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Rehabilitation of hospital buildings using passive control systems

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Abstract. In the case of hospital buildings, where seismic design requirements are very high, existing structures and especially those attacked by past earthquakes, appear, often, unable to fulfil the necessary safety prerequisites. In this paper, the retrofitting of hospital buildings is investigated, using alternative methods of repair and strengthening. Analysis of an existing hospital building in Patras, Greece, is performed. The load-bearing system is a reinforced concrete system. Two solutions are proposed: strengthening using concrete jackets around column and beam elements and application of viscoelastic dampers for the increase of the stability of the structure. Adequate finite element models are constructed for each case and conclusions are drawn on the efficiency of each rehabilitation method.

Keywords: earthquake; hospital; passive control; dampers; rehabilitation; retrofitting; finite element analsis; jackets.

1. Introduction

Earthquake design of hospital buildings should meet requirements implied by their particular social role. Protection of hospital buildings against the earthquake hazard involves two main aspects. The first one is related to their satisfactory structural performance during an imminent seismic event, while the second one regards their availability for post-earthquake facilities provision (Papaevangeliou and Syrmakezis 2004). Furthermore, the distinction between structural and non-structural damage is necessary for the damage assessment, which will determine the need for full or partial evacuation that will, possibly, influence the hospital's future. While the structural damage includes failure of the load bearing system, non-structural damage comprises portions of a hospital such as ceilings, windows, electrical/mechanical equipment, files, furnishing etc (Mackler and Richter 1987).

During an earthquake event, the problem arises from the high number of persons at risk (accommodated patients, employed staff and visitors) as a result of the possible damage or even collapse, especially in comparison with other structures, which do no have this kind of public character. In addition to this, patients, incapable of taking simple precautions to protect themselves, have to be considered, as well as interruption in care, following structural damage. Non-structural damage, on the other hand, even if not extensive, can increase the level of fear, leading to unnecessary evacuation in a state of panic.

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With regard to the post-earthquake use of hospital buildings, it has to be mentioned that the main aspects of the seismic impact on hospital buildings are failure in provision of urgent medical facilities and lack of a relief shelter, in the hours following the event. In terms of mechanical/electrical equipment, along with the malfunctions and the risk of subsequent explosions, damage can have severe economical consequences as well, since hospital equipment is usually expensive and not easily replaced.

The use of modern techniques for the mitigation of the seismic impact on hospital buildings and especially the use of vibration control systems are considered for the provision of increased levels of safety, through the modification of the seismic structural response. Passive control systems have the ability to dissipate external energy when introduced into the loading-bearing system, resulting in this way to an increased final strength of the structure (Casciati and Faravelli 2001). Especially in the case of hospitals, where small displacements are desired in order to avoid instrument and equipment damage, system specifications are selected so as to meet the imposed criteria (Syrmakezis and Sophocleous 1999).

2. The case study

In this article, a hospital building named section B in the hospital complex "Agios Andreas", in Patras, Greece, is examined. The four-story building was initially designed and constructed in the '60s with a reinforced concrete load-bearing system, as seen in Fig. 1.

Due to its location at a high risk seismic area, the structure has suffered, in the past, several

Fig. 1 General views of section B of "Agios Andreas" hospital

Fig. 2 Wall cracks on the ground floor (left) and infill walls detachment (right)

earthquakes of diverse intensity with considerable resultant effects (Fig. 2): wall cracks, detachment of infill walls from the load-bearing system, load-bearing members cracks, as well as reinforcement corrosion due to humidity. Close observation of the damage reveals that there is a strong possibility of the structure being incapable of withstanding, on an operational level, future earthquake actions.

3. Evaluation of the actual structural state

In order to evaluate the hospital's actual structural state, seismic analysis had to be performed on a three-dimensional finite element model of the reinforced concrete structure (Fig. 3), consisting of 2.064 linear elements, 10.023 shell elements and 10.674 joints. SAP2000 V.9 software was used.

Material mechanical properties were determined with non-destructive methods such as ultrasonic and hammer Schmidt testing, after statistical processing of the data. Final values were estimated as followed: Concrete's strength in compression f_{ck} = 12,00 MPa, Young's Modulus E_{cm} = 26 GPa, concrete's self-weight γ = 25/m^3 and steel reinforcement's strength in tension f_{sy} = 220 Mpa. Reinforcement detection was made using ultrasonics.

