Seismic assessment of an existing hospital

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ABSTRACT

The study is focused on the seismic performance of an existing hospital built in Tirana-Albania in 1970 and the *retrofitting* of this building.

The hospital is a six floor building, with a frame system, designed with Albanian earthquake code of that time KTP-78. The ground acceleration of this area is $0.2 m/s^2$

The building is designed with SAP-2000 computer program according to the Albanian earthquake code of that time KTP-89. The data collected from the program are compared with the Euro Code *performance level*. The program results show that all the data that are analyzed do not provide sufficient *performance level*. Therefore is an emergency need for *retrofitting* to bring it at the required level.

There are varieties of ways where we can build up our strategies for building rehabilitation, especially for a specific institution, such as a hospital which requires a *high performance level.*

The first way of *retrofitting* the frame system building is to add *shear walls*. After adding *shear walls* at the specific positions of the building, the hospital is reanalyzed and the *performance level* is not close enough to the EC *performance level.*

Since the building is very particular, we can not add *shear walls* everywhere, because this might reduce the functionality of the frame system building, so to increase the *performance level* we add *steel bracing* in the facade.

After putting *steel bracing* the hospital provide sufficient *performance level.*

The rehabilitation makes the hospital a safer place for everyone.

INTRODUCTION

Vulnerability analysis comprises a good knowledge of all basic steps in developing a structure, which are: environmental conditions (site and soil investigations as well as fitting the building by means of its dimensions and volume proportions into the surrounding environment), design (load analysis, pseudo-static seismic analysis, time history analysis and calculation of reinforcement areas in the appropriate manner) and checking its behavior versus different hazards events (can be estimated the level of damage that the structure will suffer for specific accepted events).

One of the reasons to have higher safety level of the building is the number of the people being inside the earthquake occurs, especially when these are hundreds of sick persons.

That is why the buildings that belong to Healthcare System are considered to have a higher level of safety then usual buildings, which in the vulnerability analysis terms means that they are more vulnerable toward predicted phenomena such as earthquake.

So, it is very important to know as much as possible about their behavior in case of earthquakes. This means to consider an actual building, its real reinforcement and real state, and then performing a detailed analysis in order to obtain the real capacity or the real strength of the building, independent from the predicted hazardous event for its respective site, but that derives from the manner it was reinforced or the manner it was built, or simply saying, from the code in which was based the construction procedures.

Buildings and structures in seismic regions are recommended to be designed mainly with a symmetric configuration and with mass and stiffness uniformly distributed in plan and height. To acquire this, these conditions must be accomplished:

1. Mass and stiffness distribution in height is considered as relatively uniform when the respective difference from one level (story) to the other is not larger than 50%;
2. Buildings are considered with “regular” shape in plan;
3. When the difference in height of the adjacent sections within the same building is less then 5 m the building is considered to be as “regular” in height;
4. The eccentricity between the center of mass and the center of rigidity at a floor, measured perpendicular to the direction of seismic action, is considered to be not excessive when it is less than 15% of the structure dimension in that direction. [3]

This paper is focused in the seismic assessment of an RC hospital build in Tirana before 1989, designed with KTP-89. This assessment is compared with the results that Euro-Code-8 provides to us for this category of buildings.

METHODOLOGY

The methodology used in this case to evaluate the building reaction under an earthquake is the non-linear pushover analyze.

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. [2]

Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design.

The ATC-40 and FEMA-273 documents have developed modeling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force-deformation criteria for hinges used in pushover analysis. It has five points labeled A, B, C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.) The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-273 documents. [3], [5]

We see that the performance point of the structure is not near enough to the IO performance point, this means that the hospital have an immediate need for retrofitting. There are varieties of ways where we can build up our strategies for building rehabilitation, especially for a specific institution, such as a hospital which requires a high performance level.

The first way of retrofitting the frame system building is to add shear walls. After adding shear walls at the specific positions of the building, the hospital is reanalyzed and the performance level is not close enough to the EC performance level.

