International Balkans Conferance on Challenges of Civil Engineering, BCCCE,
19-21 May 2011, EPOKA University, Tirana, ALNABIA

Damage assessment and strengthening of an existing RC building

M.Sc. Arian Lako[1], M.Sc. Markel Baballëku[2]

[1]*Civil Engineering Faculty, Polytechnic University of Tirana, Albania, arianlako@yahoo.com*

[2]*Civil Engineering Faculty, Polytechnic University of Tirana, Albania, b_kela@yahoo.com*

1 ABSTRACT

This paper investigates seismic capacity and probable damages assessment from earthquakes on existing buildings, more specifically, Archeological Museum building. Also, in this paper one of the techniques (reinforced concrete jacket) for increasing the structural capacity is applied. The importance of studying the behavior of this building is based on two issues: its essential use as well as the period of construction based on KTP-N2-89.

This building is designed as R/C frame system, and a reconstructed model is chosen to be estimate; so, conclusions are referred only to that building. However, the developed approach may be used in analyzing other structural R/C frame systems.

The first step of the study is related to the identification of the seismic zones, where the building is situated, and the period of its constructions as well as actual condition of structural elements and materials. Secondly, using the information of seismic design conditions and by performing respective pushover analyses, the capacity curve can be provided. After that, modeling bilinear capacity curves in AD format, defining the damage threshold levels; calculating cumulative probability and performing regression analysis – the fragility curves can be obtained.

Considering different seismic codes requirements (the existing Albanian Code KTP-N2-89 -still in force and Eurocode 8) the analyses of performance points makes possible to assess the probable damage levels of buildings. After results of damage assessment regarding actual structural situation, comes out, a valuation of structural strengthening is considered.

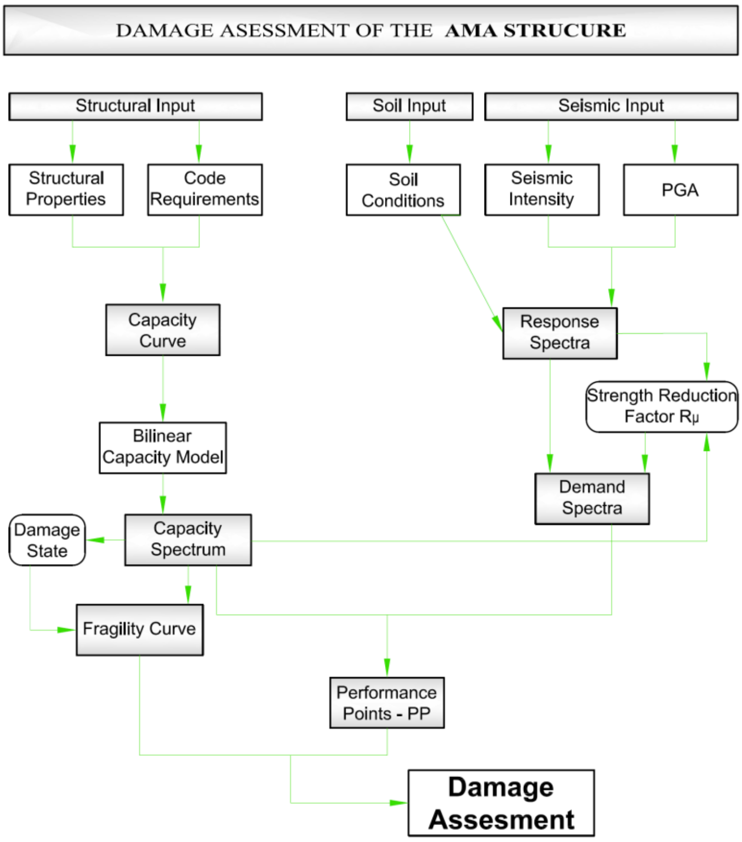
Applying reinforced concrete jacket for columns, it is recalculate the capacity of the strengthened structure. Finally, comparing the performance points of existing and strengthened model, conclusions comes out

Keywords: existing building, capacity, performance point, damage assessment, strengthening

2 INTRODUCTION

A study concerning the estimation of probable seismic damages in an existing three story RC frame structure building is presented in this paper. The flowchart presented below expressing damage approach, used in this paper, may be applied to analyze other structural types of various building typologies.

