

The PLPAK™

FIRST READ USER MANUAL

PLPAK™ Version 2.00

STRUCTURAL ANALYSIS SOFTWARE USING

THE BOUNDARY ELEMENTS METHOD

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Disclaimer

Considerable time, effort and expense have gone into the development and documentation of the PLPAK™ software. The PLPAK™ software has been thoroughly tested and used. The PLPAK™ software should be used by engineers with good understanding of concrete behavior, pre-stressing and structural mechanics. The user accepts and understands that no warranty is expressed or implied by the developers or the distributors on the accuracy or the reliability of the PLPAK™ software. The user must explicitly understand the assumptions of the PLPAK™ software and must independently verify the results produced by the PLPAK™ software.

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What is the PLPAK?

The PLPAK is special purpose software package for structural analysis of building slabs and foundations. The PLPAK uses the boundary element method as numerical method. It also uses the shear-deformable plate bending theory according to Reissner. The structural modeling is carried out according to the philosophy presented by Prof Youssef F. Rashed, the technical director of BE4E.com:

- Rashed, Y.F., Boundary element modelling of flat plate floors under vertical loading, *Int. J. Numerical Methods in Engineering*, **62**, 1606-1635, (2005).
- Rashed, Y.F., A boundary/domain element method for analysis of building raft foundations, *Engineering Analysis with Boundary Elements*, **29**, 859-877, (2005).

The PLPAK solves single floor at the time; each floor consists of single slab with several opening. The boundary element theory, on which the PLPAK is based, is published in several international journal publications as listed on the BE4E.com website. Results of the PLPAK are also validated through several examples published in several journal publications. The PLPAK philosophy is based on:

- Using the accuracy of the “boundary element method” together with its capabilities in modeling the real geometry to achieve a solution as close to reality as possible.
- Easy model preparation or model adjustments as well as fast processing.
- The PLPAK is written in modular form so engineers, researchers, and computational modelers can add their own module and integrate it within the PLPAK. Therefore the PLPAK has no ceiling and its capabilities is open to your thinking and personal inventions.
- The PLPAK development is kept to ensure the easy learning (matter of few hours) to any new engineer or numerical modeler. Learning the PLPAK does not require previous knowledge of boundary elements or even finite elements.

What you can do with the PLPAK?

The PLPAK applications are:

- Flat slabs (columns are considered with the real cross section)
- Slab with beams (beams can be considered with its actual area connection to the slab)
- Raft foundation (with beams, on non-homogeneous soil)
- Piled raft and piled foundations (piles are considered as circular area)
- Post-tensioned flat slabs or rafts

The PLPAK has the following capabilities:

- More accurate and realistic structural modeling

- More accurate punching calculations
- Solution for multiple load cases and load combinations
- Multiple DXF import to suit any changes in the structural drawing or in the as-built drawings
- Multiple Post-tensioned cable importing, to allow engineers work in parallel
- Produce results in forms of distribution along strips, contour maps , local rectangular and quadrilateral contour maps, max/min arrows for principal moments
- Results are obtained in forms of deflections, rotations, bending & torsional moments, shear forces. Also design moments according to Wood and Armer equations are produced.
- Export results to text files or Excel files

On the other hand, the PLPAK can be considered as:

- Practical check or validation for your finite element results.

Numerical tool to carry out “value engineering” process to minimize cost of materials

Why using the PLPAK?

We use the PLPAK for the following reasons:

- Real time post-processing
- Accuracy of the boundary element method and the shear deformable plate bending theory
- Easy input in forms of:
 - o Multiple exporting from DXF to the virtual model in the PLGen, makes life easy for engineers to account for any modification in design, change of column places, adding duct openings, etc. This is done without re-meshing or re-building the numerical model (please recall: the boundary element method requires boundary only-discretization).
 - o Multiple post-tensioned cables input, leading to make engineers work as groups and in parallel; this increases the work efficiency especially in large projects.
 - o Multiple level of “undo” in the PLPAK preprocessor (the PLGen).
- Capable of modeling fine details such as small duct openings.
- Easy and accurate processing.
- Easy and very accurate post processing and computation of design values.
- Results are produced fast and are mailable in terms of size.

