devices

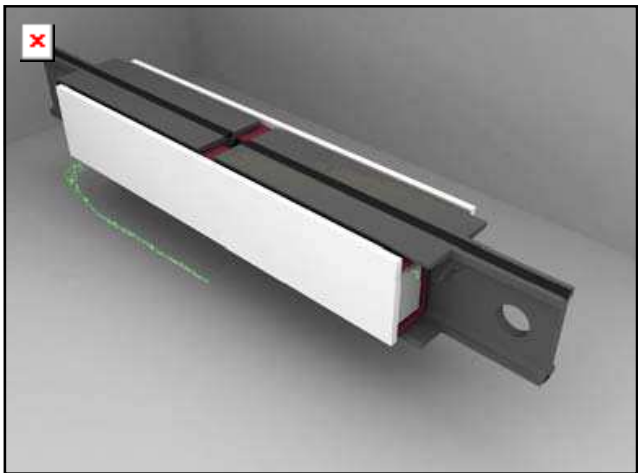


Fig. 2.5. SERB SITON V2 telescopic devices

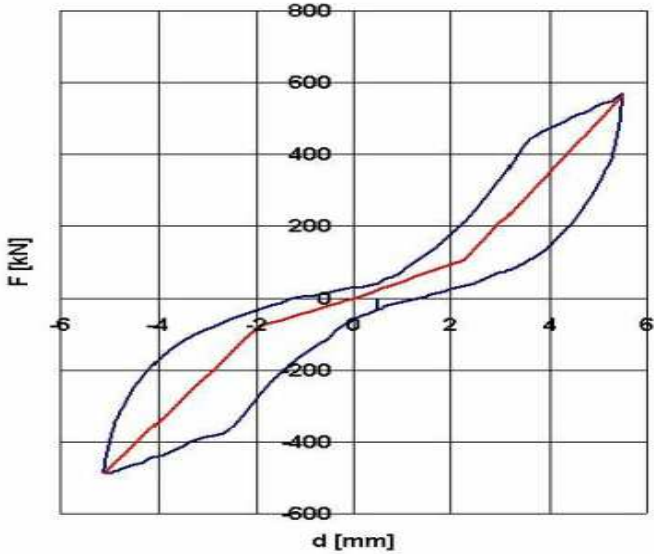


Fig. 2.6. Force-distortion diagram for V1





Fig. 2.7. SERB-SITON V2 isolation device



Fig. 2.8. NAVROM GALATI – ward B – strengthened, extended and rehabilitated.

2.1.2 Alternative 2 - building seismic isolation

The most efficient solution to reduce seismic loads on buildings is “to cut off the transfer of the seismic action from the ground to the building by isolating the building. With this case, the loads on the structures may be reduced tens of times function of the dynamic characteristic of the isolation systems, compared with the kinetic characteristics of the dynamic action.

For the isolation system to be efficient it is necessary that the system should satisfy the following requirements:

- the eigen vibration period  $T_i$  of the supra-structure – isolation device assembly should be about three times greater than the eigen vibration period  $T_r$  of the supra-structure embedded at the isolation level and respectively three times greater than the corner period  $T_c$  in the ground response spectrum;

- the isolation devices should provide the overtaking of permanent loads with no distortion on vertical, over which tensile and compression dynamic loads overlap also providing a sufficient displacement on horizontal plane;

SERB SITON isolation system is a non-linear system which can provide very large vibration periods, with large capacity of reverting to initial position and rather small relative damping lest the seismic action should be transferred from the ground to the building via the damping forces.

Limitation of site displacements to reset values as well as the revert to the initial balanced position are provided by non-linear elements with the stiffness increasing with the displacement increase, making part of the isolation device.

SERB-SITON type isolation system is made by mechanical devices which do not include safety components that may be negatively affected by ageing and sometimes radiations, humidity or temperature. They are capable to overtake permanent loads, up to 5000KN over which tensile and compression dynamic loads of  $\pm 1500$  KN are overloaded and which are also allowing translations in horizontal plane, usually up to  $\pm 300$  mm. Figures 2.9. - 2.11 show 3 alternatives of isolation devices developed by SITON.

*SERB-SITON LP 800 x 800 capsulated isolation device with sliding on plane surfaces* is made up of 2 identical boxes connected between them by a central body with a possibility of relative sliding between themselves, Fig. 2.9.

Sliding between the central body and the box is provided by 5 sliding surfaces between teflon plates confined in steel rings and stainless steel plates which operate in parallel and in series. On vertical direction, the device is stiff and allows compression loads up to 3000 kN over which tensile and compression dynamic loads are overlapped and which, for size reasons, have been limited to 1000 kN.

*SERB SITON RP 1000 X 1000 rolling or sliding capsulated device* is made of 2 identical peripheral boxes which are coupled to a central box. These boxes are connected between them by axial ball bearings or metal profiles Teflon coated which provide the overtaking of a permanent load up to 5000 kN over which tensile and compression loads of  $\pm 1500$  kN may overlap. Displacement on any direction in horizontal plane is  $\pm 300$  mm, Fig. 2.10.

*Isolation device of swinging (pendular) pillar type with controlled elasticity and damping top and bearing.* Swinging pillars, usually made of reinforced concrete, have a top and a bearing made of mechanical devices with controlled elasticity and damping for all the degrees of freedom. The translation of the isolated supra-structure in the horizontal plane is accomplished by the controlled and damped rotation of the mechanical devices on top and bearing, Fig. 2.11. Each device is provided with 4 non-linear elastic stops with strengthening in order to elastically limit the swinging vibrations to preset values. As an additional safety measure for the swinging pillars, the isolation system may be provided with a brace system with tilted telescopic devices capable to provide additional control and safety.

Strengthening of a building by isolation employing swinging pillars shows the advantage that it can be applied by substituting the existing pillars with swinging pillars step by step for a level of frame structure buildings.

Stability of the building is given by the stiffness of the hinges on top and pillar bearing as well as by the isolated supra-structure weight due to the fact that rotation on top and bearing is accomplished around some rigid elements with preset geometry arranged in elastic blade packages which can provide rotation with a slight rise of supra-structure. Reverting to undistorted position is provided both by the elastic system bearings and top and the supra-structure weight which operate as a stability element through the stability moment.



