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Pushover Analysis of Reinforced Concrete Structures Designed According to the Algerian Code

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Abstract: Reinforced concrete structures designed according to the Algerian seismic code are expected to undergo excursions in the non linear range. Such behaviour cannot be predicted by conventional seismic analysis methods. Thus, an alternative approach called pushover analysis can be used. In this study, a pushover analysis of a reinforced concrete frame designed according to the Algerian code is carried out. The results obtained suggest that pushover analysis is attractive and can help the structural engineer to better understand the behaviour of a structure for the design of new structures and also for the rehabilitation and retrofit of existing structures.

Key words: Seismic, nonlinear analysis, pushover, reinforced concrete, frames

INTRODUCTION

The recent earthquakes including the last Algerian earthquake in which many concrete structures have been severely damaged or collapsed, have indicated the need for evaluating the seismic adequacy of existing buildings. In particular, the seismic rehabilitation of older concrete structures in high seismicity area , is a matter of growing concern , since structures venerable to damage must be identified and an acceptable level of safety must be determined. To make such assessment, simplified linear-elastic methods are not adequate and structural engineers must use more complex nonlinear inelastic technique such as Nonlinear Static Pushover analysis(NSP). A reflection of this is contained in FEMA 273 (1997), ATC 40 (1996) and in the numerous publications devoted to this topic (Ashraf and Stephen, 1998; Fajfar and Eeri, 2000; Chopra and Goel, 2001; Ayed, 2002). The NSP, is a relatively simple way to explore the design of a structure. It consists of pushing a mathematical model of a building over a prescribed displacement in order to predict the sequence of damages in the inelastic range and to detect weak links. In this study, a non linear static pushover analysis is carried out in order to determine and compare the capacity and the demand curves of a concrete building designed to the Algerian code RPA99 (1999) in its original form and strengthened with shear walls. The results obtained indicate that retrofitting using shear walls can be an adequate solution and that pushover analysis can help the structural engineer to better understand the real expected behaviour of existing or new structures in future earthquakes.

MATERIALS AND METHODS

Under the NSP, a nonlinear inelastic model is laterally loaded until a predefined target displacement is met or the model collapses. The target displacement represents the maximum expected displacement for the design earthquake. The control node at which the target displacement is defined is taken at the center of mass of roof level. Many lateral load patterns can be considered, a uniform pattern or a modal pattern or any other user defined pattern. The structural model should be developed from the moment-curvature properties of the members. These properties should be representative of their actual behaviour in the elastic range with uncracked flexural stiffness to full plastic behaviour until failure. If member moment-curvature characteristics cannot be determined accurately, then experimental component testing should be performed to determine the required limit states (Bracci *et al.*, 1997). The main output of a pushover analysis is in terms of response demand curves and capacity curves. Figure 1 shows a representation of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range, Fig. 1a then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, Fig. 1b then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse.

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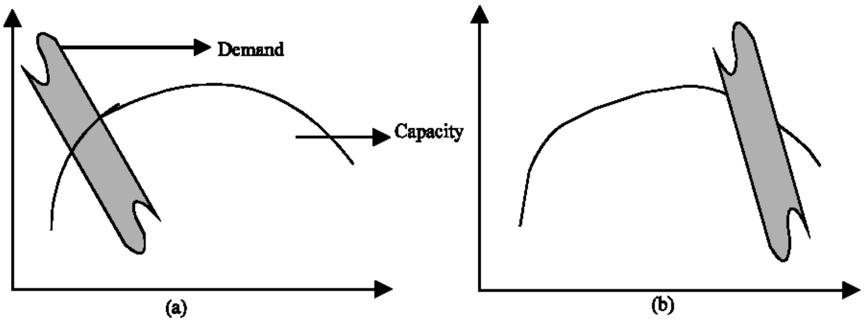

Fig. 1: Typical seismic demand versus capacity (a) safe design; (b) unsafe design

