Approaches for analysis of seismic behavior of structures: A review

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Abstract - *There are several methods to analyse any structure for seismic effects, two types of analysis are mainly used Linear and Non linear analysis. Non linear analysis further divided into two types non linear static and non linear dynamic analysis. Non linear static analysis is also called as pushover analysis and non linear dynamic analysis referred as response spectrum analysis. As name states "push-over", push the building until you reach its maximum capacity to deform. It helps in understanding the deformation and cracking of a structure in case of earthquake and gives you a kind of fair understanding of the deformation of building and formation of plastic hinges in the structure. It is a sort of approximate tool to understand your building performance. From this method you get pushover curve (strength-deflection curve).*

Recorded ground motions are used in non linear dynamic analysis. In case of non linear dynamic analysis lateral displacements, drift ratio and time period of free vibration motion of structural system are to be studied using Time History analysis and Response Spectrum analysis.

A considerable amount of work has been reported by the researchers on the measurement of seismic performance of structure on the basis of base shear, roof displacements, inter-storey drift, base bending moments, change in stiffness for various materials used and for different arrangement of structural components.

Several approaches are proposed in the literature to solve the problems related with optimization of these parameters. It is felt that a review of the various approaches developed would help to compare their main features and their relative advantages or limitations to allow us to choose the most suitable approach for a particular application and also throw light on aspects that needs further attention. In view of above, this paper presents a review of development done in the optimization of parameters related to seismic behavior of structure.

Key Words: *Base Shear, Torsional Rigidity, Roof Displacement, Plan Irregularity, Infill walls, Shear walls, Non-Linear Static Analysis.*

1. INTRODUCTION

Indian subcontinent has suffered some of the greatest earthquakes in the world with magnitude exceeding 8.0. For instance, in a short span of about 50 years, four such earthquakes occurred: Assam earthquake of 1897 (magnitude 8.7), Kangra earthquake of 1905 (magnitude 8.6), Bihar-Nepal earthquake of 1934 (magnitude 8.4), and the Assam-Tibet earthquake of 1950 (magnitude 8.7). India has had a number of the world's greatest earthquakes in the last century. In fact more than 50% of area of the country is considered prone to damaging earthquakes. Significance of Earthquakes in India can be gauged from the fact that in famous book on *Engineering Seismology* (Richter, 1958) Professor C. F. Richter (Known for the Richter scale) devotes an entire chapter entitled "Some Great Indian Earthquakes" to introduce the nature of the earthquakes: the book has no similar chapter for great earthquakes in other regions of the world. Concrete frame buildings, especially old have frequently experienced significant structural damage in earthquakes.

1.1 VARIOUS MATHODS USED IN STRUCTURAL ANALYSIS-

Seismic analysis of structures can be done by any of the following methods-

- Equivalent static analysis
- Response spectrum analysis
- Linear dynamic analysis
- Nonlinear static analysis
- Nonlinear dynamic analysis

Some of the commonly adopted methods are explained below.

1.1.1 Linear Dynamic Analysis

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsional irregularities, or non-orthogonal systems, a dynamic procedure is required. . In the linear dynamic procedure, the building is modelled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

1.1.2 Nonlinear static analysis

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism.

1.1.3 Nonlinear dynamic analysis

Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares.

1.2 FACTORS STUDIED DURING SEISMIC ANALYSIS OF STRUCTURES-

1.2.1 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear (**V**) depend on:

- soil conditions at the site
- proximity to potential sources of seismic activity (such as geological faults)
- probability of significant seismic ground motion
- the level of ductility and over strength associated with various structural configurations and the total weight of the structure
- the fundamental (natural) period of vibration of the structure when subjected to dynamic loading

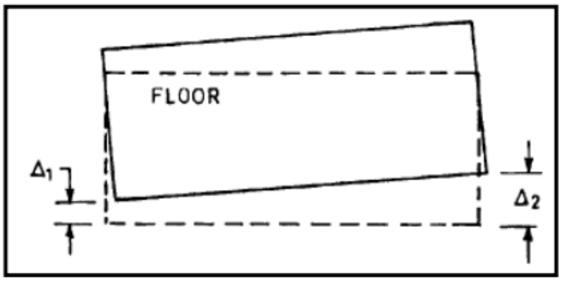
1.2.2 Storey drift and Storey Displacement

Storey drift is the drift of one level of a multistorey building relative to the level below. Interstorey drift is the difference between roof and floor displacements of any given story as the building sways during the earthquake, normalized by the story height.