Fig. 2.9. SERB - SITON LP 800 x 800 capsulated isolation device with sliding on plane surfaces

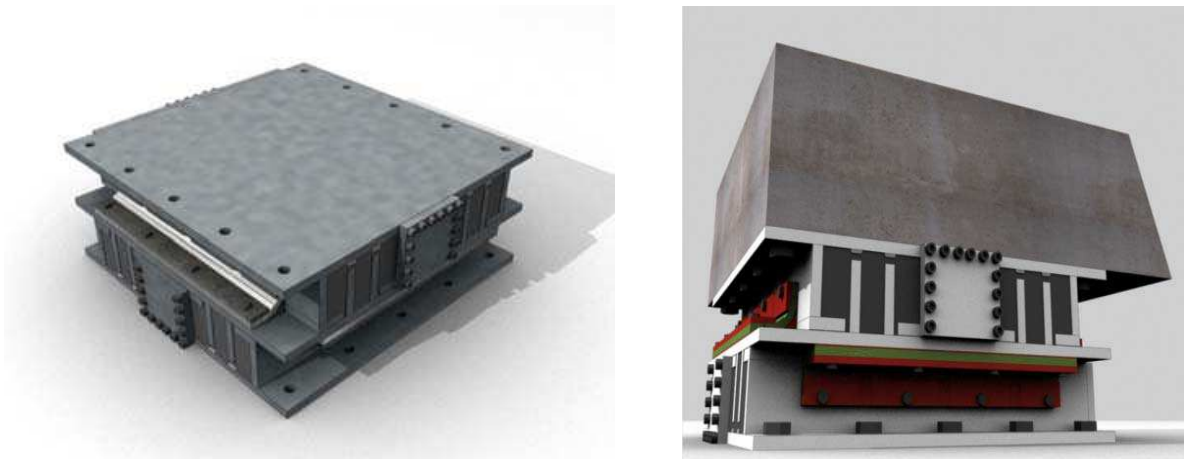


Fig. 2.10. SERB SITON RP 1000 x 1000 rolling or sliding capsulated device

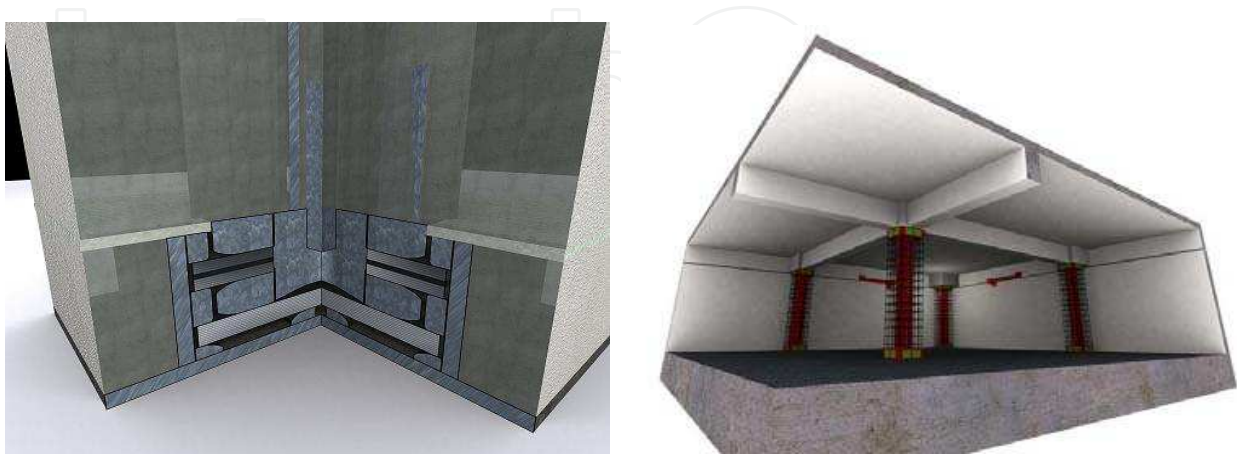


Fig. 2.11. Isolation device of swinging (pendular) pillar type with controlled elasticity and damping top and bearing



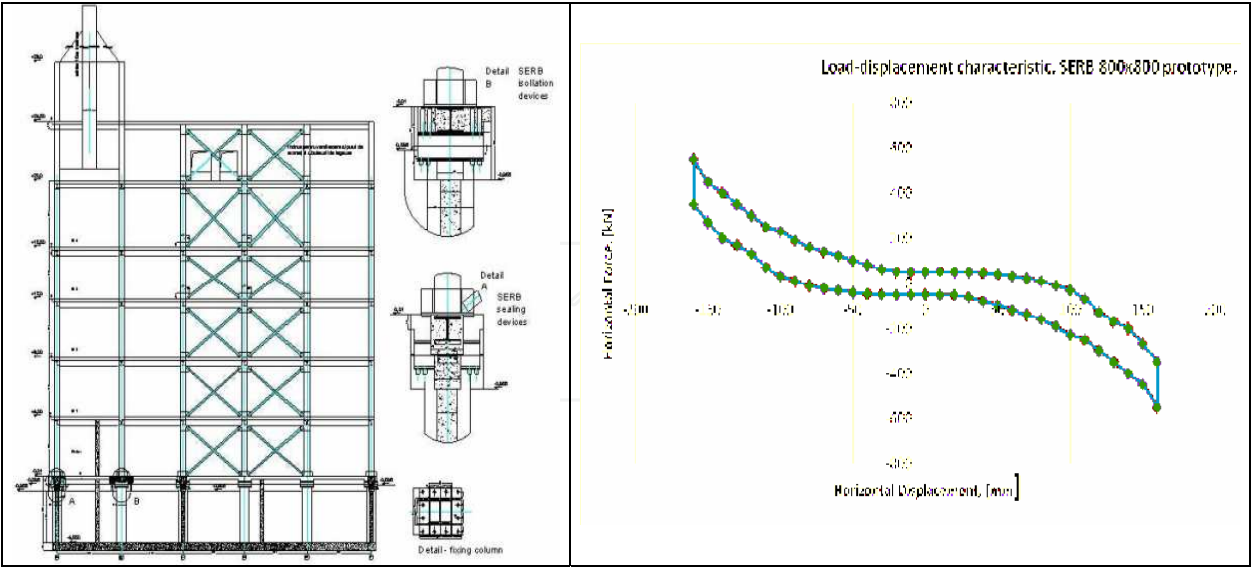


Fig. 2.12. Case study and horizontal hysteresis diagram of the insulator with slides

In order to evaluate the insulating system’s efficiency, a case study was conducted for the NPP Cernavoda detritiation building. Fig. 2.12 presents the analyzed insulating system and the horizontal hysteresis diagram of the insulating system.

