Comparative Study of Current Methods of Analysis of R.C. Structural Frames Based on Pushover Analysis

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Abstract: There has been a growth in extensive research aimed at examining the effects of seismic events on the performance of a structure. Buildings have a tendency to exhibit inelastic deformation in during seismic activities and post-elastic behavior. Hence, better insights of the performance of structure can be obtained by examining its post-elastic behavior. Non-linear static analysis (also known as Pushover Analysis) is an improved and effective modern way of examining structural performance in the event of potential seismic impact. Such an approach involves horizontally pushing a structure using a predetermined loading pattern which constantly increases over time thereby making it possible to determine the collapse conditions, associated lateral displacement and total applied shear force. It offers a sound Perception of Structural Performance against earthquake as well as damages suffered. Thus, pushover analysis makes it feasible to ascertain the responsive behavior of buildings in non-linear zones which is not catered for by conventional elastic designs.

Keywords: Earthquake, ETABS 16, Lateral Force Distribution, Non-Linear Static Analysis, Performance Based Design, Pushover Analysis, Reinforced Concrete Structural Frame, Seismic Analysis

1. Introduction to Pushover Analysis

In engineering, Seismic hazard is defined as the likelihood of a seismic occurrence in a particular location, time and at an intensity of ground movement that exceeds a given limitation. The process of forecasting the occurrence and magnitude of seismic hazard involves numerous analytical modelling and complex scientific estimations. Such computational approaches encompass determining the seismic zones together with their features, an effective model of predicting seismic hazard and establishing possible way of attenuating the possible effects of ground movements. It is apparent to note that these procedures according to the region are under consideration. However, standardized methods have proved to be significantly important for making consistent estimates and comparisons of seismic hazards around the world (Barbagallo et al., 2019).

Seismic centers are tasked with a mandate of predetermining seismic hazards before they take place and they rely on data bases and earthquake catalogues to determine seismic zones and their characteristics as well as delineate possible effects. Hence, it is essential to develop a common seismic catalogue that can be used within a particular region (Chaulagain et al., 2013). On the other hand, it is also of apparent importance to create models that are capable of determining sources of seismic effects. Such models are capable of conducting an earthquake localization and ascertaining its temporal recurrence using seism-tectonic information. Hence, it is important to use seismicity map and compile all the information pertaining to morphed-structures, geodynamics, neo-tectonics etc. because a critical examination of seismicity maps aids in determining active faults and areal seismic source zones. In this regard a suitable earthquake recurrence model is developed for each respective seismic zone using a set of predetermined algorithms and parameters that represents seismicity to estimate the seismic hazard of a particular area (Dorri, Hooman, & Andrzej, 2019).

The seismic analysis type that should be used to analyze the structure depends on dynamic properties, the structure's seismic design category, regularity and structural system. There are four types of seismic analysis as shown in Figure 1.

