THE USE OF DAMPER SYSTEMS IN BUILDINGS WITH REINFORCED CONCRETE STRUCTURES

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Abstract: This study aims to emphasize, by means of a comparative study, the efficiency of some damper systems as modern variants of consolidation / seismic structural safety enhancement used for buildings with reinforced concrete structure designed and erected according to the P13-type standards (from 1963) and considering this as an alternative possibility instead of retrofitting with reinforced concrete jackets (with significant implications for most of the structural elements at all levels of buildings). Damper devices are elements that can be easily replaced later in case of damage. Case studies were made, based on structural calculations in the linear elastic field, using the ETABS program.

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Introduction

Frame structures designed and made according to the P13-63 standard are characterized by insufficient rigidity and side resistance as compared to the seismic requirements valid around Romania without an efficient control of the structural energy dissipating mechanisms. As a rule, pillars have an insufficient cross-section and frames are the “weak pillars-strong beams” type. Due to the insufficient section and reinforcement, pillars reach the breaking point from shearing force before the expansion of the plastic joints. The high value of the normalized compression force and the insufficient joints of vertical reinforcements also contribute to the expansion of this phenomenon. The main purpose of the carried out studies is to identify if such dissipative elements can be used in order to consolidate the buildings, and be considered the more efficient way of putting it into operation.

This paper focuses on several of the modern structural safety provision methods used today (B).

Methods for ensuring the structural safety

The structural assessment of these types of structures, according to the existing seismic norms, shows that rehabilitation is needed in approximately all cases (P100-3:2008 Code of assessment and design of consolidation works on existing, seismically vulnerable buildings).

The purpose of consolidation is to impose a favorable structural mechanism of energy dissipation – in this case, the expansion of plastic areas at the beam end areas and at the pillar basis. Another purpose is to increase the lateral resistance, the rigidity and plastic deformation capacity of the structural elements and of the structure assembly (Florescu et al.,2018).

The P100-3:2008 standard, Code for the assessment and design of consolidation works for seismically vulnerable existing buildings, vol. 2 – Consolidation proposes as valid solutions for action on reinforced concrete structures the consolidation of reinforced concrete structures, the actions which do not involve a change of the structural system: reinforced concrete casing; steel casing; casing with fiber reinforced polymers (FRP), the actions involving a change of the structural system- mounting of steel bracings; mounting of reinforced concrete structural walls, the seismic rehabilitation of the buildings using energy dissipation systems; the seismic insulation of the structure basis.

Methods of ensuring the structural safety of buildings:

Traditional methods: Reinforced concrete casing of parts; Introduction/implantation of reinforced concrete structural walls.

Modern methods: Fiber reinforced polymer (FRP); Basic seismic insulators; Tuned Mass Dampers (TMD); Dampers.

Fiber reinforced polymers (FRP)

Materials from fiber reinforced polymers have a high potential for the consolidation and rehabilitation of existing structures, due to their high resistance and easy application.

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This consolidation method is used for enhancing the resistance to the shear force of the pillars, beams and walls, by applying FRP with fibers perpendicular on the element axis (parallel to shear force reinforcements), for enhancing the plastic ductility in the potentially critical areas of structural plastic elements, with fibers placed along the perimeter of the cross-sections, in order to improve the performance of reinforcement joints, by increasing the confining applied to the joint area, with FRP with the fibers placed along the perimeter.

FRP covers must be designed so as not to influence the materials' resistance before the development of plastic bending deformations in the reinforced concrete element.

Basic seismic insulators

The fundamental principle of basis insulation is to change the building response so as to determine the movement of the ground below the building, without passing the movement to it. The ideal system would involve total separation but, in reality, there must be some contact areas between the structure and the ground. Thus, structural control can be exerted to a certain extent, with the help of special devices mounted in order to allow the break of the superstructure from the foundations (Hussain and Al Satari,2007).

Seismic insulators determine an increase of the horizontal flexibility of the basis, and thereby an increase of the vibration period, so that the acceleration sent to the structure is significantly reduced.

The seismic insulation may or may not use additional damping. If the insulators have no additional damping, as in the case of elastomer or sliding devices, these can be said to increase the potential for deformation, followed by a corresponding decrease of the seismic action on the structure. With additional damping, devices with high damping are said to dissipate part of the input energy, with the purpose of reducing the amplitude of movements determined by the seismic movement.

