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BSI Newsletter

Bridge Software Institute

In this issue, we discuss recently developed features included in the release of FB-MultiPier v5.9.0.

Engineers making use of software produced by the Bridge Software Institute (BSI) are encouraged to communicate suggestions for new features and program improvements to BSI. These suggestions may be general or very specific to project needs. We recognize that you are in the best position to contribute to effective program development directions.

In this release of FB-MultiPier, the enhancements listed below were largely motivated by YOUR suggestions:

a) Prestressed high-strength stainless steel (HSSS) piles;
b) Nonlinear elastic springs
c) Through-depth p-scale factors for modeling custom lateral soil resistance; and;
d) Graphical selection of longitudinal reinforcement groups when defining member cross-sections.

The FB-MultiPier v5.9.0 enhancements are highlighted below.

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Prestressed High-Strength Stainless Steel (HSSS) Piles

Newly available cross-sections for square and cylinder piles have been implemented in FB MultiPier, based on Florida Department of Transportation (FDOT) standard drawings of prestressed High-Strength Stainless Steel (HSSS) piles. Cross-sections containing prestressed HSSS strands can be incorporated into FB-MultiPier models by manually building up cross-section definitions, or more directly, by selecting from among the FB-MultiPier database of standard cross-sections. An example database selection of the FDOT standard 24-in. square prestressed HSSS pile cross-section is shown in Fig. 1.

The default stress-strain relationship implemented for HSSS strands in FB-MultiPier is schematically illustrated in Fig. 2. Considerations are given to both tensile and compressive strains (the stress-strain curve is symmetric). The HSSS strands are assumed to behave in a linear manner, followed by softening behaviors that precede rupture. For strains that exceed rupture, the corresponding strand stresses abruptly reduce to (and remain at) zero. Further, for any load cases (or load combinations) that produce strains exceeding strand rupture, a warning message is issued as part of the program output, which includes the model location where the rupture has occurred.

All built-in cross-sections for prestressed HSSS piles are defined with utilization of 7-wire 0.6-in. diameter HSSS strands. Accordingly, the default modulus for HSSS strands is defined as 24,000 ksi. Further, the default rupture stress is defined as 240 ksi. As shown in Fig. 2, the stress-strain curve exhibits nonlinear behavior upon nearing the rupture strain. In turn, the default rupture strain is defined as 0.014 in./in.

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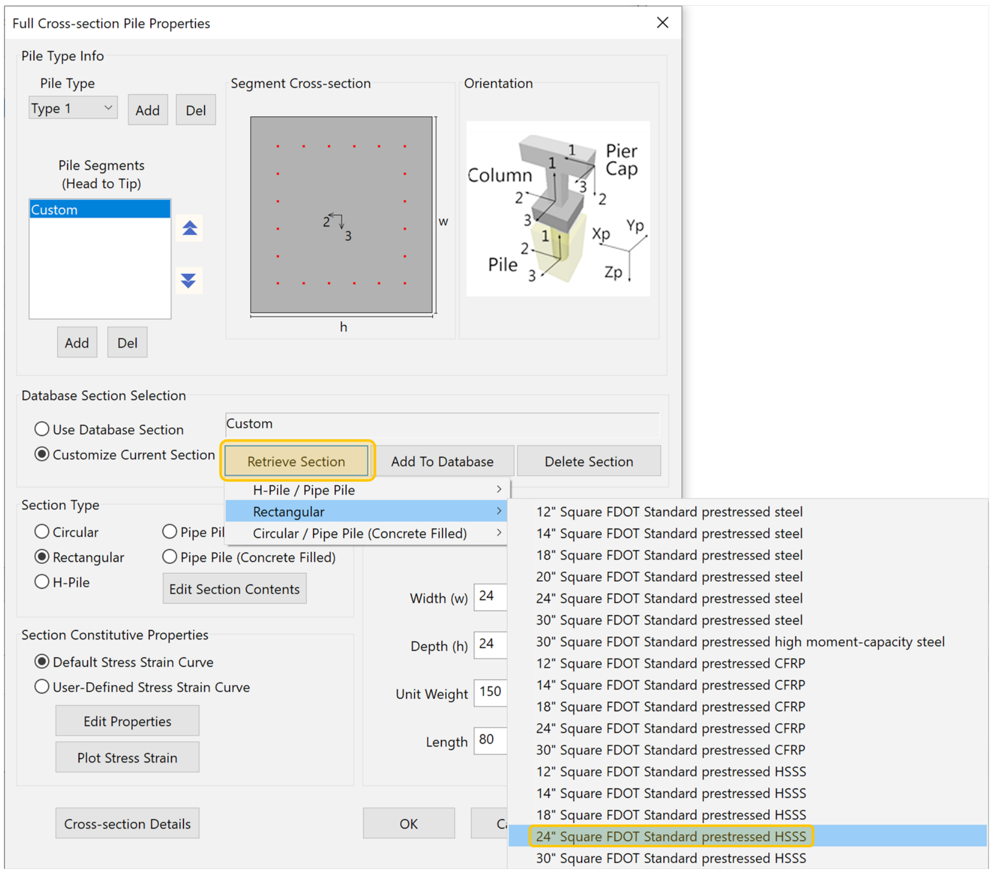