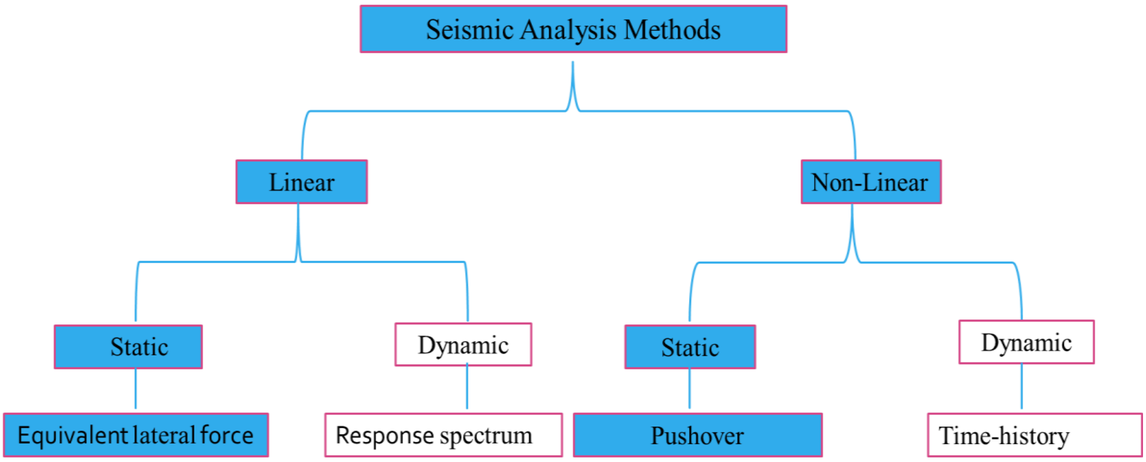

Figure 1: Seismic Analysis Methods

2. Literature Review

Dharanya, Gayathri, and Deepika (2017) applied a combination of IS 1893:2002 guidelines and ETABS to analyze the usefulness of bracing and shear walls in G+4 storey residential RC building. Their attention was placed on changes in lateral displacement, base shear, storey drift, axial and shear force, and time period as a result of seismic effects. Their findings revealed that seismic caused by earthquakes have a tendency to expose all the areas of a building to seismic forces and this problem was established to be more common in tall buildings. Henceforth, they insisted that lateral or torsional deflections were causing tall buildings to experience a lot of oscillatory movements. As a result, it is of huge importance to ensure that tall buildings are stiff enough to handle seismic effects and this is usually made possible through the use of shear walls and cross bracings. Their findings further showed that natural period can be reduced significantly by erecting shear walls in buildings and as opposed to bracings. In other words, they posited that multi-storey buildings can have their stability to guard against seismic effects enhanced by placing shear walls.

Gunderao and Hiremath (2015) conducted a study that examined variations in performance of non-ductile reinforced concrete (RC) buildings with inverted V- eccentric steel bracings. The responsiveness of the reinforced concrete was compared with that of eccentric braced frame (EBF) and the results showed that seismic hazards in buildings high as 15-storeys can be effectively reduced by using EBFs.

Choudhari and Nagaraj (2015) model a G+4 steel bare frame using SAP2000 to examine the impact of V, inverted V and X bracings with regards to their base shears, roof displacement, and time period and storey drift performance. The pushover analysis results exhibited that a steel building's structural stiffness can be enhanced by lowering maximum interstate drift and this was effectively accomplished by using X- steel bracing systems. Their findings were in support of the results established by Kevadkar and Kodag (2013).

Tande and Snehal (2013) established that high seismic zones require steel buildings that contain EBFs so as to contain the tensional forces and load triggered by seismic effects. Their motive was to outline that the presence of lateral forces caused by seismic excitation can be effectively handled by using diagonal, inverted-V and V braces. The study was based on examinations made to 4-storey and 8-storey buildings with the aid of FEMA 440. The nonlinear static analysis revealed that there is an initial occurrence of plastic hinges at the fuse section of braces which later spreads to the compressive parts of the eccentric braces.

3. Pushover Analysis

Pushover analysis is an examination of the responsiveness of structure when subjected to continuous lateral-forces until it reaches the required displacement point. As such, pushover analysis encompasses a set of predetermined elastic analysis that is used to estimate an entire structure's force-displacement curve (Pinho et al., 2013). The process usually involves the creation of either 2 or 3-dimensional models with either trilinear or bilinear load-deformation figures of the lateral force resisting elements. This is followed by a sequential application of gravity loads and continued increase in lateral forces and this is repeatedly done until the structure becomes unstable. At this stage, the global capacity curve is produced using the base shear and roof displacement.

Pushover analysis can either be conducted in the form of force-controlled or displacement-controlled analysis. The latter is characterized by insignificant negative and positive lateral stiffness caused by P-delta effects which are observable in the target displacement. In addition, it also involves the application of full load combination and is bound to suffer from numerical issues which reduce the reliability of the results obtained.

Preference to use pushover analysis to assess the seismic performance of a structure is mainly justified by its inherent simplicity to conduct computations and it is also simple express as a conceptual model. Moreover, the analysis of overall capacity curve of the structure together with failure sequence and yielding can be traced using pushover analysis as prescribed by reputable rehabilitation codes and guidelines.

