INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
*(Volume 4, Issue 3)*
Available online at: www.ijariit.com

# Steel structures, pushover analysis

*Bhavna Saini*
bbhavnasaini10@gmail.com
*Rama University, Kanpur, Uttar Pradesh*

*Satish Parihar*
satish_parihar@yahoo.com
*Rama University, Kanpur, Uttar Pradesh*

## ABSTRACT

***Steel structure has an important role in construction Industry In last decades. To perform well under seismic loads it is necessary to design a structure. According to the provisions of the current Indian code (IS 800 -2007) the seismic performance of a multi-story steel structure building has designed. By introducing Steel bracings in the structural system the shear capacity of the structure can be increased to arrange Steel bracings such as D, K, and V type eccentric bracings there are "n" numbers of solutions for various types of eccentric bracings as per the IS 800- 2007 a typical six-story steel structure building is generated. In the present study D, K, and V types of eccentric bracings are taken into consideration. Through nonlinear static analysis performance of each structure is studied.***

**Keywords:** *Analysis Pushover, Structures of Steel, Bracings, Factor of Behaviour.*

## 1. INTRODUCTION

In the construction industry, Steel structure extends an important role in past twenty years. It is compulsory to construct a save structure under seismic loads. By incorporation of Steel bracings in the structural system Shear capacity of the structure can be increased. To arrange Steel bracings there are "n" numbers of solutions are there. Such as D, K, and V type eccentric bracings. To perform well under the seismic loads design of such structure may have genuine ductility property. Push over analysis is performed to find ductility and other properties for each eccentric bracing.
For the performance-based design of building structure works subject to earthquake loading, a simple computer-based push-over analysis is a one of the technique. In the last twenty years due to its simplicity and the effectiveness of the results Push over analysis contains much importance. For different eccentric steel structures, the present study develops a push-over analysis has designed according to IS-800 (2007) and each structure ductility behavior.

### 1.1 STEEL

Steel is the most useful construction material for building. Nowadays steel industries are the backbone of industry growth of the country. Steel having ten times more strength as compared to concrete, for modern & advanced construction steel is the perfect material. Factor like strength, erection time, prefabrication requirement, and demount ability make it more useful for construction. For load-bearing structures in buildings, and as members in a structure like trusses, bridges, and space structures steel are much useful. Another application of steel is used as fire and corrosion protection structure.

### 1.2 Objectives

The major key points of the study are:

a) The main objective is to investigate the effect of D, K and V arrangements in multi-story steel structure building and studies seismic performance by the use of Nonlinear Static Pushover analysis method.
b) Calculate the performance factors for steel structures for different arrangements as per Indian code.

 

**1.3 Methodology**

a) Conceptualization study is made for seismic evaluation of building structures and pushover analysis and its application through different literature and references.
b) With various eccentric bracings arrangement, structural details are analyzed.
c) Model the selected in the seismic behavior of a steel structure with various eccentric bracings done through computer software SEISMOSTRUCT (2007) is done.
d) Pushover analysis carries out for the seismic behavior of a steel structure with various eccentric bracings arrangements and arrives at a conclusion.

## 2. LITERATURE REVIEW

**Hamer and Wraght (1977)** studied the dynamic behavior of multi-storeyed steel structure buildings with setbacks. The observations made based on a detailed parametric study are as follows. The fundamental period decreased by 36% for a setback of 91% (tower occupying 11% of the base area). The higher mode vibration of setback buildings made a substantial contribution to their seismic response; these contributions increased with the slenderness of the tower. The contribution of the higher modes increased to 41% for a setback of 91%. For very slender towers the transition region between the tower and the base was, in some cases, subjected to very large storey shears. This increase in shear force was found to be as high as 250% to 350% for a setback of 95%.

**Shahrooz and Moehle (1990)** studied the effects of setbacks on the earthquake response of multi-storeyed buildings. In an effort to improve design methods for setback structures, an experimental and analytical study was undertaken. A six-storey moment-resisting reinforced concrete space structure with 50% setback in one direction at mid-height was selected. The analytical study focused on the test structure. The displacement profiles were relatively smooth over the height. Relatively large inter-storey drifts at the tower-base junction were accompanied by a moderate increase in damage at that level. Overall, the predominance of the fundamental mode on the global translational response in the direction parallel to the setback was clear from the displacement and inertia force profiles. The distribution of lateral forces was almost always similar to the distribution specified by the UBC code; no significant peculiarities in dynamic response were detected. To investigate further, an analytical study was also carried out on six generic reinforced concrete setback structures.

