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Numerical Simulation of Soil–Structure Interaction of RC Frame

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Abstract— **An Attempt has been made to study the effect of soil media on the response of RC frame structure. Therefore, the present work focuses on the implementation of a two dimensional finite element model of reinforced concrete frame and pile foundation system which explicitly incorporates the soil response. The superstructure members have been represented by means of three-node isoperimetric beam elements with three degrees of freedom per node. The soil mass is idealized by the eight-node isoperimetric quadrilateral element at the near field and five nodes isoperimetric infinite element to simulate the far-field behavior of the soil media. The applicability of this model was demonstrated by analyzing a multi-story building. The results have shown that the influence of the soil behavior on the overall response of the structure.**

Index Terms: **Reinforced concrete frame, Soil structure interaction, Finite element analysis.**

I. INTRODUCTION

Based on the literature review, super structure and sub structure of the building were analyses in full isolation. However, the consideration of structural and geo- technical/foundation engineers interaction very approximately or neglected. Most of the structural engineer mainly focused on the structural configuration of the building, hardly care to know any known about soil other than the allowable bearing capacity and its general, provided the foundation design is within its[1].

The problem of soils structure interaction has been studied extensively by many researchers. In this section, a comprehensive review on available literature of retaining wall -soils system studies are presented.

A. Research background

Hussein and Meguid,(2013). implemented two and three dimensional (2D & 3D) fixed element analyses using abaqus software to study two different soil structure interaction problems. 3-D analysis of unconfined and confined soil with an example of a square footing over geogrid reinforced soil, 2D plane strain analysis of a box culvert pick up by EPS geofoam modulation to minimize earth pressure on the walls of the structure. In the presented study the numerical results were compared with experimental data. It has been concluded that the effectiveness of using the fixed element method to solve these classes of geotechnical engineering problems[2].

Noorzaei et al. (2010) developed a 2-D finite element model of an integral abutment bridge (IAB) system which explicitly incorporates the nonlinear soil response. The soil mass was idealized by eight nodes isoperimetric quadrilateral element at near field and five node isoparametric infinite element to simulate the far field behavior of the soil media. In their study the non-linearity of the soil mass has been represented by using the Duncan and Chang hyperbolic model. The results have shown that the soil nonlinearity has significant effect on the response of the abutment[3].

Malviya and Singh (2017) focused on the soil structure interaction behavior of three stories RC frame building constructed over shallow footing below a base of dense soil. In this study, the finite element method considering the direct method was applied to model the soil structure interaction by using abaqus. The horizontal deformation and vertical deformation of the RCC building was estimated under static and dynamic loading. The perfectly elastic plastic constitutive model has been used to model the stress behavior of the soil. The static loading under gravity and 0.1g horizontal ground acceleration respectively was used for the analysis. The results indicated that the soil structure interaction has an important role to assess the behavior of any structure with the various base of footing or foundation[4].

The impact of soil structure interaction on the out-of-plane behavior of an ancient building in Iran, named Arge-Tabriz, was investigated utilizing Finite Element Method (FEM). The presented work concluded that, SSI has a significant decreasing effect on the acceleration response due to removing the effective mode vectors from the resonance area of the acceleration response spectra. On the other hand, SSI has a remarkable increasing impact on the displacement response of Arg’s walls according to the displacement response spectra[6].

M. Ada and Y. Ayvaz (2019) examined the Structure-Soil-Structure Interaction effects on the response of the neighbouring frame structures using finite element

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method. In this work the effects of the consideration of the underlying soil on the response of the structures were compared with the fixed base conditions. Subsequently, the variation in the acceleration and basement storey drift ratios of the structures were examined to determine the effects of the presence of the neighbouring different structures. The result have shown that the consideration of the neighbouring structures could positively or negatively change the responses of the structures based on the dynamic characteristics of the case[7].