Tuned Mass Dampers (TMD)

A tuned mass damper (TMD) is a system made of a mass, a spring and a damper, attached to a structure in order to reduce its dynamic response. The damper frequency is tuned for a certain frequency of the structure, so that when driven, the damper will not vibrate in phase with the structure. The energy is dissipated by the inertial force of the damper applied to the structure (Kourakis, 2007).

Tuned mass damper assisted vibration control may be passive, active, semi-active or hybrid, depending on whether or not an active monitoring system is connected to the tuned mass, or depending on the monitoring strategies adopted for the device.

The device is characterized by mass, rigidity and damping capacity. The damper mass and rigidity with the tuned mass are thus chosen so that the frequency of the device matches the resonance frequency of the structure to be dampened.

TMDs are adapted for use in flexible structures driven by exterior phenomena with disturbing frequency levels that excite their own frequency. The most appropriate forces exerted on the structure are harmonic ones, such as the wind load on tall buildings, or useful loads for pedestrian bridges.

For random sources, such as the seismic movements, specialists can mount TMDs with tuned mass of multiple, active, semi-active or hybrid type. The use of active or semi-active TMDs for earthquakes may be a problem, due to their dependence on a source of energy.

In the case of a translation TMD, the additional mass is placed on bearing blocks with roller function, thus allowing it to produce a translation movement connected to the floor. The springs and dampers are mounted between the mass and the adjacent vertical elements exerting a lateral force to the floor, and then to the entire structural system.

The bi-directional TMD is made of springs and dampers placed along two orthogonal directions, which enables it to control the structure movement along two orthogonal planes.

The efficiency of a TMD can be enhanced by attaching an auxiliary mass and a driving mechanism, so that the response does not come in phase with the response of the tuned mass. The effect expected from putting to work the additional mass is to produce an additional force completing the force generated by the tuned mass; the result is an increase of the damping for TMD.

The semi-active tuned mass damper (STMD*)* can be made by replacing the passive damper device with an adjustable damper device, such as a variable hole, a hydraulic damper or a device using magnetorheological fluid.

The hybrid tuned mass dampers (HTMD) are made by an in-series assembly of active and passive dampers. The mass of the ATMD device is driven by an actuator in the opposed direction to that in which the TMD is moving, thus increasing the damper effect.

The problem related to the damper system supports can be neutralized by mass hanging with cables, thus allowing the system to behave like a pendulum. The floor movement excites the pendulum and its relative movement produces a horizontal force opposed to the floor movement.

Dampers

Dampers are devices which, by absorbing and dissipating a significant part of the seismic energy induced in the structure, are limiting the stress of structural elements.

Types of dampers: hysteretic dampers; friction dampers; viscous (adherent) dampers

Hysteretic dampers

The hysteretic behavior of devices with ductile materials (elastic-plastic devices) is the result of the deforming capacity of the used materials;

The dissipation device absorbs the seismic energy using the plastic deformation characteristics of the highly dissipating metals such as steel, lead and certain special alloys;

The hysteretic dampers can be used both for the passive and the semi-active monitoring of structural systems.

Devices may be used both for buildings and for bridges, thus proving very efficient in the consolidation and restauration of historic buildings. Frame-based structures are used for the following purposes: to reduce the structural response under seismic load, to reduce relative level movements, and to reduce the decay of structural elements as a result of energy dissipation.

Friction dampers

The friction damper dissipates a large amount of energy through the friction between two sliding surfaces (Shao et al.).

The use of a friction damper ensures more damping, thus reducing the lateral inertial forces and vibration amplitude.

These devices are used both for a structural passive and a semi-active monitoring.

In the case of inner structural damping, movements are due to the relative level movements applied to friction dampers. This requires the damper to connect two consecutive levels, the connection being made by structural elements such as diagonals or panels with finite rigidity. The connection is made in series with the damper.

Friction dampers are designed to avoid working under service loads or wind-driven loads. But, in the event of an earthquake, they are activated (at an optimal value of the load, before the penetration of structural elements into the plastic area) and dissipate a large amount of the seismic energy.

