

EFFECTS OF SOIL CONDITION ON BEHAVIOR OF STIFFENED RC FRAME STRUCTURES SUBJECTED TO EARTHQUAKES

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ABSTRACT *The purpose of this study is to investigate the effects of the soil condition on the linear earthquake behavior of the frame structures with different stiffening members and to compare the results obtained. These comparisons are made separately for displacement, bending moments and axial forces for frames. It is concluded that the maximum responses of the frames increase with increasing unit weight of the subsoil. It is also concluded that the effects of the changes in Poisson's ratio on the maximum responses are negligible.*

INTRODUCTION

Earthquakes occurred in the past that caused the deaths of a lot of people made human being design the structures resistant to earthquakes. The idea of earthquake resistant structure is almost as old as the structural history. Human being concentrates more on the earthquake resistant structural design after each earthquake. The principles of the design of earthquake resistant structures all over the world are almost the same depending on the intensity of the earthquake.

As well known that in the earthquake resistant structural design, selection of the type of the structural form is very important, and the following factors should be considered in this selection: (a) light building, (b) simplicity, symmetry and regularity, (c) uniformity and continuity, (d) length and shape in plan, (e) shape in elevation, (f) balanced stiffness and strength, (g) failure modes, (h) well separated or well integrated non-structural components, (i) foundation conditions (Dowrick 1987, Ayvaz and Aydemir 2000, Özdemir and Ayvaz 2002). There are many references on one or more of these factors in the technical literatures (Rosenblueth 1980, Dowrick, 1987, Celep and Kumbasar 1993, Ayvaz and Aydemir 2000, Özdemir and Ayvaz 2002).

Moment-resisting frames used widely all over the world tend to sway excessively under lateral loads, such as earthquake loads, but avoiding brittle shear failure modes is their important advantage. Shear walls are also used in many structures. The great advantage of these walls is to limit the inter-storey deflection since they are generally very rigid, but they exhibit brittle shear failure modes as seen in several earthquakes (Dowrick 1987). Also, they do not provide overall safety of structure in an earthquake because they rigidify partly the structure. Tube structures are the combination of shear walls or columns placed closely and connected to each other by strong beams. These types of structures may be considered between moment-resisting frames and shear walls. Braced frames are constructed by using bracing members (Dowrick 1987). These members can be external and/or internal. Externally bracing is constituted by the use of struts, guys,

buttresses, etc. and internally bracing can be made by one or more diagonal members within the structure.

There are many types of bracing and some problems in planning of them. The types of bracing commonly used are X-bracing, K-bracing, diagonal bracing, diagonal-yielding bracing and knee bracing (Ayvaz et al. 1997, Ayvaz and Aydemir 2000, Özdemir and Ayvaz 2002, Saatcioglu and Humar 2003). Each one has its advantages and disadvantages when they are compared to each other (Dowrick 1987). According to the capacity design procedure, braces are chosen as the primary seismic resisting elements, which produce the over strength axial tension and compression actions.

In this study, among all five structural forms shortly explained above, in addition to moment-resisting frame, linear analysis of reinforced concrete frames stiffened with X-bracing, diagonal bracing and shear walls are analyzed when they are subjected to earthquakes since engineers designing application projects generally use the linear analysis in their designs.

The purpose of this study is to investigate the effects of the soil condition on the linear earthquake behavior of frame and stiffened frame structures and to compare the results of each frame considered. These comparisons are made separately for displacements, bending moments and axial forces for frames. In the study, modal analysis (MA) is used. The frame structures considered are 7 storeys 4 bays. It is assumed that the diagonal members are capably of tensile and compression resistances. As earthquake loading, the spectrum values of East-West component and August 17, 1999 Kocaeli Yarımca Earthquake is used.

