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Seismic Performance Assessment of a Reinforced Concrete Building designed using the Albanian Seismic Code

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Abstract

A seismic performance evaluation was conducted for a reinforced concrete (RC) frame structure representative of late 1990s construction in Albania. The case study building is an eight-storey RC flat-slab office building designed for the Albanian code requirements used in this region. The performance of the existing building is compared to that of modern code designed building. The structural response is evaluated using pushover analysis. The adequacy and the performance of the buildings are checked and compared. The ATC-40 criteria were used to evaluate the seismic performance of the case study buildings. The calculated values related to the performance of the buildings indicate whether the response of the existing building is sufficient and if rehabilitation is required.

Keywords: performance evaluation, 1989 Albanian seismic code, pushover analysis, SAP2000.

1 Introduction

During the last two decades, seismic codes in many European countries have been revised and updated after destructive earthquakes [1]. Albanian seismic code (KTP-89) [2] is expected to undergo a revision in a near future after the implementation of the adoption to Eurocode norms. However, many existing Albanian RC buildings are designed according to this code and earlier versions of these code provisions.

Buildings designed according to gravity or earlier codes might have insufficient lateral load resistance. Most of the modern seismic design codes destined to provide adequate protection for life safety during severe seismic events. The response of reinforced concrete buildings designed according to the modern codes has been found to be adequate during the recent earthquakes. However, structures designed to earlier code regulations or prior to the seismic design requirements underwent severe damage because of insufficient lateral load capacity and inadequate deformation capacity of their members. Seismic capacity assessment of current building stock and estimate their responses are vital for decisions regarding the rehabilitation of deficient buildings. Performance based seismic assessment procedures [3, 4, 5] are commonly accepted as a practical approach to assess the seismic capacity of structures.

The reasons for the poor performance and deficiencies of existing RC frame structures associated with the gravity load design under seismic loads are as follows [6]; insufficient lap splice and column shear capacity due to lack of transverse reinforcement and poor detailing; weak connections due to low shear capacity as a result of wide stirrups spacing; lack of rotational capacity at beam ends due to the in adequate anchorage of positive reinforcement are some of the reasons of the poor performance of existing RC frame structures.

The main objective of this study is to evaluate the seismic performance of an existing RC building designed according to the Albanian seismic code KTP-89. The seismic response of this frame is compared with the performance of a same frame designed according to the current code provisions of the Eurocode 8 (EC8) [7]. The performance of the structure is analyzed using the results of the pushover analysis, the inter-story drifts and the roof drift.

2 Significance of Research

Being a country surrounded with seismically active regions, Albania has potential risk for its existing RC buildings. The need for a simple and rapid evaluation of existing RC building stock is of growing concern to the practicing community [1]. Pushover analysis is an efficient analytical tool which can be employed for the seismic evaluation of these buildings. The aim of this study is to provide a practical procedure to analyze existing RC buildings which were designed to earlier codes or prior to the seismic design requirements. This procedure enables modeling of ductile and non-ductile detailing in an implicit way so that existing analytical tools can be used to perform the required seismic assessment. The analysis provides an insight about the behavior of the components and the global response accounting for failure mechanism of the structure as a whole. This evaluation procedure is applied to typical eight-storey RC dual system building which reveals the inherent deficiencies as compared to modern earthquake resistant design requirements in Albania.

Although vulnerability assessment of existing RC buildings is not new application of the same techniques to gravity load designed buildings, it is not so well developed in Albania. There are several computational tools available in literature comprising of analytical modeling techniques and procedures. To this end, in the last two decades, several guidelines and recommendations [3-5] have been developed for the seismic assessment of building structures. However, applicability of these procedures has to be checked and modified for Albanian buildings. This paper follows the FEMA-356 and ATC-40 procedures to perform the pushover analysis to assess the vulnerability of existing RC building.

3 Description of the Case Study Building

Since this study is an investigation into the adequacy of reinforcement detailing in the current Albanian building stock, exact reinforcement detailing has been taken into account for the current study. Fig. 1 shows typical floor plan of the 8-storey building which was designed according to Albanian seismic code [2].

Using the same plan area and structural configurations, another imaginary building is designed according to Eurocode 8 and 2 [7-8] standards to make a comparison between the current code and Eurocode regulations. The structure studied is an 8-story dual system (mixed moment-resisting frame-shear walls). This building is placed in Elbasan which is located in central Albania. The total building height is 24.15 m; the two first stories height is 4.20 m and the other ones 3.325 m. Typical plan area of first and second floor is: 541.63 m^2 and 418.5 m^2 for the other ones. Figure 1 shows the typical floor plan view of first two stories.