APPLICATION TO UPGRADE THE EXISTING HOSPITAL

Albania is a seismic zone, in a specific way Tirana is an area with seismic intensity VII, soil category I (KTP-89), related to EC-8, Tirana is a zone with PGA 0.2 and soil category B. This information is taken from UNDP. Recently, for Albanian territory, are made different studies for identifying the expected PGA values with return period 475 years [1].

The “Pathological” hospital is part of the Mother Teresa university center. It is a RC rectangular, six story building. The columns are 50x50 or 40x50 or 40x40 and have low steel-reinforcement ratios, providing poor ductility. The hospital is build in 1970, there are no shear walls at all, the concrete used in the building is 170kg/cm^2, the slab is with S.A.P panels, some of the slabs are monolith. The substructure is with plink under the columns. This information is taken from the original project, offered from the Central Technical Archive of Albania [4].

After creating the model in SAP2000 program and defining the properties and acceptance criteria for the pushover hinges, we locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations. Then run the static nonlinear pushover analysis. Display the pushover curves as shown below.

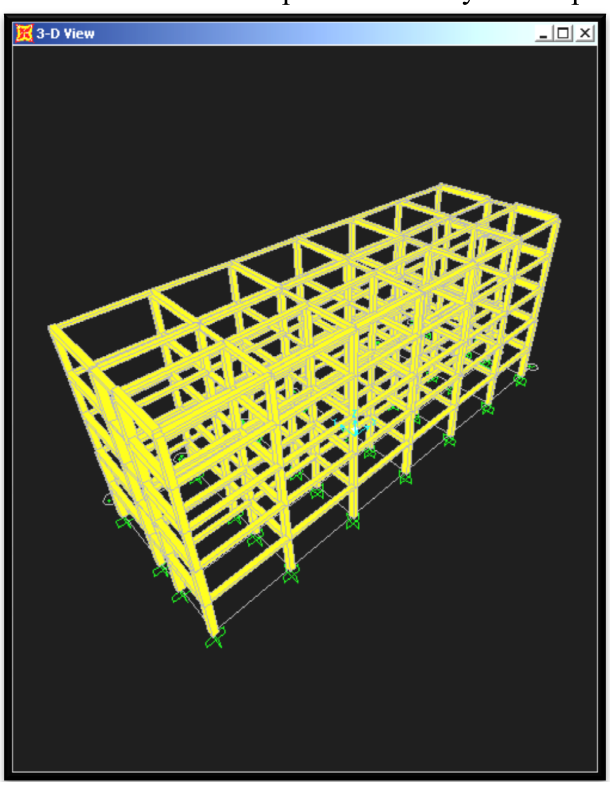

Fig.1 The existing hospital

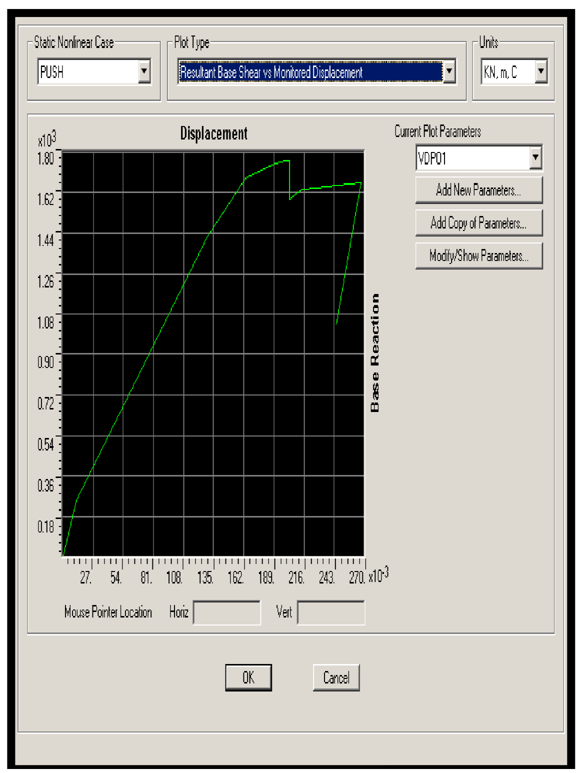

Fig.2 The resultant base shear - displacement

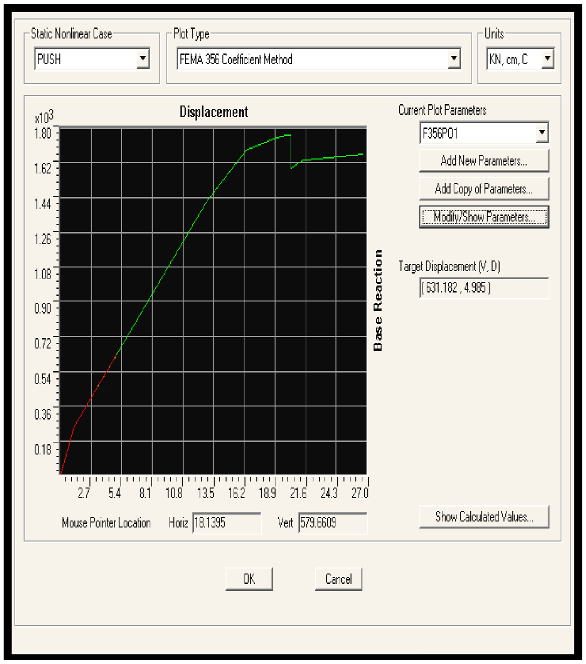

Fig.4 FEMA-356 coefficient method

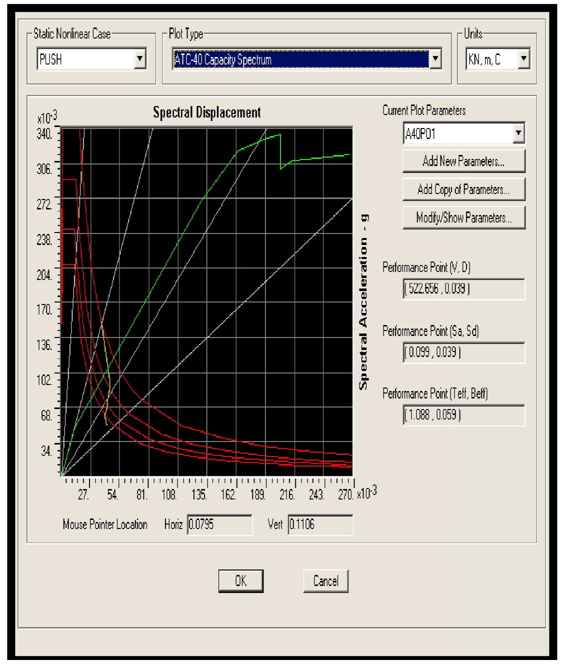

Fig.3 ATC-40 capacity spectrum

The fig.2 represents the base shear force vs the maximum displacement or the capacity curve. For the actual hospital, the maximum displacement is 26.7209cm for a shear force 1671.8644 KN.

The fig.3 represents a relation between the capacity curves (the green line), the family of demanded spectra (the red one), the single demand spectrum (ADRS) (yellow) and the constant period lines (the grey lines). The horizontal axe is the spectral displacement and the vertical axe is the spectral acceleration. The performance point V-D is (522.656; 3.897), the performance point Sa-Sd is (0.099; 3.891) and still for this graphic the performance point Teff-Beff is (1.088;0.059). All the units are KN, cm.