Numerical Examples

In addition to the moment-resisting frame (frame no: 1), frame structures and their stiffening member types used in this study are given in Fig. 1 for the frames with 7 storeys and four bays. As seen from this figure, one of these frames is the frame with diagonal bracing (Fig. 1(b)), other one is the frame with X-bracing (Fig. 1(c)) and the last one is the frame with shear walls (Fig. 1(d)). As seen from Fig. 1, the height of the first storey is taken to be 3.5 m and these of the others are taken as 3.0 m. The span lengths of all bays are taken to be 4.0 m. The cross-section dimensions of the columns, beams and bracing members in all frames are taken to be 400 mm x 900 mm, 250 mm x 500 mm, 300 mm x 300 mm, respectively, and kept constant at all storeys. The thickness of the shear wall in frame no: 4 is taken to be 200 mm.

Material properties used are as follows: Modulus of elasticity (E) = 2.7×10^7 kN/m², Poisson's ratio = 0.2, and unit weight of reinforced concrete = 25 kN/m³ as suggested in TS500 (2000). Material properties used for subsoil are as follows: Modulus of elasticity (E_1, E_2, E_3) = 80×10^3 kN/m², 120×10^3 kN/m², 160×10^3 kN/m², Poisson's ratio (ν_1, ν_2) = 0.2, 0.3 and unit weight of subsoil ($\gamma_1, \gamma_2, \gamma_3$) = 15 kN/m³, 17.5 kN/m³, 20 kN/m³, respectively. For the masses of the columns, beams, and stiffening members, different values are used depending on the cross-section dimensions and the loads on them. In calculation of the masses of the beams, a slab with 4 m span and 0.12 m thickness is also considered at each side of each beam. In the analysis, the first five modes of the frames are considered. A constant damping ratio of 2% is used for all modes considered to be conservative in the results.

For the sake of accuracy in the results, rather than starting with a finite element mesh size, the mesh size to produce the desired accuracy is determined. To find out the required mesh size, convergence of the absolute maximum displacement is checked for different mesh sizes. In conclusion, the results have an acceptable error if each column, beam, and diagonal are considered to be one element except that another node is considered at the intersection of X-bracing (see Fig. 1(c)).