Viscous dampers

The viscous damper is made of a closed cylinder filled with a viscous fluid. The fluid may be silicon, oil or any other fluid with controllable viscosity. An arm of the piston is connected to a pierced element. The pressure resulting from forcing the fluid out through the piston head holes determines a damping force which dissipates the energy (Taylor et al.).

Since the damping force only varies with the loading speed, the viscous damper can be classified as an energy-dissipating device depending on speed. In general, the viscous dampers are used as passive monitoring systems but, due to the monitoring of the hole dimensions and fluid viscosity, they can also be used in semi-active monitoring systems.

Viscous dampers are an alternative for the plastifying or break of certain structural elements, as a means to absorb the seismic energy. They can dissipate almost the entire seismic energy, leaving the structure intact and ready for use immediately after the event.

When used for buildings built on frames, these devices have the following purposes: they reduce the structural response under seismic action, along with the relative movements per level and the decay of structural elements as a result of energy dissipation.

Specific problems related to the use of damper-type devices

The traditional approach to design for seismic events is based on ensuring the combination between resistance and ductility for the structural components, and on the acceptance of a certain degree of their destruction in order to dissipate the energy involved.

For any structural system, it would be useful if the dissipation of the energy induced by the earthquake would not be a result of its degradation, but rather be achieved with the help of other non-structural elements introduced in the system. Thus, the operation safety in significantly increased and there are no costs in connection with the post-earthquake rehabilitation.

At present there are many energy dissipators based on various procedures and materials. As a rule, they are characterized by their ability to dissipate the kinetic energy from a system and to turn it into another form of energy.

In order to ensure the proper behavior of energy dissipating devices, they must be placed only in the areas where there are couples of close points, where the relative system movements are large enough.

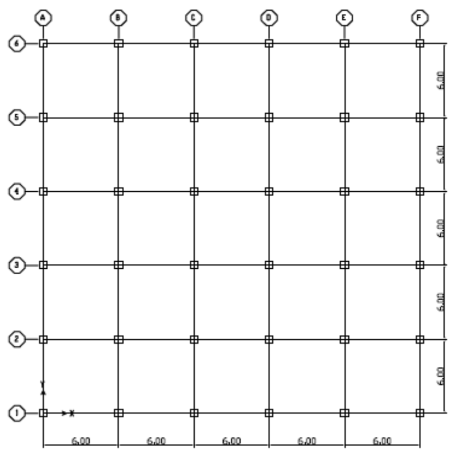
In the case of small intensity events, the role of these devices is to be rigid enough to reduce the relative movements, and to dissipate energy only when the structure is submitted to a high intensity event. If, in certain situations, these two functions of the device do not act together in the building, it is possible to produce devices made of separate elements, with parallel connection, so as to comply with both requirements. If this detail is ignored, low frequencies may appear due to the wind or traffic, thereby resulting in discomfort for the occupants of the building and may also lead to losing the energy dissipating capacity because of fatigue.

Case studies

Description of the structures

For the purpose of this case study we took as examples buildings with reinforced concrete frames, with different height regimes: 5 stories (P+4), 10 stories (P+9), 15 stories (P+14), 20 stories (P+29) and 40 stories (P+39) from Bucharest. The shape of the buildings is symmetrical, with 6m openings on the two directions, while the story height is of 3 m.

Figure 1: Diagram of the current floor of the building



Source: Authors

Loads: Dead: 1.835 kN/m^2: Slab plastering: 0.285 kN/m^2; Flooring: 1.05 kN/m^2; Partition walls: 0.5 kN/m^2; Live loads: 1.5 kN/m^2

Phases of the studies:

- Structure analysis according to P13-63;
- Structure analysis according to P100-1:2006;
- Analysis of the structures equipped with energy dissipators

Phase I: Structure analysis according to P13-63

In the first phase, we started from the premise that the 6 buildings were designed and built according to P13-63 standard, with a basic seismic coefficient of C_B=5%.

