Ain Shams University

FACULTY OF ENGINEERING

Structural Engineering

BOUNDARY ELEMENT METHOD FOR DYNAMIC ANALYSIS OF TALL BUILDINGS INCLUDING DAMPING

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

Master of Science in Civil Engineering

(Structural Engineering)

by

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B.Sc. in Civil Engineering

(Structural Engineering)

Faculty of Engineering, Ain Shams University, June 2014

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Statement

This thesis is submitted as a partial fulfilment of Master of Science 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.

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Summary

A dynamic analysis technique based on boundary element method is presented in this thesis. Forced damped vibration is conducted using calculated stiffness, mass and damping matrices formed by BEM. The stiffness for the slab was calculated by discretizing the boundary only assuming a super-element where vertical elements as area cells giving a realistic solution. The stiffness of the vertical elements are then calculated. The total stiffness matrix of the whole structure is then assembled. The mass matrix is lumped at the active degrees of freedom and calculated using BEM Two techniques (Rayleigh and Caughey) were used to evaluate the full damping matrix based on the value of the damping ratio. Finite difference Hilber-Hugh-Taylor method is carried out for the time history analysis. Verification of the introduced technique was done by, comparing the results calculated to those of the finite element method.

Key Words: boundary element method, multi-story buildings, forced vibrations, damped vibration.

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

Eslam Osama Mohamed Nabil Nagy

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CHAPTER1

INTRODUCTION

1.1 *Background*

Dynamic analysis of building structures is one of the main queries for the buildings especially with the continuous competition in tall building heights. t

Several techniques have been developed in the field of dynamics of structures in order to reach the most accurate and realistic solution. One of the leading techniques is the Boundary Element Method. It offers a very realistic solution by modeling the elements taking into consideration its real dimensions. Columns, shear walls, cores and beams are modeled with their real dimension.

The presented techniques in this thesis is used to achieve this target. A new implementation of damping in the structures using BEM is introduced. Forced vibration analysis and free vibration analysis were conducted. First the stiffness matrix of the slab is calculated using the BEM where the slab is treated as a super element and the stiffness matrix is condensed and calculated at the active degrees of freedom only, which are the connecting nodes between the slab and the vertical elements. Then the stiffness matrix of each vertical member is calculated and the whole stiffness matrix is assembled. The mass matrix is calculated using an approach based also on the BEM. The damping matrix is calculated using two techniques which are Caughey and Rayleigh. The time history analysis is carried out using the finite difference method and the results are compared to those of the finite element method.

1.2 *Thesis Organization*

Chapter 1 - Introduction

An introduction was provided to explain the aim of the flow in this thesis.

Chapter 2 – Literature Review

Previous work done in free and forced vibration calculated using BEM is explained in this chapter

Chapter 3 – Dynamic analysis using boundary element method

This chapter shows the steps to conduct the dynamic free vibbration analysis. Beginning by BEM stiffness matrix to the mass matrix then the finite deferent method used.

Chapter 4 – Damping matrix

In this chapter the basic concept of damping and its causes will be illustrated. The detailed formulation of the damping matrix using the boundary element method will be explained. Two techniques of damping are illustrated in this chapter which are Rayleigh and Caughey damping.

Chapter 5 – Software Implementation

A presentation of the developed algorithm is presented in this chapter along with a flow chart and the input and output files.

Chapter 6 – Numerical Examples and Case Studies

Both theoretical and practical examples are solved for damped forced vibration analysis using boundary element method. The earthquake used to act as the ground acceleration is EW ELCENTRO. The obtained output of these examples are the top roof displacement and the natural time period. The results was compared to those obtained using finite element method for verification.

Chapter 7 – Conclusions and Future Work

A summary of the results is illustrated and the advantages of the presented technique is shown. Some of the future work is recommended.

