EXPERIMENTAL STUDY OF BUILDING FRAME 2X2 PILE GROUPS EMBEDED IN COHESIONLESS SOIL

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Abstract— This works presents experimental study of model building frame supported by 2x2 pile groups embedded in cohesionless soil (sand) through the results of static vertical load tests. The experimental investigation model plane frame supported by pile groups embedded in cohesionless soil (sand) under the static loads (central concentrated load, uniformly distributed load (UDL) and eccentric concentrated load) is necessary to establish the fact that the soil interaction greatly alters the design parameters. The effect of soil interaction on displacements and settelement and rotation at the column base and also the shears and bending moments in the building frame were investigated.Results revealed that, shear force and bending moment values which were back calculated from the experimental results,showed considerable reduction of the ssi.

The need for consideration of soil interaction emphasized by comparing the behavior of the frame obtained from the experimental analysis with that of conventional method of analysis. Many numerical works and comparative studies are available on pile foundation, but comparatively little experimental work was reported on the analysis of framed structures resting on pile foundations to account for the soil-structure interaction.

The experimental results have been compared with those obtained from conventional method of analysis. The results reveal that the conventional method gives the shear force in the column by about 20%, the bending moment at the column top about 10%, and at the column base about 20% to 30%, more than those from the experimental results. The response of the frame from the experimental results is in good agreement.

Key Words — Building frame, cohesionless soil, nonlinear analysis, soil structure interaction,Pile goups.

1INTRODUCTION

1.0. General

Pile foundations are generally preferred when heavy structural loads have to be transferred through weak subsoil to firm strata. Building frames supported by pile foundations exposed to wind loads also fall under the category of the structures/substructures subjected to lateral loads. The problem of laterally loaded piles or pile group involves particularly the complex soil-structure interaction between the piles and pile cap. Soil settlement is a function of the flexural rigidity of the superstructure. The influence caused by the settlement of the supporting ground on the response of framed structures was often ignored in a structural design. The structural stiffness can have a significant influence on the distribution of the column loads and moments transmitted to the foundation of the structure.

1.1 Soil Structure interaction under static loads

Numerous studies have been made on the effect of soil structure interaction under static loading. These studies have considered the effect in a very simplified manner and demonstrated that the force quantities are revised due to such interaction. Several studies, experiments and research works have been carried out since a long time all over the world to understand and to evaluate the effect of pile soil interaction. Very few authors have done their research on behaviour of high rise building along with the soil pile interaction. Hence, taking in view the above research the further study in this paper is carried out on high rise building. Therefore, the author is trying to find the actual behaviour of the structure with the soil pile interaction in terms of forces, displacements and moments.

1.2. Interactive Behaviour between Soils and Framed Structures

In current design practice, structural engineers usually disregard any influence that the settlement of the supporting ground may have on the response of framed structures. Likewise, in foundation design, analysis of actual settlements is based upon a flexible loading pattern with no assessment of the effect of the stiffness of the structure on the patterns and magnitudes of foundation settlements. Although this procedure of neglecting the coupling or interaction between soil and structure tends to simplify the mathematical analysis of the problem, it is, however, an oversimplification of reality.

1.3. Non-Linear behaviour of soil

Though most of the analyses consider the behaviour of soil as linear, in practice the soil behaves in the non-linear fashion. The non-linear behaviour of soil can be represented by three dimensional constitutive models; but this will be expensive in terms of computational resources and memory requirement. Analyses of soil-structure interaction frequently involve the prediction of deformations and stresses, both in the surrounding soil mass and over areas of contact with the loading boundaries. In recent years it has become possible to compute solutions with increasingly complex descriptions of the soil properties. However, the use of non-linear calculations in engineering practice is restricted by time and cost. Moreover high quality stress-strain data are difficult to obtain. There is therefore a need for sensitivity studies using advanced soil models to investigate the significance of various features of soil behaviour such as non-linearity at small strains and local failure.

2. LITERATURE REVIEW

This litrarure review presents the brief review of Literature presented by various authors related to SSI.

