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BSI NEWSLETTER

Bridge Software Institute

In this issue, we discuss recently developed features included in the release of FB-MultiPier v6.0.0

Engineers making use of software produced by the Bridge Software Institute (BSI) are encouraged to reach out with suggestions for new features and program improvements. Inquiries ranging from project-specific to general program usage are welcomed. We firmly believe that you are in the best position to contribute to program development directions.

In this release of FB-MultiPier, the enhancements listed below include::

a) DirectX graphics windows;
b) Modeling options for pier column to pile cap connections; and,
c) User-defined option for confined concrete stress-strain curves.

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DirectX Graphics Windows

The 2D and 3D model-view windows throughout FB-MultiPier can now be viewed with use of DirectX graphics. DirectX is a collection of components that allow Windows software to make direct use of video hardware. Implementation of DirectX graphics involved assessing, reimagining, and streamlining existing graphical interactions available throughout the FB-MultiPier UI for the purposes of faster and smoother comprehension of bridge models. An example three pier model, rendered using the newly implemented DirectX feature set, is shown in Fig. 1 and is utilized to showcase the improved graphics feature set. Relative to previous program releases, the pier components (Fig. 1) are rendered using improved crispness and strengthened vibrancy in the coloration of unique structural and soil components.

Presented in Fig. 2 is a plan-view rendering of the illustrative three-pier bridge model that demonstrates one of the many benefits of the new DirectX graphics capabilities. Note that the newly implemented plan-view achieves a faithful (to-scale) orthographic projection of the three-pier layout. Included in the DirectX implementation of the bridge plan view are all model components that would be visible from the orthographic plan-view perspective, including all structural, soil, and water components. In this way, increased context regarding how substructures are positioned relative to one another within the overall model configuration can be gained via a brief visual scan.

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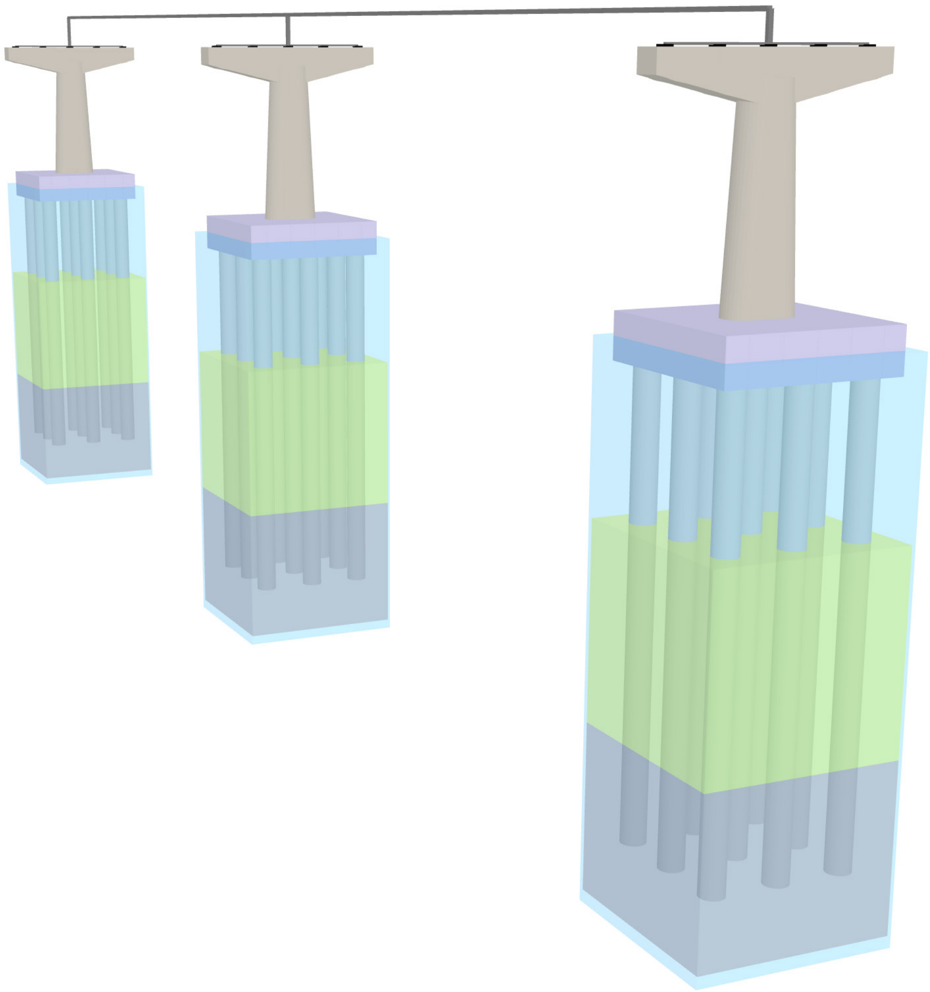

