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ASSESSMENT OF OPTIMUM STRENGTHENING DESIGN OF A REINFORCED CONCRETE BUILDING WITH VULNERABILITY CRITERIA

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Abstract. *This research deals with the assessment of the seismic behavior and capacity of a reinforced concrete building in order to examine the possibility of strengthening. This process is achieved by using the Nonlinear Static Analysis (Pushover Analysis) and is based also on performance criteria. In case of damages two different methods of strengthening are implemented: the reinforced concrete jacketing and the carbon fiber reinforced polymer wrapping (CFRP). Afterwards, the determination of the optimum strengthening design is performed, thanks to metaheuristic optimization algorithms, aiming at the minimization of the cost. Subsequently, the retrofitting measures are evaluated through a methodology defined by vulnerability criteria and fragility curves, produced either by the Incremental Dynamic Analysis (IDA) or by using Eurocode8 Regulations, the Method of Coefficients as well as the Hazus Methodology. The fragility curves refer to different earthquake performance levels and as a result they express the probability of excess of the different target damage states. A comparison between these curves, before the intervention and after that, indicates the effectiveness of the selected strengthening techniques.*

1 INTRODUCTION

The strengthening of structures has become frequent in recent years. Lots of problems arise due to failed initial design or bad application of it. Other significant factors are the materials used and the construction and maintenance conditions. Moreover, earthquakes and strong winds have an important impact on the structures and cause often damages.

For the assessment of an existing building's seismic capacity there are some determinate methods of analysis [1, 2] that can be used; linear and non-linear. To the linear category belong the elastic static analysis and the elastic dynamic one, whereas the inelastic static (Push-over Analysis) and the inelastic time history dynamic (Incremental Dynamic Analysis) belong to the non-linear category. The strong difference between the non-linear and linear analyses is that in the non-linear framework the structure continues to receive seismic loads of different intense levels even if some elements have exceeded the yield point, through their deformation, a fact that is not taken into consideration within linear analyses. Very important is to define the non-linear characteristics of the materials (concrete and steel) used [3]. For concrete the following deformation values are valid: ε_c=2‰ και ε_{cu}=3,5‰, for steel: ε_{su}=0,02. The non-linear behavior of a building is equivalent with the appearance of plastic hinges at the nodes. The determination of the plastic hinges' characteristics and the calculation of specific performance criteria in terms of chord rotation, through which the assessment of the seismic behavior of the building is achieved, are crucial.

Pushover Analysis [1] is implemented by using many seismic load combinations concerning two directions X, Y: ±X±0.3Y and ±0.3X±Y. The seismic loads are imposed to the building as acceleration in various ways: uniform and modal form. A target displacement is defined relying on ATC-40 [4] or Coefficient Methodology [1] by using the equivalent SDOF system. The acceleration increases incrementally, while the displacement at the roof of the building is recorded. At the point, that the top displacement reaches the target displacement (performance point), the increase of the acceleration is interrupted. The capacity curve V-D is produced and the yield situation of the plastic hinges is examined according to the performance criteria. Thus, an assessment of the structural capacity can be carried out.

Incremental Dynamic Analysis (IDA) [1, 5] uses a variety of accelerograms of earthquakes that have taken place in the past. Moreover, a proper scaling of each earthquake accelerogram is proceeded relatively to the selected intense levels. These scaled time history accelerograms of all the earthquakes act as seismic loads for the structure. Meanwhile, the response of the structure is monitored and expressed in terms of maximum interstorey drift. The goal is the formation of an IDA curve for each seismic record, displaying the relation between the seismic intensity measurement and the maximum interstorey drift.

Vulnerability analysis [5, 6, 7, 8] of a structure can have a great influence on the evaluation of its seismic capacity. It can be applied in two alternative ways: based on IDA curves [5] or on theoretical methods (Coefficient, Hazus) incorporating Eurocode8 assumptions [7, 8]. Vulnerability analysis aims at the construction of fragility curves; they demonstrate the probability of excess for different damage states, e.g. slight, moderate and heavy damage, while the intense of the imposed seismic effect is amplified.

The assessment of the seismic response of a structure often proves its inability to meet the demands and points out the need for repair. In fact there are many retrofitting methodologies [1, 9, 10] that are divided into two main categories: strengthening by section enlargement and strengthening by confinement. In the first kind are included the Reinforced Concrete (RC) Jackets, made of cast concrete, shotcrete or cement mortars. In the second kind of strengthening are contained the following techniques: steel angles and strips, steel collars, spiral reinforcement, steel jackets, fiber reinforced polymer laminates or sheets made of carbon, glass or aramid.

This study [11, 12] is about the assessment of the seismic capacity of an existing 4-storey reinforced concrete building through Pushover Analysis and the examination of retrofit need's existence. As strengthening methods RC Jackets and carbon fiber reinforced polymer (CFRP) wrapping are used. With purpose of cost minimization of the strengthening measures, an optimization process [13, 14, 15], based on metaheuristic algorithms and in particular on Differential Evolution, is performed. Subsequently, the optimum retrofit design is evaluated by means of IDA and in relation with the established vulnerability criteria.