The fig.4 represents a relation between the real capacity curve and the idealized bilinear force-displacement curve. The response spectrum is for a site class B and for a spectral acceleration 0.2. In other words we calculate the target displacement at each floor level.
The target displacement, δt, at each floor level shall be calculated in accordance with Equation (1)

$$\delta_t = C_0\, C_1\, C_2\, C_3\, S_a\, (T_e^2/4\pi^2)\, g \qquad (1) \qquad [2]$$

- C_0 → Modification factor to relate spectral displacement of an equivalent SDOF| single degree of freedom| system to the roof displacement of the building MDOF| multi degree of freedom| system calculated using one of the following procedures:

• The first modal participation factor at the level of the control node;
• The modal participation factor at the level of the control node calculated using a shape vector corresponding to the deflected shape of the building at the target displacement. This procedure shall be used if the adaptive load pattern
• The appropriate value from some specific tables.

- C_1 → Modification factor to relate expected maximum inelastic displacements to displacements calculated for linear elastic response:

1for Te ≥ Ts

[1.0 +(R – 1)TS / Te]/R for Te < TS

- Te→ Effective fundamental period of the building in the direction under consideration.
- Ts → Characteristic period of the response spectrum, defined as the period associated with the transition from the constant acceleration segment of the spectrum to the constant velocity segment of the spectrum
- R → Ratio of elastic strength demand to calculated yield strength coefficient calculated by Equation (1).
- C2 → Modification factor to represent the effect of pinched hysteretic shape, stiffness degradation and strength deterioration on maximum displacement response. Alternatively, use of C2 = 1.0 shall be permitted for nonlinear procedures.
- C3 → Modification factor to represent increased displacements due to dynamic P-Δ effects. For buildings with positive post-yield stiffness, shall be set equal to 1.0.

For buildings with negative post-yield stiffness, values of shall be calculated using Equation (2).

$$C3=1+|\alpha|(R-1)^{3/2}/Te \qquad (2)$$

- Sa → Response spectrum acceleration, at the effective fundamental period and damping ratio of the building in the direction under consideration,

g = acceleration of gravity

- R → The strength ratio R shall be calculated in accordance with Equation (3)

$$R=\frac{S_a * C_M}{V_Y/W} \qquad (3)$$

- Vy→ Yield strength calculated using results of the NSP for the idealized nonlinear force-displacement curve developed for the building.
- W → Effective seismic weight.
- α → Ratio of post-yield stiffness to effective elastic stiffness, where the nonlinear force-displacement relation shall be characterized by a bilinear relation [2]

In our case the coefficients values are shown in Table 1

Table 1: the coefficients values used for equation (3)

C0	**C1**	**C2**	**C3**	**Sa**	**Te**	**Ti**	**Ki**	**Ke**	**Alfa**	**R**	**Vy**	**W**	**CM**
1	**1**	**1**	**1.0338**	**0.4711**	**1.3587**	**0.9972**	**214.021**	**114.764**	**-0.1802**	**1.4016**	**1777.9**	**5290**	**1**

After that we create a model with shear walls incorporate in the building. This model is created because the existing model has some problems with the target displacement.

