Comparative study of linear and nonlinear deflection of building frame for lateral seismic loads

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ABSTRACT

This paper addresses a comparative study of linear and nonlinear behaviour of a multi-storey building frame subjected to seismic lateral loads. The lateral forces are found by seismic analysis of building frame by response spectrum / dynamic method and equivalent static analysis, both are based on IS:1893 (Part 1). The linear and nonlinear load deformation behaviour is carried out using STAAD PRO. The linear behaviour is also computed by developing a finite element based MATLAB code. A comparative study of both linear and nonlinear load deflection behaviour of different floors is presented. The linear and nonlinear deflection behaviour of the building frame due to equivalent static lateral load and dynamic lateral load are plotted and the load deformations are compared.

KEY WORDS: Modal Linear analysis, Nonlinear analysis, Finite element method, Dynamic analysis, Modal analysis, Frame deflection.

1. INTRODUCTION

The design lateral forces on a frame can be calculated by equivalent lateral force /equivalent static load and by dynamic/ modal analysis as per IS: 1893 (Part 1). The main difference between the equivalent lateral force procedure and dynamic analysis procedure lies in the magnitude and distribution of lateral forces over the height of the building

In the dynamic analysis procedure, the lateral forces are based on the properties of the natural vibration modes of the building, which are determined by the distribution of mass and stiffness over height. In equivalent lateral force procedures, the magnitude of forces is based on estimation of the fundamental period and on the distribution of forces, as given by simple formulas appropriate for regular buildings. Otherwise the two procedures have similar capabilities and are subject to the same limitation

Linear analysis in which structure which returns into original form after the removal of loads and there will be small changes in shape stiffness and no change in loading direction or magnitude. A linear FEA analysis is undertaken when a structure is expected to behave linearly, i.e. obeys Hook's Law. In linear elastic analysis, the material is assumed to be unyielding and its properties invariable and the equations of equilibrium are formulated on the geometry of the unloaded structure. In this approach the primary unknowns are the joint displacements, which are determined first by solving the structure equation of equilibrium. Then the unknown forces can be obtained through compatibility consideration.

In nonlinear analysis the structure will not regain its original shape after the removal of load. Its geometry will changes resulting in stiffness change. If a structure experiences large deformations, its changing geometric configuration can cause the structure to respond nonlinearly. Geometric nonlinearity is characterized by large displacements or rotations. It arises due to the lateral loading also. This stretching leads to a nonlinear relationship between the strain and the displacement.

Mehmed Causevic and Sasa Mitrovic (2010) studied procedures that have been implemented into the latest European and US seismic provisions: non-linear dynamic time-history analysis; N2 non-linear static method (Euro code 8); non-linear static procedure NSP (FEMA 356) and improved capacity spectrum method CSM (FEMA 440). it concluded that nonlinear static procedures are sustainable for applications. Patilet (2013) analysed the building by response spectrum method using STAADPRO with various conditions of lateral stiffness system. Analysis produced the effect of higher modes of vibration & actual distribution of forces in elastic range in a better way. Test results including base shear, story drift and story deflections were presented and got effective lateral load resisting system.

Mohammed Yousuf and Shimpale (2013) did a research about "Dynamic Analysis of Reinforced Concrete Building with Plan Irregularities". Paper aimed towards the dynamic analysis of reinforced concrete building with plan irregularity. Four models of G+5 building with one symmetric plan and remaining irregular plan had been taken for the investigation.Yajdhani Shaik (2015) describes the effect of earthquake load which is one of the most important dynamic loads along with its consideration during the analysis of the structure and study of a multi-storied framed structure of (G+9) pattern is selected. Linear seismic analysis is done for the building by static method (Seismic Coefficient Method) and dynamic method (Response Spectrum Method) using STAAD Pro as per the IS-1893-2002-Part-1.

