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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

Influence of zone type on performance of retrofitted Reinforced Concrete buildings by using Pushover Analysis☆

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Abstract

Reinforced concrete structure is an effective system for resisting lateral loads. Seismic retrofitting of constructions vulnerable to earthquakes is a current problem of great political and social relevance. During the last sixty years, moderate to severe earthquakes have occurred in Morocco (specifically in Agadir 1960 and Hoceima 2004).Such events have clearly shown the vulnerability of the building stock in particular and of the built environment in general. Hence, it is very much essential to retrofit the vulnerable building to deal with the next damaging earthquake. To evaluate the performance of framed buildings under future expected earthquakes, a nonlinear static PUSHOVER analysis has been conducted. In this paper, we propose to assess the seismic vulnerability of a reinforced concrete building using carbon fiber reinforced polymer (CFRP) for different zone.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Pushover analysis; seismic retrofitting; drift storey displacement; Spectrum response, share wall; Carbon fiber Reinforced Polymer.

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1. Introduction

Among the reasons beyond the intensive research activity in this field, one finds the huge need for diagnosis and rehabilitation of pre-code constructions, particularly in the case of historic monuments [1].Other reasons are associated to the emergence of new design approaches, which are founded on the concept of performance-based engineering. Normally, loads on these structures are low and result in elastic structural behavior. However, under a strong seismic event, a structure may actually be subjected to forces beyond its elastic limit. Although building codes can provide reliable indication of actual performance of individual structural elements, it is out of their scope to describe the expected performance of a designed structure as a whole, under large forces. Nonlinear static analysis also known as pushover analysis is a possible method to calculate structural response under a strong seismic event.

The use of the nonlinear static analysis (pushover analysis) came in to practice in 1970 but the potential of the pushover analysis has been recognized for last two decades years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well. The effectiveness of pushover analysis and its computational simplicity brought this procedure in to several seismic guidelines [2, 3] and design codes [4, 5] in last few years.

The present paper, investigates the efficiency of seismic retrofitting with a RC carbon fiber for different zone, using a Pushover analysis to estimate seismic structural deformations and displacement.

2. Non Linear Analysis (Pushover analysis)

The analysis results are sensitive to the selection of the control node and selection of lateral load pattern. In general case, the center of mass location at the roof of the building is considered as control node. The lateral load generally applied in both positive and negative directions in combination with gravity load (dead load and a portion of live load) to study the actual behavior. Different types of lateral load used in past decades are as follows:

2.1. Uniform" Lateral Load Pattern

The lateral force at any story is proportional to the mass at that story.

$$F_i = \frac{m_i}{\sum m_i} \tag{1}$$

Where:
F_i: Lateral force at i-th story
m_i: Mass of i-th storey

2.2. "First Elastic Mode" Lateral Load Pattern

The lateral force at any story is proportional to the product of the amplitude of the elastic first mode and mass at that story.

$$F_i = \frac{m_i \phi_i}{\sum m_i \phi_i} \tag{2}$$

Where:
ϕ_i: Amplitude of the elastic first mode at i-th storey

2.3. "Code" Lateral Load Pattern

The lateral load pattern is defined in Moroccan seismic Code [6] and the lateral force at any storey is calculated from the following formula:

$$F_n = (V - F_t)\frac{W_n h_n}{\sum_i^n W_i h_i} \tag{3}$$

$$\begin{cases} F_t = 0 & \text{si } T \leq 0.7s \\ F_t = 0.07TV & \text{si } T > 0.7s \end{cases}$$

Where:
F_n: Horizontal force applied to n-th storey
V: Seismic Base-force
W_n: Total load of n-th floor
h_n: Height of n-th floor measured from base
T: Fundamental period

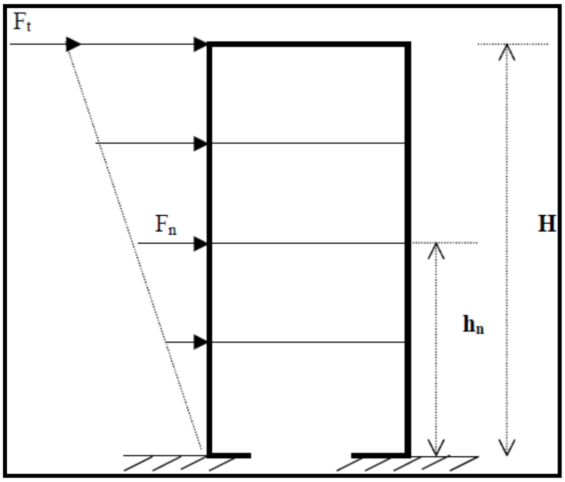

Fig. 1. Vertical repartition of seismic forces [6]