Figure 1. Database of standard FDOT cross-sections for prestressed HSSS piles

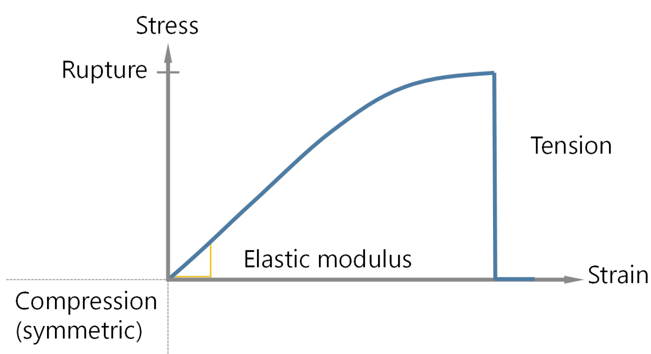

Figure 2. Stress-strain relationship for modeling prestressed HSSS strands

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In the event that other types of prestressed HSSS strands are to be utilized in a given pile cross section, the engineer can specify associated values of elastic modulus and rupture stress. Alternatively, a user-defined stress-strain relationship can be supplied, as illustrated in Fig. 3.

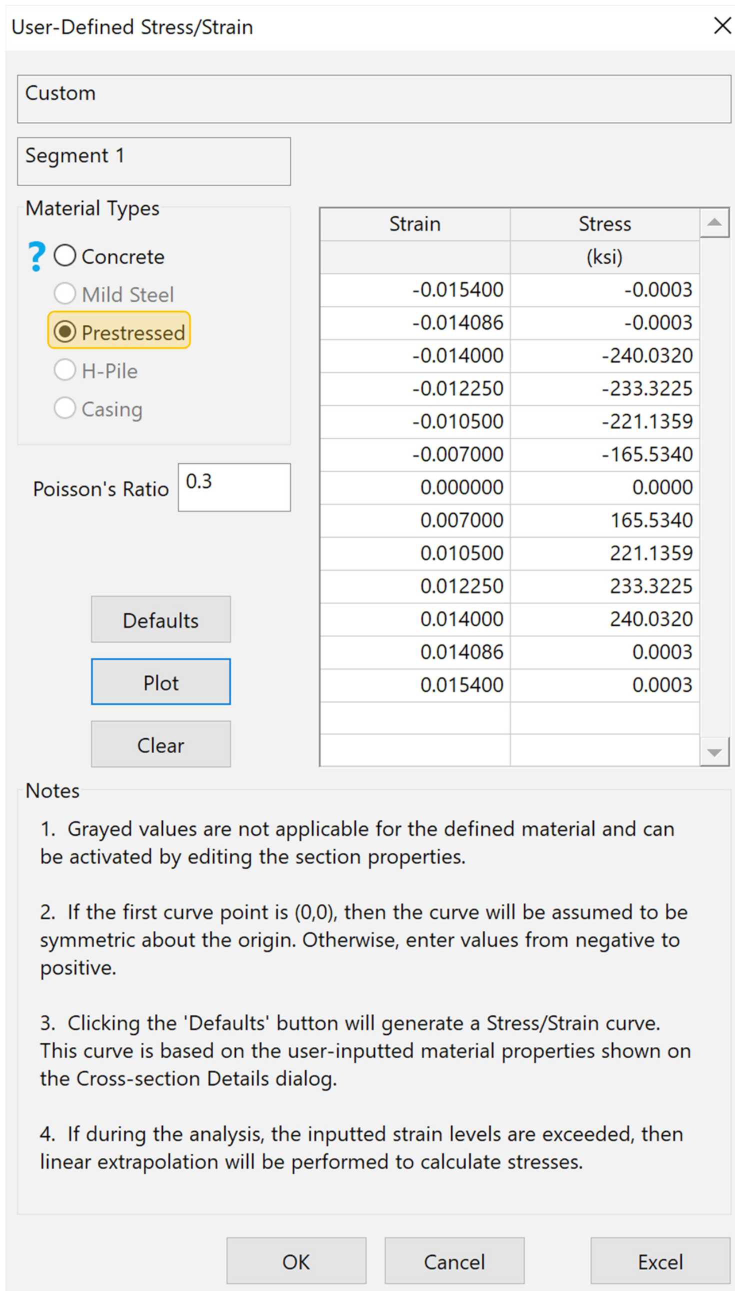

Figure 3. User-defined option for stress-strain modeling of prestressed HSSS strands

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The state of current practice is such that a single-valued resistance factor is applicable to prestressed HSSS member cross-sections when forming load-moment strength interaction diagrams. A resistance factor value of 0.75 is employed by default. However, the engineer may specify user-defined resistance factors with respect to axial and bending portions of load-moment interaction diagrams. These particular inputs can be specified on the Analysis Settings page, as shown in Fig 4.

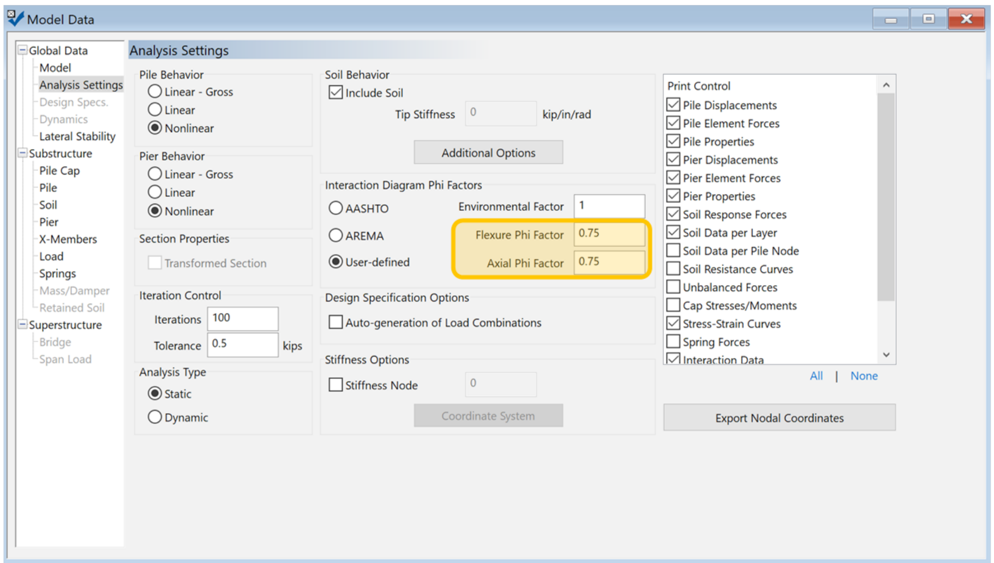

Figure 4. Analysis Settings controls for defining custom factors in load-moment interaction diagrams of prestressed HSSS pile cross-sections

Nonlinear frame elements in FB-MultiPier are formulated based on a discrete fiber-integrated beam-column. In this way, a wide range of nonlinear constitutive behaviors can be analyzed with respect to stiffness, force recovery, and section capacity calculations. When computing the 3D load-moment interaction capacities of cross-sections containing prestressed HSSS strands, two forms of material failure are assessed. These include crushing of any concrete portions of the cross-section (i.e., numerical fibers that correspond to concrete in the physical section) and rupture of any prestressed HSSS strands. For a given axial load level, whether tension or compression, a set of moments about various orientations on the cross-section are quantified. Each moment quantified in this manner corresponds to the onset of either concrete crushing in compression or strand rupture. The pairs of axial loads and moment values constitute the 3D failure surface (i.e., the load-moment interaction surface) for the cross-section. Here, crushing of the concrete is defined as a compressive strain equal to or exceeding 0.003 in./in. As noted previously, rupture strain of the strands is taken as 0.014 in./in.

