Soil Interaction of Building Frame Resting on Clayey Soil: Effect of Change of Footing Size

Anantha Kavya Supriya, Ravi Kumar Reddy C

Abstract: In every structure, the super structure and the foundation executed on soil, represent an entire structural system. The analysis of a framed structure while not modeling its foundation system and its rigidity could mislead the axial forces, moments due to bending and due to settlement. It is, thus necessary to hold out the analysis considering the type of soil, foundation and above the sub structure i.e. (super structure). Hence the analysis of the single bay single storied building frame resting on soil (Clayey Soil) is taken for present study. The analysis is carried out using "ANSYS 16.0". In this paper the effect of soil interaction on building frame design parameters as change of modulus of sub-grade reaction from 0.010 to 0.050 N/mm^3.Shear force, Bending moment and settlements have been studied for different footing sizes of 1mx1m to 4.5mx4.5m the effect of SSI is quantified using finite element analysis. The following conclusions have been drawn from the study, the shear force and axial force value in the beam and column is constant from finite element analysis are not having considerable difference. The analysis is predicting that percentage difference in bending moment in beam, column and footings are at lower EFS value i.e 0.010N/mm^3 at lower footing size 1mX1m is greater than when compared to higher EFS value i.e 0.050N/mm^3 at higher footing size 4.5mX4.5m which considers soil interaction. But in case of the footings they undergo some settlement the percentage difference of settlement is 14.41% and 6.72% at lower EFS value i.e 0.010N/mm3 at lower footing size 1mx1m when compared to higher EFS value i.e 0.050N/mm3 at higher footing size 4.5mx4.5m respectively, which considers soil interaction.

Index Terms: Clayey soil, Soil interaction, Footing sizes, Effective Foundation Stiffness (EFS).

I. INTRODUCTION

The forces and the displacements applied on the foundation elements by the superstructure or the soil medium results in the flexural, axial and shear deformations. These parameters are the demands for which the components of the foundation must be designed. These effects are more significant in the case of foundation like rafts and piles. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls.

The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils. For example nuclear power plants, high-rise buildings and elevated-highways on soft soil. The framed structures are normally analyzed with their bases considered to be either completely rigid or hinged. However, the foundation resting on deformable soils also undergoes deformation depending on the relative rigidities of the foundation, superstructure and soil.

Interactive analysis is, therefore, necessary for the accurate assessment of the response of the superstructure. Multi-storey frames are subjected to horizontal and vertical loads. Frames resist loads entirely due to the rigidities of the beam-column connections and the moment-resisting capacities of the individual members. The load from the superstructure is transferred to the supporting soil medium through the foundation. Displacements occur in the soil body due to the loading and their magnitude depends on the pressure on the foundation. The structural stiffness can have a significant influence on the distribution of the column loads and moments transmitted to the foundation of the structure. 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 structural design. Previous studies indicated that the effect of interaction between soil and structure can be quite significant. In reality, the structure is generally supported on soil mass and there exists, the interaction between structure, foundation and soil mass. The flexibility of the foundation, the compressibility of the soil mass and other factors cause redistribution of bending moments and shear forces in the superstructure due to differential settlement of soil mass. In the method of analysis, a structure is analyzed for different footing size and change in modulus of sub-grade reaction. The common practice of obtaining foundation loads from the structural analysis without allowance for foundation settlement will result in extra cost that might have been avoided had the effect of soil-structure interaction been taken into account in determining the settlements. The soil structure interaction effects on soil settlements and structural forces are studied by Mosleh and Faisal [1]. They have given a very simple procedure for the analysis of soil structure interaction of structural frames of Reinforced Concrete which are resting on various kinds of soil they have calculated the effect of interaction on the notified settlements and the loads on footings of two - dimensional framed structures of many bays. A study on soil, foundation and the super structure interaction for plane two bay frames was carried out by Hany and Mohamed [2].

