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Pushover Analysis for Multistory Building

Alinda Dey[1], Urmimala Bhattacharjee[2], Vaibhaw Sagar[3], Utkarsh[4] and P. Saha[5]

[1,2,3,4]M.Tech Student, School of Civil Engineering, KIIT, University, Bhubaneswar, Odisha
[5]School of Civil Engineering, KIIT, University, Bhubaneswar, Odisha
E-mail: [1]alinda_dey23@yahoo.com, [2]urmibhatt18@gmail.com, [3]vaibhawsagar@gmail.com,
[4]utk272727@gmail.com, [5]dr.purnasaha@gmail.com

Abstract—*Pushover is basically a nonlinear static analysis method by which the response of a building or a non-building structure can be calculated under nonlinear loading like earthquake. In this structural analysis approach a series of forces are applied on the structure to illustrate the effect of earthquake ground motion. The lateral load pattern to be increase continuously through inelastic and elastic behavior until the critical condition is reached. In the recent years pushover analysis became very popular because of its simple computer based technique to represent the different base shear range under earthquake loading. In this paper, different approaches of pushover analysis and their various applications in shear wall and moment resisting frames are discussed. For elastic high rise buildings, the regular response spectra analysis can be reformulated as modal pushover analysis (MPA). Shear walls which have the higher stiffness make the dynamic analysis easier and simpler. The steel braced frames which has capacity of efficient energy dissipation expresses more desirable behavior than the orthodox frames.*

Keywords: *pushover analysis, modal pushover analysis, shear wall, moment resisting frame, nonlinear analysis, lateral load pattern*

1. INTRODUCTION

India has had a number of the world's greatest earthquakes in the last century. There is a nation-wide attention to the seismic vulnerability assessment of existing buildings. Also, a lot of efforts were focused on the need for enforcing legislation and making structural engineers and builders accountable for the safety of the structures under seismic loading. The seismic building design code in India (IS 1893, Part-I) is also revised in 2002[1]. The magnitudes of the design seismic forces have been considerably enhanced in general, and the seismic zonation of some regions has also been upgraded. There are many literature(*e.g.*, IITM-SERC Manual, 2005) available that presents step-by-step procedures to evaluate multi-storeyedbuildings. This procedure follows nonlinear static (pushover) analysis as per FEMA 356.

Pushover is basically a nonlinear static analysis method by which we can analyze a structure. This method calculates the response of a building or a non-building structure under earthquake loading. In this structural analysis approach a series of forces are applied on the structure to illustrate the effect of earthquake ground motion. The lateral load pattern to be increase continuously through inelastic and elastic behavior until the critical condition is reached. The main goal using this analysis is to predict peak response of building and components for a given earthquake. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure.The lateral forces are increased until some 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 reason we use pushover analysis is because using this analysis, less conservative acceptance criteria can be used with consequences understood[2, 3].Estimating seismic demands at low performance levels, such as life safety and collapse prevention, requires explicit consideration of inelastic behavior of the structure. While nonlinear response history analysis (RHA) is the most rigorous procedure to compute seismic demands, current structural engineering practice uses nonlinear static procedure(NSP), or pushover analysis, described in FEMA-273 , or ATC-40 [1996], and FEMA-356 [BSSC, 2000].Now, though the yielding of the structure are approximated or assumed, the following investigations led us to estimate a good seismic demand. From the deformation of the first mode single degree freedom system the roof displacement can be evaluated [5]. Hasan et al. made two different building frameworks and presented their corresponding computational details to find out nonlinear post elastic behavior [6]. Kalkan et al. [7] worked on the scaling of earthquake records to the same target value as in inelastic deformation. The peak deformation of a single degree freedom system coming from this approach is in nearby range from the target value for both first and second mode[7]. Studies of inelastic system behavior is also evaluated by using hybrid coupled walls. El-Tawil et al. examined on 2D coupledwalls which are equivalent to frames and represents different beam column elements[8]. Similarly, Naito approximated the dynamic response under blast on SDOF frame [9]. Sung et al. investigated pushover analysis in rigid joints that is beam column joint [10]. Nonlinear time history method is also performed on RC structures. Though the modal pushover analysis is very accurate and popular, it is developed to make it more conventional including higher mode contribution to seismic loads [11-14].Beside these, nonlinear dynamic analysis is also done to compare the peak and residual drift response to the building frames. Erochko et al. investigated in the similar approach on two different set of special moment resisting frames and buckling restrained braced frames[15, 16].Same study has done on two, four and eight storey frames by Dicleli[17]. Similarly, the buckling potential of storey induced with v-braced frames is also evaluated by Cho et al.[18].