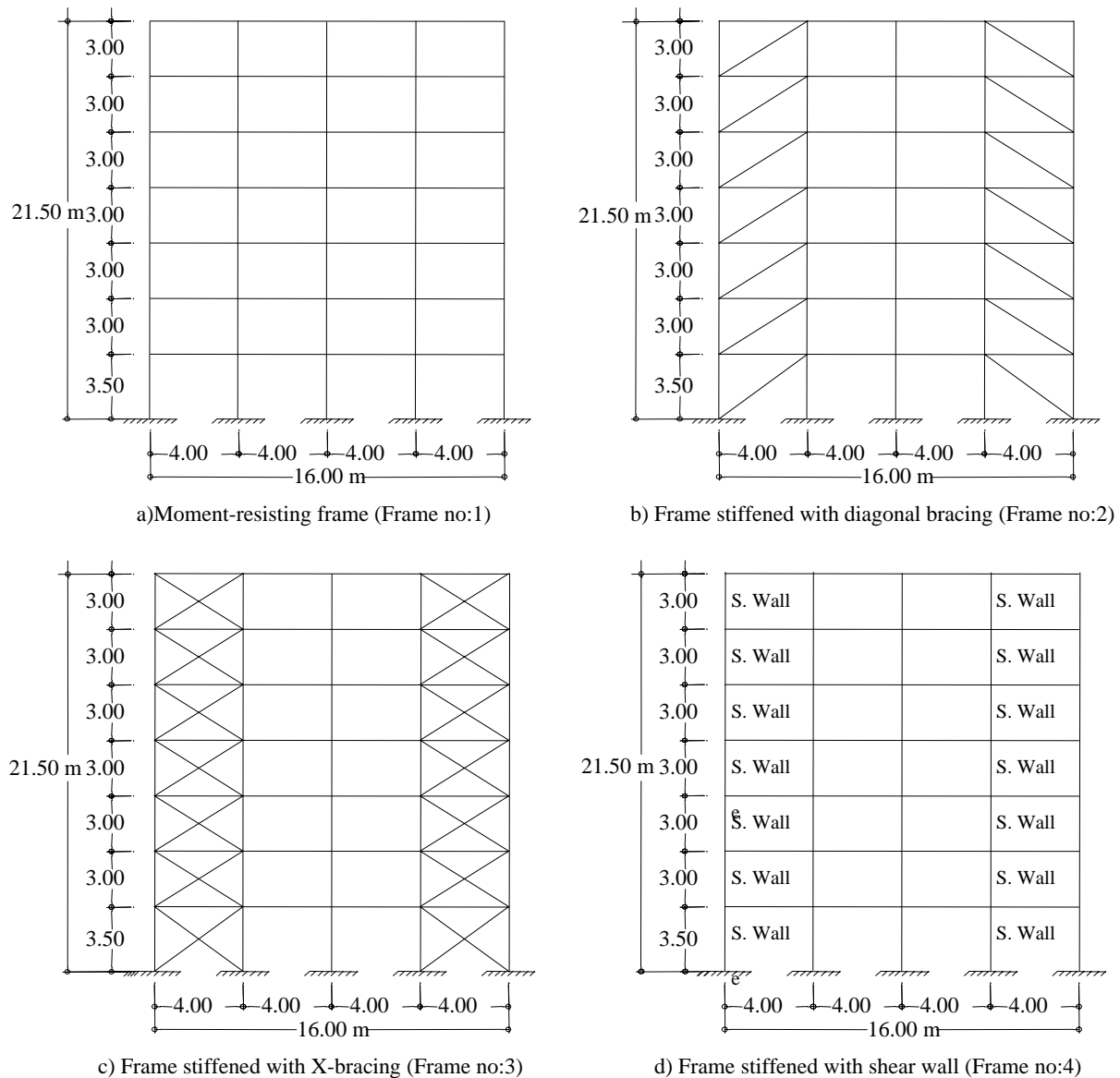


Figure 1. The sample frames used in this study

In modeling of the subsoil, 4-noded quadrilateral elements are used. The dimensions of the elements used in the subsoil mesh are not the same. They are changed by depending on the closeness to the frame. The dimensions of the finite elements which are closer to the frame are smaller than the others which are away from the frame.

RESULTS

In this study, the maximum displacements, bending moments, and axial forces of all frames are given since maximum values of these quantities are the most important ones for design. These quantities are presented in graphical forms, rather than in tabular form, to understand better the effects of the stiffening members, and subsoil properties on the maximum responses such as displacement, bending moment and axial force.

In addition to abbreviation used for subsoil and their properties, the absolute maximum displacements, bending moments, and axial forces of the frames for different subsoil properties such as modulus of elasticity, Poisson's ratio, and unit weight are given in Table 1, and these responses of the frames for subsoil unit weight of 15 kN/m^3 are presented in Figures 3, 4, and 5, respectively, for different modulus of elasticity and unit weight.

The same responses for Poisson's ratio of 0.3 are presented in Figures 6, 7, and, 8 respectively for different unit weight of subsoil.

As seen from Figure 3, absolute maximum displacement occurs in moment resisting frame (frame no:1) for any values of modulus of elasticity. As also seen from this figure, changing Poisson's ratio of subsoil does not show considerable effects on the absolute maximum displacement of the frames considered in this study. The frame stiffened with shear wall (frame 4) gives better results than the other frames from the absolute maximum displacement point of view if subsoil unit weight of 15 kN/m^3 is used.

As seen from Figure 4, absolute maximum bending moment occurs in moment-resisting frame (frame no:1) for any values of modulus of elasticity. As also seen from this figure, changing Poisson's ratio of subsoil does not show considerable effects on the absolute maximum bending moment of the frames considered in this study. In general, the frame stiffened with shear wall (frame no:4) gives better results than the other frames from the absolute maximum bending moment point of view if subsoil unit weight of 15 kN/m^3 is used.

