Short Research Article

The Effect of Gravity Loads on Seismic Lateral Displacements of R.C. Frames

ABSTRACT:

This paper includes an analytical study for an investigation of the gravity load effect on the seismic lateral displacements of a R.C. building located in Khartoum city (which lies in zone 2, of zone factor, z = 0.1), Sudan. The R.C. building used in this study is a 6-storey residential building with 3-bays in each direction. Two selected frames of the building were analyzed using STAAD-III software, linear static and dynamic analysis software, one in N-S direction and the other in E-W direction. The analysis was performed for two types of restraints: fixed and pinned, for both frames under the same loading. Four cases of damping ratios (0%, 5%, 10% and 20%) were used in the analysis. These ratios were taken as percentages of the critical damping. The software used the Dynamic Response Spectrum method (DRS) to solve the dynamic equilibrium equations of motion. The recorded ground motions of the 1940 El Centro earthquake were selected to be used as input data to calculate the seismic lateral displacements. Regardless of values of damping ratios and types of restraints used, it was found that the gravity load contributed in reducing the lateral displacements by an average amount of 25%. In other words, the lateral displacements caused by the combination of (gravity +seismic) loads are less than those caused by the seismic load only.

KEYWORDS: Gravity Load, Seismic Response, Lateral Displacements, Damping ratios.

1. INTRODUCTION:

There is growing responsiveness of multi-storey reinforced concrete structures, to accommodate growing population. The primary purpose of all kinds of structural systems used in the building type of structures is to undergo and transfer gravity loads effectively to the foundations. The most common loads resulting from the effect of gravity are dead load, live load and snow load. Besides these vertical loads, buildings are also subjected to lateral loads caused by wind, blasting or earthquake. Lateral loads can develop high stresses, produce sway movement and cause vibration. Therefore, it is very important for the structures have to be designed to support vertical loads together with adequate stiffness to resist lateral forces. Many researchers have investigated the contribution of gravity load on seismic response of structures, such as Kulkarni J. G. et al., [1] who presented an analysis of Multi-storey Building Frames Subjected to Gravity and Seismic Loads with Varying Inertia. This paper also highlighted the response of reinforced concrete frames for variation of axial force for spread of haunch and storey drift.

A. E. Hassaballa et.al.,[2] presented a paper on Seismic Analysis of a Reinforced Concrete Building by Response Spectrum Method. SAP2000 program was used as a tool for the analysis. The study found that the calculated drifts resulting from the nodal displacements due to the combination of static and seismic loads were about 2 to 3 times the allowable drifts and the compressive stresses in ground floor columns were about 1.2 to 2 times the tensile stresses. Mario Galli [3], evaluated the Seismic Response of Existing R.C. Frame Buildings with Masonry Infills. From his results obtained it can be noted that the presence of masonry infills had a dual effect on the overall structural response. When the infill panels are regularly distributed in the frame (uniformly infilled frame), the seismic response of the structure was characterized by a soft storey mechanism developing as a consequence of the brittle failure of masonry panels at a particular level, that produces a sudden reduction of strength and stiffness and an increase in the storey deformation demand.

Recent extensive analytical-numerical studies on the response of gravity load designed concrete frame buildings (with and without infills) underlined the peculiar vulnerability of the joint panel zone region. Focus has been given to the damage mechanisms occurring in the joint as well as to their interaction with the global frame response (Guido [4], ANGELO MASI [5], Pampanin [6], Calvi [7].

The objective of the herein paper is to investigate the effect of gravity load on the lateral displacements of reinforced concrete frames, located in Khartoum city, subjected to seismic loads.

2. Method of Analysis

The most commonly used methods of analysis are based on the approximation that the building responses can be accounted for by linear analysis of the building, using the design spectrum for elastic system. Forces and displacements due to each horizontal component of ground motion are separately determined by analysis of an idealized building having one lateral degree of freedom per floor in the direction of the ground motion component being considered. Such analysis may be carried out by the seismic coefficient method (static method) or response spectrum analysis procedure.