4. Purpose of Doing Pushover Analysis

The main emphasis of pushover is to offer responsiveness insights which is difficult to obtain using simple dynamic and static analysis. As a result, pushover analysis is characterized by the following aspects;

Brittle aspects such as shear force demands, moment demands and force demands on column and brace connections respectively, axial force demands etc., in reinforced concrete beams.

- Attempt to reduce the energy exerted on a structure by estimating the elements' deformations demands.
- Assessing the effects of a reduction in strength deterioration of each element and how it affects the responsiveness of a structural system.
- Identifying areas which are bound to experience high deformation demands by focusing detailing activities in such particular regions

- Identifying how strength discontinuous causes elastic changes in structural dynamic characteristics.
- Determining and controlling P-Delta effects in terms of stiffness discontinuities and/or strength caused by inter-story drifts.
- Taking into consideration of the foundation system, stiff non-structural elements and the entire structural elements to verify a load path's adequacy and completeness.

5. Background

Pushover analysis is one of the most preferable strategies of examining structural seismic performance since it takes into account of post-elastic behavior and is simple to use. However, it encompasses the use of simplifications and approximations which may cause variations in the predictive capacity of seismic effects to be observed. Despite the idea that pushover analysis plays a vital role in determining the important structural properties during seismic events, its reliability is still being questioned and procedures are criticized. However, it remains an important and favorable method of seismic analysis over traditional pushover methods. As a result, continuous effort is always being made to deal with some of its limitations. The major challenge is that such improvements always pose conceptual and computational complexities, and can sometimes prove to be impractical in engineering. Hence, it is important to ascertain the limitations and predictive capacity of pushover analysis with regards to low, mid and high-rise structures. This also includes looking at target displacement estimations and invariant lateral load patterns.

5.1 Performance-Based Design

Performance based design represents a significant change from established principles of structural analysis and the prospect of seismic research. This approach offers a sound way of ascertaining the minimum possible damages bound to be suffered in the midst of an earthquake occurrence. Most importantly, it emphasizes that preplanned yielding be used to curb damages to a structure rather than considering it as part of a structure's failure.

5.2 Static Non-Linear Analysis

Performance-based design is relatively different from code-based approach in the sense that it accounts values beyond the scope of elasticity and a notable example static non-linear analysis. Basically, pushover analysis assumes two forms;

5.2.1 Displacement Controlled

This is an exact opposite of force controlled and it is utilized when the displacement is known and load is unknown with the sole aim of making sure that a structure becomes unstable by losing its strength.

5.2.2 Force Controlled

Used to enhance a structure's ability to withstand a given load and also good example to push over analysis involving controlled force.

Three main steps involved in this process of analysis:

1. Capacity evaluation of the building.

2. Evaluation of demand curve.
3. Determination of performance point.

5.2.3 Capacity

Figure 2 provides insights of changes in the lateral displacement and ranges from 0 up to a point where the incipient of a structure collapse. This involves monotonic application of the force so as to determine a structure's strength and this is important for the generation of the capacity curve.

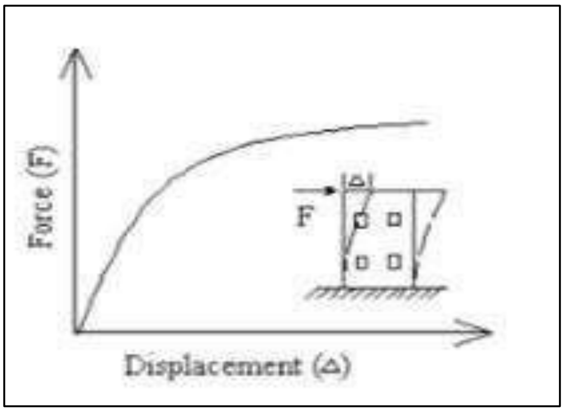

Figure 2: capacity curve

5.3 Pushover Analysis in ETABS 16

A building structure can be examined using iterative methods such as nonlinear analysis. However, it relies significantly on final displacement as effective damping relies on the loss of hysteretic energy induced by inelastic deformation, which is also determined by the final displacement. Thus, causing the entire analysis to be iterative. The problem of instability of the structure results in a negative stiffness matrix to develop near the ultimate load.