The seismic capacity of the structure is evaluated by taking into consideration, seismic inputs as required by the existing Albanian seismic Regulations (KTP-N.2-89) and Eurocode 8, too. It must be noted that in Albania the structural design is still officially based on the Albanian seismic Regulations approved in 1989. However, the basic principles and requirements of Eurocode 8 are increasingly taken into consideration by us. The official adoption of Structural Eurocodes, including EC-8, is actually considered a necessity in Albania.



3 ANALYZED BUILDINGS DATA AND THE STRUCTURAL MODEL

In order to have a realistic view of the seismic situation in Albania, two maps are used: the first one (Sulstarova et.al 1980) still in use, shows the seismic intensity zoning; the second one (UNDP 2003) is a PGA map compiled recently as a preliminary version of a seismic hazard map for Albania. The main data for this building are summarized in Table 1.

Table 1

Building location	*According to the Intensity Map*		*According to the PGA Map*		*Time of Construction*
	MSK-64 Intensity	*Soil Category*	*PGA (RP 475 year)*	*Soil Category*	
AMA Durrës	*IX*	*II*	*0.30*	*C*	*1886*

Fig. 1 shows the computer-generated structural model, which was constructed taking into consideration the main design characteristics of the buildings. The dimensions of structural elements and the amount of reinforcement in them are considered as well in the study.

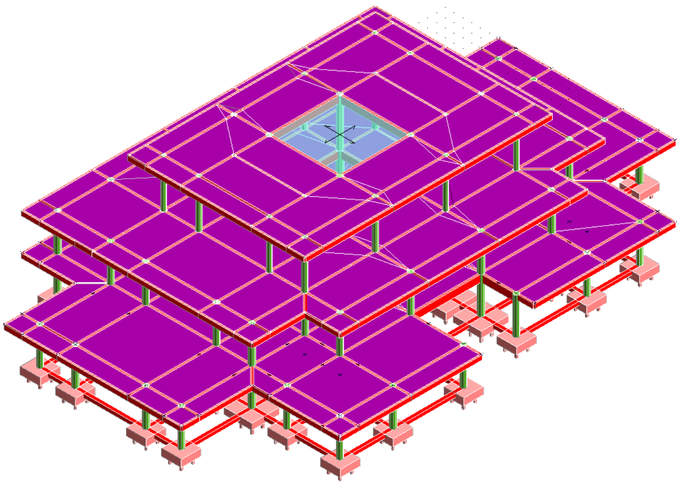


Fig. 1: Model of the building

4 CAPACITY AND DEMAND SPECTRUM

The capacity of the structure is modeled assuming that the values of dissipated energy in the "real" capacity curve and the values of an idealized elastic-perfectly plastic one are equal. The static pushover analysis is used to evaluate the capacity curve of the structural model in Fig. 1. The analysis is carried out following these steps:

Define the properties and criteria for the plastic hinges. An idealized elasto-plastic curve (moment-rotational/curvature) for plastic hinges is used.

Define pushover load cases, based on the first mode shape load pattern.

Running process of the analysis: first, the modal analysis and the gravity static analysis; second, the static nonlinear pushover analysis considering gravity static analysis.

Development of the pushover curves, referring to X axe.

Strengthening of the structure is realized using reinforced concrete jacket for columns. The existing columns are with dimensions 40 and 50cm are jacked with high strength concrete C50/60and with thickness of 5cm around existing dimensions. One story columns are also strengthened because those have light reinforcement.

In Fig. 2 the current capacity of the structure as well as strengthened structure is presented. It is noticed that the structure has approximately the same capacity in strength and ductility in both direction, so further results will be presented only for X direction.