CHAPTER 2

LITERATURE REVIEW

2.1 *Static Lateral Analysis of Structures*

The classic structural analyses, e.g. moment distribution and consistent deformation were used to solve 2D structures under both vertical and lateral loads. These methods were restricted to 2D structures and were 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 diaphram 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. [3] extended the previous works by modeling 3D shear wall structures. Optimized structural modeling of tall buildings was suggested by A.B.M. Jameel et al. [4]. The next step was to model the entire structural behavior. M.S.Thomas et al. [5] presented a practical modeling scheme for RC slab-column frames. R.W. Mohareb et al. [6] created a system for lateral analysis of structures based on floor stiffness matrix generated using boundary element method.

2.2 *Dynamic Lateral Analysis of Buildings*

Dynamic analysis of buildings is now a necessary practice for designing earthquake resistant structures. The free vibration analysis is done assuming the structure is vibrating without damping or external force [7]. This kind of analysis is important to obtain the natural modes along with the natural frequencies, in order to obtain the final vibration response of the structure a further combination of modes through modal analysis. During a free vibration analysis of building structures, the well-known Boundary element method is used to obtain the natural frequencies, time period and mode shapes of the structure as presented in [8].

A formula based on the fourth-order Sturm-Liouville differential equations was developed by [9] to obtain the natural frequencies of tube-in-tube tall buildings, and was developed into a numerical procedure to obtain the eigenvalues for the same problems [10]. Also an approximate solution procedure for tube-in-tube tall buildings was derived based on reducing the governing partial differential equations of motion into ordinary differential equations and assuming the transverse displacement to be a harmonic vibration [11].

A simplified method is proposed in [12] for preliminary design of torsional coupled buildings with horizontal setbacks, where an equivalent frame is analyzed and the response static and dynamic is obtained.

An analytical solution for free vibration of cantilevered tall structures was introduced by [13], where the structure is treated as a cantilever beam with variable cross section under axial load. The differential equations for the distribution of mass, stiffness, and axial load over the structure length are reduced to Bessel's equations or ordinary equations with constant coefficients.

2.3 *Numerical techniques in dynamic analysis:*

Several numerical techniques were used for the dynamic analysis of structures such as the finite difference method (FDM), the finite element method (FEM) and the boundary element method (BEM).

The FDM is a well-known classical method and can be used efficiently in the numerical integration in the time domain. There are several techniques that depend on the (FDM) such as Newmark □, Wilson □, Houbolt scheme, and the Hilber-Hugh-Taylor (HHT) method. The forced vibration in this research is carried out using the finite difference method. The Hilber-Hugh-Taylor method is used [14].

2.4 *The Boundary Element Method*

The boundary element method (BEM) is a semi-numerical, semi-analytical technique, which does not require any domain meshing and proved its efficiency in many engineering applications [15], [16]. The work done by Y,Rashed [17], [18], [19] introduced the use of the (BEM) in the solution of thick plates using Reissener shear deformable plate formulation. Columns and walls are modeled as internal supporting cells where the real cross section geometry is modeled [20], thus the representation of loads and supports is a real representation (i.e. area load and area support) unlike the Finite element method (FEM) which represents loads and supports as singular points, thus the BEM provides a model that better simulates the real behavior of practical structure engineering problems. The PLPAK software is used for calculating the stiffness matrix of the slab [21]. There are different approaches to obtain the integral equation for the boundary element. The main approaches are the direct and in-direct formulations.

A collocation scheme is used to relate the slab to a number of source point (usually located outside the slab) in the indirect formulation of the boundary element method [22]. The integral equation is then transformed to summation one. The unknown in this system will be a variable at these source points. Finding them will be by collocating the equation with the field points at the slab. By using the boundary conditions, a relation can be find to solve the equation. In this research we will use the direct method for the boundary integral equation. The slab is considered to be a thick plate [23].

2.5 *Dynamic Analysis Using BEM*

There are different formulations of dynamic analysis using BEM that are commonly used, namely: the domain BEM formulation (D-BEM); the dual reciprocity BEM formulation (DR-BEM); and the time-domain BEM formulation (TD-BEM) [24].