Study Non Linear Analysis of Steel Moment Resisting Frame For Ductility Ratio: A Review

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Abstract- *In India the enormous loss of life and property perceived in the last couple of decades, attributable to failure of structures instigated by earthquakes. Responsiveness is now being given to the assessment of the sufficiency of strength in framed RCC structures to resist solid ground motions. The seismic reaction of RCC building frame in terms of performance point and the earthquake forces on Reinforced building frame with the help of pushover analysis is carried out in this project. In this method of analysis a model of the building is exposed to a lateral load. Pushover analysis can afford a substantial insight into the weak links in seismic concert of a structure and we can know the weak zones in the structure. In this project effort has been made to investigate the effect of Shear Wall and Structural Wall on lateral displacement and Base Shear in RCC Frames. RCC Frames with G+13 are considered, one with soft storey and other with normal building in L-shape. The pushover analysis of the RCC building frame is carried out by structural analysis and design software ETABS.*

Keywords- Pushover, ETABS, Soft Storey, Steel moment resisting frame, Non-linear analysis

I. INTRODUCTION

The word "earthquake" refers to any kind of seismic event, natural or induced by people, that creates seismic waves. Earthquakes are often generated by the rupture of geological faults; however, they may also be induced by other events such as volcanic activity, mine explosions, landslides, and nuclear testing. Numerous buildings have a main structural system that does not fulfil contemporary seismic regulations and hence sustains significant damage during an earthquake. India is classified into four seismic zones according to the Seismic Zoning Map of IS: 1893-2002. They are zones II, III, IV, and V. Generally, these structures are loaded only by gravity, which results in elastic structural behaviour. However, in the case of a strong earthquake, a structure may be exposed to forces greater than its elastic limit. Since. Simplified linear elastic techniques are insufficient to accomplish or achieve this goal. Thus, the structural designer has devised a novel design process and earthquake procedure that incorporates performance-based structures and nonlinear techniques.

There are four types of analysis methods: linear static, linear dynamic, nonlinear static, and nonlinear dynamic. The first two are only acceptable when structural loads are minimal and stress strains are within the elastic limit. During an earthquake, structural loading may exceed collapse load, putting materialstresses above yield stresses. As a consequence, material nonlinearity and geometrical nonlinearity must be considered into the study in order to get satisfactory findings. Pushover analysis is a straightforward technique for analysing the nonlinear static behaviour of a structure. Thus, this study will discuss pushover analysis using performance levels, the pushover curve, and the pushover analysis process.

1.1 Ductility

Ductility is a term that relates to a material's ability to be drawn or twisted without breaking. As such, it represents the material's malleability or softness. Steels vary in their ductility depending on the kind and concentration of alloying elements used. Ductility is a term that refers to a material's ability to endure significant permanent deformation under tensile stress to the point of fracture, or to the material's relative ability to be stretched plastically at room temperature without breaking.

The ratio of total deflection to deflection at the elastic limit. The deflection at the elastic limit is the deflection at which the strength behaviour is reasonably assumed to transition from elastic to plastic.

$$= m / y$$

Where m is the TH displacement as determined by the NLTH study.

y is the yield displacement as determined by the PO curve.

1.2 Nonlinear Static Pushover Analysis(NSPA)

Pushover is a nonlinear static analysis approach in which a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern that continuously increases via elastic and inelastic behaviour until an ultimate state is reached.

Inelastic static (pushover) analysis was done by applying increasing monotonic lateral forces with an appropriate distribution and pushing the models to large displacements. This research may be used to determine the structure's lateral strength and force displacement relationship, which indicate the structure's capacity to endure significant lateral deformations. Displacement control, rather than force control, was used to investigate the mechanisms' creation and the structural behaviour aspects that result from mechanism formation.

1.3 Nonlinear Time History Analysis (NTHA)

Nonlinear time history analysis is well-known for precisely simulating the behaviour of a structure after a large earthquake. It is a key method for structural seismic analysis, especially for assessing nonlinear structure responses. A representative earthquake time history for the structure under consideration is required to undertake this assessment. Time history analysis is a method for examining a structure's dynamic response to a changing load through time. The time history analysis technique is used to determine the seismic response of a structure to dynamic loads induced by a typical earthquake.

1.4 Application to Special Steel Moment Resisting Frames

1.4.1 Model frames

The suggested expression for determining the response modification factor (R) was applied to the already available special steel moment resisting frames. Kang's report has an exhaustive list of member identity and size (Kang, 2003). Each frame was designed and specified in line with UBC-1997 (ICBO, 1997) standards and AISC seismic requirements (AISC, 2002). The frames were 4, 8, and 16 stories tall, with a typical story height of 3, 658 mm and a bottom story height of 5,486 mm.

