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A NON LINEAR ANALYSIS OF STRUCTURE: PUSHOVER ANALYSIS

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ABSTRACT
In this paper we propose to assess seismic performance of a six stored reinforced concrete 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 performed to assess the seismic performance of the building and detect the locations of the plastic hinges. Pushover analysis was performed using SAP2000.the results obtained from this study show that designed building perform well under moderate earthquake, but is vulnerable under severe earthquake.

INTRODUCTION
Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design.

Pushover analysis is a performance based analysis. According to ATC 40[1], there are two key elements of a performance-based design procedure - demand and capacity. Demand is the representation of earthquake ground motion or shaking that the building is subjected to. In nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformations that the structure is expected to undergo. Capacity is a representation of the structure's ability to resist the seismic demand. The performance is dependent on the manner that the capacity is able to handle the demand. In other words, the structure must have the capacity to resist demands of the earthquake such that the performance of the structure is compatible with the objectives of the design.

Pushover analysis is performed by Displacement coefficient method/Capacity spectrum method. The Capacity Spectrum Method (CSM), a performance-based seismic analysis technique, can be used for a variety of purposes such as rapid evaluation of a large inventory of buildings, design verification for new construction of individual buildings, evaluation of an existing structure to identify damage states, and correlation of damage states of buildings to various amplitudes of ground motion. The procedure compares the capacity of the structure (in the form of a pushover curve) with the demands on the structure. Objective of Displacement coefficient method is to find target displacement which is the maximum displacement that the structure is likely to be experienced during the design earthquake. It provides a numerical process for estimating the displacement demand on the structure, by using a bilinear representation of capacity curve and a series of modification factors, or coefficients, to calculate a target displacement.

TYPES OF ANALYSIS

LINEAR STATIC ANALYSIS

Linear static analysis represents the most basic type of analysis. The term “linear” means that the computed response—displacement or stress, for example is linearly related to the applied force. The term “static” means that the forces do not vary with time or the time variation is insignificant and can therefore be safely ignored. An example of a static force is a building's dead load, which is comprised of the building's weight plus the weight of offices, equipment, and furniture. This dead loak8d is often expressed in terms of N/m2.

LINEAR DYNAMIC ANALYSIS

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsional irregularities, a dynamic procedure is required. In the linear dynamic procedure, the building is modeled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

The seismic input is modeled using either modal spectral analysis or time history analysis but in both cases, the corresponding internal forces and displacements are determined using linear elastic analysis. The advantage of these linear dynamic procedures with respect to linear static procedures is that higher modes can be considered. However, they are based on linear elastic response and hence the applicability decreases with increasing nonlinear behavior, which is approximated by global force reduction factors.

NONLINEAR DYNAMIC ANALYSIS

In non-linear dynamic analysis, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios. This has led to the emergence of methods like the Incremental Dynamic Analysis.

NONLINEAR STATIC ANALYSIS

Pushover analysis is the approximate method used to evaluate the structure. It is used popularly to evaluate as well as in performance based seismic design nonlinear static analysis is an improvement over the static or dynamic analysis in the sense that it allows inelastic behavior of the structure. The method is simple to implement and provides the information about strength, deformation and ductility of the structure as well as the demand.

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CONCEPT

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 tri linear 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.

- The capacity of the structure as represented by the base shear versus roof-displacement graph.
- Maximum rotation and ductility of critical members load
- The distribution of plastic hinges at the ultimate
- The distribution of damage in the structure, as expressed in the form of load damage indices, at the ultimate load.
- Determination of the yield lateral resistance of the structure
- Estimates of understory drifts and its distribution along the height
- Determination of force demands on members, such as axial force demands on columns, moment demands on beam-column connections
- As an alternative to the design based on linear analysis.
- To assess the structural performance of existing or retrofitted buildings.