2. PUSHOVER METHODS

Pushover analysis is a technique in which any structure is subjected to incremental lateral loads which represent the inertia forces in an earthquake. The sequence of cracks, yielding, plastic hinge formation and failure of structural components are noted.For this procedure, a relation between base shear and control node displacementplotted.

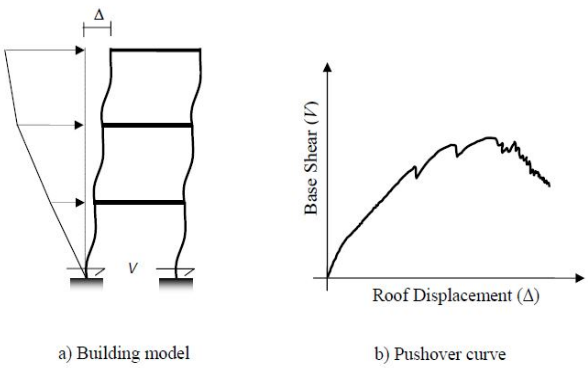


Fig. 1: Schematic representation of pushover analysis procedure

Target displacement is the overall global displacement of a structure subjected to the design earthquake. This plays a key role in the pushover analysis. The methods to evaluate target displacement are Displacement Coefficient Method (DCM) of FEMA 356 and Capacity Spectrum Method (CSM) of ATC 40.

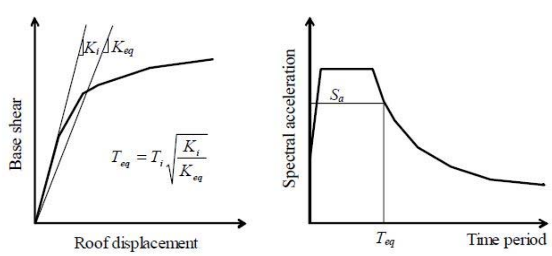


Fig. 2: Schematic representation of displacement coefficient method (FEMA 356)

The Displacement Coefficient Method (DCM) of FEMA 356 assumes the initial linear properties and considers damping for the ground motion excitation to estimate the elastic displacement of an equivalent SDOF system, thereby estimating the maximum inelastic displacement response for thebuilding at roof by multiplying with a set of displacement coefficients[8, 19].

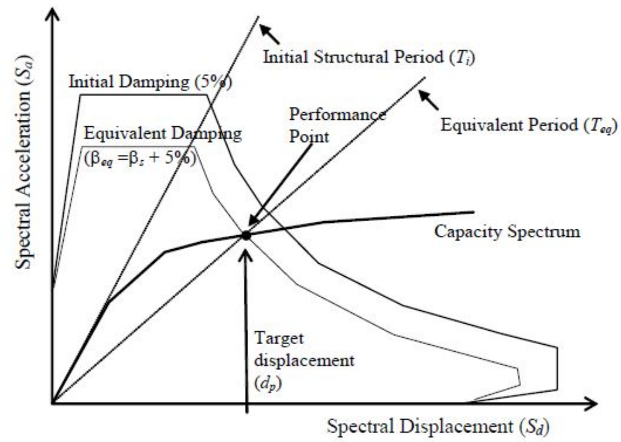


Fig. 3: Schematic representation of Capacity Spectrum Method (ATC 40)

The Capacity Spectrum Method (CSM) of ATC 40 assumes that the maximum inelastic deformation of a nonlinear SDOF system can be approximated from the maximum deformation of a linear elastic SDOF system with an equivalent period and damping.

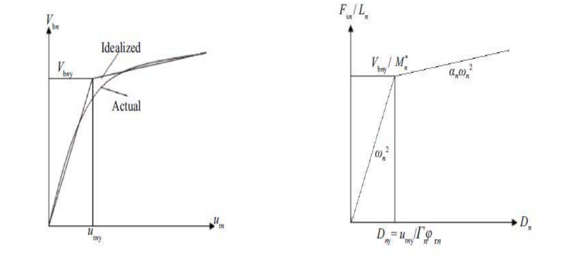
In this method, the pushover curve is used in andisplacement response spectrum (ADRS) format and the effective period and damping is calculate with the use of estimated ductility.