- The PLPAK is very light on your computer system (the installation file, without the documentations, is just about 2.5 MB)

PLPAK unique capabilities

The followings are some unique capabilities offered by the PLPAK:

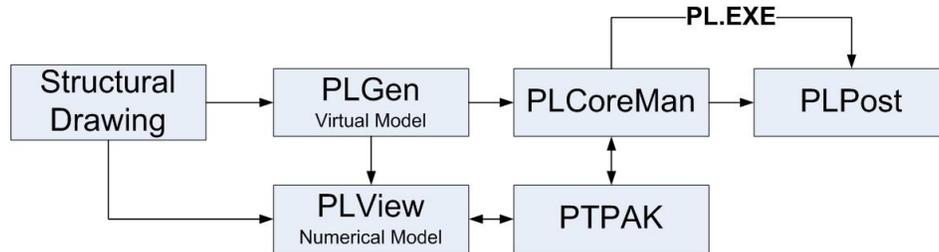
- The PLPAK provide a possible way to check the obtained finite element results in companies.
- The easy drawing capabilities of the PLPAK makes life simple for practical engineers; especially in case of having changes. Moreover the boundary only discretization will minimize errors generated by engineer in the numerical models.
- The PLPAK multiple DXF import and the multiple pre-stressing cable imports will allow engineers to work in parallel in a single project.
- The PLPAK has the capability of zooming in for local result details
- The PLPAK can generate soil stress map to check the bearing capacity violation under rafts.
- The PLPAK models beams with its actual interaction area to the slab with make it unique in case of modelling slab-beam type bridges.
- Unlike the center-line modelling of finite elements, the PLPAK considers the actual slab geometry. This makes the PLPAK more suitable for design and detailing software. Moreover it will be a perfect numerical environment for what is called the Building Information Modelling (such as REVIT) [17].
- The PLPAK uses the so called boundary domain method to model the soil support. The well-known Winkler model is build-in inside the package. However, advanced models, such as the multi-layered elastic half-space could be used. Whatever the soil model, the soil springs are considered as continuous spring patches underneath the continuum foundation plate. The allows:
 - o The capability of considering non-homogeneous soil pattern
 - o The capability of obtaining pressure map for soil reactions.
- The PLPAK models supports with their actual shapes, for example piles are considered as circular sections. Unlike finite elements, no peaking values is obtained for straining actions (such as bending moments) over columns or in vicinity of stress concentrations.

The PLPAK main components are:

- The preprocessor – the PLGen module
- The numerical model (or the boundary element model) viewer – the PLView module
- The Core manager – the PLCoreMan module
- The command line solver – the PL.EXE
- The postprocessing – the PLPost module
- The post-tensioning package – the PTPAK
- Other accessories

PLPAK operation diagram

This modeling philosophy can be illustrated and summarized in the following flowchart:



Get your design values in four steps

1. Generate Virtual Model - PLGen
First generate what is called the “virtual model” for any structural drawing. This model is very similar to the original drawing but it is inside the computer in forms of objects. Mainly three categories of objects are: the geometrical objects, the loading objects and the supporting objects.
2. Check the numerical model (optional step) - PLView
Hence this virtual model is translated to numerical model or boundary element model, which allows the user to check the boundary discretization predefined in the PLGen. It has to be noted that such discretization is virtual; therefore the plate or the slab is still one continuum leading to the well-known high accuracy of the boundary element method.
3. Run analysis model - PLCoreMan
Use PLCoreMan to run the analysis model, this run provides the user with support reactions and boundary results.
4. Get results at internal points - PLPost
Once solved on the boundary, use post-processing to obtain values (deflections, rotations, bending and torsional moments, shear forces, and any other design values) at internal points .

PLPAK Models

Structural Model

This is the model that represents the statical system which includes the geometrical definitions of the structural system i.e. the structural drawing that are used by the structural engineer. In the practical applications, this model is created by means of drafting software e.g(AutoCad®), however, the PLPAK also provides drawing tools in the PLGen module. There are some precautions that need to be taken into consideration while creating the structural drawing in order to avoid problems while importing the drawing in the PLPAK:

1. The drawing should be in plan (top) view.

2. All elements should be drawn in their actual dimensions, these elements include:
 - a. Supporting elements (except beams that have been drawn using the PLPAK) e.g., slab, columns, soil springs and walls.
 - b. Loading elements e.g. column loads, wall loads and load patches

Please note that PLPAK models plates using BEM and hence all point loads have to be defined as load patches with their actual size.