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As a benefit of implementing the approach described above when forming load-moment interaction surfaces, capacities of prestressed HSSS cross-sections are quantified under both compression-controlled (i.e., crushing) and tension-controlled (i.e., strand rupture) conditions. Stated alternatively, the interaction diagrams for prestressed HSSS sections produced by FB MultiPier encompass: 1) concrete crushing under pure compression; 2) strand rupture under pure tension; and, 3) the full range of axial loads and corresponding moments that lie in between. Interaction diagrams formed in this manner have been verified against independently generated interaction diagrams for all FDOT standard prestressed HSSS pile cross-sections. For example, shown in Fig. 5 is a comparison of two sets of points along an interaction diagram for a 24-in. square cross-section. The two sets of points were generated using FB-MultiPier and through use of the algorithm presented in Consolazio et al. (2004). Excellent agreement is observed under pure compression, near the peak moment (i.e., the "nose") of the interaction diagram, and under pure tension.

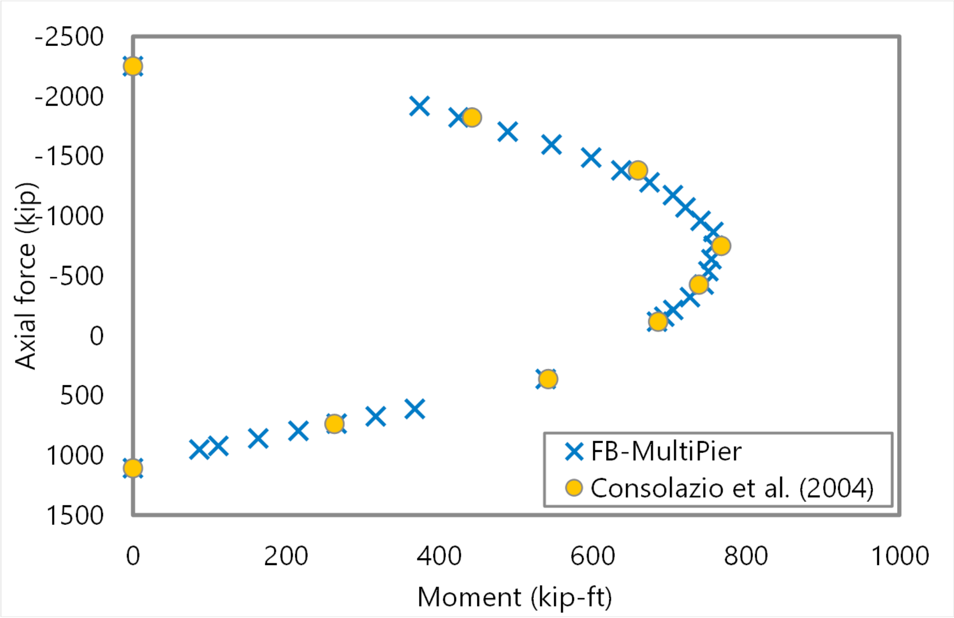

Figure 5. Comparison of interaction diagrams generated using algorithm presented in Consolazio et al. (2004) and computed using FB-MultiPier for a 24-in. standard FDOT prestressed HSSS pile cross-section

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Nonlinear Elastic Springs

The feature set pertaining to definition and assignment of discrete stiffness springs to substructure nodes has been enhanced in FB-MultiPier v5.9.0. Springs can now be defined as linear elastic or nonlinear elastic. When elastic springs are defined, discrete values of stiffness can be assigned with respect to a degree-of-freedom (DOF) of interest. For modeling of nonlinear elastic springs, custom force-displacement (or moment-rotation) relationships can be defined and assigned to the desired DOF(s). As an additional enhancement in FB-MultiPier v5.9.0, springs can now be defined as attached from a given node to “the world”, or alternatively, springs can be defined as attaching from node to node. In all cases, the stiffnesses associated with springs are assigned with respect to the Xp-Yp-Zp axes.

Shown in Fig. 6a is an illustrative configuration, where two piers founded in a layered profile are structurally tied together through use of a node-to-node spring. The corresponding finite element model is depicted in Fig. 6b. Here, a non-linear translational spring has been placed between the interior cantilever portions of the piers, where such a spring represents a member such as a strut. A lateral (Xp) nodal load is also included in the model for illustration purposes (Fig. 6b). Presented below is the manner by which the nonlinear elastic spring can be defined within FB-MultiPier v5.9.0.