Static and seismic loads were defined according to the actual Greek Aseismic Code and a Peak Ground Acceleration equal to A = 0,24 g, for the seismic zone of Patras, was considered. Response Spectrum analysis has been performed for a coefficient of importance equal to 1,30, as defined for hospital buildings.

Seismic analysis results revealed that some columns and the majority of the beams have insufficient reinforcement, especially on the basement and on the second floor. This fact increases the vulnerability

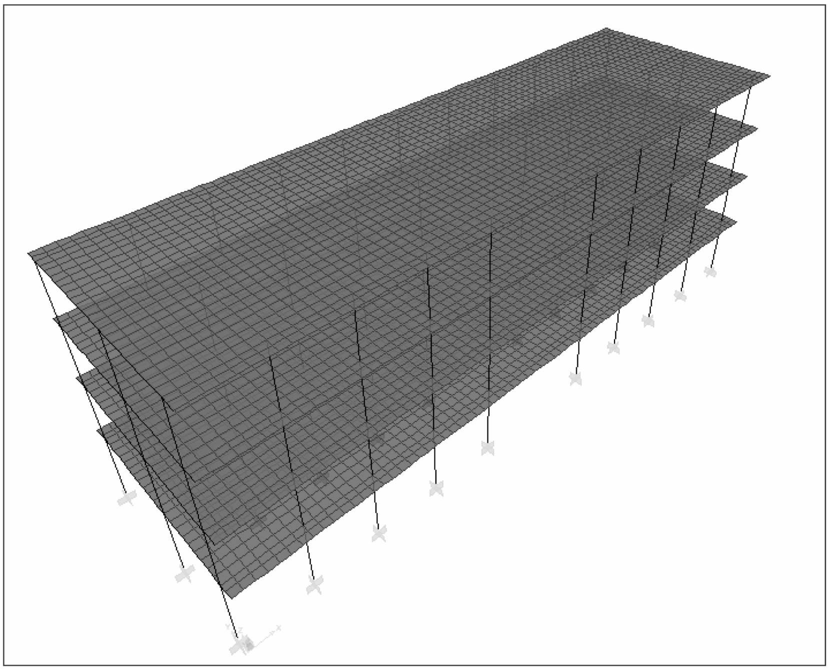


Fig. 3 Model meshing

Table 1 Indicative displacements of the existing structure

Joint ID: 5842	Earthquake along y-axis
Absolute Max. Displacements	
Ux (cm)	2,98
Uy (cm)	20,99
Rz (rad)	0,00116

of the hospital and imposes the application of an intervention method for the strengthening of the building.

Table 1 presents some indicative results of the analysis, for maximum displacements due to earthquake loading, of a joint on the highest level, in the middle of the layout of the building.

4. Selection of the repair and strengthening technique

For the repair and strengthening of the hospital, two options were considered. The first one was a traditional reinforcement method, using concrete jackets for the increase of beam and column section dimensions and the second one involved an innovative technique, using a passive control system consisting of damper braces.

The concept of structural strengthening is different for each intervention technique. The construction of concrete jackets aims at the increase of the bearing capacity of structural elements, while the application of damper braces leads to larger amounts of seismic energy dissipation and, as a result, lower values of the developed member forces.

However, required intervention to the hospital building, without any interruption of its operation can only be satisfied by the application of the second solution. Analysis was performed for both cases and comparative results were obtained.

5. Reinforcement using concrete jackets

Analysis of the existing structure proved that some of the beam and column sections are insufficiently reinforced, according to the actual Greek regulations. In order to improve the overall strength of the hospital, the increase of the dimensions of those sections has been investigated.

Concrete jackets with adequate steel reinforcement were considered for the increase of the moment of inertia of linear elements, and analysis was performed for the new structure. The width of the concrete jacket was designed to be 5 cm. Absolute maximum displacements of joint 5842, for earthquake loading along y-axis are shown in Table 2.

Table 2 Indicative displacements of the retrofitted with concrete jackets structure

Joint ID: 5842	Earthquake along y-axis
Absolute Max. Displacements	
Ux (cm)	1,98
Uy (cm)	14,16
Rz (rad)	0,00090

6. Reinforcement using damper braces

High standards imposed for large energy dissipation, can be satisfied by the effective utilization of passive control systems (Casciati and Lagorio 1996). As a result, redesign of the building was performed using viscoelastic dampers.

A bracing system was introduced along the height of the building (the height of each floor is 3,10 m), in 16 different positions, along both directions, respecting, at the same time, architectural particularities and operations of the building.