3. All drawn elements should be drawn as areas not separate lines.
4. There should be a single slab which includes all other elements.

Virtual Model

This is the model that is displayed in the PLGen module and used to define the details of the each object of statical system. All structural elements (including loading elements) are treated as objects with their actual dimensions and defined properties. The definitions of the statical system include:

1. Geometry which is partially defined from the Structural model, however, some dimensions have to be defined using the virtual model. The virtual model can also be used to modify the structural model that was previously imported.
2. Materials which are defined by three properties which are Young's Modulus, Poisson's Ratio and the unit weight of the material.
3. Loads which are defined according to the type of the loading elements and the expected type of load that is induced by the object. The PLGen allows you to define different load cases as well.
4. Supports which are defined by means of the stiff nesses of the structural supports in certain directions.

The virtual model is used to produce two other models which are:

1. Three dimensional model viewer that is created using OpenGL.
2. Boundary element model (numerical model) that is used in the structural analysis of the model. Actually, the virtual model acts like the translator which translates the structural model into the boundary element model (numerical model).

3D Model

This model is produced from the PLGen and displays a 3D view for the model based on the virtual model. The 3D model includes the geometry and supports of the structure, thus, the produced view is very similar to the actual shape of the structure. The 3D model can be used as check for the validity of the virtual model because the 3D model will not be created if there are two areas on the top of each other. This problem usually occurs when the virtual model s created from multiple ".dxf" files.

Numerical or boundary element model

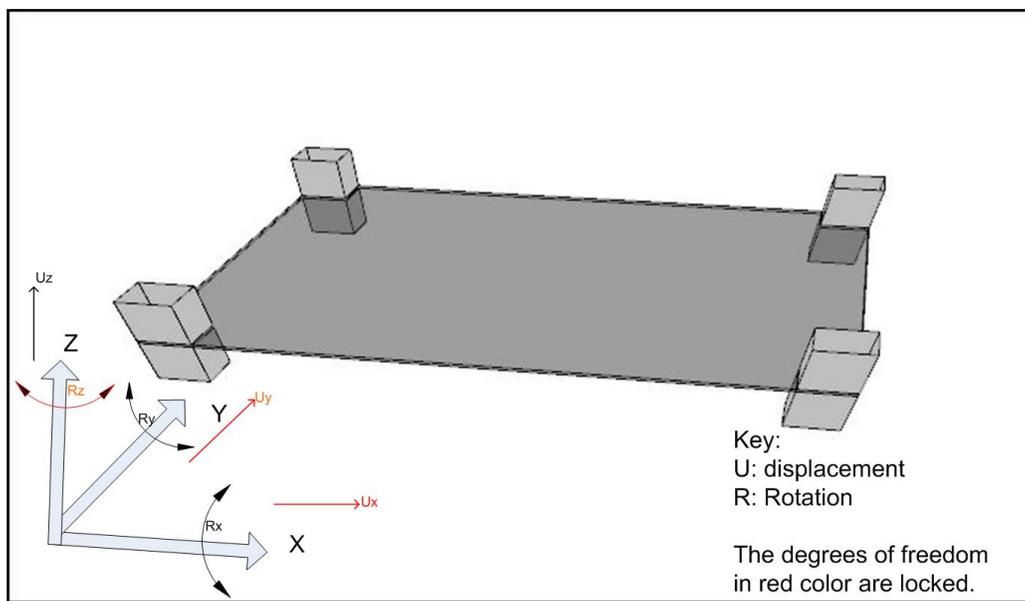
The numerical model is the Boundary Element Model that is used by the solver to find solutions. This model is useful for advanced users who have at least some background on BEM. The controls of the numerical model are through:

1. PLGen: Used to define the number of Gauss points required and the type of solver, it is also used to define the number of divisions on the supports and boundaries.
2. PLView: Used to view and edit the different properties of the numerical model e.g. nodes, points, elements, supports, loads, internal points and boundary conditions. The PL viewer also allows you to view the divisions (meshing) that will be used while solving.