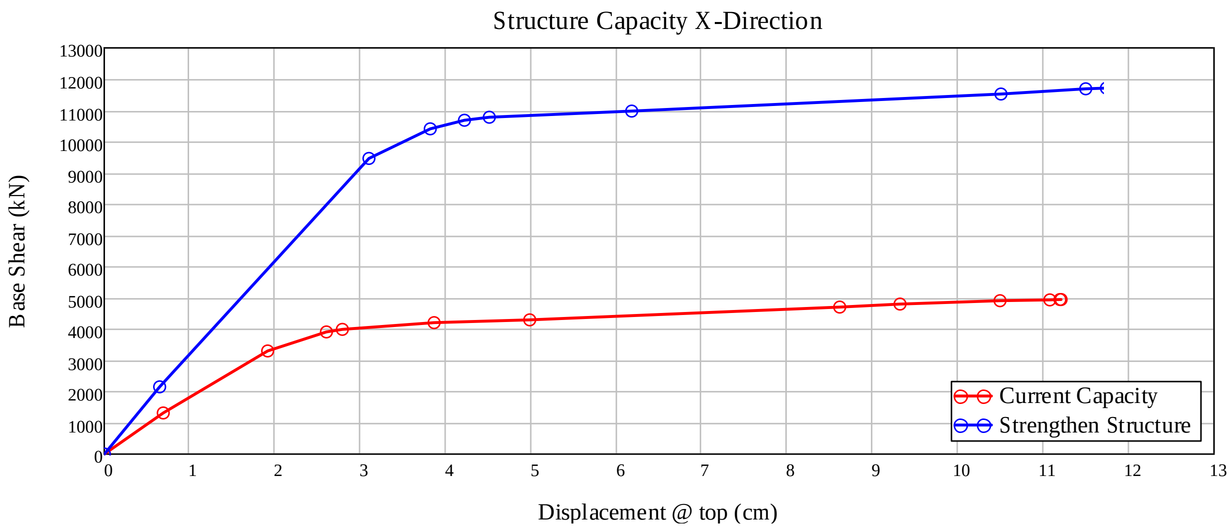


Fig.2: Pushover capacity curves for analyzed structure

The capacity of the structure is modeled following a common analytical procedure. It is assumed that the values of dissipated energy in the "real" capacity curve and the values of an idealized elastic-perfectly plastic one are equal.

4.1 *Capacity Spectra*

Initially, a convenient transformation of the capacity curves must be done in order to compare the seismic capacity of a structure taking into consideration code requirements (demand spectra). A shear force–displacement (V–Δ) capacity curve is transformed into the well-known AD Format, defined as Capacity Spectrum (S_a - S_d). In order to convert the V–Δ capacity curve into Capacity Spectrum, it is necessary to know the dynamic characteristics of the structure: the fundamental period T_1, the modal shape pattern Φ_i as well as lumped floor masses m_i. These characteristics serve to transform a MDOF system into a SDOF system. After these transformations, the final AD formats, for both orthogonal directions, were obtained (see Fig. 3).

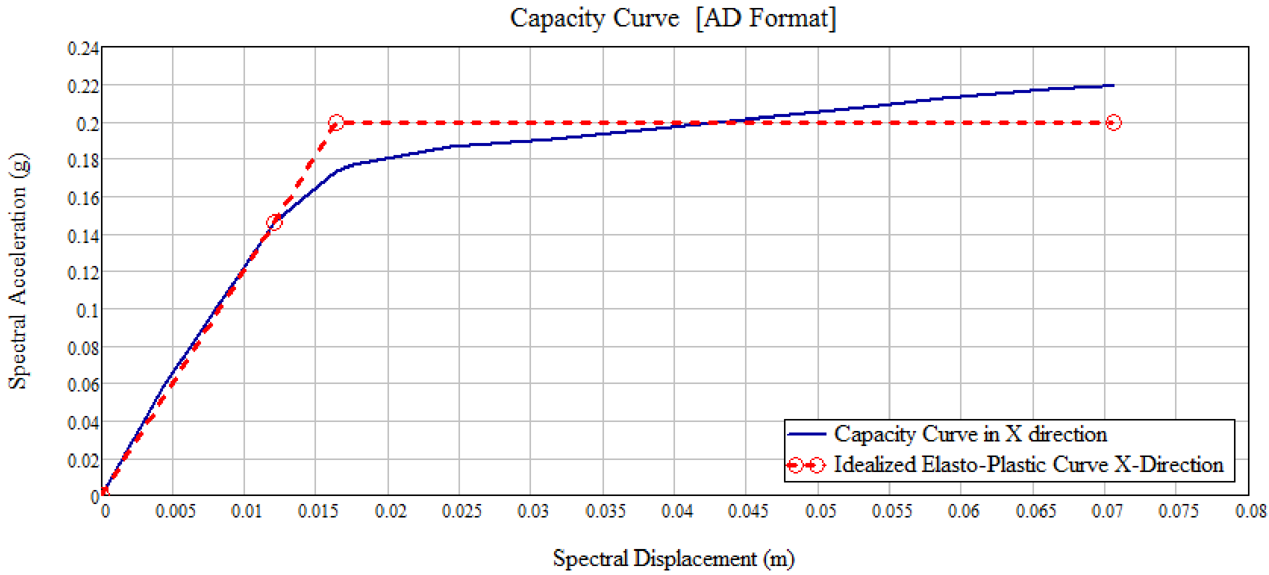


Figure 3: Real and idealized Capacity Spectra for analyzed structure

4.2 *Demand Spectra*

Elastic–Demand Spectrum

Taking into consideration the different site locations of the three school buildings and following the Albanian Technical Regulations KTP-N.2-89, three different response spectra, shown in Fig. 4-a, must be considered. A similar graph is shown in Fig. 4-b, which refers to the EC-8 seismic input requirements.