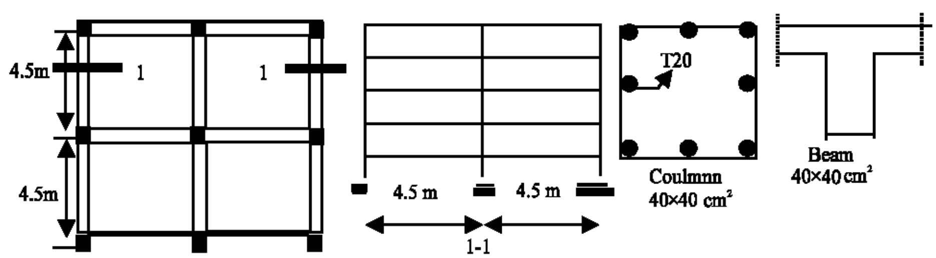

Fig. 2: Details of the original building

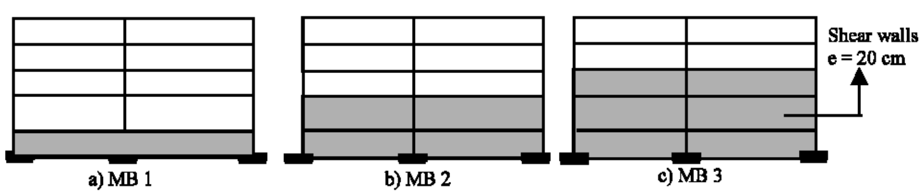

Fig. 3: Modified buildings

The basic steps in a NSP are:

- Definition of non linear hinges in the computational finite element model
- Assignment of nonlinear properties for hinges
- Definition of a load pattern
- Assignment of control node and direction and ultimate push displacement value.
- Run step by step nonlinear analysis. Equilibrium state curve "shear forces versus controlling displacement" V=V(D) is a result of nonlinear analysis.
- Conversion of equilibrium states curve V=V(D) to ADRS format(acceleration displacement response spectra) -Derivation of capacity curve $S_a^{cap} = S_a^{cap} (S_d)$, where S_a^{cap} is a spectral acceleration and (S_d) is a spectral displacement.
- Step by step search of the performance point as an intersection point between capacity curve and selected demand curve.

DESCRIPTION OF THE ORIGINAL BUILDING

The building analyzed is a fifth story reinforced framed structure with story height of 3.06 m and dimensions in plan as indicated in Fig. 2.

The masses are lumped at each story level and amount 100 t.

DESCRIPTION OF THE MODIFIED STRUCTURES

After the disaster, one of the techniques used to retrofit buildings was to add shear walls in the first story along the perimeter of the structures. To study this scheme, we will consider the following modified structures, Fig. 3a-c.

PUSHOVER ANALYSIS

The building was designed in the elastic range according the Algerian code in zone III which is a high seismicity area with a peak ground acceleration of 0.438 g. Then, nonlinear pushover analyses were performed using the SAP 2000 package by subjecting both the original and the modified buildings to a monotonically increasing pattern of lateral acceleration in the x direction representing the forces that would be experienced by the structures when subjected to ground shaking. Under incrementally increasing loads some elements may yield sequentially. Consequently, at each event , the structures experience a stiffness change as shown in Fig. 4.

where IO,LS and CP stands for immediate occupancy, life safety and collapse prevention respectively. We shall refer to this curve in the process of formation of hinges.

Pushover curves: Figure 5-8 indicate that original building can be pushed to a target displacement larger than that of the modified buildings since it is more flexible. There is a sharp decrease in the base shear capacity due to the formation of hinges for a displacement of 0.19, 0.24, 0.2 and 0.12 m for the original and modified buildings, respectively. There is a hardening for structures MB2 and MB3, thus the safety margin of these buildings is enhanced.