For the above procedure, the pushover curve is used in an accelerationdisplacement response spectrum (ADRS) format which could be obtained using the dynamic properties of the system. The pushover curve in an ADRS format is termed a ‘capacity spectrum’ for the structure. The seismic ground motion is represented by a response spectrum in the same ADRS format and it is termed as demand spectrum[19].

The Pushover analysis procedure is used to determine the seismic demands on any structure. But in case of high rise buildings, it is sometimes it is difficult to apply the pushover analysis the higher modes are not accounted in such case. So, a modal pushover analysis (MPA) procedure was used which considers the redistribution of inertia forces after the structure yields proposed by Chopra *et al*. (2001)[20].

The total seismic demand can be estimated by the combination of the first two or three terms of expansion. This provide a much more accurate estimation of seismic demands.

Despite of the accuracy, it still doesn’t avoid the consideration of lateral force distributions.



(a) Pushover curve and the idealized bilinear curve (b) Converted force-displacement relationship for equivalent SDF system

Fig. 4.

It is concluded that for low rise buildings, the improved MPA procedure in which only two phase first mode is required, provides a far better estimation of seismic demands in comparison to the traditional lateral force distribution [4].

The MPS method includes scaling of ground motions in order to match the target value of inelastic deformation of first mode inelastic single-degree-of-freedom (SDF) system , the properties of whom is determined by first mode pushover analysis[5, 7].

The Next Generation of Attenuation Project's earthquake ground-motion database was used to compile 21 earthquake ground motions which was used for further calculations[13].The MPS method provided a good degree of accuracy for estimation of seismic demands for intense ground motion. Also, for first-mode dominated structures, the scaling of earthquake records to the target value of the inelastic deformation is sufficient enough in producing accurate estimates [5].Three different procedures was used to determine the dynamic response of various structural systems which were : modal pushover analysis (MPA), uncoupled modal responsehistory analysis (UMRHA) and nonlinear RHA.It was concluded that for elastic buildings the first mode As far as the inelastic buildings were concerned, they showed a biased estimation of roof displacement in first mode SDF system which depended on the extent to which the structure was driven in the inelastic range. Also for longer-period systems , the dispersion of displacement ratio increased[7].This paper aims at the comparison and evaluation of structural response demands derived from the nonlinear static analysis procedures (NSPs) which are displacement coefficient method (DCM) recommended in FEMA 356 and capacity spectrum method (CSM) recommended in ATC 40[14]. Capacity curves (base shear-roof displacement relationship) were obtained for the buildings under lateral loads[19].

3. SHEAR WALL

In the high seismic regions the hybrid coupled walls expresses good performance in strength, stiffness and toughness. So here these walls are used as equivalent to 2D frames which represents beam- column elements [21]. Coupling ratio is basically the percentage of overturning moment which resists the coupling action of the wall[8]. Has analyzed on same prototype with different coupling ratio. Comparison between three coupled walls and three isolated walls also done by El-tawil et al. He finds the fundamental difference, in case of isolated walls the moment reaction at the base of each individual wall resists the entire overturning moment, where in case of coupled walls, the shear force transfers through the coupling beams produce compressive and tensile force couple which resists total overturning moment [22]. These panels buckle in shear and subsequently form a diagonal tension field[16].As we know shear critical structures are basically brittle and it collapse without any prior indication of distress, it is essential to consider the shear effect as a strength of concrete structure [12].To find out the damage occurs and to determine the blast resistance behavior of the wall, pushover analysis is executed on the shear wall. The plastic hinge formation is also considered in this study to designate the failure[9].As a prototype a 6ft wide shear wall has taken along with the window openings and relative blast demand is applied on the system along its height.