Storey Displacement is total displacement of its storey with respect to ground and there is maximum permissible limit prescribed in IS codes for buildings.

1.2.3 Torsional irregularity

Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure.



1.2.4 Stiffness Irregularity (Soft Storey)

A *soft storey* is one in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average of the stiffness of the three storeys above.

1.2.5 Mass Irregularity

Mass irregularity shall be considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. A roof which is lighter than the floor below need to considered.

1.2.6 Vertical Geometric Irregularity

Vertical geometric irregularity shall be considered to exist where horizontal dimension of the lateral force resisting system in any storey is more than 130% of that in an adjacent storey, one-storey penthouses need to be considered.

1.2.7 Discontinuity in Capacity (Weak Storey)

A *weak storey* is one in which the the storey strength is less than 80% of that in the storey above. The total strength is the total strength of all seismic resisting elements sharing the storey shear for the direction under consideration.

1.2.8 Reentrant Corners

Plan configurations of a structure and its lateral force resisting system contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 1.5% of the plan dimension of the structure in the given direction.

1.2.9 Diaphragm Discontinuity

Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50% of the gross enclosed area of the diaphragm, or changes in effective diaphragm stiffness of more than 50% from one storey to the next.

1.2.10 Moment resisting frame

It is a three dimensional structural system composed of interconnected members, without structural walls, so as to function as a complete self-contained unit with or without the aid of horizontal diaphragms or floor bracing systems, in which member resist gravity and lateral forces primarily by flexural actions. As per IS 1893:2002 they can be classified as:

- **Ordinary Moment Resisting Frame:** It is a moment resisting frame not meeting special ductile detailing requirement for ductile behavior. Response reduction factor (*R*) is taken as 3 in OMRF.

- **Special Moment resisting Frame:** It is a moment resisting frame specially detailed to provide ductile behavior. Response reduction factor (*R*) is taken as 5 in SMRF.

1.2.11 Infill walls

The variations in the type of the infill walls using in Indian constructions are significant. Depending on the strength and the modulus of elasticity, it can be classified as strong or weak. The two extreme cases of infill walls, strong and weak can be considered by modelling the stiffness and strength of infill walls as accurately as possible in the study. The behavior of buildings relies on the type of foundations and soils also. Depending on the foundations of structure soft or hard soils, the displacement boundary conditions at the bottom of foundations can be considered as hinged or fixed.

2. EXISTING RESEARCH WORK

Yadunandan C et al. (2017)[1] Studied the behavior of RC frame with brick infill by modeling infill as a diagonal strut. The analytical macro models are modeled and analyzed for linear dynamic analysis. Response spectrum method of analysis is adopted for the analysis of infilled frame with and without opening and soft story and the results are compared. He got that Infill increases the initial stiffness of the structure and also increases the base shear carrying capacity of the structure as well as deflection is very large in case of bare frame as compared to that of infill frame with opening and deflection will increase as the percentages of opening increases.

Mahure et al. (2016) [2] To investigate influence of positioning of shear wall on the torsional value of Building. Four different cases of shear wall position for an eleven storey building are studied as a space frame system. Twisting in building is observed to be having increasing trend with enhancement in the eccentricity between geometrical centroid of the building and centre of mass.

Rahila Thaskeen et al. (2016) [3] In this analysis both symmetric and asymmetric structures with plan irregularity are compared. To assess the torsional effect on the structures in the present study 4 types of structures having same outer perimeter area are considered and strengthened by introduction of shear wall cores. A simple linear comparison based on eccentricity is also carried out for G+12 and G+17 structures. Structures with asymmetric distribution of mass and stiffness undergoes torsional motions during earthquake. The performance of the structures is assessed as per the procedure prescribe in IS 1893:2002 and ASCE 7-05. Study it became evident that though the outside perimeters of the structures (rectangular, L shape and C shape) were taken similar, significant variation was found in torsion parameters which regarded for the plan asymmetry and introduction of stiff elements.