An analysis was conducted for a site specific design accelerating diagram and for a sinusoidal accelerating diagram with a maximum ground acceleration on two perpendicular directions on a horizontal plan of 0.3 g, values of 50% higher than the design basis acceleration for DBE.

Following the numeric analysis performed for the rolling insulators on plain surfaces, a seismic acceleration was obtained which operates over the insulating system of 0.3g, the response in acceleration is of 0.02g, according to Fig. 2.13. and the response in relative movements between insulated infrastructure and supra-structure is of maximum 10mm, as in Fig. 2.14.

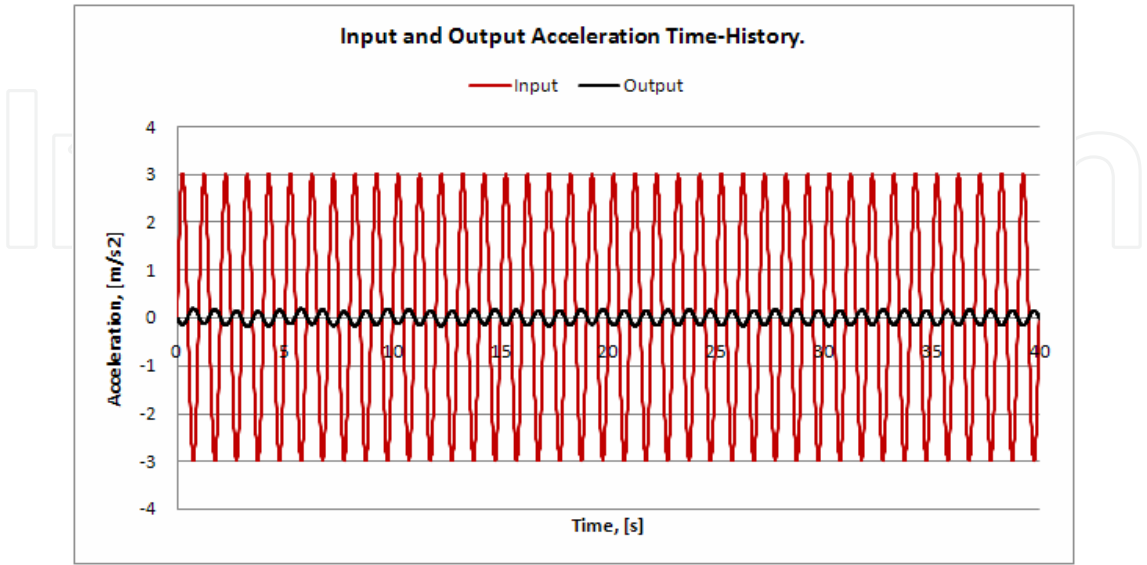


Fig. 2.13. Rolling insulators over plain surfaces. The ground acceleration = 0.3g; Acceleration of insulated supra-structure = 0.02g, for a sinusoidal acceleration diagram

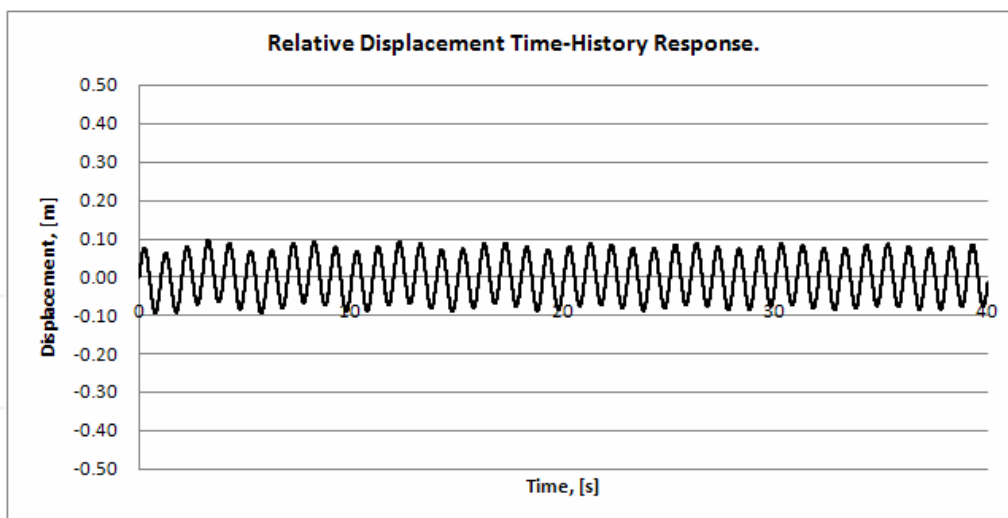


Fig. 2.14. Rolling insulators over plain surfaces. Relative movement (between insulated supra-structure and ground imbedded infrastructure) = 0.1m of the insulating system for a sinusoidal acceleration diagram

## 2.2 Reduction of the dynamic report of equipments and piping network using SERB-SITON devices

For equipments and piping network, the seismic loads, shocks and vibrations have a larger percentage in load groups than in constructions, (Panait et Serban, 2006). Moreover, in many cases, the qualifying solutions for equipments and piping network for dynamic charge-discharge are in contradiction with their qualifying solutions for charges resulting from thermal expansions, their application being possible by imposing the extra-requirements for the devices used.