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They have examined the effect of super structure's rigidity on the varying differential settlements and the contact stress for two bay plane frames. They have achieved this by making the effect of super structure members and the rigidity of footings on the average of maximum settlements and the contact stress beneath the footings.

Garg and Hora[3] carried out a study on interaction behavior of structure foundation soil system they have made an attempt to publish available alternate solutions proposed by various scientists to evaluate the phenomenal behavior of soil structure interaction from time to time. They have concluded that the prevailing forces in super structure, foundation and soil mass are changing rapidly due to interaction of soil structure. They have mentioned that to get a very appropriate accuracy in estimating the design force quantities it is compulsory to consider soil structure interaction effect. Ilamparuthi et al [4] have carried out a parametric study on soil-raft-frame interaction. They concentrated mainly on identifying the parameters which affects the interaction and these parameters are classified into relative stiffness factors krs and ksb. They have notices that there is a reduction in differential settlements due to interaction with soil. They have also identified that in case of beam there is a more variation in support moments in comparative to span moments. The axial forces in peripheral columns increase and to that extent the inner column axial loads are reduced. Garg and Hora [5] has carried out a study on Interaction effect of space frame strap footing soil system on forces in super structure. They mainly concentrated the study on conventional method of building frame analysis assumes that columns are resting on unyielding supports. In reality, the supporting soil strata deforms unevenly under the action of loads, which causes redistribution of forces in the frame members and stresses in the supporting soil media. Their analyses have been carried out to evaluate the axial force and Moment in columns, bending moments and shear force in floor, plinth and strap beams. The comparison is made between the non-interaction and interaction analyses. Nita Rajvaidya et al [6] have carried out a study on the linear soil structure interaction on the columns of an unsymmetrical plane frame for different types of soil. Their study says that the foundation of a multi-storey building resting on a Settle-able soil mass undergoes differential settlement which Change the forces in the beams and columns significantly. And it is necessary to consider building frame, foundation and soil as single integral compatible structural unit for real analysis of the system. Finite element method is a powerful tool for numerical analysis of any soil-structure interaction problem. Rajashekha et al [7] have studied the relevance of interface elements in soil structure interaction analysis of three dimensional and multi scale structures on raft foundation. In this study two extreme cases of compatibility of horizontal displacements between raft foundation and soil elements are considered to obtain pressure settlement relations of raft foundation by developing three Dimensional mathematical model and performing numerical experiments. And finally their study says that variation of horizontal displacements and horizontal stresses are there due to interaction.

II. PARAMETRIC STUDY

A. Analysis of building frame using ANSYS:

The effect of soil interaction on the design parameters in a single bay single storied building frame as the modulus of sub-grade reaction is changing from 0.010 to 0.050N/mm^3 for different footing size is evaluated by using finite element analysis with the help of "ANSYS 16.0" software. The procedure adopted for the numerical analysis of the building frame is as follows:

1. Footing sizes: 1mX1m   1.5mX1.5m
                   2mX2m   2.5mX2.5m
                   3mX3m   3.5mX3.5m
                   4mX4m   4.5mX4.5m.
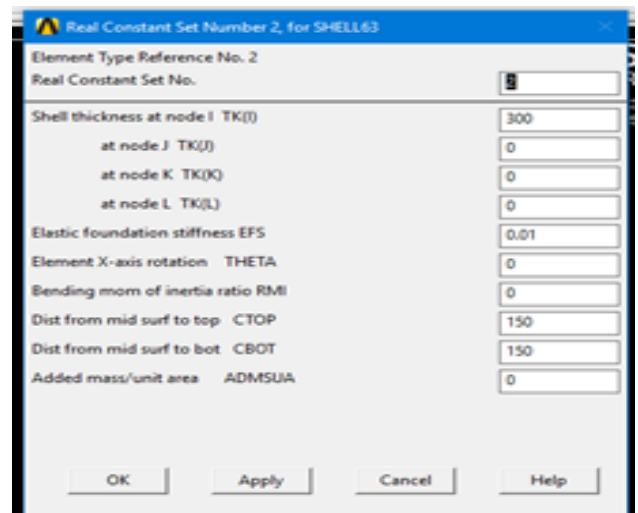2. Beam size: 5000mmX250mmX250mm.
3. Footing thickness: 300mm.

