MAT JOURNALS

Journal of Structural and Transportation Studies
Volume 1 Issue 3

Soil Structure Interaction of Framed Structure Supported on Non- Homogeneity of Soil Condition

Dr.A.Vijayakumar[1], R.Manojkumar[2], G.R.Seenivasan[3], K.Revathi[4], C.Bharathi[5]

[1]Professor and Head, Department of Civil Engineering, Coimbatore Institute of Engineering and Technology, Coimbatore, Tamilnadu, India.

[2,3,4 &5] Assistant Professor, Department of Civil Engineering, Coimbatore Institute of Engineering and Technology, Coimbatore, Tamilnadu, India.

E-mail ID - vijayakumarciet@gmail.com

Abstract

Soil often exhibits non – homogeneity, due to this non – homogeneity, different settlement occurs. This cause changes in the moments and forces in the members of superstructure frames. The order of magnitude of these changes is not known. In this paper, plane frames with differential configuration have been analysed taking into account soil- structure interaction using Finite Element Method. For the present study soil having different stiffnesses in the right and left half below the structure is considered and the effect of this non – homogeneity on superstructure forces having presented, for plane frames with number of bays varying from 3,5,7 and number of storeys 1to 6. The young's modulus ratio of soil for right and left half has been varied from 1 to 7.5. To non – homogeneity of soil increases the forces in peripheral columns and beams, which were found to be already critical even for homogeneity soil condition. Hence, in general, it is concluded at non – homogeneity of soil increases the effect of soil interaction on the super structure forces.

***Keywords**: Non – Homogeneity, Finite Eelement Method, Soil Structure Interaction, Plane Frames.*

INTRODUCTION

The rapid development of urban population and the pressure on limited space significantly influence the residential development of the city. The price of the land is high, the desire to avoid uneven and uncontrolled developing of urban area and bear on the land for needs of important agricultural production activity have all led to route residential building upwards. The local topographical restrictions in the urban area only possible solutions for construction of multi-storey buildings to full fill the residential needs. The multi-storey buildings all initially a reaction to the demand by activity of business close to each other and in city center, the less availability of land in the area. The multi-storey buildings are frequently developed in the centre of the city is prestige symbols for commercial organizations. Further, the tourist and business community.

The soil structure interaction is a special field of analysis in earthquake engineering, this soil structure interaction is defined as "The dynamic interrelationship between the response of the structure is influenced by the motion of the soil and the soil response is influenced by the motion of structure is called a soil structure interaction." However engineering community discussed about SSI only when the basement motion by interaction force as compared to the ground motion of free field. The stress and deformation in the supporting soil cause vibration of structure generates base shear, moment, displacement and alter the natural period, since in reality it is not fixed base structure, the deformation of soil further modify the response of the structure.

The structure with irregularity has to be designed at most care by understanding determinately effects of irregularities to full fill the requirements. The research finding the effect of irregularities have discussed mainly on plan irregularities because of its mass distribution, non-uniform stiffness and strength in the horizontal direction. Even though the structures are of the same region, same configuration and same earthquake magnitude, but the damages that occur during the earthquake are not of the same pattern. This means that there are some factors that affect the damage pattern like earthquake characteristics, structural system of plan, mass, stiffness, and vertical irregularities

Integrated Analysis of Frame with Isolated Footing on Non- Homogeneous Soil

In some site condition soil may not be homogeneous over the entire width of the structure. So, to study the effect of this non – homogeneous on the forces in the members, analysis was done assuming soil stiffness to be different for left half and right half of the soil below the structure. A typical system configuration is shown in Fig.1. The results of all values are given table. The Es1/E2= 1 to 7.5 for frames. Es1/Es2 =1 represents homogenous soil condition. The effect of non – homogeneity of soil was found to be only marginal in the single frame. In multi bay frames, the non – homogeneity of soil increases the forces values further , at location i.e peripheral columns and beams , which are found to be already critical even for homogeneous soil condition. This may be due to additional unequal settlement of the footing, due to non – homogeneity. Hence, non – homogeneity of soil increase the effect of inclusion of soil in the analysis on the super structure forces. Due to the non – homogeneity of soil , in multiple bay frames, the force values , both for beams and columns on the stiffer soil side, are found to be more for Es1/Es2 = 1 to 7.5.

Frame Configuration Taken Up For Study

One unit of plane frame with isolated footings resting on soil block (c/c of transverse spacing of plane frames) is analyzed. The system configuration is shown in (Fig 1).