Usually, the devices for the reduction of the dynamic response, which for equipment and ducts are called bolsters, must also allow movements in thermal expansion (which besides the takeover and damping of dynamic actions are large because of temperature variations). SERB-SITON bolsters may absorb the elasticity with pre-settled rigidity, permanent charges (usually from self weight), allow movement in thermal expansions on a direction or in a plan with elastic reactions or constant dynamic charges that they absorb. Depending on the percentage of the dynamic charge, in the group of charges and its cinematic characteristics, a few bolster (devices) options are presented below.

### Alternative 1 – Bolster for heavy equipment support, which undergoes shocks and vibrations

Usually, heavy equipments are placed on bolsters with horizontal action limiting device. In Fig. 2.15. the cassette bolster type for large loads is presented and in Fig. 2.16. the individual bolster type for large capacities. These bolsters have a non-linear and asymmetric conduct with large absorption. Insulation of heavy equipment like mould hammers lead to the obtaining of a 98 % insulation.

Alternative 2 – For the support of medium or small weight equipment, the bolts in Figs. 2.17. – 2.20. were developed which can also take over the movement in thermal charges of the ducts connected to equipment. The rigidity, the absorption and the movement allowed in any degree of freedom may be reached in the desired values on bolster types. The tunings for equipment horizontality or co-axiality of trees can be done by pre-restraining of bolsters.



Fig. 2.15. Alternative 1 for bolster and cassette equipment



Fig. 2.16. Alternative 2 bolster for heavy equipment



Fig. 2.17. Alternative 1 – isolator for cabinet





Fig. 2.18. Alternative 1 - light and medium weight equipment



Fig. 2.19. Alternative 2 - medium equipment bolster

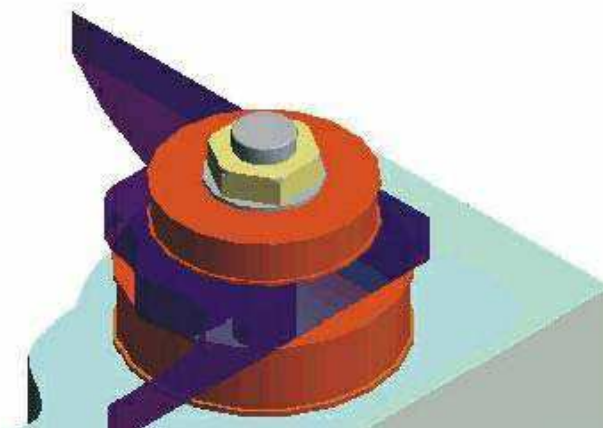


Fig. 2.20. Alternative 1 - catch of the equipment sole

*Alternative 3* - For the catch of the pipes and columns to which vibration and thermal expansion movements are imposed in pre-established values for certain directions, the bolsters in Figs. 2.21. - 2.23. are developed. The thermal expansion movement or seismic movements of catch points can be made with constant or elastic reactive forces of pre-established values.



