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Proposed nonlinear 3-D analytical method for piled raft foundations

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ABSTRACT

The load distribution and deformation of piled raft foundations subjected to axial and lateral loads were investigated by a numerical analysis and field case studies. Special attention is given to the improved analytical method (YSPR) proposed by considering raft flexibility and soil nonlinearity. A load transfer approach using *p*–*y*, *t*–*z* and *q*–*z* curves is used for the analysis of piles. An analytical method of the soil–structure interaction is developed by taking into account the soil spring coupling effects based on the Filonenko-Borodich model. The proposed method has been verified by comparing the results with other numerical methods and field case studies on piled raft. Through comparative studies, it is found that the proposed method in the present study is in good agreement with general trend observed by field measurements and, thus, represents a significant improvement in the prediction of piled raft load sharing and settlement behavior.

1. Introduction

In recent years, a number of huge construction projects, such as high-rise buildings and long span bridges, are being undertaken. The piled raft foundations are especially being recognized as an economical foundation system for high-rise buildings. Here, piles as settlement reducers have been discussed for over a quarter of a century [2] and some significant applications have been reported [12,38,42]. Optimized design strategy is a major importance for an economic construction to be achieved. An optimized design of a piled raft can therefore be defined as a design with minimum costs for the installation of the foundation and satisfactory bearing behavior for a given geometry and raft loading [35]. The piled raft is a composite foundation system consisting of three bearing elements: raft, piles and subsoil. Therefore, the behavior of a piled raft is affected by the 3D interaction between the soil, piles and raft, thus, a simple and convenient analytical method is needed to evaluate these interactions.

Much work has been done to study load sharing and settlement behavior of piled raft by many researchers. Numerical methods have been developed widely in the last two decades because numerical methods are less costly and may be used to consider many kinds of different soil and foundation geometries compared to field and model tests. Although these methods make slightly different modeling techniques, they can generally be classified into three groups: (1) simplified calculation methods [30,32], (2) approximate computer-based methods [5,9,14,15,37] and (3) more rigorous computer-based methods [12,17,18,45,48].

The first type of method is based on the linear elastic analysis of piled raft subjected to axial loading. Generally, the simplified calculation methods are most commonly used procedure for the preliminary design of a piled raft foundation. However, it is noted that these analytical methods are limited to elastic problem. Because this calculation procedure is developed for rigid raft and is assumed that the soil is perfectly elastic. Thus, it may not represent the nonlinear behavior of actual piled raft in the field: it does not take into account the actual behavior of finite flexible raft and pile–soil interaction, etc.

The second type of method has been used to investigate the piled raft system, which is analyzed as a continuous elastic medium using finite element formulation. In these methods, the research by Poulos [29], Clancy and Randolph [5], Poulos [30] and Russo [37] also have some disadvantages. It did not predict the membrane behavior of raft because the raft is generally modeled as plate element. Therefore, the raft used in these methods may not reflect the displacement due to membrane action of large size raft foundations for high-rise buildings. In addition, most of the previous research is related to piled rafts subjected to vertical loading and only semi-infinite homogeneous single soil layer was considered. The consideration of various loading condition and soil layer will be more realistic in design practice.

The third type of method is based on the three-dimensional finite-element or finite-difference techniques. Poulos [31] noted that the most feasible method of analysis was the three-dimensional linear/nonlinear FE method. However, a rigorous

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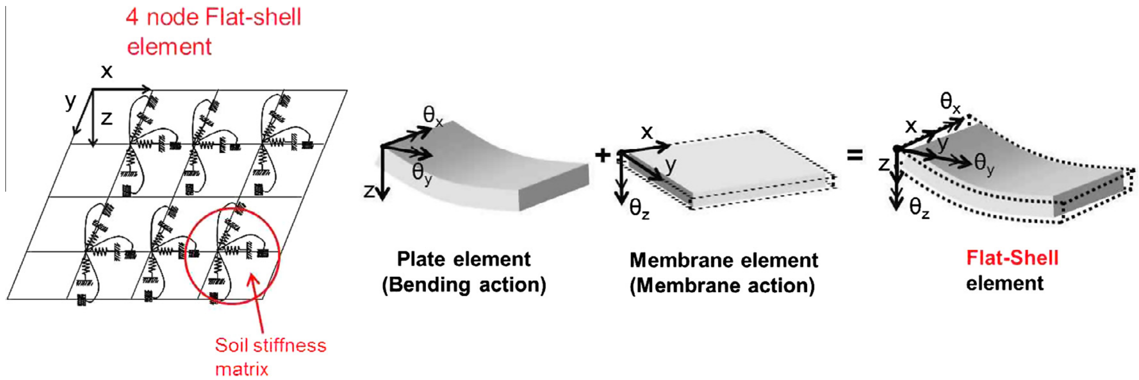

Fig. 1. Flat-shell element.