Gang Xiong et al. (2016) [4] the global stability behavior of welded structural steel beams with lateral restraints was investigated with the help of experimental programme. A special test set-up was designed to facilitate vertical loading and provide vertical and lateral restraints. In accordance with validated models, parametric studies were carried out to evaluate the effects of slenderness and height-width ratio on lateral torsional buckling of steel beams.

Shriyanshu Swarnkar et al. (2015) [5] In this study 4, 8 and 12 storey buildings with their number of bays increasing from 3 to 6 were modelled as bare and infilled frame. Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and non-linear static Pushover analysis were performed on all structures. Base shear capacity for both ESA and RSA were compared for bare and infilled frame. Pushover curves were plotted for all structures and comparison was made. Infill panels being stiffer than columns fail first and simultaneously from which it was observed that infill panels are responsible for initial stiffness of the structure. As all infill panels fail there is sudden decrease in the overall stiffness, which leads to the collapse of columns.

Tia Tobi et al. (2015) [6] the study is to evaluate the response reduction factor of RC frames. Here the nonlinear static analysis is conducted on regular and irregular RC frames considering OMRF and SMRF to calculate the response reduction factor and the codal provisions for the same is critically evaluated. the conclusion drawn was that the seismic performance of regular frame is found to be better than corresponding irregular frames in nearly all the cases. Therefore it is suggested to construct a regular frame to minimize the seismic effects. It is concluded that as the amount of setback increases, the critical storey shear force also increases. It is found that base shear yields low value in Response spectrum analysis when compared with the Equivalent static analysis.

Ambika-Chippa et al. (2014) [7] In this paper they have analysed the moment resisting frame with and without shear wall for different seismic zones .It has been concluded that story drift and base shear of structure increases as we go to higher seismic zone, storey drift & base shear increases as the number of bays increases for the same zone, story drift and base shear for frame with shear wall is less as compared to frame without shear wall.

Amin Alavi et al. (2013) [8] made an attempt to realise the seismic response of the structures, for various location of shear walls on RC building having re-entrant corners on high seismic zones. They studied a five storey building with six different shear wall locations They considered the accidental torsion of both negative and positive X and Y directions. The results proved that the structures are more vulnerable when they are more irregular, and also the eccentricities between centre of mass and centre of resistance are more significant to the torsional behaviour of structures during an earthquake.

G.V.S. Siva Prasad et al. (2013) [9] investigated the seismic behavior of the structure i.e... OMRF (Ordinary moment resisting frame) & SMRF (Special R C moment Resisting frame). The study assumed that the buildings were located in seismic zone II (Visakhapatnam region).The study involves the design of alternate shear wall in a structural frame and its orientation, which gives better results for the OMRF & SMRF structure constructed in and around Visakhapatnam region. Shear walls are designed by taking the results of the maximum value of the stress contour and calculation are done manually by using IS 456-2000 and IS 13920-1993. The displacements of the current level relative to the other level above or below are considered. The preferred framing system should meet drift requirements.

Apurba Mondal et al. (2013) [10] This research focuses on estimating the actual values of 'response reduction/modification factor' (R). For realistic RC moment frame buildings designed and detailed following the Indian standards for seismic and RC designs and for ductile detailing, and comparing these values with the value suggested in the design code. He found that the actual value of R in real life designs is expected to be even lower than what is computed here, because of various reasons, such as, irregularity in dimensions leading to minor to moderate torsional effects, lack of quality control and poor workmanship during the construction, not following the ductile detailing requirements exactly as per the guidelines, etc.

Devrim. O et al., (2012) [11] studies three 10 story steel SMRF with different spans were designed as per Turkish Codes and were analyzed using OPENSEES 15 using simulated ground motion records and model frame with span length to story height ratio of approximately 2 seems to maintain both performance and economy, while the ratio higher than 2.5 can result in relatively high deflections and high element plastic rotations in lower stories under infrequent earthquake loads.