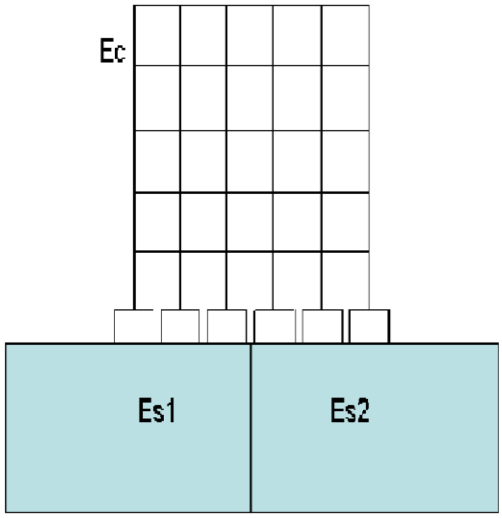

Fig 1. *Plane frame Resisting on Non-homogeneous soil*

Finite Element Model (FEM)

The superstructure members (beams and columns) are modeled by beam elements; isolated footing by shell elements and soil has been modeled by solid elements with six degrees of freedom at each of their nodes (i.e. displacements and rotation in x, y and z directions). The FE model with boundary conditions (Fig 1).

Parameters and Loading

The various geometric and material parameters, which affect the bending moments and shear force in superstructure, have been considered. The following geometrical parameters were used in the present analysis.

- No. Of bays: 3,5,7
- No. Of floors: 1,2,3,4,5,6
- Span / Height: 1.33

- Depth of beam / width of column =1
- Footing depth / Column Width: 1
- S.B.C of soil = 100 q and 200q (for some case)
- The material parameters used, the value Ec / Es has been assumed as 1000 in this analysis. For some case Ec /Es =500
- Ceiling height / width of beam = 10
- The loading has been taken as vertical pressure on beams.
- The young's modulus ratio of soil for right and left half has been from 1- 7.5.

Presentation of Results

Finite Element analysis of integrated system of soil – foundation superstructure and also frame without including soil and foundation were carried out by varying the above parameters. The results of the bending moments and shear forces are presented in tabular form.

The ratio of the bending moments, shear force and axial force from the integrated and that from separate analysis is termed as bending moment ratio (BMR), shear force ratio (SFR) and axial force ratio (AFR). If the ratios are greater than unity, it indicates there is increase in that force (Bending moment or shear force or Axial force) due to soil – structure interaction. If the ratios are less than unity there is reduction in the force due to interaction. If there is negative sign there is reversal sign if forces.

Discussion of Results

In the Tables, following notations have been used.

- G Plinth Level;
- G+1 First Floor Level;
- G+2 Second Floor Level
- G+3 Third Floor Level
- G+4 Fourth Floor Level
- G+5 Fifth Floor Level
- B1, B2, B3 ,B4,B5,B6 ,B7– Beams spanning from left end to right end
- L- Left end of beam; R – Right end of beam;
- C1, C2, C3, C4, C5, C6, C7– Column from outer end to the middle of the structure
- T – Top end of columns; B – Bottom end of column
- D – Depth of footing

COMPARISON OF RESULT

Three Bay Frame

Beams

From analysis of three bay frames, it can be seen that in the center of the beam the BMR are nearly equal to unity indicating that the effect of inclusion of soil is negligible as shown in Table1. However, at the left end of the beams the BMR is large and reduces in the inner locations. The effect if interaction is to increase the bending moment by about 30%of homogeneous soil. For softer soil this may be more, and Non – homogeneous of soil is 50%.It is observed that BMR slightly increases as the number floors increases. The adverse effects are more at the bottom and top floor beams, at the ends.

The shear force ratio is more at the bottom floor level beams than at other floor levels. The shear force ratio increases as the number of storeys increases at all levels for Ec / Es = 1000 & 500 as shown in Table3. The reduction of SFR is seen at the interior beams and increases as the number of storeys reduces. The increase in shear forces is observed to be maximum at the top floor and bottom floor levels. The magnitude of this increase is about 20% of homogeneous soil and 47% of Non – homogeneous soil.

Columns

One of the striking observations in the case of inner columns is that the BMR is very high at the top of the most columns of all frames analyzed as shown in Table2. As the number of floors increases the magnitude of moment’s increases[3-5]. Also there is reversal of moments with large magnitude. This may appear to affect the design critically. But the magnitude of moments was found to be very small compared to the moments in the end columns.

The axial force ratios (AFR) in the column of three bay frames are more in the outer columns [1,2]. The effect is more (about 20%) at the top floor columns and is less at bottom floor column (about 17%) of homogeneous soil, and 50% of Non-Homogeneous of soil. This effect reduces for frames with less number of floors. The AFR reduces to values less than unity in inner columns.