**Wood (1992)** investigated the seismic behaviour of the reinforced concrete structure with steps and setbacks. Two small-scale reinforced concrete 9-storeyed test structured structures (one -with steps and the other with setbacks) were constructed and subjected to simulated ground motion. The displacement, acceleration and the shear force responses of these structures were compared with those of seven previously tested regular structures. The setback structure comprises two-storey base with seven additional storeys in the tower portions. The stepped structure includes a three storey tower, a three storey middle section and a three storey base. The displacement and shear force responses of these two structures were governed primarily by the first mode. Acceleration response at all levels exhibited the contribution of higher modes. The mode shapes for both the structures indicated kinks at the step locations. However, distributions of maximum storey shear were well redeclayer by the equivalent lateral force distributions for all structures as given in UBC for regular structures. The differences between the linear dynamic analyses of regular, stepped and setback structures were not significant.

**Ghobarah A.F (1997)** the control of inter story drift can also be considered as a means to provide uniform ductility over the stories of the building. A story drift may result in the occurrence of a weak story that may cause catastrophic building collapse in a seismic event. Uniform story ductility over all stories for a building is usually desired in seismic design.

**Foley CM. (2002)** a review of current state-of-the-art seismic performance-based design procedures and declayer the vision for the development of PBD optimization. It is recognized that there is a pressing need for developing optimized PBD procedures for seismic engineering of structures.

**R. Hasan and L. Xu, D.E. Grierson (2002)** conducted a simple computer-based push-over analysis technique for performance-based design of building structure works subject to earthquake loading. And found that rigidity-factor for elastic analysis of semi-rigid structures, and the stiffness properties for semi-rigid analysis are directly adopted for push-over analysis.

**B. AKBAS.*et.al*.(2003**) conducted a push over analysis on steel structures to estimate the seismic demands at different performance levels, which requires the consideration of the inelastic behavior of the structure.

**X.-K. Zou et al., (2005)** declayer an effective technique that incorporates Pushover Analysis together with numerical optimization procedures to automate the Pushover drift performance design of reinforced concrete buildings. PBD using nonlinear pushover analysis, which generally involves tedious computational effort, is highly iterative process needed to meet code requirements.

**Oğuz, Sermin (2005)** Ascertained the effects and the accuracy of invariant lateral load patterns Utilized in pushover analysis to predict the behavior imposed on the structure due to randomly Selected individual ground motions causing elastic deformation by studying various levels of Nonlinear response. For this purpose, pushover analyses using various invariant lateral load Patterns and

Modal Pushover Analysis were performed on reinforced concrete and steel moment resisting structures covering a broad range of fundamental periods. The accuracy of approximate Procedures utilized to estimate target displacement was also studied on structure structures. Pushover analyses were performed by both DRAIN-2DX and SAP2000. The primary observations from the study showed that the accuracy of the pushover results depended strongly On the load path, the characteristics of the ground motion and the properties of the structure.

**Mehmet et al., (2006),** explained that due to its simplicity of Push over analysis, the structural engineering profession has been using the nonlinear static procedure or pushover analysis. Pushover analysis is carried out for different nonlinear hinge properties available in some programs based on the FEMA-356 and ATC-40 guidelines and he pointed out that Plastic hinge length (Lp) has considerable effects on the displacement capacity of the structures. The orientation and the axial load level of the columns cannot be taken into account properly by the default-hinge properties (Programme Default).

**Shuraim et al., (2007)** summarized the nonlinear static analytical procedure (Pushover) as introduced by ATC-40 has been utilized for the evaluation of existing design of a building, in order to examine its applicability. He conducted nonlinear pushover analysis shows that the structure is capable of withstanding the pre-assumed seismic force with some significant yielding at all beams and columns.

**Girgin. et.,(2007**), Pushover analysis has been the preferred method for seismic performance evaluation of structures by the major rehabilitation guidelines and codes because it is computationally and conceptually simple. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as the progress of overall capacity curve of the structure.

**A. Shuraim et al., (2007)** the nonlinear static analytical procedure (Pushover) as introduced by ATC-40 has been utilized for the evaluation of existing design of a new reinforced concrete structure. Potential structural deficiencies in reinforced concrete structure, when subjected to a moderate seismic loading, were estimated by the pushover approaches. In this method, the design was evaluated by redesigning under selected seismic combination in order to show which members would require additional reinforcement. Most columns required significant additional reinforcement, indicating their vulnerability when subjected to seismic forces. The nonlinear pushover procedure shows that the structure is capable of withstanding the presumed seismic force with some significant yielding at all beams and one column.