2 ASSESSMENT OF THE STRUCTURE WITH PERFORMANCE CRITERIA

First and foremost to assess the capacity of a building it is necessary to define its seismic behavior and resistance to the design earthquake. In this particular study, numerous regulations and restrictions, implied by the Interventions Regulation in Buildings of Reinforced Concrete (KANEPE) [1], are followed, according to which a methodology, based on specific performance criteria, is implemented through the Pushover Analysis.

2.1 Adjustment to KANEPE

Distinction between primary and secondary structural elements

Primary elements [1] are the elements that participate in the stiffness of the structure and in the redistribution of the loads by receiving, apart from vertical loads, also horizontal seismic loads. On the contrary the secondary elements [1] are characterized by lower stiffness, capacity or ductility and therefore they contribute to the absorption only of the vertical loads. As a result the damage restriction for the primary elements is more crucial. In this research all of the structural elements of the building are considered as primary.

Structural performance states and hazard levels

There are three basic Performance States (PS) [1, 2, 7, 16] of a structure, which correspond actually to the expected damage states: a) Immediate Occupancy (IO): The damage is very light, none of the operations of the structure is prevented and only hairline cracks are allowed. b) Life Safety (LS): The damage is moderate and repairable, no death or serious injury is expected. c) Collapse Prevention (CP): Severe damage is inevitable and no satisfactory safety is ensured.

As far as the hazard levels are concerned, there are three: a) Occasional Earthquake: with excess probability 50% in a life cycle of 50 years. That means that the period of reoccurrence amounts to 72 years. b) Rare Earthquake: with excess probability 10% in 50 years and period of reoccurrence 475 years. c) Maximum Considered Earthquake: with excess probability 2% in 50 years and period of reoccurrence 2475 years. In the present study as assessment target is considered the performance state "Life Safety" for the Rare Earthquake.

Data reliability levels and proposed methods of analysis

For the assessment of an existing building, important data about materials, construction details and geometrical properties of the structural elements are needed and collected in order to achieve the most successful estimation of its available capacity. The quantity and quality of these data define the data reliability levels (DRL) [1, 2]: high, satisfying and low, according to which the proper safety factors are selected. Depending on the available DRL there are some methods of analysis, proposed by KANEPE: Linear Static Analysis or Linear Dynamic Analysis regardless of the DRL and Non Linear Static Analysis (Pushover Analysis) or IDA in case the DRL is at least satisfying.

2.2 Pushover analysis

First of all it is essential to determine the plastic hinges of the building. Possible position of a plastic hinge's appearance is each edge of the structural elements, so it is significant to form the deformation curve of each element. Subsequently the performance criteria for each section, in terms of the chord rotation θ, are calculated through the following expressions [1], where γ_{Rd}=1.80 :

$$\theta < \delta_y = \theta_y \qquad \text{for Immediate Occupancy} \tag{1a}$$

$$\theta < \delta_d = 0.5 \cdot \left(\theta_y + \theta_u\right) / \gamma_{Rd} \qquad \text{for Life Safety} \tag{1b}$$

$$\theta < \delta_d = \theta_u / \gamma_{Rd} \qquad \text{for Collapse Prevention} \tag{1c}$$

The horizontal seismic load is imposed in two ways, as uniform load and as inverted triangular load along the building height [1]. There are several load combinations used concerning the load direction along the axes X and Y. In fact the implemented load combinations are ±X±0.3Y and ±0.3X±Y. The load V is gradually incremented and simultaneously the displacement of a check node D is monitored until the target displacement is reached. The check node is on the top of the building and very close to the center of gravity. The target displacement corresponds to the performance point, which is calculated through the methodology ATC-40 [4] and by means of Acceleration – Displacement Response Spectrum ADRS (Sa-Sd:) that refers to the equivalent SDOF system. Finally the Capacity Curve (V- Δ_{TOP}) is formed and the situation of the plastic hinges of the structure at the performance point for all the load combinations is examined.

Load Shape	Load Comb	V (KN)	Δ_{TOP} (m)	A to B	B to IO	IO to LS	LS to CP	CP to C	Total Number
Uniform	+X+0,3Y	2635,24	-0,063	201	30	57	0	0	288
	-X-0,3Y	-2637,13	0,063	199	32	57	0	0	288
	+Y+0,3X	2570,65	-0,061	186	12	88	2	0	288
	-Y-0,3X	-2586,55	0,063	182	17	87	2	0	288
Inverted Triangular	+X+0,3Y	-2364,99	0,067	191	28	69	0	0	288
	-X-0,3Y	2340,15	-0,065	193	30	65	0	0	288
	+Y+0,3X	-2275,06	0,070	161	33	93	1	0	288
	-Y-0,3X	2270,29	-0,068	172	37	79	0	0	288

Table 1: Situation of the plastic hinges of the initial building at the performance point [11].