Table 1: Pre-sizing of the structural elements of the building

Levels	Nb [kN]	fcd [kN/m²]	As,nec [m²]	Pillar size [cm]	Beam size [cm]	Plate thickness [cm]
5	1980	20000	0.33	60x60	25x60	15
10	3960	20000	0.66	80x80	25x60	15
15	5940	20000	0.99	100x100	25x60	15
20	7920	20000	1.32	120x120	25x60	15
30	11880	20000	1.98	140x140	25x60	15
40	15840	20000	2.64	160x160	25x60	15

Source: Ezzaki, 2018

The analysis made with the ETABS program gave the following vibration periods, with movement in the first two vibration modes and torsion in the third vibration mode.

Table 2: Fundamental vibration periods

	Vibration period (sec.)					
	P+4	P+9	P+14	P+19	P+29	P+39
T1	0.614126	1.16745	1.70851	2.247298	3.44232	4.685634
T2	0.614126	1.16745	1.70851	2.247298	3.44232	4.685634
T3	0.54784	1.032182	1.49208	1.929241	2.862054	3.72865

Source: Ezzaki, 2018

Phase II: Analysis of the structures according to P100-1:2006

In the second phase, calculations were made for each of the 6 models, the seismic coefficient being computed according to P100-1:2006, in order to show the building behavior at this moment.

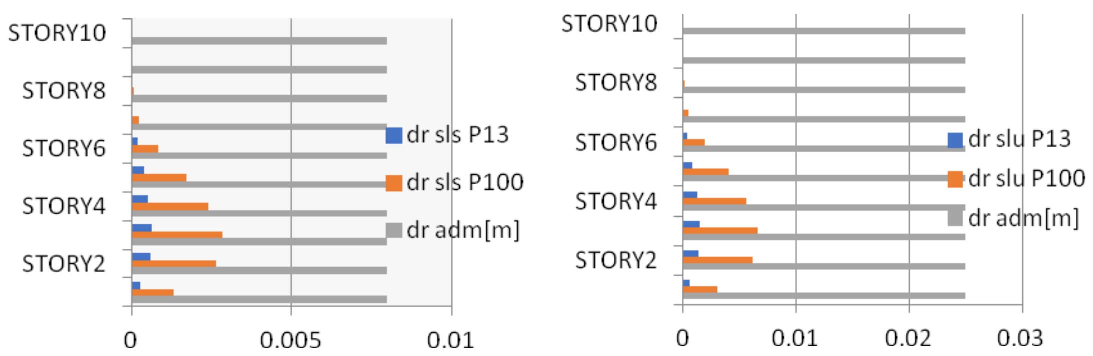
$$C_B = \frac{\gamma I * \beta * ag * \lambda}{q_{constr.exist}} = \frac{1 * 2.75 * 0.24 * 0.85}{2.5} = 22.44\% \quad \text{(P100-3:2008)}$$

We compared the relative level movements and stresses in the structural elements between the structure made according to P13-63 and the one designed according to P100-1:2006:

Relative level (story) movements

The stiffness was checked according to the seismic design code P100-1:2006, annex E, which states that the maximum relative movement along the two main directions, dr. LSS and dr. ULS, must not exceed the admissible value set for the Limit Service State (LSS) as dr.adm. LSS=0.008* h_{level}=0.024m, while the value admissible for the Ultimate Limit State (ULS) must be dr.adm.ULS=0.025* h_{level}=0.075m (Figure 2).

Figure 2: Test of the limit service state and of the ultimate level state for a 10-story building