B. *Concluding Remarks*

It is evident from the above literature review that, continuous efforts should be made to arrive a realistic numerical modeling of soil-structure interaction (SSI). Based on the literature review embedded in this chapter, the following major points can be drawn:

- Soil type has considerable effect on soil and structure interaction where the stresses concentration are influenced by different types of soil.
- The nonlinearity of the soil has a significant effect on the response of the structure. Therefore, more accurate constitutive material model is required for more realistic results.
- There was a considerable difference in response of the structure if the effect of SSI is considering.

II. COMPUTER CODE

Based on the proposed physical and material models the finite element code which was developed by (A. A. Abdulrazeg, 2013)[5], has been used in the present study. The current version of the program has several 2-D isoperimetric Elements, two dimensional infinite elements and joint elements in its element library. The program can take into account the nonlinear stress-strain characteristics of soil. The nonlinearity can be handled by the incremental, iterative and combination of incremental iterative technique.

A. *Linear Elastic Constitutive Relationship*

In linear stress analysis, the stress strain relation for isotropic materials is expressed as;

$$\{\sigma\} = [D]\left([B]\{\delta\}^e - \{\varepsilon_0\}\right) + \{\sigma_0\} \qquad (1)$$

Where ε_0 is the initial strain vector, σ_0 is the initial stress vector and δ is the displacement vector. [D] for the element material matrix which for isotropic material is given by (Zienkiewicz and Taylor, 2006) [8].

$$[D] = \frac{E}{(1-\nu^2)}\begin{bmatrix} 1 & \nu & 0 \\ & 1 & 0 \\ Symmetric & & \frac{1-\nu}{2} \end{bmatrix} \qquad (2)$$

III. CASE STUDY

A six storeys plan frame resting on a pile foundation is considered for the parametric study. The frame is 19m high with 4×2 bay of each bay is of 4m×4m in plan. The height of the first floor is 4 m and the other storeys is 3m. The slab at the top is supported by beam 300mm wide and 500mm deep which rest on the column of size 300mm×250mm. While dead load is considered according to unit weight of materials of which the structural component of the frame are made up for the parametric study. Table 1 shows the soil properties.

TABLE I. SUMMARY OF SOIL PROPERTIES

Description	Clay	Sand Clay	Sand slit	Dense Sand
Modules of elasticity	25000 kN/m²	45000 kN/m²	50000 kN/m²	150000 kN/m²
K modulus number	200	200	200	198
n, Exponent	0.98	0.995	0.9	0.82
R_f, Failure ratio	0.846	0.88	0.875	0.855
C, cohesion	10 KN / m²	22 KN / m²	21 KN / m²	70 KN / m²
Φ, Angle of friction	4	19	19	22

IV. PROPOSED PHYSICAL NODEL

In order to numerically simulate the reinforced concrete frame and pile foundation system the following elements are utilized:

- Eight node conventional parabolic finite element to represent the abutment, and the soil mass shown in figure 1[3].
- Three node isoparametric beam bending element with three degrees of freedom per node to represent the superstructure and pile shown in figure 1. This beam element takes into account the effect of transverse shear forces and axial-flexural interaction[3].
- Five–node isoperimetric infinite element is used to model the soil at the far field [3].

The two-dimensional serendipity types of finite and infinite Elements and beam element along with their shape functions are presented in Table 2.

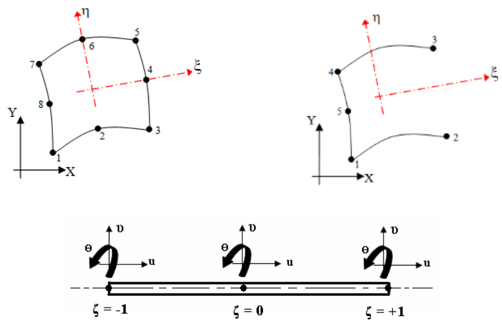

Figure 1. Isoperimetric elements

Table 1. Shape functions for elements were used in idealization of the structure

Type of element	Shape functions
3-node isoparametric beam bending element	$N_1 = -\frac{1}{2}\xi(1-\xi)$ $N_2 = (1-\xi^2)$ $N_3 = -\frac{1}{2}\xi(1+\xi)$
8-node finite element	For corner nodes: Ni = ¼ (1+ζζi)(1+ηηi)(ζζi+ ηηi-1) For midside nodes: Ni = ζi² /4 (1+ζζi)(1+η²) + η² / 2(1+ ηηi)(1-ζ²)
5-node infinite element	N1 = - ξ (-η) (1 – η) / (1 – ξ) N2 = (1 + ξ) (1 – η)/ (2(1 – ξ)) N3 = (1 + ξ) (1 + η)/ (2(1 – ξ)) N4 = - ξ (η) (1 + η) / (1 – ξ) N5 = -2 ξ (1 –η* η) / (1 – ξ)