Editing the numerical model has to be done by means of editing the input tables which represent the input file, therefore, the editing process has to be done by advanced users carefully. Although the editing process is complicated, the process allows the user to have capabilities that are not available through the PLGen model (Virtual model). In some cases, the model may have error that cannot be discovered unless the numerical model is viewed using the PLViewer.

As previously mentioned, the PLPAK is structural analysis software for the slabs and foundations i.e. all problems are two dimensional problems in the XY (horizontal) plane. In order to define this piece of information, some degrees of freedom of the whole system have to be locked. As shown in the below figure, in the 2D analysis of slabs, the system should not be allowed to:

1. Translate in X and Y directions
2. Rotate about Z direction



The PLPAK components

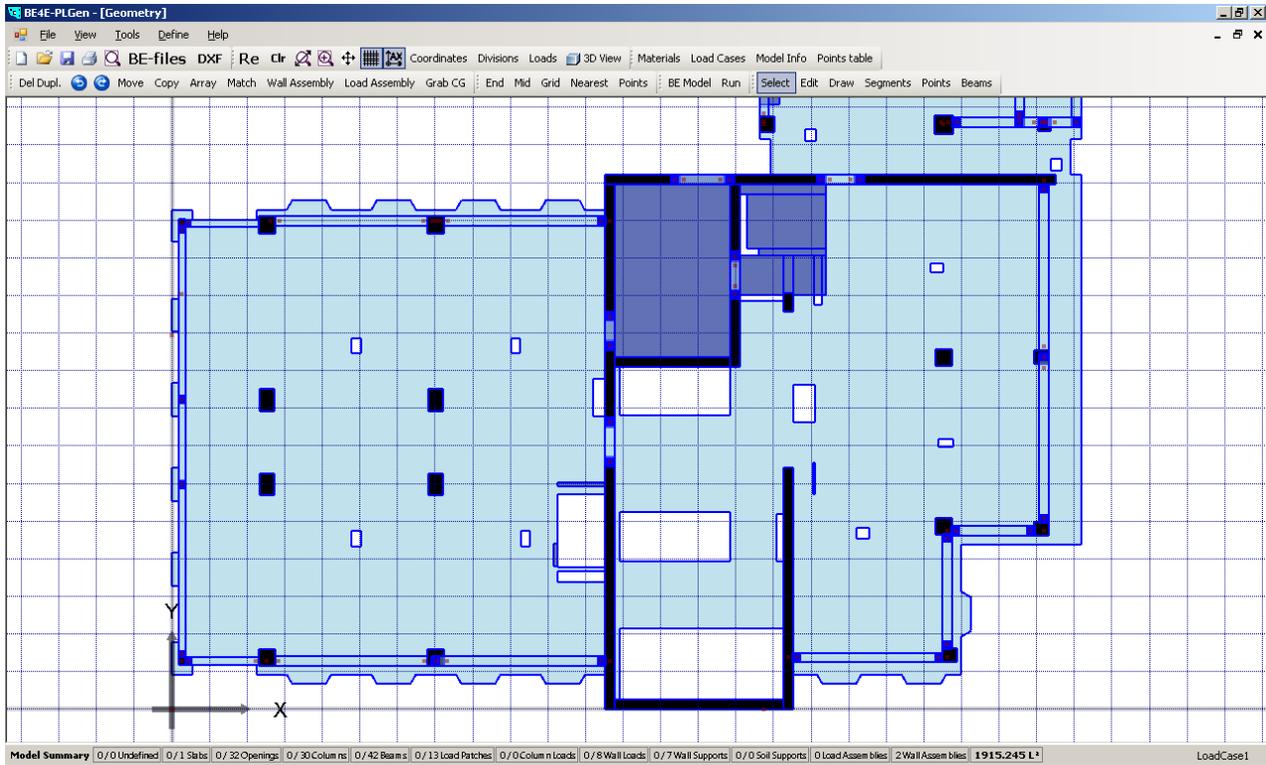
The PLPAK software is an integrated development environment helps the user to generate his model using the PLGen module. It allows the user to view or/and edit the used boundary element model via the PLView module. Hence he can solve it using the PLCoreMan module. The PLPost module serves as a post-processing module for the obtained results. The package could be linked to other packages such as the PTPAK which provide the capability of adding post-tensioned cables to the model.