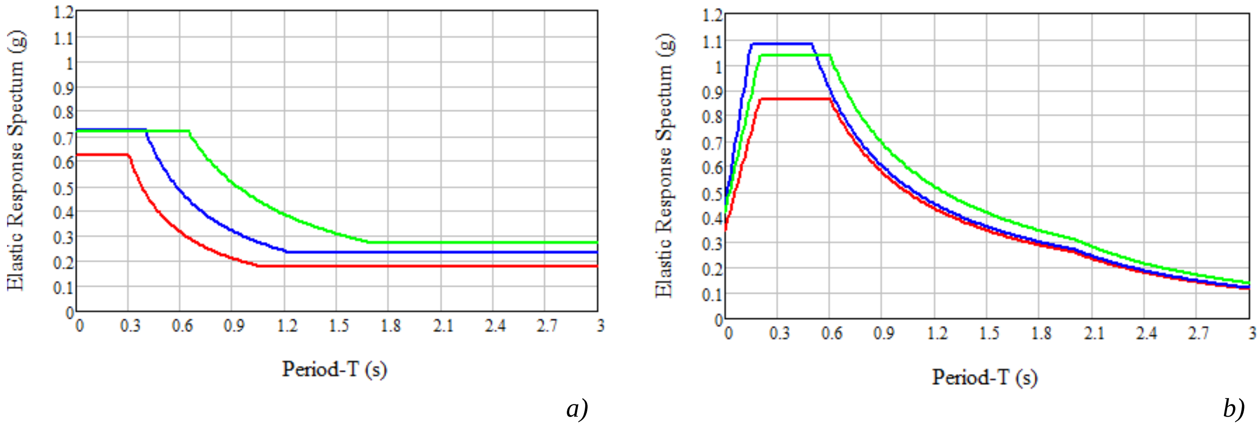


Fig. 4: Elastic response Demand Spectra: a) according to KTP-N.2-89; b) according to EC-8

Conversion of the Elastic–Demand Spectra into AD Format

For an elastic SDOF system the known relation between the elastic acceleration (S_{ae}) and the respective displacement (S_{de}) response spectra values, is:

$$S_{de}(T) = \frac{S_{ae}(T)}{4\pi^2}T^2 \quad (1)$$

The respective reduction factors, which depend on the ductility of the structure, must be used in order to plot the final design demand spectra in AD format.
Based on the actual damping value and on accepted ductility, the reduction R_μ factor (Fajfar and Vidic 2000) converts the elastic response spectra [$S_{ae}(T)$] of Fig. 4-b, to the corresponding nonlinear response spectra [$S_a(T)$]. The same may be done for the demand spectra compiled according to the KTP-N.2-89 Code (Fig. 4-a).

5 FRAGILITY MODEL

Fragility is a function of system's capacity against each limit state as well as the probable uncertainties in the capacity. The capacity controls the central location of the fragility curve (mean values) and the uncertainty controls the shape (standard deviation) of the fragility curve. The fragility model predicts conditional probabilities for a building, which is in or exceeding specific damage states (d_s) at specified levels of ground motion (y_k).
The damage states can be expressed also differently – by using the static nonlinear analyses – as a function of the roof displacements. When considering the capacity spectra, the median spectral displacements defining the damage state limits, are determined in a simple way. For the following damage states 1-slight, 2-moderate, 3-extensive and 4-collapse, the corresponding means spectral displacement can be determined as follows (Risk-EU Project, WP4, 2003):

$$\bar{S}_{d,1} = 0.7 \cdot D_y; \;\; \bar{S}_{d,2} = 1.0 \cdot D_y; \;\; \bar{S}_{d,3} = D_y + 0.25 \cdot (D_u - D_y); \;\; \bar{S}_{d,4} = 1.0 \cdot D_u \qquad (2)$$