Pourazarm (2011) research about "Reduced stiffness method for nonlinear analysis of structural frames" gives a numerical algorithm for nonlinear analysis of frames, using the unit displacement method, in generating a reduced stiffness matrix of the structure. This algorithm can properly be used in nonlinear static analysis or in the incremental response spectral method. Remseth (1979) explains the methods of nonlinear static and dynamic analysis of structures, particularly for application to geometrically nonlinear space frames. The displacement formulation of FEM is adopted and large displacements are accounted for by using a material description of motion from a mixed reference frame, assuming small strains and moderately large rotations.

Kashinath N. Borse and Shailendrakumar Dubey (2013) addressed to the review of advances, techniques and theoretical background of the non-linear analysis of steel beam. The formulation of beam element in bending has constituted the most exiting area in the development of the solution techniques. The behaviour of flexure members in linear analysis and nonlinear analysis are compared. Shi and Atluri (1989) deals with the effect of nonlinearly flexible hysteretic joints on the static and dynamic response of space frames. it is shows that a complementary energy approach based on a weak form of the compatibility condition as a whole of a frame member, and of the joint equilibrium conditions for the frame, is best suited for the analysis of flexibly jointed frames.

Comparative study of linear and nonlinear load-deflection behaviour of a multi-storey (G+3) building frame subjected to lateral loads only is discussed in below section. The lateral forces are found by seismic analysis of building frame by response spectrum method and equivalent static analysis based on IS 1893(Part 1). The nonlinear load deformation behaviour is carried out using STAAD PRO software and linear behaviour is using MATLAB and STAAD PRO. A finite element based code is also used for finding deformation of building frame. Comparative study of load deformation behaviour due to equivalent static and dynamic method lateral loads were also covered for different floors and deflection of different floor wise also discussed.

2. METHODOLOGY

Problem statement: Four-storey reinforced concrete office building shown in Fig.1. The building is located in Shillong (seismic zone V). The soil conditions are medium stiff and the entire building is supported on a raft foundation. The reinforced concrete frames are in filled with brick-masonry. The lumped weight due to dead loads is 12 kN/m2 on floors and 10 kN/m2 on the roof. The floors are to cater for a live load of 4 kN/m2 on floors and 1.5 kN/m2 on the roof. The column and beam size is assumed as 0.4 m X 0.4m by Jain (1995)

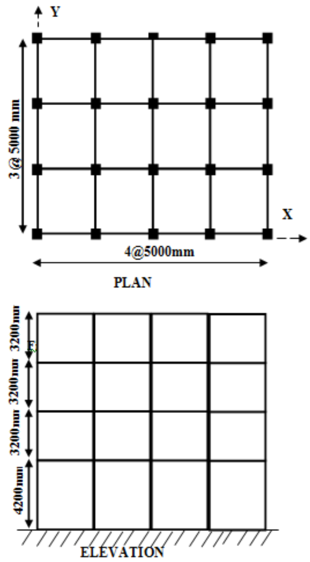

Figure.1.Building configuration

This building where analysed by both equivalent lateral force procedure and dynamic analysis procedure for getting lateral loads at each storey. After getting the lateral forces for each cases load deformation behaviour for linear and nonlinear analysis is carried out by using STAAD PRO and MATLAB. For nonlinear analysis deformation, load step is taken as four thousand which means it divide the total loads into four thousand increments and number of iteration is taken as 100, which is enough for getting accurate answer.In nonlinear analysis at each load increment case the tangent stiffness matrix is updating.

3. RESULTS & DISCUSSIONS

Analysis is done using STAAD PRO and MATLAB for both linear and nonlinear cases. In analysis part we consider only the lateral forces that is obtained from theequivalent static and dynamic seismic analysis based on IS 1893(PART 1). The lateral forces on building frame obtainedbyseismic equivalentstatic and dynamic analysis are given inFig.2 and Fig.3respectively (here we are considering the lateral forces in Y direction only). Even though the base shear by the static and dynamic analyses are comparable but there is a considerable difference in the lateral load distribution with building height.