Figure 1. 3D view of illustrative bridge model

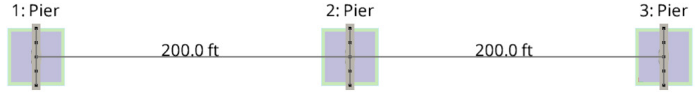

Figure 2. Bridge Plan View window

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For the bridge and individual substructure 3D-view windows, both improved and wholly new visualization modes have been implemented. As illustration, consider the central pier from the three-pier configuration (i.e., pier 2) as rendered in three distinct modes in Fig. 3. Shown in Fig. 3a is a "thick mode" rendering of pier 2, which emphasizes the physical dimensions of the substructure configuration and the layered soil medium. The thick mode rendering also showcases both the anti-aliasing and updated aesthetics of the DirectX graphics implementation in FB-MultiPier v6.0.0.

Visualization of the underlying finite element model for pier 2 is illustrated in Fig. 3b. When viewed in "thin mode", model components exclusive to analysis can be visualized (e.g., assemblages of nodes, elements; node attaching entities such as loads, discrete springs). To better understand the relationship between the physical pier configuration and the finite element model, a new 3D "overlay" visualization mode is introduced. Benefits of the overlay mode, which simultaneously displays the thick and thin view modes, are exemplified for pier 2 in Fig. 3c. Positioning of applied nodal loads, for example, is made clear with respect to the corresponding physical pier dimensions.

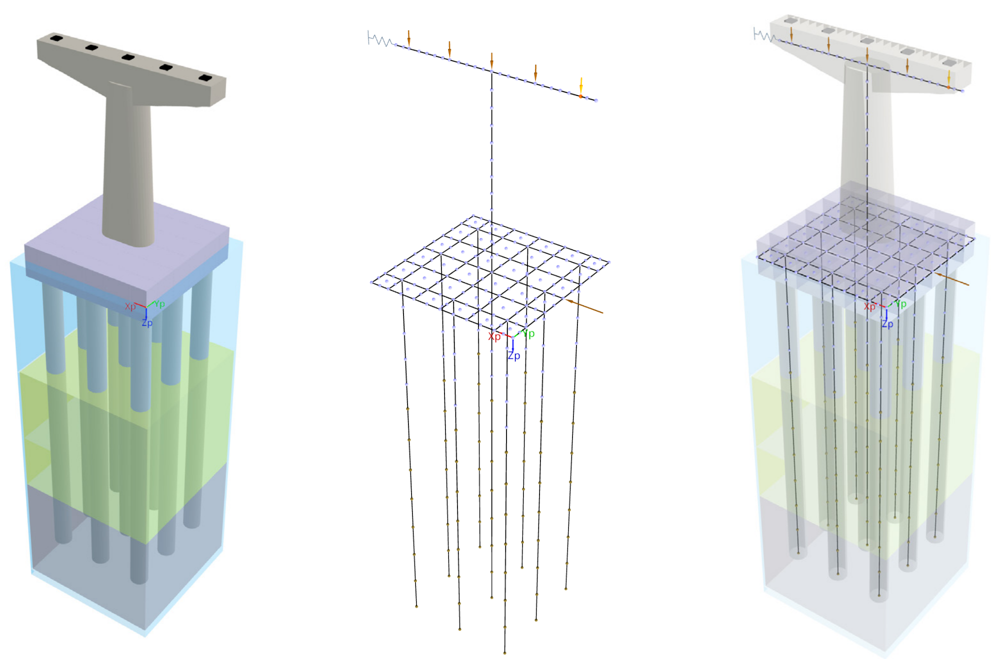

Figure 3. Options for visualizing 3D models: a) Thick mode; b) Thin mode; c) Overlay mode

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Highlighted in Fig. 4 is the Soil Edit window, comprised of a pile of interest and the layered soil medium (as pertaining to the pier 2 configuration). In addition, as a new visualization option, a "silhouette" of the broader pier foundation can be included among the Soil Edit window contents. The option for including the foundation silhouette within the Soil Edit window is yet another aspect of the DirectX implementation, with an overall focus on providing improved model contextualization capabilities when creating FB-MultiPier models.

