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STRUCTURAL STRENGTHENING OF BUILDINGS FOR FUTURE EARTHQUAKES WITHOUT INTERRUPTING THE ACTIVITIES AND EVACUATION OF TENANTS

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Violent earthquakes generate great direct and indirect material damages, most of them accompanied by loss of human lives.

The current solutions for building structural strengthening take time and involve the interruption of the activities and the evacuation of the tenants for a long period of time.

This paper presents innovative solutions for structural strengthening or the construction of seismically safe buildings employing SERB-SITON mechanical devices.

Key words: buildings, earthquakes, structural strengthening, safety.

1. Introduction

The effect of earthquakes on the buildings is depending both on the intensity of the seismic action and on the response of the building to the seismic action, response which in its turn, is depending on the building damping capacity and on the harmonization or de-harmonization of their eagen movement with the seismic movement.

The seismic movement is a forced dynamic action which is applied on the building base in quite a short time, in an average number of 20-60 cycles of variable amplitude oscillation, with the dominant periods encompassed between 0.1 and 1.6 seconds for the Romanian territory, as per P100/2006 Seismic Design Standard [1].

The excitation may transfer to the building a great quantity of energy per one vibration cycle, equal or smaller than the seismic energy function of the harmonization or de-harmonization of the building eagen movement with the seismic movement kinetics.

According to P100/2006 Seismic Design Standard, the current policy for building protection against earthquakes and for their structural rehabilitation, is to accept controlled damages at code seismic actions known as “ plastic hinges”. The building strengthening consists in lining the structural elements in order to increase their structural capacity and ductility and/or by the insertion of new structural elements. On the other hand, building strengthening as per solutions specified in P100/1006 standard, involves a long implementation time and the evacuation of the tenants from the building subjected to strengthening works.

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Because of the impossibility to provide an alternative temporary living space for the evacuated tenants, the solution is practically impossible to be applied.

Accepting the plastic hinges is a solution which in many cases, is not reliable enough for the case of slow earthquakes such as the Vrancea earthquakes, and other solutions need to be found to dissipate the seismic energy by mechanical devices inserted into the building rather than by the damage of the structural elements. For slow earthquakes with eagen periods dominant in the seismic action ranging between 0.5 – 1.6 sec, the acceptance of plastic hinges may lead to an increase of the energy transfer from the seismic action to the damaged building and to the overload of the structural elements by enhancing the relative level displacements, and finally, to collapsing.

This paper presents a new way to perform the structural strengthening of buildings or to construct new seismically safe buildings. This new solution consists in the control, limitation and damping of the relative level distortions of a building or the isolation of the building by SERB-SITON mechanical devices installed in braces or isolating the building.

2. Mathematical substantiation of the strengthening method

A building subjected to seismic actions is a n oscillating system which is put into a vibration motion by a forced action applied on the base (see Fig. 2.1).

In order to see the way in which the total seismic load (action + response) of the building can be reduced, the building behavior in the domain of time and efficiency on an oscillating system with a degree of freedom subject to a harmonic dynamic action is analyzed.

The simple oscillating system to which the ratio is subject to a harmonic oscillating movement $u_s(t)$ of T_s period.

Write x(t); x'(t); x"(t) and y (t); y'(t) si y"(t) the displacement, speed and relative and absolute acceleration of the system mass, m.

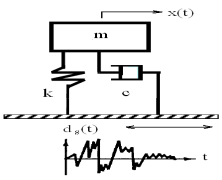


Fig.2.1.One degree of freedon system

In order to point-out the role the dominant period of the oscillating system (building - foundation ground) is having as to the spectral component of the excitation, the duration of the excitation and of the system damping on the system response an analysis of the system behavior in the time frequency domain need to be conducted.

In point of the dynamic components a building may fall-in the resonance range, super-harmonized or under-harmonized as to the seismic movement. Under such circumstances there are two extreme cases: “transport” case when the building is very stiff as to the seismic movement and “isolation” case when the building is very flexible as to the seismic movement.

The oscillating systems may be situated in 5 cases as to the dynamic action:

- Case A - “stiff” system when $0.707 = T < T_s = 1.00$
- Case B - “ half-stiff” system when $0.707 = T < T_s = 1.00$
- Case C - “in resonance” system when $0.90 = T < T_s = 1.00$
- Case D - “half-flexible” system when $1.00 = T = T_s = 1.00$
- Case E - “flexible” system when $1.414 = T > T_s = 1.00$

Figs. 2.2 - 2.6 illustrate the variation of the kinetic and potential energy function of time of the oscillating system for Cases A-E, 5% damping and the diagram 2.7 illustrates the variation of the oscillating system relative displacement in the resonance range for 5%, 10% and 20% damping.