The frames were consistent with the floor plan and geometry, with a four-bay three-bay configuration with bay size of 7,315 mm7,315 mm. All floors have a dead load of 4.8 kN/m2. The floor and roof had live loads of 2.4 kN/m2 and 1.2 kN/m2, respectively. As seen in Fig. 2, models were created for two structural framing systems: the perimeter frame (PF) and the distributed frame (DF).

The perimeter frames entirely withstood lateral stresses in the PF model, whilst the inner frames resisted gravity loads. All frames withstood lateral loads and gravity loads in the DF model.

1.4.2 Nonlinear static analysis

The frames were subjected to a non-linear static analysis by submitting them to a monotonically increasing load. increasing lateral forces. increase lateral forces. The DRAIN-2D+ computer application was utilised for that purpose (Tsai and Li, 1994). Selecting an acceptable lateral load distribution is a critical step in non-linear static analysis. Prior to doing the pushover study, eigenvalue evaluations were performed to identify the elastic natural periods and mode forms of the model frames. Then, by gradually increasing the lateral narrative forces corresponding to the basic mode form, pushover studies were used to determine the global yield limit state and frame capacity. The DRAIN-2D+ beam-column element (element 2) with 1% strain hardening is the major element employed in these investigations for frame modelling. The panel zones' strength, stiffness, and shear distortions were not addressed. The floor slab's contribution was omitted. To determine the displacement ductility ratio, a drift limit of 0.04 inter-story drift at every story is assumed.

The ductility ratio () may be calculated at the element, narrative, and system levels. The ductility ratio may be stated at the element level in terms of strain ductility, curvature ductility, and rotation ductility. Normally, the ductility ratio () is represented in terms of the displacement ductility ratio at the story and system levels. The displacement ductility ratio at the system level is employed to calculate the ductility factor (R) in this research. It must be remembered that, regardless of the ductility parameter chosen, the ductility factor is a measure of the nonlinear response of the whole framing system, not a component of the framing system. Several displacement ductility ratio computations for prototype constructions are presented.

1.4.3 Evaluation of prototype frame R factors

For a 16-story SCWB perimeter frame, for example, the response modification factor (R) is computed as follows, where the soil profile is SC and the seismic zone factor is 0.4. The displacement ductility ratio () is 3.23 and the period (T) is 1.847 sec, as determined using nonlinear static analysis. Eq. calculates the ductility factor (R) for the SDOF system.

1.5 OBJECTIVES

The main objective of this study was to develop a new design procedure based on steel moment resistant frame (MRF) using constant ductility ratio.

To find the ductility ratio of Special moment resting frame from nonlinear static pushover analysis (NSPA) and nonlinear time history analysis (NTHA).

- To study the performance of steel moment resistant frame (MRF) structure under lateral loads .
- To study the performance of steel moment resistant frame (MRF) structure with or without soft storey with respect to Different parameters such as story drift, story displacement, base shear, etc.
- To study the variation of pushover curve for a framed structure with shear wall and for a framed structure with soft storey

II. LITERATURE REVIEW

2.1 Prishati Raychowdhury (2011) Seismic response of low-rise steel moment-resisting frame (SMRF) buildings incorporating nonlinear soil–structure interaction (SSI)

Nonlinear behavior at the soil–foundation interface due to mobilization of the ultimate capacity and the associated energy dissipation, particularly in an intense earthquake event, may be utilized to reduce the force and ductility demands of a structure, provided that the potential consequences such as excessive settlement are tackled carefully. This study focuses on modeling this nonlinear soil–structure interaction behavior through a beam-on-nonlinear-Winkler-foundation (BNWF) approach. The results are compared with those from fixed-base and elastic-base models. It is observed that the force and displacement demands are reduced significantly when the foundation nonlinearity is accounted for. Moreover, the foundation compliance is also found to have a significant effect on the structural response.

2.2 MALEKPOUR, H. GHAFFARZADEH (2011) Direct Displacement Based Design of Regular Steel Moment Resisting Frames

Displacement Based Design method represents a new approach to performance-based design. This research tries to assess the Direct Displacement Based Design (DDBD) method for regular steel moment resisting frames and develop a reliable design method for them so that they withstand various seismic levels within certain performance levels. For this purpose, regular steel frames with 4, 8, 12, 16 stories are designed based on DDBD approach utilizing displacement spectrum of the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard No. 2800). In order to evaluate seismic response of the designed structures, a series of non-linear time-history analyses have been performed under different records compatible with Standard No. 2800. All the non-linear analyses were carried out using the fiber-element models developed in Seismostruct computer program. According to the results, inter-story drift profile of the structure which is corresponding to its damage was less than the allowable value in most cases. Also, Maximum displacement profile of the structure along its height is completely matched with the primary assumed design profile. The structures have mostly experienced similar residual drift values under different records. In summary, the method performed quite satisfactorily in terms of story maximum displacements, maximum inter story drifts and story ductility demands, even for tall models.

