A Consistent BEM Based Modelingof Tall Buildings

By

Ahmed Usama Said SaidAbdelhady

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
In
Structural Engineering

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Title of Thesis:

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Key Words:

BEM, Stiffness Analysis, Warping, Tall Buildings

Summary:

A novel coupled boundary element method and stiffness analysis technique for modelling of tall buildings is developed through this research.The floor stiffness matrix is computed in two different ways using the boundary element method.Columns, walls and cores are modelled using frame elements with a real geometry floor contact area.Warping effects are considered in the formation of the frame element stiffness matrix.Additional stiffness matrices may be added to the overall building in order to model the building's foundations including soil structure interaction. Post-processing is carried out for floor, beam and frame elements.The results of several examples done in this research are compared against numerical finite element results.

ACKNOWLEDGMENTS

I would like to express my gratitude and appreciation to my family: **Usama Said Said**, **YousriaAbdelazim** and **Hazem Usama** who are always my backbone, they devoted their lives to make me a successful person.

I would like to thank **Prof. Wael Mohamed Khalil El-Degwy** for the support he provided to the completion of this research thesis.

I would like to express my gratitude to **Prof. Youssef FawzyRashed**. He always provides all means of support whenever and wherever needed.

I would like to also thank my colleagues in the CUFE-BE research team; especially **Eng. Ahmed FadyFarid**and **Eng. AnasAbdulhakimAburawwash**who contributed to the accomplishment of this research work

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

ABSTRACT

A novel coupled boundary element method and stiffness analysis technique for modelling of tall buildings is developed through this research. The floor stiffness matrix is computed in two different ways using the boundary element method. In the first one (mode 1), the floor stiffness matrix is computed and condensed at column cells' degrees of freedom. In the second one (mode 2), floor stiffness matrix is computed at column and beam cells' degrees of freedom.

Columns, walls and cores are modelled using frame elements with a real geometry floor contact area. Warping effects are considered in the formation of the frame element stiffness matrix. The torsion and warping constant, and warping function are evaluated using the boundary element method. Additional stiffness matrices may be added to the overall building in order to model the building's foundations including soil structure interaction. Post-processing is carried out for floor, beam and frame elements.

The proposed technique is compared against well-known FEM based software. The results of several examples done in this research show that the proposed technique is superior for value engineering purposes, particularly computationally and economically.

Chapter 1: Introduction and Review of Literature

Over the past decades, structural analysis and design of tall buildings became a part of the daily structural engineering practice. In tall buildings, the effects of lateral loads e.g. seismic and wind loads are critical; they have to be considered in the structural analysis process.

Several methods were implemented to perform structural analysis of structures due to lateral loading. Initially, the simple structural geometry allowed simple manual calculations to provide a good enough solution [1]. The traditional Moment Distribution method and Matrix Analysis of structures were applied to regular framed structures. Many researches contributed to the techniques of modeling the irregular vertical elements (shear walls and cores). Some efforts presented analytical solutions via presenting a solution to partial differential equations [2]. Other solutions were based on numerical modeling of walls.

The increasing complexity of the geometries increased the difficulty of the implementation of manual calculations leading to a need for more flexible numerical techniques. Hence, the finite element method [3] and [4] started to present itself as a convenient solution for structural analysis problems. The flexibility of the finite element method allows the modeling of any floor shape, hence, get its stiffness matrix. A typical finite element model of a structure gets the stiffness of the floor as a two-dimensional element, either shell or plate, and assembles it with stiffness matrix of vertical elements modeled as one-dimensional element for columns and two dimensional elements for walls and cores.

The finite element modeling of structures passed through many development stages. Works in [2], [3], [5] and [6] presented improved and more efficient modeling schemes to deal with tall structures containing coupled shear walls and cores. Improvements included reduction in computational effort and reduced numerical errors. Other models were concerned with the modeling of coupling beams as continuous connections; this is based on the high in-plane stiffness of horizontal floors. The impacts of the variations of the walls' cross-sections along the building's height were considered in [7], [8], [9], [10], [11], [12],[13], [14], [15], [16],[17], [18] and [19].

Recently many efforts have been done to create a system for analysis of tall buildings based on boundary element method and stiffness analysis of structures[20].

The analysis technique used in this thesisis considered as a development for the work done in[20]. The technique is based on computerized matrix analysis of structures. The floor stiffness matrix is derived from a boundary element formulation; the floor stiffness matrix is condensed at the frame nodes (mode1) or at the frame and beam nodes (mode 2). The stiffness matrices of columnsare computed as one-dimensional element (frame element). The stiffness matrices of complex wall shapes are computed as one-dimensional element, however, the twisting behavior is included via adding warping degree of freedom. The boundary element model of plates and the boundary element computation of warping functions for frames are reviewed. The computation of stiffness matrices and solution of equations is explained. Introducing additional stiffness matrix, space frame element transformation, vertical loading and cases of loading are added to the developed software. Numerical examples are provided to illustrate the validity and efficiency of the proposed analysis technique.

1.1 Thesis Objective

In this thesis a numerical technique is developed for modeling tall buildings based on the boundary element method (BEM) coupled with the stiffness analysis of structures. The advantage of this method is to model slabs without any internal meshing, only boundary discretization, and to model the real geometry of the slab-column and slab-beam connections. Warping effects in the analysis of tall buildings are also consideredin the developed technique.