2.1. Response Spectrum Analysis

A response spectrum is simply a plot of the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency, that are forced into motion by the same base vibration or shock. In the response spectrum method, the response of a structure during an earthquake is obtained directly from the earthquake response (or design) spectrum. This procedure [8] gives an approximate peak response, but this is quite accurate for structural design applications. In this approach, the multiple modes of response of a building to an earthquake are taken into account. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass. The responses of different modes are combined to provide an estimate of total response of the structure using modal combination methods such as complete quadratic combination (CQC), square root of sum of squares (SRSS), or
absolute sum (ABS) method. Response spectrum method of analysis should be performed using the design spectrum specified or by a site – specific design spectrum, which is specifically prepared for a structure at a particular project site. The same may be used for the design at the discretion of the project authorities.

The following procedure is generally used for spectrum analysis:

[1] Select the design spectrum.

[2] Determine the mode shapes and periods of vibration to be included in the analysis.

[3] Read the level of response from the spectrum for the period of each of the modes considered.
[4] Calculate participation for each mode corresponding to the single-degree-of –freedom response read from the curve.
[5] Add the effect of modes to obtain combined maximum response.
[6] Convert the combined maximum response into shears and moments for use in the design of structures.

3. FRAME DETAILS AND STUDY CASES:

A residential six-storey three-bay R. C. frame building in Khartoum City with 15 m X 12.5 m plan, as shown in Fig.1, was considered for the analysis. Two selected frames of this building were analyzed and checked using STAAD III software, one in North- South (N-S) direction and the other in East–West (E-W) direction as shown in Fig. 2. The sections of columns and beams are shown in Table 1.

Table 1: Sections of columns and beams of the studied frame

Floor Level	Ground Floor	1^{st} Floor	2^{nd} Floor	3^{rd} Floor	4^{th} Floor	Roof
Columns' sections (mm)	500*250	500*250	400*250	400*250	300*250	300*250
Beams' sections (mm)	500*250	500*250	500*250	500*250	500*250	400*250

Typical slab thickness is 125 mm.

The three designed loads used in the analysis were the actual dead load, live load and seismic load. Three combinations of load cases were applied as follows:

- Load Case 1 (LC1) is gravity load (dead and live).
- Load Case 2 (LC2) is seismic load only.
- Load Case 3 (LC3) is (gravity + seismic) loads.

The following load combinations (*A*) can be considered [9]:

$$A = 1.4D + 1.6L \quad (1)$$

$$A = D + Lp + E \quad (2)$$

$$A = 0.85\,D + E \quad (3)$$

Where

D = dead load;

L = live load;

P = incidence factor for live load; and

E = earthquake load.

In addition, seismic load only is used in this analysis as an assumed load combination aiming to investigate the impact of gravity load on lateral seismic displacements.

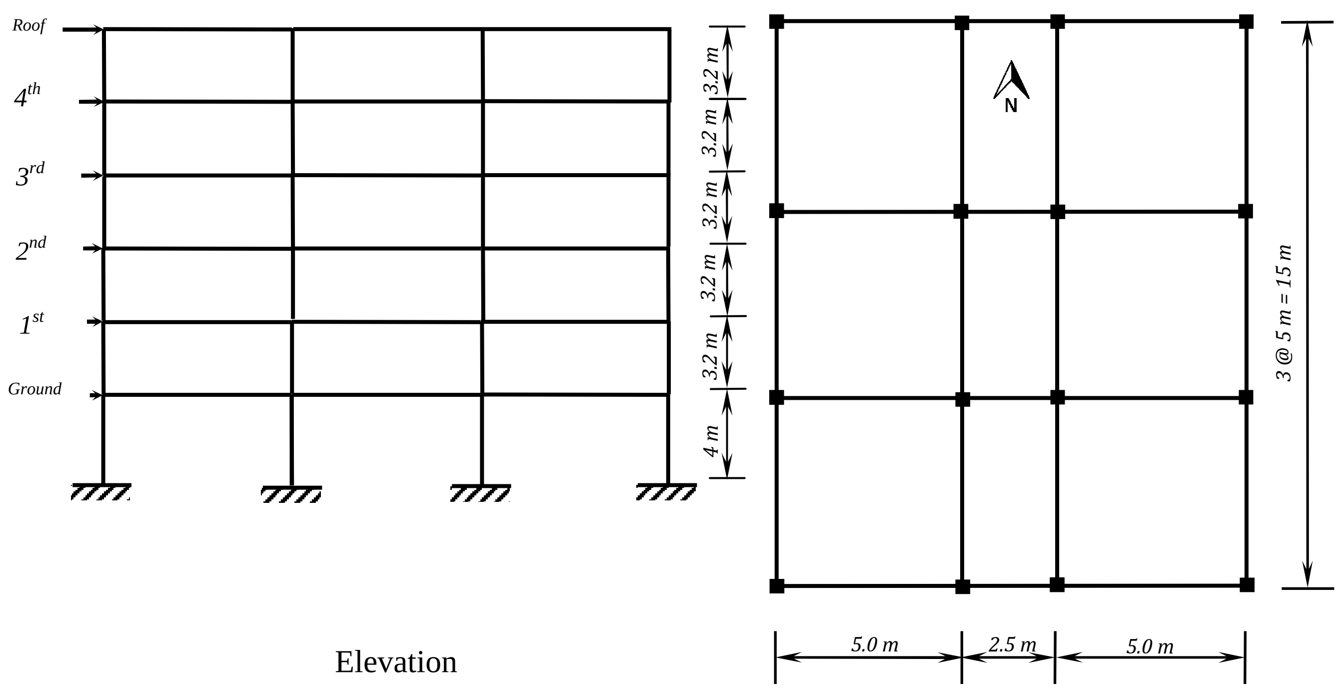
Load case 1 (LC1) follows the rules given in the (BS 8110) [10].

