ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 9, Issue, 2(F), pp. 24147-24149, February, 2018

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

ANALYSIS OF PLANE FRAMES RESTING ON PILED AND RAFT FOOTINGS WITH SOIL PARAMETERS

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DOI: http://dx.doi.org/10.24327/ijrsr.2018.0902.1606

ARTICLE INFO

Article History:

Received 16th November, 2017
Received in revised form 25th December, 2017
Accepted 23rd January, 2018
Published online 28th February, 2018

Key Words:

Piled foundation, stiffness, boundry conditions, ANSYS.

ABSTRACT

A piled raft foundation consists of a thick concrete slab reinforced with steel which covers the entire contact area of the structure, in which the raft is supported by a group of piles or a number of individual piles. Bending moment on raft, differential and average settlement, pile and raft geometries are the influencing parameters of the piled raft foundation system. The mutual interaction between the soil, foundation and superstructure is dependent on various parameters including the type and configuration of the structure, type of foundation, type of soil, loading etc. This paper attempts to quantify this interaction effect for plane frame structures resting on two types of foundations viz. piled foundations and raft foundations. The study is made based on the finite element approach with the help of the finite element package ANSYS.

A linearly elastic model for structure and a linearly elastic plane strain model for soil is used for the analysis. The variation of stresses for the various components of the frame and footing are analysed for a range of parameters. Non-dimensional tables are arrived at incorporating the parameters under consideration, which may be used to study the effect of inclusion of soil in the analysis for plane frames. The results obtained from this study are compared with the conventional method of analysis. The results obtained from the study suggests that there is some variation due to the inclusion of soil in the analysis but it is very small and thus may not considerably affect the design of such structures except a few locations, where the stresses do not govern the design.

INTRODUCTION

In the conventional method of structural analysis adopted for practical design, the effect of compressibility of soil is ignored. The superstructure and footings are designed based on the assumption that they are resting on un-yielding soils or on the assumptions that the bottom ends of columns are either fixed or hinged. Foundations, however, are subjected to concentration of loads, which may induce high pressures in soil causing considerable soil deformations. This might result in an under estimation of design forces in some members leading to unsafe design. For a realistic estimation of these deformations and design forces, it is necessary to carry out an analysis considering soil structure interaction. Until recently, such analyses were carried out only for very important structures like atomic reactors mainly due to the computational requirements.

Very few authors have investigated about the effect of soil mainly due to the high indeterminacy associated with such problems. A full-scale three-dimensional analysis of such systems needs heavy computing requirements, which till recently was not available. Previous studies based on simplified 2D models have reported that soil structure interaction can have serious effects on plane-framed structures. The present study is an investigation into the behaviour of plane frame structures resting on two different types of foundations, piles on strip raft and raft footings. In the present work, analysis is performed on plane strain models including the effect of soil lying beyond the foundation level.

Background

Brain and yean (1996) studied the effect of the sequence of construction on the interaction behaviour of space frame raft soil systems and found that the effective stiffness of a building during construction is about half the stiffness of the completed structure. Viladkar *et al* (1993) examined the effect of linear soil creep with regard to differential settlement of 3D structures. J.Sreeram babu(2002) studied the influence of soil

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structure interaction behaviour of plane frame parameters for various types of soils. In soil structure interaction problem, modeling of the soil to represent its real behaviour is very important. The types oF discrete and continuum models have been studied. Finite element packages like ANSYS are also available which can be used to analyze any type of systems with any boundary conditions and discretisation

Modelling and Analysis

A three dimensional linearly elastic plane strain finite element model is created for the purpose of analysis. The superstructure, footings and piles are modeled using 20 noded isoparametric elements with three displacement degrees of freedom at each node, i.e. translations in x, y, z directions (Fig 1). The material is taken as M 20 concrete and the connections between superstructure, footings and piles are assumed fully adhesive. The soil medium is modeled using two types of elements. The soil surrounding the piles are modeled using 8 noded isoparametric elements with three displacement degrees of freedom at each node (Fig 2). The soil lying beyond the piles are modeled using 10 noded tetrahedral isoparametric elements, also with three displacement degrees of freedom at each node (Fig 3). The total width of soil medium considered is six times the clear small and depth equal to five times the clear span of the frame. Plane strain condition is imposed on unit width (equal to the c/c distance of frames in the perpendicular direction) of soil mass. This is achieved by arresting the displacements of the soil mass in the direction perpendicular to the plane of the frame. The vertical displacements along the bottommost boundaries are restricted.