Where η and ξ are the natural coordinates

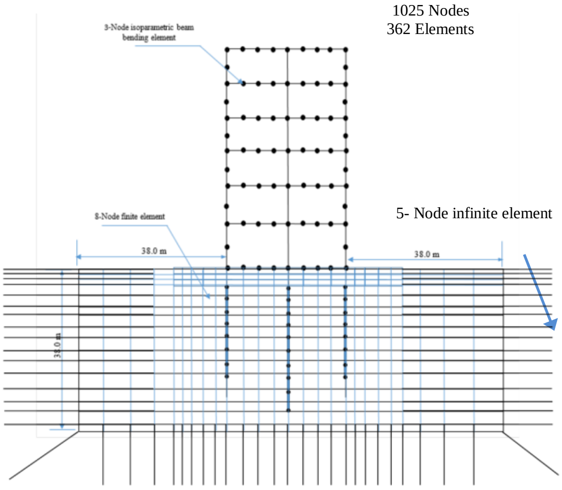

Figure 2. Finite Element Modeling Structure- Mat Foundation- Pile/ Soil

V. COLLECTION OF DATA

Collection the necessary information should be done in conjunction to the objectives that have been set. Data collection is essential to a researcher since it equips them knowledge and highlights relevant matters on the issue to be researched on. It can also shed light on what is important and what is not on the matter. Data can be put in two general categories as stated in the following.

B. Primary Data Source

The primary data for this research is conducted by computer analysis. The analysis of a multi-story building was carried out using a Finite Element Program (FEP).

C. Secondary Data Source

A comprehensive review of the relevant literature including a computer aided search will be undertaken to develop an understanding of the behavior of multi- story building. For this research, most of the literature is downloaded from the Internet as well as writings from past researchers [4].

VI. WIND LOAD

Wind load: from the basic speed map of Libya (Benghazi City), basic speed is considered to be V_b = (121 Km/h - 33.61 m/s) , above the mean sea level, In the present study the wind pressure has been determined according to ACI code using the following.
equation:

$$F_2' = (1.5\times 0.442 + 1.5\times 0.471)\times 16 = 21.912kN \qquad (3)$$

Whereas the wind speed (qz) is calculating as following:

$$[p] = [q][G][cp] - [qi](GCpi)N/m^2 \qquad (4)$$

Table 2. New designation of wind speed zones

Previous numbering of zones	New designation of zones	The design wind speed with a return period 50 year (Km/h)
1	1	105
3	2	110
4	3	115
2	4	121