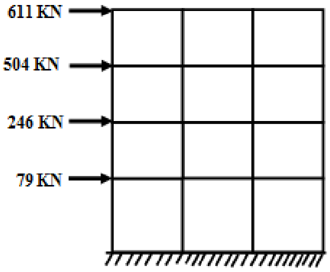

Figure.2. Lateral forceson building frame by equivalent static method

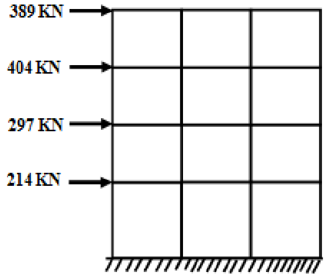

Figure.3. lateral force on building frame by response spectrum method

Table 1 and Table 2, Table 3 and Table 4 shows the linear and nonlinear deflection of fourth and third storey of building frame due to lateral loads only. In case of fourth storey up to thirty percentage of total load, the load-deformation is varying almost linear for equivalent static lateral load caseand response spectrum method lateral load case. Both linear and nonlinear, load-deflection curves forequivalent static and dynamic seismic lateral loads for first storey, second storey, third storey and fourth storey is shown in Fig.4, Fig.5, Fig.6, and Fig.7 respectively. It is clear that the deflection of frame due to static lateral loads gives more in all cases.

Table.1 Linear and Nonlinear Deflection of Fourth Floor Due To Seismic Lateral Load by Equivalent Static Procedure

Load percent	Displacement for equivalent static lateral force(mm)		
	Linear fem analysis using matlab	Linear analysis using staad pro	Nonlinear analysis using staad pro
1	2.21	2.27	2.27
2	4.43	4.64	4.53
5	11.06	11.33	11.32
10	22.12	22.65	22.56
20	44.25	45.31	44.57
30	66.37	67.96	65.49
50	110.62	113.27	102.00
80	177.00	181.25	136.81
100	221.24	226.54	142.68

Table.2 Linear and Nonlinear Deflection of Fourth Floor Due To Seismic Lateral Load by Dynamic Procedure

Load percent	Displacement for dynamic lateral force(mm)		
	Linear fem analysis using matlab	Linear analysis using staad pro	Nonlinear analysis using staad pro
1	1.77	1.81	1.81
2	3.53	3.62	3.62
5	8.83	9.04	9.03
10	17.67	18.09	18.01
20	35.34	38.18	35.55
30	52.90	54.15	52.15
50	88.35	90.44	80.75
80	141.31	144.67	106.14
100	176.69	180.88	107.56

Table.3 Linear and Nonlinear Deflection of Third Floor Due To Seismic Lateral Load By Equivalent Static Procedure

Load	Displacement for equivalent static lateral force(mm)		
	Linear fem analysis using matlab	Linear analysis using staad pro	Nonlinear analysis using staad pro
1	1.91	1.96	1.96
2	3.83	4.02	3.92
5	9.57	9.79	9.79
10	19.13	19.59	19.53
20	38.27	39.17	38.69
30	57.40	58.76	57.15
50	95.67	97.83	90.63
80	153.10	156.70	128.34

100	191.33	195.86	143.14

Table.4 Linear and Nonlinear Deflection of Third Floor Due To Seismic Lateral Load By Dynamic Procedure

Load	Displacement for dynamic lateral force(mm)		
	Linear fem analysis using matlab	Linear analysis using staad pro	Nonlinear analysis using staad pro
1	1.6	1.6	1.60
2	3.1	3.2	3.21
5	7.8	8.0	8.00
10	15.7	16.0	15.98
20	31.3	32.1	31.58
30	46.9	48.0	46.46
50	78.4	80.2	72.61
80	125.3	128.3	98.34
100	156.7	160.4	103.75

Table.5 Linear Equivalent Static And Dynmic Lateral Load Deflection Of First And Second Storey