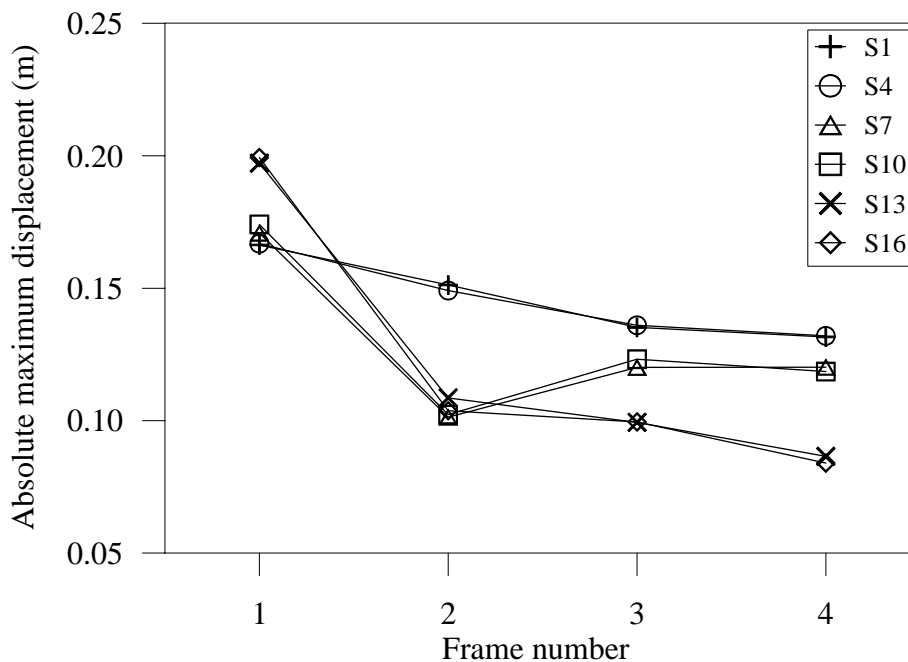


Figure 3. Absolute maximum displacements of frames for the subsoil unit weight of 15 kN/m^3

Table 1. The absolute maximum displacement, bending moment, and axial forces of all frames related to the subsoil properties.

Frame number	Subsoil Properties			Soil name	Absolute Maximum Displacement (m)	Absolute Maximum Bending Moment (kNm)	Absolute Maximum Axial Force (kN)
	E (kN/m ²)	ν	γ (kN/m ³)				
1	8x10 ⁴	0.2	15	S1	0.1663	2176	1873
			17.5	S2	0.1701	2214	1930
			20	S3	0.1742	2254	2002
		0.3	15	S4	0.1668	2188	1873
			17.5	S5	0.1712	2237	1956
			20	S6	0.1754	2273	2025
	12x10 ⁴	0.2	15	S7	0.1708	2390	2064
			17.5	S8	0.1720	2389	2061
			20	S9	0.1739	2414	2120
		0.3	15	S10	0.1741	2436	2108
			17.5	S11	0.1756	2440	2123
			20	S12	0.1775	2465	2169
	16x10 ⁴	0.2	15	S13	0.1972	2830	2412
			17.5	S14	0.1993	2870	2441
			20	S15	0.2015	2897	2473
		0.3	15	S16	0.1993	2869	2449
			17.5	S17	0.2017	2909	2480
			20	S18	0.2041	2941	2521
2	8x10 ⁴	0.2	15	S1	0.1521	1844	4743
			17.5	S2	0.1662	2029	5336
			20	S3	0.1805	2186	5684
		0.3	15	S4	0.1491	1813	4724
			17.5	S5	0.1648	2001	5290
			20	S6	0.1802	2173	5716
	12x10 ⁴	0.2	15	S7	0.1013	1411	3979
			17.5	S8	0.1035	1437	3961
			20	S9	0.1056	1461	3974
		0.3	15	S10	0.1023	1423	4075
			17.5	S11	0.1042	1444	3953
			20	S12	0.1068	1476	4038
	16x10 ⁴	0.2	15	S13	0.1086	1616	4420
			17.5	S14	0.1136	1686	4644
			20	S15	0.1193	1766	4967
		0.3	15	S16	0.1037	1543	4269
			17.5	S17	0.1095	1624	4551
			20	S18	0.1153	1707	4889

