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Seismic Demand Study on Steel Structural systems using Pushover analysis-An overview

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Abstract- **Presented in this paper is the overview of Response reduction factor for the Steel structural systems. Seismic codes consider a reduction in design loads since the structures possess significant reserve strength (overstrength) and capacity to dissipate energy (ductility). The overstrength and the ductility are incorporated in structural design through a force reduction or response modification factor (R) to make the structures linearly elastic. Nonlinear static pushover analysis is a computer based analysis technique carried out by softwares such as ETABS, SAP 2000, SeismoStruct etc. Pushover curves (base shear vs displacement) obtained from the analysis are used to calculate various seismic demand parameters such as overstrength factor, ductility factor, response reduction factor for various structural systems in various papers.**

Index terms- Pushover analysis, Response reduction factor, Strength factor, ductility factor

I. Introduction

Response reduction factor represents ratio of maximum seismic force on a structure during specified ground motion if it was to remain elastic to the design seismic force. Thus, actual seismic forces are reduced by the factor "R" to obtain design forces.

Seismic Analysis is a subset of structural analysis and is the calculation of the response of a building (or non building) structure to earthquakes. It is part of the process of structural design or structural assessment and retrofit in regions where earthquakes are prevalent. Providing strength, stability and ductility are major purposes of seismic design.

The assessment of the seismic vulnerability of structures is very complex issue due to the non-deterministic characteristics of the seismic action and the need for an accurate prediction of the seismic responses for levels beyond conventional linear behaviour. Lateral stability has always been a major problem of structures especially in the areas with high earthquake hazard.

Steel is by far most useful material for building construction in the world. Steel is also used in conjunction frame and shear wall construction. Due to its large strength to weight ratio, steel structures tend to be more economical than concrete structures for tall buildings and large span buildings and bridges. Steel structures can be constructed very fast and this enables the structure to be used early thereby leading to overall economy steel offers much better compressive and tensile strength than concrete and enables lighter constructions.

II. RESPONSE REDUCTION FACTOR

Seismic codes consider a reduction in design loads, taking advantage of the fact that the structures possess significant reserve strength (over-strength) and capacity to dissipate energy (ductility). The overstrength and the ductility are incorporated in structural design through a force reduction or a response modification factor (R).

R factor represents ratio of maximum seismic force on a structure during specified ground motion if it was to remain elastic to the design seismic force. Thus, actual seismic forces are reduced by the factor "R" to obtain design forces. The basic flaw in code procedures is that they use linear methods but rely on nonlinear behavior. R factor reflects the capacity of structure to dissipate energy through inelastic behavior. It is a combined effect of over strength, ductility and redundancy. Thus, the factor R is such a factor with which the MCE level .Response Spectrum has to be scaled- it will come in the denominator.

Generally the Response reduction factor (R) is expressed as a function of various parameters of the structural system, such as strength, ductility, damping and redundancy:

$$R = R_s \cdot R_\mu \cdot R_\xi$$

Where
R_S is the strength factor,
R_μ is the ductility factor,
R_ξ is the damping factor.

The strength factor (R_s) consider that the real lateral strength is greater than the design lateral strength because components are designed with capacities greater than the design actions, material strength exceed nominal strength, and because drift limitation and detailing requirements generally determinate an overstrength of structural members.

This factor is generally expressed as follows:

$$R_s = R_\rho \cdot R_\Omega$$

Where
R_ρ is the redundancy factor,
R_Ω is the overstrength factor.

Redundancy factor (R_ρ) is the ratio between the seismic action intensity at the development of a plastic collapse mechanism and that one corresponding to first yielding in the structure.

Over strength factor (R_Ω) is the ratio between the seismic action intensity corresponding to the formation of the first plastic hinge to that corresponding to the allowable stress state for the frame as defined by conventional design.

The ductility factor (Rμ) is related to several parameters many of which are correlated to characteristics of the structural system and some of them are independent from the structure and are related to the other parameters such as respected loading (the time history of earthquake). The Rμ will be correlated to a set of factors, especially the ductility factor of structure and its performance characteristics in the nonlinear state, if we consider a specific earthquake for a particular place.