A three-dimensional pushover analysis of a building can be performed using programs and systems that are capable of monitoring deformation on the entire hinge and deal with difficult geometry using a Structural Analysis Finite Element Program and Extended Three-Dimensional Buildings Systems (ETABS) 16. The pushover analysis performed by in steps as follows;

1. Developing a computer model.
2. Establishing acceptance criteria and defining the properties of the pushover hinges using a program that accommodates numerous built-in default hinge characteristics whose average values range from ASCE 41to 13 for concrete members. Such built in features are essential for conducting preliminary examinations.
3. Locate the pushover hinges on the model by evaluating at least one or more frame members as well as assigning to them one and more pin locations and characteristics so as to help choose at least one frame member.
4. Controlling lateral and gravity load pushovers using ETABS which is capable of running at least 16 pushovers at once.

5. Running either dynamic or static analysis before conducting a static nonlinear pushover analysis.
6. Produce the pushover curves and tables.
7. Using a step-by-step to review the hinge formation's displaced pushover sequence and shape.

5.4 Plastic Deformation Curve:

The plastic deformation and yield value for each degree of freedom are determined using five-point moment-rotation or a force-displacement curve with points ranging from A to E as depicted in Figure 3.

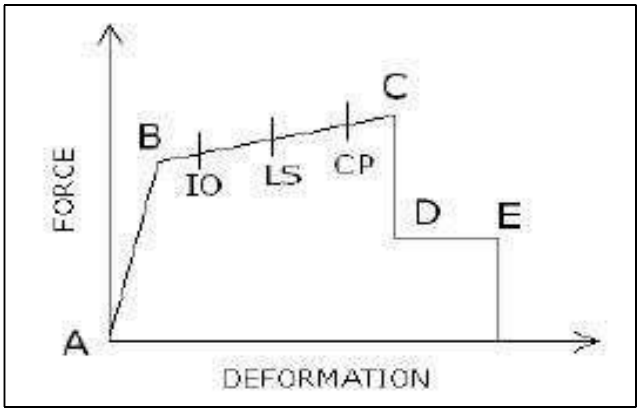

Figure 3: Force V/s Deformation curve

Pushover analysis is undertaken by examining the shape of the curve depicted in Figure 3. Considerations must be made that the point of origin is fixed at Point A and does not change. On the other hand, yielding is denoted by Point B represents yielding. The existence of various deformation value of B does not cause the hinge to deform at any point from A to B. The displacement at point B is deducting from the deformations at point C, D, and E.

Linear response to active yield (B) from unloaded state (A) defines the load deformation relationship. Then the consistency drops from point B to point C. Point C has strength equitable to nominal strength and immediately a sudden reduction in lateral resistance to response of reduced resistance (D) to final resistance loss (E). The line BC gradient is commonly between 0 and 10% of the preliminary gradient. Line CD is the member's original error. Line DE is the member's accumulated power (Hakim, Alama, & Ashour, 2014).

Such points are defined by Federal Emergency Management Agency (FEMA) to determine hinge rotation behavior of RC members. The points between (B) and (C) represent acceptance criteria for the hinge, which is immediate occupancy (IO), life safety (LS), and collapse prevention (CP).

In order to categorize and define status of the building it needs at the performance point lateral deformation from Pushover curve need a comparison with limitation of deformations as per Table 1 from (ATC-40 Seismic Evaluation & Retrofit of Concrete Buildings, 2018). The inter-story drift at the performance point displacement is defined maximum drift.

Table 1: Deformation limits for each performance levels (ATC-40)

Immediate occupancy	Damage control	Life safety	Structural stability
0.01	0.01-0.02	0.02	0.33

Adapted from (ATC-40 Seismic Evaluation & Retrofit of Concrete Buildings, 2018).

6. Conclusion

The literature details in this study revealed that the behavioral effects of structures in a non-linear zone can be effectively examined using pushover analysis (non-linear static analysis). Thus, conducting pushover analysis is an effective way of ascertaining the exact nature of failure modes that are bound to be observed on a building structure as a result of seismic actions. Further examinations in this area are essentially required. Pushover analysis will define category status of the building at performance point, and confirm serviceability status of the structure.

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