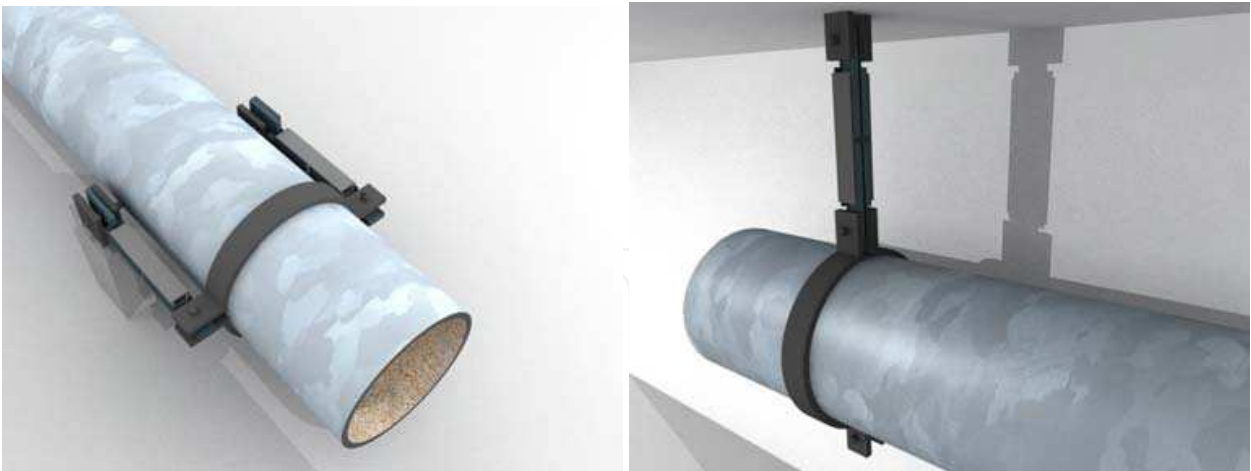


Fig. 2.21. Alternative 1, 2 – Bolster equipment

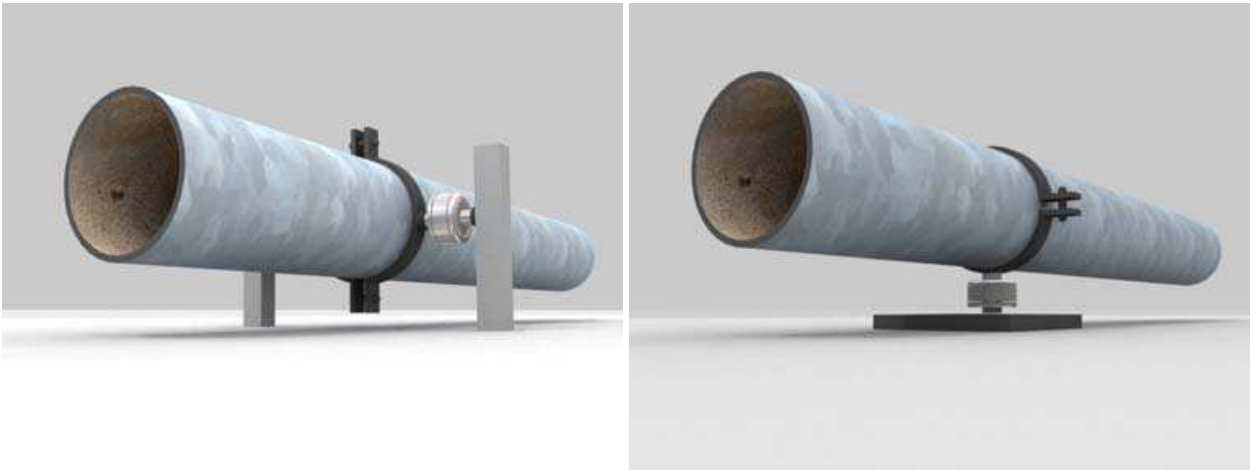


Fig. 2.22. Alternative 3,4 – Bolster equipment

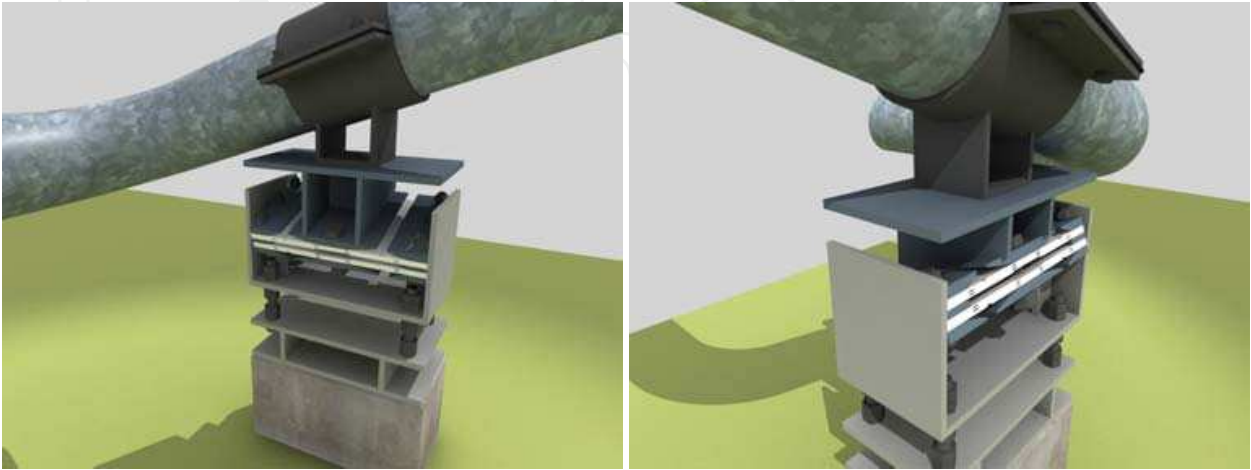


Fig. 2.22. Alternative 5,6 – Bolster equipment

### 3. Dynamic analysis of structures subjected to Time-History acceleration

The structure in time behavior at dynamic actions, controlled by non-linear mechanical devices with large absorption and to which the shaping force is hysteresis type with consolidation (not degrading), can be done analytically through specific mathematical models, which can take into consideration the increase of rigidity along with an increase in deforming. The present commercial computing programs allow the use of non-linear materials and devices behavior, with only degrading hysteretic characteristics because the mathematical methods used for integration do not allow the use of hysteresis curves with strengthening because these lead to numeric instability.

The new computing method of structures is simple, containing a limited number of masses and elements of rigidity aligned on a vertical line, in which are included the hysteresis curves with rigidity increase, once with an increase in deforming, associated to the non-linear mechanical and absorption devices. Considering the behavior in materials elasticity and the fact that only devices have non-linear behavior, these models are representative for structures.

The proposed mathematical method is the direct and simultaneous integration of non-linear differential equations, which include the uni-dimensional model of structure simultaneously with the hysteresis curves with the rigidity increase, mathematically shaped through Bouc-Wen models, (Sireteanu et al., 2008).

### 4. BOUC-WEN model

The Bouc-Wen model, widely used in structural and mechanical engineering, gives an analytical description of a smooth hysteretic behavior. It was introduced by Bouc (Bouc, 1967) and extended by Wen (Wen, 1976), who demonstrated its versatility by producing a variety of hysteretic characteristics. The hysteretic behavior of materials, structural elements or vibration isolators is treated in a unified manner by a single nonlinear differential equation with no need to distinguish different phases of the applied loading pattern. In practice, the Bouc-Wen model is mostly used within the following inverse problem approach: given a set of experimental input-output data, how to adjust the Bouc-Wen model parameters so that the output of the model matches the experimental data. Once an identification method has been applied to tune the Bouc-Wen model parameters, the resulting model is considered as a “good” approximation of the true hysteresis when the error between the experimental data and the output of the model is small enough from practical point of view. Usually, the experimental data are obtained by imposing cyclic relative motions between the mounting ends on the testing rig of a sample material, structural element or vibration isolator and by recording the evolution of the developed force versus the imposed displacement. Once the hysteresis model was identified for a specific input, it should be validated for different types of inputs that can be applied on the testing rig, such as to simulate as close as possible the expected real inputs. Then this model can be used to study the dynamic behavior of different systems containing the tested structural elements or devices under different excitations.

Various methods were developed to identify the model parameters from the experimental data of periodic vibration tests. A frequency domain method was employed to model the hysteretic behavior of wire-cable isolators, iterative procedures were proposed for the

parametric identification of a smoothed hysteretic model with slip (Li et al., 2004), of a modified Bouc-Wen model to portray the dynamic behavior of magnetorheological dampers, etc. The Genetic Algorithms were widely used for curve fitting the Bouc-Wen model to experimentally obtained hysteresis loops for composite materials (Horning), nonlinear degrading structures (Ajavakom, 2007) or magnetorheological fluid dampers (Giuclea, 2004 et Kwok, 2007).