In case a plastic hinge has exceeded the PS "Life Safety", it is considered that the particular element has been damaged and needs to be retrofitted. As a consequence, from the analysis results [11] it is proved that 5 of the columns have exceeded LS and have to be strengthened.

3 OPTIMUM STRENGTHENING DESIGN OF THE STRUCTURE

3.1 Strengthening techniques

In case of structural elements' damages numerous strengthening techniques can be implemented aiming at the retrieval of the initial capacity of the structure. In this particular study [11, 12] two different techniques are selected for the column strengthening: the reinforced concrete jacketing and the carbon fiber reinforced polymer wrapping (CFRP).

Reinforced concrete jacketing

Reinforced Concrete Jacketing [9, 10] is a strengthening method that requires sectional increase of the damaged element and is realized through additional concrete layers and reinforcement. Reinforced Concrete Jackets are usually produced by cast concrete, shotcrete or cement mortars. They contribute to the increase of the stiffness and also to the reduction of the slenderness and do not influence the architecture of the building.

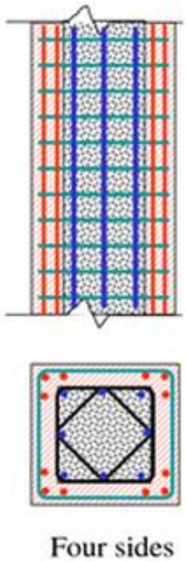

Figure 1: Simulation of reinforced concrete jackets [17].

Fiber reinforced polymer wrapping

Fiber Reinforced Polymer Wrapping [9, 10] is another strengthening method, which is succeeded through confinement of the existing section. This confinement can be achieved by means of fiber sheets of carbon, glass or aramid. They have low weight and can be easily installed. In addition they have high corrosion resistance and conduce not only to the reduction of the slenderness but also to the increase of the compression strength and ductility.

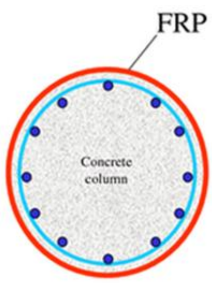

Figure 2: Simulation of CFRP wrapping [17].

3.2 Initial building strengthening

A random building strengthening is initially attempted [11] that includes RC Jackets with 7cm thickness and quality C30/37 as well as 8 additional longitudinal reinforcement bars with diameter 20mm and quality S500. A wrapping retrofitting technique, using CFRP, is also tested. The characteristics of the carbon fiber sheet are the following: layer thickness 0.275mm, modulus of elasticity E_f=240GPa, tensile strength $f_{u,f}$=3500MPa and ultimate deformation $\varepsilon_{f,u}$=0,015. For the columns C1 and C15, 9 CFRP layers are used, whereas for the columns C4, C13 and C14, 8 CFRP layers are chosen. Comparing with the original column section (unconfined concrete), the confined with FRP concrete demonstrates a definitely improved behavior since its failure stress and strain reach much higher values, according to KANEPE [1].

After the implementation of the two different retrofitting techniques and the application of the Pushover analysis on the building, the new performance points (V, Δ_{TOP}) and the new situation of the plastic hinges are defined [11].

Load Shape	Load Comb	V (KN)	Δ_{TOP} (m)	A to B	B to IO	IO to LS	LS to CP	CP to C	Total Number
Uniform	+X+0,3Y	3138,59	-0,060	186	27	75	0	0	288
	-X-0,3Y	-3148,96	0,060	200	37	51	0	0	288
	+Y+0,3X	3053,86	-0,057	185	27	76	0	0	288
	-Y-0,3X	-3053,33	0,059	184	31	73	0	0	288
Inverted Triangular	+X+0,3Y	-2852,53	0,064	186	46	56	0	0	288
	-X-0,3Y	2810,37	-0,064	182	35	71	0	0	288
	+Y+0,3X	-2775,29	0,067	169	45	74	0	0	288
	-Y-0,3X	2780,54	-0,065	163	43	82	0	0	288

Table 2: Situation of the plastic hinges of the strengthened with RC jackets building at the performance point [11].

Load Shape	Load Comb	V (KN)	Δ_{TOP} (m)	A to B	B to IO	IO to LS	LS to CP	CP to C	Total Number
Uniform	+X+0,3Y	2735,01	-0,063	198	15	75	0	0	288
	-X-0,3Y	-2752,14	0,064	198	20	70	0	0	288
	+Y+0,3X	2649,53	-0,062	201	36	51	0	0	288
	-Y-0,3X	-2644,72	0,063	190	41	57	0	0	288
Inverted Triangular	+X+0,3Y	-2441,56	0,067	184	32	72	0	0	288
	-X-0,3Y	2412,81	-0,066	187	34	67	0	0	288
	+Y+0,3X	-2345,56	0,070	171	54	63	0	0	288
	-Y-0,3X	2333,64	-0,069	184	47	57	0	0	288

Table 3: Situation of the plastic hinges of the strengthened with CFRP wrapping building at the performance point [11].