Table 1. Continued

Frame number	Subsoil Properties			Soil name	Absolute Maximum Displacement (m)	Absolute Maximum Bending Moment (kNm)	Absolute Maximum Axial Force (kN)
	E (kN/m ²)	v	γ (kN/m ³)				
3	8x10 ⁴	0.2	15	S1	0.1352	1553	4979
			17.5	S2	0.1375	1586	5145
			20	S3	0.1508	1723	5552
		0.3	15	S4	0.1360	1549	5034
			17.5	S5	0.1392	1600	5293
			20	S6	0.1500	1703	5579
	12x10 ⁴	0.2	15	S7	0.1201	1593	5359
			17.5	S8	0.1203	1598	5423
			20	S9	0.1189	1562	5192
		0.3	15	S10	0.1232	1629	5557
			17.5	S11	0.1238	1628	5511
			20	S12	0.1233	1611	5421
	16x10 ⁴	0.2	15	S13	0.0994	1412	4850
			17.5	S14	0.1017	1442	4935
			20	S15	0.1055	1496	5282
		0.3	15	S16	0.0995	1408	4873
			17.5	S17	0.1024	1448	5034
			20	S18	0.1055	1496	5282
4	8x10 ⁴	0.2	15	S1	0.1316	1578	4077
			17.5	S2	0.1347	1604	4140
			20	S3	0.1393	1686	4381
		0.3	15	S4	0.1320	1559	4107
			17.5	S5	0.1357	1590	4186
			20	S6	0.1393	1671	4432
	12x10 ⁴	0.2	15	S7	0.1202	1709	4566
			17.5	S8	0.1255	1797	4832
			20	S9	0.1288	1830	4901
		0.3	15	S10	0.1185	1672	4566
			17.5	S11	0.1252	1777	4874
			20	S12	0.1296	1803	4907
	16x10 ⁴	0.2	15	S13	0.0865	1347	3723
			17.5	S14	0.0904	1403	3866
			20	S15	0.0944	1467	4049
		0.3	15	S16	0.0840	1304	3684
			17.5	S17	0.0882	1357	3815
			20	S18	0.0927	1434	4047