Fig no: 1. Footing Details.

In this analysis, Elastic foundation stiffness (**EFS**) is varied as given below: **0.010N/mm^3, 0.015 N/mm^3,**

0.020N/mm^3, 0.025N/mm^3,
0.030N/mm^3, 0.035N/mm^3,
0.040N/mm^3, 0.045N/mm^3,
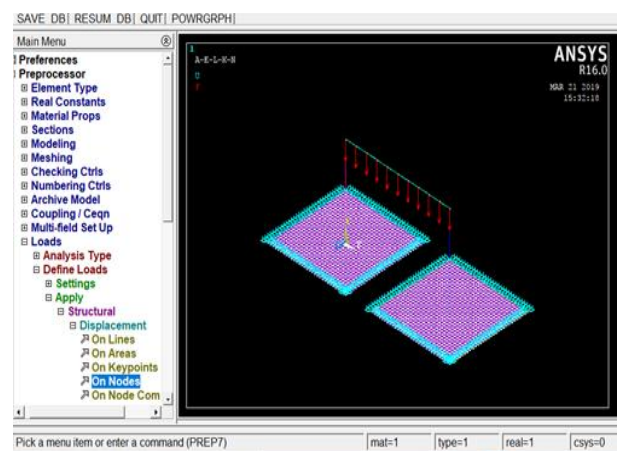**0.050 N/mm^3** for different footing sizes.

Fig no: 2. After applying all conditions to the frame.

After applying boundary conditions, the frame must be analysed. Similarly the Footing size changes from 1m,1.5m,2m,2.5m,3m,3.5m,4m,4.5m are also analysed. From the General post processor, the required design parameters like,

- Shear forces(F_y) and bending moments (M_z) in beams,
- Shear force(F_x),Axial force(F_y) and bending moments(M_z) in columns,
- Deflection (Δ) and bending moments in X, Z-directions (M_x & M_z) are obtained.

Detailed discussion on the results obtained for the other case of building frame with varying EFS value of the clayey soil for different footing size is given in the next chapter to follow.

III. RESULTS

The following are the results of analysis of the single bay single storied building frame. The analysis is carried out using ANSYS by assuming that the base of the frame is resting on soil for evaluating the effect of soil interaction on the design parameters when the modulus of sub-grade reaction is changed from 0.010 to 0.050 N/mm^3 for different footing sizes from 1m X 1m,1.5m X 1.5m,…….. 4.5m X 4.5m.

