RESEARCH ARTICLE OPEN ACCESS

An Investigation on the Effect of Asymmetry in Pushover Analysis by Seismic Interception

Ankit Jena [1], NilimaBaisakhi[2]

[1] *Assistant Professor, Department of Civil Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar*

[2]*Assistant Professor, Department of Civil Engineering, Gandhi Engineering College, Bhubaneswar*

ABSTRACT

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. It helps in evaluating the real strength of the structure. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. Structural asymmetries are commonly found in constructions. In this paper an attempt is made to study the applicability of Pushover Analysis to frames having different types of asymmetries with seismic interpretation and developing a method for arriving at failure loads based on spectral stiffness and to take care of asymmetries in PO analysis. Reference graphs developed yield the accurate results for the effect of asymmetry without doing pushover analysis repeatedly for different asymmetries. A need for interpretation in terms of seismic loads exists as it will help in assessing damage and rehabilitation methods on site, without resorting to sophisticated analysis. It gives indicators on safety of the frame with asymmetry, with the original frame designed for a specific zone. In this study SAP2000, a state-of-the-art, general purpose, three dimensional structural analysis program, is used as a tool for performing non linear staticanalysis.

KEYWORDS: Pushover analysis, Seismic Interpretation, Seismic Loads.

I. INTRODUCTION

Structural asymmetries play a vital role in catastrophe during earthquakes. This is commonly found in construction due to design requirement, damage of a component due to age or excess load, settlement of foundation. Analytical methods are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic analysis. In these the first two is suitable only when the structural loads are small and at no point the load will reach to collapse load. During earthquake loads the structural loading will reach to collapse load and the material stresses will be above yield stresses. So in this case material nonlinearity and geometrical nonlinearity should be incorporated into the analysis to get better results. Non Linear Static analysis or Push-over analysis is a technique by which a computer model of the building is subjected to a lateral load of a certain shape (i.e., parabolic, triangular or uniform). The intensity of th elateral load is slowly increased and these quence of cracks, yielding, plastichinge formations, and failure of various structural components is recorded. The performance criteria for pushover analysis are generally established as the desired state of the building, given roof- top displacement amplitude. The non-linear static analysis is then revisited to determine member forces and deformations at target displacement or performance point. Base shear versus top displacement curve of the structure, called pushover curves, are essential outcomes of pushover analysis. The generation of the pushover curve also provides the nonlinear behaviour of the structure under lateral load. Capacity spectrum is the seismic intrepretion of pushover curve. In this paper an attempt is made to develop a method to provide seismic interpretation of the frame incorporate with the effect of asymmetry parameters using spectral stiffness. It includes devolepment of curves for variation in spectral stiffness – defined as spectral acceleration/spectral displacement. (as mass remains constant) with respect to the normal frame for the asymmetry cases. Thereby to check whether the frame which is designed and safe in one zone will continue to be safe with asymmetry using the results of the originalframe.

II. LITERATURE REVIEW

De La Llera and Chopra (1995) studied on the design of torsionally insensitive structures, i.e. structures with an arrangement of stiffness elements adequate for the control of torsional deformations. Michael Mehrain and FarzadNaeim (2003) presented a modelling technique by which a complete three dimensional structural analysis of a structure can be performed using two-dimensional models, and hence 2-D software. The approach includes the effect of torsion, walls perpendicular and inclined to the direction of motion as well as walls with L, T, and H shapes in plan. The method can be used with linear and nonlinear analysis. Applied technology council; California; (1996) had conducted studies on nonlinear behaviour of structural elements and earthquake forces. They published their results as guidelines for nonlinear static analysis as Seismic evaluation and retrofit of concrete buildings, vols. 1 & 2 (ATC-40). American Society of Civil Engineers for Federal Emergency Management Agency (2000) also conducted studies for earthquake analysis along with ATC and developed guidelines for nonlinear static analysis in FEMA-356 (2000).