Multiple factors are known that affluence on the relation between Rμ and μ , such as materials, period of system, damping, P-Δ effects, the load-deformation model in the hysteresis loops and the type of soil that exists in the site. If we consider the assumption that the ductility in the structures with short period is the same as those that have longer periods, then the smaller Rμ is obtained.

Also, New Mark and Hall suggested the following equations for calculation of the force reduction factor of structures.

$R\mu = 1$ $\quad T < 0.125$ sec

$R\mu = (2\mu - 1)^{0.5}$ $\quad 0.125 < T < 0.5$

$R\mu = \mu$ $\quad 0.5 < T$

The damping factor R_ξ accounts for the effect of added viscous damping and is primarily applicable for structures provided with supplemental energy dissipating devices. Without such devices, the damping factor is usually assigned a value equal to 1.0.

$$C_d = \frac{\Delta_{\max}}{\Delta_S} = \frac{\Delta_{\max}}{\Delta_y} \times \frac{\Delta_y}{\Delta_s} = \mu \times R_s$$

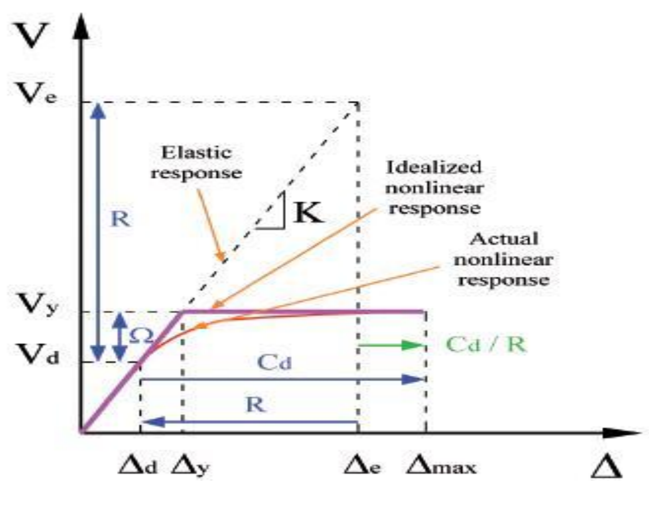

Fig 1: Typical Pushover response curve for evaluation of response reduction factor, R

Table 1: Values of Response Reduction Factor as per IS 1893(part 1):2002

Building frame systems

Steel frame with concentric braces - 4.0

Steel frame with eccentric braces - 5.0

Steel moment resisting frame designed as per SP 6 (6) - 5.0

Building with shear wall

Ordinary reinforced concrete shear wall - 3.0

Ductile shear wall - 4.0

Building with dual systems

Ordinary shear wall with OMRF - 3.0

Ordinary shear wall with SMRF - 4.0

Ductile shear wall with OMRF - 4.5

Ductile shear wall with SMRF - 5.0

Table 2: Values of the behaviour factor for RC framed structures, as per EC8.

Medium ductility class (DCM) - 4.0 α_u/α_l

High ductility class (DCH) - 5.0 αu/αl

III.PUSHOVER ANALYSIS

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 behaviour and load reversals being estimated by using a modified monotonic force- deformation criteria and with damping approximations. Pushover analysis may be classified as displacement controlled pushover analysis when lateral displacement is imposed on the structure and its equilibrium determines the forces. Similarly, when lateral forces are imposed, the analysis is termed as force-controlled pushover analysis. The target displacement or target force is intended to represent the maximum displacement or maximum force likely to be experienced by the structure during the design earthquake. Response of structure beyond maximum strength can be determined only by displacement controlled pushover analysis.

Response characteristics that can be obtained from the pushover analysis are

a) Estimates of force and displacement capacities of the structure and Sequence of the member yielding a
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 plan or in elevation) of the building.

IV. LITERATURE REVIEW

[1]. ***Bhagat et al (2015)*** performed the pushover analysis of steel frame. A typica1 2 storey regular steel frame having Zone V building is designed for various types of concentric bracings like Diagonal, V, Inverted V ,K, X, and Exterior X are made to know the realistic behavior of building during earthquake. Using different types of material sections i.e. ISMB and ISA or any tubular or hollow sections are used to compare for same patterns of bracing. The length of the building is 21m and width is 16m with each 3.65m floor height. The columns are assumed to be fixed at the ground level. Non linear static push over analysis is done and the capacity curves are obtained. Performance of each frame is studied through nonlinear static analysis. Out of this bracing “X” bracing gives maximum base shear. The result of “X” bracing increases more than 30% than of diagonal or K bracing. Also using ISMB section the capacity of base shear increases very well.