Load	First floor deflection		Second floor deflection	
	Static	Dynamic	Static	Dynamic
1	0.80	0.71	1.44	1.23
2	1.63	1.41	2.96	2.46
5	3.99	3.53	7.21	6.14
10	7.97	7.07	14.42	12.27
20	15.94	14.14	28.84	25.55
30	23.91	21.11	43.25	36.71
50	39.85	35.34	72.09	61.37
80	63.77	56.53	115.3	98.17
100	79.71	70.68	144.2	122.7

Table.6 Linear Equivalentstatic and Dynmic Lateral Load Deflection of Third and Fourth Storey

Load	Third floor deflection		Fourth floor deflection	
	Static	Dynamic	Static	Dynamic
1	1.96	1.60	2.27	1.81
2	4.02	3.21	4.64	3.62
5	9.79	8.02	11.33	9.04
10	19.59	16.04	22.65	18.09
20	39.17	32.08	45.31	38.18
30	58.76	48.00	67.96	54.15
50	97.83	80.19	113.27	90.44
80	156.70	128.27	181.25	144.6
100	195.86	160.38	226.54	180.9

The difference between the deflection by linear finite element based MATLAB code and linear STAAD based values are almost same. The MATLAB value is less than that of STAAD value, but the difference is negligible. The fourth storey deflection due to lateral load by equivalent static method using STAAD PRO is 226.54mm, whereas by using finite element formulated MATLAB code is 221.24mm, and in case of dynamic seismic lateral load the values are 180.88mm and 176.69mm respectively. Only a small difference exists between the value of STAAD PRO and finite element based MATLAB code.

In nonlinear analysis, at the initial load increment stages it behaves like linear only. After reaching a particular load percentage the deflection value start decreasing slowly and at final stages of load percent it decreases highly.

Linear seismicequivalent static and dynamic lateral load deflection for different storeys are presented in Table 5 and Table 6.

As the floor level increases the difference between static deflection and dynamic deflection also increases. The difference between the deflection due to equivalent static lateral load and dynamic method lateral load are 9mm,21.5mm,35.5mm,45.5mm respectively for first, second, third and fourth floor. So the difference between the deflection due to equivalent static lateral load and dynamic lateral load is increasing with increase in storey height. The difference between the deflections of consecutive floor is maximum in dynamic lateral load case. The difference in case of first and second floor is 65mm in equivalent static lateral load case, but it is 52mm in dynamic lateral loadcase. The static method is an approximate method, so it is over estimating the value.

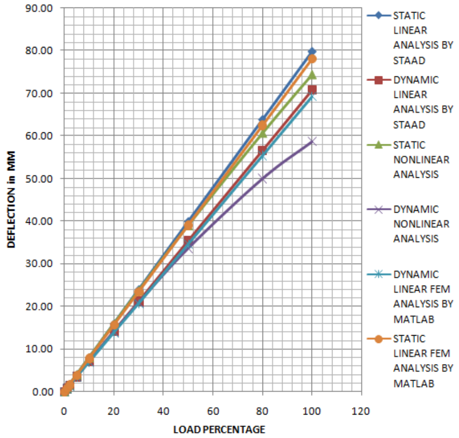

Figure.4. Load vs deflection for first storey

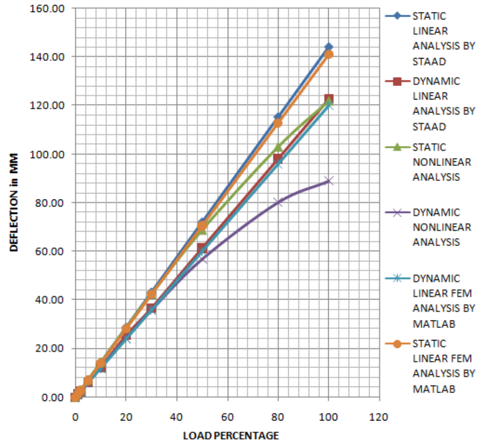

Figure.5. Load vs deflection for second storey

In equivalent static lateral load case for first storey, nonlinearity starts at fifty-two percentage of total load, where as in dynamic lateral seismic load case nonlinear behaviour starts at forty-four percentage of total load. In case of second storey for equivalent static lateral load case it is forty percentage of total load and for dynamic procedure lateral load it is thirty-six percentage of total load. But for third and fourth storey the nonlinear behaviour occurs at almost same load percentage.