In 1987, **R. J. Jardine, D. M. Potts, A. B. Fouriet and J. B**. **Burland** have done their investigation on Studies of the influence of non-linear stress-strain characteristics in soil-structure interaction. Recent field and laboratory studies have shown that, even at very small strains, many soils exhibit non-linear stress-strain behaviour. In this Paper the measured non-linear stress-strain properties of low plasticity clay are used in the finite element analysis of footings, piles, excavations and pressure meter tests to assess the influence of small strain non-linearity in comparison with linear elastic behaviour.

In 1997, **Jaswant N. Arlekar, Sudhir K. Jain and C.V.R. Murty** have done investigation on Seismic Response of RC Frame Buildings with Soft First Storeys. Open first storey is a typical feature in the modern multistorey constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes.

In 1998, **Daniel Wayne Wilson** has done his investigation on Soil-Pile-Superstructure Interaction in Liquefying Sand and Soft Clay. The behaviour of pile foundations under earthquake loading is an important factor affecting the performance of many essential structures. In 2001, **Mosleh A. Al-Shamrani and Faisal A. Al-Mashary** have done their investigation on A Simplified Computation of the Interactive Behavior between Soils and Framed Structures. In 2008, **Mustafa Kuntanis and Muzaer Elmas** have done their investigation on Non-Linear Seismic Soil-Structure Interaction Analysis Based on the Substructure Method in the Time Domain. To investigate the effects of SSI the following types of analysis were performed: linear SSI analysis and non-linear SSI analysis. In 2009, **Hamid Zolghadr Zadeh Jahromi** has done his investigation on Partitioned Analysis of Nonlinear Soil-Structure Interaction. the aim of this work has been to develop advanced numerical methods for nonlinear coupling of soil-structure interaction problems, where the partitioned approach is adopted as a framework for coupling field-specific tools with minimal intrusion into codes.

In 2012, **H.S. Chore, R.K. Ingle and V.A. Sawant** have done their investigation on the parametric study of laterally loaded pile groups using simplified F.E. Models. The results obtained using the simplified approach of the F.E. analysis are further compared with the results of the complete 3-D F.E. analysis published earlier and fair agreement is observed in the either result.In 2012**, S.A.Rasal, Chore H.S, P.A.Dode** have done their investigation on interaction frame with pile foundation. The effect of soil structure interaction on response of the three storeyed building frame supported on pile foundation is reported in this paper.

3. EXPERIMENTAL PROGRAM

3.1Frame and Pile Groups

Using the scaling law proposed by Wood et al. (21) the material and dimensions of the model were selected

$$\frac{E_m I_m}{E_p I_p} = \frac{1}{n^5}$$

where Em is modulus of elasticity of model, Ep is modulus of elasticity of prototype, Im is moment of inertia of model, Ip is moment of inertia of prototype, and 1/*n* is scale factor for length. An aluminum round rod with diameter of 12 mm was selected as the model pile with a length scaling factor of 1/10. This is used to simulate the prototype pile of 300 mm diameter solid section made of reinforced concrete of M40 grade. Square aluminium rods of size 12mmx12mm was selected as model beam and columns .This is to simulate columns of height 3.2 m, beam of span 5 m of M20 grade concrete and Fe415 grade steel. Aluminum plates of 12 mm thickness were used as the pile caps. In the pile group setup, pile spacing of eight diameter (8D) was adopted and the length of the piles was so selected as to maintain a length to diameter (L/D) ratio of 30. A sufficient free standing length (of about 20 mm) was maintained from the bottom of the pile cap to the top of the soil bed, because the pile cap is modeled as rigid and its interaction with the soil is neglected. Beam column junctions were made by welding for the fixed condition. Screwing of the piles and columns in the threads provided in the pile cap leads to partial fixity condition.

Fig.1 Photograph of Instrumented Model frame setup

3.2 Experimental procedure

Static vertical loads were applied on the model frame by placing weights on the hangers. The loads were applied in increments and were maintained for a minimum period to allow the deflection to stabilize. During the application of static loads, the lateral, vertical displacements at the base of the column and the rotation of the pile cap were measured using the instrumentation setup.