3.1 Beam Results:

3.1.1 Shear Force in Beam:

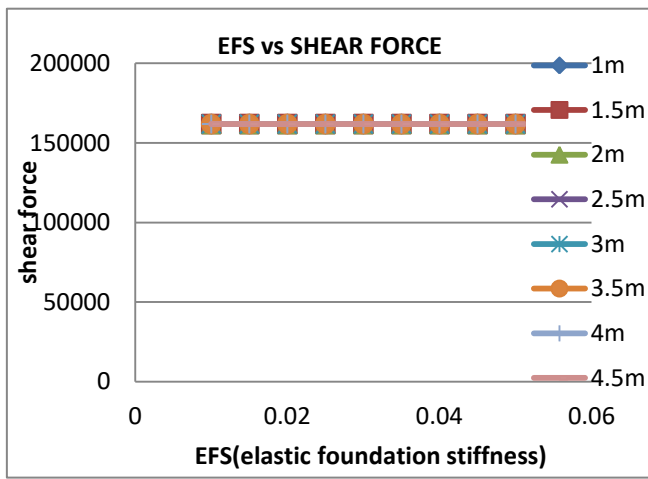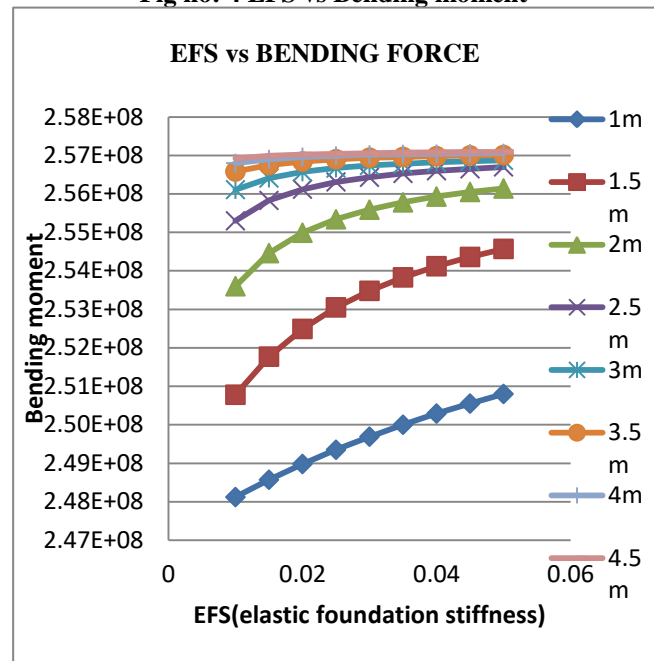Shear force (F_X) value of beam=161790N.

Fig no: 3 EFS vs Shear force

The graph plotted between modulus of sub-grade reaction and shear force. From the graph it is clearly observed that soil with different EFS value have constant shear force value even footing size is increased. Therefore there is no soil interaction effect in case of a shear force in beam.

3.1.2 Bending Moment in Beam:

Fig no: 4 EFS vs Bending moment

The EFS value of the frame is varied from 0.010 to 0.050N/mm^3 for different footing size respective bending moment values are increases from 0.24812x10^9 to 0.25692x10^{9}Nmm at EFS 0.010 and 0.050 N/mm^3 for footing size of 1mX1m and 4.5mX4.5m.From the above graph represents, initially bending moment is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m bending moment becomes linear. The percentage difference in bending moment for footing size of 1mX1m to 4.5mX4.5m is 3.54% at EFS is 0.01 and 2.50% at EFS is 0.050. Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reaction.
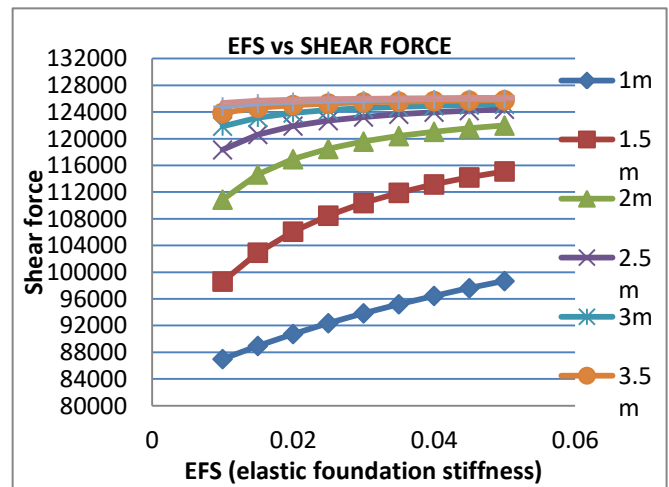
3.2 Column Results:

3.2.1 Shear Force in Column:

Fig no: 5 EFS vs Shear force

The EFS value of the frame is varied from 0.010 to 0.050N/mm^{3}for different footing size respective shear force values are increases from 86984 to 0.12537e^6 N at EFS 0.010 and 0.050N/mm^3 for footing size of 1mX1m and 4.5mX4.5m. From the above graph represents, initially shear force is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m shear force becoming linear.