2.4. "FEMA-273" Lateral Load Pattern

The lateral load pattern defined in FEMA-273 is given by the following formula that is used to calculate the internal force at any story:

$$F_i = \frac{m_i h_i^k}{\sum_i^n m_i h_i^k} \tag{4}$$

Where:
h_i: height of the i-th story above the base
K: a factor to account for the higher mode effects (k=1 for ≤0.5 sec and k=2 for >2.5 sec and varies linearly in between)

2.5. "Multi-Modal (or SRSS)" Lateral Load Pattern

The lateral load pattern considers the effects of elastic higher modes of vibration for long period and irregular structures and the lateral force at any story is calculated Square Root of Sum of Squares (SRSS) combinations of the load distributions obtained from the modal analysis of the structures as follows:

a. Calculate the lateral force at i-th storey for n-th mode from equations

$$F_i = \Gamma_n m_i \phi_{in} A_n \quad (5)$$

Where:
Γ_n: Modal participation factor for the n-th mode
ϕ_{in}: Amplitude of n-th mode at i-th storey
A_n: Pseudo-acceleration of the n-th mode Single Degree Of Freedom (SDOF) elastic system

b. Calculate the storey shears:

$$V_{in} = \sum_{j=1}^{N} F_{jn} \quad (6)$$

Where N is the total number of storeys

c. Combine the modal storey shears using SRSS rule:

$$V_i = \sqrt{\sum_n (V_{in})^2} \quad (7)$$

d. Back calculate the lateral storey forces, F_i, at storey levels from the combined storey shears, V_i starting from the top storey.

e. Normalize the lateral storey forces by base shear for convenience such that

$$F'_i = \frac{F_i}{\sum F_i} \quad (8)$$

The contribution of first three elastic modes of modal analysis was considered to calculate the 'Multi-Modal (or SRSS)' lateral load pattern in this study.

3. Description of the building

3.1. Geometry

The building is a reinforced concrete eight storeys building with a gross area of 240 m². The building height is 27 m with 3m in each storey. The RC structure is composed from three bays with a 4 m in each one. The slabs thickness is 25 mm (20+5).The beams size is 25x25mm. For the columns, there are four types with size “40x40”, “35x35”, “30x30”, “25x25”.

3.2. Material properties

The tables below show the properties for each material used in our study:

Table 1. Concrete properties.

Weight per unit volume (t/m^3)	2.5
Modulus of Elasticity (MPa)	32164
Poisson's ratio	0.2
Coefficient of thermal expansion	1.2.10^{-5}
Concrete compressive strength (MPa)	25

Table 2. Steel properties.

Weight per unit volume (t/m^3)	7.85
Modulus of Elasticity (MPa)	2.1.10^5
Poisson's ratio	0.29
Coefficient of thermal expansion	1.1.10^{-5}
Concrete compressive strength (MPa)	500

Table 3. Carbon fiber properties.

Weight per unit volume (t/m^3)	17.5 t/m^3
Modulus of Elasticity (MPa)	4.5.10^5
Poisson's ratio	0.2
Coefficient of thermal expansion	0.02.10^{-5}
Concrete compressive strength (MPa)	2500

3.3. Seismic Data

The table 4 resumes the different parameter introduced in SAP 2000 for each zone:

Table 4. Seismic Data of each zone.

Parameter	Zone 3	Zone 2	Zone 1
Total weight W (t)	329.94	329.94	329.94
Horizontal ground acceleration A	0.16	0.08	0.01
Soil factor S	1.2	1.2	1.2
Amplification factor D	2.31	2.31	2.31
Priority factor I	1	1	1
Behavior factor K	2	2	2
Shear force V (t)	73.17	36.58	4.57

4. Result

The lateral loads applied to the structure are calculated with Moroccan seismic Code (RPS2000). The following table resumes the results of the lateral force applied to each floor for each zone.

Table 5. Lateral loads result for each zone.

ZONE	Level	V (kN)	h_i (m)	F_i (kN)
ZONE 3	1	731.8	3	16.3
	3		9	146.4
	6		18	585.4
	9		27	1317.2
ZONE 2	1	365.8	3	8.1
	3		9	73.2
	6		18	292.7
	9		27	658.5
ZONE 1	1	45.7	3	1.0
	3		9	9.1
	6		18	36.6
	9		27	82.3

The pushover analysis of the structure is performed using SAP2000, a structural calculator software that allow us to perform analysis and seismic design of buildings. The hinges placed on columns is defined to P-M3 type, for beams the hinges are all type M3.

