Soil - Pile Nonlinear Interaction

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Abstract— Present study is carried out the nonlinear interaction of soil-pile and pile cap, study shows the behavior of soil and pile under the working load condition. The 8-story plane frame is constructed using Software ANSYS and a 2D plane of soil and pile is created using Beam188 and Plane 183 element. In this analysis beam-columns are of size 300mm *300 mm and piles are of 400mm having its pile cap of width 2m and thickness of 300mm is considered. Soil of medium stiffness having modulus of elasticity E-15, E-35 and E-65 is considered. Load of 40Kn/m of dead load and live load and seismic load as per IS:1893 (Part I):2002 considering of zone V is applied on 8-story plane frame .The analysis is carried-out using Finite Element Analysis (contact surface pairing) to evaluate the interaction between Soil-pile. The results are evaluated in the form of X- Displacement, Y-Displacement, von misses stress contour, Contact Pressure and their contact status. From the results conclusion is made that soil having Young's modulus of elasticity E-35 shows greater stiffness that than E-15 and E-65.these results are shown by graphically and the contour diagrams of the respective analysis for different types of soil. At the end the future scope of the project is discussed with references.

Key words: Non Linear Interaction, Soil and Pile, Pile Cap, ANSYS, Stiffness and Finite Element Analysis

I. INTRODUCTION

A. Introduction

In case of the civil engineering structures foundation involves with direct contact with Soil.The foundation of a structure resting on a settable soil mass under goes differential settlement which alters the forces in the structural elements significantly. In case of analysis of multistory building, the seismic loads and wind loads are necessary to take as design loads and the building frame, foundation and soil mass are considered to act as single, compatible structural unit. The linear or nonlinear behavior of soil mass is main cause of differential settlement which redistributes the forces in the elements of the structure mainly in the beams and column. When the external forces such as earthquake act on these systems, the structural displacements and the ground displacements both are independent of each other. The processing which the response of the soil affects the motion of the structure and the motion of the structure affects the response of the soil is termed as Soil-Structure Interaction (SSI).

B. Soil Properties

Various soil properties used for linear and nonlinear interaction analysis are given below:

C. Motivation behind the Study

The building frame and its foundation along with the soil on which it rests, together constitute a complete structural system. In the conventional analysis, a structure is analyzed as an independent frame assuming unyielding supports and the interactive response of soil foundations disregarded. This kind of analysis does not provide realistic behavior and sometimes may cause failure of structure. Thus it is essential to consider the soil-structure interaction effect especially in case of high rise buildings. The resulting differential settlements of soil mass are responsible for the redistribution of forces.

D. Objectives of the Study

- Analysis of the Soil-Pile interaction using Contact Pairing by considering the linear material but nonlinear analysis.
- Comparing the results of different soil.

II. LITERATURE SURVEY

Following are the brief description on the works already done on the soil-structure interaction:

Mohebkhah et al. (2008) proposed a two-dimensional numerical model utilizing the specific discrete component system (DEM) programming UDEC (2004) produced for the nonlinear static examination of stone work infilled steel outlines with openings subjected to in-plane monotonic stacking. In this study, pivot and the vast removals between brick work pieces are contemplated. It was found that the model can be utilized absolutely to foresee joint breaking design, breakdown load. It can be investigate the conceivable disappointment methods of workmanship Infilled steel outlines with a given area for openings and relative zone. Results from the numerical displaying and past test ponders found in the writing and both are analyzed which demonstrates a decent relationship between's them. Moreover, a nonlinear examination was completed to research the impact of door jamb on transverse burden limit and firmness of in filled edges with a focal opening.

III. METHODOLOGY

A. Introduction

The methodology adopted in modeling and analysis of an eight storey building frame has been discussed in this chapter. ANSYS software is used for analyzing the frame with and without considering structure-soil interaction. The overview of the program in the form of flow chart has been detailed.

B. Properties of Frame

1) Geometrical Properties

S. No	Structural components	Properties and size of the components
1.	All floor and plinth beam	0.3m*0.3m
2.	Columns	0.3m*0.3m

3.	Footings	2m*2m*1m
4.	Number of bays	3
5.	Number of storeys	8
6.	Floor beam and plinth beam uniformly distributed loading	40kN/m
7.	Depth of soil	5.0m

Table 1: Geometrical properties of the super structure and foundation

2) Material Properties

The material of super-structure and foundation i.e. concrete is considered to behave in linear elastic manner. Table 2 shows the material properties of the structure and soil.