Locations of the braces are shown in Fig. 4 (numbers in circles), while in Fig. 5 two views of the building (tranversal, A and longitudinal, B) are illustrated, presenting placement of dampers along its height.

The response of dampers was simulated by the Maxwell linear model of viscoelasticity, with effective damping equal to 5000KN-sec/m (Casciati 2001, 1996). New analysis results were obtained. Absolute maximum displacements of the same joint, 5842, for earthquake loading along y-axis, are shown in Table 3.

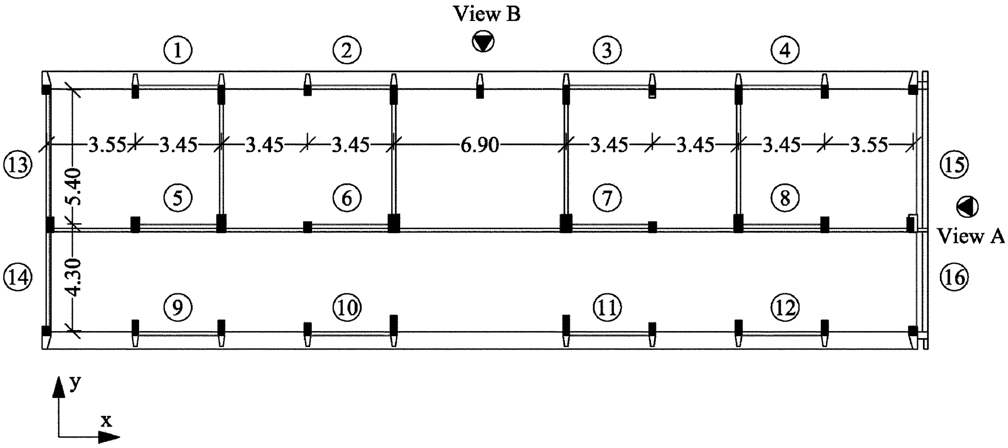
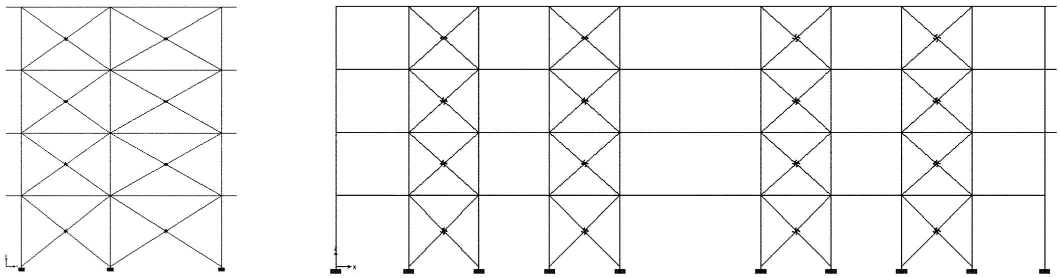


Fig. 4 Damper braces placement on the typical floor plan



View A View B

Fig. 5 Damper braces placement along the building’s height

Table 3 Indicative displacements of the retrofitted with damper braces structure

Joint ID: 5842	Earthquake along y-axis
Absolute Max. Displacements	
Ux (cm)	1,39
Uy (cm)	10,61
Rz (rad)	0,00022

7. Comparative results

In order to demonstrate the modification of the seismic response of the hospital building, comparative results of absolute maximum displacements of the considered joint 5842 are used, for the loading combination corresponding to earthquake along y-axis.

Fig. 6 illustrates the comparative results for displacements *Ux* and *Uy*, while Fig. 7 shows the calculated rotation *Rz* for each of the three models. These charts, also present the reduction of the calculated deformations for both retrofitting techniques. The reduction of horizontal displacements for the application of damper braces is remarkable.

An important but smaller reduction is also noticed in the case of the concrete jackets use. Concerning the x-axis, small displacements were observed even before the interventions, which are further reduced by the application of both reinforcement techniques.