The mode of failure of this type of structure under seismic excitations is plastics hinges formation. The figure below show the plastics hinges formation for the lateral load and the deformed shape of the unreinforced structure for each zone.

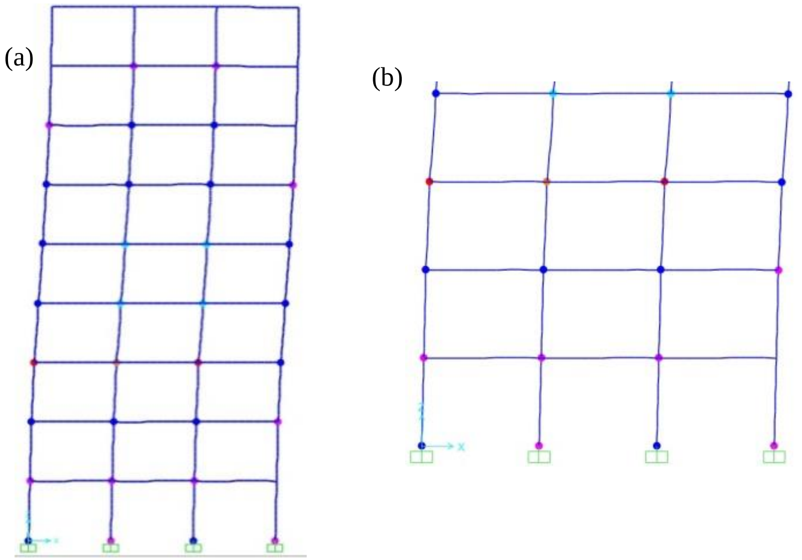

Fig. 2. (a) Plastic hinge formation in the unreinforced structure for zone 3; (b) Zoom on the lower of the unreinforced structure for zone 3.

The following figure show the pushover curve; a curve which the variation of displacement is represented by the base-force.

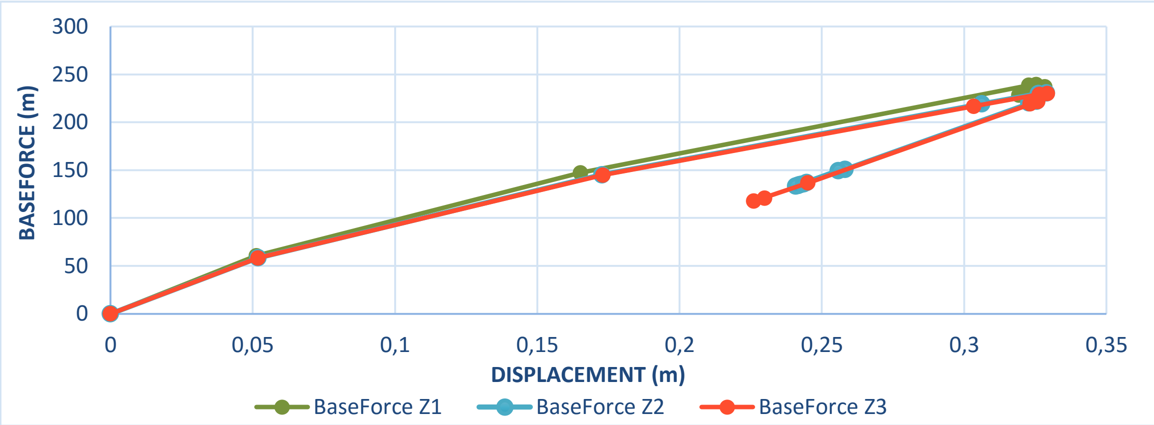

Fig. 3. Pushover curve of unreinforced structure for three zone

The tables below (6, 7) show a comparison of the maximal displacement for the three zones for each structure.

Table 6. Displacement of unreinforced structure for each zone.

Displacement Z1 (m)	Displacement Z2 (m)	Displacement Z3 (m)
0.327	0.328	0.329

Table 7. Displacement of reinforced structure by CFRP for each zone.

