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BSI Newsletter

Bridge Software Institute

In this issue's Technical Corner, we discuss the latest feature made available in the newly released FB-MultiPier 4.19.1, i.e., condensed stiffness calculation and non-linear bearing feature.

The articles Technical Corner and Discussions are open for input from all readers. If you have a topic that you think should be discussed, let us know. Did you create a great model with features that you want to share? Everyone is welcome to submit articles for possible inclusion in subsequent issues.

Please contact BSI at **BSI@ce.ufl.edu** with your ideas.

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What's New at BSI

We are pleased to announce the release of FB-MultiPier v4.19.1. This program and other structural analysis software are available for download from the **BSI** website. The new version of FB-MultiPier contains fixes to the latest reported bugs and also includes a number of new features.

Technical Corner - New Features

Equivalent Stiffness Calculation Feature

Presented in this article is the newly enhanced Equivalent Stiffness calculation feature in FB-MultiPier v4.19.1. While this feature allows users to easily characterize an equivalent stiffness for a foundation system, we strongly recommend applying the method to quantification of a system stiffness only at the following model locations (**Fig. 1**):

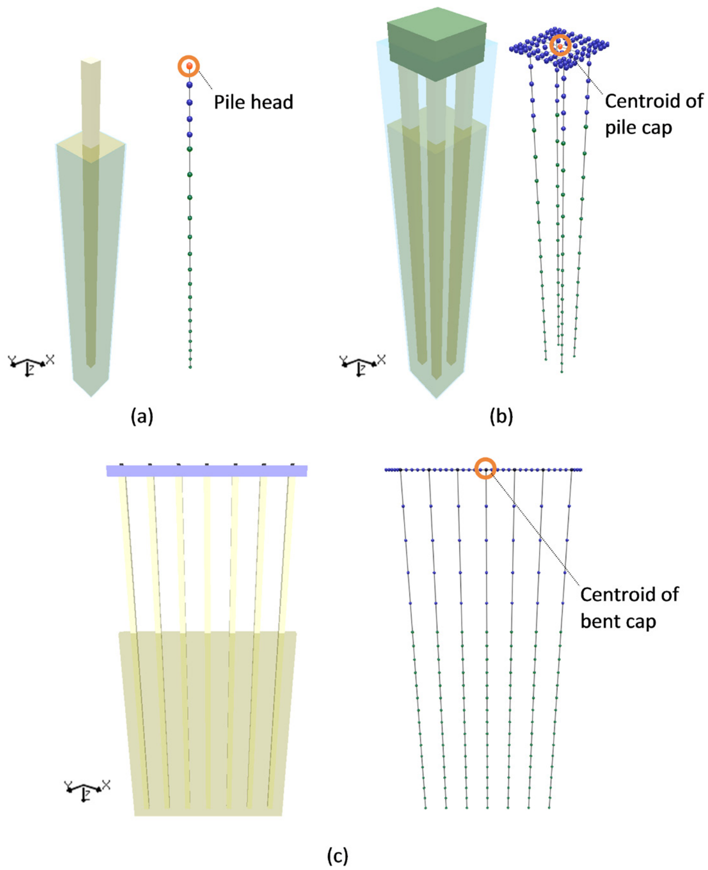

Fig. 1 Supported locations for calculating equivalent stiffness: a) Pile head of single pile; b) Centroid of pile cap; c) Centroid of pile bent cap.

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1. The pile head node of a Single Pile model;
2. A node at the centroid of the cap for a Pile and Cap model; and,
3. A node at the centroid of the bent cap for a Pile Bent model.

The equivalent stiffness matrix incorporates the non-linear behavior of both soil and structural components of FB-MultiPier models. Further, the equivalent stiffness is calculated per load case, and is viewable in the FB-MultiPier text output file. Step by step instructions for generating the equivalent stiffness matrix for a particular node of interest are given below, and in addition, this newly enhanced feature is validated against manual calculations. Specifically, a single pile model shown in **Fig. 2** is used as demonstration. For simplicity, linear constitutive behavior is attributed to the pile, where resultant cross-section properties are given. Further, the 40 ft long, 18 in. x 18 in. square pile is fixed at its base and, to facilitate manual calculations, soil is not included in the analysis.