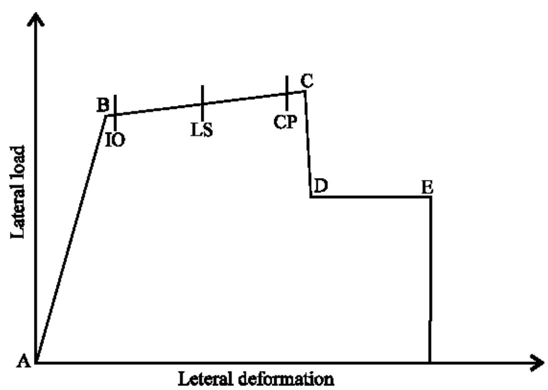

Fig. 4: Load-deformation curve

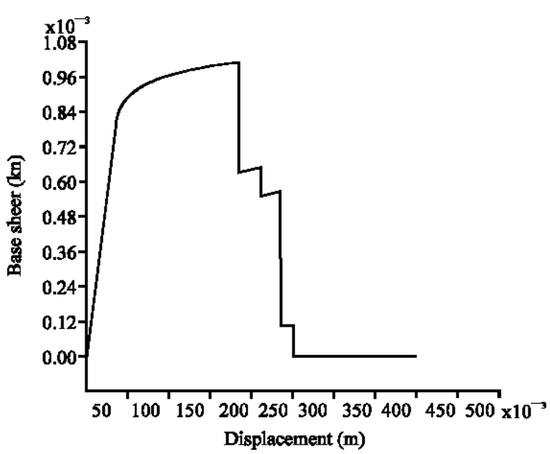

Fig. 5: Pushover curve MB 2

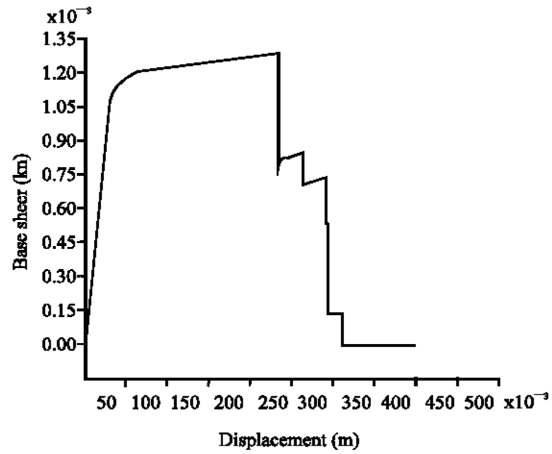

Fig. 6: Pushover curve MB 3

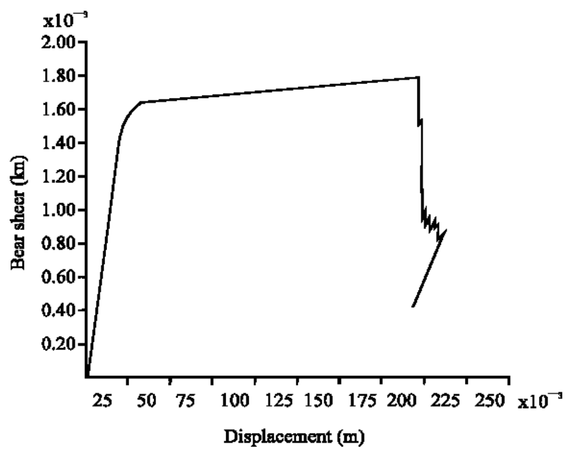

Fig. 7: Pushover curve MB 2

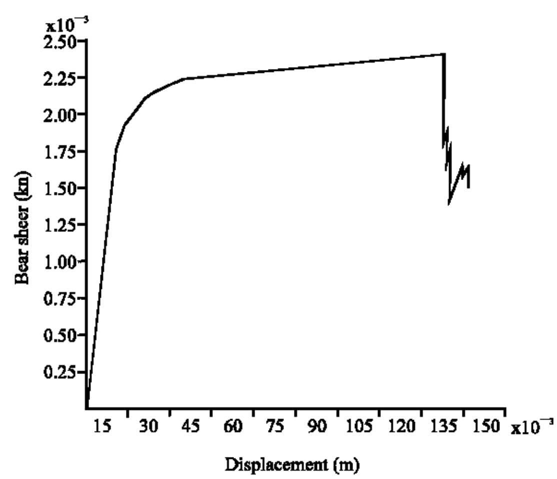

Fig. 8: Pushover curve MB 3

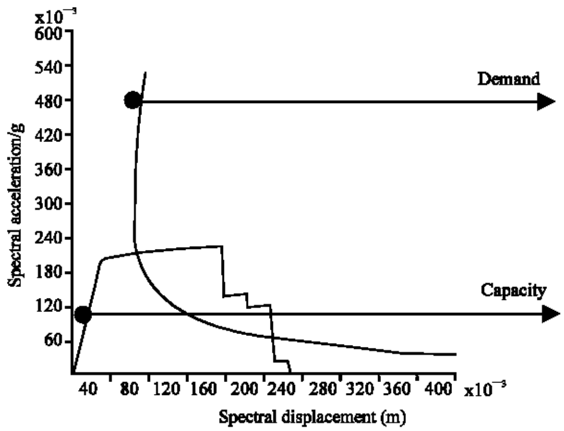

Fig. 9: Demand-capacity Curve original bulding

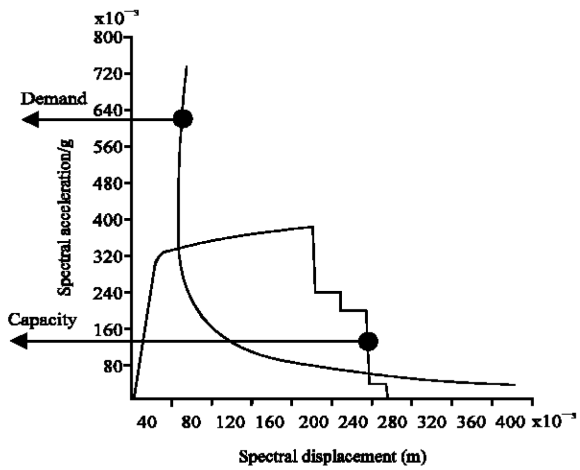

Fig. 10: Demand-capacity Curve MB 1

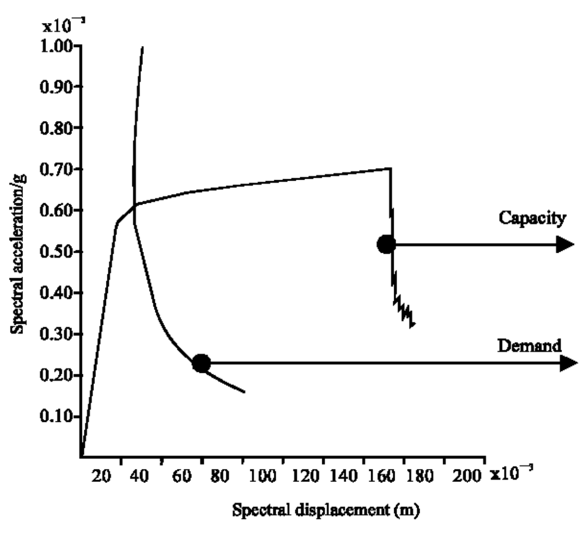

Fig. 11: Demand-Capacity Curve MB2

The performance point which represents the global behaviour for each building is given in Table 1.

Demand-capacity curves: Figure 9-12 are shown the demand and capacity curves for the original and modified buildings respectively. The demand is important for the original building since it intersects the capacity curve near the event point LS. For the modified building MB1, the intersection occurs near the event point IO. For MB2 and especially MB3, the demand curve intersects the capacity curve near the event point B, which means an elastic response and the security margin is greatly enhanced. Thus, adding more shear walls, not only in the first story, will increase the level of safety since the demand curve tends to intersect the capacity curve near the elastic domain. Therefore, it can be concluded that the margin safety against collapse for the original building is small, whereas for the modified buildings MB2 and MB3, there are sufficient strength and displacement reserves.

Formation of hinges: The formation of hinges over the structures indicates clearly that the original building will suffer great damages especially in the first level where columns yielded at event E., Fig. 13. The modified building MB1 also exhibited quite poor bahaviour, Fig. 14. For the modified building MB2, there is a hinge formation in the columns just above the shear walls and columns yielded at event D, Fig. 15 but since they are supported by shear walls, there is no risk of collapse. For the modified building MB3, there is a great improvement since columns yielded at event LS, Fig. 16 indicating a safe design.