[2]. ***Gholamreza Soltanzadeh et al (2015)*** studied the seismic response of steel frame designed for wind load. An Ordinary 7 storey steel moment resisting frame model resting on Soil type II and located in a seismic zone V is created. Based on the average values of the FEMA-356 for the steel members, the several integrated defaults hinge properties are included in this program. By maintaining a PUSHOVER strength up to a particular level, a load case can be controlled or it can also be controlled by pushing a movement to a specified displacement. A behavior bending strength of a hinge in each member showing the hinges in the beams is defined by life safety, prevention of collapse, immediate occupancy, and some limited hinges are listed in a column. Through this process, an estimate of the maximum base shear that the structure is able to resist during earthquake can be evaluated. It also helps to create an estimate about the global stiffness in the case of the regular buildings. Investigation of the seismic performance of a 7 story, 3bays steel moment resistance frame designed only for wind and gravity loads by pushover analysis shows that for PGAs below 0.221g, the performance of the frame is acceptable for life safety seismic level. However for PGAs more than this limit, it couldn’t satisfy life safety performance level.

[3]. ***Bhagat et al (2015)*** carried out nonlinear (Pushover) analysis of steel frame with external bracing. A typical 12 storey regular steel frame building having seismic zone V is designed for various types of concentric bracings such as Diagonal, V, X and Exterior X . The building dimensions are L= 21m, B=16m and height 3.65m on each story. Columns are assumed to be fixed at Ground level. STAAD PRO software is used for bracing different types of material sections i.e. ISMB, ISMC and ISA or any tubular or hollow sections are used to compare for same patterns of bracing. Displacement controlled pushover method is used for analysis of structural steel frames with and without bracings. The provision of only exterior bracing, shear capacity of frame increases by 30% to 40% by using different types of section with optimum dead load. Increasing size of section or bracing in the building, the base shear capacity will be increased by 70% to 80%. The Displacement can be neglected by using bracing with increasing small sectional dead load. X Bracing is more effective for increasing base shear capacity & decreasing displacement of structure.

[4]. ***Muhammed Tayyab Naqash et al (2014)*** conducted a study on the fundamental period of vibration of Steel moment resisting frames of 9, 7 and 5 storey with different spans (9.15m, 7.63m, 6.54m and 5.08m) comprising the inter storey height of 4m. The frames are designed according to EC8 with the assumed design behaviour factor (q = 6.5, 4, 3 and 2) considering type C soil stratigraphic profile (dense sand or gravel or stiff soil) and 0.25g peak ground acceleration. Numerical studies are carried out with the help of SAP 2000 using modal dynamic analysis for low and medium-rise buildings. The result shows that the fundamental period is directly related to the use of behaviour factor and obviously to the drift limit. The obtained fundamental period from the code are in the same range to the one obtained from the modal analysis when the strict drift limit (0.005h) is employed in the design. Whereas it is higher in the case of drift limit (0.0075h) and (0.01h).

[5]. ***Mohammed Idrees Khan et al (2014)*** performed seismic analysis of steel frames with bracings. Thirteen models of high rise steel frame building (G+15) floors are made to know the realistic behavior of building during earthquake. Models include one bare frame model, four models of ISMB Sections, Four models of ISA Sections, and Four models of ISMC Sections. Same pattern of bracings i.e.(Diagonal, V, X, and Exterior X) are used for all types of sections and steel sections are selected by considering same cross sectional area. The length of the building is 24m and width is 12m. The zone considered is zone v with medium soil. The columns are assumed to be fixed at the ground level. Non Linear static push over analysis is carried out using ETABS. Push over curves is plotted ie Base shear vs Roof displacement. It reveals that the provision of bracing enhances the base shear carrying capacity of frames. Base shear capacity for V-Brace, Diagonal Brace, X-Brace, increases up to 40-50 % and the roof displacement reduces to 70 to 80% as compared with bare frame model. Exterior X-Brace gives maximum base shear, increases up to 70 % and displacement reduces to 90% as compared with bare frame. ISMB sections gives

more base shear whereas ISMC sections reduces more displacements when compared to angle and channel sections.