The percentage difference in shear force for footing size of 1mX1m to 4.5mX4.5m is 44.12% at EFS is 0.01 and27.80% at EFS is 0.050.Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reaction.

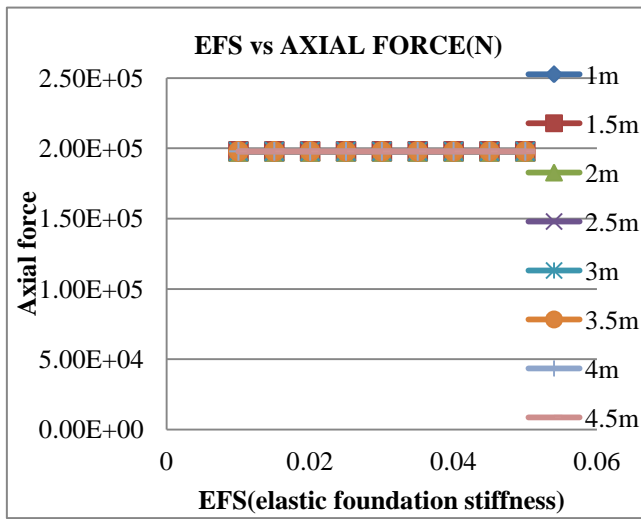*3.2.2 Axial Force in Column:*

Axial load in column=197740N.

Fig no: 6 EFS vs Axial force

The EFS values varied from 0.010 to 0.050N/mm^3 and the axial load value is 197740N with is constant for different footing size also. Therefore there is no soil interaction effect in case of an axial load.
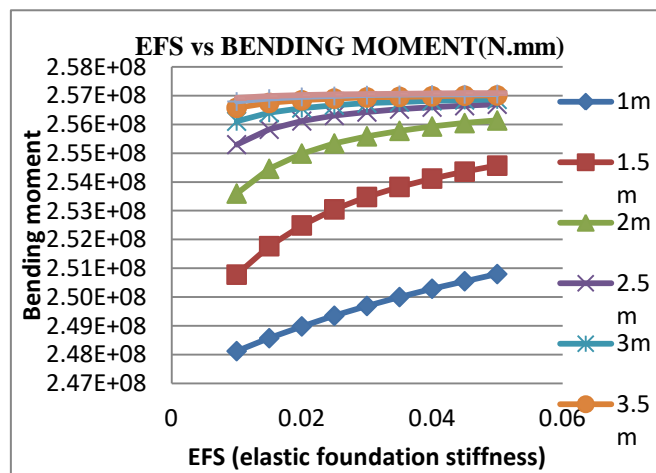
3.2.3 Bending Moment in Column:

Fig no:7 EFS vs Bending moment

Respective bending moment values are increases from 0.24812x10^9 to 0.25692x10^9 Nmm at EFS 0.010 and 0.050 for footing size of 1mX1m and 4.5mX4.5m.From the above graph represents, initially bending moment is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m bending moment becoming linear.

The percentage difference in bending moment for footing size of 1mX1m to 4.5mX4.5m is 3.54% at EFS is 0.01 and 2.50% at EFS is 0.050. Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reaction.