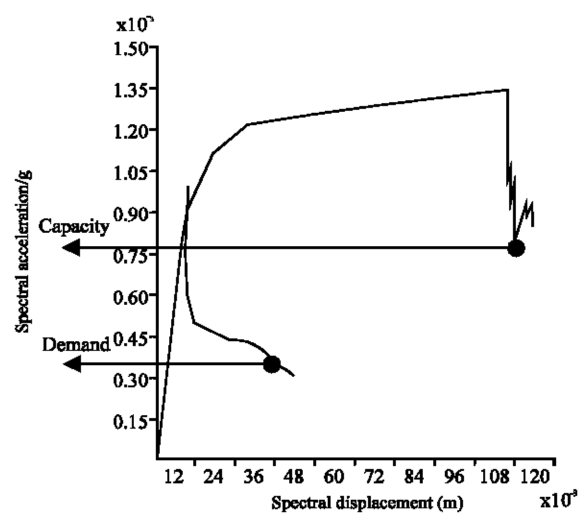

Fig. 12: Demand-Capacity Curve MB3

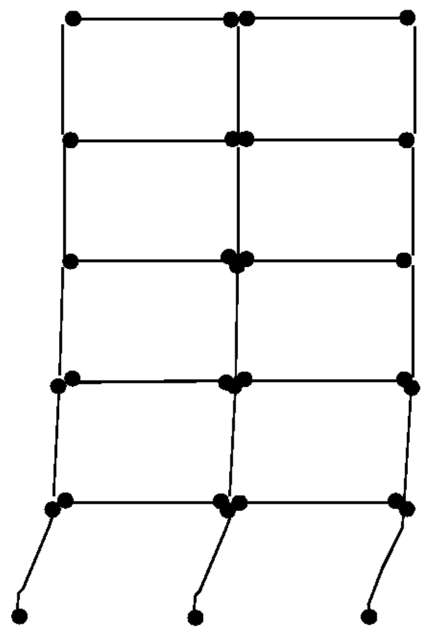

Fig. 13: Original bulding

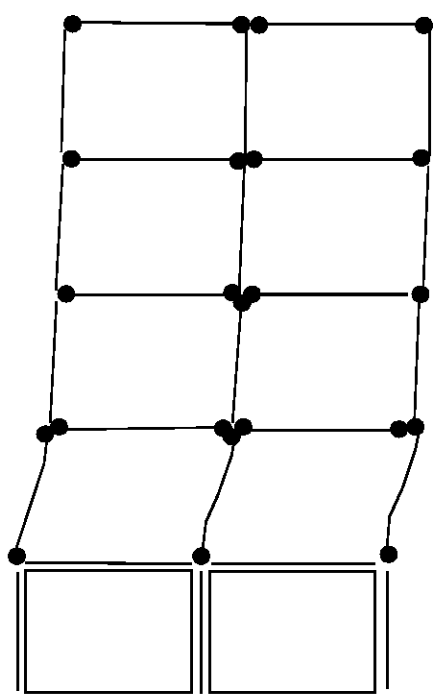

Fig. 14: MB 1

Table 1 we can see that displacement demand decreases as the number of shear walls is augmented and for the modified building MB3, its value is very small and this confirms the preceding conclusions.

Table 1: Performance point-displacement-damand

Performance point	Sd (displacement demand)
Original building	0.067
MB1	0.046
MB2	0.026
MB3	8.8E-3

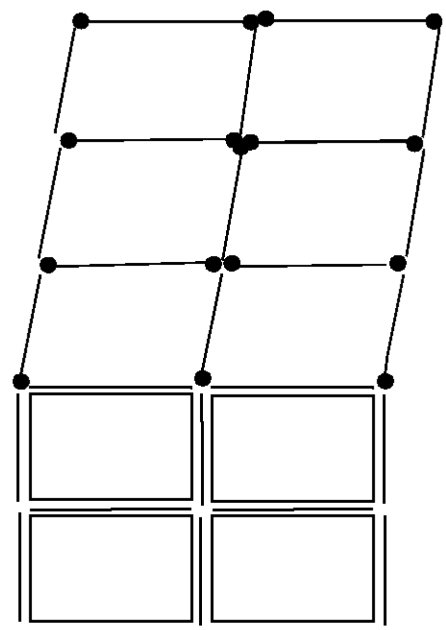

Fig. 15: MB 2

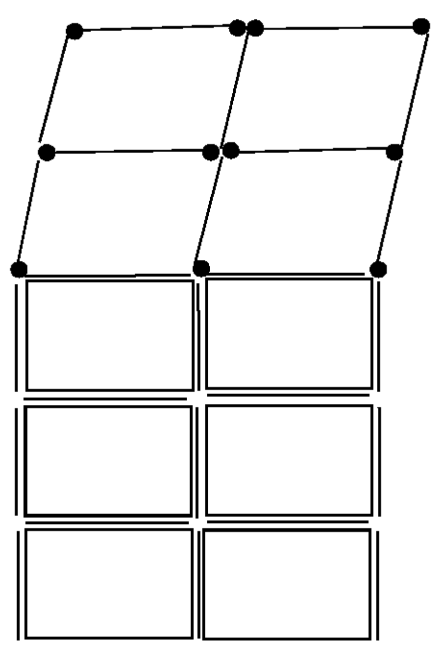

Fig. 16: MB 3

CONCLUSION

The behaviour of the original building is not very adequate and this is expected since the structure is of weak column, strong beam type which is typical in structural design in Algeria. Adding shear walls and not only in the first story, can drastically improve the behaviour of the building and the fourth modified building MB3 shows clearly a great improvement in the safety margin because it behaves almost elastically. Thus, strengthening buildings with shear walls can be adopted as a solution but one has to study many cases in order to determine the optimal solution and great care must be given to the design of the columns just above the shear walls. Pushover analysis is a powerful and very useful tool that allows structural engineers to investigate many schemes of retrofitting for existing buildings and to design new structures that will adequately perform in future expected earthquakes. The results obtained from a pushover analysis in terms of demand, capacity and plastic hinges patterns give an insight into the physical behaviour of the structure.

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