III. METHODOLOGY AND FORMULATION

Present paper comprises of study on a Single Storey Single Bay frame called as SSSB. A SSSB frame is designed for dead load and live load and size of beam and columns adopted are 230mm X 500mm and 400mm X 400mm respectively. The grade of the concrete used is M20 and grade of steel used is Fe415. The material nonlinearities are assigned as hinges. Hinges considered are default hinges given in SAP2000. Number of hinges required for the failure of a single storey single bay frame is three. In the present paper seven locations of the hinges are considered ; Two hinges at the ends of the left and right column, two hinges at ends of beam and one at the centre of the beam. Altogether thirty five models can be created with three hinges. All the combination gives different pushover curves showing the path to failure is nonlinear. Also the stiffness variation shows nonlinear behaviour. In order to simplify the study, failure is assumed to occur when three failure criterions are arrived. They are maximum deflection, maximum load and final stiffness become 5% of the initial stiffness denoted as FC1, FC2and FC3 respectively. Asymmetry parameters considered are damage asymmetry, design asymmetry and foundation asymmetry.

For failure criteria FC1, the deflection is limited to a maximum deflection of h/200. From the ratio obtained from the curves for a particular aymmetry, the spectral stiffness of the new frame with asymmetry can be obtained if the spectral stiffness of the normal frame is known. Knowing the spectral displacement, spectral acceleration can be obtained for any asymmetries. From the spectral displacement and spectral acceleration obtained, the position of the failure point for the particular failure criteria can be obtained. For failure criteria FC2, the failure is assumed to be obtained at the point when maximum load reaches in pushover analysis. From the ratios obtained from the graph spectral displacement can be obtained as the failure criterion assumed is failure at maximum load. Knowing spectral acceleration and spectral displacement, the position of the failure point can be obtained for any asymmetry. For the failure criterion FC3 where the final stiffness become 5% of the initial stiffness, from the ratios obtained from the curves, the final stiffness for the any asymmetry case can be obtained. The new spectral displacement can be obtained from the ratios obtained. From the new spectral displacement, spectral acceleration are obtained from the new spectral stiffness. Using both values, the position of the failure point can be obtained. Plotting the new failure points obtained from the method, on the curves for the normal case, it possible to check whether the frame which is designed safe for one zone still remains safe in that zone by watching the position of the point above or below the elastic spectrum for a particular zone.

Formulation Of Reference Curves

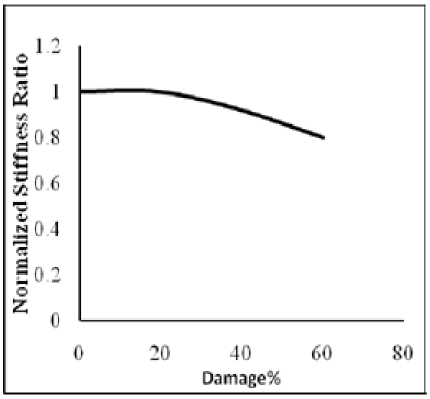
A method which can be used as an indicator on safety of the frame with asymmetry, with the original frame designed for a specific zone is obtained. The method includes the formation of curves with normalized spectral stiffness ratio vs. asymmetry. The spectral stiffness can be obtained from the pushover analysis for a typical frame with and without asymmetry. Asymmetries considered are same as previous one. Spectral stiffness of each case can be obtained and normalized it with that of the normal frame.For damage asymmetry pushover analysis is performed for no damage condition together with 20%, 40% and 60% damage in one column. The present study considers the column damage as percentage reduction in Modulus of Elasticity (E) value. Second asymmetry considered are design asymmetry in which moment of inertia (I) value of one column is used for quantifying asymmetry. Pushover analysis is carried on 0.8I , 1.5I and 2I and normalised ratio and curves are obtained. The third asymmetry considered is foundation settlement. The foundation settlement considered are in terms of the height of the building as h/300,h/200 and h/100, where h is the height of the building. From the curves generated, corresponding to any asymmetry, normalised ratio is obtained. The spectral stiffness for any frame can directly obtained by multiplying the ratio with spectral stiffness of the normal frame without asymmetry. The method is checked with a new frame of beam and column size of 230 mmx250mm and 250mm x 250mmrespectively.