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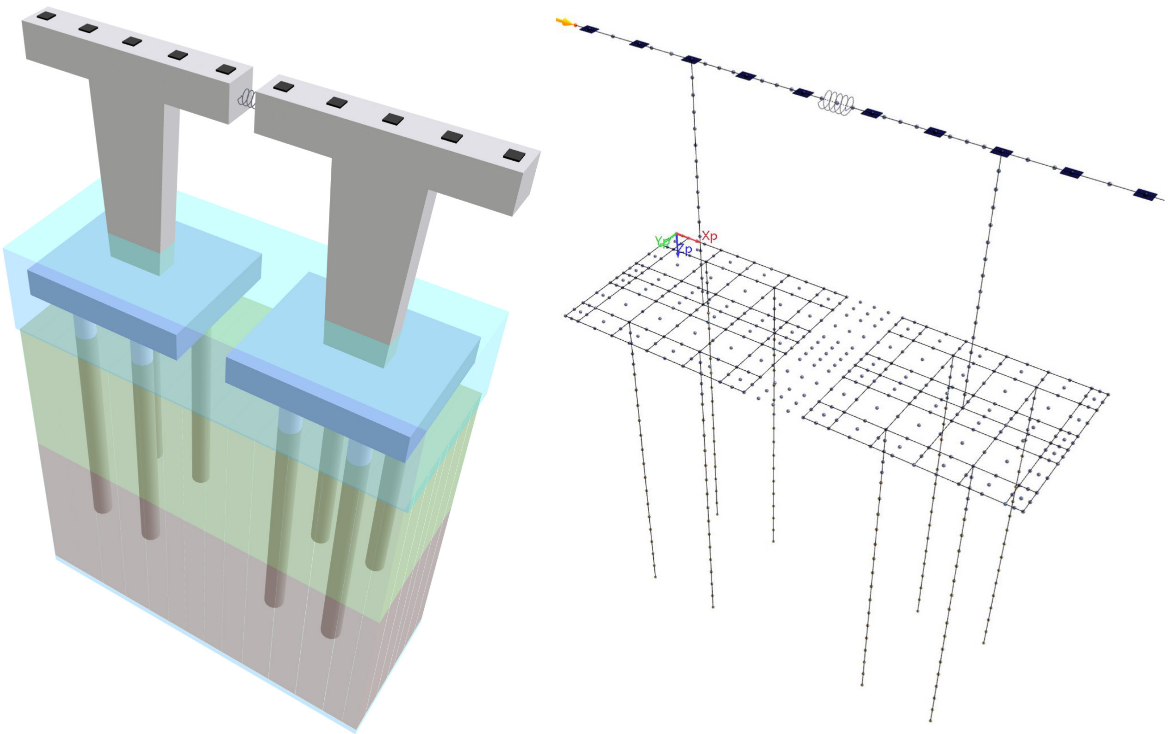

a) b)

Figure 6. Illustrative pier model with nonlinear spring attached between interior cantilever members: a) Configuration; b) Finite element model

Controls that facilitate definition and assignment of discrete springs to substructure nodes are located on the Springs page within the Model Data window (Fig. 7). Visually scanning from left to right across Fig. 7, springs can be assigned as active or inactive with respect to a given Load Case (or Load Combination when modeling AASHTO or AREMA loading). Located within the center portion of the Springs page is a table, which allows for tabulated input of the I-Node, J-Node, and Stiffness Type associated with a give spring. For springs that attach node to “world”, the J-Node should be input as zero valued. For springs that attach node-to-node, non-zero node numbers should be supplied for both the I-Node and the J-Node entries for a given spring.

The Stiffness Type can be input as either 0 or 1. In this context, a zero-valued Stiffness Type signifies that the spring is of a linear elastic nature, and is associated with input of discrete stiffness terms for one or more DOF (e.g., kip/in. for translational stiffness; kip-in./rad for rotational stiffness). For spring definitions where the Stiffness Type is input as 1, nonlinear elastic force-displacement (or moment-rotation) relationships can be assigned to one or more DOF.