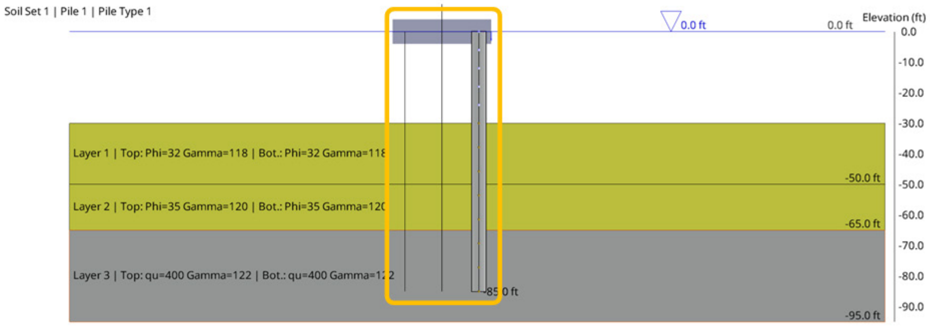

Figure 4. Soil Edit window with selected pile, soil layering, and foundation "silhouette"

The DirectX implementation in FB-MultiPier v6.0.0 encompasses not only the graphics windows associated with model creation and editing (i.e., pre-analysis model views), but also, all 2D and 3D graphics windows associated with viewing analysis results. For example, shown in Fig. 5 is a 3D view of the deformed shape of the three-pier configuration when (for illustration purposes) each pier is subjected to self-weight and transverse lateral loading. Superimposed atop the pile cap (shell elements) of pier 2 is a contour plot of the vertical (Z) displacements. For convenience, also included in the 3D results view is the contour plot legend.

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Figure 5. Deformed structure with vertical displacement contours of the pier-2 pile cap

Presented in Fig. 6 and Fig. 7 are additional examples of the enhancements and benefits that can be leveraged by viewing models via the DirectX graphics implementation. As shown, the pier 2 substructure is subjected to both vertical and lateral loading (for illustration). The regions highlighted in red signify that the load-moment demand-capacity ratios (D/C ratios) at those model locations have exceeded unity.

To facilitate post-analysis inspection for scenarios where the demands pertaining to a given subset of elements (or even individual elements) are of interest, enhanced zoom capabilities have been incorporated into the 3D results viewing windows. As highlighted in Fig. 6, the process of zooming into the desired viewpoint (e.g., the shaft section immediately beneath the pier column) can now be achieved in a seamless manner without encountering graphics issues such as progressive deceleration of camera zoom or clipping planes. Furthermore, “fly throughs” of models can be carried out, even if (for example) such model navigations proceed beneath, into, and through the various model components (Fig. 7).

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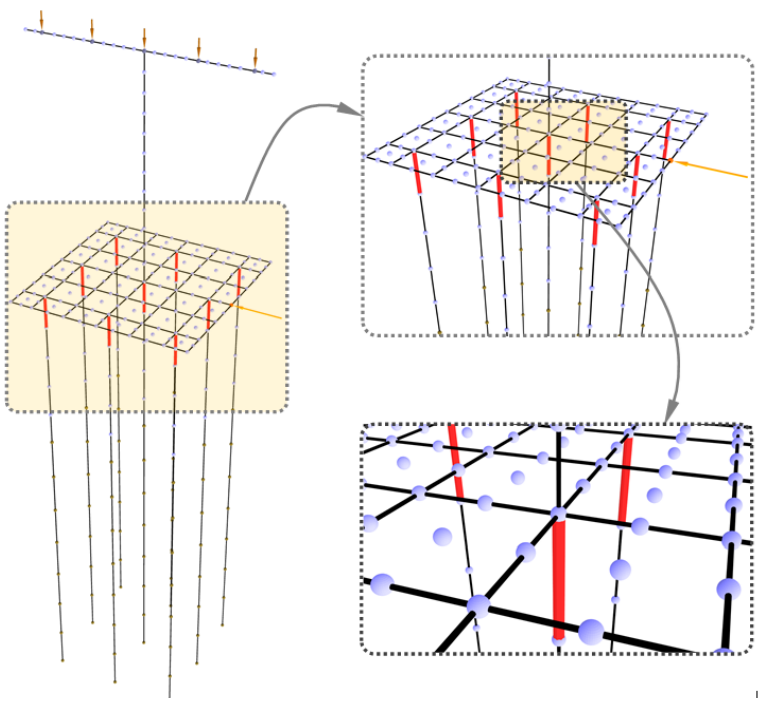