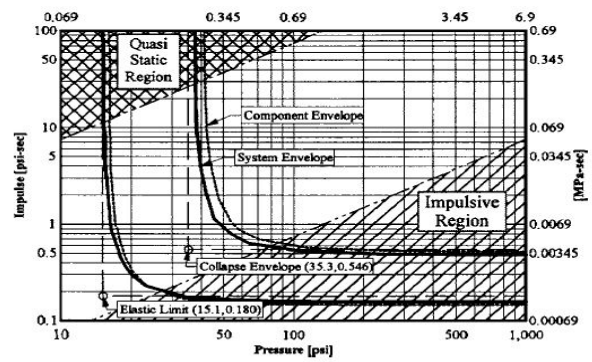


Fig. 5: Comparative resistance envelope

After the wall reaches its yield moment plastic hinge forms and from the above pressure-impulse curve the damage and the blast resistance potential is obtained easily [9].

In another investigation cold-formed steel plates were taken as the shear wall. Here the buckling mode in tension is observed from load-displacement curve [21]

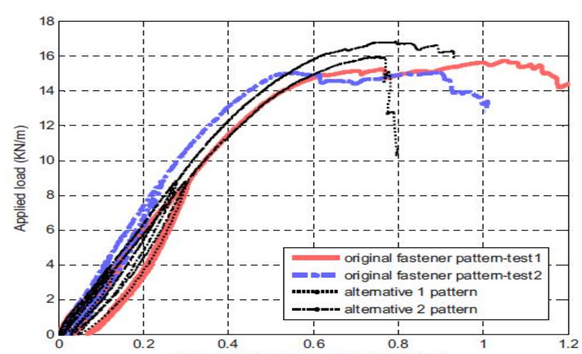


Fig. 6: Applied load versus displacement curves different fastener patterns

It can be obtained from the above studies that coupling ratio has an influence on the deformation of the walls in different manner parameters like target displacement, base shear, wall rotation, axial force, shear distortion, bending moment and maximum connection gap[10]. In another study the other parameters like displacement profile, story drift ratio, wall shear distortion was investigated to see the effect of coupling [22].

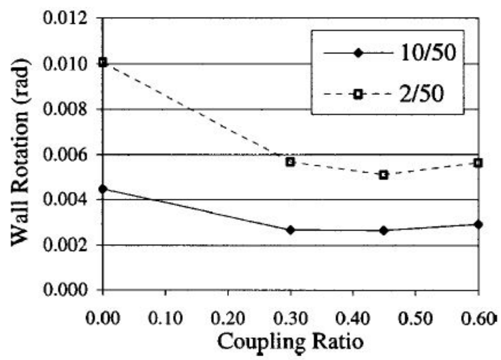


Fig. 7: Variations in wall rotations at wallbase for middle shear wall

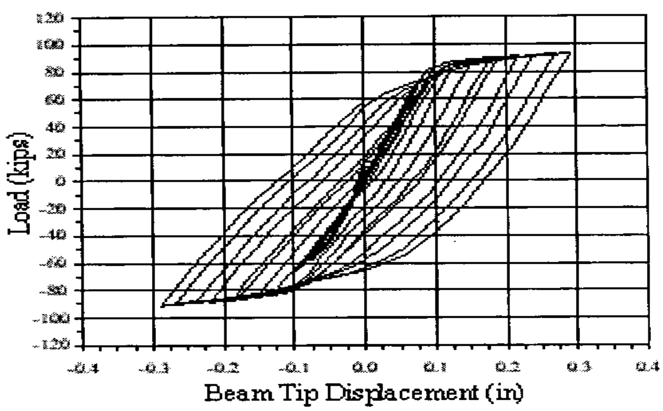


Fig. 8: Load pattern for a wall subjected to lateral loading

To check out the adequacy of dual strip model, a two story steel plate shear wall (SPSW) was made along with RBS beam connection. This analysis shows the comprehensive manners of the SPSW sample can be suitably predicted by dual strip model [16].Another shear wall specimen under monotonically increasing load was examined having the span-depth ratio 2:1.But the analytical responses are stiffer than the experimental responses. In additional, some computed parameters like member deformations, crack width, reinforcement strain responses presented solid correlation with experimental outcomes [12].

4. MOMENT RESISTING FRAMES

As one of the most important property of steel is ductility, steel frames are designed to enforce the ductile mechanism which provides warning sign before the structure to collapse [17]. Capacity design concept says seismic energy should be dissipated through cyclic yielding of tension and buckling due to compression [18]. He has analyzed nine steel framed building to inspect the efficiency of the methods of forecasting seismic performance [23]. Due to the nonlinear behavior of the system the everlasting deformation of the structure occurs which leftovers at the end of the seismic excitation is basically residual drift [23]. Erochko et al. has considered the residual drift to evaluate the structural performance of the system under seismic excitation [15]. Cho et al. has preferred the V-braced steel frame to obtain the potential damage and potential of story buckling [18].Due to the high ductile property moment resisting frames are used very commonly in steel building constructions. It gives highly sensitive response and results in dissipation of energy [17]. A six story building frame using different bracings (D,K,V) are analyzed by Mishra [24].