2.3 Massimiliano Ferraioli (2009) Behaviour factor of code-designed steel moment-resisting frames

Current seismic codes are based on force-controlled design or capacity design, using the base shear concept. The most important parameter in this approach is the response modification factor, also called behaviour factor, which is used to design the structure at the ultimate limit state by taking into account its capacity to dissipate energy by means of plastic deformations. In this paper overstrength, redundancy and ductility response modification factors of steel moment resisting frames are evaluated. In order to cover a wide range of structural characteristics, 12 steel moment resisting frames (6 regular and 6 irregular in elevation) have been designed and analysed. Both static pushover analyses and nonlinear incremental dynamic analyses have been performed. The investigation focuses on the effects of some parameters influencing the response modification factor, including the regularity, the number of spans and the number of storeys. As a conclusion, a local ductility criterion has been proposed to improve the provisions given in the Italian seismic code.

2.4 Moghaddam & S.M. Hosseini Gelekolai (2012) Evaluation of Various Proposed Lateral Load Patterns for Seismic Design of Steel Moment Resisting Frames

The seismic design of buildings is normally based on the equivalent lateral forces provided in seismic design guidelines. The height-wise distribution of these lateral design loads predominantly correspond to the first vibration mode. However, as structures exceed their elastic limits in severe earthquakes, these load patterns may not represent the nonlinear response, and therefore they would not necessarily lead to efficient distribution of strength within the structure. A brief review of alternative lateral load patterns resulting from investigations on nonlinear seismic response of structures is presented. Due to the limits caused by idealizations and simplifications inherent in such investigations, the practicality and accuracy of the proposed load patterns should be evaluated and verified before proceeding into the practice. This paper examines the efficiency of various patterns for seismic design of 5 and 10-storey SMRFs. The nonlinear response and seismic performance of these models are studied under five different seismic records.

2.5 Farshad Hashemi Rezvani (2015) Effect of span length on progressive collapse behaviour of steel moment resisting frames

This paper presents results of an investigation into the effect of span length on progressive collapse behaviour of seismically designed steel moment resisting frames which face losing one of their columns in the first story. Towards this aim, several nonlinear static and dynamic analyses were performed for three frames designed for a high seismic zone considering various span lengths. The analysis results revealed that beams and columns of the studied frames had adequate strength to survive one column loss in the first story. However, in order to determine the residual strength of the frame, a series of nonlinear static analyses called pushdown analyses were performed. It was shown that by decreasing the span length to half, the strength of the studied frames increases 1.91 times based on the performance-based analysis perspective. Besides, results of nonlinear static analyses revealed that by increasing the applied loads, the investigated structures are more susceptible to progressive collapse when they lose an internal column.

2.6 Cheol-Kyu Kang and Byong-Jeong Choi (2011) New Approach to Evaluate the Response Modification Factors for Steel Moment Resisting Frames

The design force levels currently specified by most seismic codes are calculated by dividing the base shear for elastic response by the response modification factor (R). This is based on the fact that the structures possess significant reserve strength, redundancy, damping and capacity to dissipate energy. This paper proposed the evaluation methodology and procedure of the response modification factors for steel moment resisting frames. The response modification factors are evaluated by multiplying ductility factor (Rμ) for SDOF systems, MDOF modification factor (RM) and strength factor (RS) together. The proposed rules were applied to existing steel moment resisting frames. The nonlinear static pushover analysis was performed to estimate the ductility (Rμ), MDOF modification (RM) and strength factors (RS). The results showed that the response modification factors (R) have different values with various design parameters such as design base shear coefficient (V/W), failure mechanism, framing system and number of stories.

2.7 Martinez-Rodrigo (2003) An optimum retrofit strategy for moment resisting frames with nonlinear viscous dampers for seismic applications

The dynamic response of a multi-story steel moment resisting frame (MRF) equipped with fluid viscous (VS) dampers and subjected to seismic loads is investigated numerically. The structure is retrofitted with two fluid VS dampers per story in its middle bay. Its dynamic response is analyzed when retrofitted with linear and nonlinear VS dampers. Two performance indices are developed in order to evaluate by means of a simple procedure the adequacy of each retrofitting option. The different options are evaluated and an optimum design is selected. The main objective of this numerical research is to build a simple methodology leading to an optimum retrofitting option with nonlinear fluid VS dampers. A secondary objective of the study is to compare the structure response retrofitted with linear and nonlinear VS dampers and finding an optimum retrofit strategy attending to two performance indices that are developed. The seismic behavior of a six-story steel structure is analyzed and it is found that the maximum force experienced by the dampers in the nonlinear case may be reduced in more than a 35% in comparison with the linear retrofitting case with a similar structural seismic performance.

