Ain Shams University

FACULTY OF ENGINEERING

Structural Engineering

DYNAMIC ANALYSIS OF BUILDINGS USING THE BOUNDARY ELEMENT METHOD

A Thesis submitted in partial fulfillment of the requirements of the degree of

Doctor of PhilosophyinCivil Engineering

(Structural Engineering)

by

ENG. MOHAMED AHMED ABDELWAHAB

Master of ScienceinCivil Engineering

(Structural Engineering)

Faculty of Engineering, Ain Shams University, 2009

Supervised By

Prof. ABDELSALAM AHMED MOKHTAR

Prof. YOUSSEF FAWZY RASHED

Cairo - (2015)

AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Structural

DYNAMIC ANALYSIS OF BUILDINGS USING THE BOUNDARY ELEMENT METHOD

by

Mohamed Ahmed Abdelwahab

Master of Science inCivil Engineering

(Structural Engineering)

Faculty of Engineering, Ain Shams University, 2015

Examiners' Committee

Name and Affiliation	Signature
Prof. ABDELSALAM AHMED MOKHTAR Structural , Ain Shams University	………………
Prof. YOUSSEF FAWZY RASHED Structural , Cairo University	………………
Prof. Sameh Samir Fahmy Mehany Structural , Cairo University	………………
Prof. Ashraf Ayoub Structural , City University, London	………………

Date:11 November 2015

Statement

This thesis is submitted as a partial fulfillment of Doctor of Philosophy in Civil Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Student name

Mohamed Ahmed Abdelwahab

Signature

…………..……….

Date:11 November 2015

Researcher Data

Name : Mohamed Ahmed Abdelwahab…….

Date of birth : 30/10/1980……………………………….

Place of birth : Cairo, Egypt …………………….

Last academic degree : Masters of Science…………….

Field of specialization : Structural Engineering…………….

University issued the degree : Ain Shams University………

Date of issued degree : 2009……………………………….

Current job : T.A. at Faculty of Engineering

Thesis Summary

The present thesis develops a new technique for dynamic analysis of structures using the boundary element method where free and forced vibrations analyses are considered. A new technique is developed to derive the stiffness matrix of each floor slab using the boundary element method. Each slab is considered as a super finite element and its stiffness matrix is computed at the degrees of freedom which are assigned at the connections between the vertical elements and the slab. The stiffness matrices of the frame elements and the slabs are then assembled and a diaphragm constraint is applied to all slab degrees of freedom. A new technique is developed to compute the diagonal mass matrix, where the boundary element method is used to compute the load vector for the case of own weight only resulting by locking all the active degrees of freedom of the slab. These forces together with the diaphragm masses represent the diagonal elements of the mass matrix. A numerical technique is used to compute the eigen values of the structure in the case of free vibration, and the displacement response along time is computed using a suitable finite difference method in the case of forced vibration. The present formulation results are compared to those obtained from the finite element method for verification.

Key Words: boundary element method, building structure, multi-story buildings, forced vibrations, Eigen value analysis, free vibrations, finite difference.

AKNOWLEDGMENT

Above all, I thank Allah who gives us the power and the hope to success.

I would like to express my appreciation to the members of my advisory committee for their direction and guidance. My special thanks are extended to my supervisors, **Prof.Abdulsalam Mukhtar,** and **Prof. Yousef Rashed**, who has been extremely helpful and supportive throughout the study. I am very grateful for his advice and personal concern for the study. Their encouragement and the confidence they placed in me during the study that made the task a lot more enjoyable.

I would like also to give special thanks and credit to my research colleagues, **Eng. Ramiz Wahby** and **Eng. Taha Hussein**, for their cooperation and support

Special thanks are given to all my family for their support, guidance and dedication.

May Allah make this modest work benefit all concerned and rewards us all.