Cross-sectional details and material properties:

Square pile width	=	18	in
Pile length (L)	=	40	ft
Area (A)	=	324	in^2
Inertia @ 2 Axis (Ix)	=	8748	in^4
Inertia @ 3 axis (Iy)	=	8748	in^4
Torsional Inertia (J)	=	17496	in^4
Young's Modulus (E)	=	4030	ksi
Shear Modulus (G)	=	1679	ksi

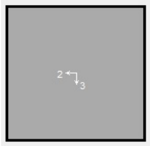

Fig. 2 Square pile.

The pile model is divided into ten discrete cross-section frame elements (**Fig. 3**). The pile head node (i.e., node 1) is selected as the location for which the equivalent stiffness matrix is to be estimated.

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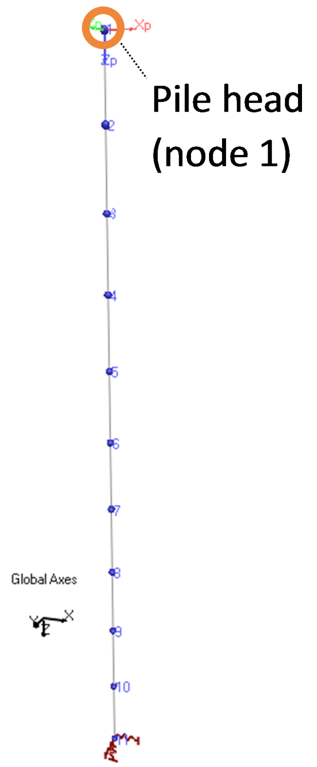

Fig. 3 Finite element model of the single pile.

To obtain the equivalent stiffness matrix at the pile head, carry out the following steps:

Step 1: Create a 'Single Pile' model. This will open a default Single Pile model in FB-MultiPier.

Step 2: Update the cross-section, material, and length data listed above.

Step 3: Enter the analysis tab as shown in **Fig. 4**, and input the node of interest within the Stiffness Option panel. Alternatively, the node of interest can be graphically selected, as shown in **Fig. 5**, where Node 3 is selected.

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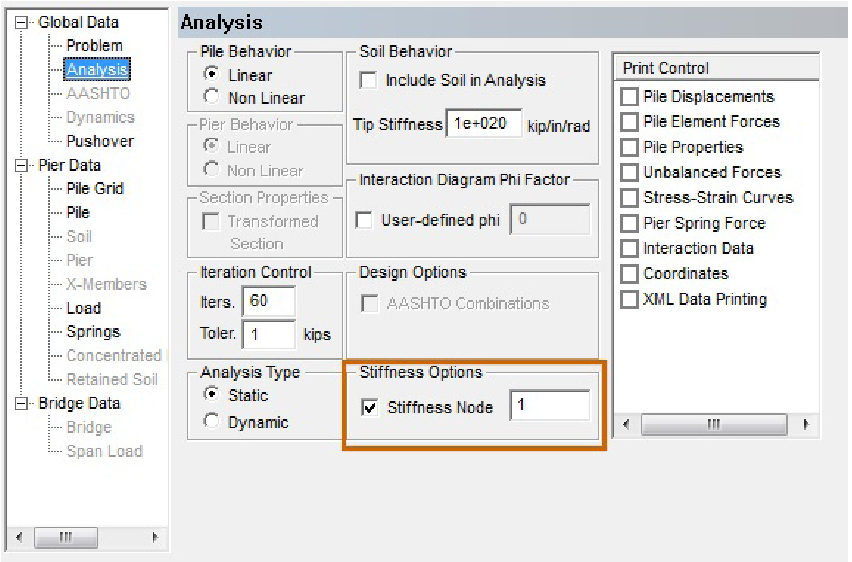

Fig. 4 Selecting the node (node 1) for calculating equivalent stiffness.

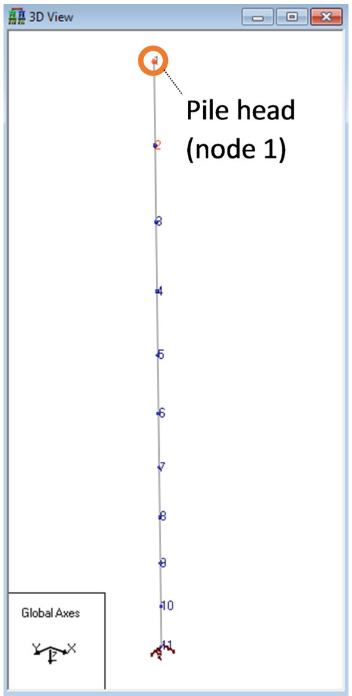

Fig. 5 Alternative selection of the pile head (node 1) from the 3D edit window.

