

# Seismic Damage Prediction of Reinforced Concrete Buildings Using Pushover Analysis

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## Abstract:

This paper investigates the seismic damage of a six storey reinforced concrete frame building designed according to the Moroccan seismic code RPS2000 [1]. The building is residential and has a reinforced concrete frame structural system. In the first time a set of dynamic analysis are carried out to compute dynamic properties of the building (fundamental period, natural frequencies, deformation modes,), in the second time a pushover analysis is carried out. Performances levels are used with the pushover analysis to assess the seismic damage of the building. Three performance levels considered in the present study are immediate occupancy, life safety and collapse prevention.

**Keywords:** Analysis, building, pushover, damage, performance point, reinforced concrete, seismic.

## 1. Introduction

The earthquakes that occurred recently in the world, Loma Prieta 1989, Northridge 1994, Kobe 1995, Izmit 1999 Bam 2003, El Hoceima 2004 and in other parts of the world has highlighted the seismic vulnerability of existing buildings. In urban areas, this vulnerability, combined with a high concentration of buildings built before the introduction of seismic standards, can cause high seismic risk, even in areas where the seismicity is considered moderate. The pushover analysis is a powerful tool in this area which allows the evaluation of the seismic performance of buildings by estimating damage to structural and non-structural elements caused by a future shaking. Pushover analysis [2, 3, and 4] has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedure is relatively simple and considers post elastic behaviour.

Pushover analysis is an analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analyses, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or trilinear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the capacity curve (Fig 1).

The pushover analysis is very useful in estimating the following characteristics of a structure.

- 1) The capacity of the structure as represented by the base shear versus roof- displacement graph
- 2) Maximum rotation and ductility of critical members load
- 3) The distribution of plastic hinges at the ultimate load
- 4) The distribution of damage in the structure, as expressed in the form of load damage indices
- 5) Determination of the yield lateral resistance of the structure
- 6) Estimates of inter-story drifts and its distribution along the height

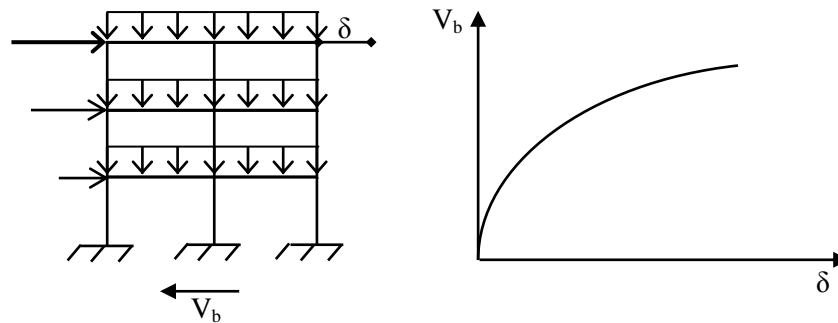


Figure 1. Construction of pushover curve

## 2. Building performance levels

The seismic performance of buildings [6, 11] is measured by the state of damage under a certain level of seismic hazard. The state of damage is quantified by the drift of the roof and the displacement of the structural elements. Initially, gravity push is carried out using force control method. It is followed by lateral push with displacement control using SAP2000 [10]. For carrying out displacement based pushover analysis, target displacement need to be defined. Pushover analysis gives an insight into the maximum base shear that the structure is capable of resisting. A building performance level is a combination of the performance levels of the structure and the nonstructural components. A performance level describes a limiting damage condition which may be considered satisfactory for a given building with specific ground motion. The performances levels as per FEMA [6], ATC 40 [8] and vision 2000[11] are:

**Immediate occupancy IO:** damage is relatively limited; the structure retains a significant portion of its original stiffness and most if not all of its strength.

**Life safety level LS:** substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

**Collapse prevention CP:** at this level the building has experienced extreme damage, if laterally deformed beyond this point; the structure can experience instability and collapse.

