A Study on Frame Structure-Thick Raft-Soil Interaction

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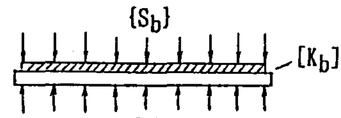
Abstract: In this paper the substructure method and thick plate theory are used to analyse the frame structure-thick raft-soil interaction for 2-D abd 3-D problems. As a typical example, the interactive analysis of frame structure and thick raft on non-linear elastic soil (Duncan-Chang model) has been made and compared with the results obtained by linear elastic soil (E_0 model).

Introduction: The substructure method to analyse structure-raft-soil interaction has been proven to be one of effective methods. However, it is not necessarily to use the substrucure method to analyse the supporting soil, because soil is critical and should be appropriately chosen. In that case mix method generally would be prefered to be used, i.e. the substructure method is used to analyse the superstructure while the other method to analyse the supporting soil.

Analytical Method: The general equilibrium equation for whole structure including foundation can be written as follows (see Fig.1):

$$[K_b]\{U_b\} = \{S_b\} - \{R\}$$

Fig.1



where

$[K_b]$ = equivalent boundary stiffness matrix including raft stiffness, $[K_r]$

$\{S_b\}$ = equivalent boundary load vector

$\{U_b\}$ = displacement vector at boundary nodes

$\{R\}$ = reaction force vector, $\{R\} = [K_s]\{S\}$, in which $[K_s]$, $\{S\}$ are stiffness matrix of soil and settlement vector, respectively

Based on the displacement compatibility between foundation and soil, i.e. $\{S\} = \{U_b\}$, then the equation above can be written as

$$[[K_b] + [K_s]]\ \{U_b\} = \{S_b\}$$

It is a general expression for analysing structure-foundation-soil interaction. For Duncan-Chang model (nonlinear elastic model) the incremental theory must be used.

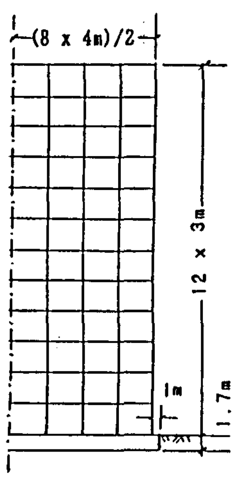


Fig.2

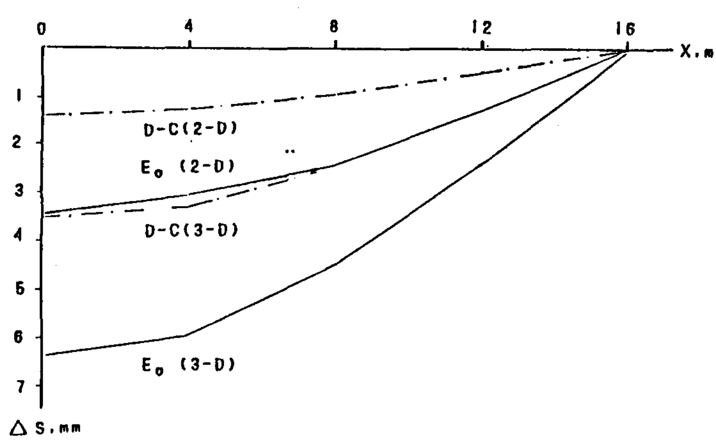


Fig.3

Case Study: This building is a 12-storey founded on raft foundation. The raft foundation is 34.0m x 34.0m in plan, 1.7m thick, as shown in Fig.2 and the soil parameters are listed in the following Table.

Layer	t, m	γ, tf/m^3	E_0 model	D-C model						
			E, tf/m^2	u	v	k	n	G	F	D
1	3	1.90	600	0.513	1.813	43.6	0.625	0.33	0.15	2.44
2	7	1.80	340	-0.077	3.009	53.8	1.470	0.34	0.07	2.40
3	11	1.75	210	0.544	0.760	70.7	1.130	0.36	0.06	2.20
4	11	1.95	1850	1.073	1.610	26.8	2.010	0.30	0.04	0.80

Note:

$$(\sigma_1-\sigma_3)_{ult} = up_a + v\sigma_3, \qquad E_i = kp_a\left(\frac{\sigma_3}{p_a} + 10\right)^n,$$

$$\nu_i = G - F\log\left(\frac{\sigma_3}{p_a} + 10\right), \qquad \varepsilon_1 = -\frac{\varepsilon_3}{\nu_i - D\varepsilon_3}.$$

Analysis of Results:

1. Characteristics for interaction between space frame structure, raft and soil using two soil models (E_0 and D-c models)

The calculated settlements at center of foundation obtained by E_0 model and D-C model are 59.10cm and 56.82cm respectively, and both are close while differential settlements by E_0 model are greater than that by D-C model. For E_0 model there is a high stress concentration at the corner, the ratio of stress at corner, σ_c to the stress at center, σ_0, σ_c/σ_0 = 32.4/7.7 = 4.21 and the stresses at interior parts appear considerably uniform. However, for D-C model σ_c/σ_0 = 20.2/9.1 = 2.22, this value is less about 1/2 than that for E_0 model. The bending moments in frame and raft are controlled by the differential settlements, not by the absolute settlement. It is clearly that the bending moment at center, M_0 obtained by E_0 model is greater than that by D-C model, $M_{0,Eo}/M_{0,D-C}$ = 87.4/52.6 = 1.66.

2. Comparison of results for two structures (space and plan frame structures) and two models (E_0 and D-C models)

As stated above for space frame structure (3-D analysis) the total settlements obtained by E_0 and D-C models are 59.10cm and 56.82cm, respectively. Now, for plan frame structure (2-D analysis) the total settlements obtained by E_0 and D-C models are 25cm and 38cm, respectively. Regarding the differential settlement, no matter what the soil model is used in analysis for space frame structure, it is greater than that for plan frame structure, in which the differential settlement obtained by D-C model is always less than that by E_0 model (see Fig.3). Obviously, the bending moment at center, M_0, using E_0 model is greater than that using D-C model. As to contact pressure distribution, the uneven phenomenon for space frame structure is more than that for plan frame structure, in which there is somewhat improved using D-C model.

Conclusions: In analysis of interaction between space frame structure, thick raft and soil, it seems to be inadequate to use 2-D analysis instead of 3-D. Obviously, D-C model is better than E_0 model.