Five Bay Frame

Beams

From analysis of five bay frames, it can be seen that the BMR are more than those for three bay frames at the outer ends. This shows that the BMR increases as the number of bays increases. In the mid spans of the beams the BMR are nearly equal to unity indicating that the effect of inclusion of soil is negligible. At the left end support of the beams the BMR is maximum and it reduces at inner supports and is minimum at the middle supports. The effect if interaction of soil is to increase the bending moment by about 50% for Homogeneous soil, and 70% of Non-homogeneous soil. For softer soil this may be more. It is observed that BMR slightly increases as the number floors increases. The adverse effects are maximum at the end of the bottom and top floor beams.

It can be seen that the SFR is more at the bottom floor level beams than that at other floor levels. The shear force ratio increases as the number of storeys increases. The reduction of SFR below unity is seen at the interior beams. SFR is slightly more for frame with large number of storeys. Maximum increases in shear force are observed at the top floor and bottom floor levels. The magnitude of this increase is about 27% for Homogeneous soil and 70% of Non- homogeneous soil, for softer soil the effect may be more.

Columns

One of the striking observations in the case of inner columns is that the BMR is very high at the top of the top most column of all frame analyzed. As the number floors increases the magnitude of moment's increases by large magnitude and there is also reversal of moments along with large magnitude. This may appear to affect the design critically. But the magnitude of moments was found to be very small (-0.1830e^{-1} units) compared to the moments in the end columns (0.73452 units).

The AFR is more in the outer columns. The effect is more (about 27%) at the top floor columns and is less at the bottom floor columns (about 20%) for Homogeneous soil and 90% of Non-homogeneous soil. This effect reduces for frames with less number of floors. The AFR reduces to values less than unity in inner columns, indicating load is thrown from inner column to outer column, due to soil structure interaction.

Seven Bay Frame

Beams

The BMR in mid span of the beams is nearly equal to unity indicating that the effect of inclusion of soil is negligible. At the left end support of the beams, the BMR is maximum and it reduces at inner locations. The BMR is minimum at the middle supports of the frame. The effect of interaction of soil is to increase the bending moment by about 70% and for softer soil this may be more and 90% of Non- Homogeneous soil. The adverse effects are at the top and bottom floor beams, at the ends. It is observed that BMR increases as the number floors increases.

The SFR is more at the bottom floor level beams than that at other floor levels. The SFR increases as the number of storeys increases. The reduction of SFR is seen at the interior beams and increases as the number of storeys reduces. At inner location the value of SFR reduces to value less than unity. Maximum increase in shear force is observed at the top floor and bottom floor levels. The, magnitude of this increase is about 50%, for homogeneous soil and 91% of Non – homogeneous soil.

Columns

The striking observations in the case of inner columns is that the BMR is high at the top of the top most column, as observed in three bay and five bay frames. As the number floors increases the magnitude of moment's increases by large magnitudes and there is also reversal of moments along with large magnitude. This may appear to affect the design critically. But the magnitude of moments was found to be very small ($-0.8828e^{-2}$ units) compared to the moments in the end columns (0.7435 units). When the values from separate analysis are compared, the magnitude in the inner locations is much smaller compared to those at end columns.

The AFR is more in the outer columns. The effect is more (about 47%) at the top floor columns and is less at the bottom floor column (about 44%) for Homogeneous soil and 70% of Non – Homogeneous soil. This effect reduces for frames with less number of floors. The AFR reduces to values less than unity in inner columns, indicating that load is thrown from inner column to outer column.

Table 1. *Bending Moment Ratios (BM_{IA} / BM_{SA}) for Beams*

FIVE BAY						
	EC / ES=1000				**EC / ES=500**	
	B1	**B2**	**B3**	**B4**	**B5**	
	L	**R/L**	**R/L**	**R/L**	**R/L**	**R**
SIX STOREY						
G+5	1.762	1.181	0.647	0.548	1.176	1.467
G+4	1.758	1.176	0.641	0.543	1.172	1.461
G+3	1.753	1.171	0.639	0.536	1.168	1.458
G+2	1.747	1.168	0.634	0.531	1.163	1.454
G+1	1.741	1.163	0.628	0.527	1.158	1.448
G	1.774	1.187	0.668	0.551	1.179	1.487
FIVE STR						