[6]. ***Vaseem Inamdar et al (2014)*** conducted pushover analysis of complex steel frame with bracing using Etabs. Seven models of steel frame building of 15 floors include bare frame along with alternate X, alternate Y and exterior bracings of ISMB and ISNB (hollow pipes). The length of the building is 84m and varying width from 12 to 36m. Height of typical story is 3.5m. Building is symmetrical about X and Y-axis. Beams and columns are modeled as frame element and joined node to nodes. The columns are assumed to be fixed at the ground level. Non linear static push over analysis is done. Capacity and demand spectra curves are constructed by converting the pushover curve (base shear vs displacement) to an equivalent capacity curve (spectral acceleration vs spectral displacement). The lateral displacement of complex steel frame studied is reduced to greater extent by the provision of exterior steel bracing. Stiffness of models increased by an amount of 71.5% using ISMB bracing and 68% using hollow pipes sections. Column beam hinge mechanism obtained is 3.5 times more for bare frame with exterior bracing. Spectral displacement of exterior ISMB bracing at performance point is greatly (62%) increased.

[7]. ***Elavenil (2014)*** performed the pushover analysis of steel frames. The buildings are modelled as a series of stories from 5 to 40 with same bay width and storey height. Steel frames of two different sections ie solid and hollow sections are modelled using STAAD Pro V8i software. The frames are assumed to be firmly fixed at the bottom and the soil–structure interaction is neglected. The zone is considered as zone V with medium soil. Pushover analysis is done and the results are compared. When the number of storey decreases corresponding base shear increases and also number of storey increases corresponding displacement increases. Formation of plastic hinges was maximum, when the storey levels are minimum. Base shear vs. displacement curve indicates that the hollow section is far better than solid sections. The analytical procedure developed to estimate the inelastic deformations of beams, columns and connections are validated by incorporating the same in pushover analysis. Based on the analysis results it is observed that inelastic displacement of the structure is within the collapse prevention level.

[8]. ***Massimiliano Ferraioli et al (2014)*** investigated the accuracy of advanced methods for nonlinear static analysis of six steel moment-resisting frames (three regular and three irregular in elevation), that according to the Italian Code have been considered in the numerical analyses. 1) 5-storey, 3-bay (5S3B); 2) 7-storey, 3-bay (7S3B); 3) 9-storey, 3-bay (9S3B). The design seismic action has been defined assuming soil class A, damping ratio=5%, peak ground acceleration PGA=0.25g, behaviour factor q=6.5 for regular frames and q=5.2 for irregular frames. The Nonlinear static pushover analysis is carried out. The effectiveness and accuracy of the approximated analysis is verified through four advanced nonlinear static procedures. a) N2-EXT: Extended N2 method considering higher mode effects both in plan and in elevation; b) MMPA: Modified Modal Pushover Analysis procedure assuming higher modes as elastic; c) ACSM1: Adaptive Capacity Spectrum Method based on Inelastic Demand Response Spectrum; d) ACSM2: Adaptive Capacity Spectrum Method based on high damping modified acceleration-displacement response spectrum (MADRS). In order to evaluate the accuracy of the mentioned approaches in predicting seismic demands, the results of considered pushover procedures have been compared with nonlinear dynamic analysis assumed as a reference solution. Pushover methods accounting for higher mode effects along the elevation provide more accurate estimation of seismic demands when compared with traditional pushover methods based on load pattern using first mode. The accuracy of nonlinear static procedure based on invariant load patterns at the lower storey levels is worse, especially for higher or irregular frames. Adaptive nonlinear static procedures tend to have a less sensitive response to the input ground motion when compared to response history analysis and other pushover procedures based on invariant load patterns. The modified modal pushover analysis may give much sensitive response to the input ground motion, especially for irregular frames.