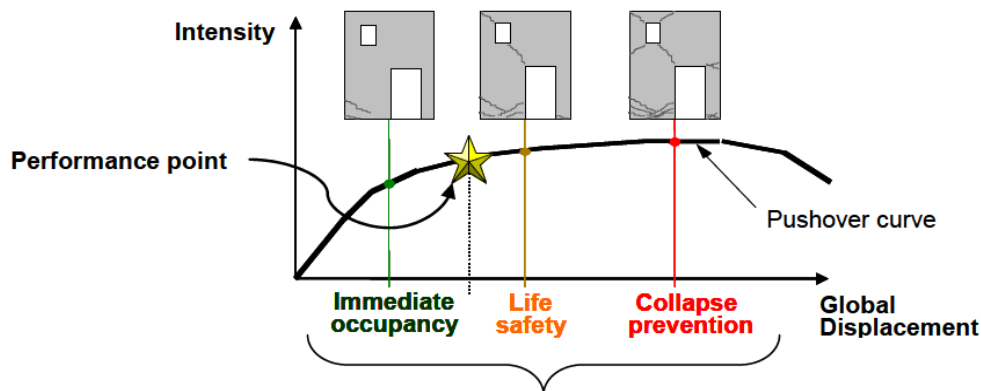


Figure 2. Performance levels described by a pushover curve [6]

## 3. Case Study

### 3.1. Building description

The building studied here is a six storey reinforced concrete building, for residential use. The building has 2 spans of 3.50m, and 4 bays of 3.00m. The slab thickness is 12 cm, column section is 35x35cm, and the beam section is 25x35cm. The height of each level is 3m; the building is located in seismic zone 3[1], based on soil type S2[1]. The materials used are  $f_c=25\text{MPa}$  for concrete and HA500 for longitudinal and shear reinforcement. The building is designed according to the Moroccan seismic code RPS2000 [1].

For the pushover analysis, 3 load cases were considered:

- PUSHGRA – applying the gravity loads.
- □ PUSHX– applying lateral loads in the X-X direction.
- PUSHY – applying lateral loads in the Y-Y direction

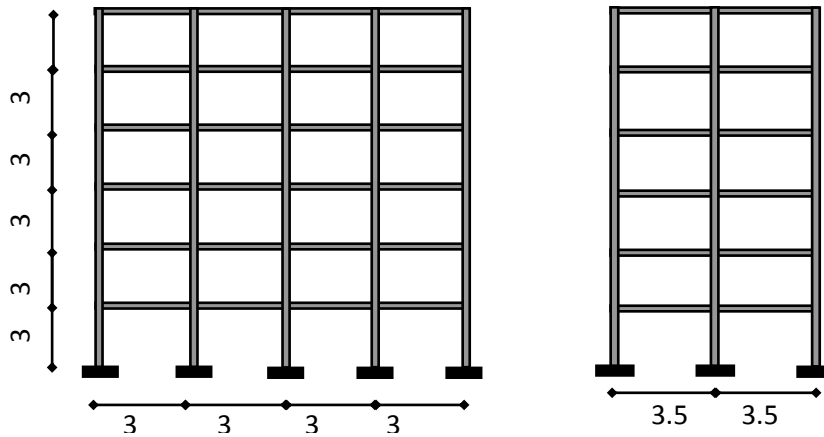


Figure 3. Building elevation

## 4. Results

### 4.1 modeling parameters

The structure was analyzed using SAP2000 computer code. The superstructure was modelled as a spatial frame, considered fixed at the base of the ground floor. The reinforced concrete floor has substantial stiffness and resistance to take over the stresses produced by the lateral forces, and due to the regularity and homogeneity of the structure, it can be considered non-deformable in its plan. The beam and column elements are modelled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of beams and columns.

### 4.2 pushover analysis

Results of the Push-Over analysis are presented in Figures 4, 5, 6 and 7 (push-over curves, in each of the 2 main directions). The performance point at the intersection of the capacity spectrum with the single demand spectrum for different levels of shaking (moderate, severe) has been obtained. Figures 8 and 9 show the floor displacement. Plastic hinge formation for the building mechanisms has been obtained at different displacements levels. The hinging patterns are plotted in figures 10 and 11. Plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories.