S. No.	Structural components	Properties and size of components
1.	Modulus of elasticity of concrete (N/mm2)	2.17 x 107 kN/m2
2.	Poisson's ratio of concrete	0.15

Table 2: Material properties of the structure and soil

C. Properties of Soil

The elastic constants for different types of soil used in interaction analysis are given in Table 3.

Soil Type	Soil Designation	Modulus of Elasticity (kN/m^2)	Poisson ratio
Hard	E-65	65000	0.35
Medium Hard	E-35	35000	0.4
Soft	E-15	15000	0.4

Table 3: Soil Elastic Constant

D. Design Loads

The building frame is analyzed for the gravity loads and seismic load.

1) Gravity Load

The floor beam and plinth beams carry a UDL of 40 kN/m including dead load and live load.

2) Seismic Load

The seismic loads are evaluated considering the structure located in seismic zone V of Indi aand using static method as per IS:1893 (Part I):2002. The parameters used for estimation of seismic forces are provided in Table 3.4

S. No.	Parameters/ Particulars	Value/Type
1.	Seismic Zone	V
2.	Seismic Intensity	Severe
3.	Zone factor	0.36
4.	Type of soil	Medium
5.	Importance factor	1.0
6.	Type of building	Moment resisting
7.	Response reduction facto	5.0

Table 4: Parameters used for estimation of seismic forces

IV. Finite Element Analysis on Soil-Pile Interaction

A. Introduction

In this chapter the finite element analysis has been carried out using the software ANSYS.Three types of cases are taken into consideration:

- Soil pile interaction analysis considering soil of E-65.
- Soil pile interaction analysis considering soil of E-35.
- Soil pile interaction analysis considering soil of E-15.

B. Design Load Calculation

1) Gravity Load

A uniformly distributed load of 40 kN/m is taken as dead load & live load.

2) Seismic Load

Total seismic weight of the structure (W) = 8x40x16=5120 kN.

a) EL in X-direction

$T = 0.09h/\sqrt{d}$ $T = 0.09x23/\sqrt{16}$ $T = 0.5175$ sec

The building is located on Type II (medium soil).

From figure 2 of IS: 1893, for T= 0.5175 sec, Sa/g = 2.5

$$Ah = \frac{ZI}{2R} \times \frac{sa}{g} \qquad Ah = \frac{0.36\times1.0}{2\times5} \times 2.5$$

$$Ah = 0.09$$

Design Base Shear (Vb) = A_h x W

= 0.09 x 5120 = 460.80kN

Lateral Load Distribution with height by the Static Method is calculated in Table 5.

Storey Level	Wi (kN)	hi (m)	Wi x hi2 x 1000	Wihi^2/Σ Wihi^2	Lateral Load (Pi)
8	640	23	338.56	0.325	P8= 149.76
7	640	20	256.0	0.246	P7= 113.357
6	640	17	184.96	0.178	P6= 82.022
5	640	14	125.44	0.120	P5= 55.296
4	640	11	77.44	0.074	P4= 34.099
3	640	8	40.96	0.039	P3= 17.971
2	640	5	16	0.015	P2= 6.912
1	640	2	2.56	0.002	P1= 0.922
0	640	0	0	0	0
Σ	5120		1041.92	1.000	460.339

Table 5: Lateral load distribution by Static method

C. Modelling of building frame

Various geometrical and material parameters used in modelling of the building frame are shown in table 6.

S. No	Structural components	Size	Elastic Modulus (Es) kN/m^2	Poisson Ratio (μ)	Element Used
1.	All floor and plinth beam	0.3*0.3m	2.17 x 10^4	0.15	Beam 188
2.	Columns	0.3*0.3m	2.17 x 10^4	0.15	Beam 188
3.	Footings	3.0mx 3.0mx1.0m	2.17 x 10^4	0.15	Plane 183
4.	Soil-65	10m Depth	65000	0.3	Plane 183
5.	Soil-35	10m Depth	35000	0.4	Plane 183
6.	Soil-15	10m Depth	15000	0.4	Plane 183

Table 6: Parameters used in modelling of the building frame

D. Description of the Elements

To carry out the nonlinear interaction analysis Beam 188 element is used to model the frame and Plane 183 element is used to model the soil, pile and its pile cap .Three types of soil having different modulus of elasticity E-65, E-35and E-15 are considered.

In this analysis to carry out the non-linear analysis contact between the soil and pile is created and the results of the analysis is in the form of Von mises stress contours, Displacement along X direction and Displacement along Y direction, Contact Pressure, and Contact status.