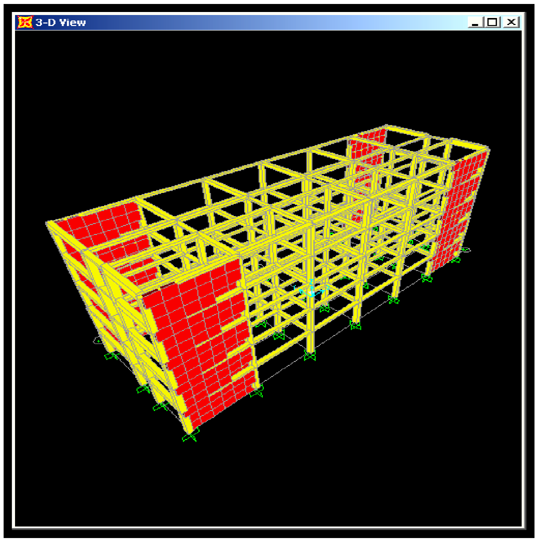

Fig.5 The retrofitted building

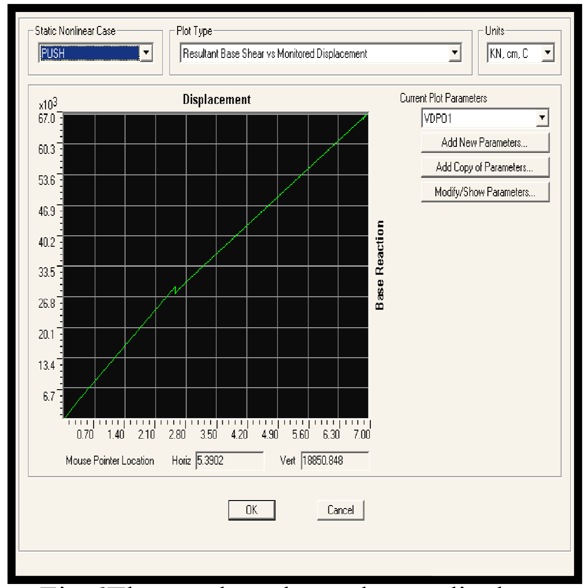

Fig.6The resultant base shear - displacement

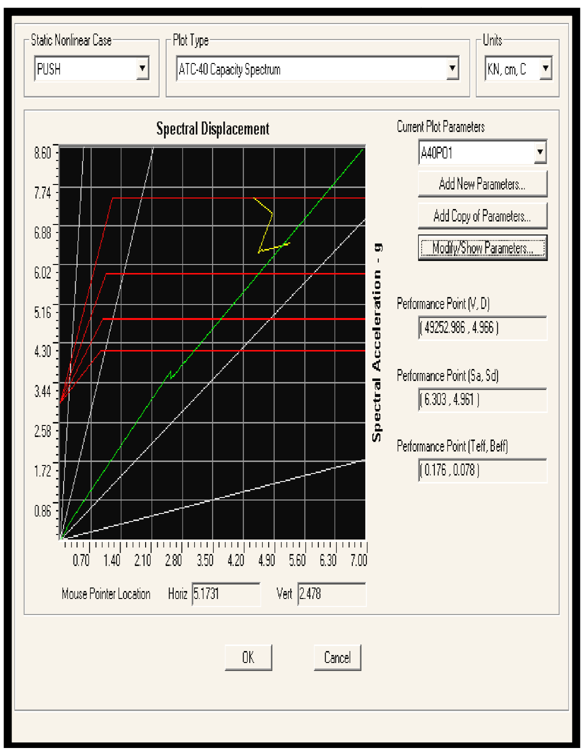

Fig.7 ATC-40 capacity spectrum

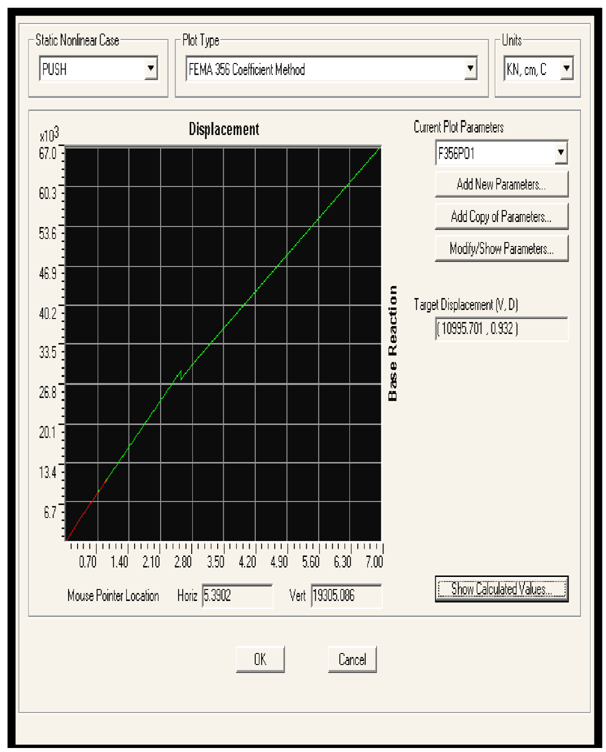

Fig.8 FEMA-356 coefficient method

The fig.6 represents the base shear force vs the maximum displacement or the capacity curve. For the actual hospital, the maximum displacement is 6.96cm for a shear force 67000KN.