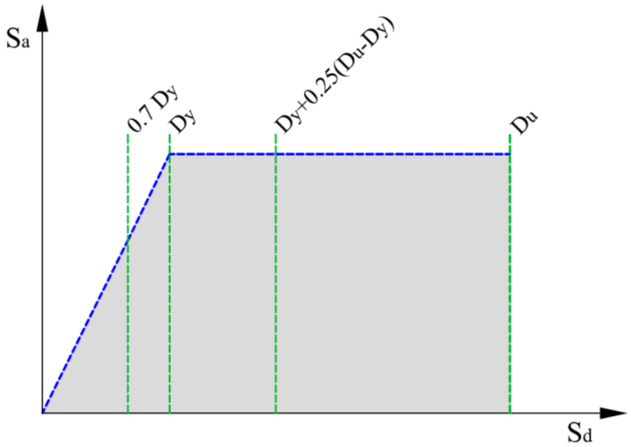


Fig. 5: Define damage threshold levels

As known, each fragility curve is characterized by the median value (μ) and the lognormal standard deviation (β) of seismic hazard parameter, i.e. the spectral displacement S_d:

$$P[d_s / S_d] = \Phi\left[\frac{1}{\beta_{ds}} \cdot \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] = \int_0^{S_d} \frac{1}{\beta_{ds} \cdot y \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}\cdot\left(\frac{\ln(y)-\ln(\bar{S}_{d,ds})}{\beta_{ds}}\right)^2} dy \qquad (3)$$

In Eq. (3), S_d is the spectral displacement; $\bar{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches a certain threshold of the damage state d_s; β_{ds} is the standard deviation of the spectral displacement of damage state, ds; Φ is the standard normal cumulative distribution function.
The method presented in the RISK-EU Project is used to developing fragility models, according to the following steps:
1.– Definition of bilinear capacity spectra in AD format. Two characteristic points are needed for this purpose: yielding point (D_y, A_y) and ultimate point (D_u, A_u). (see Fig. 7).
2.– Definition of damage threshold levels, explained by the formulae above (see Fig. 5). In our case, damage threshold levels for both orthogonal directions are presented in Table 2.

Table 2: Damage threshold levels

	S_d**1**-*Slight*	S_d**2**-*Moderate*	S_d**3**-*Extensive*	S_d**4**-*Collapse*
Current	*1.150 cm*	*1.643 cm*	*2.997 cm*	*7.058 cm*
Strengthen	*1.612 cm*	*2.303 cm*	*3.575 cm*	*7.392 cm*

3. Calculate cumulative probability (CP), for being in or exceeding certain damage state (k) at certain S_d level. The discrete probabilities for each damage threshold level are not calculated but, taken directly from Table 3 (Milutinovic et al. 2002).

Table 3: Probabilities by β–distribution

Condition	$P_\beta(1)$	$P_\beta(2)$	$P_\beta(3)$	$P_\beta(4)$
$P_\beta(1)=0.5$	0.500	0.119	0.012	0.000
$P_\beta(2)=0.5$	0.896	0.500	0.135	0.008
$P_\beta(3)=0.5$	0.992	0.866	0.500	0.104
$P_\beta(4)=0.5$	1.000	0.988	0.881	0.500

4. Median value of the spectral displacement (μ_{ds}) as well as lognormal standard deviation (β_{ds}) corresponding to each damage threshold level (Table 2) are calculated by regression analysis using the lognormal standard distribution model (Eq.3). The four calculated sets of values (μ_{ds}, β_{ds}) for both orthogonal directions are presented in Table 4.

Table 4: Fragility curve parameters

		S_d**1**-*Slight*	S_d**2**-*Moderate*	S_d**3**-*Extensive*	S_d**4**-*Collapse*
Current	*Mean - μ_{ds}*	1.150 cm	1.725 cm	3.117 cm	7.051 cm
	St.Dev. - β_{ds}	0.283 cm	0.417 cm	0.599 cm	0.670 cm
Strengthen	*Mean - μ_{ds}*	1.612 cm	2.348 cm	3.730 cm	7.383 cm
	St.Dev. - β_{ds}	0.284 cm	0.349 cm	0.481 cm	0.563 cm

6 BUILDINGS DAMAGE ASSESSMENT

The objective of building damage assessment is to estimate expected seismic losses at a given level of earthquake ground motions. The conditional probability that the building will reach certain damage state is determined according to these steps:

1- Define the capacity model and convert it into capacity spectrum.
2- Determine the model of building's site-specific demand spectra.
3- Calculate buildings expected response by intersecting the capacity and demand spectra, (performance points).
4- Based on the corresponding fragility model, estimate conditional probabilities that relate to the calculated performance point, for which the building will exhibit certain damage states.