For the case of the Sudan [9], Incidence factor (*p*) is shown in Table (2).

Table 2: Incidence factor for live load (*p*)

Type of Structure	Incidence factor (*p*)
1. Residential buildings, hotels, offices, hospitals, public buildings, etc.	0.25
2. Storage areas and warehouses	0.50
3.Tanks, reservoirs, silos and the like	1.00

A uniformly distributed gravity load of 20 kN/m was applied including the own weights of members. The software uses the Dynamic Response Spectrum method (DRS) to solve the dynamic equilibrium equations of motion. The ground accelerations versus time period were used as an input data to calculate the seismic response spectrum parameters, i. e., displacements in this research. The ground excitations used were selected from the 1940 El centro earthquake, as shown in Fig. 3, and a total time of vibration of 8 seconds was considered. The analysis was performed for two types of restraints; fixed and pinned for the same frames under the same loadings using four values of damping ratios (0%, 5%, 10% and 20%) as representative values of damping for the range of construction. The damping ratios were taken as percentages of the critical damping.



Elevation

Typical Floor Plan

Fig. (1) Dimensions of the Studied Frame Building

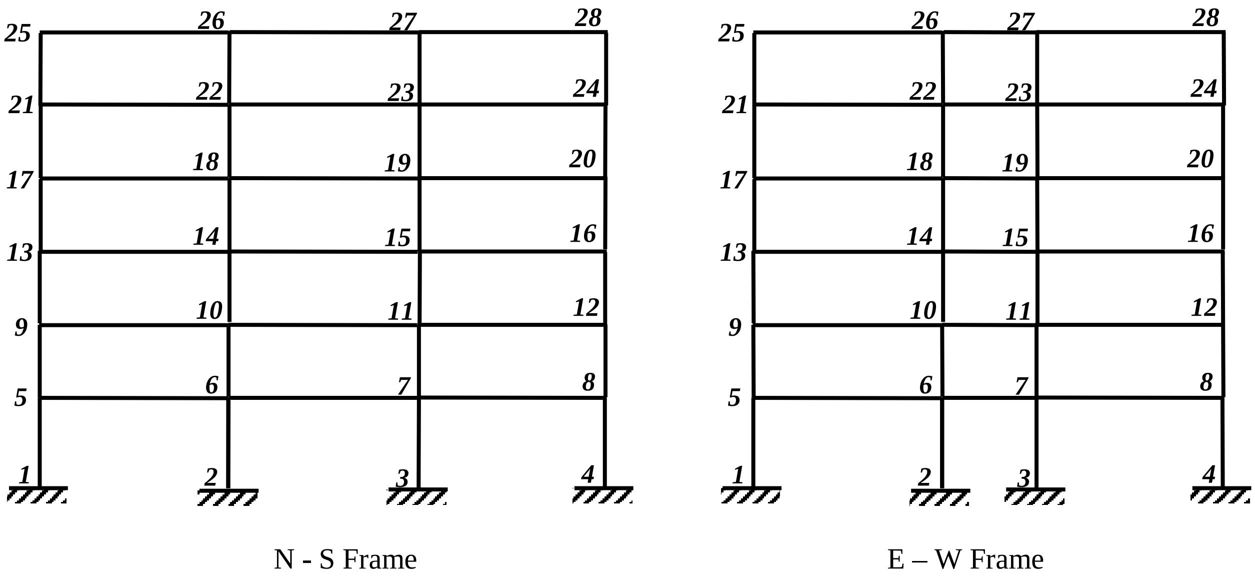


Fig. (2) Selected Nodes of the Studied Frames

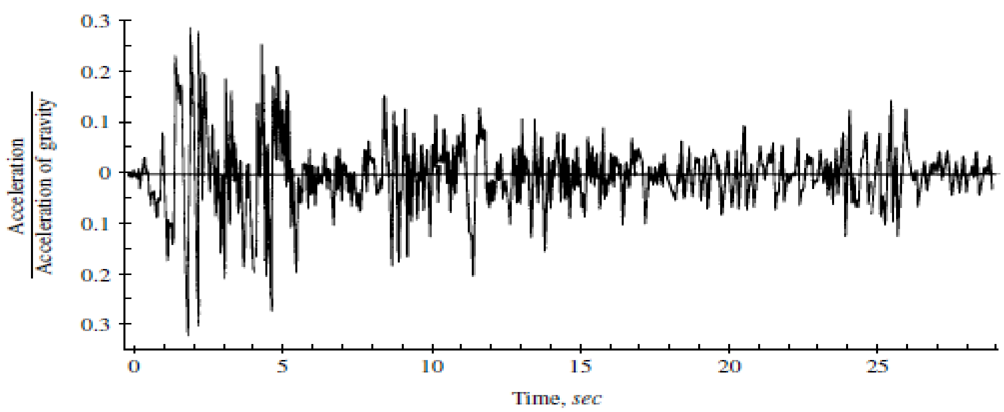


Fig. (3) Accelerogram from El Centro earthquake, May 18, 1940

3.1. Lateral displacement

It is displacement caused by the Lateral Force on the each storey level of structure. Each storey has its own displacement. The maximum lateral displacement is obtained at the top of the building. Hence after analyzing the Building the results obtained for these models in both longitudinal and transverse direction and the comparisons between them are presented in tabular form.

3.2. Damping ratios

The damping ratio is a parameter, usually denoted by ζ (zeta) [11] that reflects capacity of dissipating energy and has significant influence on the vibrations of buildings, is regarded as a constant in the seismic design at present. The damping ratio is dimensionless, because it is the result of dividing the units of the damping constant ($N \cdot s/m$) by the critical damping constant ($N \cdot s/m$); the units cancel out.

4. Results of the Analysis

The analysis was performed for static and seismic loads. The seismic analysis used horizontal input motion of earthquake with moderate horizontal peak ground acceleration (PGA_H). The results of the analysis are shown in Tables (3 and 4) and graphically depicted in Figures (4 to 7) to show the influence of gravity load and damping ratios on reducing lateral displacements of the framed analyzed in this paper.

4.1 Results of N-S Frame Building:

Table 3: The Effect of gravity load on lateral displacements (mm) for fixed restraint using four values of damping ratios