Testing Phases:

Static vertical load tests were conducted on the model frame supported on pile groups embedded in the sand bed. Tests were conducted for the following cases:

1. Central concentrated load is applied in increments (1, 2, 3 kg up to 30kg) at the centre of the beam.
2. Uniformly distributed load (UDL) is simulated by loading the beam at third points with equal loads in increments (3, 6, 9 kg up to 45kg.).
3. Eccentric concentrated load is applied in increments (1, 2, 3 kg up to 30kg.) at a nominal eccentricity of 10% of the span of the beam

4. ANALYTICAL PROGRAMME

The analysis of the model plane frame is carried out using ANSYS for the following cases:

i) Frame with fixed bases to evaluate the shear force and bending moment in the column, which is the usual practice done known as the conventional method.

ii) Frame with bases released by imposing the lateral displacements, vertical displacements and rotations measured from the experiments for the corresponding loading on the frame to get the back figured shear forces and bending moments generated in the beam and columns.

4.1. BEAM 4: Element Description

BEAM4 is a uniaxial element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses.

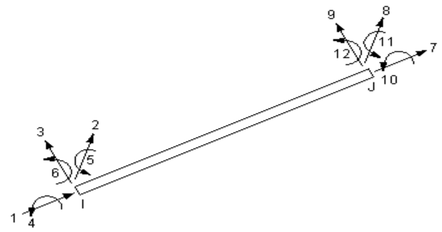


Fig 2: Order of Degrees of Freedom for BEAM 4 element

4.2 Modeling

The building frame is modeled in the ANSYS. Conventional method of bases fixed condition and displacements are applied at the base of the frame for the Ansys model for obtaining shear forces and bending moments in the frame. This is shown in the figure 3.

4.3 Spacing 4d pile groups

In this the analysis of the building frame is done by applying lateral displacement, settlement and rotation at the base of the column of building frame model and load corresponding to this displacements is applied on frame and analyzed for shear forces and bending moments in the frame. This analysis is done by restraining the whole frame in the Z-direction by restraining 'uz' value at the four corners of the frame. This is shown in the figure 4.

4.4 Procedure

The building frame is modeled in ANSYS using beam 4 elements. The conventional method is done in ANSYS by doing frame with fixed bases and applying corresponding load such as centre point load, uniformly distributed load and eccentric load on the Ansys model of building frame created in ANSYS. The shear forces and bending moment values in the frame are obtained for the conventional method from ANSYS.

The lateral displacement, settlement and rotation at base of frame obtained from experiment is given in the Ansys model of building frame at the base of the frame for each type of load as central point load, uniformly distributed load and eccentric load and load corresponding to the displacements is applied on the building frame model and analyzed for shear forces and bending moments for the corresponding condition. The shear force and bending moment's values in the frame are obtained from ANSYS.

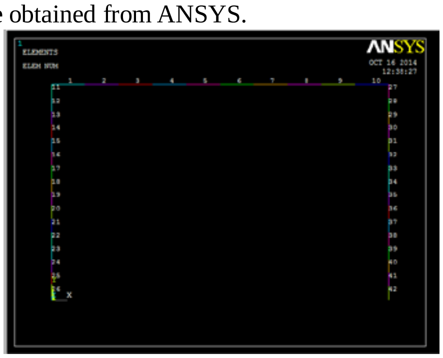


Fig 3: Ansys model of building frame

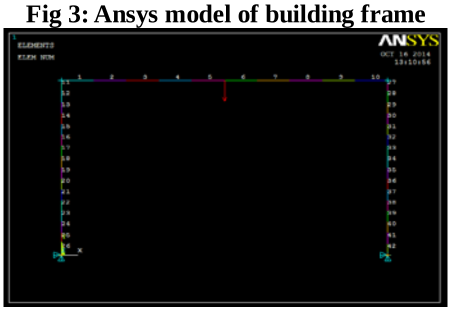


Fig 4: Ansys model with static loads by applying dis placements ,settelements,rotations at base of frame

5. RESULTS AND DISCUSSION

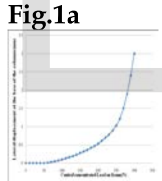
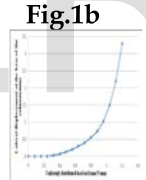
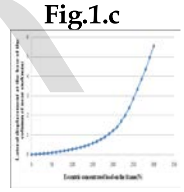
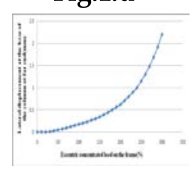
This presents the results obtained from experiment and ANSYS. The lateral displacement, settlement and rotations obtained from experiment for each type of load are presented in this chapter. The shear forces and bending moments obtained from the ANSYS software for conventional method and for the spacing done by applying displacement values at base of frame are also presented in this.