[9]. ***Vijay et al (2013)*** studied the performance of steel frames by Pushover analysis for solid and hollow sections. 2D models of 5, 10, 15, 20, 25, 30, 35 and 40 storey steel frames with same bay width and storey height are created for both solid and hollow section using STAAD Pro V8i software. The zone considered is zone V with medium soil. Non linear static pushover analysis is done. The roof displacement is plotted with base shear to get the global capacity curve. It is concluded that the number of storey increases corresponding displacement increases. The drift to height ratio is limited to 35 stories despite of increased base width. The performances of all the solid and hollow section 2-D models are lies in between life safety and collapse prevention. Formations of plastic hinges were maximum, when the storey levels are minimum. Base shear vs. displacement curve indicates that the hollow section is far better than solid sections Effect of lateral displacement for 5-storey 2-D frame with hollow section provides 16.73% reduction when compared with the solid sections. Base shear values for 5-storey 2-D frame with hollow section when compared with solid section which is increased up to 54 %. When storey level get increased pushover load steps get decreased, so the capacity curve become linear for some models corresponding to its storey level. The hollow section is having maximum dead weight than solid sections. Comparatively 60% of self weight values get increased in hollow section than the solid section.

[10]. ***Padmakar Maddala (2013)*** performed push over analysis of a 6-story steel frame building designed for various types of eccentric bracings such as D, K and V type as per IS 800:2007. The building frame considered is assumed to be located in Indian seismic zone V with medium soil conditions. The design peak ground acceleration (PGA) of this zone is specified as 0.36g. Seismic loads are estimated as per IS 1893 (2002) and the design of the steel elements are carried out as per IS 800 (2007) standards. Push over Analysis is performed to estimate ductility and other properties for each eccentric bracing. Push Over curves and behavior factors for the different eccentric steel frames are compared to find the relative performance of various frames considered. Modal analysis of a 2D steel frame models

reveals that, there is huge difference between Computational Time periods and IS code Time period. Steel-braced dual systems exhibit higher ductility and therefore higher R factors. Considering the range of ductility capacities shown by different systems discussed, it is found that the bracing arrangement in D and K family, D1 & K4 respectively are found to be performing better compared to that of others.

[11]. ***Madhusudan G. Kalibhat et al (2013)*** analyzed the seismic performance of concentric braced steel frames from pushover analysis. 1- Bay 2D steel structural frame with different concentric bracings (viz. X and inverted-V type bracing) and structures without bracing has been modelled and analyzed using ETABS. Nonlinear static pushover analysis is used to determine parameters such as initial stiffness, yield load, yield displacement, maximum base shear and maximum displacement. A typical pushover curve ie. Base shear versus roof displacement is plotted for gradually increasing lateral loads till failure. Beyond elastic limit, different states such as Immediate Occupancy, Life Safety Collapse prevention and collapse are defined as per ATC 40 and FEMA 356.

[12]. ***Esmaeili et al (2013)*** studied the seismic behavior of steel moment resisting frames associated with RC shear walls. A 10-storey and 20 storeys building in the form of steel moment resisting frame accompanied with reinforced concrete shear wall is analyzed. The height of all the stories is 3.5 m. The frame members are designed to tolerate 25 percent of earthquake forces in addition to bearing gravity load. Box-shaped and I- shaped sections are used for the section area of columns and beams, respectively. The thickness of the shear wall adopted is 20, 30, 35, 40, 45 and 50mm. In this study the chord rotation model (consider the member as a whole and essentially require one to specify only the relationship between end moment and end rotation) for beams and columns has been selected. The basic model used is a symmetrical beam with equal and opposite end moments and no loads along the beam length. The F-D relationship developed is utilized for all beams and columns components. For beam components, F is end moment and D is end rotation. For column elements, F is force and D is axial displacement and end rotation. Three nonlinear static analysis approaches are used for each model are 1.Uniform nonlinear static procedure (UNSP); 2.Triangular nonlinear static procedure (TNSP); 3.Modal pushover analysis (MPA).The center of mass at the roof level is selected as a control point of the displacement of structure in all analysis. Since the relative lateral displacement (drift) of roof is used as a reference relative lateral displacement, for plotting the capacity curves of the structures and for interpretation of the results obtained from these analyses. The mean value of ductility factor (μ), force reduction factor ($R\mu$) for 10-story structure is 2.84, whereas 3.96 for 20-story structure and over-strength factor (Rs) are 2.35 and 1.62. It shows that the ductility factor and the response modification factor increased as the structure height increased. However, the over-strength factors increased as the structure height decrease. The conversion coefficient of linear to nonlinear displacement (Cd) factor obtained is 6.67 and 6.42 which is more than 0.7R specified in Standard No.2800.