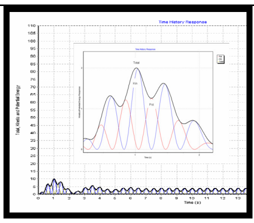


Fig. 2.2. Case A. T=0.707s.Ts=1,0s, $\beta = 5\%$

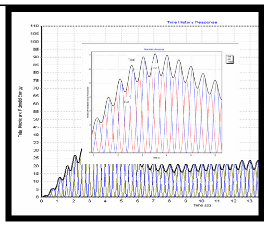


Fig. 2.3. Case B. T = 0.9s. Ts = 1.0s, $\beta = 5\%$

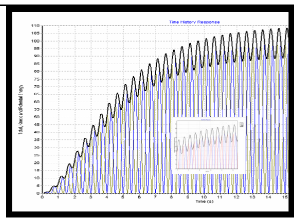


Fig. 2.4. Case C. T = 1s. Ts = 1.0s, $\beta = 5\%$

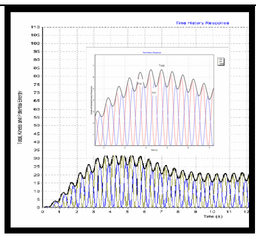


Fig. 2.5. Case D. T = 1,1s. Ts = 1.0s, $\beta = 5\%$

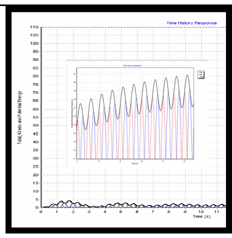


Fig. 2.6. Case E. T = 1.414s. Ts = 1.0s, $\beta = 5\%$

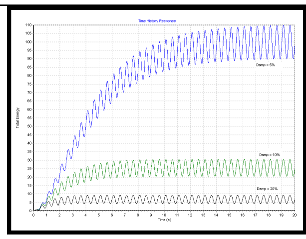


Fig. 2.7. Relative displacemment of the oscilqanty system for $\beta = 5\%$ 10% si 20%. T = T_s = 1.0s

The analysis of an oscillating system in the frequency range is conservative without the analysis in time because it refers to a stationary regime of behavior which, in the case of buildings, many times is not reached during an earthquake because of the small duration of the earthquake, but it offers a better qualitative analysis of the phenomena and allows the substantiation of a new innovative design solution.

The amplitude of the power transferred from the excitation to the oscillating system, Pe, and of the amplitude of the power dissipated, Pd, by the oscillating system are given for one mass unit of the oscillating system, function of the ratio between the oscillating system period and the excitation period, T/TO, for a 5% fraction of the critical damping, β de 5%, in Fig 2.8 and 20% in Fig.2.9.

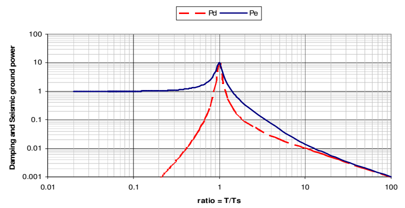


Fig 2.8. Pe amplitude and Pd amplitude function of T/Ts for $\beta = 5\%$

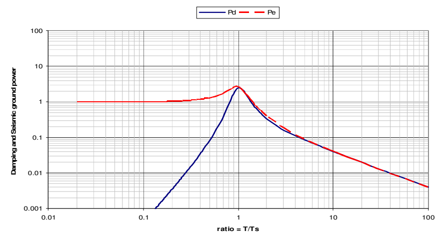


Fig. 2.9. Pe amplitude and Pd amplitude function of T/Ts for $\beta = 20\%$

3. Building Strengthening According To SERB-SITON Solution

SERB-SITON solution for building strengthening by the control, limitation and damping of distortions, consists in the installation of some telescopic devices into the buildings (Fig.3.1; 3.2) or by building isolation (Fig 3.3.).

SERB telescopic devices [2,3] can be made in a large range of types-dimensions ranging between 1000 – 5000 KN; relative level distortions between ±10 mm to ±20 mm; non-linear geometric force-distortion characteristic; 30%-80% damping dissipated energy of the elastic energy associated to the oscillation cycle. The force-distortion characteristics may be achieved in any desired shape (see fig. 3.4.; 3.6; 3.7; 3.9).

