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A practical boundary element analysis of slab-beam floor type

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A B S T R A C T

This paper presents the analysis of slab-beam type floors using the boundary element method. The shear-deformable plate bending theory according to Reissner is used to model the slab, whereas the Bernnoli–Euller beam model (without losing the generality) is used to model beams. The developed formulation embeds the system of grid beams stiffness matrix into the plate bending integral equation. In other words, it can be regarded as coupling between the slab boundary elements and the beam finite elements. The resulting integral equations are solved by collocation at boundary elements and internal supporting beam nodes. The present formulation allows considering the beam real intersecting area with the slab along the beam's span. The corresponding numerical model is implemented into computer code. Applications to simple examples and real building slabs are solved then results are compared to those obtained from analytical solution, finite element method, and literature to ensure the validity of the developed formulation.

1. Introduction

Plates supported on beams or stiffened plate problem has been subjected to research in the last two decades. In finite element analysis, such a problem is straight forward as both plate and beam stiffness matrices are assembled together. In boundary element analysis, on the other hand, the plate bending problem is well developed in many textbooks [1,2]. But the problem of plates supported on beams takes more concern.

Hu and Hartley [3] used the direct boundary element method to model thin plate supported with beams but the beams should be on the edge of the plate only to incorporate directly with boundary elements, i.e. internal beams cannot be modelled. Hartley [4] extended the work in [3] to model building slabs (thin plate) supported on columns, which is considered in [5], and edge beams.

Paiva [6] presented a boundary element formulation to model thin plates supported on columns and beams. Vertical forces only (no bending moments) are transmitted between plates and beams. No numerical examples are demonstrated in [6] to show the validity of the formulation. Paiva and Mendonca [7] modelled the interaction between plate, thin plate, and beam by replacing the beam by its actions on the plate using the differential equation of beam. Oliveira et al. [8] extended the work in [7] by testing it on more general slabs. Results show agreement with finite element analysis.

Sapountzakis and Kastikadelis [9] presented a boundary element formulation for thin plates rested on beams. This formulation takes into account both the in-plane stretching forces and the plate bending effect. The beams are connected to the slab with batches (cells). This is to model the beam actual connecting geometry to the slab. The authors in [10] extended their formulation in [9] to account for slabs resting on pre-stressed beams taking into account the effect of creep and shrinkage. Sapountzakis and Mokos in [11,12] extended the formulation in [9] to account for deformable connection considering warping of beams. The stiffeners at this case are modelled using a suitable one dimensional integral equation.

Fernandes and Venturini [13] modelled the beams as plate region with different thickness and properties. In this formulation the two sides of the beams together with the beam widths have to be discretized into boundary elements. Discontinuous elements are placed at corners between the beam and the slab. Such a formulation is not practical, as it introduces several artificial internal boundaries along each beam. This leads to a lot of inaccuracies near these boundaries. According to [14] if the beam width is small with a relatively large depth, this could generate problems.

Fernandes and Venturini [15] extended the formulation presented in [13] to account for the beam eccentricity. Hence additional degrees of freedom are necessary to be added to represent the plate stretching. This makes the situation worse in case of having large building floor. It has to be noted that inclusion of the beam eccentricity is easy by modifying the beam stiffness matrix without any addition of DOF as presented by Katz and Hartmann [16].

Waidemam and Venturini [17] extended the formulation presented in [13] to allow separation between beam and slab regions using initial moment field. The same authors extended their formulation in [18] to account for the plate stretching effect as presented previously in [15].

Fernandes et al. [14,19,20,21] extended the formulation previously presented in [15] but with the plate modelled using Reissner plate bending theory, coupling the stretching-bending problem and modelling beams with different materials.

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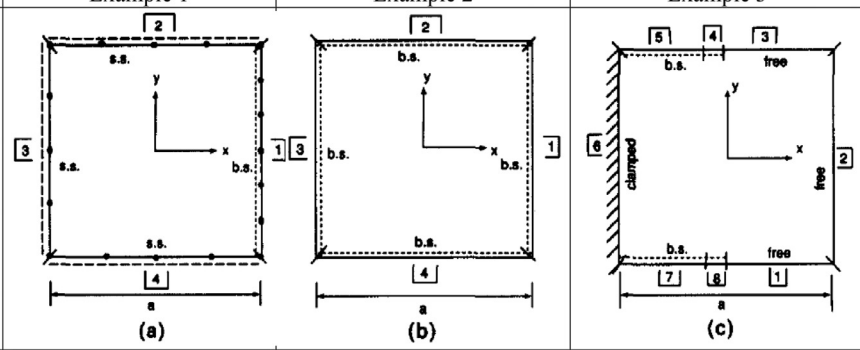
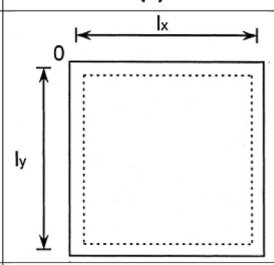
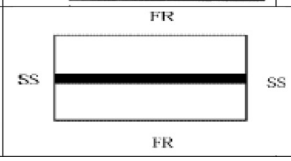
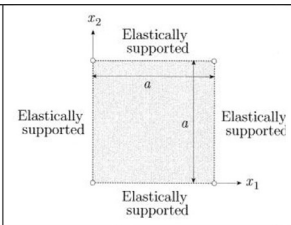
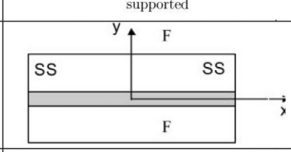
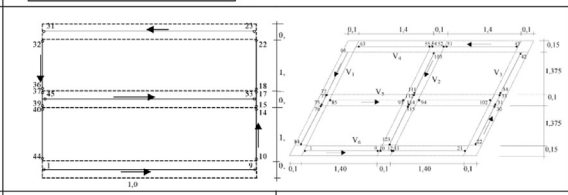
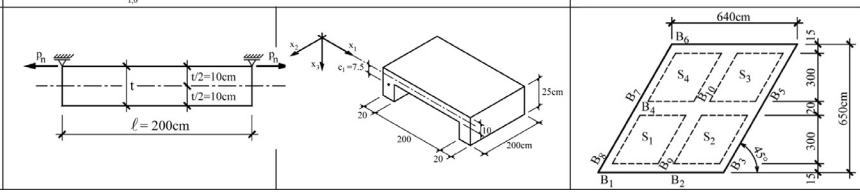
One of the most challenging difficulties that faces the boundary element method is that most of the carried out research is always regarded of theoretical nature with limited applications. Consequently, in all conferences related to the boundary element method, scientists and researchers always wonder when BEM will be seen extensively in the industry. Table 1 demonstrates snapshots for examples solved in previous research work. It is clear that none of them is a real building slab.

The strength of the BEM is mainly in the continuum models, however one dimensional elements can be solved efficiently using stiffness analysis without any approximations. The advantage of using the stiffness analysis is the well-known assembly procedure which is very versatile.

In this work, a practically oriented boundary element formulation using the shear-deformable plate bending theory is derived to take

Table 1
Examples solved in previous research work [23].

Reference	Example 1	Example 2	Example 3	Example 4
[3]				N/A
[22]		N/A	N/A	N/A
[9]		N/A	N/A	N/A
[23]		N/A	N/A	N/A
[10]		N/A	N/A	N/A
[13]		N/A	N/A	N/A
[15]				N/A

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