G+4	1.683	1.167	0.547	0.461	1.159	1.368
G+3	1.678	1.162	0.542	0.458	1.156	1.363
G+2	1.671	1.158	0.539	0.453	1.149	1.359
G+1	1.663	1.153	0.536	0.449	1.146	1.352
G	1.691	1.188	0.549	0.467	1.163	1.381
FOUR STR						
G+3	1.541	0.986	0.528	0.446	0.952	1.268
G+2	1.536	0.979	0.524	0.438	0.948	1.263
G+1	1.531	0.971	0.519	0.433	0.941	1.258
G	1.569	0.989	0.531	0.456	0.961	1.286
THREE STR						
G+2	1.436	0.846	0.519	0.431	0.843	1.178
G+1	1.432	0.841	0.513	0.429	0.839	1.169
G	1.441	0.863	0.526	0.438	0.861	1.196
TWO						
G+1	1.326	0.763	0.431	0.329	0.751	1.159
G	1.361	0.769	0.469	0.336	0.764	1.163

Table 2. *Bending Moment Ratios (BM_{IA} / BM_{SA}) for Columns*

FIVE BAY												
	EC / ES=1000						**EC / ES=500**					
	C1		**C2**		**C3**		**C4**		**C5**		**C6**	
	T	**B**	**T**	**B**	**T**	**B**	**T**	**B**	**T**	**B**	**T**	**B**
SIX STOREY												
G+5	1.741	1.738	1.297	1.296	9.263	9.252	7.268	7.119	1.198	1.196	1.541	1.538
G+4	1.738	1.734	1.296	1.291	9.252	9.139	7.119	7.109	1.196	1.191	1.538	1.532
G+3	1.734	1.726	1.291	1.286	9.139	9.112	7.109	7.103	1.191	1.186	1.532	1.526
G+2	1.726	1.722	1.286	1.281	9.112	9.009	7.103	7.007	1.186	1.182	1.526	1.513
G+1	1.722	1.718	1.281	1.274	-9.009	-33.412	-7.007	-11.436	1.182	1.176	1.513	1.509
G	1.718	1.713	1.274	1.271	-33.412	-43.612	-11.436	-19.237	1.176	1.171	1.509	1.503

FIVE STR												
G+4	1.642	1.638	1.176	1.172	8.263	8.126	6.142	6.132	1.164	1.158	1.498	1.491
G+3	1.638	1.632	1.172	1.168	8.126	8.007	6.132	6.129	1.158	1.153	1.491	1.486
G+2	1.632	1.623	1.168	1.163	8.007	8.005	6.129	6.117	1.153	1.149	1.486	1.483
G+1	1.623	1.617	1.163	1.159	- 8.005	- 11.437	- 6.117	- 24.217	1.149	1.143	1.483	1.476
G	1.617	1.608	1.159	1.153	- 11.427	- 19.467	- 24.217	- 33.612	1.143	1.138	1.476	1.471
FOUR STR												
G+3	1.541	1.538	1.132	1.129	7.623	7.229	5.043	5.001	1.126	1.125	1.362	1.358
G+2	1.538	1.531	1.129	1.126	- 13.439	- 13.416	- 8.631	- 8.007	1.125	1.119	1.358	1.351
G+1	1.531	1.526	1.126	1.121	- 13.416	- 19.126	- 16.216	- 23.167	1.119	1.116	1.351	1.346
G	1.526	1.512	1.121	1.119	- 19.126	- 21.171	- 23.167	- 36.182	1.116	1.111	1.346	1.338
THREE STR												
G+2	1.427	1.418	1.086	1.081	6.176	6.123	4.136	4.123	1.041	1.039	1.246	1.241
G+1	1.418	1.406	1.081	1.079	-6.123	- 8.186	-4.123	- 8.621	1.039	1.031	1.241	1.239
G	1.406	1.401	1.079	1.071	-8.186	- 17.137	-8.621	- 12.123	1.031	1.026	1.239	1.230
TWO												
G+1	1.321	1.316	1.043	1.038	5.034	5.009	3.143	3.129	1.012	1.009	1.149	1.141
G	1.316	1.309	1.038	1.036	-5.009	-9.073	- 119.21	- 126.46	1.009	1.002	1.141	1.126