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Step 4: Run the analysis, and view the output file for the equivalent stiffness matrix (**Fig. 6**).

```
single-pile.out - Notepad
File  Edit  Format  View  Help

*****************************************************************
* Averaged Flexibility in FB-MultiPier global coord. system    *
* Load Case:    1 Node:    1                                   *
* Translations: in/kip  Rotations: rad/kip-in                  *
*****************************************************************

                Fx           Fy           Fz           Mx           My           Mz
Delta   0.1046E+01   0.0000E+00   0.0000E+00   0.0000E+00  -0.3268E-02   0.0000E+00
Delta   0.0000E+00   0.1046E+01   0.0000E+00   0.3268E-02   0.0000E+00   0.0000E+00
Delta   0.0000E+00   0.0000E+00   0.3676E-03   0.0000E+00   0.0000E+00   0.0000E+00
Theta   0.0000E+00   0.3268E-02   0.0000E+00   0.1362E-04   0.0000E+00   0.0000E+00
Theta  -0.3268E-02   0.0000E+00   0.0000E+00   0.0000E+00   0.1362E-04   0.0000E+00
Theta   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.1634E-04


*****************************************************************
* Condensed Stiffness in FB-MultiPier global coord. system     *
* Load Case:    1 Node:    1                                   *
* Translations: kips/in Rotations: kip-in/rad                  *
*****************************************************************

             Delta        Delta        Delta        Theta        Theta        Theta
   Fx   0.3825E+01   0.0000E+00   0.0000E+00   0.0000E+00   0.9181E+03   0.0000E+00
   Fy   0.0000E+00   0.3825E+01   0.0000E+00  -0.9181E+03   0.0000E+00   0.0000E+00
   Fz   0.0000E+00   0.0000E+00   0.2720E+04   0.0000E+00   0.0000E+00   0.0000E+00
   Mx   0.0000E+00  -0.9181E+03   0.0000E+00   0.2938E+06   0.0000E+00   0.0000E+00
   My   0.9181E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.2938E+06   0.0000E+00
   Mz   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.6120E+05


*****************************************************************
* Condensed Stiffness in standard coordinate system            *
* (FB-MultiPier -> Standard: X -> X; Y -> Z; -Z -> Y)          *
* Load Case:    1 Node:    1                                   *
* Translations: kips/in Rotations: kip-in/rad                  *
*****************************************************************

             Delta        Delta        Delta        Theta        Theta        Theta
   Fx   0.3825E+01   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.9181E+03
   Fy   0.0000E+00   0.2720E+04   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
   Fz   0.0000E+00   0.0000E+00   0.3825E+01  -0.9181E+03   0.0000E+00   0.0000E+00
   Mx   0.0000E+00   0.0000E+00  -0.9181E+03   0.2938E+06   0.0000E+00   0.0000E+00
   My   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.6120E+05   0.0000E+00
   Mz   0.9181E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.2938E+06
```

Fig. 6 Equivalent stiffness matrix from the .out file.

Each node along the frame elements of the single pile possesses six degrees of freedom. Correspondingly, for the selected pile head node (node 1) we take a 6x6 stiffness matrix into consideration. Note that the single pile, for this demonstration, is simplified to resemble a cantilever beam. In this way, we can check the validity of the feature manually. **Eqn. 1** gives the equivalent stiffness matrix for cantilever frame element.

$$K = \begin{bmatrix} \frac{12EI}{L^3} & 0 & 0 & 0 & \frac{6EI}{L^2} & 0 \\ 0 & \frac{12EI}{L^3} & 0 & -\frac{6EI}{L^2} & 0 & 0 \\ 0 & 0 & \frac{AE}{L} & 0 & 0 & 0 \\ 0 & -\frac{6EI}{L^2} & 0 & \frac{4EI}{L} & 0 & 0 \\ \frac{6EI}{L^2} & 0 & 0 & 0 & \frac{4EI}{L} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{GJ}{L} \end{bmatrix} \qquad \textbf{Eqn. 1}$$

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Where,
K – Stiffness Matrix (Translation - k/in, Rotations – k-in/rad)
A – Area of the cross-section of beam (in^2)
E – Elastic modulus (ksi)
G – Shear Modulus (ksi)
I – Moment of Inertia (in^4)
J – Polar moment of inertia (in^4).