Mohamed Ahmed Abdelwahab

Contents

CHAPTER 1

INTRODUCTION..1

1.1 Background **1**

1.2 Aim of The Research..**2**

1.3 Thesis Organization..**2**

CHAPTER 2

LITERATURE REVIEW..**5**

2.1 General **5**

2.2 Static Lateral Analysis of Buildings..**5**

2.3 Dynamic Lateral Analysis of Buildings **6**

2.4 The Super Element Technique **8**

2.5 Numerical Techniques in Dynamic Analysis.....................................**9**

2.6 The Boundary Element Method **9**

2.7 Dynamic Elastoplastic Analysis..**10**

CHAPTER 3

Static and Dynamic Analysis Using the Boundary Element Method

....**12**

3.1 The Basic Equations of The Reissner's Plate Bending Theory

....**12**

3.2 BEM for Flat Plates Rested on Columns **14**

3.3 Introducing Drops and Beams for the Formulated Stiffness Matrix **17**

3.4 The Numerical Technique for The Assembly of the Slab Stiffness Matrix...........**26**

3.5 Formulating and Assembling The Stiffnes Matrix of Vertical Elements...............**28**

3.6 The Total Stiffness Matrix Assembly **33**

3.7 Formulating and Assembling The Mass Matrix...............................**34**

3.8 The Eigen Value Problem **37**

3.9 Finite Difference Using Hilber-Hugh-Taylor Method **39**

CHAPTER 4

Numerical Examples and Case Studies **41**

4.1 Example 1 .... **43**

4.2 Example 2 .... **49**

4.3 Example 3 .... **55**

4.4 Example 4 .... **59**

4.5 Results Discussion **62**

4.6 Case Studies **63**

4.7 Earthquake Records **63**

4.8 Example 5 .... **70**

4.9 Example 6 .... **80**

4.10 Concluison **86**

4.1 Example 1 .... **43**

CHAPTER 5

summary and concluisons **88**

REFERENCES **88**

CHAPTER1

INTRODUCTION

1.1 Background

Dynamic analysis of building structures is becoming one of the common tasks of the structural engineering industry especially with the continuous competition in tall building heights. Many commercial software packages can be used to carry out such an analysis using the finite element method, so the innovation in such a field can be achieved only by developing new techniques that make the dynamic analysis of buildings much easier and at the same time more accurate. The boundary element method offers such an opportunity when compared to the finite element method.

The boundary element method (BEM) is a well known technique which does not require any domain meshing unlike the finite element method (FEM) which requires domain meshing and the accuracy of the solution depends on the mesh density especially at stress concentrations and zones of high stress gradient. This advantage is highly favorable in structural engineering applications where frequent changes occur and require essentially a rapid and accurate change of the model. So the BEM is preferred because the descritization is needed only on the boundary without interference with the domain changes.

The solution of boundary integral equations in the direct BEM is more accurate than the solution of differential equations in the FEM, also the representation of loads and supports is a real representation (i.e. area load and area support) unlike the FEM which represents loads and supports as singular points. Thus the BEM provides a model that better simulates the real behavior of practical structural engineering problems.

1.2 Aim of The Research

The aim of the current research is to introduce the merits of boundary element into the dynamic analysis field of buildings. This target is achieved and implemented through the current thesis. The present thesis develops a new technique for dynamic analysis of structures using the boundary element method where free and forced vibrations analyses are considered. A new technique is developed to derive the stiffness matrix of each floor slab using the boundary element method. Each slab is considered as a super finite element and its stiffness matrix is computed at the degrees of freedom which are postulated at the connections between the vertical elements and the slab. The stiffness matrices of the frame elements and the slabs are then assembled and a diaphragm constraint is applied to all slab degrees of freedom. A new technique is developed to compute the diagonal mass matrix, where the boundary element method is used to compute the load vector for the case of own mass only resulting by locking all the active degrees of freedom of the slab, these forces together with the diaphragm masses represent the diagonal elements of the mass matrix. A numerical technique is used to compute the eigen values of the structure in the case of free vibration, and the displacement response along time is computed using a suitable finite difference method in the case of forced vibration. The present formulation results are compared to those obtained from the finite element method for verification, and to demonstrate the efficiency of the proposed analysis. It has been demonstrated that the present formulation is in good agreement with the finite element method, not only with the columns modeled as skeletal element but also when they are modeled as solid elements. Also it was proven that the proposed method has time saving efficiency and more realistic drift predictions due to the area modeling effect inherent in it.