IV. RESULTS AND DISCUSSIONS

PO stiffness is obtained at the failure criterions FC1, FC2 and FC3 and the normalized ratios of spectral stiffness of the frame with that of normal frame are obtained. PO stiffness is obtained by taking the ratios of load and deflection after performing POA. The load, displacement obtained after POA and normalized ratios obtained, are given in the Table 1, Table 2 and Table 3 for damage asymmetry, design asymmetry and foundation settlement. The curves drawn with normalized stiffness ratio vs. damage asymmetry for three failure criteria are shown in Figures 1 to9.

Table 4.1 Normalized Spectral Stiffness Ratios for Damage Asymmetry

Failure Criterion	Damage %	Spectral Acceleration Sa-g	Spectral Displacement Sd (mm) x 10^3	Spectral Stiffness x 10^{-3}	Normalized Stiffness Ratio
FC1	No Damage	2.6213	0.02	131.305	1
	20	2.605	0.02	130.49	0.9981
	40	2.408	0.02	120.406	0.9176
	60	2.0877	0.02	104.38	0.7983
FC2	No Damage	2.9159	0.04319	67.51	1
	20	2.9282	0.04425	66.1598	0.9859
	40	2.9351	0.0451	65.0796	0.964
	60	1.883	0.0845	22.27	0.3308
FC3	No Damage	1.6599	0.10583	15.6846	1
	20	1.63894	0.10693	15.3279	0.9859
	40	1.60478	0.10763	14.9103	0.964
	60	1.5788	0.11814	13.3637	0.3308



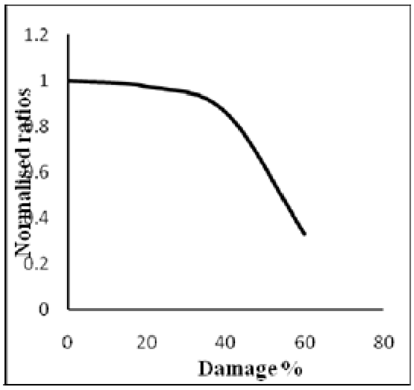


Fig. 1 DamageAsymmetry-FC1 **Fig. 2 Damage Asymmetry-FC2**

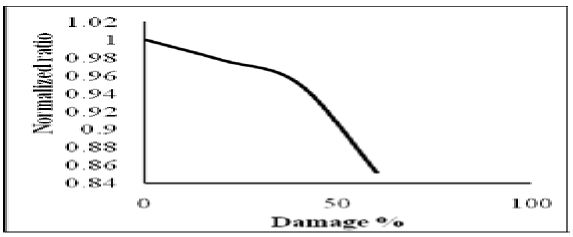
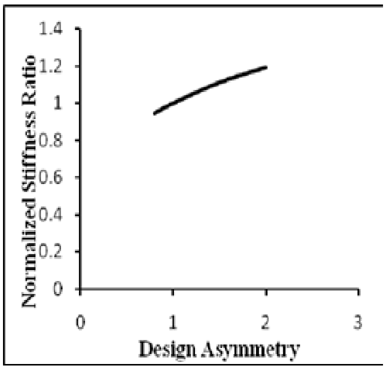


Fig. 3 Damage Asymmetry- FC3

Table 4.10 Normalized Spectral Stiffness Ratios For Design Asymmetry

Failure Criterion	Design Asymmetry in Terms of I	Spectral Acceleration Sa-g	Spectral Displacement Sd (mm) x 10^3	Spectral Stiffness x 10^{-3}	Normalized Stiffness Ratio
FC1	0.8	2.4848	0.02	124.24	0.94626
	1	2.6213	0.02	131.305	1
	1.5	2.917	0.02	145.87	1.11108
	2	3.129	0.02	156.47	1.19169
FC2	0.8	2.9233	0.04386	66.64	0.98717
	1	2.9159	0.04319	67.51	1
	1.5	2.897	0.0405	71.471	1.05868
	2	2.988	0.04103	72.808	1.07849
FC3	0.8	1.6245	0.1089	14.9101	0.95062
	1	1.6599	0.10583	15.6846	1
	1.5	1.8251	0.10698	17.0593	1.08765
	2	1.889	0.10857	17.3984	1.10927