**Athanassiadou (2008)** analyzed two ten-storeyed two-dimensional planes stepped structures and one ten-storeyed regular structure designed, as per Euro code 8 (2004) for the high and medium ductility classes. This research validates the design methodology requiring linear dynamic analysis recommended in Euro code 8 for irregular buildings. The stepped buildings, designed to Euro code 8 (2004) were found to behave satisfactorily under the design basis earthquake and also under the maximum considered earthquake (involving ground motion twice as strong as the design basis earthquake). Inter-storey drift ratios of irregular structures were found to remain quite low even in the case of the „collapse prevention‟ earthquake. This fact, combined with the limited plastic hinge formation in columns, exclude the possibility of formation of a collapse mechanism at the neighborhood of the irregularities. Plastic hinge formation in columns is seen to be very limited during the design basis earthquake, taking place only at locations not prohibited by the code, i.e. at the building base and top. It has been concluded that the capacity design procedure provided by Euro code 8 is completely successful and can be characterized by conservatism, mainly in the case of the design of high-ductility columns. The over-strength of the irregular structures is found to be similar to that of the regular ones, with the over-strength ratio values being 1.50 to 2.00 for medium-high ductility levels. The author delayers the results of pushover analysis using „uniform‟ load pattern as well as a „modal‟ load pattern that account the results of the multimodal elastic analysis.

**Karavasilis et. al. (2008)** delayer a parametric study of the inelastic seismic response of plane steel moment resisting structures with steps and setbacks. A family of 120 such structures, designed according to the European seismic and structural codes, were subjected to 30 tremors from inside the earth ground motions, scaled to different intensities. The main findings of this paper are as follows. Inelastic deformation and geometrical configuration play an important role in the height-wise distribution of deformation demands. In general, the maximum deformation demands are concentrated in the tower-base junction in the case of setback structure and in all the step locations in the case of stepped structures. This concentration of forces at the locations of height discontinuity, however, is not observed in the elastic range of the seismic response.

**A.Kadid and A. Boumrkik (2008), the** proposed use of Pushover Analysis as a viable method to assess damage vulnerability of a building designed according to Algerian code. Pushover analysis was a Series of incremental static analysis carried out to develop a capacity curve for the building. Based on a capacity curve, a target displacement which was an estimate of the displacement that the design tremor from inside the earth would produce on the building was determined. The extent of damage Experienced by the structure at this target displacement is considered representative of the Damage experienced by the building when subjected to design level ground shaking. Since the Behaviour of reinforced concrete structures might be highly inelastic under seismic loads, the global inelastic performance of RC structures would be dominated by plastic yielding effects and consequently, the accuracy of the pushover analysis would be influenced by the ability of the Analytical models to capture these effects.

**Kala.Pet. al. (2010),** conducted a study on steel water tanks designed as per recent and past I. S codes and they found Compression members are more critical than tension members. And he pointed out that, in Limit state method the partial safety factors on load and material have been derived using the probability concept which is more rational and realistic

 

**P. Poluraju and P.V.S.N.Rao (2011),** has studied the behavior of the structured building by conducting Push over Analysis, most of the buildings collapsed were found deficient to meet out the requirements of the present day codes. Then G+3 building was modeled and analyzed, results obtained from the study shows that properly designed structure will perform well under seismic loads.

**Haroon Rasheed Tamboli & Umesh N. Karadi (2012),** performed seismic analysis using Equivalent Lateral Force Method for different reinforced concrete (RC) structure building models that included bare structure, in filled structure and open first story structure. In modeling of the masonry Infill panels, the Equivalent diagonal Strut method was used and the software ETABS was used for the analysis of all the structure models. In filled structures should be preferred in seismic regions than the open first story structure, because the story drift of the first story of open first story structure is Very large than the upper stories, which might probably cause the collapse of the structure. The infill Wall increases the strength and stiffness of the structure. The seismic analysis of RC (Bare structure) structure leads to under estimation of base shear. Therefore other response quantities such as time period, natural frequency, and story drift were not significant. The underestimation of base shear might lead to the collapse of the structure during tremor from inside the earth shaking.