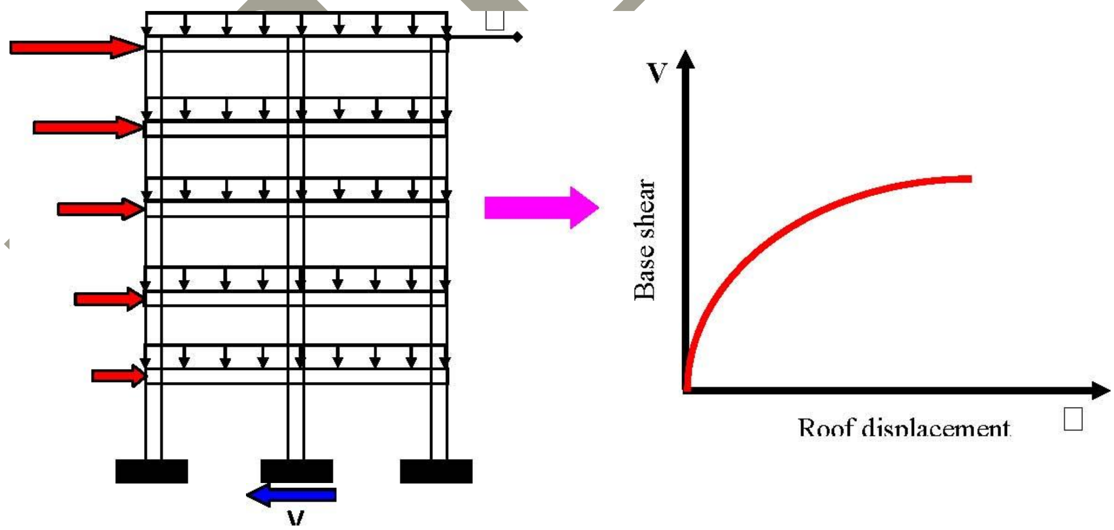


Fig.1 construction of pushover curve

PERFORMANCE OF PUSHOVER ANALYSIS

Pushover analysis can be performed as force con;2trolled or displacement controlled. The results by this method are accurate and hence commonly used in practice.

FORCE CONTROLLED PUSHOVER ANALYSIS

In the is type the force is given the approximate limit to run the program of pushover analysis it is kept constant or the increment of load is done up to that limit of force. This method is used only when the load is known i.e. (gravity load). Some of the numeric problem affects the result as the target displacement may be associated with very small positive or even a negative lateral stiffness because of the development of load mechanism and p delta effect.

DISPLACEMENT CONTROLLED PUSHOVER ANALYSIS

In this method the target displacement or the approximate maximum displacement is assumed and limited while analysis. This method does not have any limitation and can be used in any condition or even if the gravity loads are not known.

METHODOLOGY

Frame structure is loaded first with general loading and then pushover load is applied monotonically at its deformed configuration of general loading. 2nd story (from Joint 3 indicated in figure 1) displacement is monitored up to 12inches. Lateral allowable story drift is taken from table12.12-1, ASCE7-10[2] as 6.48 inches defined by following expression._ =0.02h, h = story height form ground label After yielding, plastic hinges will form at different location indicating the risk of occupants shown in the figure 4. The performance point is calculated from the guideline defined inFEMA-356[2] and ATC-4[1]

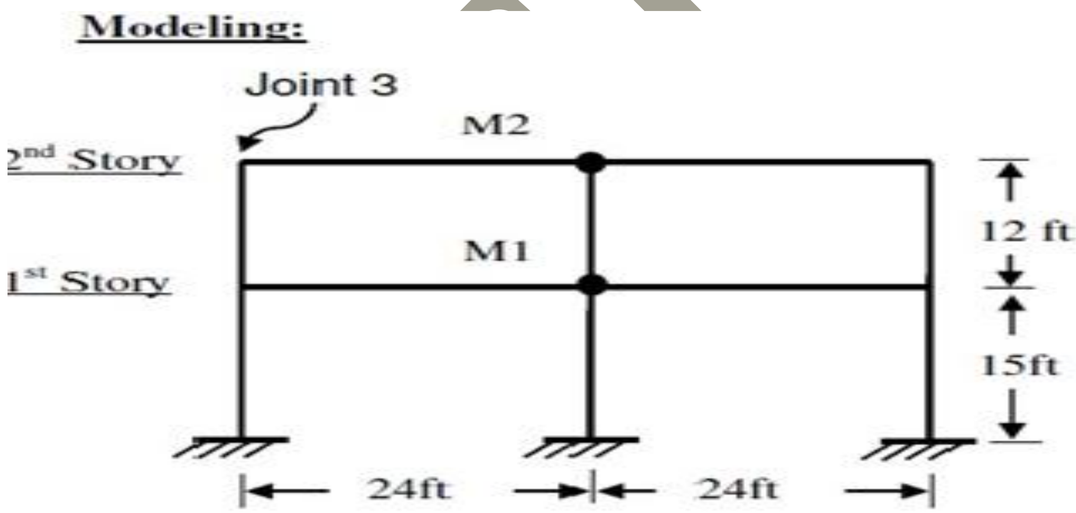


Fig.2 Steel Structure Frame

SEISMIC PERFORAMNACE ASSESSMENT OF BUILDINGS

The seismic performance of building 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 [7]. 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 [2,3] and ATC 40 [1] 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.