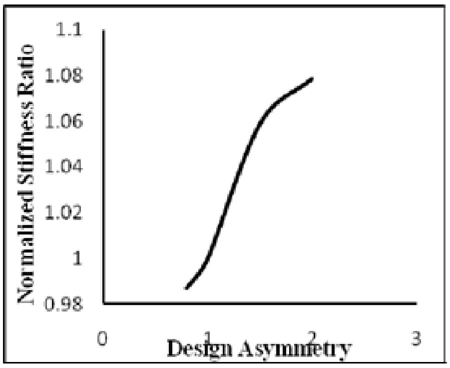


Fig. 4 DesignAsymmetry-FC1 **Fig. 5 Design Asymmetry-FC2**

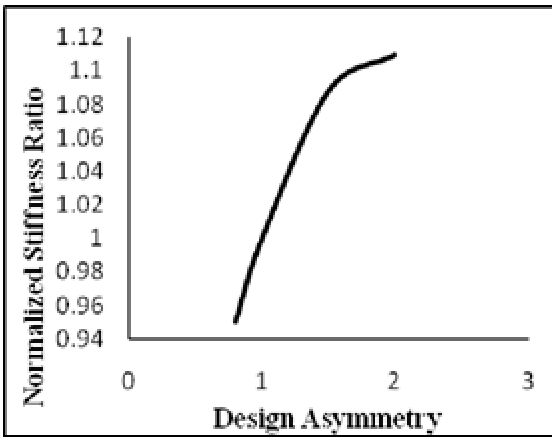
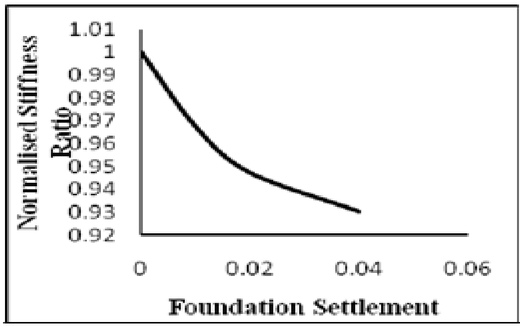


Fig. 6 Design Asymmetry- FC3

Failure Criterion	**Design Asymmetry in Terms of I**	**Spectral Acceleration Sa-g**	**Spectral Displacement Sd (mm) x 10^3**	**Spectral Stiffness x 10^{-3}**	**Normalized Stiffness Ratio**
FC1	0.8	2.4848	0.02	124.24	0.94626
	1	2.6213	0.02	131.305	1
	1.5	2.917	0.02	145.87	1.11108
	2	3.129	0.02	156.47	1.19169
FC2	0.8	2.9233	0.04386	66.64	0.98717
	1	2.9159	0.04319	67.51	1
	1.5	2.897	0.0405	71.471	1.05868
	2	2.988	0.04103	72.808	1.07849
FC3	0.8	1.6245	0.1089	14.9101	0.95062
	1	1.6599	0.10583	15.6846	1
	1.5	1.8251	0.10698	17.0593	1.08765
	2	1.889	0.10857	17.3984	1.10927