**Narender Bodige, Pradeep Kumar Ramancharla (2012),** modeled a 1 x 1 bay 2D four storied building using AEM (applied element method). AEM is a discrete method in which the elements are connected by a pair of normal and shear springs which are distributed around the edges of the element and each pair of springs totally represents stresses and deformation and plastic hinges location are formed automatically. Gravity loads and laterals loads as per IS 1893-2002 were applied to the structure and designed using IS 456 and IS 13920. Displacement control pushover analysis was carried out in both cases and the pushover curves were compared. As an observation, it was found that AEM gave good representation capacity curve. From the case studies, it was found that capacity of the building significantly increased when ductile detailing was adopted. Also, it was found that effect on concrete grade and steel were not highly significant.

## 3. PUSH OVER ANALYSIS AND BEHAVIOUR FACTORS

### 3.1 Pushover Analysis

**An Overview**

The use of the nonlinear static analysis (pushover analysis) came in to practice in 1970"s 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 tremor from inside the earth. 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 into several seismic guidelines (ATC 40 and FEMA 356) and design codes (Euro code 8 and PCM 3274) in last few years.

Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a „target displacement" is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the building roof expected under selected tremor from inside the earth ground motion. The structural Pushover analysis assesses performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are storey drifts, global displacement(at the roof or any other reference point), storey forces, and component deformation and component forces. The analysis accounts for material inelasticity, geometrical nonlinearity and the redistribution of internal forces. Response characteristics that can be obtained from the pushover analysis are summarized as follows:

a) Estimates of force and displacement capacities of the structure. The sequence of the member yielding and the progress of the overall capacity curve.
b) Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.
c) Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the 20 earthquake ground motion considered.
d) Sequences of the failure of elements and the consequent effect on the overall structural stability.
e) Identification of the critical regions, when the inelastic deformations are expected to be high and identification of strength irregularities (in the plan or in elevation) of the building. Pushover analysis delivers all these benefits for an additional computational effort (modeling nonlinearity and change in analysis algorithm) over the linear static analysis. Step by step procedure of pushover analysis is discussed next.

### 3.2 Pushover Analysis Procedure

Pushover analysis can be performed as either force-controlled or displacement controlled depending on the physical nature of the load and the behavior expected from the structure. The force-controlled option is useful when the load is known (such as gravity loading) and the structure is expected to be able to support the load. The displacement controlled procedure should be used when specified drifts are sought (such as in seismic 2 1 loading), where the magnitude of the applied load is not known in advance, or where the structure can be expected to lose strength or become unstable.

 

Some computer programs (e.g. Seismostruct, DRAIN-2DX, Nonlinear version of SAP2000, ANSYS can model nonlinear behavior and perform pushover analysis directly to obtain a capacity curve for two and/or three-dimensional models of the structure. When such programs are not available or the available computer programs could not perform pushover analysis directly (e.g. ETABS, RISA, SAP90), a series of sequential elastic analyses are performed and superimposed to determine a force-displacement curve of the overall structure. A displacement-controlled pushover analysis is basically composed of the following steps:

- A two or three-dimensional model that represents the overall structural behavior is created.
- Bilinear or tri-linear load-deformation diagrams of all important members that affect lateral response are defined.
- Gravity loads composed of dead loads and a specified portion of live loads are applied to the structural model initially.
- A pre -defined lateral load pattern which is distributed along the building height is then applied.
- Lateral loads are increased until some member(s) yield under the combined effects of gravity and lateral loads.
- Base shear and roof displacement are recorded at first yielding.
- The structural model is modified to account for the reduced stiffness of yielded member(s).
- Gravity loads are removed and a new lateral load increment is applied to the modified structural model such that additional member(s) yield. Note that a separate analysis with zero initial conditions is performed on the modified structural model under each incremental lateral load. Thus, member forces at the end of an incremental lateral load analysis are obtained by adding the forces from the current analysis to the sum of those from the previous increments. In other words, the results of each incremental lateral load analysis are superimposed.
- Similarly, the lateral load increment and the roof displacement increment are added to the corresponding previous total values to obtain the accumulated values of the base shear and the roof displacement.
- Steps 7, 8 and 9 are repeated until the roof displacement reaches a certain level of deformation or the structure becomes unstable.
- The roof displacement is plotted with the base shear to get the global capacity (pushover) curve of the structure

