UNIVERSITI PUTRA MALAYSIA

INELASTIC ANALYSIS OF SOIL-STRUCTURE INTERACTION SYSTEM

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MOHAMMED ABDULLA ISMAIL AL-GORAFI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

December 2005

DEDICATION

To My Family

I Dedicate This Work

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

INELASTIC ANALYSIS OF SOIL-STRUCTURE INTERACTION SYSTEM

By

MOHAMMED ABDULLA ISMAIL AL-GORAFI

December 2005

Chairman: Associate Professor Waleed A. Thanoon,PhD

Faculty : Engineering

Inelastic response of a framed structure is significantly different from the elastic response. Inelastic response can identify the possible locations of distress in a building as well as its failure mode. It also generates useful information such as maximum deformation, forces at important locations and the ductility requirements. Inelastic analysis of 2D frames is well reported by many researchers using either lumped plasticity models or detailed finite element models.

Soil-structure interaction is another important element for a more accurate prediction of stresses in both the structure and the supporting soil. Many structural models were developed and used to solve the soil-structure interaction problems either at macroscopic or microscopic level. In macroscopic approach, Winkler model is the most popular modeling used to solve the soil-structure interaction problems. At microscopic level, finite element method is used to model both the frame structure and soil media. Most of the analyses presented in the literature focused on soil-structure interaction within elastic range of loading. Very limited research focuses on the effect of nonlinearity and inelasticity of soil on the structural response.

This study covers the effect of the interaction analysis on the structure inelasticity, moment redistribution and failure mode of a 2D reinforced concrete frame considering nonlinear behaviour of the soil media. The study further highlights the effect of different foundation-soil relative stiffness and the rigidity of beam-column joint on the inelastic response of the frame soil system.

Finite element method integrated with stiffness matrix method is used to analyze the frame-foundation-soil system under combined vertical and lateral loading. A computer code is developed to trace the inelastic response of the frame-foundation-soil system. The developed code predicts the sequential formation of plastic hinges in the frame member and the continuous deterioration of the stiffness of the frame and soil media. The failure criteria used was based on actual nonlinear analysis of reinforced concrete section.

The 2D beam element is used to model the frame members and the combined footing. The beam is assumed to retain elastic property while the inelastic property is assumed to be lumped at the ends of the beam in a form of a plastic hinge. The inelastic property is evaluated considering the actual behaviour of the reinforced concrete section, the stiffness deterioration of the frame members with the loading history, and the behaviour of the yielded section. The actual non-linear behaviour of reinforced concrete sections is carried out so that a 2D yield surface has been evolved. The formation of 2D plastic hinges in a member is based on the interaction of actual moment-axial force in the section.

Plane strain 4-noded element was implemented to model the underlying soil. The stiffness of the soil was formulated using the usual finite element method. The degradation of the soil stiffness with the increase of the stress level was carried out using tangent modulus of elasticity derived from hyperbolic stress-strain model.

The results indicate that the non-interaction elastic analysis underestimates the moment at different beams and columns compared to the interaction elastic analysis. Extending the analysis to the inelastic range will further significantly alters the bending moment diagrams and the percentage increase or decrease in the bending moments compared to inelastic non interaction analysis. Furthermore, the inelastic interaction analysis does not only alter the sequential formation of the plastic hinges in the frame but it will also alter the load factors at which these hinges occurs, and number of plastic hinges and their locations compared to non-interaction analysis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS TAK KENYAL SISTEM INTARAKSI STRUKTUR-TANAH

Oleh

MOHAMMED ABDULLA ISMAIL AL-GORAFI

December 2005

Pengerusi: Profesor Madya Waleed A. Thanoon, PhD

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Tindakbalas kenyal sebuah struktur kerangka adalah sangat berbeza jika dibandingkan dengan tindakbalas tak kenyal. Dengan mengetahui tindakbalas tak kenyal, bahagian-bahagian yang berbahaya dan mod kegagalannya boleh dikenalpasti. Ia juga boleh memberi maklumat seperti deformasi maksimum, daya-daya di bahagian yang mustahak dan kekuatan tegangannya. Analisis struktur kerangka 2D telah banyak dikaji oleh penyelidik-penyelidik sebelum ini tetapi dengan hanya menggunakan kaedah model himpunan plastik ataupun kaedah unsur tidak terhingga.

Interaksi tanah dengan struktur juga adalah merupakan satu lagi topik yang memerlukan kajian dari segi jangkaan tegasan-tegasan yang lebih tepat di bahagian struktur serta tanah. Kebanyakan model sedia ada hanya setakat mikroskopik atau makroskopik. Untuk kaedah makroskopik, model Winkler adalah yang paling terkenal. Untuk mikroskopik pula, kaedah unsur terhingga digunakan. Kebanyakan kajian yang telah dilakukan setakat ini adalah dalam julat kenyal sahaja. Tidak banyak literatur dari segi ketakkenyalan tanah terhadap respons struktur.