According to the Pushover analysis' results [11], the solution of RC jackets show a larger increase and decrease of the base shear force V and top building displacement Δ_{TOP} respectively, at the performance point, which means that they offer larger carrying capacity than the CFRP sheets. On the other hand, the situation of the plastic hinges seems to be better in case of CFRP sheets' exploitation and that is due to the further ductility they provide. Generally speaking, both of the methods are effective since the situation of the plastic hinges is undoubtedly improved, none of them has exceeded the PS "Life Safety" and as a result no damage appears.

3.3 Building strengthening optimization

Optimization Process

The goal of the building strengthening optimization is the minimization of the cost in a way that the seismic behavior of the structure is absolutely safe. The first step is the definition of the problem [13, 14, 15]. The cost, concerning both materials and labor, is set as *objective function*, the comparison criterion between the optimum and the other possible solutions. Afterwards, the *design variables* are determined: The thickness t and the quality of the jacket concrete as well as the mechanical reinforcement ratio ρ_s are set for the RC Jacketing, whereas the number of fiber sheet layers is set for the CFRP Wrapping. As *restriction* of the problem functions the fact that all of the plastic hinges must not exceed the PS "Life Safety".

The optimum design is performed thanks to a metaheuristic optimization algorithm, based on a methodology of Differential Evolution [13, 14, 15]. The algorithm produces generations of solutions until the optimum one is achieved. In fact the algorithm includes 10 parametric vectors for each generation, where the first one of the first generation is equal with the initial strengthening and the others have random prices. The design variables change, satisfying the restrictions and the minimum objective function is determined for each generation. The optimization comes to the end and the optimum design is reached when the same price of the objective function arises for 4 consecutive generations and this is actually the final one.

Optimization Results

The metaheuristic optimization algorithm [11] for the RC Jacketing produces finally 15 generations and concludes to the following strengthening for the damaged building: RC Jackets, only for columns C1, C4 and C15, with thickness 7cm, concrete quality C30/37 and 4 additional longitudinal reinforcement bars with diameter 22mm and quality S500. This solution ensures the normal operation of the structure and reduces the retrofitting cost from 3170 € regarding the initial design, to 1163€ regarding the optimum design.

The optimum strengthening design through CFRP Wrapping according to the metaheuristic optimization algorithm [11], respectively, contains: 6 fiber sheet layers for columns C1 and C15, 7 fiber sheet layers for column C4 and none for columns C13 and C14. In this case the retrofitting cost declines from 3441 € regarding the initial design, to 2338€ regarding the optimum design.

4 VULNERABILITY ANALYSIS

4.1 Vulnerability analysis through Incremental Dynamic Analysis

Incremental Dynamic Analysis

In the beginning, [12] 12 real accelerograms from different places of the world, most of them from Greece, are collected via PEER Strong Motion Database. The Spectral Acceleration for the first eigenperiod of the structure and damping 5% ($Sa(T_1,5\%)$) and the Peak

Ground Acceleration (PGA) are defined as Intensity Measures (IM). As Damage Measure (DM) is considered the maximum interstorey drift θ_{max}. In order to examine the structural seismic response to lots of different intensity levels IM_i, the original accelerogram of each earthquake has to be scaled depending on the proper Scale Factor (SF). SF is equal with IM_i / IM_o [5,6], where IM_o is the IM corresponding to the original Response Spectrum. Afterwards, all of the scaled accelerograms of each earthquake are enforced to the building in a non-linear way, through IDA, and the structural performance is recorded in terms of the maximum interstorey drift θ_{max}. Thus, the IDA curves can be formed by correlation between IM_i and $\theta_{max,i}$.

Fragility Curves IDA

The performance of the structure is assumed by comparing the resulting interstorey drift $\theta_{max,i}$ of each IDA with the minimum interstorey drift limits θ_{PS} [7] that correspond to the PS: Immediate Occupancy, Life Safety and Collapse Prevention. In case $\theta_{max,i} > \theta_{PS}$ the building has exceeded the particular PS.

Performance State	**Interstorey drift θ_{PS}**
Immediate Occupancy	$0{,}002 < \theta < 0{,}004$
Life Safety	$0{,}010 < \theta < 0{,}018$
Collapse Prevention	$\theta > 0{,}03$

Table 4: Interstorey drift limits for each performance state.

