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Study of Pushover Analysis of Steel Bracing System–An Overview

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Abstract—*The present study has been carried out to study the behaviour and effectiveness of different types of steel bracing system used in steel buildings. The study emphasize on seismic performance of steel framed building with or without bracing system. Various types of bracing systems used for study are V-braced frame, Chevron braced, Cross braced frame and quantity of steel used for bracing was kept constant for different types of bracing systems. The seismic performance of 2D frame steel structure depending upon parameters like height of the building, type of bracing, type of lateral load pattern have been studied. Non-linear static analysis (pushover analysis) carried out to compare sequential failure of members, roof displacement, base shear, inter-storey drift, performance point, seismic capacity etc. It has been studied that V-bracing and Chevron bracing is more useful in compared to other because these two bracings meeting the desirable displacement with sufficient base shear capacity.*

1. INTRODUCTION

Steel structures have a vital role in civil engineering construction, especially for industrial buildings and tall buildings. It is necessary to design the steel structure in a way that it has to perform well under seismic loading. It has been observed that steel frames without bracing performed poorly under past earthquakes. The seismic performance of steel structures with bracing could be increased by using different types of bracing systems. From the past experience engineers came to know that seismic performance of steel structures greatly depends on type of bracing, bracing configuration, height of building and type of lateral load pattern. Nowadays bracings have been used for retrofitting of buildings those are damaged during light and moderate earthquakes. There are different types of bracings are available such as X-bracing, V-bracing and Chevron bracing. It has been observed that ductility is main concern about seismic design of steel buildings. Ductility is the property of material by which it can undergo deformation without compromising strength or at constant stress. The seismic performance of steel frames with and without bracings can be evaluated by using a technique known as non-linear static analysis (pushover analysis).

Non-linear static analysis (pushover) is a very popular technique; it has been used for evaluating the seismic performance of upcoming structures or existing structures. Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behaviour until an ultimate condition is reached. The present study has been performed to evaluate seismic performance of steel braced frames those are designed according to IS-800 (2007).

2. OVERVIEW ON PAST STUDIES

Roeder CW And Propov ED (1978) proposed new bracing system, named as eccentric bracing. It has combined features of both moment resisting frame and concentric braced frame. In eccentric braced frame, energy dissipation capacity enhanced by providing shear link and it is an integral part of the beam. After a severe earthquake shear link get damaged, so that should be replaced with new one. But the replacement of shear link is very expensive and time consuming process. This is major drawback of eccentric bracing system.

Ashok K.Jain (1985) investigated that the effect of steel bracing in reinforced concrete frame when subjected to earthquake. Actually steel bracings members are widely used in steel building in order to reduce the lateral displacement in structure and also bracing could increase the stiffness of structure. Inelastic seismic behaviour of the RC frames with K and X bracing was investigated. For that he took a two bay six storied frame. It was designed by limit state method. Then that frame was subjected to 1.25 times of North-South component of the 1940 El-Centro earthquake and also subjected to artificially produced B1 earthquake. He observed that both K and X braced frame performed well under the El Centro earthquake. But only X-braced frame performed quite satisfactory when it subjected to modified B1 earthquake. There was a considerable increase in column axial force due to the presence of bracings members.

Ochao JD (1986) proposed an alternative system called knee braced frame (KBF). He introduced one fuse element that should prevent failure of KBF by energy dissipation through structural yielding process of knee elements.

T. Balendra (1991) investigated on an earthquake resistant structural system made up of steel called knee braced frame (KBF). Here the lateral stiffness provided by a diagonal brace with one end connected to knee element. Performance of this system mainly relies on ductile behaviour of knee element and this critical element was tested to notice its behaviour under cyclic loading. He introduced one analytical model which helps for investigating moment and rotational relationship of knee element. Energy dissipation characteristics of KBF clearly observed by the help of that analytical model.

A.K Chopra, R.K Goel (2001) developed an improved pushover analysis procedure named as Modal Pushover Analysis (MPA) which is based on structural dynamics theory. Initially the procedure was applied to linearly elastic buildings and it was shown that the procedure is equivalent to the well-known response spectrum analysis. Then, the procedure was extended to estimate the seismic demands of inelastic systems by describing the assumptions and approximations involved. Earthquake induced demands for a 9-story SAC building were determined by MPA, nonlinear dynamic analysis and pushover analysis using uniform, "code" and multi-modal load patterns. The comparison of results indicated that pushover analysis for all load patterns greatly underestimates the story drift demands and lead to large errors in plastic hinge rotations. The MPA was more accurate than all pushover analyses in estimating floor displacements, story drifts, plastic hinge rotations and plastic hinge locations. MPA results were also shown to be weakly dependent on ground motion intensity based on the results obtained from El Centro ground motion scaled by factors varying from 0.25 to 3.0. It was concluded that by including the contributions of a sufficient number of modes (two or three), the height-wise distribution of responses estimated by MPA is generally similar to the exact results from nonlinear dynamic analysis.

D.C Rai, S.C Goel (2003) Their investigation was mainly emphasized to determine drawbacks of existing CBFs and they suggested some remedies for the current system. For this study they selected a building in north Hollywood area which was damaged during 1994 Northbridge earthquake. They suggested that seismic performance of CBFS can be improved by delaying the fracture of the braces, for this plain concrete filled hollow braces used here. And also further improvement achieved by redesign the brace and floor beam to weak brace and strong beam.

Mahmoud R.Maheri, R.Akbari (2003) studied related to seismic behaviour factor R for steel X-braced and Knee braced reinforced concrete buildings. They investigated about some parameters which are really influenced value of R. Those parameters were height of building, type of bracing system. Finally they proposed tentative value for R steel braced moment resisting RC frame dual systems for different ductility demand.