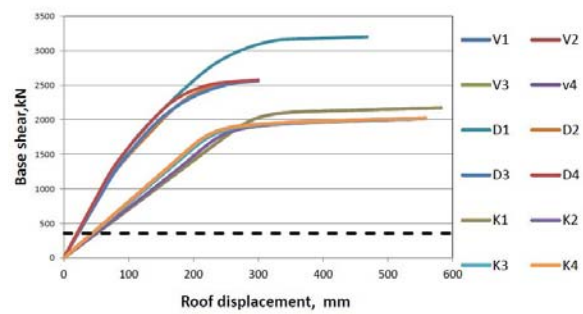


Fig. 9: Comparison of Pushover Analysis of all types of frames

Here is the comparison of pushover curve for D, K and V braced frames. It is observed from the study that inclusion of different type of bracings increase the shear capacity of the frame and these can be used in retrofitting as well [24].Erochko et al. has investigated the pushover analysis on a typical steel frame of a building and also showed the comparison between special moment resisting frame (SMRF) and buckling restrained braced frame(BRBF) [15].

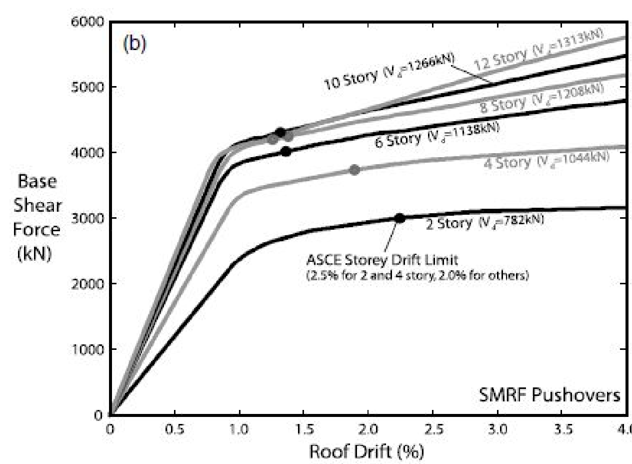


Fig. 10: Pushover results for SMRF's

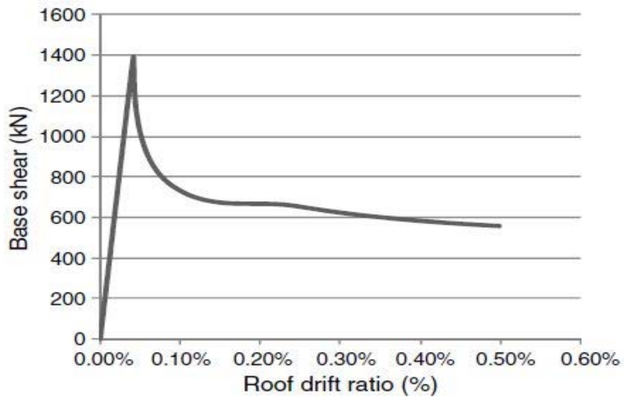


Fig. 11: Typical soft story formation in a poorly designed inverted V-braced frame

From the different methods of pushover analysis on the inverted V braced frames the axial force capacity is obtained. The inelastic dynamic analysis on different stories detects the high buckling potential and the dynamic behavior of the frames [18]. SMRF system gives the larger drift response for the shortest building and also where soft story formation has occurred. But BRBF performed marginally better in maximum reliable seismic level [15]