SERB-SITON solution for building strengthening shows the following advantages:

- materials required for strengthening: 1/10 ÷ 1/20 of the materials required for a classic strengthening solution;
- resulted wastes: 1/10 ÷ 1/20 of the wastes resulted from the classical strengthening solution;
- duration of the strengthening works: 1/3 ÷ 1/5 of the classical strengthening solution.

- surface of the site temporary facilities: 1/10 ÷ 1/50 of the surface required with the classical strengthening solution.
- Price: 0.7 ÷ 0.9 of the price of a classical strengthening solution.

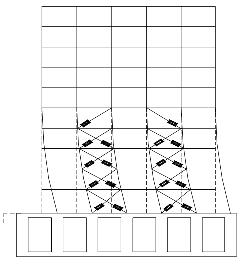
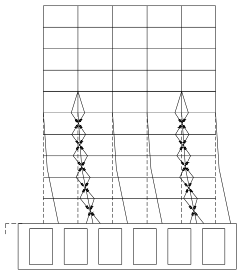
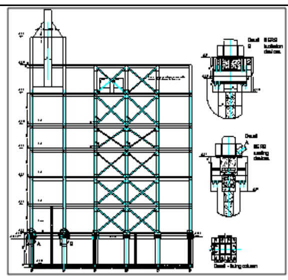
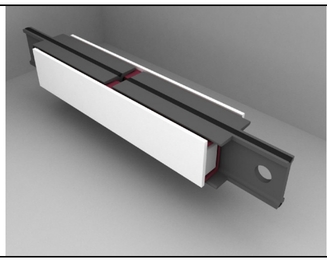
		

Fig. 3.1. Alternative 1 – Installation of device in braces	Fig. 3.2. Alternative 2 – Installation of devices around the nodes	Fig. 3.3. Alternative 3 – Buiding seismic isolation

		
Fig.3.4. SERB-SITON V1 Telescopic Device	Fig.3.5. SERB-SITON V2 Telescopic Device	Fig.3.5. SERB-SITON V3 Isolating devices

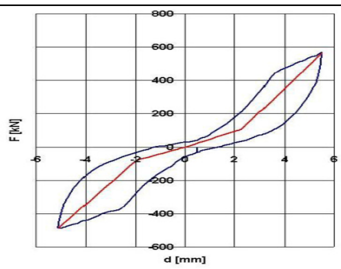
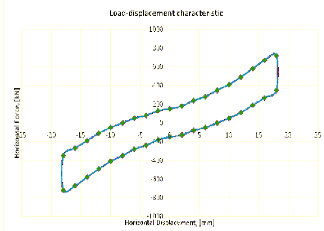
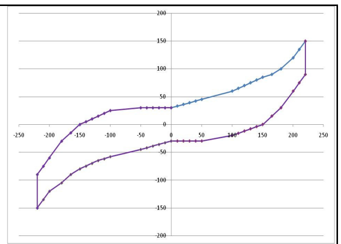
		

Fig.3.6.Force-distantion diagram for V1	Fig.3.7.Force-distantion diagram for V2	Fig.3.7.Force-distantion diagram for V3

The analysis of the diagrams presented in chapter 2 show that one of the most efficient ways for building strengthening to withstand future earthquakes, is the increase of the fundamental vibration period of the building over a dominant period of the seismic movement, increase that can be accomplished by the building isolation. If the isolation of the buildings is not possible, the next efficient way is to enhance the damping capacity so to make the building structure behave in the elastic range.

For the isolation solution result in a minimum energy transfer from the ground to the building and the building energy be less than the seismic energy corresponding to an oscillation cycle of the ground, the eagen vibration period of the building should be 3 times greater than the dominant period of the seismic movement on the building site.

For the territory of Romania which is affected by intermediate Vrancea earthquakes, the dominant period of the seismic movement ranges between 0.7 – 1.6 sec [1] which assumes that the eagen vibration period of the seismically isolated building is greater than 2.1 – 4.8 sec., function of the area in which the building site is located. Moreover, the minimum displacement the isolation system should provide, need to be greater than 5- 20 cm, with a margin which depends on the isolation system and the area the building is located.