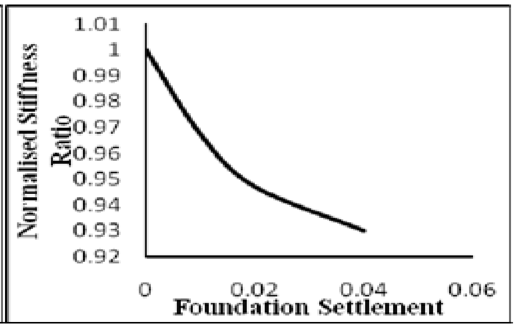


Fig. 7 FoundationSettlement-FC1 Fig. 8 Foundation Settlement-FC2

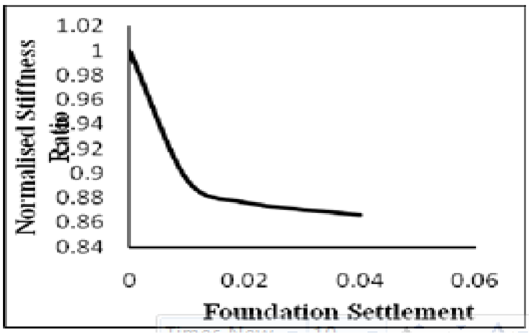


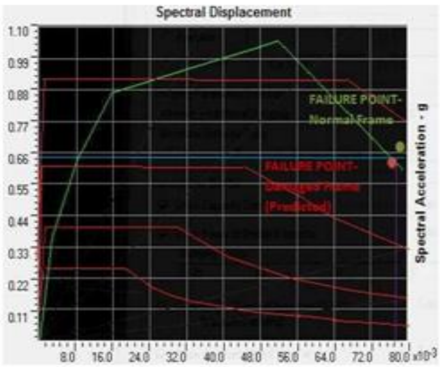
Fig. 9 Foundation Settlement- FC3 Validation of The Method using a New Frame

The method obtained is verified using another frame of beam and column size of 230mm x 250mm and 250mm x 250mm. The grade of concrete and steel used are M20 and Fe415 respectively. Height of the columns used are 4 meters. The method obtained is verified with various asymmetries such as damage asymmetry of 40% damage in column, design asymmetry of of 0.85I in one column and a foundation settlement of h/200 metres. Spectral stiffness obtained from the method generated and from the analysis for the asymmetries considered for failure criteria FC1, are given in the Tables 4.4. Predicted values and the obtained values from analysis for failure criterion FC1, are well correlated with minimum error. Similar verification is conducted for failure criteria FC2 and FC3. Also for new frames for all failures. The obtained value for all cases are well corelated with predicted values.

Table 4.14 Verification Table for FC1

Asymmetries	**Description**	**Sa-g x10^{-3}**	**Sd mm**	**Spectral Stiffness**	**Error %**
40% Damage	Normal Frame	890.897	19.994	44.5544	0.269
	Damaged Frame-Obtained Values	819.721	20	40.9861	
	Damaged Frame - From Analysis	817.51	20	40.8755	
Design Asymmetry of .85I	Normal Frame	890.897	20	44.5449	2.71
	Damaged Frame -Obtained Values	855.36	20	42.768	
	Damaged Frame - From Analysis	832.17	20	41.6085	
Foundation Settlement of h/200	Normal Frame	890.897	20	44.5549	3.5
	Damaged Frame -Obtained Values	815.7	20	40.785	
	Damaged Frame - From Analysis	806.1	20	40.305	

The usefulness of the method to check the safety of the frame with asymmetry for a failure criteria for the zone considered can be explained with the help of an illustrative example. Asymmetry considered is 60% damage and failure criteria FC3. Figure 4.38 shows the failure point obtained for normal frame from analysis the predicted point for 60% asymmetry. The normal frame is initially safe for the zones 2, 3 and 4. The obtained failure point falls below zone 4 indicating that the frame, which is safe under zone 4 become unsafe with an asymmetry of 60% damage. Failure point obtained from the analysis is given in Figure 4.39. Failure point obtained from the analysis is well correlated with the failure pointpredicted.