Figure 6. Enhanced zoom capabilites for inspecting 3D models

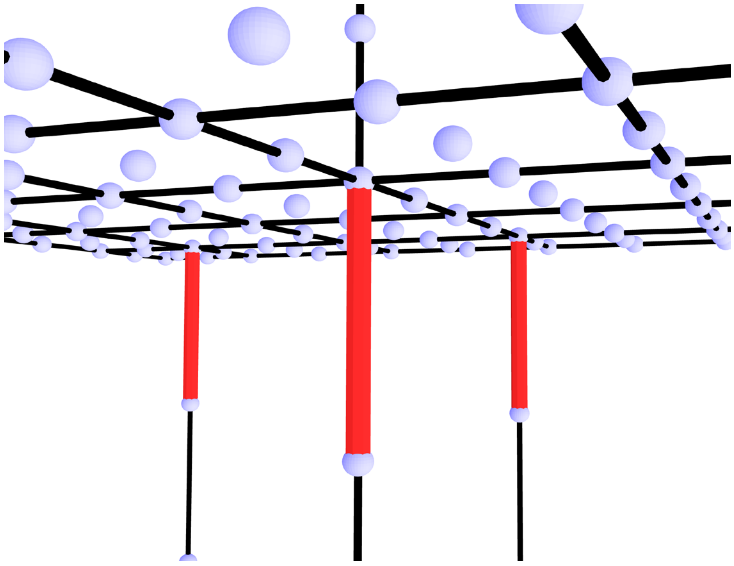

Figure 7. Enhnaced navigation capabilites for traversing 3D models

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To offer a customizable experience for engineers that utilize the DirectX model viewing features, numerous settings can be configured from within the Graphics Windows tree menu item of the Program Settings dialog (Fig. 8). For example, Mouse Sensitivity to 3D model panning, rotation, and zoom actions can be set to the preferred level by the engineer. In addition, for any instances where the legacy graphics implementation is desired, the engineer can select OpenGL from the Graphics API pulldown list. The program will then automatically prompt for a session restart so that the selected graphics API can be loaded.

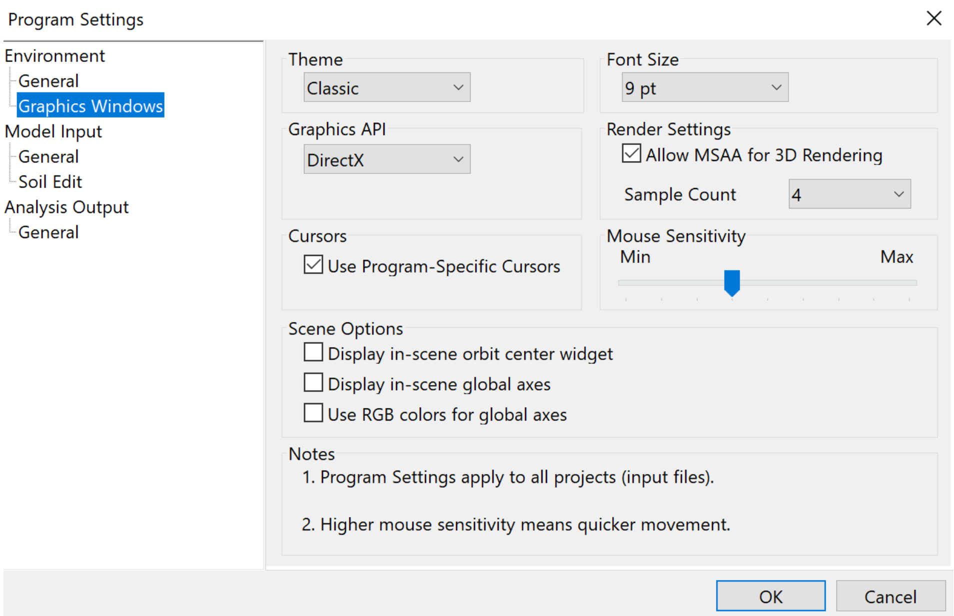

Figure 8. Program Settings dialog with Graphics Windows options

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Modeling Options for Pier Column to Pile Cap Connections

A new feature has been introduced to allow for more control over modeling of pier column to pile cap connections. This feature is particularly applicable when engineers utilize high-resolution cap models in FB-MultiPier models, and leads to more realistic estimation of cap design forces.

