A New Tool for Structural Designers

Boundary element modeling software developed for building systems

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In today's design office, building slabs and mat foundations are generally analyzed and designed using software based on the finite element method (FEM). A typical commercial FEM software program allows designers to model the domain of a slab using plate bending elements, for example, and it allows columns or piers to be modeled using beam elements. Automatic mesh generators can simplify modeling, but the analysts may still need to manually adjust the mesh to adequately model slab penetrations or slabs with irregular geometries.

The meshing (discretization) of the slab, combined with centerline modeling of beam elements, however, can lead to geometrical differences between the numerical model and the physical structure. Also, peaking of moments near nodes at idealized supports or connections of plate elements to beam elements makes it necessary to average the results in automated design routines. Similar issues arise when a concentrated force must be applied at an FEM node.

The boundary element method (BEM) is an alternative numerical method that overcomes problems presented by FEM. With BEM, domain meshing is no longer required, and actual geometries can be accurately modeled.[1,2] Until recently, however, commercial BEM applications were largely focused on analysis of mechanical or aerospace systems. This article provides a brief introduction to a commercially available BEM software program devoted to building design.

BEM in Structural Engineering

Our company, Boundary Elements For Engineers (BE4E), has developed a plate analysis package called PLPAK, a BEM software program specifically for the analysis and design of building slabs and foundations. The software is based on Reissner's theory for shear-deformable plates in bending,[3] so PLPAK can be used for the analysis and design of thick plates, such as mat foundations and transfer slabs. PLPAK is capable of modeling the actual geometry of structural elements, including supporting and loading elements and openings. The boundaries in the model match the boundaries of the real structure. Discretization of the slab is not required. Results at internal points are produced through numerical solution, so the refinement level can be adjusted as needed.

Because only the boundary requires discretization, modeling errors can be minimized. Accurate geometric modeling allows clear data exchanges between the BEM analysis and structural design and detailing software tools. Peaking effects are eliminated, so averaging of results isn't needed. Also, bar terminations can be determined directly, rather than using interpolated data. Finally, the absence of domain discretization simplifies the steps required before performing a reanalysis—only minor adjustments are needed for internal details.

Structural Modeling

The stages required for structural analysis (Fig. 1) are:

- Model generation;
- Boundary solution; and
- Calculation and presentation of internal results.

The first stage, model generation, can be based on a building information model in which structural objects are defined using their engineering attributes. Model generation can also be based on data in DXF files. Figure 2 illustrates the boundary element discretization of a problem. As the figure demonstrates, very few boundary elements are required to obtain detailed results.

The software allows three-dimensional views of the model, and the system provides user-friendly tools for defining boundary attributes and properties in the model.

The second stage is to run the boundary element analysis. Any number of load conditions can be applied. Values of boundary displacements and tractions, as well as internal support reactions, are computed. The third stage comprises determining forces and deflections for internal points and displaying the results. The user can choose to view results along linear strips or as contour maps (Fig. 3). Depending on the desired level of refinement, contours can be generated over the full model or over a small area.

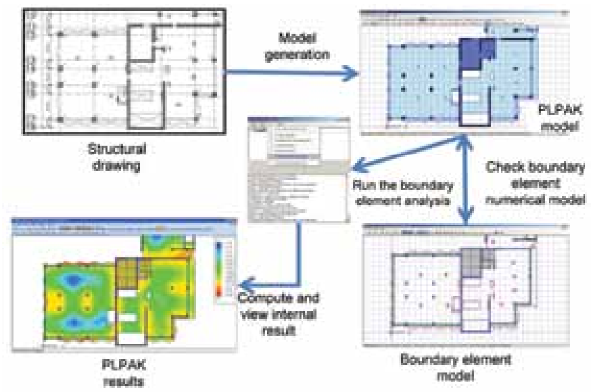

Fig. 1: Process flowchart using PLPAK software for analysis of a floor slab

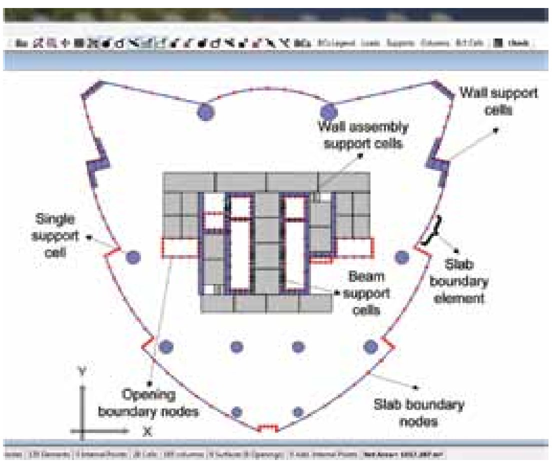

Fig: 2: An example of a boundary element model for a complex floor plate. Discretization is required only at the slab and opening boundaries. Columns, beams, and walls are modeled as support cells

Design moments can include the effects of twisting moments. Forces on beams can be presented along the length of the beam. Also, wall and core reactions can be presented directly.

Load combinations may be defined after the computation of internal point results. Moreover, the PLPAK software allows the user to export all results to a spreadsheet or text file for additional processing or presentation.

Added Power

In addition to the basic capabilities previously described, post-processors are available for the design of post-tensioned slabs, lateral analysis of buildings, and advanced soil modeling. Tools developed and incorporated into PLPAK include: PTPAK (post-tensioning analysis), EHSPAK (elastic half-space analysis), LTPAK (lateral analysis), and PLDesign (reinforced concrete structure design). A demo version of PLPAK can be reviewed on the BE4E website.

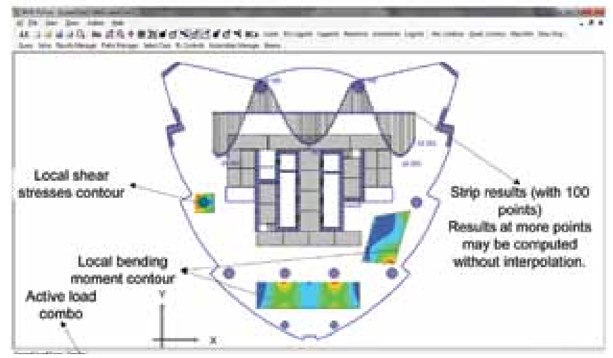

Fig. 3: Sample results. Moments and shears can be displayed along linear strips or as contours

References

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