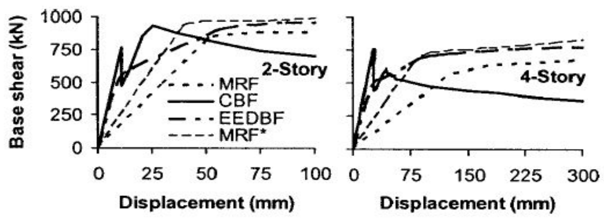


Fig. 12: Base shear versus top displacement for two and four story frames

By eliminating the drawbacks of moment resisting frame(MRF) and chevron braced frame(CVF) Dicleli et al. has proposed energy efficient dissipating braced frame(EEDBF). So this newly proposed frame gives more elastic lateral stiffness and it also has steadier lateral force-displacement relationship than other predictable frames [17].Since the most of the buildings and bridges are made of reinforced concrete, the pushover analysis on RC structures are done to predict the structural damage followed by unexpected failure of the structure under earthquake loading.Basically beam column joints of a structure is treated as the rigid joints under seismic loads and based on strong column weak beam design formation of plastic hinge was allowed in beam elements [10]. Similarly the properties of different hinges in a frame is examined when it is under seismic loading [11].Specimen consists of three bay and three story was taken under pushover procedure and the behavioral sequence and failure pattern of the beam column joint were observed [10]. Chintanapakdee et al. investigated the pushover analysis on different irregular frames to examine the impact of vertical irregularities in strength distribution and stiffness[13, 25]The beam column joint has a strong influence on the seismic behavior of the RC structure (Fig. 12). From the above study the behavior of the joint and the failure sequence of the plastic hinge is observed [10]. For the first story beam column the linear pushover analysis result shows lower damage ratio comparing to nonlinear dynamic analysis [11]. From the modal pushover analysis on different height of story frames it is observed that the irregularities in stiffness and strength has individually as well as combined strong influence on the story drifts [13].

5. CONCLUSION

Thispaper reviewed the earlier investigations and studies on the seismic response of different building structures under earthquake loadings successfully. The different method of pushover analysis procedure is also observed which can be utilized in various practices of structural engineering. This study led to the following conclusion:

For elastic high rise buildings the regular response spectra analysis can be reformulated as modal pushover analysis (MPA). By the pushover analysis the peak response of an elastic structure subjected to the lateral loading can be predicted. The MPA system can give the estimation of accurate seismic demand in case of unsymmetrical structures. Another study concludes, to analyze the behavior of beam column joints and failure manner of plastic hinges can be an effective and useful approach of pushover analysis.

Study says short buildings are less sensitive than tall buildings, which accomplishes in case sensitivity to residual drift the braced resistant building frames (BRBF) come first than special moment resisting frame (SMRF). The steel braced frames which has capacity of efficient energy dissipation expresses more desirable behavior than the orthodox frames. In case of nonlinear buildings modal pushover based scaling (MPS) method is also developed which gives the median values of story drift, plastic rotation, floor displacements etc. It is also obtained from the study that eccentric axial loading is the only reason for the unpredicted distortional buckling of the cold formed steel plate. This buckling can govern the failure of shear walls. In the regions of higher seismicity the impact of the coupling ratio on the seismic response must checke before designing the structure. Shear walls which have the higher stiffness make the dynamic analysis easier and simpler.

Stiffness, strength has an effective influence in the seismic behavior of the structure. Usually vertical irregularities have no influence on the roof displacements but drift demand has the same. Though the consideration of shear effects and implementation of unbalanced force approach is essential for safe and realistic seismic response.

REFERENCES

[1] Chopra A.K, G.R.K., *A modal pushover analysis procedure for estimating seismic demands for buildings.* Department of Civil and Environmental Engineering,University of California at Berkeley, 2002. **31**: p. 561-582.

[2] Apirakvorapinit P, M.J., Shen J, *Analytical Investigation of Potential SeismicDamage to a Skewed Bridge* , Practice Periodical on StructuralDesign and Construction, 2012. **17**(1): p. 5-12.

[3] Park H.G, E.T., Lee H, *Factored Modal Combination for Evaluation of EarthquakeLoad Profile* Journal of Structural Engineering, 2007. **133**(7): p. 956-968.

[4] Jianmeng M, C.Z., Lili X, *An improved modal pushover analysis procedure for estimating seismic demands of structures.* Institute of Engineering Mechanics, China Earthquake Administration, 2008. **7**(1): p. 25-31.

[5] Chopra A.K, G.R.K., Chintanapakdee C, *Statistics of Single-Degree-of-Freedom Estimate of Displacement for Pushover Analysis of buildings* Journal of Structural Engineering, 2003. **129**(4): p. 459-469.