In previous versions of FB-MultiPier, column to cap connections were modeled using four rigid beam elements (referred to as quad-links) that connected the bases of pier columns to pile caps. Engineers also had the option to define the extents of the quad-links. In the current release of FB-MultiPier, an option has been added to allow for a collection of rigid links (referred to as multi-links) to be distributed throughout the footprints of pier columns. Rather than distributing column loads to pile caps using four link elements, a collection of rigid links are instead modeled for connecting column base-nodes (i.e., bottommost nodes) to all nodes on the pile cap that lie within the user defined physical extents (e.g., the physical dimensions of the column cross-section). Using this newly implemented feature, engineers can obtain pile cap design forces that better reflect transfer of loads at column-cap interfaces.

Various options to control the column to pile cap connection exist within the Column To Cap Connection dialog (Fig. 9), which can be accessed from the Pier page within the Model Data window of the UI. To access the multi-link feature set, first check the Enable Custom Options for Connector Elements checkbox. Then, check the Attach Connectors to Cap Nodes within Xp, Yp Extents checkbox. The physical extents of the connector (i.e., link) elements can also be specified in this dialog (Fig. 9). For rectangular pier columns, a rectangular pattern is utilized when building up the collection of multi-link elements. For circular pier columns, a circular pattern is utilized.

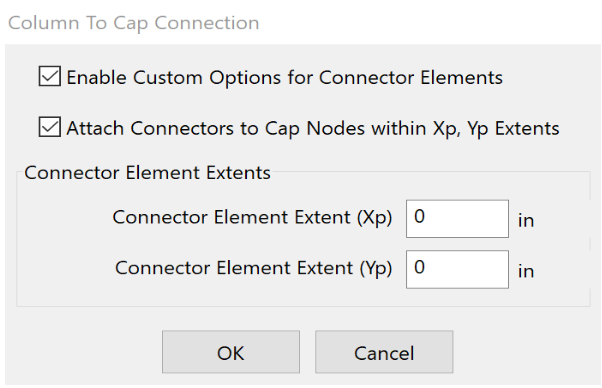

Figure 9. Column to Cap Connection dialog

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The effectiveness associated with a given approach for modeling column-to-cap connections is influenced by the resolution of the pile cap mesh. Use of the multi-links feature can result in improved calculations of response quantities such as pile cap internal forces, particularly for models that contain relatively high-resolution pile cap meshes. As an illustration of the potential benefits afforded by use of the multi-link feature, a demonstration case consisting of a single pier structure is presented below. This demonstration case was developed to highlight scenarios in which utilizing multi-links, rather than quad-links, leads to improved calculations of maximum design forces.

Demonstration Case – Pier

The demonstration model is shown in Fig. 10. Structurally, the model consists of a 28 ft x 28 ft x 8 ft (length x width x depth) pile cap that is supported by a uniform and symmetric grid of piles. The column is 50 ft tall, with cross-section dimensions of 72 in x 165 in. The pile-cap is modeled using a mesh of 121 shell elements, while the column is modeled using frame elements (Fig. 11). Analyses are carried out using the pier configuration, where the column-to-cap connection is modeled using quad-links (Fig. 11a), and separately, where the column-to-cap interface is modeled using multi-links (Fig. 11b). For the analyses, the extents of the quad-links and multi-links were set equal to the cross-sectional dimensions of the column, and a pushover analysis was conducted by applying an increasing horizontal load to the top node of the pier column.