Displacement Z1 (m)	Displacement Z2 (m)	Displacement Z3 (m)
0.15	0.16	0.17

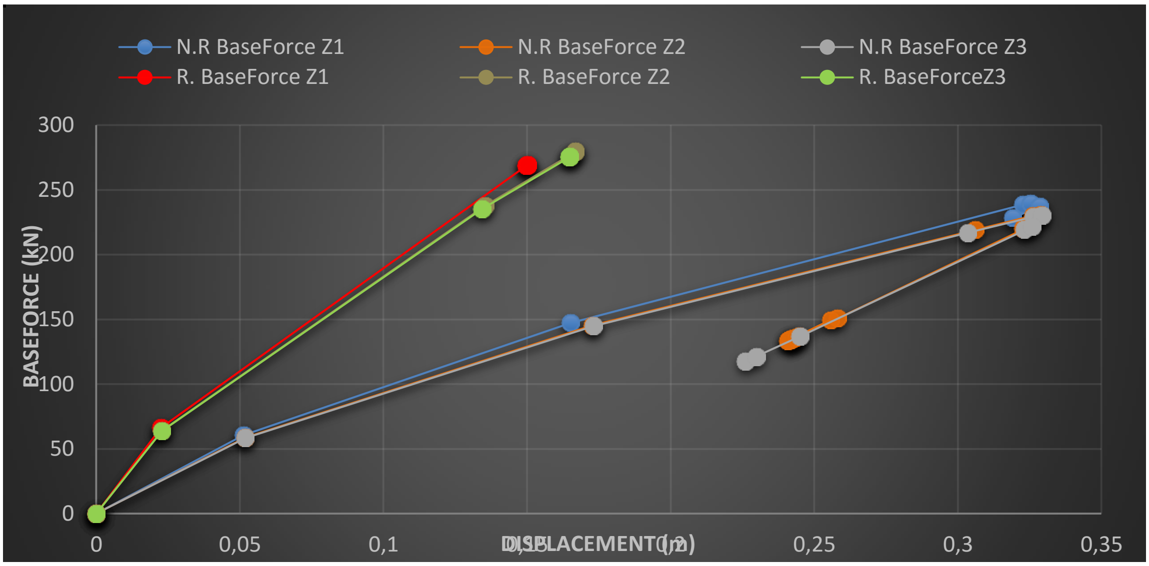

Fig. 4. Pushover Curves of the two structures in three three zones

In the figure 4, there is six pushover curves, each three is for a type of structure and we can see a decreasing in the maximal displacement for the two structure.

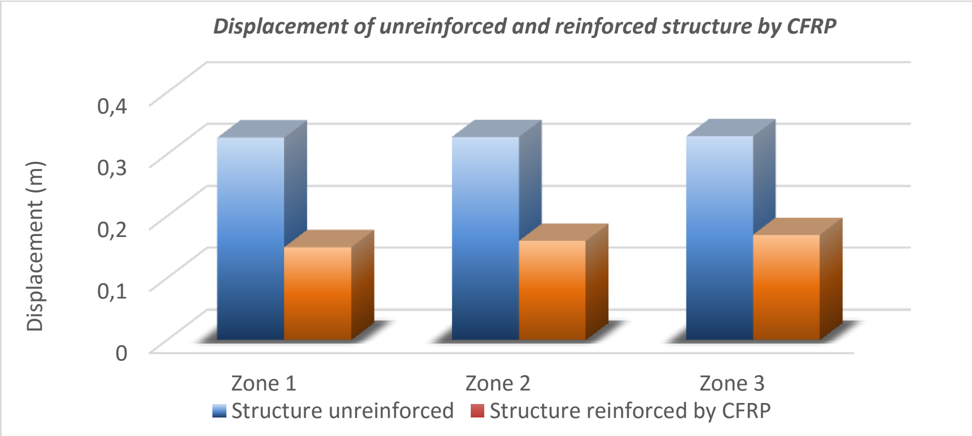

Fig. 5. Comparison of displacement for the two structures

The figure 5 shows a comparison of displacement in the three zones for the reinforced and unreinforced structures.

5. Conclusion and Discussion

As can be seen from the pushover curves and table (6,7), the unreinforced structure had a displacement of 0.327 m for zone 1 and for zone 3 a displacement of 0.329m, which means that the displacement increases from zone to another. Even in the structure reinforced by CFRP, we had an increase in the displacement, for zone 1 we have 0.15 and a 0.17 m for zone 3. In other words, whatever the type of reinforcement adopted, the displacement the structure will be an increase from zone 1 to zone 3. This increase in displacement is due to the variation in the lateral force applied on the structure, specifically the acceleration coefficient; for zone 1, the acceleration coefficient is 0.01 and for zone 3, coefficient is 0.16, which means –according to formula (3) - the lateral force of the third zone is sixteen times higher than that of the first one. However, as we can see in figure 6, if we compare the displacement of each zone for the two types of structures, we can see a decrease of 55% in the maxim displacement, which means, that the reinforcement using the CFRP is a recommended technique for rehabilitation.

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