1.3 Thesis Organization

The current thesis will be organized in the following chapters:

Chapter 1 - Introduction

It is an introductory chapter for the thesis that explains the aim and the organization of the following chapters.

Chapter 2 – Literature Review

This chapter shows in details the previous work done in the field of static and dynamic analysis of the building structures, and sheds the light on the previous work on the boundary element method for flat plates.

Chapter 3 - Static and Dynamic Analysis Using the Boundary Element Method

This chapter explains in details the formulation of the slab stiffness matrix using the boundary element method and the formulation of the stiffness matrix of other elements attached to the floors in order to assemble the total stiffness matrix of the structure. Also it explains the formulation of the mass matrix using the boundary element method, and the adopted numerical schemes to perform free and forced vibration analyses on the building structure.

Chapter 4 – Software Implementation

This chapter provides a general description of the developed program algorithm and flowchart showing the input, output, and the main processes. Also, a description of the input and output files is given in this chapter.

Chapter 5 – Numerical Examples and Case Studies

This chapter provides practical numerical examples solved for both free and forced vibration analysis cases under practical earthquake records by the proposed boundary element method. The buildings responses obtained are then compared to those obtained using the finite element method for verification and for highlighting the advantages of the proposed method.

Chapter 6 – Conclusions and Future Work

This chapter summarizes the results of the thesis and draws the conclusions. Also it provides recommendations for the future research to be continued based on the current research results.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The dynamic analysis of buildings became a necessity in the engineering field given the frequency of earthquake events and the increasing demand on high rise buildings, so it became mandatory to perform advanced and accurate analysis of these buildings under lateral loads due to earthquakes to prove the adequacy of the design and to fulfill the building codes requirements.

As the computational capacities of the computers increased dramatically during the last few decades, also the solution techniques for the dynamic analysis problem evolved over time to take advantage of this computational revolution, and so it became common practice to carry out sophisticated analyses with less time and effort than before. In the next part the development of the dynamic analysis for buildings will be discussed.

2.2 Static Lateral Analysis of Structures

The classic structural analyses, e.g. consistent deformation and moment distribution were used to solve 2D structures under both vertical and lateral loads. These methods were restricted to 2D structures and could not be developed for medium or high rise buildings. As the advancements dictated the solution of medium to high rise buildings, A.Ghali et al. [1]

developed an analysis technique to solve structures under both vertical and lateral loads introducing the diaphragm effect methodology to account for the in-plane rigidity of the slab and to reduce the size of the solved problem.

The work of B.S.Taranath [2] provided the solution of 2D frames under lateral loads using the matrix analysis technique. A finite element model was presented by H.C.Chan et al. in [3] for analyzing shear walls. R.Rosman [4] solved structures with non-symmetric shear wall patterns. J.K. Biswas et al. [5] and J.Wdowicki et al. [6] extended the previous works by modeling 3D shear wall structures. A. Coull et al. [7] and J.Wdowicki et al. [6] worked on modeling shear walls of variable cross-sections.A. Pisanty et al. [8] introduced simplified analysis of coupled shear walls with variable cross-sections. Optimized structural modeling of tall buildings was suggested by A.B.M. Jameel et al. [9]. The next step was to model the entire structural behavior. M.S.Thomas et al. [10] presented a practical modeling scheme for RC slab-column frames. R.W. Mohareb et al. [11] created a system for lateral analysis of structures based on floor stiffness matrix generated using boundary element method.

2.3 Dynamic Lateral Analysis of Buildings

The free vibration analysis is performed assuming the structure is vibrating without damping or external force [17]. This kind of analysis is important to obtain the modes of vibration along with the natural frequencies and time periods, while a further combination of modes