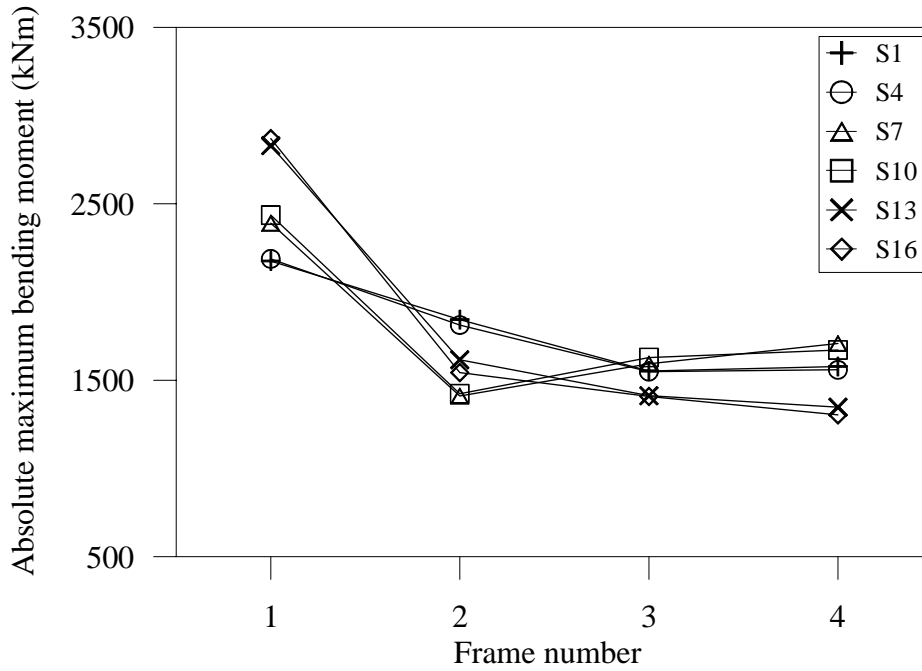


Figure 4. Absolute maximum bending moments of frames for the subsoil unit weight of 15 kN/m^3

As seen from Figure 5, absolute maximum axial force occurs in the frame stiffened with diagonal X-bracing (frame no:3) for any values of modulus of elasticity. As also seen from this figure, changing Poisson's ratio of subsoil does not show considerable effects on the absolute maximum axial force of the frames considered in this study. The moment resisting frame (frame no:1) gives better results than the other frames from the absolute maximum axial force point of view if subsoil unit weight of 15 kN/m^3 is used.

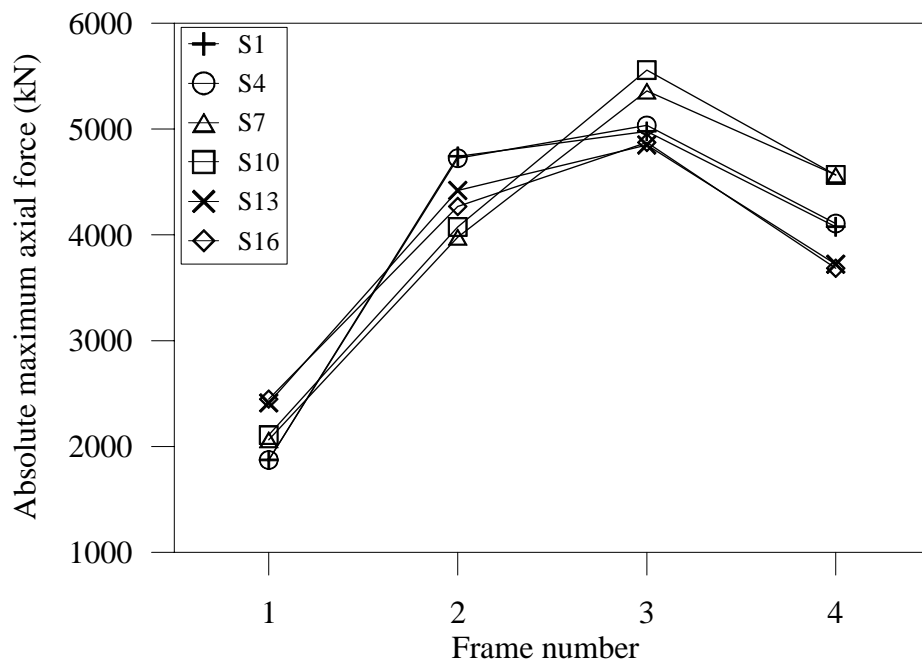


Figure 5. Absolute maximum axial forces of frames for the subsoil unit weight of 15 kN/m^3