5.1 Lateral displacement, Settlement and Rotation at the base of the column from the experiment

Figures 4.1a and 4.1b represent the variation of lateral displacement with the static load applied on the frame as central concentrated load and uniformly distributed load. Figures 4.1c and 4.1d are the plots showing the variation of lateral displacement with the eccentric concentrated load applied at the near end and far end, respectively.

From the plots shown herein, it is observed that, for relatively lower loads on the frame, the lateral displacements predicted by all the three methods are nearly the same. For higher loads on the frame, the lateral displacements predicted by the experiment deviate significantly. This clearly indicates that soil structure interaction over estimates the capacity of the structure indicating lower displacements than the actual. The lateral displacement from the experiment is 24.84-52.24% more than that by the conventional in the vicinity of the failure load on the frame. The displacement from the experiment shows a variation of 6.93-11.29% with respect to that from the conventional.

Fig.1a **Fig.1b** **Fig.1.c** **Fig.1.d**

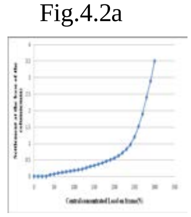
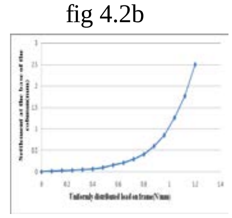
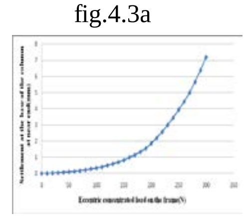





Settlement

The variation of settlement at the base of the column with respect to the central concentrated load and UDL on the frame is presented in Figs 4.2(a) and 4.2(b), respectively, and the variation of settlement at the near end and far end of the column base for the frame under the eccentric concentrated load is presented in figs 4.3(a) and 4.3(b), respectively.

From the plots mentioned herein, it is observed that the settlement from the experiment is 30.79-45.45% .

Fig.4.2a fig 4.2b fig.4.3a

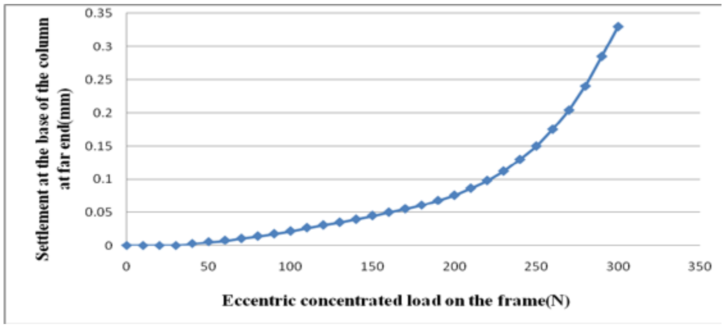


Fig.4.3b

Rotation

The variation of rotation at the base of the column for the central concentrated load and UDL applied on the frame is presented in Figs 4.4(a) and 4.4(b), respectively. Meanwhile, the variation of rotation at the column base of the near and far end, respectively, of the frame under the eccentric concentrated load is presented in Figs 4.5(a) and 4.5(b). From the plots shown herein, it is observed that the rotation from the experiment is 28.21-36.08 % . Hence the rotation from the experiment is in good agreement.