In the present work, our primary focus is to give closed analytical relationships to determine the parameters of the Bouc-Wen model such as the predicted hysteresis curves and the experimental loops to have same absolute values of the maximum forces and same coordinates of the loop-axes crossing points. The derived equations can be used for fitting the Bouc-Wen model to both symmetric and asymmetric experimental loops. The asymmetry of experimental hysteresis curves is due to the asymmetry of the mechanical properties of the tested element, of the imposed cyclic motion, or of both factors. In most cases, the identified model output turns out to be a "good" approximation of experimental output. When this approximation is not satisfactory, the obtained parameter values can be used as initial values within an iterative algorithm to improve the model accuracy.

#### 4.1 Fitting the Bouc-Wen model to symmetric experimental hysteresis loops

Suppose the experimental hysteretic characteristic is a asymmetric loop,  $-F_m \leq F(x) \leq F_m$ , obtained for a periodic motion  $-x_m \leq x(t) \leq x_m$ , imposed between the mounting ends of the tested element. The loop-axes crossing points are: A(0,  $F_0$ ), C( $x_0$ , 0), D(0,  $-F_0$ ) and E( $-x_0$ , 0). By introducing the dimensionless magnitudes:

$$\begin{aligned} \tau = t/T, \quad \xi(\tau) = x(\tau T)/x_u, \quad \xi'(\tau) = d\xi/d\tau, \quad z(\xi) = F(x_u \xi)/F_u, \\ \xi_m = \max|\xi(\tau)|, \quad z_m = \max|z(\xi)|, \quad \xi_0 = x_0/x_u, \quad z_0 = F_0/F_u \end{aligned} \quad (4.1)$$

Where,  $T$  is the period of the imposed cyclic motion and  $x_u, F_u$  are displacement and force reference units such as  $\xi_m \leq 1, z_m \leq 1$ , a generic plot of the symmetric hysteresis loop  $z(\xi)$  can be represented as shown in Fig. 4.1.

The Bouc-Wen model, chosen to fit the hysteresis loop shown in Fig. 4.1., is described by the following non-linear differential equation:

$$\frac{dz}{A - |z|^n [\beta + \gamma \operatorname{sgn}(\xi' z)]} = d\xi \quad (4.2)$$

where  $A, \beta, \gamma, n$  are loop parameters controlling the shape and magnitude of the hysteresis loop  $z(\xi)$ . Due to the symmetry of hysteresis curve, only the branches AB, BC and CD, corresponding to positive values of the imposed displacement  $\xi(\tau)$ , will be considered. The model parameters are to be determined such as the steady-state solution of equation (4.2) under symmetric cyclic excitation to satisfy the following matching conditions:

$$z(0) = z_0 \text{ at A, } z(\xi_m) = z_m, \quad z(\xi_0) = 0, \quad z(0) = -z_0 \text{ at D} \quad (4.3)$$

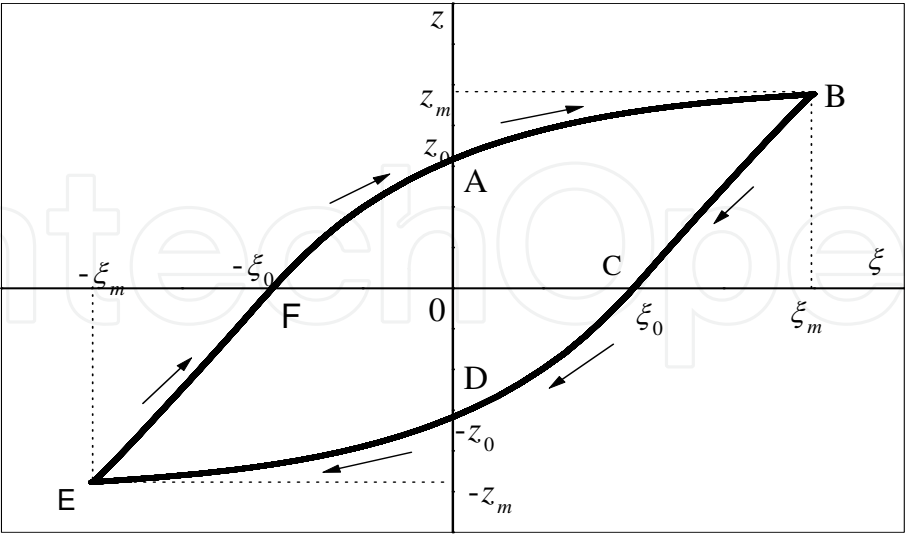


Fig. 4.1. Generic experimental hysteresis loop

Equation (4.2) is solved analytically for  $n = 1$  and 2. For arbitrary values of  $n$ , the equation can be solved numerically. In the present work, the proposed method for fitting the solution of equation (4.2) to the experimental hysteresis loop shown in Fig. 4.1., is illustrated for  $n = 1$ . Introducing the notation:

$$\sigma = \beta + \gamma, \delta = \beta - \gamma \tag{4.4}$$

the equation (4.2) takes on three different forms for each the three branches AB, BC and CD shown in Fig. 4.1.:

$$\text{AB: } \frac{dz}{A - \sigma z} = d\xi, \text{ BC: } \frac{dz}{A - \delta z} = d\xi, \text{ CD: } \frac{dz}{A + \sigma z} = d\xi \tag{4.5}$$

From equations (4.5) one can calculate straightforward the slopes  $\alpha_1$  and  $\alpha_2$  of AB and BC branches in the point B:

$$\alpha_1 = \left. \frac{dz}{d\xi} \right|_{\substack{\xi \rightarrow \xi_m \\ \text{on AB}}} = A - z_m \sigma, \alpha_2 = \left. \frac{dz}{d\xi} \right|_{\substack{\xi \rightarrow \xi_m \\ \text{on BC}}} = A - z_m \delta \tag{4.6}$$

Since the condition  $\alpha_1 < \alpha_2$  holds for any physical hysteresis loop, from equation (4.6) one obtains  $\sigma > \delta$ . Therefore, the Bouc-Wen model can portray a real hysteretic behavior only for positive values of parameter  $\gamma$ .

Integration of equations (4.5) on each branch yields three different relationships between the parameters  $\xi_m, \xi_0, z_m, z_0$ , measured on the experimental loop, and the Bouc-Wen model parameters  $A, \sigma, \delta$ .