M.R.Maheri, R.Kousari (2003 investigated the seismic behaviour of scaled models of RC frames, X-braced and knee braced frame and pushover analysis technique was adopted for the investigation. They observed that the yield capacity and the strength capacity of ductile RC frame increased by large margin and its global displacement reduced into large extent by the addition of X and Knee bracing. They noticed that X-bracing can provide better stiffness to the system but decreased the ductility of frame up to some extent but Knee bracing provided adequate ductility for ductile design. Anyway they concluded that both X-bracing and Knee bracing system can be used for design or retrofit for a damage level of earthquake but Knee bracing system is very suitable for collapse level earthquake.

Himoghaddam and I,Hajrasouliha(2006) investigated the potentialities of the pushover analysis to estimates the seismic deformation demands of concentrically braced frames. Relevance of the pushover analysis evaluated and verified by conducting non-linear dynamic analysis of 5, 10 and 15 storey frames subjected to 15 synthetic earthquake records representing a design spectrum. From the results it was observed that pushover analysis with predetermined lateral load pattern gives questionable estimates of inter storey drift. In this study, a multi-storey frame reduced to an equivalent shear building model by performing pushover analysis and also a conventional shear building model has been modified by the addition of spring. It was observed that modified shear building models have a better estimation of non-linear dynamic response of real framed structures compared to non-linear static structures.

C.S.Yang, Roberto T.Leon(2008) proposed a design methodology for a zipper braced system to achieve a desirable ductility for that three models was designed and those three models has to carry same masses as the three, nine and twenty storey SAC model building with moment resisting frame. Pushover analysis was performed to evaluate the over strength factor, inelastic strength and deformation capacities of the entire structures and for observing the sequential yielding and buckling of members in the structure. They concluded that zipper strut can distribute damage uniformly over the height of building. So that it can help to minimise the strength losses all over structure.

R.Tremblay, M.Lacerte(2008) examined on seismic response of 2,4,6,8,12,16-storied steel frame with self-centring energy dissipative (SCED) bracings and compared with the seismic response of identical building with buckling restrained bracings. Push over analysis and nonlinear dynamic analysis was performed for the above buildings those assumed to be located at California. They observed that SCED frames experienced smaller peak drift, lesser damage concentration on entire height of the building and lateral deformation smaller in case of SCED braces as compared with BRB braces. They also conclude that higher design loads is required for low rise SCED and BRB system in order to enhance collapse prevention performance.

M.Razavi, M.R Sheidaii(2012) investigated the seismic performance of suspended cable zipper braced frame; zipper elements of stories are help to transfer unbalanced force from lower floor to upper floors. So that more force was concentrated especially in upper floors, for transferring this force large cross section is required, this is very expensive especially in high rise building. They proposed new solution to this problem i.e. Use the steel cables instead of zipper elements with different pre-stressing ratios. Pushover analysis was carried out; results obtained from analysis shown that significant improvement of seismic performance in medium to high rise structures with smaller pre-stress ratios.

Hendramawat, A.Basuki (2013) investigated the possible improvement in existing structure with bracing. For evaluating seismic behaviour of structure they used three methods like nonlinear static pushover coefficient method as per FEMA 356, improved pushover analysis as per FEMA 440 and dynamic time history analysis as per Indonesian code of seismic resistant building criteria. The performance of existing building gets improved due steel bracing. Non-linear static analysis shown that target displacement get reduced due to addition of bracing, dynamic analysis indicated that storey drifts of the retrofitted building within the limit criteria. But this study didn’t give size of bracing it can improve the seismic performance of the building.

Esra Mete Güneyisi, Guler Fakhraddin Muhyaddin (2014) performed non-linear static and dynamic analysis to compare structural types of moment resisting frame (MRF) building consists with concentric diagonal braces under seismic loading. For these study two different types of MRFs was used such as flexible MRFs and rigid MRFs. 4,8,12 and 16 storied building with same plan and three bays on both direction were studied. Diagonal braces in the middle of each frame. The results obtained as there was a substantial improvement in the earthquake performance of the frames with the incorporation of concentric diagonal braces, depending on the storey height and especially stiffness level of the frame. The results obtained that the CBFs were very effective in diminishing drifts since the reduction of inter-storey drifts with respect to the original frames were on the average 55%.

Zhe Qu, Shoichi Kishiki (2015) studied about previous bracing system and its configuration, then proposes a new buckling restrained brace frame system in RC frame and that was arranged in zigzag configuration. They conducted experiments on a realistic model of brace connection in proposed system and observed that buckling restrained braces are well efficient to reduce the seismic response in the building. Anyway, the strength demands of brace connection significantly influenced by higher modes in consideration.

Dhanaraj M.Patil, Kesav K.Sangle (2015) investigated on seismic behaviour of steel moment resisting frame with or without bracing. They analysed the building with varying height and load pattern and observed that seismic performance of really influenced by type of bracing, loading pattern and the height of building. They analysed the building with use of SAP 2000 and noticed that chevron braced frame and V-braced frame responded well under pushover analysis as per FEMA- 356 and ATC-40.

3. CONCLUSION

From this literature survey it was found that that seismic performance of steel frames mainly depends upon the parameters like type of bracing, type of load pattern applied and height of building. Nonlinear static (pushover) analysis is the generally accepted and time saving technique and also Pushover Analysis in the recent years is becoming a popular method of predicting seismic forces and deformation demands for the purpose of seismic performance evaluation of existing and new structures

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