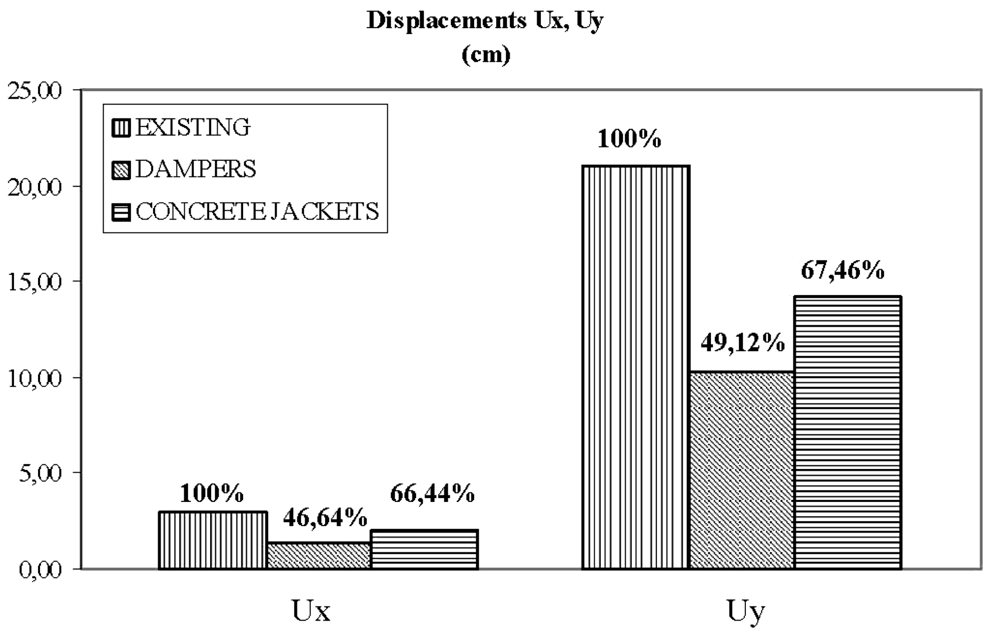


Fig. 6 Indicative displacements for earthquake loading

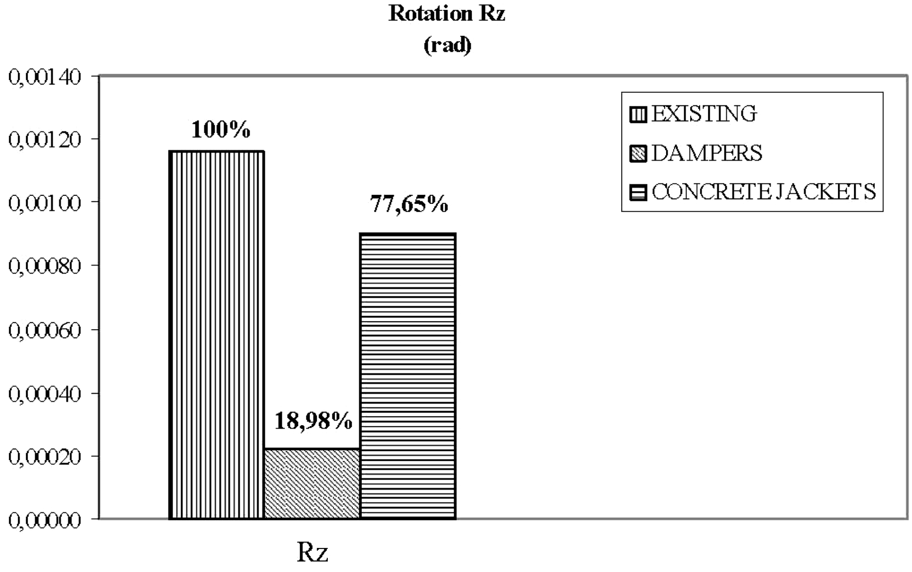


Fig. 7 Indicative rotation for earthquake loading

8. Conclusions

In this paper, the retrofitting of an existing hospital building has been examined. Two strengthening methods have been investigated: a conventional one, using concrete jackets and an innovative one, using a passive control system consisting of damper braces. Three finite element models were used, one for the existing structures and two for the retrofitted structures, respectively. Response spectrum analysis was performed and member forces as well as deformation results were calculated.

Their comparison revealed that in the case of damper braces application, displacement values reduce significantly, providing increased levels of safety. Application of concrete jackets was also proved to be effective, however lower values of displacement reduction were obtained. It is also worth noting the significant reduction of the rotation of the structure around the vertical z-axis, due to earthquake loading along y-axis.

As a result the efficiency of viscoelastic dampers for the dissipation of seismic energy is obvious, especially in comparison with traditional strengthening methods. Such an intervention can lead to satisfactory safety levels of the structural system of the hospital. At the same time, minimization of the cost resulting from interruption in hospital function is achieved, as well as avoidance of demolition or reconstruction of mechanical and electrical installations.

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