[13]. ***Onur Merter et al (2013)*** performed a comparative study on nonlinear static and dynamic analysis of six and ten-story RC frame structures, which are primarily designed according to Turkish Seismic Design Code, are performed by using seven ground motions recorded at different soil sites of Turkey. Nonlinear static pushover analyses of frames are also carried out using SAP 2000. Base shear forces and interstorey drift ratios obtained from the above said analysis were compared. Interstorey drift ratios obtained from nonlinear static analysis are larger than those obtained from other four earthquakes. Interstorey drift ratios obtained from linear dynamic analysis are generally smaller. The base shear forces obtained from nonlinear time history analyses are smaller than those obtained from pushover analysis. In case nonlinear time history analyses are not performed. Pushover analysis methods give valuable information about nonlinear behaviour of structures and they are more practical.

[14]. ***Sejal P Dalal et al (2012)*** did the comparison of a 20 storey steel moment resisting frame designed by elastic design and performance based plastic design method by both nonlinear static (Push over Analysis) and nonlinear dynamic analysis (Time history analysis) under different ground motions. Performance based Plastic design method is a rapidly growing design methodology based on the probable performance of the building under different ground motions. The design base shear for a selected hazard level is calculated by equating the work needed to push the structure monotonically up to the target drift to that required by an equivalent single degree of freedom to achieve the same state. In this design approach, the designer selects the target drifts consistent with acceptable ductility and damage, and a yield mechanism for desirable response and ease of post earthquake damage inspection and reparability. SAP2000 is one of the most sophisticated and user friendly software which is used to perform the non-linear static (Push Over) and non- linear Time history analysis in a very simple way. Nonlinear static push over analysis was performed by assigning the hinges at 6 inches from the column face. The Nonlinear Time history analysis is performed when the frame is subjected to six different ground motions (Santa Monica, Petrolia, Lacco North 90 degrees, Lacco North 0 degrees, Corralotos, and Altedena Earthquake ground motions) was also carried out . Inelastic static and dynamic analyses of the steel frame when designed using elastic design and PBPD showed very good behavior of the PBPD frame under static pushover loads. No unexpected plastic hinging was observed in the columns of the PBPD frame. The hinges are formed in beams only and the bottom of base columns which converts the whole structure into a mechanism and avoids the total collapse. The increased hysteretic energy dissipation of the frame indicates that the structure utilizes its capacity lying in the inelastic zone. The PBPD method is superior to the elastic design method in terms of the optimum capacity utilization.

[15]. ***Mohssen Izadinia et al (2012)*** investigated the response modification factor for steel moment-resisting frames by different pushover analysis methods. Three steel moment-resisting frames of 3, 9 and 20 stories adopted from SAC steel project are analyzed. The Seismostruct software is used to perform all pushover analyses. This software takes advantage of fiber elements that are capable of accounting for material nonlinearity. The PΔ effect is considered in the

analyses. Nonlinear behavior of steel is assumed to be bilinear with 3% strain hardening. Three main types of pushover analysis are performed in this study:
1) Conventional pushover analysis (CPA), 2) force based adaptive pushover analysis (FAPA), 3) displacement based adaptive pushover analysis (DAPA). In CPA the load pattern is kept constant throughout the analysis. Two constant load patterns considered are: 1) UNIFORM load pattern 2) MODAL load pattern. Response spectrum analysis of the structures was performed by the ETABS software. In all modal and adaptive pushover analyses the first 10 modes are used. For each building eight pushover analyses are performed: two CPA (with constant load patterns of Uniform and Modal), three FAPA (for three mentioned earthquakes), and three DAPA (for the three earthquakes). The bilinear idealization of the pushover curves was performed following the criteria set by ASCE 41-06 by the MATLAB software. R factors and ductility ratio (μ) obtained by the methods of conventional (CPA) and adaptive (FAPA or DAPA) pushover analyses tend to be different. The maximum relative difference for response modification factors was about 16% and ductility ratios was about 17% due to larger results in adaptive pushover analysis. DAPA yield higher inelastic lateral displacements. For high-rise and mid-rise buildings different shapes of constant load pattern in CPA result in close R factors. The use of different earthquake response spectra for high-rise and mid-rise buildings in FAPA method does not have considerable effect on the R factors.