The target of the vulnerability analysis is to define the possibility $P(\theta_{max,i}>\theta_{PS})$, for every intensity level, which is determined according to the following relationship [5, 6]:

(2)

where m is the average and sd is the standard deviation of the IM_{PS} of all the seismic records for each PS. The IM_{PS} of each seismic record is identified through the IDA curves in relation to the limits of θ_{PS}. The fragility curves express the relation between the possibility $P(\theta_{max,i}>\theta_{PS})$ and the IM_i. It is noted that in order to form the fragility curves referring to the retrofitted structure, the optimized strengthening characteristics [11] are taken into consideration for both RC jackets and CFRP wrapping.

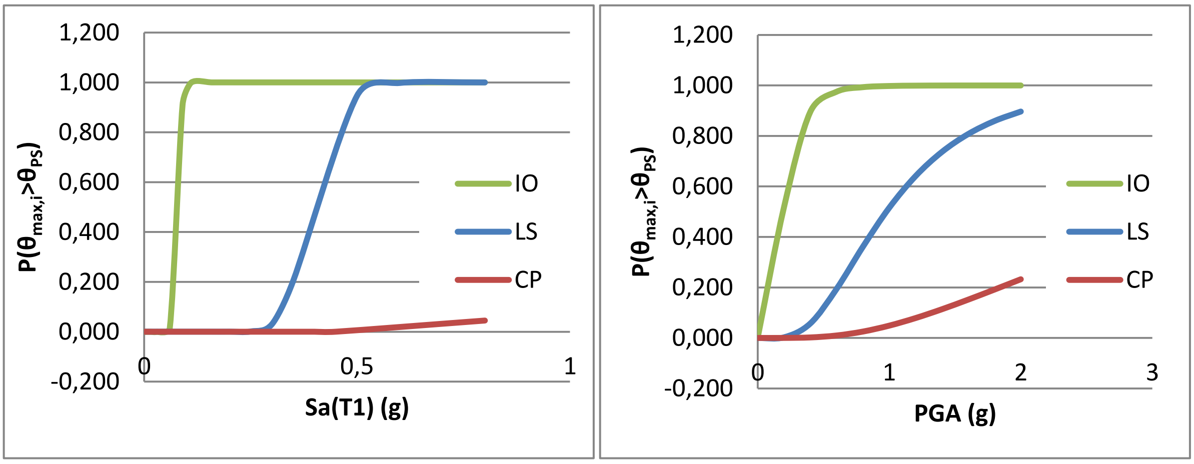

Figure 3: IDA fragility curves for the initial building considering IM= Sa(T1,5%) and PGA respectively [12].

4.2 Vulnerability analysis through EC8

Coefficient Method

The capacity curves of the initial and strengthened structure are formed based on the results of Pushover Analysis. The output of the Pushover Analysis constitutes the seismic response of the building in terms of displacement. Nonetheless it is possible to convert these terms to terms of maximum interstorey drift for each step of the Pushover Analysis and relate the top responding displacements Δ_{TOP} to the θ_{max} values. As a consequence, the interstorey drift limits θ_{PS} can be easily transformed to top displacement limits $\Delta_{TOP,PS}$ [12].

Using the Coefficient method [1, 18] it is feasible to construct a bilinear approximation of the capacity curves. Furthermore, the target displacement can be obtained from the relationship:

$$\Delta_t = C_0 \cdot C_1 \cdot C_2 \cdot C_3 \cdot Sa \cdot \frac{T_e^{\,2}}{4\pi^2} \tag{3}$$

where C_0 is the factor that relates the top building displacement to the spectral displacement, C_1 is the factor that relates the displacements of the inelastic system to those of the respective elastic one, C_2 is the factor that accounts the effect of the hysteresis shape on the maximum displacement response and C_3 figures the displacement increase due to P-Δ effects. Sα is the response spectrum acceleration for the effective fundamental period of the building T_e. Using this formula the top displacement limits $\Delta_{TOP,PS}$ can be finally transformed to response spectrum acceleration limits $S\alpha_{PS}$. The SF_{PS} is calculated for each PS as follows: $S\alpha_{PS}/S\alpha(T_e,5\%)$, where $S\alpha(T_e,5\%)$ is acquired from the design response spectrum [19]. Relatively to the SF_{PS} the elastic response spectrum is scaled.

Fragility Curves based on Hazus Methodology

The possibility $P(\theta_{max,i}>\theta_{PS})$, for every intensity level, according to the Hazus Methodology [8] is defined through the formula:

(4)

where (5)

The factors β_C, β_D and $\beta_{T,PS}$ refer to uncertainties about the shape of the capacity curve and other assumptions. The value $CONV[\beta_C,\beta_D]$ is estimated through tables of Hazus Methodology and $\beta_{T,PS}$ is considered due to simplification equal with 0.2, 0.4 and 0.6 for the PS: Immediate Occupancy, Life Safety and Collapse Prevention respectively. Thus the following fragility curves arise [12].