6.1 *Performance Points*

The AD format allows the demand spectrum to be "overlapped" on building's capacity spectrum. The intersection of the demand and capacity spectra represents the Performance Point (PP). The procedure used in our study is the same one described in ATC 40. However, for the Elastic-Perfectly Plastic Capacity Spectrum, a closed mathematical solution (Fajfar, 2000) is used. A well-known estimation method (the simple technique called "the equal displacement approximation") is used to calculate the displacement due to a given seismic demand. It is based on the assumption that the inelastic spectral displacement S_d is the same as the one that would occur if the structure remained perfectly elastic S_{de} (Fig. 6).

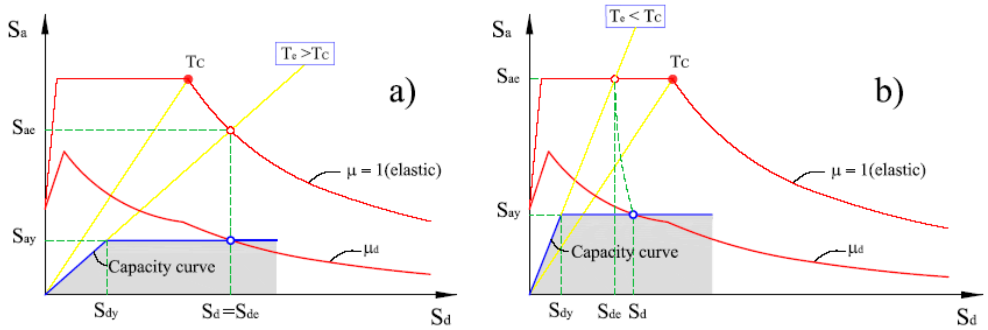


Figure 6: Finding Performance Point in case of elastic-perfect plastic capacity spectrum

They (PP) refer to three different demand spectra (Fig. 4-b) obtained according to the EC-8 seismic demands with the new draft PGA Seismic Map.

Performance Point for existing structure

Fig. 7 shows the positions of the three performance points for the existing structure corresponding to the capacity regarding the X direction. The Demand Spectra shows that the performance point (except one) falls out of the actual capacity of the building. The damages are directly related to the position of the PP in the nonlinear range of capacity spectra.

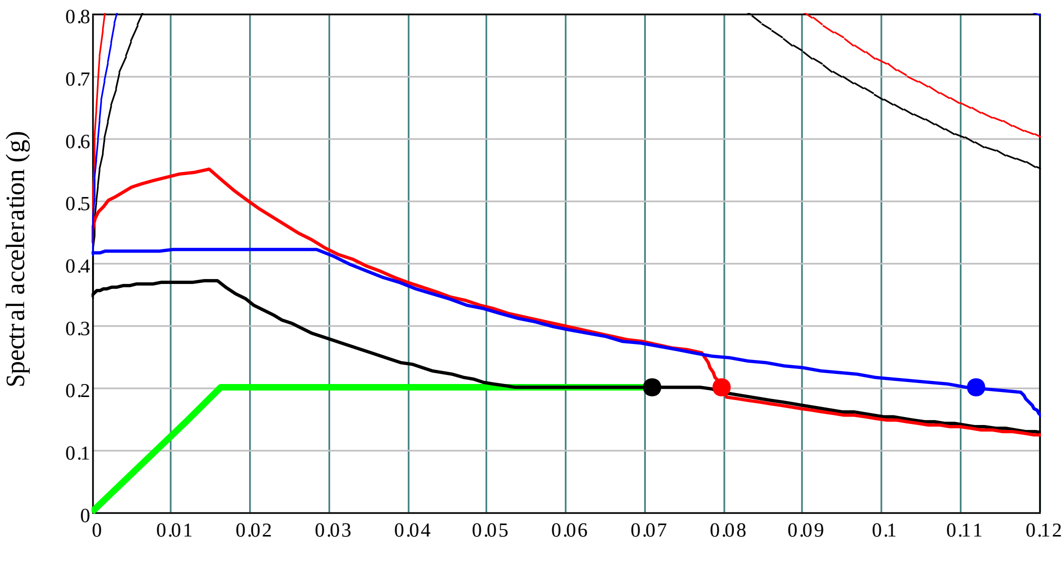


Figure 7: Different Performance Points for existing structure

Performance Point for strengthen structure

Fig. 7 shows the positions of the three performance points for the strengthen structure. The Demand Spectra shows that the performance point falls in of the actual increased capacity of the building.