The fig.7 represents a relation between the capacity curves (the green line), the family of demanded spectra (the red one), the single demand spectrum (ADRS) (yellow) and the constant period lines (the grey lines). The horizontal axe is the spectral displacement and the vertical axe is the spectral acceleration. The performance point V-D is (49252.986; 4.966), the performance point Sa-Sd is (6.303; 4.961) and still for this graphic the performance point Teff-Beff is (0.176;0.078). All the units are KN, cm.

The fig.8 represents a relation between the real capacity curve and the idealized bilinear force-displacement curve. The response spectrum is for a site class B and for a spectral acceleration 0.2. In other words we calculate the target displacement at each floor level. The target displacement, δt, at each floor level shall be calculated in accordance with Equation

$$\delta_t = C_0\, C_1\, C_2\, C_3\, S_a\, (T_e^2/4\pi^2)\, g \qquad (1) \qquad [2]$$

After retrofitting the building with shear walls we have these values:

Tab 2: coefficient values used in equation (1) for the second case

C0	C1	C2	C3	Sa	Te	Ti	Ki	Ke	Alfa	R	Vy	W	CM
1	1.1477	1	1	1	0.1541	0.1541	13034	13034	0.8592	1.986	3934.71	7814.23	1

The retrofitting of a special building, such as a hospital, with shear walls has some problems with the functionality of the building and the weight that become higher. An other alternative for retrofitting a hospital with out raising it weight and with out having problems with the functionality are the steel bracing in the facade. But this part want be in this paper because the retrofitting with shear walls provide sufficient safety for the building.

CONCLUSIONS

Seismic vulnerability analyses of RC Building structure – Hospital, which belong to the health care system of Albania located in Tirana – is compute in this thesis. A detailed procedure is used, in order to have reliable results.

Below I will try to emphasize some of the main conclusions regarding to this paper.

- Capacity of the structure can be obtained directly by performing Pushover analysis
- Response Spectra as a combination of the seismic requirements and soil category are different for KTP-89 and EC-8 requirements. As they use different seismic inputs (KTP-89 use intensity scale and EC-8 use ground acceleration), it is worthy to emphasize that a considerable difference exist in response spectra. Referring to our building, it have to support a seismic force 50% bigger if EC-8 requirements will apply;
- The seismic assessment of the "Pathological" hospital shows that the maximum displacement of the RC building is 26.7209cm for a shear force 1671.8644 KN. This value for the retrofitted building is 6.96cm for a shear force 67000KN. The reason of this difference in RC building displacement is the presence of shear walls incorporated in the longest side of the building. The performance point of the non retrofitted building is Sa-Sd is (0.099; 3.891), on the other hand the performance point of the hospital with shear walls is Sa-Sd (6.303; 4.961).

All this facts shows that the retrofitted hospital have a better performance that the one without shear walls

REFERENCES

[1] United Nations Development Program (2003), Disaster Risk Assessment in Albania, Tirana, Albania,

[2] FEMA 356 / November 2000- PRESTANDARD AND COMMENTARY FOR THE SEISMIC REHABILITATION OF BUILDINGS

[3] ATC-40 –Seismic evaluation and retrofit of concrete buildings

[4] Central Technical Archive of Albania.

[5] FEMA-273- Building Seismic Safety Council. NEHRP Guidelines for the Seismic Rehabilitation of Buildings, FEMA-273, Federal Emergency Management Agency, Washington, D.C., 1997