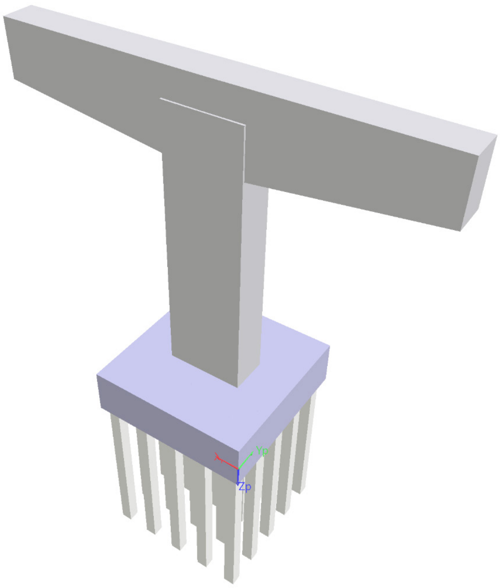

Figure 10. Demonstration case

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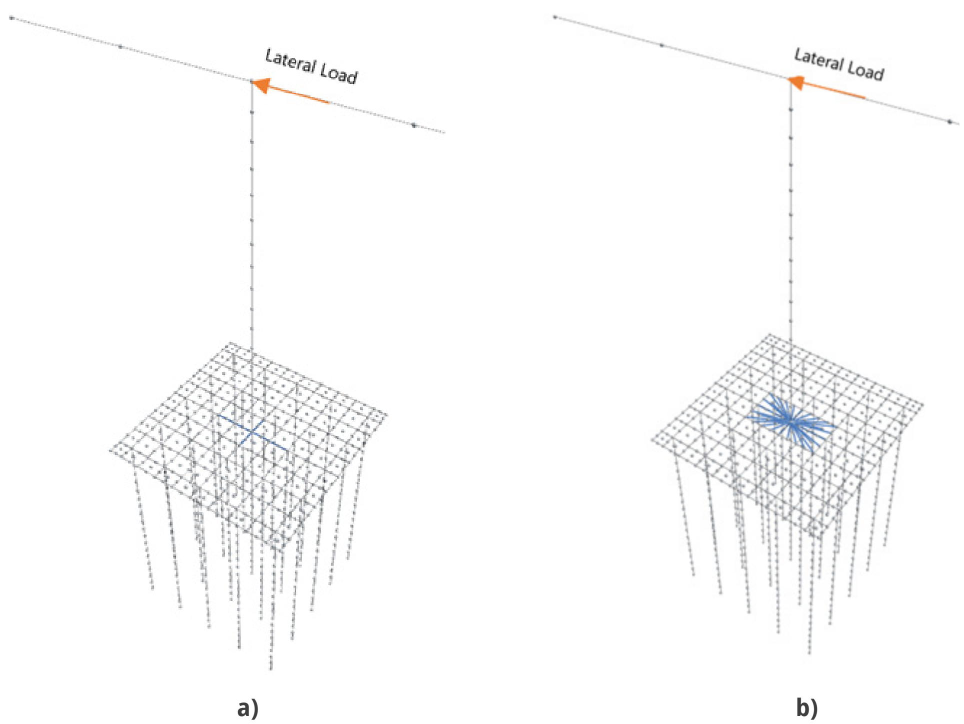

Figure 11. Model configurations: a) Quad-link approach; b) Multi-link approach

Results obtained from the analyses are compared in two regards: 1) nodal displacements at the top of the pier column; and, 2) moment distributions within the pile cap. The model locations selected for comparing computed displacements and the cut line used to quantify moments are shown in Fig. 12. Comparisons of the pushover analysis results are presented in Fig. 13 for displacements and Fig. 14 for moments. Note that the moment calculations constitute estimated design moments for determining bottom-steel layouts in the pile cap.