For Bucharest the solutions for building isolation should provide a large vibration period (greater than 4.8 sec) case in which the building might vibrate during an earthquake with a maximum acceleration of 0.06g (about 4 times smaller than the ground maximum acceleration). The isolation system should provide a relative displacement of minimum 20 cm between the building infra-structure and supra-structure.

4. Strengthening of ward "b" in NAVROM – GALATZI

The overtaking of the seismic loads of the strengthened and rehabilitated building is made with telescopic brace panels symmetrically arranged on transversal and longitudinal directions as shown in Fig. 4.1 – 4.2.

The transfer of the forces between the telescopic braces and the existing reinforced concrete structure was provided by the provision of some metal lining on the columns. Beams and nodes in the braced panels as per Fig. 4.3.

The analysis on the seismic behavior of the building strengthened by SERB-SITON devices was made on a 3-D non-linear model for a o.24g maximum acceleration on the two directions on the horizontal plane (longitudinal and transversal). The analyses were conducted by SAP Version 7.4 computer program by non-linear direct integration with the independent synthetic time-histories as input. The existing reinforced concrete structure lined with metal profiles show a linear behavior because the relative level displacements are limited to 4‰ of the height of the telescopic brace level 4‰ and there is no plastic hinges, the behavior coefficient being $q = 1,0$.

The soil–structure interaction was entered by a set of springs uniformly distributed in the foundation beam crossing nodes.

The hysteresis curves of SERB-SITON devices with strengthening (see Fig. 3.6) used for Ward B, were modeled by 3 elements: SPRING, HOOK, GAP.

Fig. 4.4. illustrates the vibration modes 2 & 4 for the assembly made-up of the concrete structure and metal structure connected between themselves by

SERB devices and Fig. 4.5 shows the variation of the maximum seismic acceleration with the building height in columns H and F of the reinforced concrete structure.

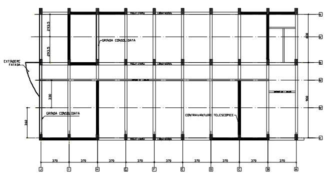


Fig. 4.1. NAVROM-WARD B horizontal section

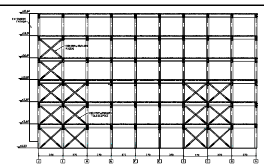


Fig. 4.2.NAVROM-WARD B Longitudinal section– AXIS"c"

Fig. 4.3. NAVROM-WARD B. Telescopic braces of node anchioring details

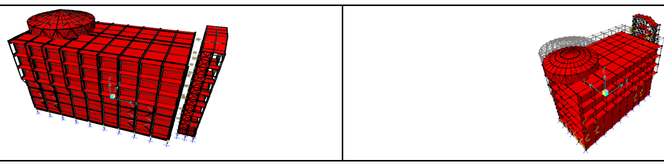


Fig. 4.4. NAVROM-WARD B. Vibration Nodes 2 & 4

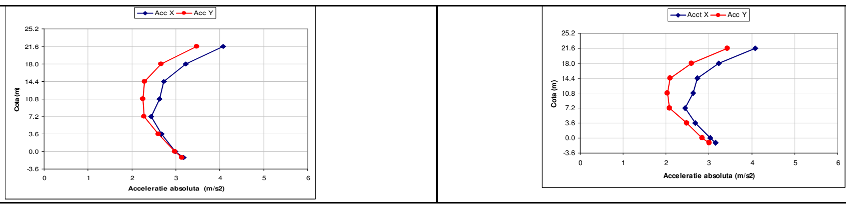


Fig. 4.5. NAVROM-WARD B . Maximum acceleration variations with height. Column H/b & B/b

5. Conclusions

1. The efficient solutions to reduce the seismic response of a building are the seismic isolation or the increase of the damping capacity while maintaining the structural elements within the linear load range.

2. The innovative SERB-SITON method to construct/strengthen the building shows the following advantages:

- strengthening of the building can be carried-out without evacuating the tenants;

- reduction of seismic loads by cutting-off the transfer of the seismic action from the ground to the building or by increasing the damping capacity;
- the structural elements of the building do not reach the local overloading that may lead to their damaging and to the occurrence of plastic hinges;
- easy fabrication process by the use of low quantities of materials and consequently small quantities of wastes;
- the construction time and costs are low.

3. For the innovative strengthening solutions may be applied, first it is necessary that the evaluators of the building technical condition should include the solutions in the technical expertise report.

R E F E R E N C E S

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