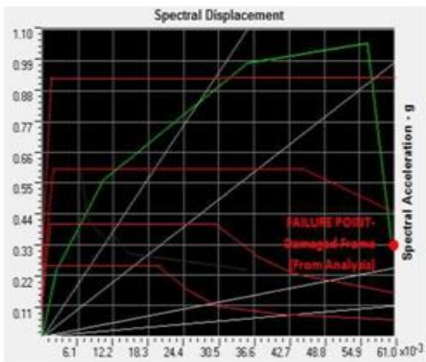


Fig.10 PredictedFailurePoint **Fig.11 Failure Point from Push overAnalysis**

V. CONCLUSIONS

A method to provide seismic interpretation of the frame incorporated with the effect of asymmetry parameters using spectral stiffness is developed. Graphs showing variations of different asymmetries for dimensionless ratios are obtained. The patterns of the curves obtained for damage asymmetry are similar for all failure criterions. The patterns show slight variation for design asymmetry and foundation settlement for different failure criteria. From the studies conducted for variation of spectral stiffness by keeping asymmetries constant, all failure criterions show similar variations for damage asymmetry, for design asymmetry FC1 shows maximum effects, for foundation settlement, FC2 shows maximum variation of stiffness. From the studies conducted for variation of spectral stiffness by keeping failure criteria constant, damage asymmetry and design asymmetry shows maximum variation of spectral stiffness with failure criteria FC1, foundation settlement shows maximum variation with FC2 and FC3. Failure points obtained are well correlated with analysis results for all asymmetries and failure criteria. Among the various failure criterions considered, FC3 causes maximum effect in various asymmetries considered. A method to check whether the frame which is safe in one zone will continue to be safe with asymmetry ,using the results of the original frame, isobtained.

REFERENCES

[1]. De La Llera, J. and A. Chopra (1995) Understanding The Inelastic SeismicBehaviour Of Asymmetric Plan Buildings. Earthquake Engineering and Structural Dynamics , Vol.24, No.4 , 549-572.

[2]. Michael Mehrain and FarzadNaeim (2003) ‘‘Exact’’ Three-Dimensional Linear and Nonlinear Seismic Analysis of Structures with Two-Dimensional Models. Earthquake Spectra, Vol. 19, No.4, 897–912

[3]. Paulay, T. (1997) Seismic Torsional Effects on Ductile Structural Wall Systems. Journal of Earthquake Engineering 1997, Vol. 1, No.4,721-45.

[4]. Erduran, E (2008) Assessment of Current Nonlinear Static Procedures On The Estimation Of Torsional Effects In Low-Rise Frame Buildings. Engineering Structures, Vol. 30,2548–2558

[5]. Moghadam, A.S. and W.K Tso (2000) 3D Pushover Analysis For Damage Assessment of Buildings, JSEE, Vol. 2, No.3,120-159.

[6]. Krawinker, H and G.D.P.K Seniveratna (1998) Pros And Cons Of Pushover Analysis Of Seismic Performance Evaluation. Engineering Structures , Vol.20, Nos 4-6 ,452-464

[7]. Kadid, A and A. Boumrkik (2008) Pushover Analysis Of Reinforced Concrete Frame Structures. Asian journal of Civil Engineering (building and housing) Vol. 9, No. 1,75-83

[8]. Chen, P, K.R Collins (2000) Some Observations On Performance-Based And Reliability-Based Seismic Design Of Asymmetric Building Structures J. Engineering Structures, Vol.23, 1005– 1010.

[9]. Jan, T.S., M.W Liu and Y.C Kao (2004) An Upper-Bound Pushover Analysis Procedure For Estimating Seismic Demands of High-Rise Buildings. J. Engineering Structures, Vol.26, 117– 28.

[10]. Kalkan, E., and S.K Kunnath (2007) Assessment of Current Nonlinear Static Procedures For Seismic Evaluation Of Buildings. J. Engineering Structures, Vol.29,305-316.

[11]. Applied Technology Council, ATC-40 (1996). Seismic evaluation and retrofit of concrete buildings, Vols. 1 & 2.California;.

[12]. ASCE FEMA (2000) PrestandardsAnd Commentary For Seismic Rehabilitation Of Buildings (2000) Report No. FEMA 356. Washington, D.C.

Ankit Jena “ An Investigation on the Effect of Asymmetry in Pushover Analysis by Seismic Interception” *International Journal of Engineering Research and Applications (IJERA*), vol.8(8), 2018, pp 79-85.