One of the main objectives of thiswork is to enhance the developed software that is based on the boundary element method.

1.2 Proposed Tall Building System

This section presents the proposed structural analysis model used in this thesis and implemented in the Tall Building package (TBpak) software to analyze tall building structures.Figure (1.2-1) shows the used structural elements: Floor element, frame element and beam element.Floor element'sstiffness matrix is generated using the boundary element method (B.E.M) considering the real geometry of connection between the slab and either the frame or the beam element, this facilitates the inclusion of warping effects. The derived floor stiffness matrix may be obtained including the beam stiffness (mode 1) or not (mode 2). In mode 2 beam stiffness should be computed and added to the building overall stiffness matrix. Figure (1.2-2) and figure (1.2-3) shows the system of degrees of freedom (DOF) in mode 1 and the assembly of building overall stiffness matrix.Figure (1.2-4) and figure (1.2-5) shows the system of degrees of freedom (DOF) in mode 2 and the assembly of building overall stiffness matrix. Derivation of floor element stiffness matrix as well as beam element stiffness matrix is illustrated in chapter 2.

Frame element stiffness matrix may be obtained considering warping effects or not. It may be also take any orientation in 3D space. Torsion and warping functions are illustrated in chapter 3. Derivation of frame element stiffness matrix is illustrated in chapter 4.

Additional stiffness matrix may be added to the building overall stiffness matrix which may model the substructure to include soil structure interaction, any connected structure with the modeled building ...etc.

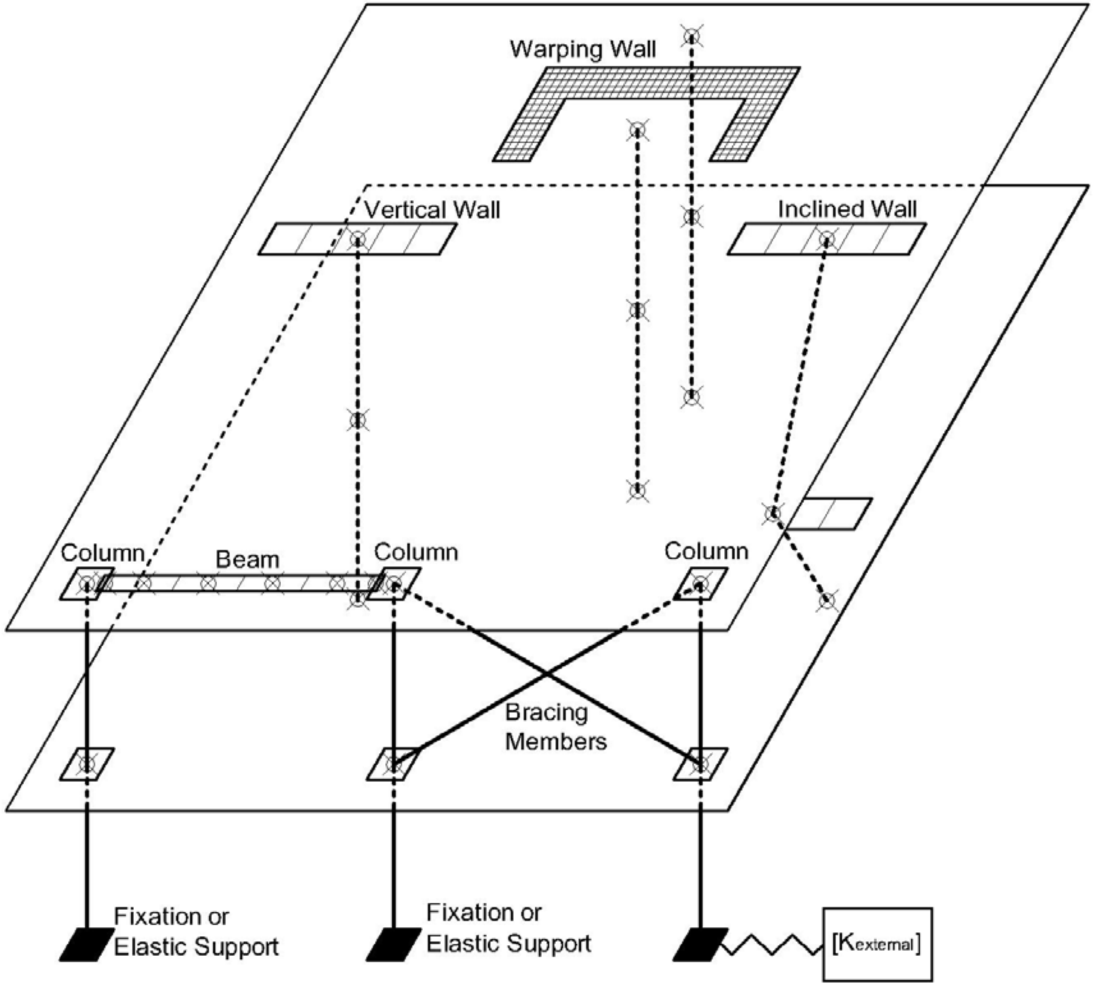

Figure 1.2-1:Proposed structural analysis model