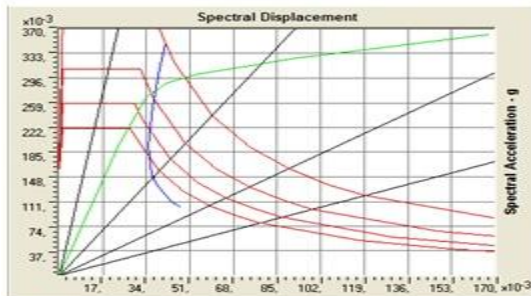


Figure 4. Performance point A=0.16g/X-X

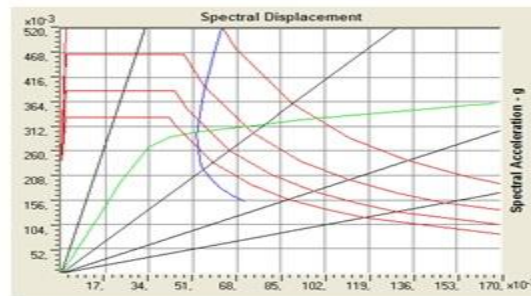


Figure 5. Performance point A=0.24g/X-X

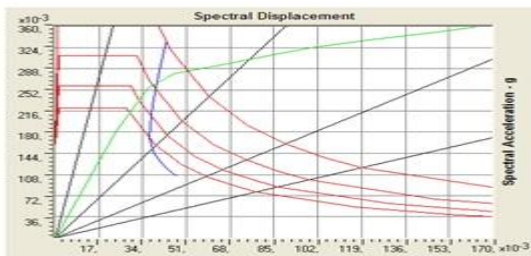


Figure 6. Performance point A=0.16g/Y-Y



Figure 7. Performance point A=0.24g/Y-Y

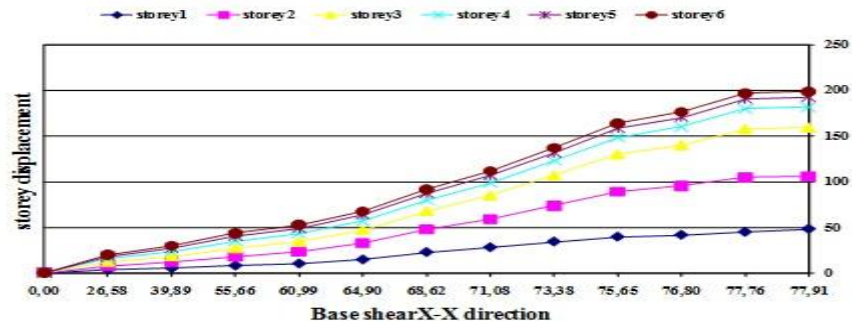


Figure 8. Base shear versus storey displacement X-X direction

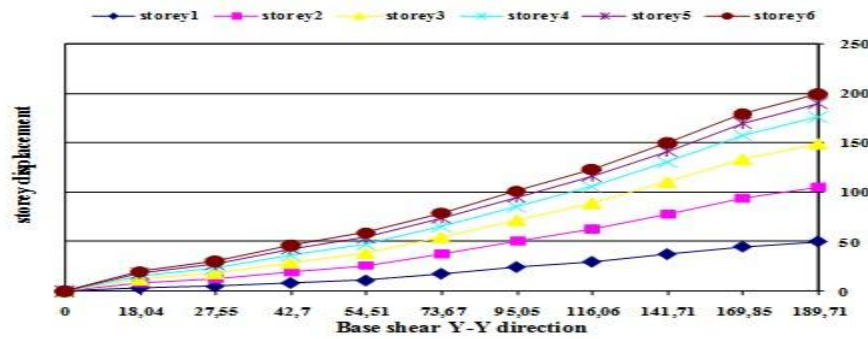


Figure 9. Base shear versus storey displacement Y-Y direction

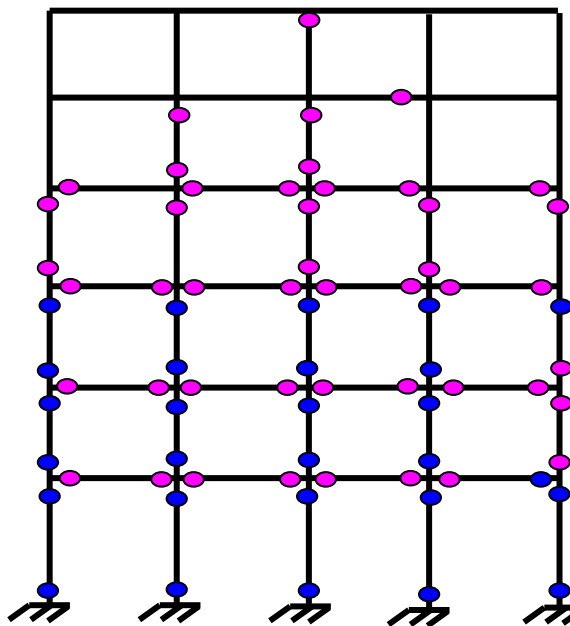


Figure 10. Plastic hinges IO under moderate shaking

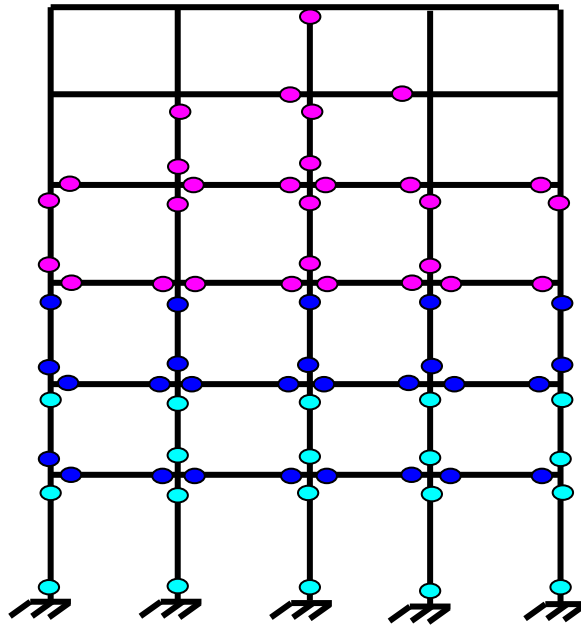


Figure 11. Plastic hinges LS under high shaking

First yield Immediate occupation Life Safety Collapse Prevention

## 5. Conclusion

Under moderate shaking, we see from Figures 4, 6 and 10 that demand curve intersects the capacity curve at event IO (immediate occupation), plastic hinges occurred so the structure remains stable with onset of damage privileges, minor cracking of facades, partitions, and ceilings as well as structural elements, no permanent drift, structure substantially retains original strength and stiffness. Repair lightweight non-structural elements, any repairs to the structural elements are required.

Under high shaking we see from Figures 5, 7 and 11 that the demand curve intersects the capacity curve at event LS (life safety), plastic hinges occurred, the structure is damaged, it lost its rigidity and its original strength, Some structural elements and components are severely damaged, but this has not resulted in large falling debris hazards, either within or outside the building. Injuries may occur during the earthquake; however, it is expected that the overall risk of life-threatening injury as a result of structural damage is low. It should be possible to repair the structure; however, for economic reasons this may not be practical. The amount of damage in the buildings is limited and collapse is prevented. Finally the pushover analysis combined with the performance levels is able to evaluate the seismic damage of buildings, to examine the state of the structure under the action of an earthquake and thus provide information on the damage that can be sustained by a structure and the elements that will be affected in a future earthquake.

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