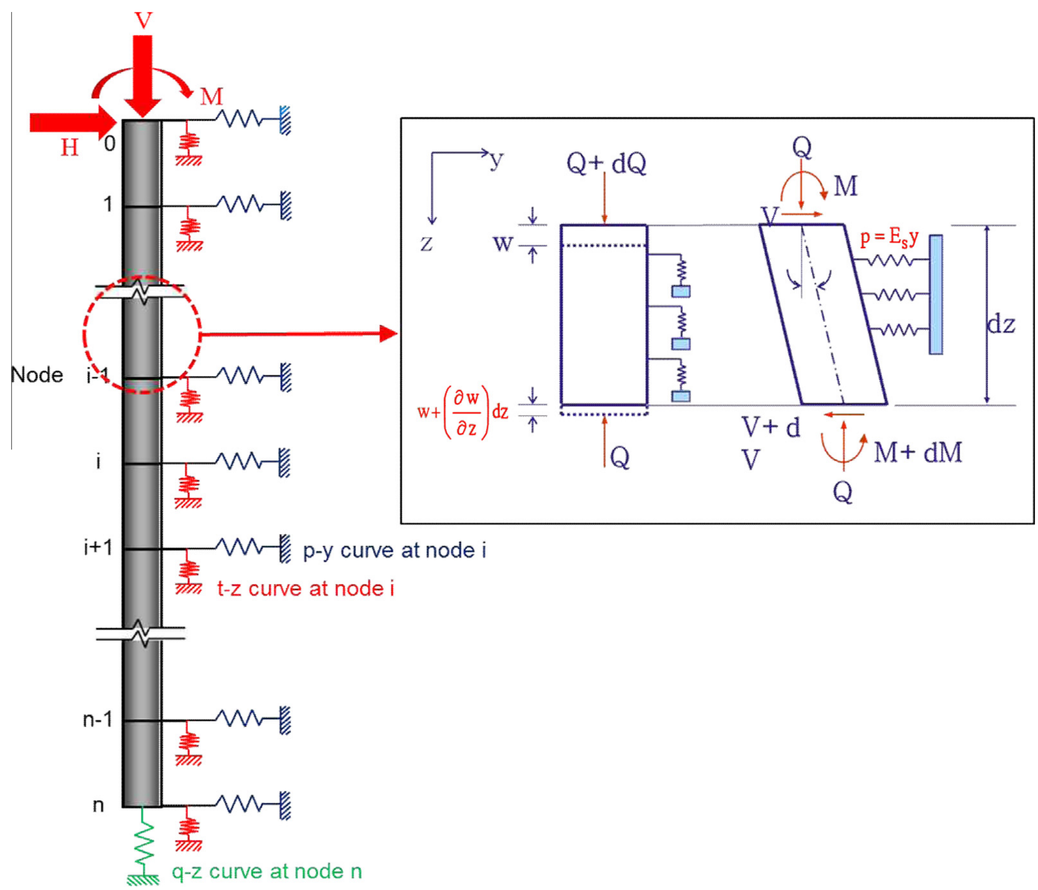

Fig. 2. Modeling of pile element.

numerical approach of the piled raft system is computationally expensive and requires extensive training because of the three-dimensional and nonlinear nature of the problem. Therefore, a finite element analysis is more suitable for obtaining benchmark solutions against which to compare simpler analysis methods, or for obtaining solutions of a detailed analysis for the final design of a foundation, rather than as a preliminary routine design tool [15].

In this study, an improved analytical method (YSPR) for the design of piled raft has been proposed to overcome some limitations of the existing methods. It is intermediate in complexity and theoretical accuracy between the second and third type of method. In the present method, a numerical technique is used to combine the soil and pile head stiffness with the stiffness of the raft. In order to examine the validity of the proposed method, the analysis results are compared with the available solutions from previous researches. In the field case study, comparative analyses between YSPR and a field measurement data are carried out for the pile load and settlement behavior.

2. Method of analysis

2.1. Modeling of flexible raft

Finite element techniques have often been used for the analysis of raft by different researchers such as Clancy and Randolph [5], Zhang and Small [49], Kitiyodom and Matsumoto [14]. According