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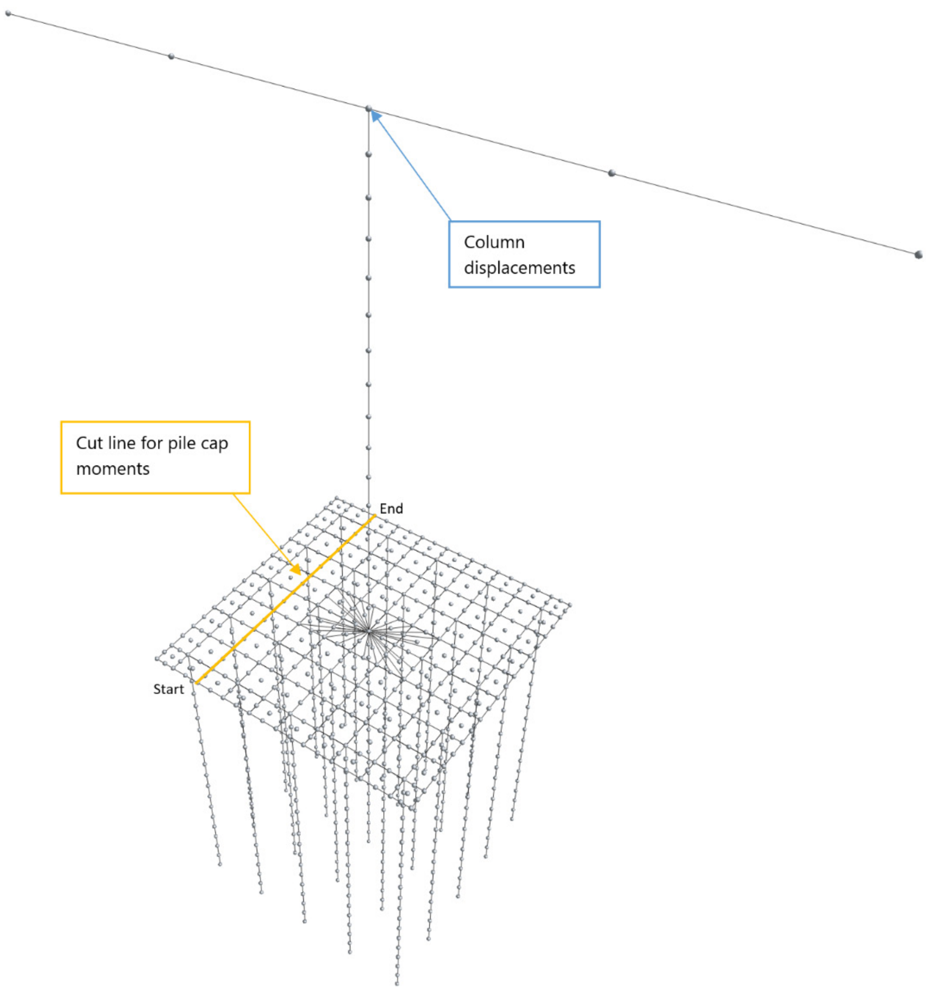

Figure 12. Selected locations for comparing analysis results

The computed results indicate that use of the multi-link feature does not necessarily influence overall foundation response quantities such as lateral displacements in the pier column (Fig. 13). However, use of the multi-links feature can bring about (when appropriate) more uniform distributions of pile cap moments in comparison to those obtained from use of the quad-links approach (Fig. 14). Therefore, use of the multi-link feature can lead to more optimized design calculations of pier components.

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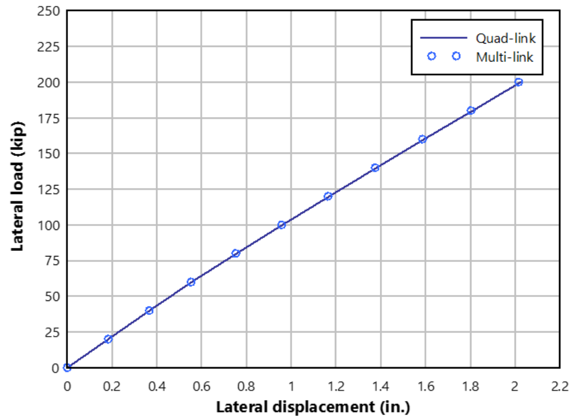

Figure 13. Lateral load v. lateral displacement at location of applied lateral load

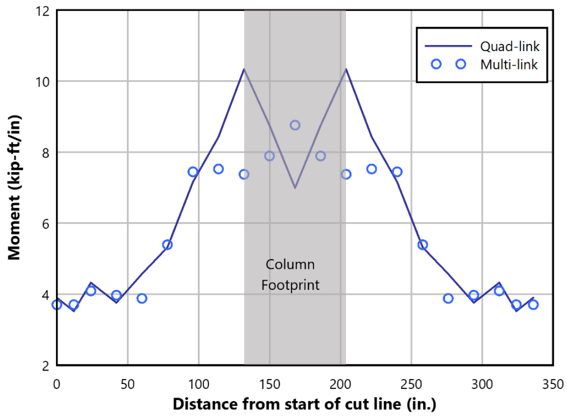

Figure 14. Bottom steel moment vs. location on cut line

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User-Defined Option for Confined Concrete Stress-Strain Curves

FB-MultiPier allows for modeling of confined and unconfined concrete within circular and rectangular concrete cross-sections. In program versions prior to v6.0.0, both unconfined and confined stress-strain relationships used during analysis were determined based on a pre-defined (empirical) constitutive formulation and input of macroscopic material parameters such as concrete elastic modulus and unconfined compressive strength. However, beginning in v6.0.0, an option is available that allows engineers to directly specify the abscissa and ordinate values of the stress-strain relationships that pertain to unconfined and confined concrete regions of structural member cross-sections.