Misam et al.(2012) [12] proposed that, on adding shear wall to the building in different arrangement in order to reduce soft story effect on structural seismic response. It was found that location and numbering of shear wall acts an important factor for the soft story structures to displace during earthquake. Also the soft story has been eliminated as the shear wall is added to the consider floor, the horizontal and vertical movements of building with shear wall installed in most bays are much reduced during earthquake compare with other models. So it shows that the use of shear wall is effectively reduced effect of soft story on structure response in earthquake excitation. And vulnerability level of multi-storied buildings is assess by analysis of different arrangement of shear wall on building and it can also advantageous for retrofitting of structure on consider level of operation and safety with minimum requirements.

Alireza et al. (2010) [13] proposed the concept of an Artificial Neural Network (ANN) based model was developed and its predictions compared with the results obtained from numerical analysis. The dynamic response of 112 different buildings were selected and used as a database. 84 of these data were employed as the training set and 28 data were used as the validation set. The ANN model was checked with a testing set that was not used in the training process. They proved that the ANN-based model can successfully determine the response of buildings in terms of roof displacements, base shear forces and base bending moments. A careful study of the results leads to observations of excellent agreement between ANN predictions and FEA outcomes. Their study has shown the feasibility of the use of ANN model in determining the response of buildings subjected to earthquakes. The promising results were observed in their study is dynamic analysis of RC buildings indicate that the ANN models enable the designers to rapidly evaluate the buildings 'responses during the preliminary design stage.

Santiago Pujol et al. (2008) [14] a full-scale three-story flat-plate structure was strengthened with infill brick walls and tested under displacement reversals. The results of this test were compared with results from a previous experiment in which the same building was tested without infill walls. In the initial test, the structure experienced a punching shear failure at a slab-column connection. The addition of infill walls helped to prevent slab collapse and increased the stiffness and strength of the structure. The measured drift capacity of the repaired structure was 1.5 %. A numerical model of the test structure was calibrated to match experimental results. Numerical simulations of the response of the strengthened structure to several scaled ground motion records suggest that the measured drift capacity would not be reached during strong ground motion.

Oğuz, Sermin (2005) [15], ascertained the effects and the accuracy of invariant lateral load patterns utilized in pushover analysis to predict the behaviour imposed on the structure due to randomly Selected individual ground motions causing elastic deformation by studying various levels of Nonlinear response. For this purpose, pushover analyses using various invariant lateral load patterns and Modal Pushover Analysis were performed on reinforced concrete and steel moment resisting frames covering a broad range of fundamental periods. The accuracy of approximate Procedures utilized to estimate target displacement was also studied on frame structures. Pushover analyses were performed by both DRAIN-2DX and SAP2000. The primary observations from the study showed that the accuracy of the pushover results depended strongly On the load path, the characteristics of the ground motion and the properties of the structure.

Nina ZHENG et al. (2004) [16] Studied seismic design codes of China GB50011-2001, USA UBC97 and Europe EC8. To evaluate torsion effects caused by irregularity of plan layout of seismic structures. Two types of structures with torsional irregularity are designed, one with eccentricity in one direction and the other with eccentricity in two directions .Elementary conclusion can be drawn that the co-relationships between torsion effects and θ are not definite.

The specific analysis performed in the different areas as discussed by this review paper

Table 1 The specific analysis is performed in the different areas as discussed by this review paper