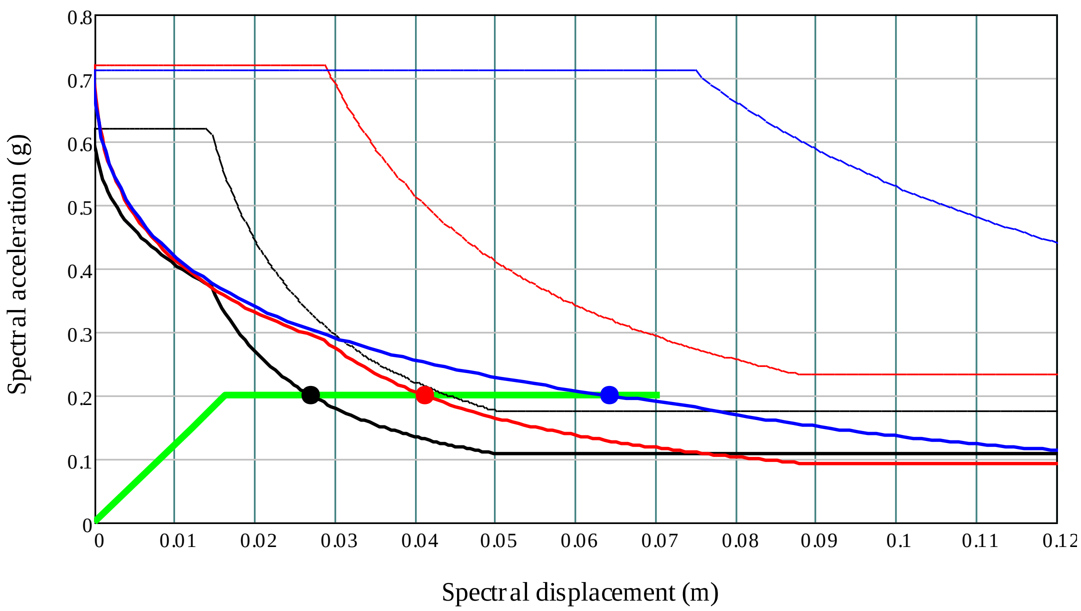


Figure 8: Different Performance Points for strengthen structure

6.2 *Building Damage Assessment*

Based on the analytical damage assessment, the obtained results for EC-8 seismic requirements considering the new draft PGA Seismic Map are summarized below:

For existing structure (Fig.9):

<u>For PGA = 0.25g, Soil Category C</u>, the level of probable damages are:
100% *of exceeding the* **slight** *and the* **moderate** *damages;* **91%** *of exceeding the* **extensive** *damages, and* **50%** *probability to* **collapse**.
<u>For PGA = 0.3g, Soil Category B</u>, the level of probable damages are:
100% *of exceeding the* **slight** *and the* **moderate** *damages;* **94%** *of exceeding the* **extensive** *damages, and* **57%** *probability to* **collapse**.
<u>For PGA = 0.3g, Soil Category C</u>, the level of probable damages are:
100% *of exceeding the* **slight** *and the* **moderate** *damages;* **99%** *of exceeding the* **extensive** *damages, and* **76%** *probability to* **collapse**.