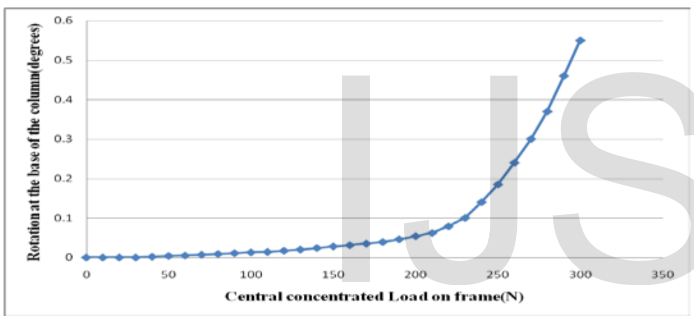


Fig.4.4a

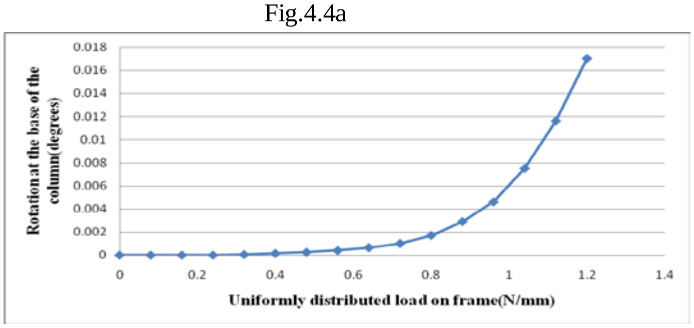


Fig.4.4b

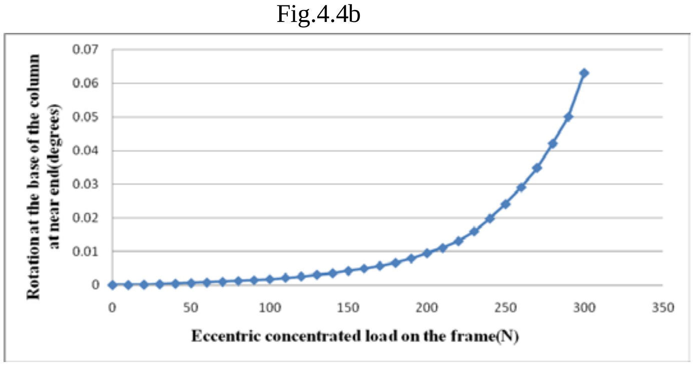


Fig.4.5a

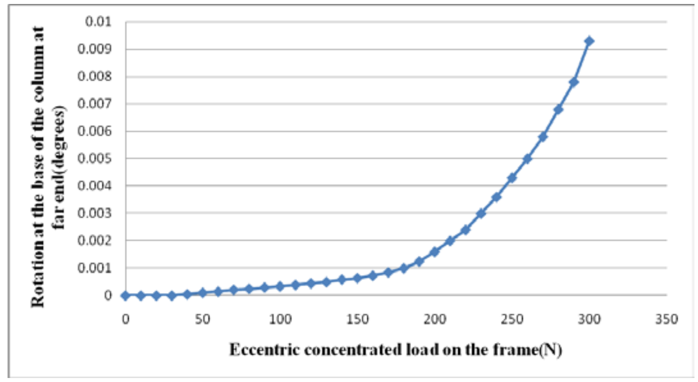


Fig.4.5b

5.2 Shear force and Bending Moment in the frame by Conventional method and Experiment

The shear force in the frame under the central concentrated load, UDL, and eccentric concentrated load have been plotted in Figs 4.6(a) , 4.6(b),4.6(c)respectively. From these plots, it can be observed that the shear force predicted by the conventional method is always on the higher side. For relatively lower loads on the frame, the shear force predicted by experiment follow closely the shear force by the conventional. The shear force predicted by the conventional method is 40.21% higher than that by experiment for higher levels of loading.

The shear force obtained from the experiment deviates by about 7.96-9.49% of that given by the conventional, which indicates that the experiment soil model is in good agreement with the experimental results. The shear force predicted by the conventional method is 54.1-60.24% more than that of the experiment for higher loads acting on the frame. the soil relatively becomes flexible and it allows more displacements and rotations at the base of the frame that is why the values of shear force reduce. Hence soil structure interaction is very much significant for low rise buildings. In practice, 90% of the buildings are low rise buildings.