#### 4.2 Fitting the Bouc-Wen model to asymmetric experimental hysteresis loops

Suppose the experimental hysteretic characteristic is a asymmetric loop  $-F_{m2} \leq F(x) \leq F_{m1}$ , obtained for a periodic motion  $-x_{m2} \leq x(t) \leq x_{m1}$ , imposed between the mounting ends of the tested element. As before, the loop-axes crossing points are: A(0,  $f_0$ ), C( $x_0$ , 0), D(0,  $-f_0$ ) and E( $-x_0$ , 0).

With notations similar to (1), the asymmetric hysteresis loop  $z(\xi)$  is modeled by:

$$\begin{aligned} z(\xi) &= \frac{1}{2} z_1(\xi_1) [1 + \text{sign} \xi_1] + \frac{1}{2} z_2(\xi_2) [1 - \text{sign} \xi_2], \\ \xi(\tau) &= \frac{1}{2} \{ \xi_1(\tau) [1 + \text{sign} \xi_1] + \xi_2(\tau) [1 - \text{sign} \xi_2] \} \end{aligned} \quad (4.7)$$

where  $z_1(\xi)$  and  $z_2(\xi)$ , are the solutions of the symmetric Bouc-Wen equations:

$$\frac{dz_1}{A_1 - |z_1| [\beta_1 + \gamma_1 \text{sgn}(\xi'_1 z_1)]} = d\xi, \quad \frac{dz_2}{A_2 - |z_2| [\beta_2 + \gamma_2 \text{sgn}(\xi'_2 z_2)]} = d\xi \quad (4.8)$$

For each of these equations, the loop parameters are determined according to the fitting algorithm presented in the previous section. As the loop-force axis crossing points of both branches have same coordinates,  $z(\xi)$  is continuous in these points. By using equations (4.8), the continuity conditions of its derivative in these points lead to:

$$A_1 - z_0 \sigma_1 = A_2 - z_0 \sigma_2, \text{ where } \sigma_1 = \beta_1 + \gamma_1, \sigma_2 = \beta_2 + \gamma_2 \quad (4.9)$$

As the parameters  $A_1, \sigma_1, A_2, \sigma_2$  are uniquely determined such as  $z(\xi)$  to have imposed extreme values and axes crossing points, one must take into consideration a trade-off between these requirements and curve smoothness condition (4.9), such as to minimize a given accuracy cost function. This optimization of Bouc-Wen model fitting to asymmetric experimental hysteresis loops can be approached by iterative or Genetic Algorithms methods.

#### 4.3 Application to experimental asymmetric hysteresis loops

The fitting method was applied to identify the differential Bouc-Wen models, which portray the hysteretic behavior of two vibration control devices: SERB-B-194 for earthquake protection of buildings by bracing installation (Serban et al., 2006), and SERB-B 300C for base isolation of forging hammers. The results presented in Figs. 4.2 and 4.3 prove the efficiency of the proposed method for fitting experimental hysteresis loops. Only a few iterative steps were needed in order to obtain a good approximation of experimental data.

### 5. Application and characteristics

The new technology developed by SITON has been applied by now in classic and nuclear objectives as follows:

- In 2003, the isolation of vibration shocks and seismic actions of a forging hammer located in IUS Brasov-Romania, and having the weight of 360kN which, as per the initial foundation solution, the shocks generated by the hemmer blow were transferred



Fig. 4.2. Vibration control device SERB-B-194

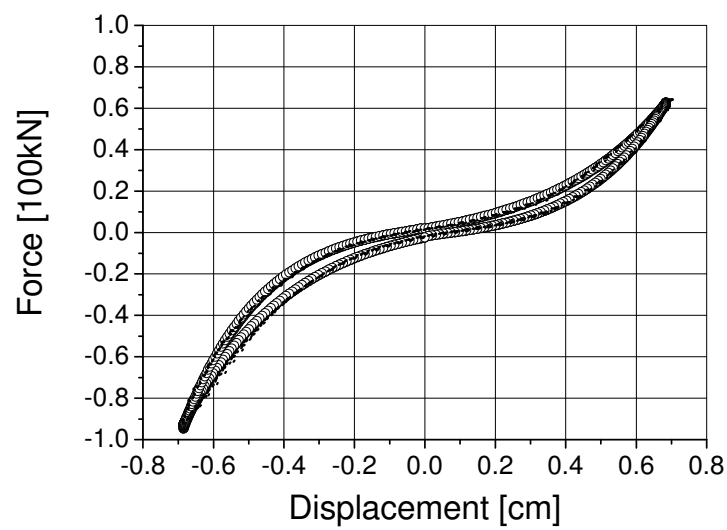


Fig. 4.3. Fitting the hysteretic characteristic of vibration control device SERB-B-194.

— analytical model:  $A_1 = 0.22, \beta_1 = -3.6, \gamma_1 = 0.7; A_2 = 0.28, \beta_2 = -3.9, \gamma_2 = 0.7$   
..... experimental data:  $\xi_{m1} = \xi_{m2} = 0.69, z_{m1} = 0.65, z_{m2} = 0.92, \xi_0 = 0.07, z_0 = 0.02$



Fig. 4.4. Device SERB-B 300C



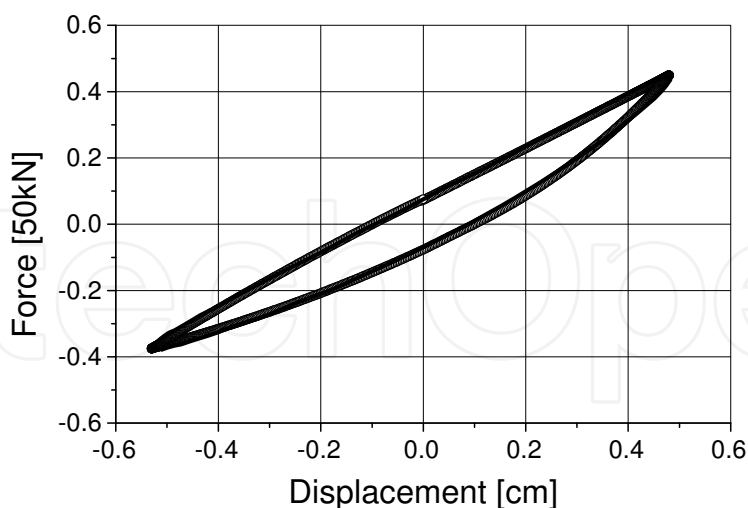


Fig. 4.5. Fitting the hysteretic characteristic of vibration control device SERB-B 300C.