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As displayed in Fig. 7, a nonlinear elastic spring (Stiffness Type is 1) is defined for the illustrative configuration (recall Fig. 6). The spring is defined as a node-to-node spring that attaches Node 409 to Node 411 (i.e., the tips of the interior cantilevers from the otherwise independent piers). Given that the spring is nonlinear elastic, a custom force-deformation curve (here, a force-displacement curve) is defined and assigned to the Xp-translation DOF. The custom force-displacement curve is so-defined by clicking the Custom Force-Deformation Curve button on the Springs page (Fig. 7), which leads to the Custom Spring Curve dialog (Fig. 8).

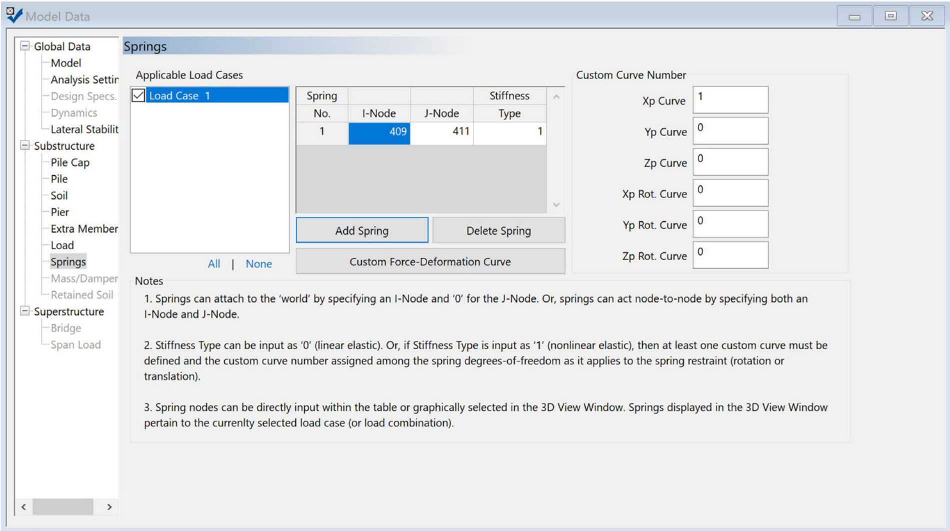

Figure 7. Springs page within the Model Data window

The Custom Curve is defined by clicking “Add Curve”, which creates the “Custom 1” curve. Note that this curve number (1) is assigned to the Xp-translation DOF for the spring, as shown above in Fig. 7. The spring Curve Type (Fig. 8, upper right) is designated as a Translational Spring (e.g., kip/in.) and can therefore only be assigned to translational DOF. Up to 25 unique spring curve abscissa (displacement) and ordinate (force) values can then be supplied to define the spring force-displacement relationship. To showcase the robustness of the spring definitions that can be modeled and analyzed, a nonlinear elastic spring with hyperelasticity up to a rupture load at 200 kip is defined, as plotted in the middle-right portion of Fig. 8.

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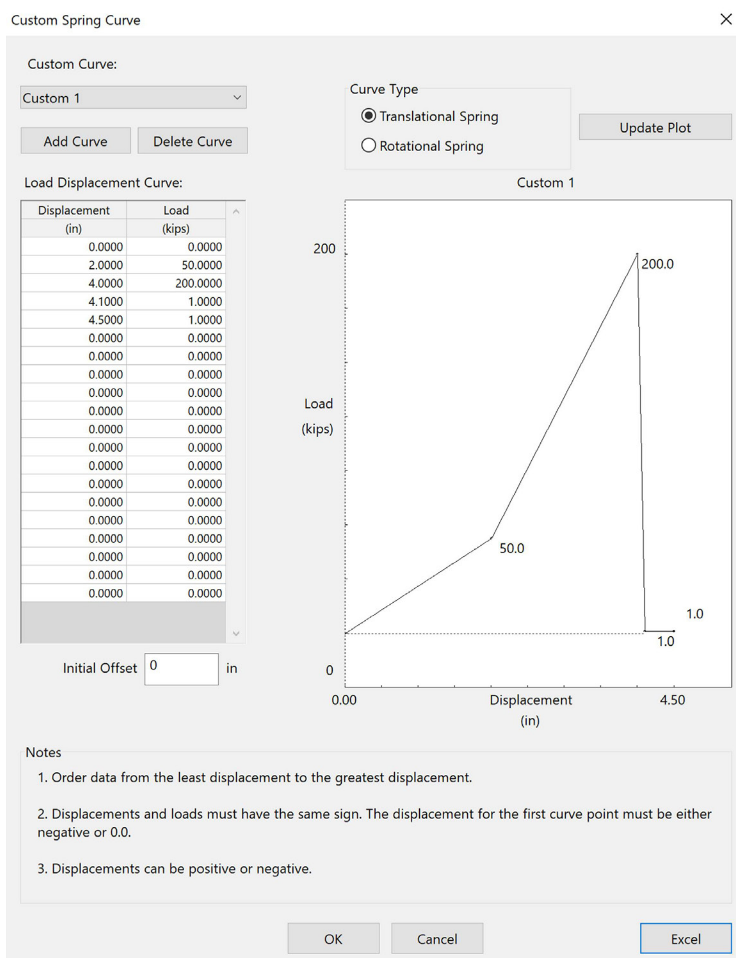