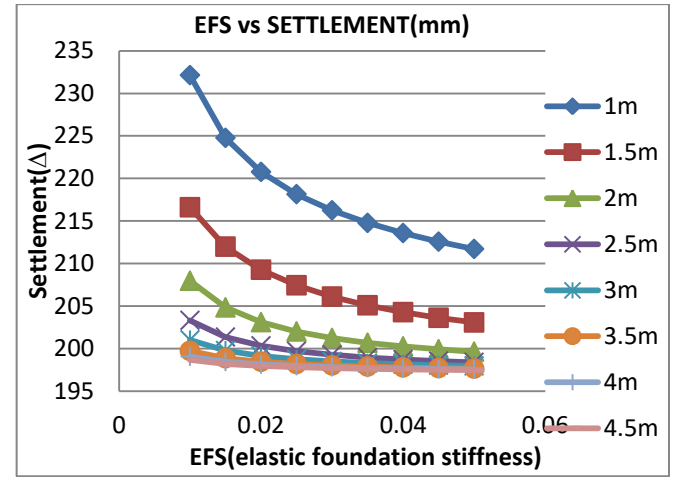*3.3 Footing Results:*

3.3.1 Settlement in Footing:

Fig no: 8 EFS vs Settlement

Respective deflection values are increases from **232.14mm** at EFS 0.010 and **197.47mm** at 0.050N/mm^3 for footing size of 1mX1m and 4.5mX4.5m.From the above graph represents, initially deflection is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m deflection becoming linear. The percentage difference in deflection for footing size of 1mX1m to 4.5mX4.5m is 14.41% at EFS is 0.01 and 6.72% at EFS is 0.050N/mm^3.Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reactions.
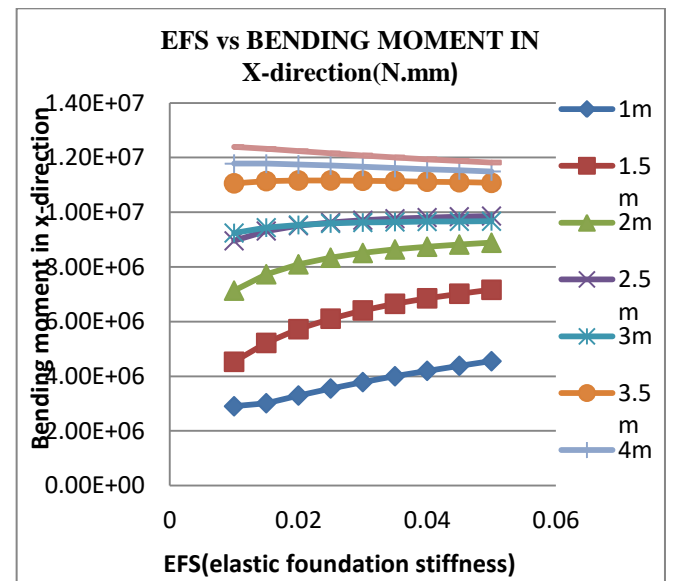
3.3.2 Bending Moment In X-Direction:

Fig no: 9 EFS vs Bending moment in X-direction

Respective bending moment in x-direction values are increases from $0.29026e^7$ at EFS 0.010 and $0.11821e^8$ N.mm at EFS 0.050 for footing size of 1mX1m and 4.5mX4.5m.From the above graph represents, initially bending moment in x-direction is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m bending moment in x-direction becoming linear.

The percentage difference in bending moment in x-direction for footing size of 1mX1m to 4.5mX4.5m is 76.56% at EFS is 0.01 and 61.49% at EFS is 0.050.Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reactions.
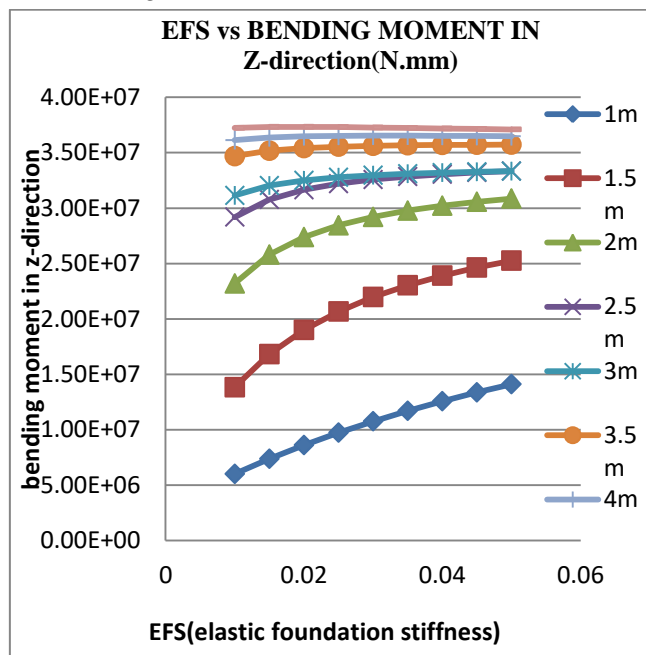
3.3.3 Bending Moment In Z-Direction:

Fig no: 10 EFS vs Bending moment in Z-direction

Respective bending moment in z-direction values are increases from $0.60162e^7$ at EFS 0.010 and $0.37099e^8$ at EFS 0.050N/mm^3 for footing size of 1mX1m and 4.5mX4.5m.From the above graph represents, initially bending moment in z-direction is non-linear by increasing footing size from 1mX1m to 4.5mX4.5m bending moment in z-direction becoming linear.

The percentage difference in bending moment in x-direction for footing size of 1mX1m to 4.5mX4.5m is 83.84% at EFS is 0.01 and 63.59% at EFS is 0.050N/mm^3.Finally, by increasing footing sizes the effect of soil interaction is becoming linear for various modulus of sub-grade reactions.

IV. CONCLUSIONS

The following conclusions have been drawn from the study mentioned here with,

A. Beam Results:

- **Shear Force**: The shear force value in the beam from finite element analysis is constant. So, there is no effect of soil interaction in beam.

- **Bending moment**: The percentage difference in bending moment values in the beam obtained from finite element analysis is 3.42% at EFS 0.010 for footing size 1mX1m and 2.44% at EFS 0.050N/mm^3 for footing size 4.5mX4.5m. The analysis is predicting that at lower EFS value have higher bending moment when compared to the higher EFS which considers soil interaction. Hence there is an effect of soil interaction for this case.

B. Column Results:

- **Shear force**: The percentage difference in shear force values in the column obtained from finite element analysis is 30.61% at EFS 0.010 for footing size 1mX1m and 21.75% at EFS 0.050 for footing size 4.5mX4.5m. The analysis is predicting that at lower EFS value have higher bending moment when compared to the higher EFS which considers soil interaction. Hence there is a effect of soil interaction for this case.

- **Axial load:** The axial force value in the column from finite element analysis is constant. So, there is no effect of soil interaction in beam.

- **Bending moment:** The percentage difference in bending moment values in the beam obtained from finite element analysis is 3.42% at EFS 0.010 for footing size 1mX1m and 2.44% at EFS 0.050N/mm3 for footing size 4.5mX4.5m. Thanalysis is predicting that at lower EFS value have higher bending moment when compared to the higher EFS which considers soil interaction. Hence there is an effect of soil interaction for this case.

C. Footing Results:

- **Footing settlement**: The percentage difference value in settlement is 14.4% at EFS 0.010 for footing size 1mX1m and 6.72% at EFS 0.050 for footing size 4.5mX4.5m.It shows the settlement is decreased by increasing footing size at higher EFS value.

- **Bending moment in X-direction:** The percentage difference in bending moment in x-direction in the footing obtained from finite element analysis is 76.56% at EFS 0.010 for footing size 1mX1m and 61.49% at EFS 0.050 for footing size 4.5mX4.5m. The analysis is predicting that at lower EFS value have higher bending moment when compared to the higher EFS which considers soil interaction. Hence there is an effect of soil interaction for this case.

- **Bending moment in Z-direction:** The percentage difference in bending moment in z-direction values in the footing obtained from finite element analysis is 83.84% at EFS 0.010 for footing size 1mX1m and 63.59% at EFS 0.050 for footing size 4.5mX4.5m. The analysis is predicting that at lower EFS value have higher bending moment when compared to the higher EFS which considers soil interaction. Hence there is an effect of soil interaction for this case.

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Retrieval Number: B3618078219/19©BEIESP
DOI: 10.35940/ijrte.B3618.078219
Journal Website: www.ijrte.org

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