[16]. ***Ferraioli et al (2012)*** has assessed the behaviour factor for regular and irregular in elevation steel moment resisting frames (3, 5,7,11 & 13 storey). Three different methods are used: 1) Static Approach; 2) Dynamic approach and 3) Mixed Approach. In the Static Approach the estimation is carried out from the force-displacement response curve obtained from pushover analysis. In the Dynamic Approach the behaviour factor is estimated from the Incremental Nonlinear Dynamic Analysis (IDA) of the moment resisting frame. In the Mixed Approach the behaviour factor is based on two components, the first one estimated with nonlinear dynamic analysis, the second one estimated with nonlinear pushover analysis. A plastic hinge model implemented in SAP2000 nonlinear computer program is considered in the analyses. The results obtained with Static Approach, Dynamic Approach and Mixed Approach is compared. The behaviour factor that relates the real nonlinear dynamic response to simplified linear design response of moment-resisting steel frames is investigated. The over strength reduction factor recommended by EC8 and Italian Code for multi-bay multi-story frames is conservative. The behaviour factor proposed by these codes may be not conservative. This result derives from the effect of axial force that reduces the plastic moment capacity of the first-story columns in more high-rise steel frames. A local ductility criterion based on a limit of the axial force ratio is proposed to control the ductility of columns and so ensure that the recommended behaviour factor is conservative.

[17]. ***Qian et al (2008)*** has investigated the application of pushover analysis on earthquake response predication of complex large-span steel structures. This paper introduces application of pushover analysis of two projects, namely, Beijing A380 hangar at Capital Airport and the National Stadium for 2008 Beijing Olympic Games. The seismic fortification intensity of both structures is 8, and the design basic acceleration of ground motion for both structures is 0.2g. The first mode lateral loading pattern for the hangar structure and twelve cases for the stadium steel structure are adopted to perform the pushover analysis respectively. A three-dimensional FE model of each structure is built respectively using SAP2000 software (CSI, 2002). By pushover analysis the capacity curves of two structures are obtained. Then the capacity curves are transformed to the capacity spectrum curves. Pushover analyses results indicate that plastic hinges appear at few members and the whole structure is within elastic under severe earthquakes. For certain types of complex large-span steel structure, when the total modal mass participation factor is larger than about 0.65, results of pushover analysis will be close to those of dynamic analysis. In this case, pushover analysis appears to be accurate for predicating responses of complex large-span steel structures under severe earthquakes. For complex larger-span steel structures with huge numbers of members, pushover analysis has high efficiency to find out the weak part of the structure, while non-linear time history analysis is time consuming.

[18]. ***Erol kalkan et al (2004)*** investigated the method of modal combinations for pushover analysis of buildings. Three special moment resisting steel frame buildings of 4, 6 and 13 storey were selected to evaluate the Method of modal combinations (MMC) procedure. The building was designed in according to 1988 UBC specifications. It is 16.15m in elevation and has a rectangular plan with plan dimensions of 33.27m x 19.2m. For four-story building, the MMC procedure was developed from lateral forces using a modal combination based on Mode 1 ± Mode 2. For the thirteen-story building, the MMC procedure was developed from lateral forces using a modal combination based on Mode 1 ± Mode 2 + Mode 3. Modal push over analysis and Time History analysis is done. Both the results were compared with MMC results. Pushover methods utilizing lateral force distributions based on a single mode are not capable of predicting the story level at which the critical demands occur. The results of modal combination procedure appears to be promising in terms of better estimating peak values of critical inelastic response quantities such as inter-story drifts and plastic hinge rotations. The influence of higher modes in the inelastic phase of the response can be incorporated by introducing modification factors that account for changes in spectral demands due to inelastic effects.

[19]. ***Hasan et al (2002)*** conducted the pushover analysis for performance-based seismic design. The three-story and nine-story steel moment-frames have rigid moment-connections and fixed supports, and are perimeter frames of buildings designed in accordance with the earthquake provisions of the Uniform Building Code. The fundamental period for the three-story frame is 1.01 s, while that for the nine-story frame is 2.34s. The analysis procedure is approximate in that it represents a MDOF building system by an equivalent SDOF system. Fundamental mode of vibration of the MDOF system is often selected as the response mode of the equivalent SDOF system. Push-over analysis provides valuable information for the performance-

based seismic rehabilitation of existing steel moment-frame buildings. The overall ductility demands provide a basis for checking compliance with global ductility limits. The inter story ductility demands serve to identify the existence of soft stories and provide a means to assess the adequacy of the earthquake-resistant capacity of a building for corresponding seismic events. The proposed push-over analysis procedure is also an effective tool for the performance-based seismic design of new steel moment-frame buildings.