The proposed PLPAK package consists mainly of three main parts (separate modules) as follows:

1. The BE model generator (**the PLGen module**).
2. The BE model viewer (**the PLView module**).
3. The core solver module (**the PLCoreMan module**).
4. The post-processor (**the PLPost module**).

The PLGen module

The PLGen module stands for the virtual model generator or the pre-processor of the PLPAK. It mainly changes any structural drawing to what is called the “virtual model”. Modeler can import structural drawings from DXF CAD files or can draw then directly using the CAD capabilities of the PLGen. The virtual model looks very similar to the original structural drawing. The PLGen mainly define the structure using series of objects. These objects are classified into one of three categories: the geometrical objects (single slab and openings), the loading objects (column load, wall load, load patch, load assembly) and the supporting objects (column, wall, wall assembly, soil support, beam). Using such objects the modeler can define all elements in the building slab. It has to be noted that the virtual model represents the actual slab shape (not like the centre-line model of the finite element method). Columns and walls are represented by the actual cross section shape. The PLGen can also input the numerical models of each object such as the number of boundary elements for each segments, the discretization of the beam-slab contact areas, etc. Load cases only (i.e. no load combinations) are defined in the PLGen module. Material properties are also defined herein. The below Figure demonstrates the graphical user interface of the PLGen module.



The following table states the types of objects available in the PLGen module.

Structural Object	Typical modeling usages
Slab	Modeling building slabs and foundations
Opening	Add openings to the slab object
Column/Pile	Modeling supports of mean dimensions like most of structural columns supporting Building slabs or Piles supporting foundations
Beam	Modeling of beams supporting the slabs
Wall Support	Modeling supports elongated in one direction like a buildings shear walls
Support Assembly	Modeling supports of complex geometry like buildings cores or broken shear walls
Load Patches	Add a distributed load over a quadrilateral part of the slab object
Column Load	Add vertical force and two moments over a quadrilateral part of the slab object
Wall Load	Modeling Loads elongated in one direction like a buildings shear walls loads over a raft foundation and loads over slabs due to brick walls
Load Assembly	Modeling Loads of complex geometry like buildings cores loads over a raft foundation
Soil Support	Modeling the soil supporting the building foundation

The proposed capabilities of this module can be summarized as follows:

1. Construct a virtual structural model for the problem using object-based modeling. This is proposed to be done through an interactive graphical interface that can construct and edit the virtual model.
2. Generate a BE model from the virtual model.
3. Control the generated BE model through the graphical interface using parameters settings.
4. Import CAD drawings to facilitate the construction of the virtual model.
5. Store the virtual model in a binary form so that it can be recalled later.
6. Undo and redo changes made to the virtual model.
7. Construct a 3D view of the virtual structural model.
8. Handling different load cases and generating a BE model for each one.

The PLView module

The PLView module is a MDI (multiple document interface) graphical environment that allows the modeler to view or/and to edit the boundary element numerical model of the considered problem. Boundary element discretization and internal loading or supporting patches are viewed. The PLView could be launched directly from the PLGen module. Practical engineers or beginners can skip this module. It has to be noted that the expert modelers can write their own input text file for the considered numerical model and input it directly to the PLView model without passing through the PLGen module. The below Figure demonstrates the graphical user interface of the PLView module.