Figure 8. Custom Spring Curve dialog

Through-depth P-Scale Factors for Modeling Custom Lateral Soil Resistance

When modeling substructure foundations under lateral loads, additional considerations for the lateral soil resistance of pile (or shaft) groups must be taken into account. Typically, such considerations include scaling the ordinates of the lateral soil resistance curves (i.e., the "p-y" curves) distributed along the embedded portions of piles within a group. Namely, p-multipliers are commonly used in practice when modeling pile groups under lateral loading, where recommended distributions of p-multipliers are provided in design specifications (e.g., the AASHTO LRFD specifications). In practice, p-multipliers do not typically vary with respect to depth. However, in certain instances (e.g., when

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modeling sloped soil or rock layerings), it may be desirable to further modify the more commonly utilized distributions of p-multipliers.

Accordingly, in FB-MultiPier v5.9.0, through-depth scale factors that act on the "p" values of p-y springs can be supplied. During analysis, the p-y curves are formed for embedded nodes in the usual manner. Then, when p-scale factors are defined, the "p" values are scaled by the respective p-scale factor.

The manner in which p-scale factors values may be accessed and input, from within the Advanced dialog on the Soil page of the Model Data window, is presented in Fig. 9. Note that input of through-depth p-scale factors is managed per layer within FB-MultiPier. The p-scale factors can be input as linearly varying from top to bottom of given layer, and further, unique values of p-scale factors can be supplied for motions in the Xp and Yp directions.

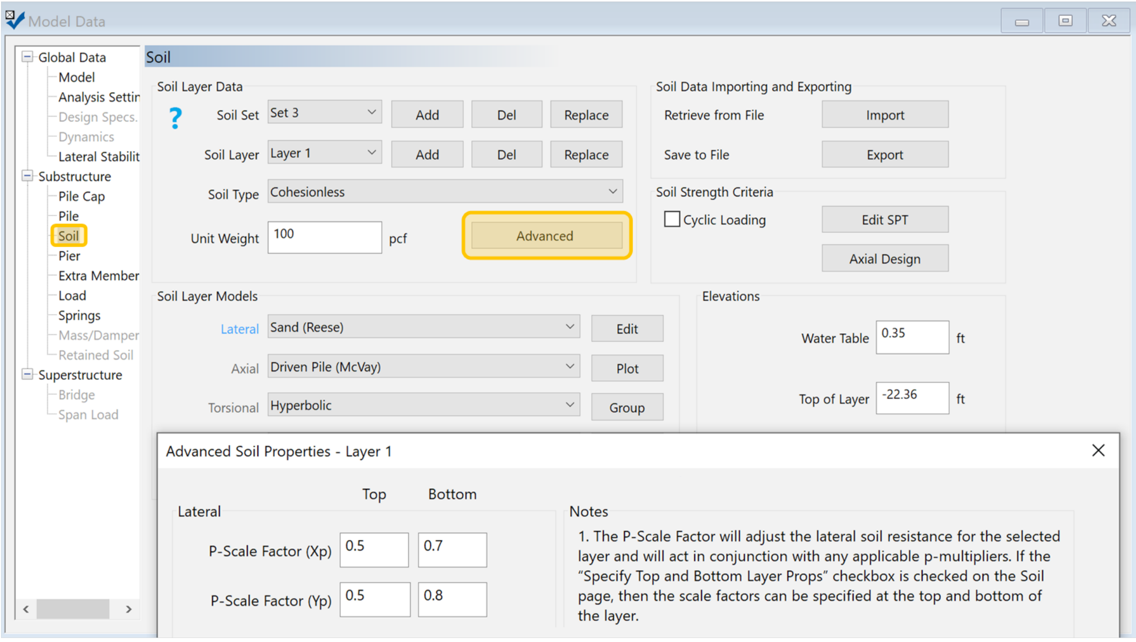

Figure 9. Input of p-scale factors per layer

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Graphical Selection of Longitudinal Reinforcement Groups when Defining Member Cross-Sections

In FB-MultiPier, longitudinal reinforcement is defined for member cross-sections as a collection of bar (or prestressed strand) groups. A given group may consist of one or more bars (or prestressed strands) distributed along a line or distributed in a circular manner. When defining longitudinal reinforcement layouts for member cross-sections, there may be instances that require definition of several unique bar groups.