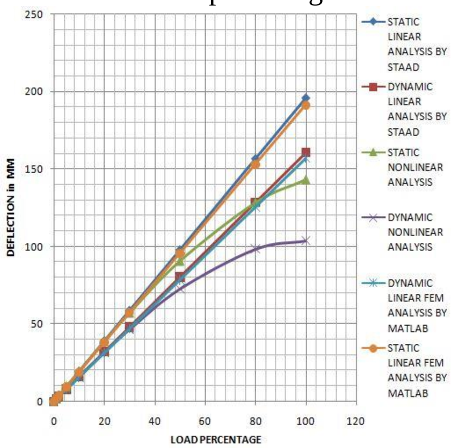

Figure.6. Load vs deflection for third storey

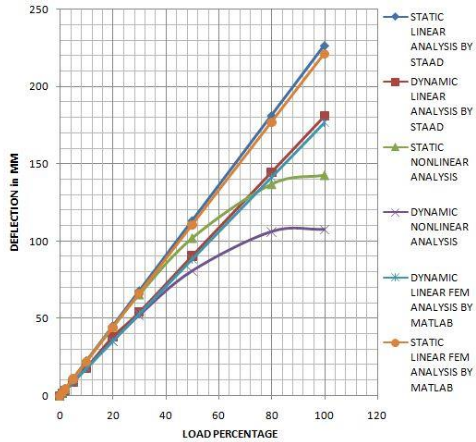

Figure.7. Load vs deflection for fourth storey

So it is clear from all graphs that the nonlinear behaviour start first in dynamic seismic lateral load case. A similar comparison has been made for each storey by considering the load as some percentage of the total load and a plot between the load percentage of the total load and the deflection behaviour is presented in Fig 8 and Fig 9.

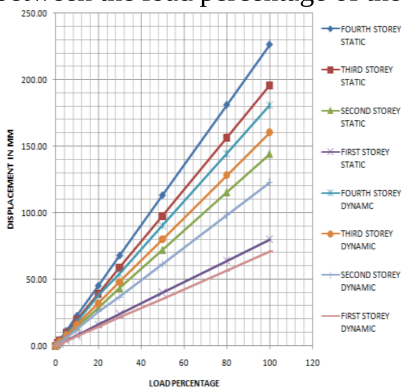

Figure.8. Linear- load vs deflection for different storeys

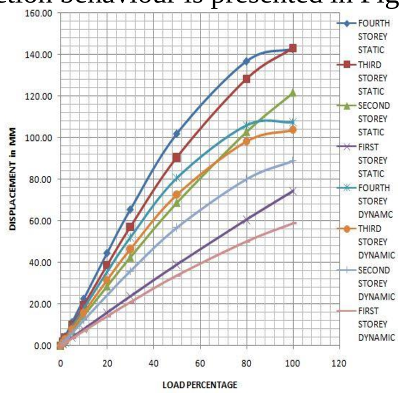

Figure.9. Nonlinear- load vs deflection for different storeys

4. CONCLUSIONS

In this paper we discussed about the linear and nonlinear behaviour of a multi-storey building subjected to lateral loads only. At first we calculated the seismic lateral loads by equivalent static method and dynamic method based on IS 1893 part1. Linear and nonlinear deflection is calculated using STAAD PRO and finite element based MATLAB code.

The studies on Software and theoretical results associated with them lead to the following conclusions:

- Base shear by the static and dynamic analyses are comparable but there is a considerable difference in the lateral load distribution with building height

- From the load-deformation curves it is clear that the deflection due to lateral forces by static method is more than that of dynamic method.
- Fourth storey showing nonlinear behaviour first and it is followed by third, second and first storey respectively
- Linear displacement that we obtained from STAAD pro and linear FEM code by MATLAB values are almost same.

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