Fayoum University
Faculty of Engineering

THREE DIMENSIONAL BOUNDARY ELEMENT ANALYSIS OF RAFTS AND PILED RAFTS OVER NON-HOMOGENEOUS SOIL

By

Eng. Emad Omar Ali Ali Azzam

A thesis submitted in partial fulfillment

Of

The requirements for the degree of

Doctor of Philosophy

In

Engineering Sciences

(Structural Engineering)

Department of Civil Engineering

Faculty of Engineering, Fayoum

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ABSTRACT

In this thesis, linear and non-linear analysis of raft and piled-raft foundations over non-homogeneous soil is performed using an innovative and efficient boundary element technique. In order to reach this effective technique, this research has passed through five stages. The first stage represents the new modelling technique of the soil beneath the raft foundations, where the soil continuum is divided into boundary element sub-regions, where each sub-region can be regarded as a super finite element with zero nodal displacements at the far field zone. Hence, the stiffness matrix and the load vector of each super finite element is computed using the boundary element method. Such stiffness matrices as well as load vectors are computed at interface nodes and are assembled. Then the system of equations K u = P is solved and the displacements at interfaces nodes are calculated. As a post-processing step, each super finite element is solved separately to calculate the other nodes displacements and tractions. Using this technique produces system of algebraic equations which is smaller than that in case of using the traditional finite element method (FEM), accordingly the computational efforts are lesser. However, there is a problem in case of solving large practical problems in which computers with high specifications in terms of RAM capacity and CPU speed are needed. This issue is solved in the second stage.

In the second stage, out-of-core solution algorithms are used for analyzing large 3D soil problems. Such problems involve huge number of degrees of freedom. The overall stiffness matrix resulted from the multi-region boundary element problem is large, sparse and non-symmetric. The soil stiffness matrix is divided into series of sub-matrices according to the available computer memory. Each sub-matrix is assembled individually, hence only the non-zero elements are stored on the hard disk (out-of-core). The BiCGStab (l) and GMRES (m) iterative solvers are implemented to solve the overall system of equations. The innovative part is the coupling of the developed out-of-core solution with these iterative solvers. Read-in algorithms are developed where the non-zero elements of each sub-matrix are read-in element-by-element sequentially, to fit within

relevant operations inside the used iterative solvers. Such a procedure reduces the used computer memory and accelerates the solvers time.

In the third stage, practical rafts over non-homogenous soil is solved. The soil continuum beneath the raft is modeled using the illustrated technique in the first and second stages and the raft is modeled as shear deformable plate bending using the direct boundary element method (BEM). The condensed stiffness matrix of the soil at the raft-soil interface elements is calculated and then added to the BEM formulation of the raft. The condensed stiffness matrix is obtained using set of simultaneously load cases which are applied to the raft-soil interface elements. In order to make this technique more efficient, a decomposition is performed between the near and far field soils, and for each load case, prescribed nodal displacements at the interface nodes between the two soils are calculated using Mindlin's solution to implicit the regularity condition at infinity. Thus, the system of algebraic equation became very small compared to this obtained from using the all soil continuum without decomposition.

In the fourth stage, the piled-raft is analyzed using BEM-FEM coupling technique. In this coupling technique, the problem domain is divided into two sub-domains; the super-structure sub-domain (raft) and the sub-structure sub-domain (soil continuum including the piles). Each sub-domain is analyzed separately and only the interface information is exchanged between the two sub-domains. The sub-structure sub-domain is modeled using the FEM commercial software SAP2000, whereas the super-structure sub-domain is modeled as a thick plate bending using the BEM software PLPAK. A coupling tool is developed to automate the analysis procedure, where the condensed stiffness matrix is calculated using SAP2000 and added to PLPAK to make the piled-raft analysis.

In the fifth stage, a simplified non-linear technique is introduced to perform non-linear analysis of rafts and piled rafts rested on a non-homogeneous soil. This technique is based on updating the sub-structure condensed stiffness matrix every load increment or iteration step without including the soil continuum in the non-linear analysis. As a result, the computational effort becomes irrelevant.