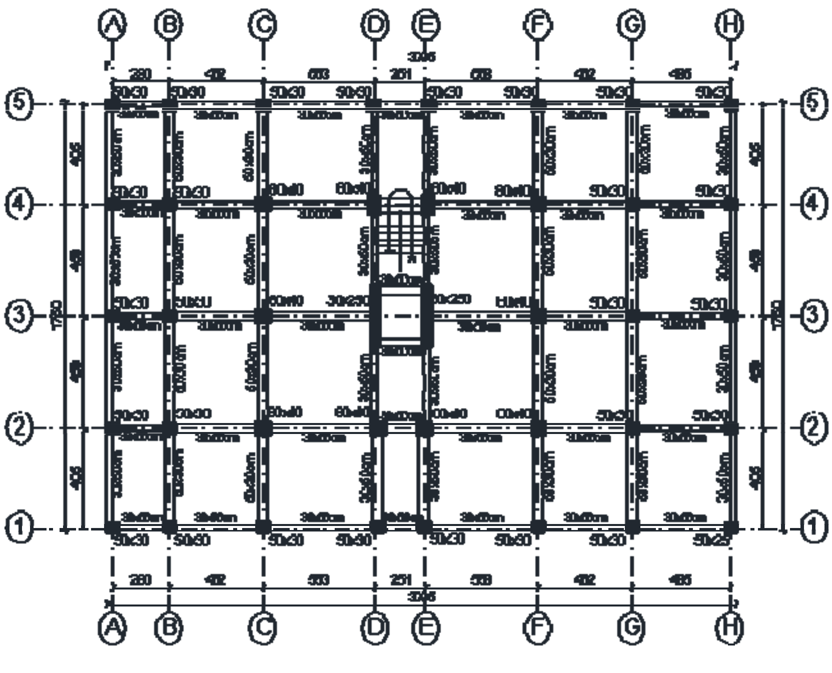

Figure 1.Typical floor plan view of first two stories.

To evaluate the seismic response of the building, elastic analyses and nonlinear static analysis are performed using the computer program SAP2000 [9]. The pushover analyses of the buildings are carried out separately in the longitudinal and the transverse directions. Seismic responses of the structures are given only for *x*-direction is comparatively presented with graphs in this paper. Sample finite element model is shown in Fig.2.

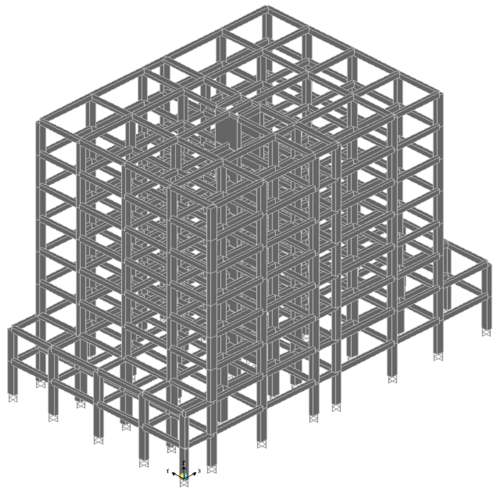

Figure 2: View of 3-D finite element model of the case study building.

The joints connecting the base columns to the foundation system were restrained for all degrees of freedom assuming an infinitely rigid foundation. Therefore, there is no finite element model for subsoil to consider soil-structure interaction. All nodes at floor level were constrained to move as a rigid diaphragm in order to prevent in-plane membrane deformations. Columns and beams are modelled with frame elements, structural walls are modelled with wide column analogy. No slabs were defined; instead, slabs weight was distributed to the perimeter beams as dead loads. Another load case was defined to introduce the live loads applied on the structure. Masses assigned to the stories were calculated using the dead and live load values. The calculation of these masses, live loads and dead loads were made according the Albanian standards [2].

In the analysis, Young's modulus and unit weight of concrete are taken to be 28000-30000 MPa and 25 KN/m^3, respectively. The damping ratio is assumed as 5% in all modes.

4 Nonlinear Modelling of the Case Study Building

Aforementioned inputs are enough for a linear finite element analysis. However, modeling of a building for inelastic range requires the determination of the nonlinear properties of the elements. Nonlinear version of SAP2000 [9] is used for pushover analysis. The nonlinear static procedure of FEMA 356 [4] is implemented in SAP2000 which feature is in the present analysis. The capability of the program is the definition of plastic hinge properties and the nonlinear static analysis tool. It allows for the direct input of moment rotation properties characteristic of sections. Moment rotation backbone curves (Figure 3) are used according to FEMA-356 guidelines for each type of structural elements.