Joints	Displacements (mm) due to seismic load only (LC2)				Displacements (mm) due to (seismic+gravity) loads (LC3)				Difference (%): {(LC2 – LC3)/LC2}*100			
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**2-6**	**3-7**	**4-8**	**5-9**
	0%	**5%**	**10%**	**20%**	**0%**	**5%**	**10%**	**20%**	**0%**	**5%**	**10%**	**20%**
5	7.533	2.460	1.840	1.516	5.647	1.842	1.376	1.134	25.044	25.134	25.179	25.216
6	7.551	2.466	1.844	1.519	5.662	1.848	1.382	1.138	25.015	25.070	25.060	25.076
7	7.551	2.466	1.844	1.519	5.665	1.851	1.384	1.141	24.985	24.956	24.935	24.931
8	7.533	2.460	1.840	1.516	5.653	1.847	1.383	1.140	24.957	24.866	24.821	24.781
9	14.380	4.703	3.514	2.888	10.787	3.529	2.637	2.167	24.990	24.971	24.957	24.952
1o	14.371	4.700	3.511	2.886	10.778	3.526	2.634	2.165	24.997	24.990	24.988	24.985
11	14.371	4.700	3.511	2.886	10.777	3.525	2.633	2.164	25.003	25.010	25.014	25.016
12	14.380	4.703	3.514	2.888	10.784	3.526	2.634	2.165	25.010	25.031	25.040	25.048
13	22.173	7.265	5.421	4.439	16.629	5.448	4.064	3.328	25.005	25.015	25.022	25.024
14	22.177	7.266	5.421	4.439	16.632	5.449	4.066	3.329	25.002	25.006	25.007	25.009
15	22.176	7.266	5.421	4.439	16.633	5.450	4.066	3.330	24.998	24.995	24.992	24.991
16	22.173	7.265	5.421	4.439	16.631	5.450	4.067	3.330	24.995	24.983	24.979	24.972
17	28.476	9.340	6.961	5.679	21.359	7.007	5.223	4.261	24.993	24.980	24.972	24.967
18	28.470	9.338	6.970	5.678	21.354	7.005	5.220	4.259	24.998	24.993	25.102	24.987
19	28.470	9.338	6.959	5.678	21.352	7.003	5.219	4.258	25.002	25.008	25.010	25.012
20	28.476	9.340	6.961	5.679	21.355	7.003	5.219	4.258	25.007	25.021	25.028	25.033
21	35.516	11.651	8.671	7.043	26.636	8.737	6.503	5.281	25.003	25.008	25.011	25.013
22	35.519	11.652	8.672	7.043	26.639	8.739	6.504	5.282	25.001	25.003	25.003	25.004
23	35.519	11.652	8.672	7.043	26.639	8.739	6.504	5.283	24.999	24.998	24.997	24.995
24	35.516	11.651	8.671	7.043	26.638	8.739	6.504	5.283	24.997	24.992	24.989	24.986

25	39.168	12.842	9.552	7.740	29.381	9.636	7.168	5.809	24.988	24.963	24.950	24.938
26	39.168	12.842	9.551	7.740	29.377	9.633	7.165	5.806	24.996	24.988	24.983	24.980
27	39.168	12.842	9.551	7.740	29.374	9.630	7.162	5.803	25.004	25.013	25.016	25.021
28	39.168	12.842	9.552	7.740	29.371	9.627	7.159	5.800	25.012	25.037	25.049	25.061
% Average Difference									**25.000**	**25.000**	**25.000**	**25.000**

4.2 Results of E-W Frame Building:

Table 4: The Effect of gravity load on lateral displacements (mm) for fixed restraint using four values of damping ratios