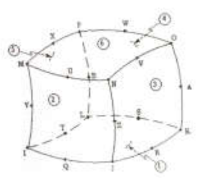


Fig 1

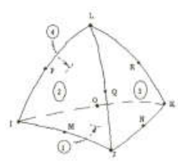


Fig 2

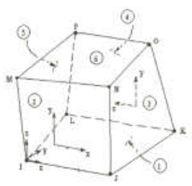


Fig 3

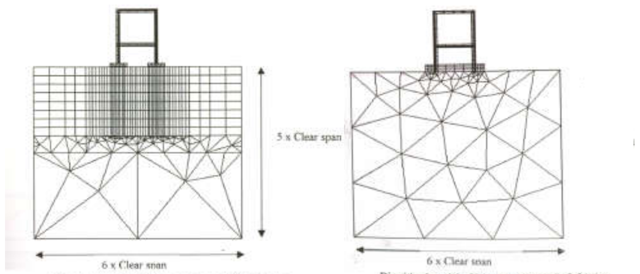
The following are the assumptions made in the study.

1. Both the superstructure and soil mass are assumed to behave in a linearly elastic fashion. The Young's modulus of the material of the superstructure and foundation (Ec) are taken to that corresponding to M-20 concrete. The Young's modulus of soil (Es) is fixed in such a way that the E ratio, Ec/Es, varies from a value of 200 to 1500, which represents the realistic values for most of the practical cases encountered for soil.
2. All materials are assumed to homogenous and isotropic
3. The contact pressure distribution is assumed to be uniform
4. The connections between the superstructure foundation and soil are assumed to be perfectly adhesive, hence satisfying full compatibility
5. Plane strain models are used instead of full three dimensional models
6. No lateral loading is considered, as under normal circumstances, the chances of lateral loading for single and two storied frames are sparse
7. The effect of soil mass lying above the foundation level is neglected

The various parameters considered for the study are

1. Young's modulus of concrete (Ec), corresponding to M 20 concrete
2. Young's modulus of soil (Es), corresponding to Ec/Es = 300, 600, 1200, 1700
3. Poisson's ratio 0.15 for concrete and 0.3 for soil
4. Span/strip footing width =2
5. Pile depth / span 1 & 2
6. MI of beam / MI of column = 1
7. Beam depth / footing depth = 1
8. Span / footing depth = 2
9. No of bays & floors –single bay single storied with pile foundations & single bay single storied plane frames with raft footing

The discritized models are shown below



Discritized model of Frame resting on pile footings

Discritized model of Frame resting on Raft footing

RESULTS

The results obtained from the above analyses were compared with that obtained from conventional analysis, i.e. considering the bottom of columns are fixed. For the purpose of comparison, the ratio of direct stresses obtained from the present analysis to the conventional method ($\sigma_{IA}/\ \sigma_{CA}$) is computed along the top and bottom portion of beams where direct stresses are maximum. The results are presented in the form of non-dimensional tables for both the cases under study (see Appendix 1).

From the results it can be concluded that the direct stress ratios, which is an indication of the effect of inclusion of soil in the analysis, does not vary considerably for the cases studied and the values are in fact quite close to 1. Also as the Pile depth to span ratio increases, the effect is still smaller as expected. The same is the case when Raft depth to the beam depth ratio increases. This may be attributed to the increase in the stiffness of the raft when the depth is more. It is also observed from the results that the interaction effect does not vary much with change in the Ec/Es ratio.