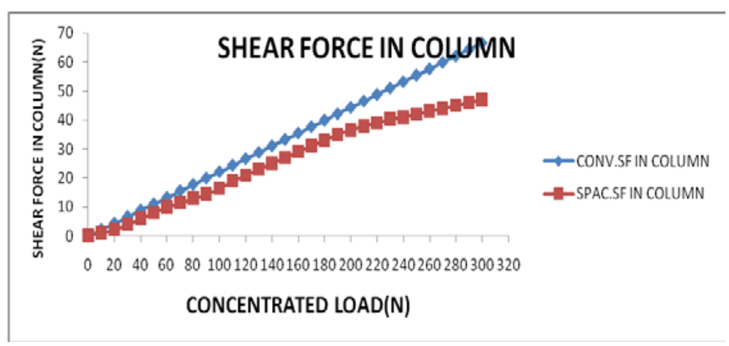


Fig.4.6a

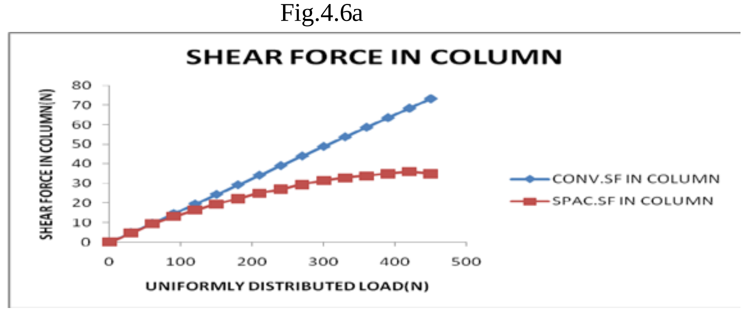


Fig.4.6b

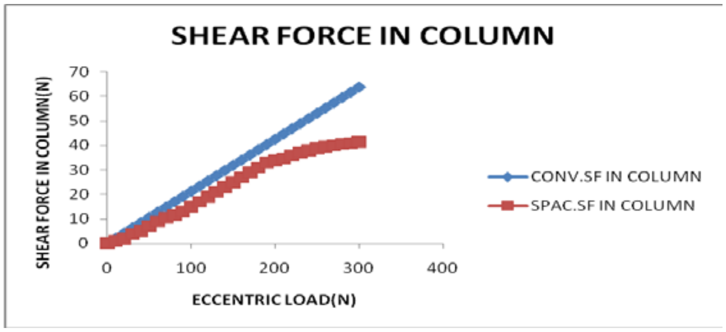


Fig.4.6c

5.3 Bending moment at top of the column by conventional method, experiments.

The bending moment at the top of the column of the frame under the central concentrated load and UDL is plotted in Figs 4.7(a) and 4.7(b), respectively, and the one of the near end and far end, respectively, of the frame under the eccentric load is plotted in Figs 4.8(a) and 4.8(b).

From the plot, it is observed that, the bending moment at top of the column is reduces. And the percentage of reduction in bending moment is reduced from 27.72 to 8.88.

From the above figures, it is observed that the bending moment predicted by the conventional method is higher than that by the experiment methods of analysis, indicating that the conventional method of analysis for obtaining the design moment is uneconomical. Compared with the experimental result, the bending moment predicted by the conventional method is 19.25-26.48% more. This indicates the need for consideration of soil interaction in evaluating the design parameters in a building frame. For the above reason, the designers may favor the use of linear analysis concerning the economy in design. The point to be noted with respect to the bending moments at the top of the column of the frame predicted by different methods is that though the percentages of variation may not be great, the differences are significant because the magnitudes of bending moment are of multiples of thousands.