Joints	Displacements (mm) due to seismic load only (LC2)				Displacements (mm) due to (seismic+gravity) loads (LC3)				Difference (%): {(LC2 – LC3)/LC2}*100			
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**2-6**	**3-7**	**4-8**	**5-9**
	0%	**5%**	**10%**	**20%**	**0%**	**5%**	**10%**	**20%**	**0%**	**5%**	**10%**	**20%**
5	6.859	2.153	1.615	1.341	5.141	1.612	1.208	1.003	25.043	25.142	25.187	25.229
6	6.878	2.160	1.620	1.345	5.159	1.619	1.215	1.008	25.004	25.014	25.021	25.022
7	6.878	2.160	1.620	1.345	5.159	1.620	1.215	1.009	24.996	24.986	24.985	24.978
8	6.859	2.153	1.615	1.341	5.147	1.618	1.214	1.009	24.956	24.858	24.816	24.774
9	12.879	4.048	3.033	2.513	9.661	3.037	2.277	1.886	24.988	24.964	24.952	24.941
1o	12.865	4.043	3.030	2.510	9.649	3.033	2.273	1.883	24.999	24.997	24.999	24.997
11	12.865	4.043	3.030	2.510	9.648	3.032	2.273	1.882	12.865	25.002	25.002	25.001
12	12.879	4.048	3.033	2.513	9.658	3.034	2.274	1.883	12.879	25.036	25.048	25.057
13	19.902	6.263	4.688	3.870	14.926	4.696	3.515	2.901	19.904	25.016	25.023	25.029
14	19.903	6.263	4.688	3.870	14.927	4.697	3.516	2.902	19.903	25.002	25.004	25.005
15	19.903	6.263	4.688	3.870	14.927	4.698	3.516	2.902	19.903	24.998	24.997	24.997
16	19.902	6.263	4.688	3.870	14.928	4.699	3.517	2.903	19.902	24.982	24.977	24.972
17	25.654	8.079	6.041	4.970	19.242	6.061	4.532	3.729	25.654	24.979	24.972	24.965
18	25.646	8.077	6.039	4.968	19.235	6.058	4.529	3.726	25.646	24.998	24.996	24.997
19	25.646	8.077	6.039	4.968	19.234	6.057	4.529	3.726	25.646	25.002	25.003	25.003
20	25.654	8.079	6.041	4.969	19.239	6.058	4.529	3.726	25.654	25.022	25.030	25.034
21	32.221	10.149	7.578	6.207	24.165	7.610	5.683	4.655	32.221	25.010	25.013	25.016
22	32.221	10.149	7.578	6.207	24.166	7.611	5.684	4.655	32.221	25.001	25.001	25.001
23	32.221	10.149	7.578	6.207	24.166	7.612	5.684	4.656	32.221	24.999	24.999	24.998
24	32.221	10.149	7.578	6.207	24.167	7.612	5.685	4.657	32.221	24.990	24.987	24.983
25	35.626	11.216	8.371	6.842	26.724	8.417	6.283	5.136	35.626	24.960	24.947	24.936
26	35.626	11.216	8.371	6.842	26.720	8.413	6.279	5.132	35.626	24.996	24.993	24.992
27	35.626	11.216	8.371	6.842	26.719	8.412	6.278	5.131	35.626	25.002	25.006	25.008
28	35.626	11.216	8.371	6.842	26.715	8.408	6.274	5.127	35.626	25.039	25.053	25.066
% Average Difference									**25.000**	**25.000**	**25.000**	**25.000**