[20]. ***Moghadam et al (2000)*** conducted the 3-D pushover analysis for damage assessment of two uniform seven-storey reinforced concrete buildings. Building S is symmetric and Building A is plan-eccentric ie mass eccentric, and has a constant floor eccentricity equal to 10% of plan dimension. Each building has a rectangular plan measuring 24m by 17m. The lateral load resisting elements in the y-direction consist of three identical ductile moment resisting frames. The strength of the buildings is designed based on a base shear value equal to 15% of the elastic base shear so that when exposed to ground motions of design intensity, the buildings will be excited well into the inelastic range. The fundamental periods of building S and building A are 1.35 second and 1.52 second respectively. The 3-D pushover analyses and inelastic dynamic analyses were carried out using the computer code CANNY. The accuracy of the 3-D push over analysis is similar to that of the currently used push over analysis method for planar structures. The seismic demands at or near the flexible edge of plan-eccentric buildings are higher due to the torsional effect. The pushover analysis procedure is more successful to predict global response parameters such as edge displacements, interstorey drift ratios, and fundamental period changes than local damage parameters such as member ductility demands.

V.CONCLUSIONS OF THE LITERATURE REVIEW

- Base shear vs. displacement curve indicates that the hollow section is far better than solid sections.
- When storey level get increased pushover load steps get decreased, so the capacity curve become linear for some models corresponding to its storey level.
- Fundamental period is directly related to the use of behaviour factor and obviously to the drift limit.
- The fundamental period given by the code could be obtained from the modal analysis of the frame when designed with strict drift limitation (0.005h).
- The provision of bracing enhances the base shear carrying capacity of frames.
- Bracing acts as an extra redundant in frames there by reducing inter storey drift.
- The steel frames with insufficient lateral stiffness can be retrofitted with braces. Braces are the viable solutions to provide both global lateral stiffness and strength of the frame.
- Stiffness of models increased by an amount of 71.5% using ISMB bracing and 68% using hollow pipes sections.
- Exterior X-Braced steel frame gives maximum base shear which increases up to 70 % and spectral displacement increased to 62% as compared with bare frame model and ISMB Sections gives more base shear compare to angle and channel section for similar type of brace.
- Steel-braced dual systems exhibit higher ductility and therefore higher R factors.
- Increasing size of section or Bracing in the Building, the base shear capacity will be increased by 70% to 80%.
- The displacement can be neglected by using bracing with increasing small sectional dead load.
- For high-rise and mid-rise buildings different shapes of constant load pattern in push over analysis results in close R factors.
- For complex large-span steel structure like Beijing A380 hangar, Beijing National Stadium, when the total modal mass participation factor is larger than about 0.65, results of pushover analysis will be close to those of dynamic analysis.
- For complex larger-span steel structures with huge numbers of members, pushover analysis has high efficiency to find out the weak part of the structure, while non-linear time history analysis is time consuming.
- The ductility factor and the response modification factor increased as the structure height increased. However, the over-strength factors increased as the structure height decreased.
- Pushover methods accounting for higher mode effects along the elevation provide more accurate estimation of seismic demands when compared with traditional pushover methods based on load pattern using first mode.
- R factors and ductility ratio (μ) obtained by the methods of conventional (CPA) and adaptive pushover analyses tend to be different.
- The maximum relative difference for response modification factors was about 16% and ductility ratios was about 17% due to larger results in adaptive pushover analysis.
- The accuracy of nonlinear static procedure based on invariant load patterns at the lower storey levels is worse, especially for higher or irregular frames.
- The inter story ductility demands serve to identify the existence of soft stories and provide a means to assess the adequacy of the earthquake-resistant capacity of a building for corresponding seismic events.
- A local ductility criterion based on a limit of the axial force ratio is proposed to control the ductility of columns and so ensure that the recommended behaviour factor is conservative.

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