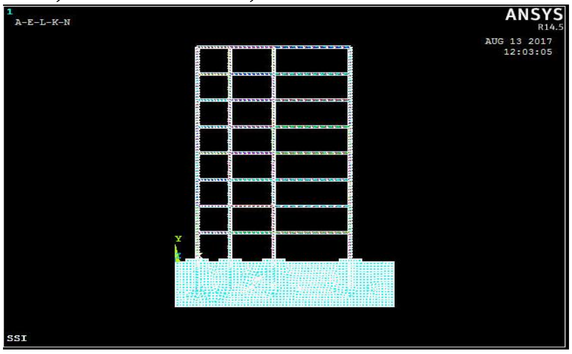

Fig. 1: Discretised model of frame for NLIA

V. RESULT DISCUSSION AND CONCLUSION

In this chapter the results of analysis are discussed for the four cases NLIA-65, NLIA-35 and NLIA-15. The main outcomes are:

- Comparison of displacements in X-direction at different footings.
- Comparison of displacements in Y-direction at different footings.
- Comparison of Vonmises at different footings.
- Comparison of Contact pressure at different footings.

A. *X-Direction Displacements*

Type of Soil	E-65	E-35	E-15
X-Displacement in (mm)	0.15	0.05	1.85

Table 7: X-Displacement in (mm)

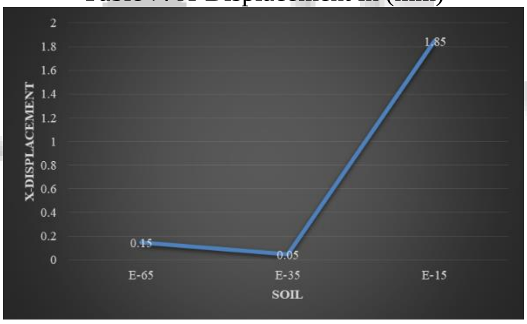

Fig. 2: X-Direction displacement of various soil

B. *Y-Direction Displacements*

Type of Soil	E-65	E-35	E-15
Y-Displacement in (mm)	0.00925	0.01525	0.245

Table 8: Y-Displacement in (mm)

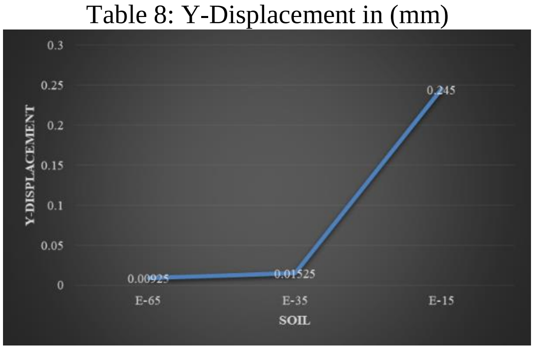

Fig. 3: Y-Direction displacement of various soil

C. *Vonmisses stress*

Type of Soil	E-65	E-35	E-15
Vonmises (Mpa)	14.62	1.82	57.90

Table 9: Vonmises Stresses

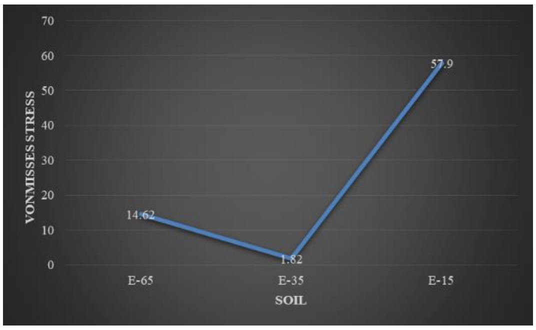

Fig. 4: Vonmisses of various soil

D. *Contact stresses*

Type of Soil	E-65	E-35	E-15
Contact Stresses (Mpa)	5.35	0.60	14.62

Table 10: Contact Stresses

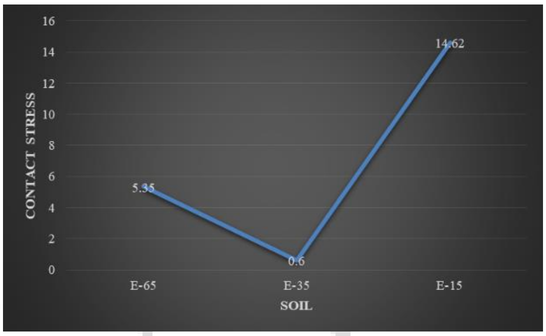

Fig. 5: Contact stresses of various soil

VI. CONCLUSIONS MADE FROM THE OBSERVATION

1) Maximum displacement in x-direction and in Y-direction is on soil having modulus of elasticity E-15.
2) Contact stresses of soil E-65 are 16% higher than E-35 soil and Contact stresses of E-15 soil are 2.73 times higher than E-65 soil.
3) Vonmisses stresses of E-65 are 8 times higher than E-35 soil and vonmisses stresses of E-15 soil are 4 times higher than E-64 soil.
4) Soil E-35 shows more stiffness than E-65 and E-15.