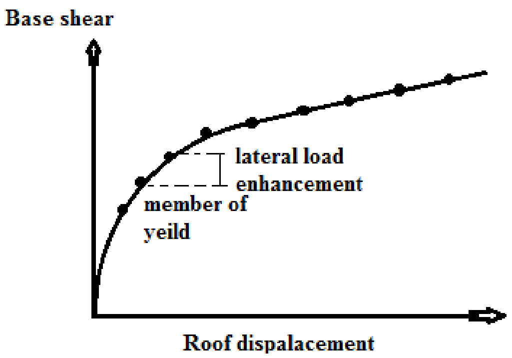


**Figure: Global Capacity (Pushover) Curve of Steel Structure**

### 3.3 Limitations of Pushover Analysis

Although pushover analysis has advantages over elastic analysis procedures, underlying assumptions, pushover predictions are accuracy and limitations of current pushover procedures must be identified. Selection of lateral load patterns and identification of failure mechanisms for an estimate of target displacement due to higher modes of vibration are important issues that affect the accuracy of pushover results. In a design tremor from inside the earth target displacement is global displacement are expected. The mass center of roof displacement structure is used as target displacement. The estimation of target displacement accurate associated with specific performance objective affects the accuracy of seismic demand predictions of pushover analysis. Target displacement is the global displacement expected in a design tremor from inside the earth. The estimate of target displacement, identification of failure mechanisms due to higher modes of vibration are important issues that affect, selection of lateral load patterns the accuracy of pushover results.

## 4. STRUCTURAL MODELLING

### 4.1 Introduction

Study of this paper depends on nonlinear analysis of steel structures with eccentric bracings models. By keeping the total weight of the building is same, Different configurations of structures are selected such as D, K and V structures. A summary of various parameters has been declayer in this chapter for defining the computational models; in this study, the basic assumptions and the steel structure geometry are considered. In the nonlinear analysis, the accurate modeling of the nonlinear properties of various structural elements is very essential. Using fiber based element using the software Seismostruct in this present study, beams and columns were modeled with inelastic flexural deformations.

### 4.2 Structure Geometry

Obtained the details of structures from literature. To be representative of the building along one direction the buildings are assumed to be symmetric in the plan, and hence a single plane structure may be considered. In this study, a typical column height and bay width are selected as 3m and 6m respectively. In this study, a configuration of 6 stories and 6 bays (G+5) is considered. Different arrangements of steel structures such as K, D and V structures are considered as shown in fig. 4.

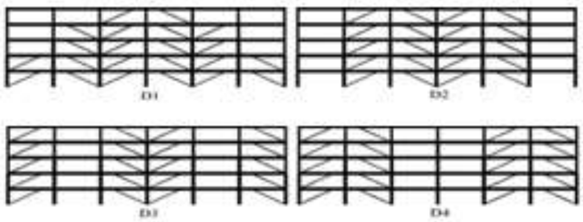


**Fig 4. (a): D-structures**

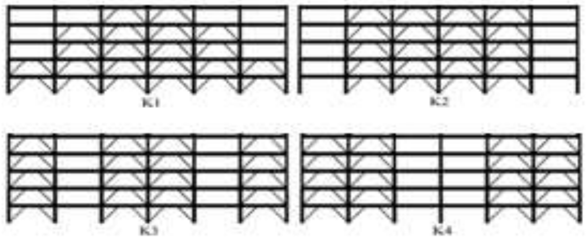


**Fig 4. (b): K-structures**

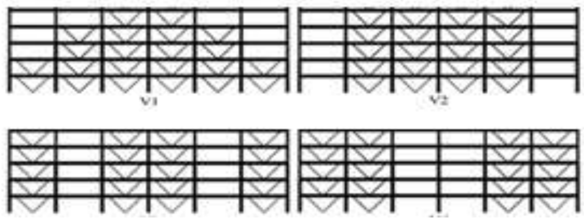


**Fig 4. (c): V-structures**

**Fig 4.1.Braced structure Layout (a) D-structures, (b) K-structures and (c) V-structures**

## 5. CONCLUSIONS

From the present study following conclusions are obtained.

- There is a huge difference between Computational Time periods and IS code Time period in modal reveals analysis of a 2D steel structure.
- Due to its height Ductility of a moment-resisting steel structure is affected to some extent. The height dependency of ductility is greatly magnified when bracing systems are included.
- For higher R factors Steel-braced dual systems exhibit higher ductility.
- This is found that the bracing arrangement D1 & K4 respectively are found to be performing better in D and K family, compared to that of others by considering the range of ductility capacities shown by different systems discussed.

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