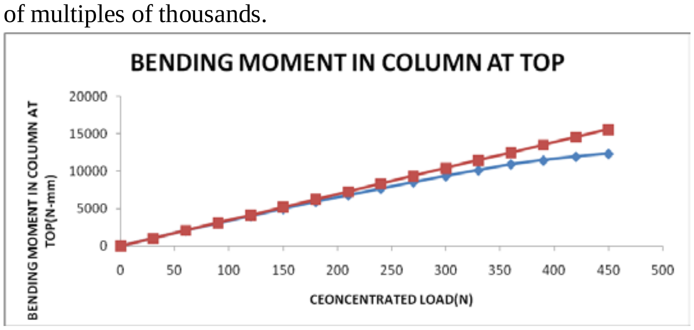


Fig.4.7a

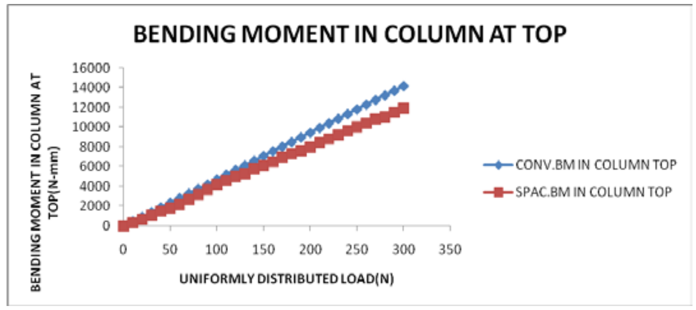


Fig.4.7b

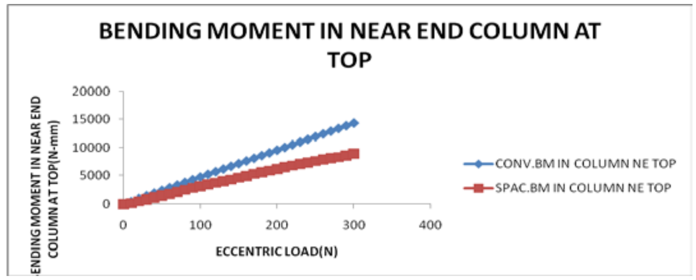


Fig.4.8a

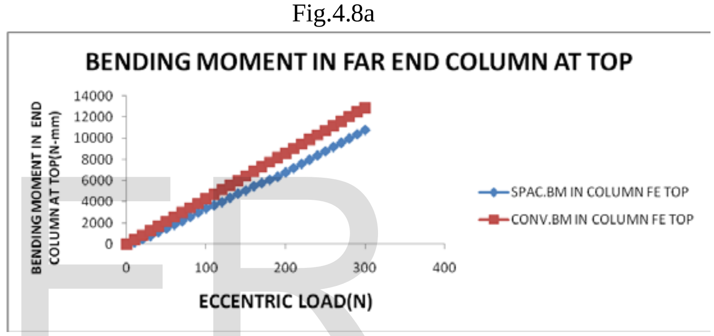


Fig.4.8b

5.4 Bending moment at the base of the column by conventional method, experiment.

The variation of bending moment at the base of the column of the frame under the central concentrated load and UDL have been plotted in Fig 4.9(a) and 4.9(b), respectively. These figures show that, for the conventional method and experiment as the load increases the bending moment increases in the linear manner, as the load-displacement curves are linear. The conventional method gives a bending moment 76.79% higher value than that by the experiment. The bending moments given by the experiments agree well with those by the experiment with a variation of 5.78-10.48%.

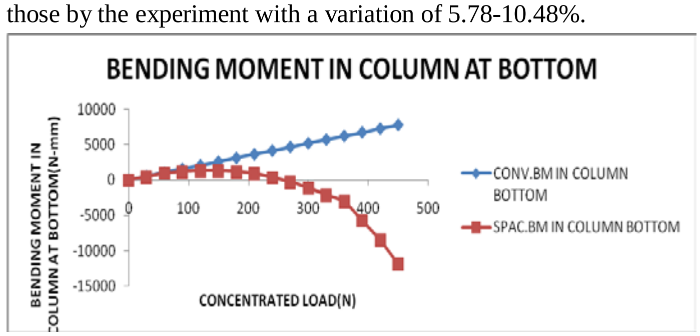


Fig.9a

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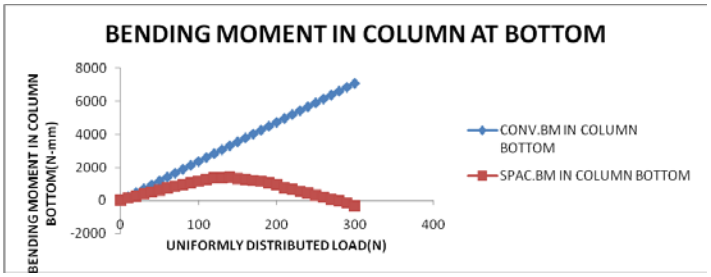