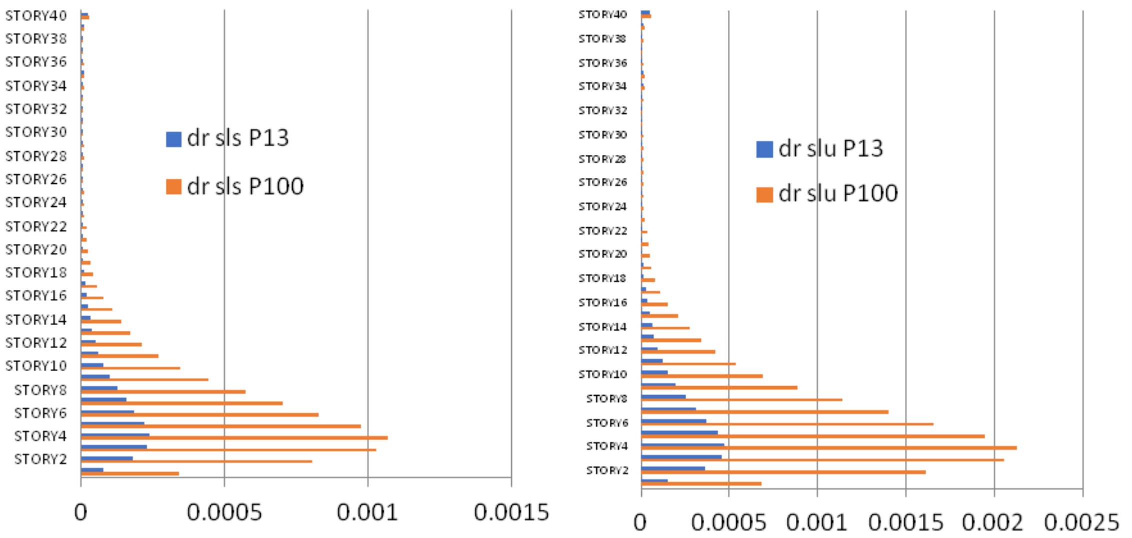
Source: Ezzaki, 2018

The diagrams show a comparison of the relative level movements for all the height regimes taken into account, both for the structure according to standard P13-63 and for the one built according to P100-1:2006.

In each case, movements in the limit service state and ultimate limit state were checked, for buildings observing the provisions of both P13-63 and P100-1:2006.

For the cases under analysis, movements do not exceed the admissible values established by the standard but increased relative movements per level by 1.15÷4.75 can be seen in the case of buildings calculated with the basic seismic coefficient P100-1:2006 (Figure 3).

Figure 3: Test of the limit service state and of the ultimate level state for a 40-story building

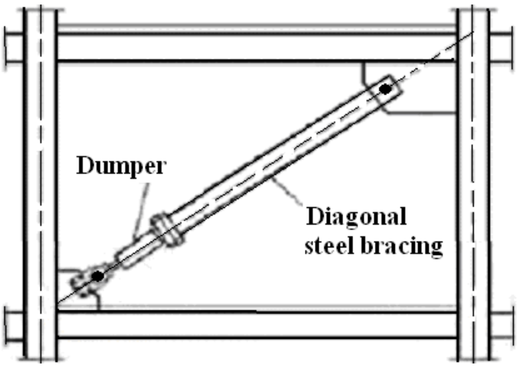


Source: Ezzaki, 2018

Phase III: Analysis of structures equipped with energy dissipators

The structural and non-structural damage induced by strong earthquakes is a direct consequence of the deformation of building elements. In order to reduce the damage to a minimum, and implicitly to limit the direct losses produced by strong earthquakes it is necessary to limit deformations through a constant monitoring of the lateral movements of the building. The monitoring of these lateral movements can be made either by increasing the structure rigidity, or by reducing lateral movements with a supplementary viscous damping of the building. This supplementary damping can be made with the help of viscous fluid dampers placed in the resistance structure of the building, the seismic energy dissipating systems being adequate for relatively flexible structures (P100-3:2008). For the present study we chose the mounting of viscous fluid dampers in the external frame (perimetral) openings, as a method for the consolidation of buildings with a reinforced concrete frame. They were mounted in the centric diagonal structures (Figure 4):

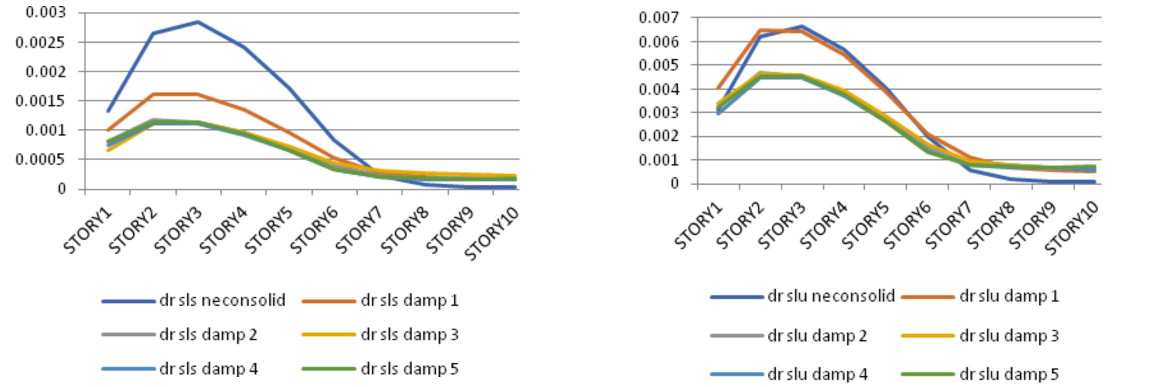
Figure 4: Damper mounted in a diagonal steel bracing