VII. SCOPE FOR FUTURE WORK

1) In this work linear interaction analysis has been carried out. For more realistic work a space frame may be analyzed.
2) Nonlinear interaction analysis can be carried out considering the nonlinear behavior of the soil.
3) A layered soil mass can be taken in place of homogeneous soil mass.
4) Raft foundation can be used in place of isolated column footing.
5) Analysis can be carried out considering wind load effect.
6) Effect of infills can be investigated.

REFERENCES

[1] A.I.M. Aljanabi, B.J.M. Farid, and A.A.A. Mohamed, Interaction of plane frames with elastic foundation having normal and shear moduli of subgrade reactions, Comput. Struct., 36(6), 1990, 1047-1056.

[2] Ramakant Agrawal, M.S. Hora, Nonlinear interaction behaviour of plane frame-layered soil system subjected to seismic loading, Int. J. Struct. Eng. Mech., 41(6), 2012.
[3] Ramakant Agrawal, M.S. Hora, Coupled finite-infinite elements modelling of building frame-soil interaction system ARPN Journal of Engineering and Applied Sciences., 41(6), 2012, 711-734.
[4] Agrawal R. and Hora M.S., Effect of differential settlements on nonlinear interaction behaviour of plane frame-soil system. ARPN Journal of Engineering and Applied Sciences.5(7), 2010, 75-87.
[5] D. K. Jain, M. S. Hora, Interaction analysis of space frame-shear wall-soil system to investigate foundation forces under seismic loading, ARPN Journal of Engineering and Applied Sciences., 9(8), 2014, 1267-1281.
[6] M. Hora, Nonlinear interaction analysis of infilled building frame-soil system, J. Struct.Eng., 33(4), 2006, 309-318.
[7] Ramakant Agrawal, Vivek Garg, M.S. Hora, Collapse load assessment for infilled framesoil media interaction system, Int. J. Civil Eng., 1(2), 2009, 101-109.
[8] Garg Vivek and Hora M.S., Interaction effect of space frame-strap footing-soil system on forces in superstructure, ARPN Journal of Engineering and Applied Sciences, 7(11), 1402-1415.
[9] J. Noorzaei, Concepts and application of three dimensional infinite elements to soilstructure-interaction problems, Int. J. Eng., 9(3), 1996, 131-142.
[10] M.A. Al-Shamrani, and F.A. Al-Mashary, A simplified computation of the interactive behavior between soils and framed structures, Eng. Sci., 16(1), 2003, 37-60.
[11] R. Roy, K. Bhattacharya, and S. C. Dutta, behavior of grid foundation under static gravity loading, J. Inst. Eng. (India),85, 2005, 261-268.
[12] H. S. Chore, R. K. Ingle, and V. A. Sawant, Building Frame- pile foundation- soil interaction analysis: a parametric study, J. Interact. Multiscale Mech., 3(1), 2010, 861-878.
[13] T. Guzman, heavily loaded strap footing design, detailing and behavior, Structure Magzine, 2010, 12-15.
[14] D. Thangaraj and K. Ilamparuthi, parametric study on the performance of raft foundation with interaction of frame, Electron. J. Geotech. Eng., 15, 2010, 861-878.
[15] Y. Xiujuan, X. Zongxiang, Z. Lisong, and Y. Xiangzhen, 3D simulation of weak foundation for good-sized oil storage tank, Proc. Of International Conference on Mechanic Automation and Control Engineering, China, 2010, 1345-1348.
[16] H. M. Rajshekhar Swamy, Krishnamoorthy, D. L. Prabakhara, and S. S. Bhavikatti, Relevance of interface elements in soil structure interaction analysis of three dimensional and multiscale structure on raft foundation, Electron. J. Geotech. Eng., 16, 2011, 199-218.
[17] J.M. Duncan, and C.Y. Chang, Nonlinear analysis of stress and strain in soils, J. Soil Mech. Found. Eng. Div. ASCE, 96(5), 1970, 1629-1653.