- analytical model:  $A_1 = 0.77$ ,  $\beta_1 = -1.1$ ,  $\gamma_1 = 1.05$ ;  $A_2 = 0.80$ ,  $\beta_2 = 0.3$ ,  $\gamma_2 = 0.7$   
 ..... experimental data:  $\xi_{m1} = 0.48$ ,  $z_{m1} = 0.45$ ,  $\xi_{m2} = 0.53$ ,  $z_{m2} = 0.37$ ,  $\xi_0 = 0.1$ ,  $z_0 = 0.07$

to the near-by building (300 m and 800 m distance) and were resulting in the vibration of the building floors by a speed up to 52 mm/sec exceeding by 3,5 times the allowable limit of 15 mm/sec. After having installed SERB-SITON isolation devices, the value of the building floor vibration speed was reduced down to 6,75 mm/sec;

- also in 2003, the isolation against shocks, vibrations and seismic actions of pressurized air inlet and outlet pipes to the forging hammer. By the installation of the isolation devices the volume compensator on these pipes with an average service-life of 30 days were eliminated and the costs related to the maintenance and repairs were reduced;
- In 2005 a similar work with the one in 2003 for another forging hammer. The adopted solution was more performant meaning that the values of the building floor vibration speed was reduced to 0.085mm/sec from 52mm/sec. The isolation rate experimentally determined is 89%;
- Between 2005-2006 the strengthening, extension and rehabilitation of an old reinforced concrete framework building in order to withstand violent earthquakes with a 0.29g acceleration on 2 orthogonal directions in horizontal plane. Strengthening was done by inserting a small number of panels braced by SERB type telescopic devices symmetrically arranged as to the building symmetry plane. SERB device are controlling, limiting and damping the relative level displacements of the building. The columns (pillars) and beams of the building have not been strengthened, except those pertaining to the placed panels which have been lined with metal profiles;
- In 2006, installation of a SERB-SITON type of support on the pipe 1056 located in Drobeta-Turnu Severin Factory-Romania. After the installation the amplitude of the pipe vibrations was reduced 6 times;
- In 2007, the isolation of the electric and I&C panels associated to the H<sub>2</sub>S compensators in GS3 section in ROMAG PROD against shocks and vibrations and seismic movements



by the use of SERB type sliding supports. After the installation of the seismic isolation devices in the cabinets, the serial components inside the cabinet could be also installed but without verifying the behavior of the cabinet during an earthquake because the seismic acceleration transferred to the cabinet by the isolating;

- In 2008, seismic qualification of COLD-BOX columns for the radioactive tritium separation located in the Cryogenic Research (ICSI) in Ramnicu-Valcea, Romania. The seismic qualification consisted of the installation of 4 SERB supports on each column for to control, limit and damp the swinging movement of the columns during an earthquake;
- In 2009, the isolation of the electric and I&C panels associated to the H<sub>2</sub>S compensators in GS4 section ROMAG PROD against shocks and vibrations and seismic movements by the use of SERB type rolling supports;

## 6. Conclusions

The purpose of this work is to demonstrate that in SITON was developed an innovative method of reduction of dynamic response of structures subject to dynamic actions like shocks, vibrations and seismic movements starting with the new types of devices used for structure isolation and/or dissipation of the energy transferred, up to the use of adequate mathematic models and analysis method that allow a representative evaluation of structures conduct in dynamic actions. The method developed by SITON was checked on physical models, on prototypes on a 1/1 scale and by certain applications in classical and nuclear industry.

This method can be successfully applied to the rehabilitation or achievement/construction of classical and nuclear objectives, because it possesses the following advantages over the current methods:

- Reduces the seismic response of constructions through the enlargement of absorption capacity, including at small and medium deformations as well as through the control and limitation of relative level deformations to small values so as the structure of the building remains in the linear behavior range. Seismic energy is taken over and damped by these devices on a hystheretic cycle;
- The structural element of the construction do not reach local overload which may lead to their degrading and to the appearance of plastic articulations including in case of a violent earthquake, and the construction in functional after an earthquake, exceeding with up to 50% the designed earthquake level;
- The control and limitation of level movements is performed with SERB-SITON mechanical devices, which can be installed either in central and ex-central bracing, or around the nodes of a panel or at the interface between building parts;
- The typical SERB-SITON telescopic devices can take over axial charges of stretch and compression up to 1500 kN and can scatter the seismic energy on a cycle up to 80% of a seismic energy on a cycle. The SERB-SITON isolator devices can take over compression load up to 5000kN and tension load up to 1500kN;
- The consolidation of the constructions can be made without the evacuation of the inhabitants and the time needed for the consolidation is reduces two or three times more than the classic method and the price is lowered with approx. 10-30%;

- The devices for equipment and piping network can be used to isolate these and/or to the reduction of the relative movement; These can take over the movements in thermal expansions with the elastic or constant reaction force;
- The SERB-SITON mechanical devices work efficiently at low speeds as well as high vibrating speed which allows their use without any restrictions, both in case of fast surface earthquakes and slow earthquakes like the intermediary ones or the earthquakes on unconsolidated soft soils;
- The devices are not affected by the aging phenomenon and can be installed including in areas with high radiation flux;
- The devices are safe, cheap, have a low weight and are easy to install unlike the hydraulic absorbers or other devices existent on the market.

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The grandest accomplishments of engineering took place in the twentieth century. The widespread development and distribution of electricity and clean water, automobiles and airplanes, radio and television, spacecraft and lasers, antibiotics and medical imaging, computers and the Internet are just some of the highlights from a century in which engineering revolutionized and improved virtually every aspect of human life. In this book, the authors provide a glimpse of new trends in technologies pertaining to devices, computers, communications and industrial systems.

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