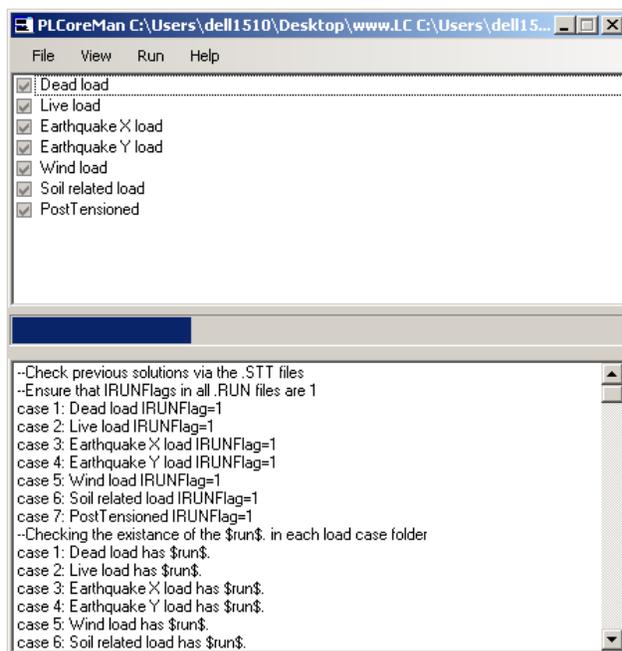
This is the BE model viewer that is developed to visualize the generated boundary element models generated by the PLGen module or from user text input. This module has also some model editing capabilities that are considered a secondary benefit. Only advanced users who have thorough understanding of boundary element modeling can make use of this feature. The core component of this module is proposed to be a dataset that contains data tables of all the entities forming the model. This dataset can be thought of as a database that resides in the computer memory rather than on the computer hard disk. This technique is usually faster for data centric applications especially when the size of data is not large, as the case when using BEM. The dataset is populated using the data that already exist in the input text file (*.in) and then the populated dataset is used to visualize the model. The model data typically consist of material parameters, linear equation solver parameters, nodes coordinates, points coordinates, elements connectivity data, columns definition, cells definition and internal points coordinates.

The proposed capabilities of the BE model viewer can be summarized in the following:

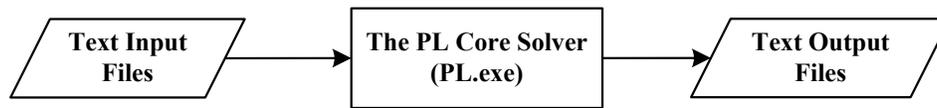
1. Display all the model data graphically.
2. Display all the model data in tabular form.
3. Edit the model data in the tables.
4. Store the model again in text format after editing.

The PLCoreMan

The PLCoreMan module serves as a link between all of the PLPAK modules. It allows solution for multiple load cases. It also allows adding any additional loading (such as pre-stressing loading) or sophisticated supporting elements (such as any substructure). It also acts as solution tracer. The below Figure demonstrates the graphical user interface of the PLCoreMan module.