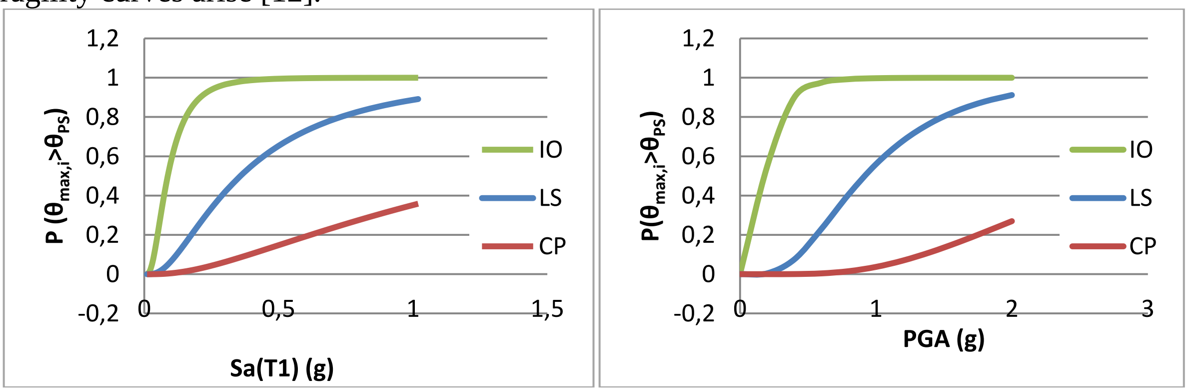

Figure 4: Hazus fragility curves for the initial building considering IM= $Sa(T_1,5\%)$ and PGA respectively [12].

5 ASSESSMENT OF THE OPTIMUM STRENGTHENING DESIGN WITH VULNERABILITY CRITERIA

The assessment of the optimum retrofitting measures is achieved by plotting the IDA fragility curves corresponding to a particular PS on a common diagram for all phases of the structure: initial, strengthened with RC jackets and strengthened with CFRP sheets [12]. The effectiveness of each strengthening technique can be easily evaluated by a comparison between the relative fragility curves and those reflecting the original building.

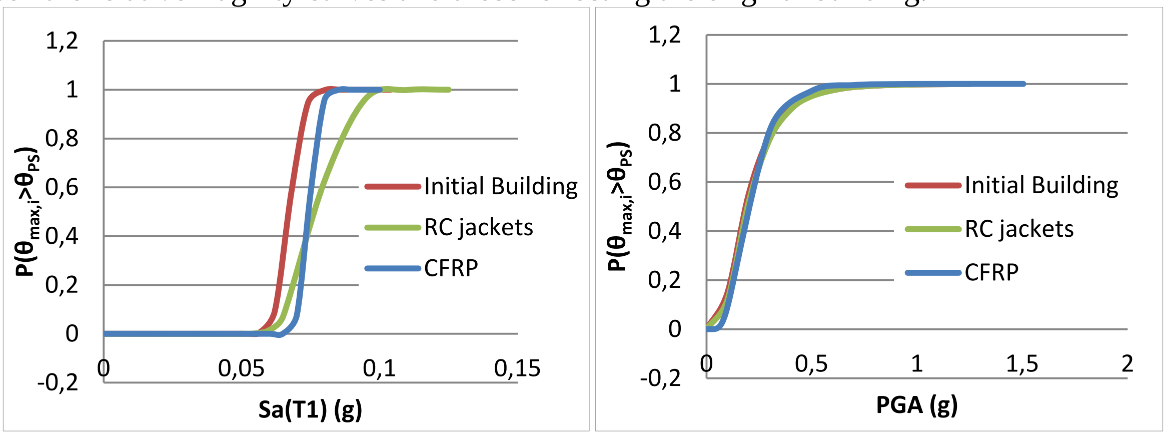

Figure 5: IDA fragility curves for Immediate Occupancy considering IM= Sa(T1,5%) and PGA respectively[12].

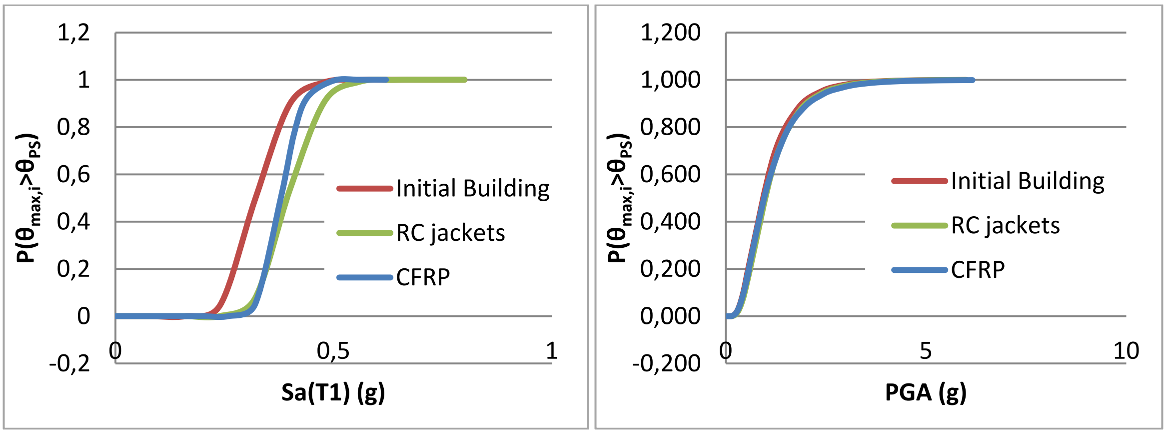

Figure 6: IDA fragility curves for Life Safety considering IM= Sa(T1,5%) and PGA respectively[12].