NAME	YEAR	OBJECTIVE	TYPE OF ANALYSIS	STRUCTURE	SOFTWARE USED	PARAMETER S STUDIED
Rahila Thaskeen et al.	2016	Torsional behavior of structures with plan irregularity	Linear static, Response spectrum analysis	Symmetric and asymmetric (G+7)	ETABS 2015	Eccentricity Torsional irregularity, Drift, Story Displacement
Amin Alavi et al.	2013	Plan irregularity with accidental torsion	Linear static, Response spectrum analysis	Plan irregularity with ductile shear wall, RC special moment resisting frame (SMRF)	ETABS V 9.7	top storey displacement, storey drifts
Nina ZHENG et al.	2004	Regulations for torsional irregularity in GB50011-2001, UBC97 and EC8 studied for rationality and practicability		Two types of structures analysed, one with eccentricity in one direction and the other with eccentricity in two directions.	SAP 2000	relative eccentricity, inter-story drifts
Mahure S.H. et al.	2016	Effects of positioning of shear walls on the torsional value of building	Linear static (Pushover analysis)	(G+11)	ETABS	Torsion, Base shear, Maximum displacement, minimum drift
Alireza Mortezaei et al.	2010	ANN model to determine dynamic response of Vertical irregular structure	Non Linear Dynamic (Time History analysis)	RC special moment resisting frame (SMRF), (G+3, G+6, G+10, G+13)	MATLAB and FEA package	ANN model to study Roof displacement, base shear, Base bending moments
Misam. A et. at.	2012	Seismic response of soft story building with shear walls	Linear static method	Different arrangements of shear walls(G+14)	SAP 2000	Relative stiffness, drift, story displacement,
Shriyanshu Swarnkar et al.	2015	Focused on seismic behavior of RC frames infilled with masonry panels	Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and non-linear static Pushover analysis	Infill structure with varying floor and bays	SAP 2000	Base shear capacity for bare and infilled frame. Comparison of pushover curved
Yadunandan C et al.	2017	Study of infill as diagonal strut, study of various	Response spectrum method of analysis	G+3 RC SMRF structure.	ETABS	Base shear, story drift, lateral loads,

		macro models, effect of openings and soft stories on RC frames				story displacement, time period and column forces in Bare frames infill frames and infill frames with 20% and 40% opening
Santiago Pujol et al.	2008	Experimental Study of structures with and without infill walls	Numerical simulation and Experimental analysis	G+3 RC structure based on US design practices in low seismicity region		Base shear vs. top Drift response, change in strength and stiffness
Tia Toby et al.	2015	Study of stiffness irregularity, mass irregularity and vertical geometric irregularity	Non linear static pushover analysis	SMRF and OMRF	SAP 2000	Roof displacement and Base shear of regular, Geometric irregular, soft storied, mass irregular frames
G.V.S.SivaPrasad et al.	2013	For this purpose 5th, 10th, 15th , 20th storied structure were modeled and analysis was done using	Linear static (Pushover analysis)	The study assumed that the buildings were located in seismic zone II with G+5, 10, 15, 20 stories	STAAD.PRO 2006	Deflection of OMRF and SMRF frames in Zone II
Ambika-Chippa et al.	2014	Compare seismic analysis and design of RC moment resisting space frame with shear wall (Dual System)	Analysis and designing of structure	RC moment resisting space frame with shear wall (Dual System) in case of SMRF and OMRF (G+4, 6, 8, 10)	STAAD ProV8i	Cost is calculated and economic structure is being found out.
Mondal et al.	2013	Study conducted to check the validity of response reduction factor as per IS 1893	Non linear static analysis (Pushover analysis)	RC frames with 2, 4, 8, 12 stories	DRAIN-2DX	Base shear, Roof displacement, Time period analysed
Devrim. O et al.	2012	Simulated ground motion records and model frame with span length to story height ratio of approximately 2	designed as per Turkish Codes	studies three 10 story steel SMRF with different spans	OPENSEES 15	Study of deflections and element plastic rotations, performance and economy,

Oğuz, Sermin et al.	2005	Ascertained the effects and the accuracy of invariant lateral load patterns utilized in pushover analysis	Modal Pushover Analysis	RC and Steel Moment resisting frames	DRAIN-2DX and SAP2000	load path, characteristics of the ground motion and properties of the structure
Gang xiong et al.	2016	Nonlinear finite element analysis for numerical simulation and experimentation to test program	Nonlinear finite element analysis		ABAQUS	Effect of slenderness and height width ratio on torsional buckling of beam

3. CONCLUSION

The analysis of researches in the area of seismic effects on structures over past decades reveals that the performance of a building/structure is generally evaluated on basis of various performance parameters in which major ones was Base shear, story drift, story displacement, time period, and comparison of pushover curves. The performance is affected by Geometry of structure, type of material, ductility parameters, loading types and zones of earthquake. The review paper evaluates the major areas and subareas where structure analysis has been deployed and software commonly adopted.

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