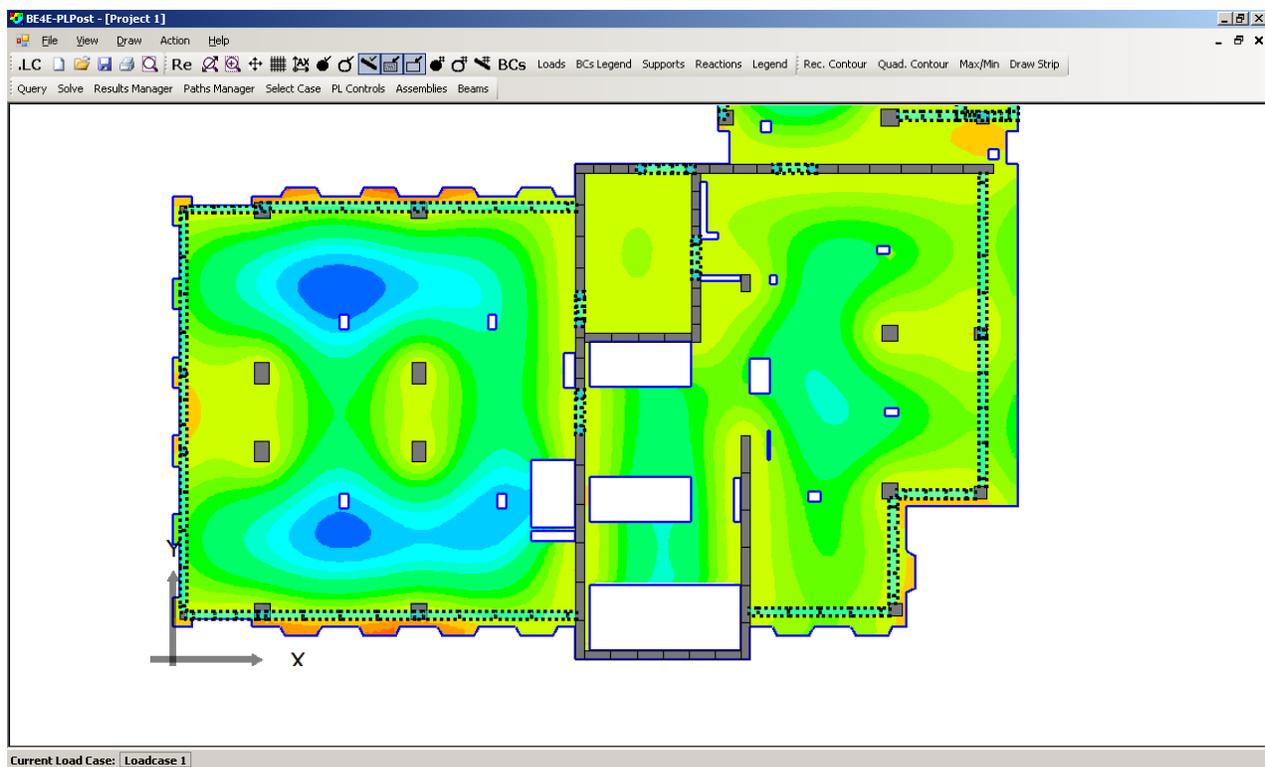


This is the part of the PLPAK that is responsible for solving the boundary element model (saved by the PLGen) using Reissner plate bending equations. The main part of the module is the PL.exe which is the core solver. This module allows the user to add post tensioning cables and updates the input files according to the cables added. The below Figure demonstrates the generic operation diagram for the PL.exe core solver.



The PLPost module

The PLPost module allows the user to display the results in forms of strips, contours, and colour patches. It has to be noted that all results obtained in the PLPost environment are computed using analytical integral equations. In other words, no approximation is involved. Load combinations are defined herein. Results of any form could be exported easily to text files or to spreadsheets programs. The below Figure demonstrates the graphical user interface of the PLPost module.



The proposed capabilities of the post processor can be summarized in the following:

1. Represent the results at a point.
2. Represent the results along a line.

3. Represent the results over an area using contour plots.
4. Export the results in formatted text files.
5. Store the results in a binary form, so that it can be recalled without repeating the analysis.
6. Perform the load combinations of different load cases.
7. Display the columns reactions or soil contact pressures under the raft graphically.

Typical modeling process

Modeling steps

The typical scenario for modeling a plate using the developed package will involve the following procedures:

- Drawing the structural elements using a CAD software,
- Exporting the drawing in the standard DXF format,
- Importing the DXF using the PLGen module,
- Defining different structural objects in the PLGEN module to produce a virtual structural model,
- Defining different load cases through the PLGen module,
- Assigning the loads over the structure and defining the supports conditions using the PLGen module,
- Exporting the text input files of the BE model and the load cases file and visualizing the model using the PLView module,
- Calling the core solver in the first mode through the PLCore manager to solve for the boundary solution,
- Opening the load cases file and the input files using the PLPost module,
- Calling the core solver in the second mode of solution to solve for internal points through the PLPost module,
- Defining load combinations in the PLPost module,
- Visualizing the analysis results using PLPost capabilities,
- Saving the results in the binary results file (.res) and exporting them in a formatted text file (*.csv).

It has to be noted here that the developed PLGen module has some drawing capabilities; this means that the first three steps in the previous scenario can be replaced by drawing the structure directly in the PLGen module.

Getting help, technical Support and updates

The PLPAK is supports the users with different types of documentation and troubleshooting system. In case of beginner user or a practicing user who has problems dealing with any aspect of PLPAK, please refer to the following as applicable:

- Manuals

The documentation manuals provide detailed explanation for all options and facilities that are provide by the PLPAK. Each component of the PLPAK has its own manual in addition to generic parts that explain the modeling philosophies, steps and provide troubleshooting mechanism for the user.

- Video tutorials

The video tutorials are the ideal gateway for PLPAK beginners. More than 25 tutorials are available to help the beginner users with using the program. The tutorials are accompanied by step by step examples that can be printed to help the user to follow up with the tutorial.

- In case if the manuals, video tutorials do not provide enough help, please inform the PLPAK customer support team by mailing the problem to:

plpak@be4e.com