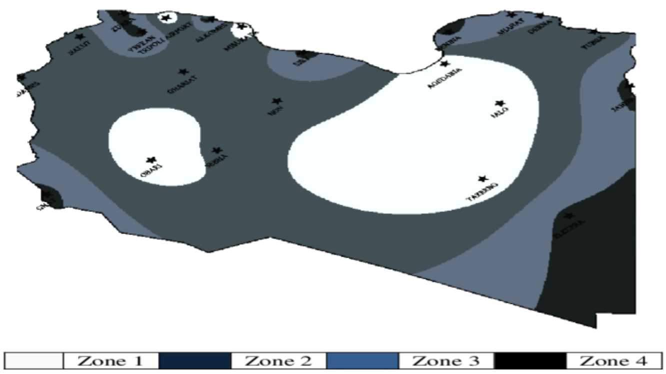

Figure 3. The design wind speed contour map of Libya with a 50- year

VII. RESULT AND DISCUSSION

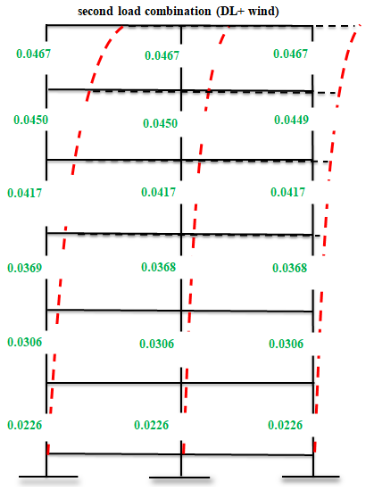

Figure 4. Lateral Displacement of the building due to wind load

After the structure was modelled and placed on the finite and infinite elements representing the foundation and surrounding soil, the wind load is applied to the structure, the displacements of the stories were recorded and plotted as can be seen in Figure. 3. It should be noted that the force-depending stiffness of structure elements.

Figure 4, show the Contour of variation σ_x of soil. From the plots it can be seen that, the tension stresses will be developed on the left pile and compression on the right side and this attributed to the wind load as it push the building from the left to the right.

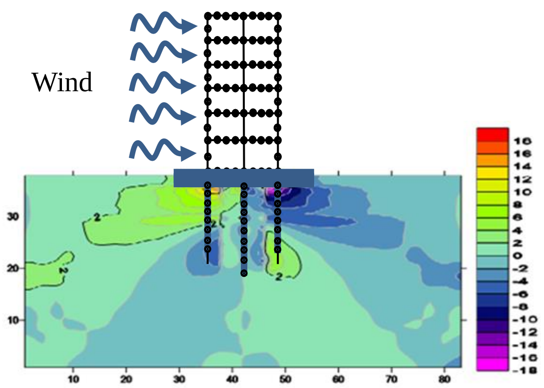

Figure 5. Contour of variation σ_x

Deformation of pile depends in many factors such as; the load combination and the position of load along the slab. The lateral movement of pile not only because of lateral load, lateral movement can be caused by the vertical load as well. Therefore, the lateral loading causes lateral displacement on planes perpendicular to the vertical axis of the pile along the pile length. It is usually of greatest interest to know the largest displacement on these planes, particularly at the ground level as shown in figure 5 and 6.

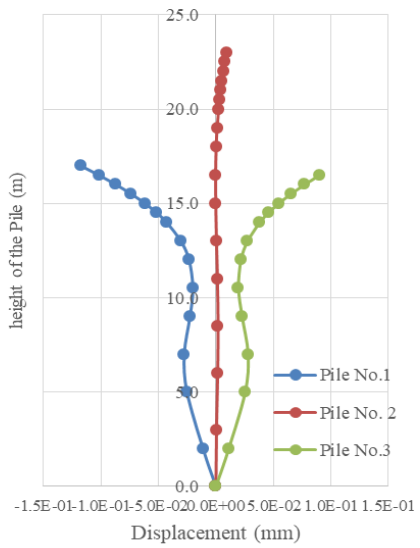

Figure 6. Lateral movement of the piles for the first load Combination (dl+ll)

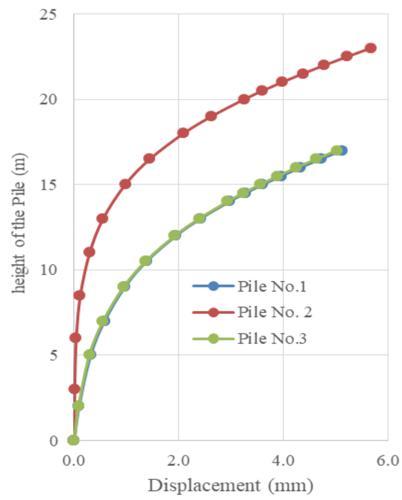

Figure 7. Lateral movement of the piles for the Second load Combination (dl+wind)

VIII. CONCLUSION

The handling of soil-structure interaction in the analysis and design of integral RC frame has always been problematic. A full 2-D finite element model of an structure, foundation, and soil system has been constructed which automatically incorporate the soil response.

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