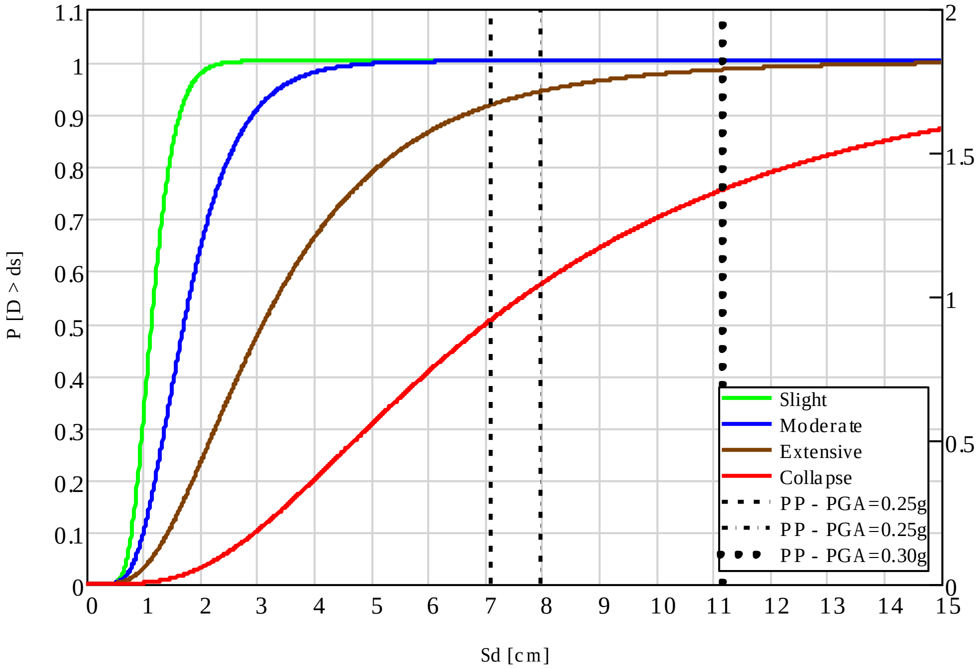


Figure 9: Damage assessment for existing building

For strengthen structure (Fig.10):

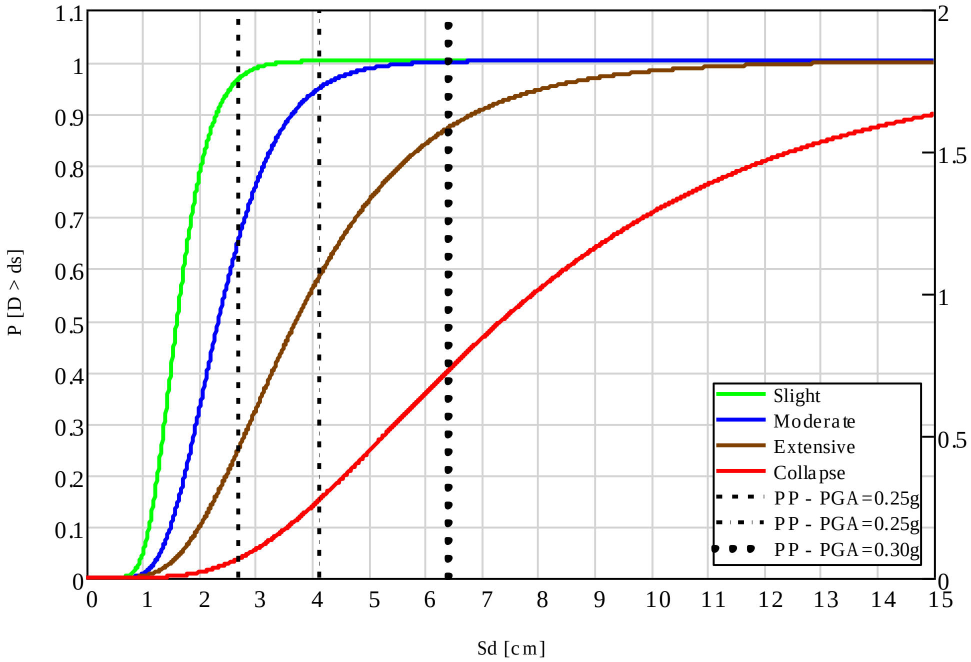


Figure 10: Damage assessment for existing building

For PGA = 0.25g, Soil Category C, the level of probable damages are:
97% *of exceeding the* **slight** *damages;* **66%** *of exceeding the* **moderate** *damages;* **25%** *of exceeding the* **extensive** *damages, and* **4%** *probability to* **collapse**.
For PGA = 0.3g, Soil Category B, the level of probable damages are:
100% *of exceeding the* **slight** *damages;* **95%** *of exceeding the* **moderate** *damages;* **58%** *of exceeding the* **extensive** *damages, and* **15%** *probability to* **collapse**.
For PGA = 0.3g, Soil Category C, the level of probable damages are:
100% *of exceeding the* **slight** *damages;* **100%** *of exceeding the* **moderate** *damages;* **87%** *of exceeding the* **extensive** *damages, and* **40%** *probability to* **collapse**.

7 CONCLUSIONS

Response Spectra as a combination of the seismic requirements and soil category are different for the requirements of two Seismic Codes considered: KTP-N.2-89 and EC-8 combined with the new draft PGA Seismic Map. The building used in this study has to support a seismic force 50% higher if EC-8 seismic requirements would apply.

The results obtained from this study show that: extensive damages even Collapse in existing building may be occur in case of strong earthquakes. Capacity is increased adequately in case of strengthen structure. So, although this study considers only one structure, needed is to consider the adequately increase of seismic structural capacity of other buildings.

Also, comparing performance point it is clear the retrofitted structure has an increased capacity comparing with existing one.

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