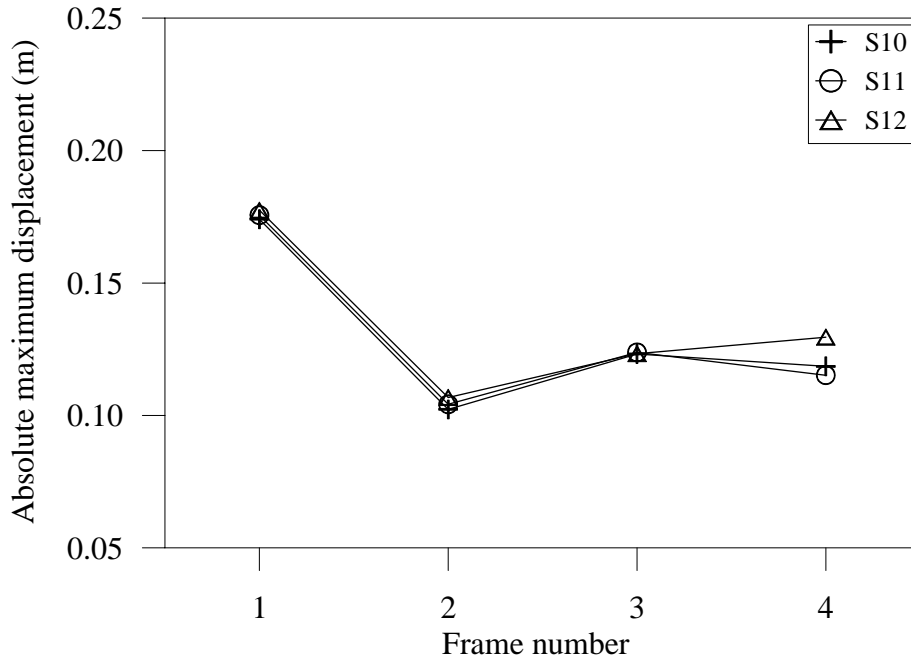


Figure 6. Absolute maximum displacements of frames for Poisson’s ratio of 0.3

As seen from Figure 6, absolute maximum displacement occurs in moment-resisting frame (frame no:1) for any values of unit weight of subsoil. As also seen from this figure, changing the unit weight of subsoil does not show considerable effects on the absolute maximum displacement of the frames considered in this study. The frame stiffened with diagonal bracing (frame no:2) gives better results than the other frames from the absolute maximum displacement point of view if Poisson’s ratio of 0.3 is used.