For the pushover analysis, plastic hinges are assigned at the ends of the primary structural elements, assuming that plasticity was concentrated at the ends of these elements. The contribution of infill stiffness is neglected in this particular study but their weight is included in mass calculations. The effective moment of inertia of 0.5 Ig (Ig is the gross moment of inertia) is considered for modeling the beams and columns. The foundation is treated to be fixed and the building is assumed to be in Zone 3 as per KTP-89 [2].

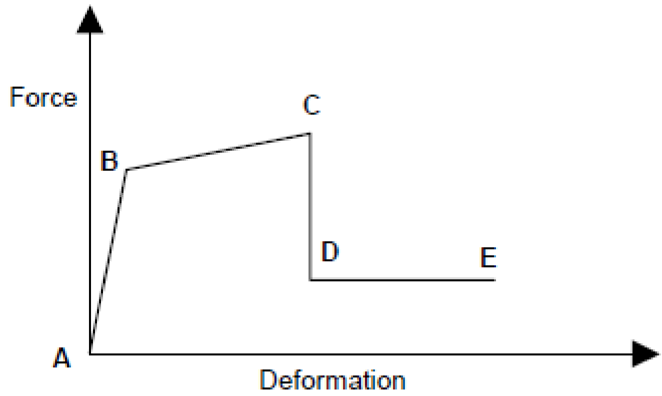

Figure 3: Typical force deformation relationship

The moment rotation properties for beams and columns are obtained from FEMA-356 depending on the level of transverse reinforcements and concrete strength provided in the sections. Flexural hinge (M3) is assigned for beams and axial moment hinge (PMM) for columns. The building is confirmed for the possibility of shear failures in the flexural components and it is found to be safe against such failures.

5 Performance Assessment of the Case Study Building

Three different pushover analyses are performed using the tool SAP2000 as follows;

1. Gravity push, which is to apply gravity load (DL + 0.3 LL)
2. Lateral push in *x*- direction
3. Lateral push in *y*- direction

Obtained results of the pushover analysis of the existing and the newly designed building according to EC8 are shown in Figure 4 for *x*- direction. Base shear (V) is normalized with the weight of the building (W) in vertical axis and the roof displacement is normalized with the height of the building in horizontal axis.

Although there is not a big difference on the ductility of the existing frame and the EC8 code designed building, the results indicate that the EC8 code designed frame sustained a lateral load as high as 0.19 W whereas, the existing frame sustained a yield load of 0.07 W and an ultimate load of 0.09 W.

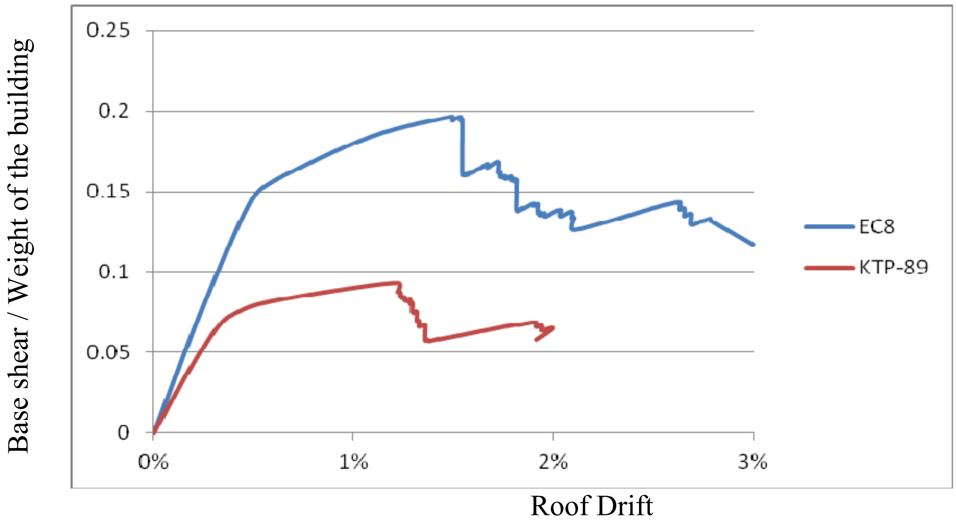

Figure 4: Relations between base shear and roof drift of the case study building (*x direction*)

The hinge mechanism at failure for both frames after the pushover analysis is shown in Figure 5. From comparing the plastic hinge distribution of the two frames, it is observed that the EC8 code designed building has less hinges in the columns and beams than the existing frame.