[6] Hasan R, X.L., Grierson D.E, *Push-over analysis for performance-based seismic design.* Department of Civil Engineering, University of Waterloo, 2002. **80**: p. 2483-2493.

[7] Kalkan E, C.A.K., *Modal-Pushover-Based Ground-Motion Scaling Procedure* Journal of Structural Engineering, 2011. **137**(3): p. 298-310.

[8] El-Tawil S, K.C.M., *Pushover of Hybrid Coupled Walls. II: Analysis and Behavior* Journal of Structural Engineering, 2002. **128**(10): p. 1282–1289.

[9] Naito C.J, W.K.P., *Blast Assessment of Load-Bearing Reinforced ConcreteShear Walls.* Practice Periodical on Structural Design and Construction, 2006. **11**(2): p. 112-121.

[10] Sung Y.C, L.T.K., Hsiao C.C, Lai M.C, *Pushover analysis of reinforced concrete frames considering shear failure at beam-column joints.* Earthquake Engineering and Engineering Vibration, 2013. **12**(3): p. 373-383.

[11] Cavdar O, B.A., *Pushover and nonlinear time history analysis evaluation of a RC building collapsed during the Van (Turkey) earthquake on October 23, 2011.* Nat Hazards, 2014. **70**: p. 657-673.

[12] Guner S, V.F.J., *Pushover Analysis of Shear-Critical Frames:Verification and Application.* ACI Structural Journal, 2010. **107**(1): p. 72-80.

[13] Chintanapakdee C, C., *Seismic Response of Vertically Irregular Frames: ResponseHistory and Modal Pushover Analyses* Journal of Structural Engineering, 2004. **130**(8): p. 1177-1185.

[14] Irtem E, H.U., *Investigation of Effects of Nonlinear Static Analysis Procedures to Performance Evaluation on Low-Rise RC Building* of Performance of Constructed 2009. **23**(6): p. 456-466.

[15] Erochko J, C.C., Tremblay R, Choi H, *Residual Drift Response of SMRFs and BRB Frames in Steel Buildings Designed according to ASCE 7-05.* Journal of Structural Engineering. **137**(5): p. 589-599.

[16] Qu B, B.M., Lin C.H, Tsai K.C, *Testing of Full-Scale Two-Story Steel Plate Shear Wall with Reduced Beam Section Connections and Composite Floors.* Journal of Structural Engineering, 2008. **134**(3): p. 36417.

[17] Dicleli M, M.A., *Efficient Energy Dissipating Steel-Braced Frame to Resist Seismic Loads* Journal of Structural Engineering, 2007. **133**(7): p. 969-981.

[18] Cho C, L.C.H., Kim J.J, *Prediction of Column Axial Forces in Inverted V-braced Seismic Steel Frames Considering Brace Buckling.* Journal of Structural Engineering, 2011. **137**(12): p. 1440-1450.

[19] SETHY, K., *APPLICATION OF PUSHOVER ANALYSIS TO RC BRIDGES*, in *DEPARTMENT OF CIVIL ENGINEERING*. 2011, NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA: ROURKELA(INDIA). p. 48.

[20] RK, C.A.a.G., *A Modal Pushover Analysis Procedure to Estimate Seismic Demands for Buildings: Theory and Preliminary Evaluation.* 2001.

[21] C, Y., *Distortional Buckling of Cold-Formed Steel Shear WallStuds under Uplift Force* Journal of Structural Engineering, 2010. **136**(3): p. 317-323.

[22] El-Tawil S, K.C.M., *Pushover of Hybrid Coupled Walls. I:Design and Modeling* Journal of Structural Engineering, 2002. **128**(10): p. 1272-1281.

[23] G.G, D., *SUMMARY OF SAC CASE STUDY BUILDING ANALYSEs.* Journal of Performance of Constructed Facilities, 1998. **12**(4): p. 202-212.

[24] MADDALA, P., *PUSHOVER ANALYSIS OF STEEL FRAMES*, in *Department of Civil Engineering*. 2013, NATIONAL INSTITUTE OF TECHNOLOGY ,ROURKELA: Rourkela(India). p. 53.

[25] Chintanapakdee, C., *Evaluation of The Modal Pushover Analysis Procedure Using Vertically Regular and Irregular Generic Frames*, in *Civil and Environmental Engineering*. 2002, University of California, Berkeley: USA p. 213.