Source: Ezzaki, 2018

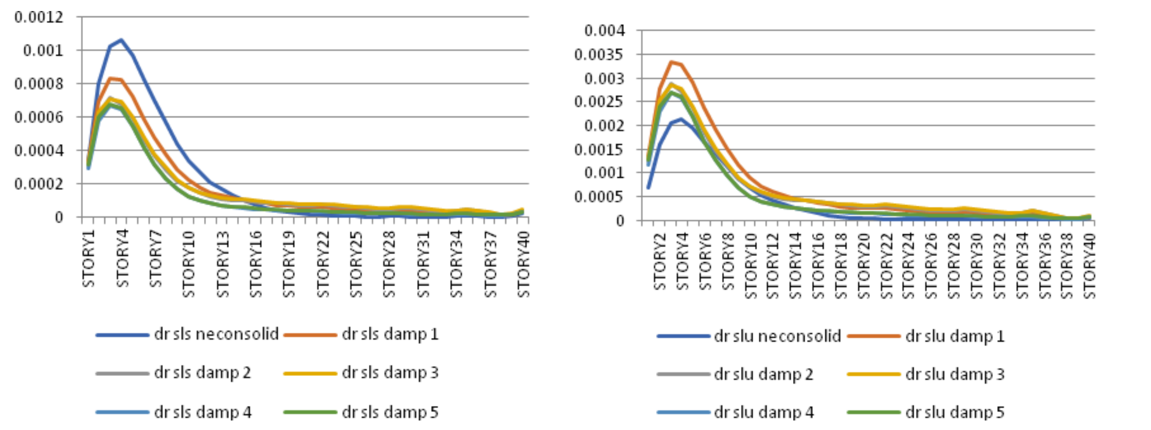
Comparisons of relative level movements, between the non-consolidated and the consolidated structures with viscous dampers (Figure 5, Figure 6):

Figure 5: Relative movements per story for LSS/ ULS (10-story building)



Source: Ezzaki, 2018

Figure 6: Relative movements per story for LSS/ ULS (40-story building)



Source: Ezzaki, 2018

The diagrams above show an improved behavior of the structures, in terms of movements, in both LSS and ULS, but only for height regimes up to 10 stories. Their variation on the height of the consolidated building is much more uniform.

In the case of buildings with more than 10 stories, their behavior is improved for LSS, but not for ULS, even if values do not exceed the values given in P100-1:2006.

Conclusions

The present study includes details regarding the use of damper-type devices in order to reduce the seismic vulnerabilities of existing buildings with a reinforced concrete frame(Ezzaki, 2018).

For this purpose, the analysis included a series of structures with different height regimes, designed according to the technical requirements used in the first anti-seismic code P13-63. In time, this standard was constantly revised, and the earthquake which took place in Vrancea on March 4, 1977 changed the entire design code valid at the time.

The behavior of the structures at present pointed out the fact that the dimensioning was made for much smaller stresses than those taken into consideration in the seismic code in force at present. Significant differences of their rigidity, but also the partial erosion of the portent capacity of structural elements being affected by earthquakes of various intensities led to the need of their consolidation, in order to prevent potential structural damages in the event of a future earthquake.

Modern consolidation methods have a series of advantages in comparison to traditional ones, and these advantages are presented for each case in turn, in the last sub-chapters.

The consolidation method chosen for the case study requires the use of damper-type devices, that is, of viscous dampers mounted diagonally in the exterior frame openings, in different positions. The consolidated resistance structure showed a significantly improved rigidity and resistance, leading to an optimal behavior of the buildings in the case of seismic events.

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