Appendix – I

Frames Resting on Piled Foundations

Direct stress ratio ($\sigma_{IA}/\ \sigma_{CA}$) along Plinth Beam

Pile depth / span = 1				
Ec/Es	**X/L**	**0**	**0.5**	**1.0**
300	Top	1.0226	1.0223	1.0105
	Bottom	0.9960	1.0767	0.9994
600	Top	1.0011	0.9995	1.0010
	Bottom	0.9975	1.0015	0.9976
1200	Top	1.0227	1.0223	1.0015
	Bottom	1.0253	0.9998	1.0154
1700	Top	1.0319	0.9978	1.0118
	Bottom	1.0118	0.9914	1.0119
Pile depth / span = 2				
Ec/Es	X/L	0	0.5	1.0
300	Top	1.0016	1.0339	1.0022

	Bottom	0.9876	1.0198	0.9889
600	Top	1.0018	1.0028	1.0007
	Bottom	0.9921	1.0080	0.9922
1200	Top	1.0019	0.9989	1.0024
	Bottom	0.9996	0.9998	0.9999
1700	Top	1.0029	1.0032	1.0041
	Bottom	1.0070	1.0073	1.0082

Direct stress ratio (σ_{IA}/ σ_{CA}) along First Floor Beam

Pile depth / span = 1				
Ec/Es	**X/L**	**0**	**0.5**	**1.0**
300	Top	1.0027	0.9979	1.0027
	Bottom	1.0033	0.9973	1.0032
600	Top	1.0005	1.0001	1.0007
	Bottom	1.0006	1.0008	1.0010
1200	Top	0.9979	1.0030	0.9982
	Bottom	0.9982	1.0040	0.9975
1700	Top	0.9988	1.0071	0.9999
	Bottom	0.9966	1.0063	0.9987
Pile depth / span = 2				
Ec/Es	X/L	0	0.5	1.0
300	Top	1.0046	0.9986	1.0056
	Bottom	1.0057	0.9966	1.0066
600	Top	1.0050	0.9991	1.0040
	Bottom	1.0066	0.9975	1.0045
1200	Top	0.9998	1.0009	0.9998
	Bottom	0.9978	1.0053	0.9948
1700	Top	0.9989	1.0038	0.9989
	Bottom	0.9955	1.0063	0.9964

Frames Resting on Raft Foundations

Direct stress ratio (σ_{IA}/ σ_{CA}) along Plinth Beam

Raft depth / Beam depth = 1				
Ec/Es	**X/L**	**0**	**0.5**	**1.0**
200	Top	1.0001	1.0128	0.9999
	Bottom	0.9636	1.0294	0.9640
500	Top	1.0001	1.0133	0.9998
	Bottom	0.9620	1.0306	0.9628
1000	Top	1.0001	1.0137	0.9998
	Bottom	0.9609	1.0315	0.9618
1500	Top	1.0001	1.0139	0.9998
	Bottom	0.9604	1.0319	0.9613
Raft depth / Beam depth = 2				
Ec/Es	X/L	0	0.5	1.0
200	Top	1.0001	1.0120	1.0000
	Bottom	0.9658	1.0277	0.9660
500	Top	1.0001	1.0121	1.0000
	Bottom	0.9654	1.0281	0.9656
1000	Top	1.0001	1.0122	1.0000
	Bottom	0.9652	1.0282	0.9655
1500	Top	1.0001	1.0122	1.0000
	Bottom	0.9651	1.0283	0.9654

Direct stress ratio (σ_{IA}/ σ_{CA}) along First Floor Beam

Raft depth / Beam depth = 1				
Ec/Es	**X/L**	**0**	**0.5**	**1.0**
200	Top	1.0113	0.9896	1.0112
	Bottom	1.0142	0.9864	1.0144
500	Top	1.0118	0.9891	1.0116
	Bottom	1.0148	0.9858	1.0105
1000	Top	1.0121	0.9888	1.0119
	Bottom	1.0152	0.9854	1.0155
1500	Top	1.0123	0.9887	1.0121
	Bottom	1.0154	0.9852	1.0157
Raft depth / Beam depth = 2				
Ec/Es	X/L	0	0.5	1.0
200	Top	1.0106	0.9902	1.0105
	Bottom	1.0134	0.9872	1.0135
500	Top	1.0107	0.9900	1.0107
	Bottom	1.0136	0.987	1.0137
1000	Top	1.0108	0.9900	1.0107
	Bottom	1.0137	0.9869	1.0138
1500	Top	1.0108	0.9900	1.0107
	Bottom	1.0137	0.9869	1.0138

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How to cite this article:

Padmanaban M S and Sreeram Babu J.2018, Analysis of Plane Frames Resting on Piled and Raft Footings With Soil Parameters. *Int J Recent Sci Res.* 9(2), pp. 24147-24149. DOI: http://dx.doi.org/10.24327/ijrsr.2018.0902.1606

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