Node 1 is selected in the demonstration model. So the length L, to be used in **Eqn. 1** will be the distance from node 1 to the fixed tip (i.e. L = 40ft = 480in). Using the cross-sectional and material properties listed above, the equivalent stiffness matrix at Node 1 is given as:

$$K_{Node1} = \begin{bmatrix} 3.825 & 0 & 0 & 0 & 918.08 & 0 \\ 0 & 3.825 & 0 & -918.08 & 0 & 0 \\ 0 & 0 & 2720.25 & 0 & 0 & 0 \\ 0 & -918.08 & 0 & 293787 & 0 & 0 \\ 918.08 & 0 & 0 & 0 & 293787 & 0 \\ 0 & 0 & 0 & 0 & 0 & 61199.55 \end{bmatrix}$$

Recalling **Fig. 6**, the manually calculated stiffness matrix shows agreement with the program-generated results.

Non-Linear Bearing Feature

A frequent request has been to provide for the use of non-linear bearings and "gap bearings". These are used in a variety of ways but basically control the movement of a bridge superstructure relative to the substructure.

This version of FB-MultiPier (v4.19.1) allows for the input of non-linear bearings. The following example demonstrates the use of a "Gap Bearing" for lateral restraint of a four-span bridge subjected to an 800 kip transverse vessel collision load at the central pier, as indicated in **Fig. 7**.

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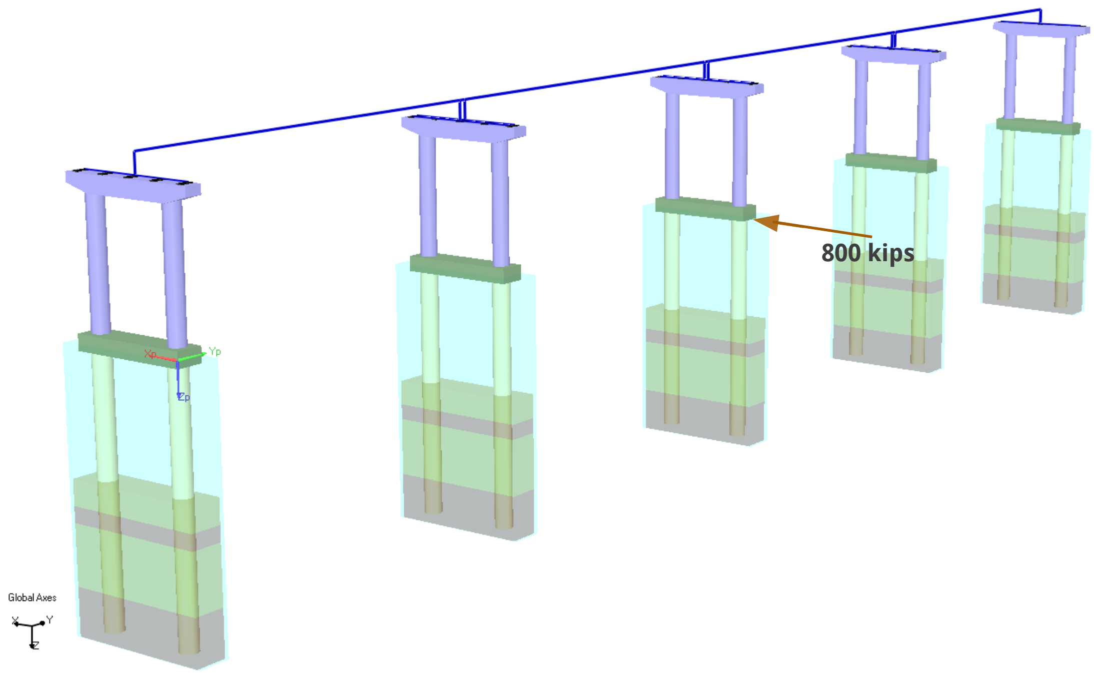

Fig. 7 Four-span bridge model subjected to transverse loading.

The bridge superstructure consists of five concrete I-girders supported on laminated neoprene bearing pads. There are ten pads located at the impacted pier, and the deck slab is cast continuous. The construction details allow for the transverse movement of the deck, while engaging the bearings, through a transverse displacement of 1.25 in. For transverse displacements exceeding 1.25 in., the bearings may no longer translate transversely, and the deck and substructure are basically fixed with respect to lateral movement.

The FB-MultiPier input for this bearing condition is shown in **Fig. 8**. This "custom 5" bearing is used as input for the global X-translation of all bearings. The bearings may translate 1.25 inches reaching a force of 14 kips and then, encountering an effectively rigid "stop", the bearing force increases to 400 kips at 2 in. of lateral translation. Supplying sudden increases in stiffness greater than two orders of magnitude can lead to numerical convergence issues within the solution iterations, and thus, it is recommended to approximate "rigid stops" accordingly. Summarily, for transverse displacements exceeding 1.25 in., the deck and substructure are effectively locked together.