To facilitate positioning of bar groups within member cross-sections, bar groups can now be graphically selected. For example, consider the bullet cross-section shown in Fig. 10. Existing bar groups may now be graphically selected by left-clicking on any bar in the graphical depiction of the cross-section (Fig. 10, center). The currently selected group (e.g., the 8 bars comprising Group2) is identified using a white dashed line, and is highlighted in the Bar Groups list (Fig. 10, upper-left).

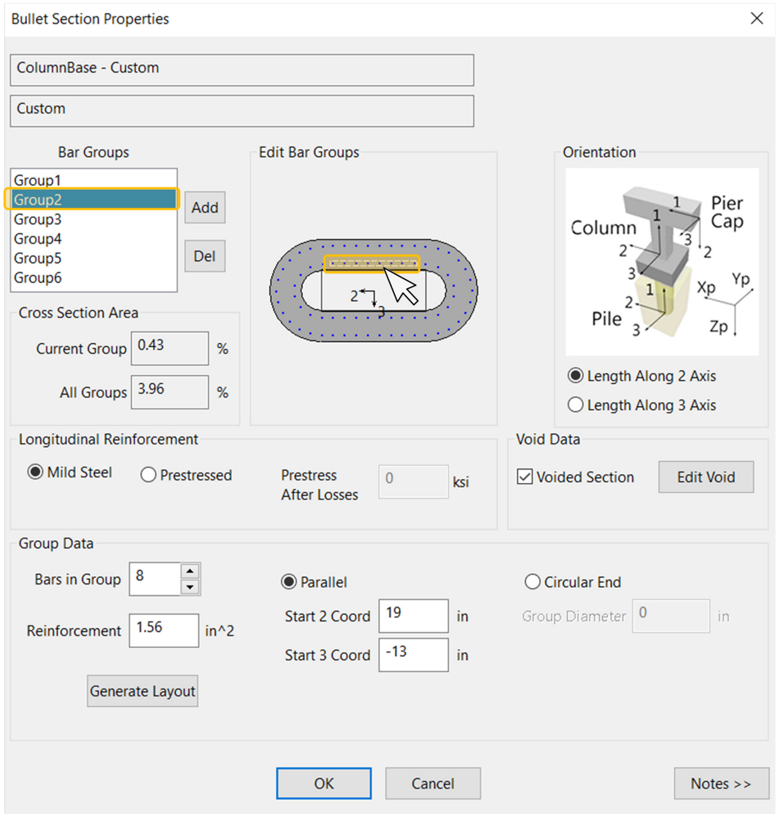

Figure 10. Graphical selection of Bar Groups within a cross-section

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BSI Program Status

FB-MultiPier v5.9.0 Download a FREE demo today!

Released July 2021 - Continuing Development - Technical Support Available

FB-MultiPier allows for the modeling of bridges, bridge piers, pile bents, and other foundation structures. In addition to allowing for multiple load cases and AASHTO load combinations, FB-MultiPier is also capable of performing dynamic analysis (time-history and RSA). For more information about FB-MultiPier, click **here**.

FB-Deep v3.0.0 Download a FREE demo today!

Released Feb 2020 - Continuing Development - Technical Support Available

FB-Deep is 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. For more information about FB-Deep, click **here**.

GeoStat v1.1.0

Released Dec 2020 - Continuing Development - Technical Support Available

GeoStat allows engineers to leverage statistical methods when estimating pile/shaft axial resistance quantities, variability, and uncertainty. GeoStat accepts collections of borings/corings, performs both spatial variability analysis and method error estimation, and then generates through-depth profiles of both factored resistance and associated variability. For more information about GeoStat, click **here**.

Atlas v7.1

Released June 2019 - 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, and two-point attachments systems. For more information about Atlas, click **here**.

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