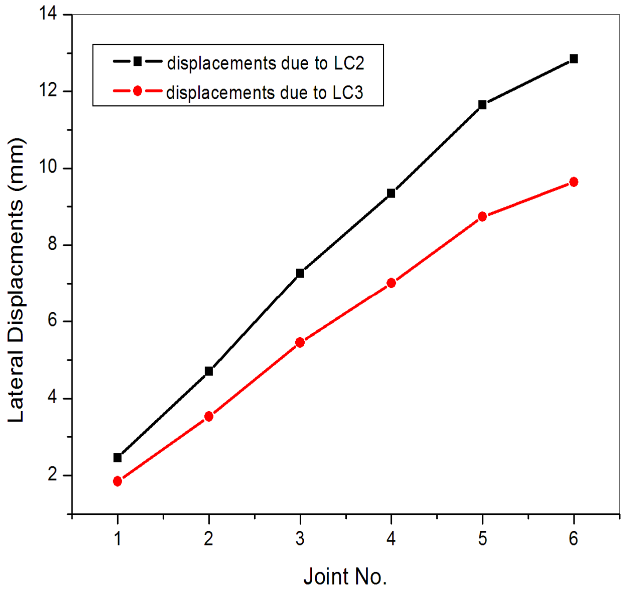


Fig. (4) Effect of gravity load on lateral displacements for damping ratio of 5%

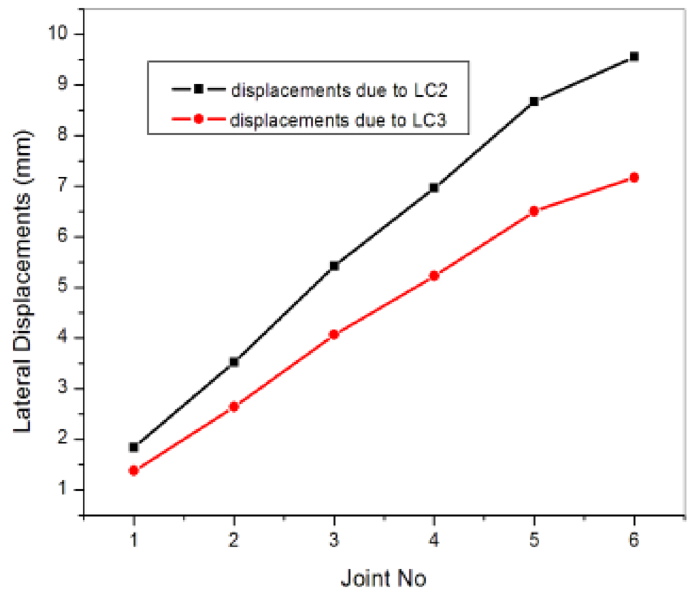


Fig. (5) Effect of gravity load on lateral displacements for damping ratio of 10%

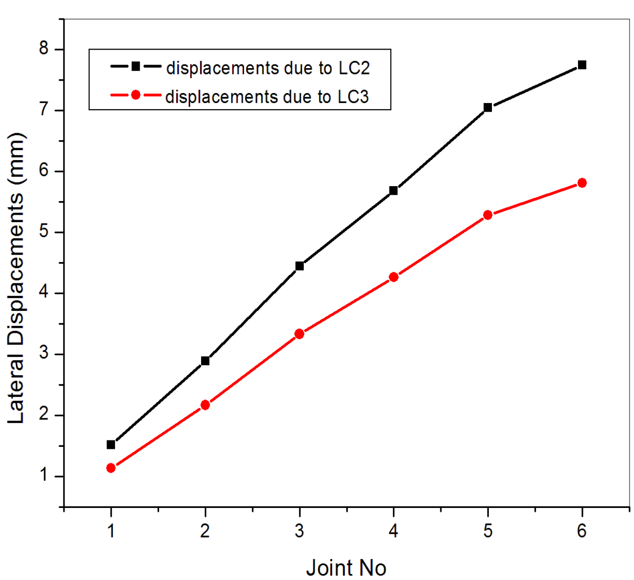


Fig. (6) Effect of gravity load on lateral displacements for damping ratio of 20%

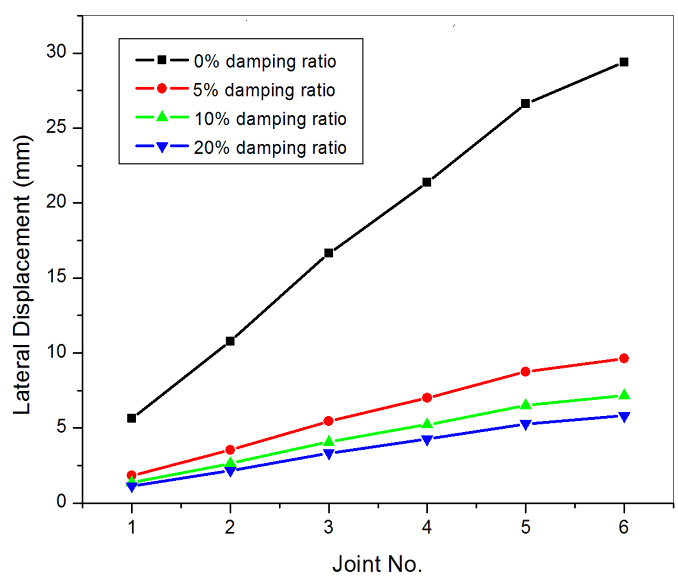


Fig. (7) Effect of damping ratios on lateral displacements for N-S frame

5. Discussion of the Results:

Tables (3 and 4) show that the displacements increase when using pinned restraint, being nearly double that for fixed restraint as depicted graphically in Figures (4 to 7). The effect of damping ratios is clearly noticed for fixed and pinned restraints, i.e., when damping ratio increases, displacements decrease. It is found that the presence of gravity load in the analysis resulted in minimizing the lateral displacements by an amount of 25%. This effect of gravity load on displacements occurred in all cases of analysis, regardless of types of restraints, values of damping ratios and orientation of frames, whether in N-S or E-W direction.

6. Conclusions:

The herein paper presents an investigation of the role of gravity load on seismic lateral displacements generated from a horizontal component of ground motion. From the results obtained it can be concluded that:

- It was found that the gravity load contributed in reducing the lateral displacements by an average amount of 25%, for all cases of damping ratios and types of restraints.

7. References

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