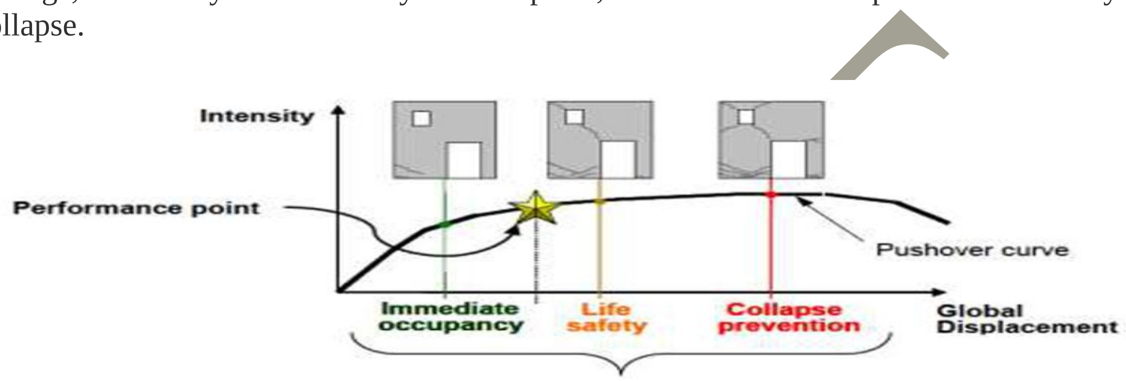


Fig.3 Performance level described by Pushover Curve

PERFORMANCE OF THE BUILDING

Results of the Push-Over analysis are presented in Figures 1 and 2 (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. Figure 3 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 4 and 5. 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.

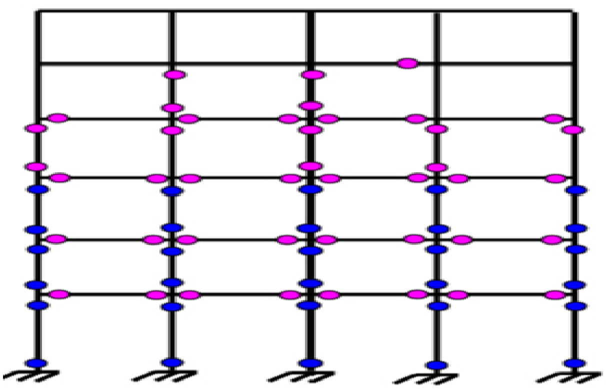


Fig.10 Plastic Hinges IO under moderate shaking

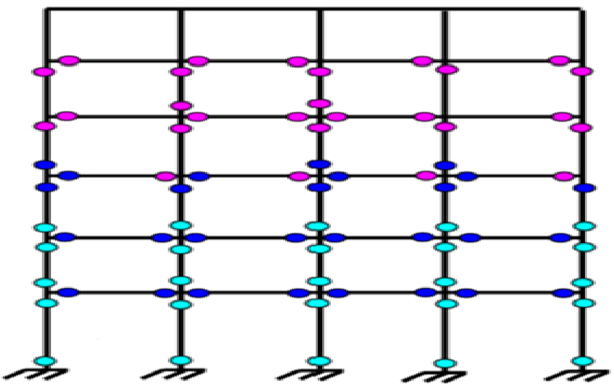
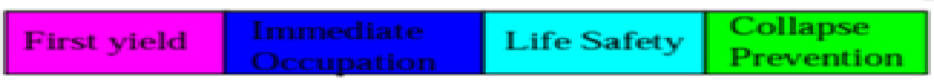


Fig.11 Plastic Hinges IS under severe shaking



CONCLUSIONS:

The conclusions from this study can be summarized as follows:

1) The pushover analysis is an efficient tool to assess the seismic performance of buildings under different levels of shaking.
2) The pushover analysis is a relatively simple way to explore the nonlinear behavior of building.;8
3) The behavior of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns but with limited damage
4) The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behavior of structures.
5) It would be desirable to study more cases before reaching definite conclusions about the behavior of reinforced concrete frame buildings.

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