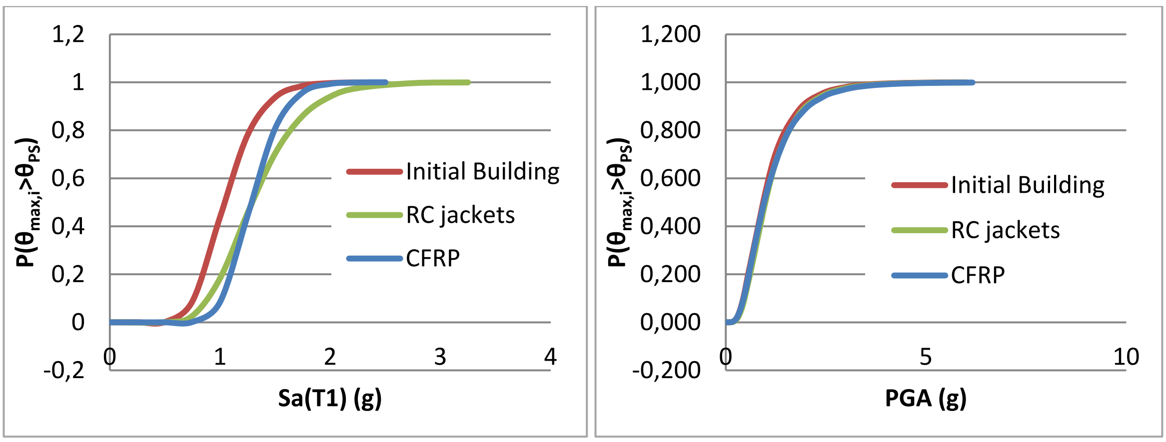

Figure 7: IDA fragility curves for Collapse Prevention considering IM= Sa(T1,5%) and PGA respectively[12].

As a first notice, the $Sa(T_1,5\%)$ seems to be a more representative criterion as IM than PGA, since the corresponding fragility curves offer a more distinct image about the difference of the structural behavior before and after the strengthening, as well as the deviation of contribution between the two different techniques. It is also clear that both of the strengthening techniques are productive and help the building respond more effectively to seismic forces, either by entering to a PS ($P(\theta_{max,i}>\theta_{PS})\geq 0$) or by exceeding it ($P(\theta_{max,i}>\theta_{PS})\leq 1$) because of more intense seismic loads (IM_i) than previously. Another verification, additionally, is that CFRP wrapping influences more positively the structure in case of low intense level, when the value of $P(\theta_{max,i}>\theta_{PS})$ fluctuates around zero. On the other hand, RC jackets are more satisfying in case of high intense level, when the value of $P(\theta_{max,i}>\theta_{PS})$ is around one. That can be explained by the fact that CFRP sheets confer further ductility to the structural elements, whereas RC jackets increase the capacity of the building, as it is proven through the Pushover Analysis [11], too. The exact profits of the strengthening are displayed below.