2.8 **Xingquan Guan (2020) Python-based computational platform to automate seismic design, nonlinear structural model construction and analysis of steel moment resisting frames**

We provide an end-to-end computational platform for seismic design, nonlinear structural model development, and static and dynamic response modelling of steel moment resistant frames. A modular structure is used in conjunction with the object-oriented programming paradigm to guarantee the platform's versatility. The seismic design module generates code-compliant section sizes and detailing for beams, columns, and beam-column connections iteratively based on relevant input design variables such as the building configuration (e.g., the number of stories, the number of lateral-force resisting systems, and the building dimensions), loads (e.g., dead and live loads on each floor), and site conditions (mapped spectral acceleration parameters). The nonlinear model creation and analysis module takes the design findings as input and generates structural models that accurately represent the degradation of flexural strength and stiffness in the frame beam-column parts, as well as pushover and response history studies. The platform's reliability, accuracy, and efficiency are demonstrated through illustrative examples. The platform significantly reduces the time and effort required to produce iterative structural designs and conduct nonlinear analyses, both of which are required for performance-based seismic design. Additionally, the platform may be used to compile a comprehensive database of archetypical steel moment frame structures in order to facilitate the development of analytics-driven design methodologies.

2.9 Ayoub Shakouri (2021) Effects of ductility and connection design on seismic responses of base-isolated steel moment-resisting frames

The research investigates the impacts of ductility level and connection type on the seismic responses of fixed-base and base-isolated structures with steel moment-resisting frames using nonlinear time history analysis. For the purpose of comparing reactions, a collection of twenty-four seismically built models is used, comprising three- and nine-story base-isolated and conventional structures with ordinary (OMF), intermediate (IMF), and special (SMF) ductility levels. Each model has two distinct sorts of connections: WUF-W and RBS. All structures are three-dimensionally modelled in OpenSees software, and their seismic reactions are evaluated for two earthquake scenarios. Seismic responses of structures are estimated and studied, including peak floor acceleration, peak floor shear force, peak story drift, and residual and maximum displacement of isolators. The findings reveal that the ductility levels and connection types of base-isolated and fixed-based structures have a substantial effect on their seismic reactions. The RBS connection decreases peak drift needs in comparison to the WUF-W connection, and the difference is larger as the building's height increases. In comparison to the IMF and OMF superstructures, the SMF superstructure reduces peak floor acceleration and peak shear force. Additionally, the peak floor drift ratio of OMF superstructures in base-isolated buildings is greater than that of IMF and SMF superstructures. The maximum difference between the OMF and SMF superstructures is approximately 80%.

III. CONCLUSION

Design Pushover analysis was carried out on 13 storey building models as per IS 1893: 2002 (part 1). 5 different models were selected and analysis was done using ETABs 2016. Storey displacement, storey drift, Storey stiffness and Base shear of each models are obtained as results and comparative study was carried out for finding model with better performance.

- As we shift soft storey to higher level it can be seen from pushover and capacity spectrum curve that time period goes on reducing from 0.716 Sec. for 3rd floor soft storey to 0.446 Sec. at 10th floor soft storey.
- Which means soft storey is safer at higher level in high rise building. Most of the hinges developed in the beams and few in the columns.
- It is observed that plastic hinges are developed in columns of ground level soft storey which is not acceptable criteria for safe design.

REFERENCES

[1] Malekpour, S., Ghaffarzadeh, H., & Dashti, F. (2011). Direct displacement based design of regular steel moment resisting frames. *Procedia Engineering*, *14*, 3354–3361. https://doi.org/10.1016/j.proeng.2011.07.424

[2] Martinez-Rodrigo, M., & Romero, M. L. (2003). An optimum retrofit strategy for moment resisting frames with nonlinear viscous dampers for seismic applications. *Engineering Structures*, *25*(7), 913–925. https://doi.org/10.1016/S0141-0296(03)00025-7

[3] Hashemi Rezvani, F., Yousefi, A. M., & Ronagh, H. R. (2015). Effect of span length on progressive collapse behaviour of steel moment resisting frames. *Structures*, *3*, 81–89. https://doi.org/10.1016/j.istruc.2015.03.004

[4] Kang, C. K., & Choi, B. J. (2011). New approach to evaluate the response modification factors for steel moment resisting frames. *International Journal of Steel Structures*, *11*(3), 275–286. https://doi.org/10.1007/s13296-011-3003-1

[5] Ferraioli, M., Lavino, A., & Mandara, A. (2014). Behaviour factor of code-designed steel moment-resisting frames. *International Journal of Steel Structures*, *14*(2), 243–254. https://doi.org/10.1007/s13296-014-2005-1

[6] Moghaddam, H., Hosseini Gelekolai, S. M., Hajirasouliha, I., & Tajalli, F. (2012). Evaluation of Various Proposed Lateral Load Patterns for Seismic Design of Steel Moment Resisting Frames. *15th World Conference on Earthquake Engineering*.