Tesis ini melihat kesan analisis interaktif terhadap ketakkenyalan struktur, sebaran semula momen dan mod kegagalan sebuah struktur kerangka konkrit bertetulang dengan mengambil kira kelakuan tidak kenyal tanah. Selain itu, kesan kekukuhan tanah-asas dan kelakuan sambungan rasuk-tiang keatas ketakkenyalan sistem kerangka tanah juga dikaji dari segi respons sistem kerangka-tanah.

Kaedah unsur terhingga diintegrasikan bersama kaedah matriks kekukuhan telah digunakan untuk menganalisis sistem tanah-asas-struktur dibawah beban gabungan tegak dan sisi. Sebuah kod komputer telah dibangunkan untuk mengesan tindakbalas tak kenyal struktur kerangka-tanah. Kod ini boleh meramal urutan bentukan engsel plastik pada anggota kerangka dan kemerosotan kekukuhan media kerangka dan tanah. Kriteria kegagalan yang digunakan adalah berdasarkan analisis tidak kenyal bahagian konkrit bertetulang.

Unsur rasuk 2-D telah digunakan untuk model anggota struktur kerangka dan cantuman asas. Rasuk-rasuk dianggap memelihara sifat kenyal dan ketakkenyalan dianggap sebagai longgokan di bahagian hujung rasuk tersebut dalam bentuk engsel plastik. Sifat tidak kenyal telah dinilai dengan menganggap kelakuan konkrit bertetulang, kekukuhan kemerosotan anggota kerangka dengan sejarah bebanan dan kelakuan mengalah yang sebenarnya.

Unsur permukaan 4 nod telah diimplimentasi untuk model bawah tanah. Kekukuhan tanah diformulasi menggunakan kaedah unsur terhingga biasa. Kemerosotan kekukuhan tanah dengan kenaikan tegasan tanah telah dilakukan dengan modulus tangen kekenyalan yang diterbitkan dari model hiperbolik tegasan-terikan.

Keputusan yang diperolehi menunjukkan bahawa analisis tidak interaktif meremehkan analisis interaktif kenyal. Melanjutkan analisis kepada lingkungan tidak kenyal akan mengubah dengan drastik gambarajah momen lenturan. Selain itu, analisis tidak kenyal interaktif bukan sahaja mengubah urutan terbentuknya engsel plastik, tetapi juga faktor bebanan di engsel serta lokasinya jika dibandingkan dengan analisis tidak interaktif.

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I certify that an Examination Committee has met on 25th November 2005 to conduct the final examination of MOHAMMAD ABDULLA ISMAIL AL-GORAFI on his Master of Science thesis entitled "Inelastic Analysis of Soil-Structure Interaction System" in accordance with Universiti Pertanian Malaysia (Higher degree) Act 1980 and Universiti Pertanian Malaysia (Higher degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Uiversiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the supervisory committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institution.

MOHAMMED A. AL-GORAFI

Date: 5/10/2005

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CHAPTER I

INTRODUCTION

1.1 General

The response of any system that consists of more than one component is always interdependent. The frame superstructure; its foundation and the soil, on which it rests, together constitute a complete system. However, the common conventional design assumes that the superstructure is fixed at the base of the foundation, hence neglecting the flexibility of the foundation, the compressibility of the soil and the effect of the foundation settlement on distribution of bending moments, shear forces and axial forces in the superstructure.

Soil structure interaction is an important consideration for a more accurate prediction of stresses in both the structure and the supporting soil. Many structural models had been developed and used to model and analyze soil-structure interaction problems either at macroscopic or microscopic level. In macroscopic approach, Winkler model is considered to be the most popular model used to include the soil-structure interaction. At microscopic level, finite element method was used to model both the superstructure and the soil media.

Inelastic response of a framed structure as well as underneath soil media might be significantly different from the elastic response. Inelastic response can identify the possible locations of distress in a building. It also generates useful information such as maximum deformation, forces at important locations and the ductility requirements.

1.2 Problem Statement

Most of the analyses presented in the literature focused on the soil-structure interaction within an elastic range of loading. Limited researches focus on the effect of soil non-linearity on the structural response. Moreover, the effect of the interaction analysis on the superstructure inelasticity has not been known yet and it needs to be investigated. Special attention is supposed to be given to the way the superstructure fails compared to that predicted using non-interaction analysis.

This research focuses on the effect of the interaction analysis on the inelasticity in the framed structure considering linear as well as non-linear soil responses. The deformational characteristic, moment distribution, sequentional formation and location of the plastic hinges and stresses in soil resulted from elastic and inelastic interaction and non-interaction analyses will be discussed.

1.3 Scope and Objectives of the Study

The scope of this research is to investigate the effect of soil-structure interaction on the inelasticity of the superstructure compared to non-interaction analysis.

The main objectives of this study are:

i- To develop a computer code capable of analyzing soil-structure system at elastic as well as inelastic range of loading.

ii- To investigate the structure response of soil-structure system with consideration on the effect of :

1- Inelasticity and failure of superstructure

2- Interaction and non-interaction analysis.

3- Linear and non-linear behaviour of soil.

4- Relative stiffness of soil-structure interaction

5- The effect of beam-column end rigidity.

The structure response will be investigated in terms of horizontal deformation, bending moment variation, formation of plastic hinges in frame member and the stresses in soil media.