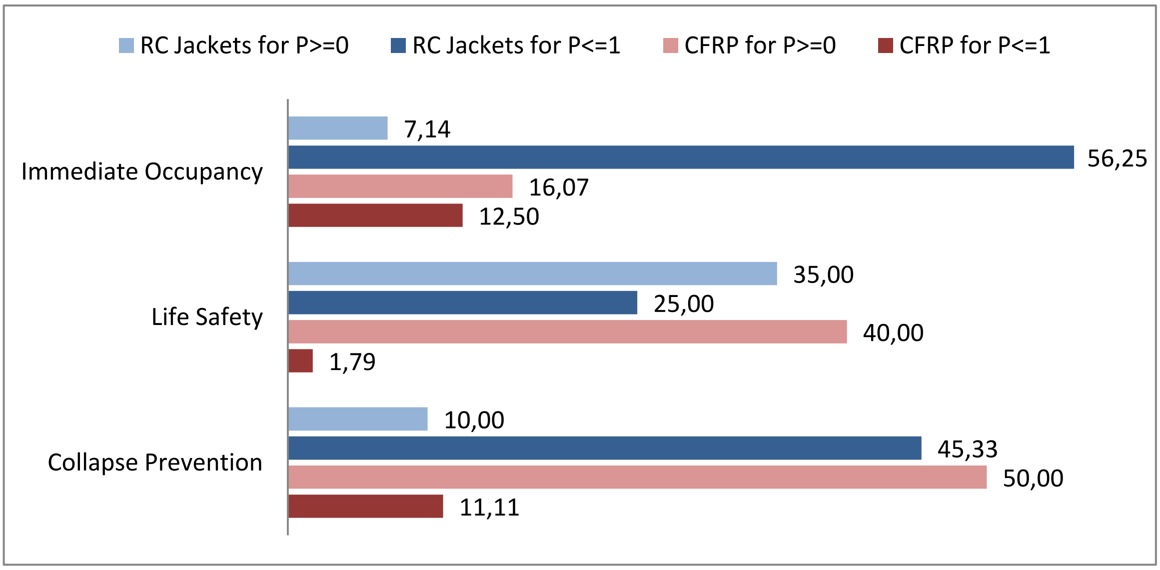

Figure 8: Structural Response Profit (%) thanks to retrofitting measures for IM= $Sa(T_1,5\%)$ [12].

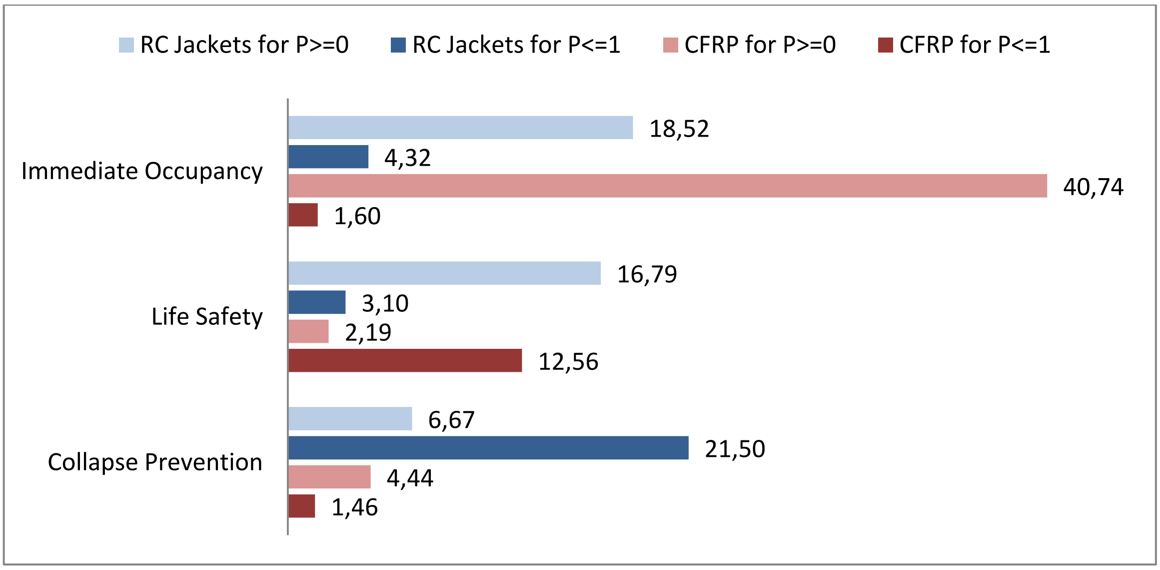

Figure 9: Structural Response Profit (%) thanks to retrofitting measures for IM= PGA [12].

6 CONCLUSIONS

In this work, the assessment of the seismic behavior of a 4-storey reinforced concrete building is attempted by using Pushover Analysis and performance criteria. The inadequate seismic response of the structure and the appearance of damages at 5 columns lead to strengthening solutions through RC jackets and CFRP wrapping. Their minimized cost is set as target; therefore, an optimization process is proposed to define the optimum characteristics of the strengthening measures. Another non-linear analysis, specifically the IDA is performed to assess the retrofitted building. IDA is based on accelerograms of real earthquakes that are imposed to the building in order to monitor its reaction. Afterwards, the IDA curves can be constructed. Different intense levels of the seismic loads are implemented in order to cover as many possible seismic effects as possible. The reliability of IDA results is directly connected with the number of seismic records taken into account. If this number is large, the results approach the real situation; however the computational length of time is huge due to the large amount of data being processed. Subsequently, vulnerability criteria are proposed for the assessment through fragility curves, which can be formed either by means of IDA curves or by applying regulations of EC8 and methods, like Coefficient and Hazus. The two methodologies vary greatly, because the first one is based on real data, whereas the second one follows widespread methodologies, assumptions and codes.

Finally, the results of this study indicate that the optimization process is successful, since the goal of cost reduction is reached and the retrofitting measures satisfy the seismic demands. The superiority of any technique is not clear, because each technique seems to have privileges towards the other in different sectors. For instance, carrying capacity of the building increases more thanks to RC jackets, but CFRP sheets amplify more the ductility. In general, both of them are characterized as effective since they combine low cost and total restitution of the existing damages.

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