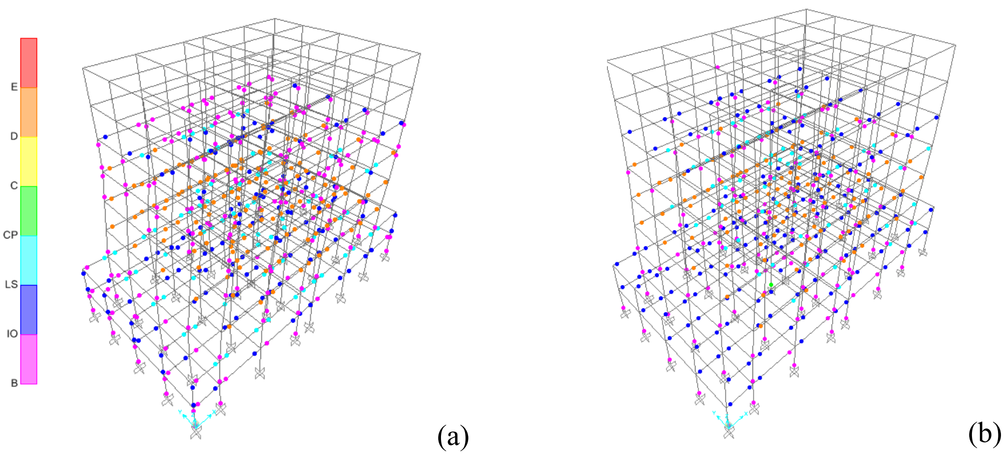

Figure 5: Plastic hinge distribution at failure from the pushover analysis: a) Existing building; b) EC8 code designed building (*x- direction pushover*)

The performance point is obtained at a base shear level of 0.126 W and a displacement of 0.26 m which lies below the performance objective required for Life safety of 2% of building height (0.48 m) according to ATC-40 (Figure 6). The existing building does not meet the required performance objective of Life safety under the maximum earthquake and should be rehabilitated. On the other hand, the building designed to EC8 provisions performed satisfactorily.

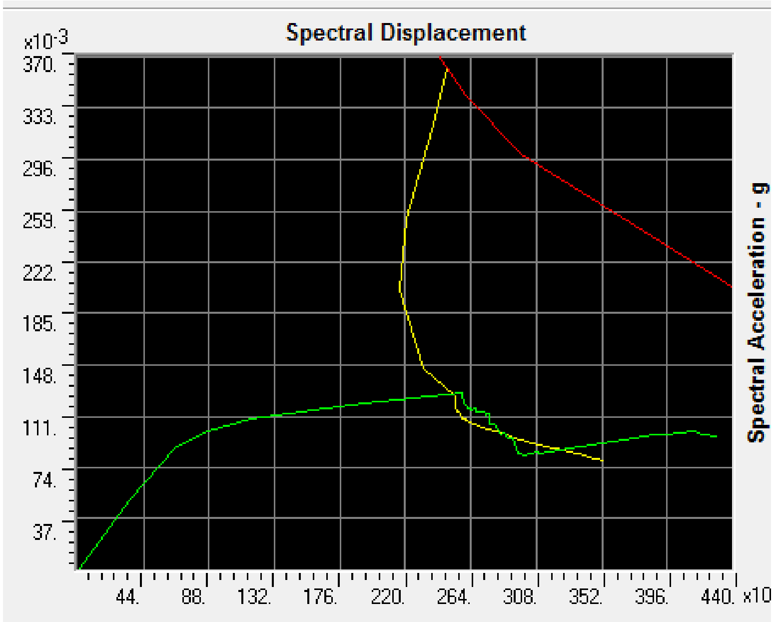

Figure 6: Capacity and demand curve in the ADRS plot for the eexisting building

6 Conclusions

The performance of an existing RC residential building from Albania is evaluated and compared to the performance of the same structure designed according to the EC8 seismic provisions. The inadequacies in detailing are incorporated in the model in the form of moment-rotation properties for the structural elements. The results of the analysis showed that the performance of the existing building is not satisfactory due to the low lateral strength capacity and high drift state demands. The building designed to EC8 code provisions performed satisfactorily. The pushover analysis results indicated a desirable plastic hinge distribution at failure.

This employed procedure gives a quick estimation of the base shear and desirable performance of the buildings. This method is efficient to determine the deficient members and the global performance of the building. Considering the number of old building stock in Albania, such a kind of evaluation procedure might provide a quick evaluation for the buildings which need to be retrofitted.

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