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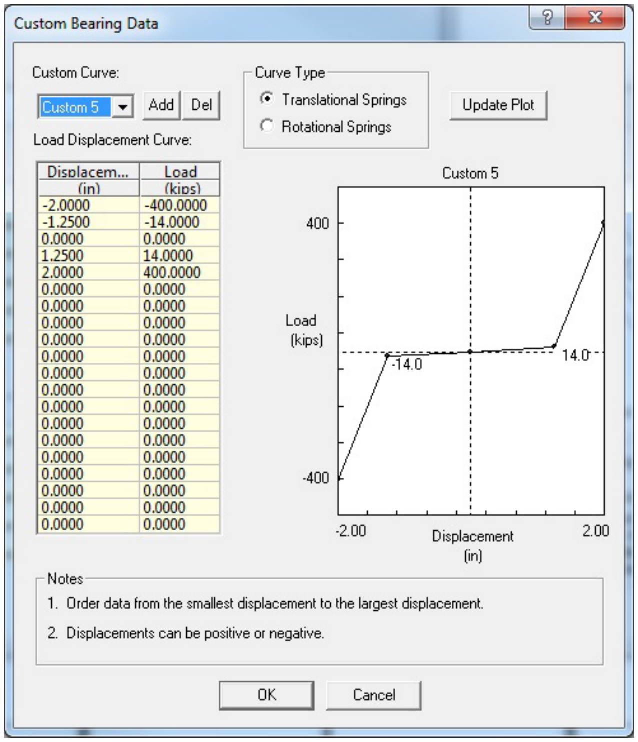

Fig. 8 Custom bearing data

For the model containing constraint-based bearings between the pier and the superstructure (with respect to transverse displacements), 348 kips of lateral force develops at the bearing location, and the corresponding displacement is 2.67 in. In contrast, when the "gap bearing" is modeled, 316 kips develop at the bearing, while the pier translates 4.52 in. and the superstructure translates 3.24 in.

For Technical Support

Cary Peterson
Technical Support, Bridge Software Institute

Technical support questions. When requesting technical support for any BSI software, it is recommended to email the input file (.in file for FB-MultiPier and Atlas or .spc file for FB-Deep) to the BSI address bsi@ce.ufl.edu along with a brief explanation and any supporting documentation of the issue. This will allow the support staff to provide the users prompt technical support.

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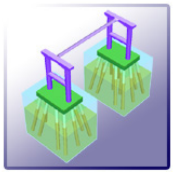
Identifying the program version. It is important that users have the current most up-to-date version of the BSI software. Thus we recommend that users regularly visit the home page of the **BSI** website. To identify the current version of program installed on your computer, open the program and go to Help > About to see the program version number.

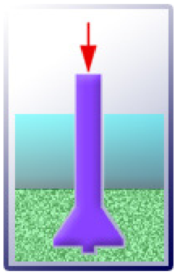
BSI Program Status



FB-MultiPier V4.19.1 Download a FREE demo today!

Released: August 19, 2014 - Continuing Development - Technical Support Available

FB-MultiPier is the successor to FB-Pier. In addition to all the capabilities of FB-Pier the FB-MultiPier program allows for the modeling of a bridge that consists of multiple piers that are connected with bridge spans. In addition to the multiple load cases and the AASHTO coefficients that are available in FB-Pier, the new program is capable of performing dynamic analysis for the bridge. For more information about FB-MultiPier, click here.



FB-Deep V2.04 Download a FREE demo today!

Released: May 28, 2012 - Continuing Development - Technical Support Available

The FB-Deep computer program is a Windows based program used to estimate the static axial capacity of drilled shafts and driven piles. The methodology is based upon Federal Highway Administration (FHWA) reports. FB-Deep guides the user through pile and shaft materials data, shape and dimensional inputs, soil properties, and boring log info. FB-Deep presents the data analysis in both clear graphical and text form. For more information about FB-Deep, click here.

Atlas V6.04

Released: December 8, 2011 - Limited Web Support Available

Atlas is a finite element analysis program that is used for the design/analysis of cable supported traffic signal systems. The Atlas program models dual cable supported systems including single-point or two-point attachments and suspended box systems. For more information about Atlas, click here.

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