***Table 3.** Shear Force Ratios (SF_{IA} / SF_{SA}) for Beams*

FIVE BAY						
	EC / ES=1000				**EC / ES=500**	
	B1	**B2**	**B3**	**B4**	**B5**	
	L	**R/L**	**R/L**	**R/L**	**R/L**	**R**
SIX STOREY						
G+5	1.752	1.342	1.178	0.972	1.146	1.481
G+4	1.748	1.339	1.171	0.969	1.141	1.476
G+3	1.743	1.332	1.163	0.956	1.137	1.463
G+2	1.738	1.327	1.158	0.943	1.131	1.459
G+1	1.733	1.316	1.150	0.932	1.126	1.451
G	1.760	1.356	1.183	0.981	1.157	1.496
FIVE STR						
G+4	1.643	1.246	1.146	0.843	1.082	1.386
G+3	1.637	1.240	1.143	0.838	1.076	1.374
G+2	1.633	1.235	1.139	0.831	1.063	1.369
G+1	1.648	1.230	1.126	0.827	1.056	1.363
G	1.689	1.256	1.152	0.852	1.089	1.393
FOUR STR						
G+3	1.548	1.164	1.072	0.752	1.056	1.248
G+2	1.536	1.158	1.068	0.747	1.053	1.243
G+1	1.524	1.143	1.047	0.741	1.041	1.236
G	1.559	1.179	1.079	0.789	1.063	1.256
THREE STR						
G+2	1.432	1.131	1.042	0.643	0.963	1.176
G+1	1.426	1.123	1.038	0.638	0.958	1.165
G	1.455	1.139	1.049	0.649	0.976	1.184
TWO						
G+1	1.306	1.045	0.986	0.543	0.846	1.141
G	1.377	1.056	0.994	0.559	0.849	1.149

Table 4. *Axial Force Ratios (AF_{IA} / AF_{SA}) for Columns*

FIVE BAY						
	EC / ES=1000				**EC / ES=500**	
	C1	**C2**	**C3**	**C4**	**C5**	**C6**
SIX STOREY						
G+5	1.781	1.463	0.849	0.678	1.373	1.564
G+4	1.776	1.458	0.843	0.671	1.368	1.558
G+3	1.772	1.446	0.836	0.669	1.361	1.546
G+2	1.768	1.438	0.832	0.662	1.353	1.539
G+1	1.763	1.431	0.827	0.658	1.348	1.533
G	1.758	1.428	0.816	0.651	1.339	1.526
FIVE STR						
G+4	1.643	1.349	0.728	0.541	1.261	1.486
G+3	1.638	1.346	0.722	0.538	1.258	1.471
G+2	1.632	1.338	0.718	0.531	1.253	1.468
G+1	1.628	1.335	0.711	0.526	1.249	1.463
G	1.623	1.326	0.709	0.522	1.247	1.458
FOUR STR						
G+3	1.549	1.261	0.643	0.446	1.186	1.341
G+2	1.542	1.258	0.638	0.442	1.183	1.336
G+1	1.536	1.253	0.633	0.438	1.178	1.326
G	1.531	1.249	0.628	0.421	1.174	1.319
THREE STR						
G+2	1.436	1.161	0.546	0.316	1.046	1.246
G+1	1.431	1.158	0.541	0.308	1.041	1.238
G	1.428	1.146	0.536	0.301	1.038	1.231
TWO						
G+1	1.321	1.041	0.432	0.246	1.028	1.146
G	1.316	1.026	0.429	0.238	1.016	1.139

CONCLUSIONS

Based on the discussion made in the previous pages, the following conclusions can be drawn.

- The outer ends of the outer beams and outer columns feel the effect of soil structure interaction. The forces in these locations increase substantially.
- This effect on bending moments, shear forces and axial forces increases as the number of bays increases.

- This effect on bending moments, shear forces and axial forces increases as the number of storeys increases.
- The increase in the bending moment is more (up to 100% for G+5, seven bay frame) than the increase in the shear force (91% and axial force about 70%) this increase (particularly the bending moment increase) may affect the design critically as the percentage of increase in bending moment is about 100% in some cases.
- In the case of inner columns, the BMR is very large (with reversal of sign in some cases). But this may not affect the design critically, as the magnitudes are very small.

REFERENCES

1. Narasimhan S.L. and Sreeambabu J. Proceeding of the INCONTEST 2003 Implication of soil Structure Interaction on Plane Frame Behavior.
2. V. Marun Proceeding of the National conference on research scholars on application of emerging technologies Mar 2005, Hosur , A study on soil structure Interaction.
3. Spyrakos C.C (2003), "Soil structure Interaction of Massive Flexible Strip Foundation Embedded in Layered Soils by Hybrid FEM", Journal of Soil Dynamics & Earthquake Engineering Vol. 23 pp. 383 – 389.
4. Sreerambabu . J & Narasimhan. S.L (2001), "Effect of non homogeneity of soil on Framed Structures testing on Isolated Footing" Proceedings of National Seminar on Soil Structure Interaction pp. 87 – 96.
5. Genda & Franklin (2000), "Soil Structure Interaction Effect on Active Control of Multi – storey Buildings Under Service Loads", Journal of Structural Engineering & Mechanics Vol. 10 No.6 pp 517 – 532.