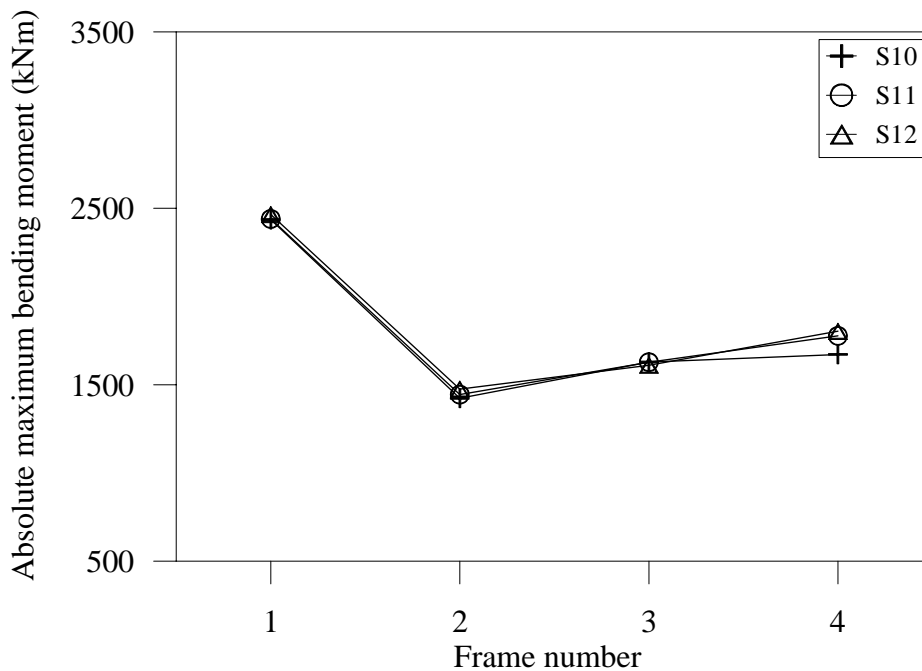


Figure 7. Absolute maximum bending moments of frames for Poisson’s ratio of 0.3

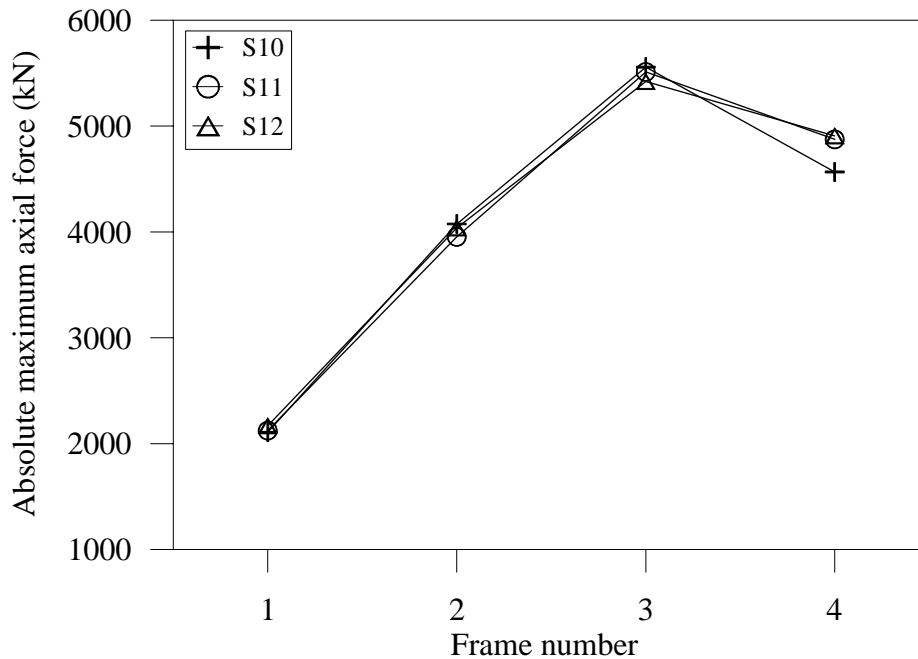


Figure 8. Absolute maximum axial forces of frames for Poisson's ratio of 0.3

As seen from Figure 7, absolute maximum bending moment occurs in moment-resisting frame (frame no:1) for any values of unit weight. As also seen from this figure, changing the unit weight of subsoil does not show considerable effects on the absolute maximum bending moment of the frames considered in this study. The frame stiffened with diagonal bracing (frame no:2) gives better results than the other frames from the absolute maximum bending moment point of view if Poisson's ratio of 0.3 is used.

As seen from Figure 8, absolute maximum axial force occurs in the frame stiffened with diagonal X-bracing (frame no:3) for any values of unit weight. As also seen from this figure changing the unit weight of subsoil does not show considerable effects on the absolute maximum axial force of the frames considered in this study. The moment resisting frame (frame no:1) gives better results than the other frames from the absolute maximum axial force point of view if Poisson's ratio of 0.3 is used.

CONCLUSIONS

The behavior of reinforced concrete structures subjected to earthquakes changes depending on the dynamic characteristics of the subsoil, structures and earthquake excitations. Therefore, to generalize the results obtained in this study, the responses of the different structures subjected to different earthquakes should be evaluated all together. Therewithal, the following conclusions can be drawn from the results obtained in this study.

The maximum responses of the frames increase with increasing unit weight of the subsoil.

The maximum responses considered in this study vary with increasing modulus of the elasticity depending on the frame type.

The effects of the changes in Poisson's ratios on the maximum responses are negligible.

The frames stiffened with shear walls (frame no: 5) give better results than the others for all responses obtained in this study

The stiffening members types used in this study induce the axial force from lateral loads and decrease the bending moment at any section of the frame. This may results with the yielding of columns in compression if not carefully designed.

Degrees of decrease and increase in the responses make the selection of the type of bracing important since they change depending on the type of bracing.

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