Fig.9b

Moreover, the bending moment at the base of the column changes its sign, when the load reaches some value. This is due to the fact that for relatively smaller loads on the frame, the column is rigidly connected to the pile cap and the soil is in its linear range hence it behaves like a frame with fixed base. As the load on frame increases, the connection between base of the column and pile cap becomes partially rigid and the behaviour of the soil will be in the nonlinear range, increase in the rotation of the pile cap will be so high hence the nature of bending of column at the base will change its sign. The conventional method gives a bending moment at the column base that is about 81.75-84.65% higher than that by the experiment.

Fig 4.10(a) and 4.10(b) show the variation of bending moment at the base of the column of the near end and far end, respectively, of the frame under the eccentric concentrated load. Clearly, based on the conventional method the bending moment at the far end of the column base of the frame is higher than that of the near end, whereas the nonlinear FEA and experiment show that the near-end bending moment at the base is dominant for higher loads on the frame. The conventional method gives a bending moment of about 81.98-86.77% higher than that of the experimental result. The sign change of the bending moment is observed to occur at an earlier stage of loading at near end than at the far end.

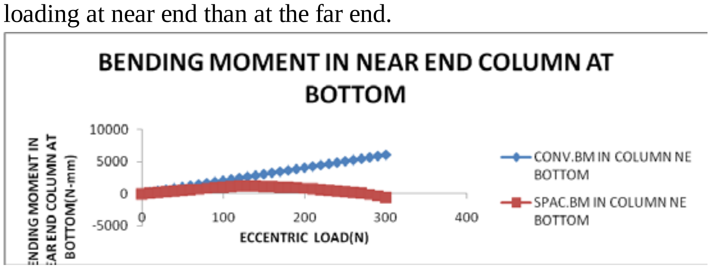

Fig.10a

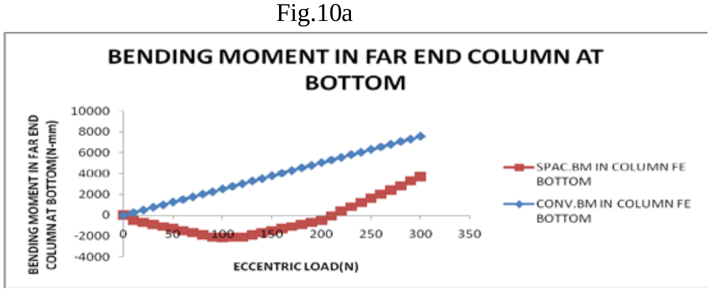

Fig.10b

6. CONCLUSIONS

Based on the results of the present experimental and numerical investigations on the model building frame resting on pile groups embedded in cohesionless soil, the following conclusions.

• As the load on the frame increases, the behavior of the frame in terms of displacement and rotation at the base of the column predicted by the experiment appears to be linear for relatively smaller loads. For higher load range, the experimental results show a nonlinear variation and considerable deviation results.

Based on the results of the present experimental investigations on the model pile groups supported frame, the following conclusions are drawn; the soil behavior are generally good for representing the load-displacement response of the soil.

- The percentage decrease of shear force in columns is 22.6% for concentrated load, 37.983% for uniformly distributed load, 20.2% for eccentric concentrated load compared to conventional method because of soil structure interaction .
- The percentage decrease of bending moment at top is 17.7% for concentrated load, 31.5% for uniformly distributed load, 13.5%, 19.5% for near end and far end incase of eccentric concentrated load compared to conventional method because of soil structure interaction..
- The percentage decrease of bending moment at bottom is 46.3% for concentrated load, 69.6 % for uniformly distributed load, 74.2%, 75.1% for near end and far end incase of eccentric concentrated load compared to conventional method because of soil structure interaction.

.Hence the soil structure interaction has to be considering for the design of building frame economical.

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