The phenomenon of concrete confinement is pertinent to bridge structural member design under extreme event loading such as that arising due to seismic events. For scenarios where nonlinear behaviors are anticipated in reinforced concrete structural members, the ability to compute the responses for both the unconfined and confined portions of member cross-sections is of particular importance. As examples, incorporating nonlinear behaviors such as spalling of unconfined concrete and post spalling redistribution of internal forces throughout the remaining portions of structural members may be necessary in certain design applications.

A widely adopted empirical model for analyzing cross-sections containing confined concrete derives from Mander et al. (1988). In the following, the associated constitutive model (as implemented in FB-MultiPier) is referred to as the “Mander model”. For FB-MultiPier models that do not make use of user-defined stress-strain relationships in confined concrete members, the Mander model serves as the basis for automatically producing both the confined (and unconfined) concrete stress-strain curves utilized during analysis.

Depicted in Fig. 15 are illustrative stress-strain curves for modeling of unconfined and confined portions of a concrete member cross-section. Both the unconfined and confined curves approximately adhere to the same initial slopes at relatively small strain levels. Additionally, in the tensile region, both stress-strain curves vary linearly up to a maximum tensile stress, ft. However, in the compression region, the unconfined material exhibits a lower-magnitude peak stress of f’c while that of the confined material reaches a greater stress magnitude, f’cc. After passing the peak compressive stress of f’c, the unconfined material steadily diminishes to the point of no longer being able to develop compressive stress. In contrast, the confined stress-strain exhibits relatively pronounced ductility.

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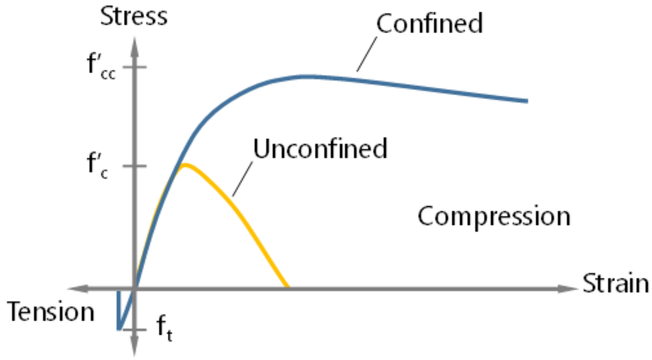

Figure 15. Stress-strain relationships for modeling of confined and unconfined portions of concrete cross-sections

Illustrative Modeling of User-Defined Stress-Strain Curves for Confined Concrete Members

Presented in the following is an illustrative input set of user-defined stress-strain curves as pertaining to a confined reinforced concrete circular member. As guidance to engineers wishing to utilize this feature set, emphasis is placed on an example navigation through the relevant dialogs within the FB-MultiPier UI. For this illustrative input set, a 96-in. circular cross section along a 50-ft drilled shaft is considered (Fig. 16). The unconfined compressive strength (f'c) for this illustrative scenario is given as 5 ksi. The user-defined feature set is accessible from within UI dialogs that pertain to cross-sections of pile, pier column, and pier (or bent) cap members. The Full Cross-Section Pile Properties dialog is presented in Fig. 16. Note that, within the "Section Constitutive Properties" region of the dialog shown in Fig. 16, the "User-Defined Strain-Strain Curves" radio button is selected. Clicking the "Edit Section Contents" button leads to the option for accessing the Confined Concrete dialog.

Shown in Fig. 17 is an illustrative input set, within the Confined Concrete dialog, pertaining to shear reinforcement along the length of the 96-in. diameter drilled shaft member. When utilizing the user-defined stress-strain curve feature set for confined circular concrete members, only the shear bar diameter (Fig. 17) is required as input within the Confined Concrete dialog. As additional context, the shear bar diameter is required along with other geometric parameters to calculate the diameter of the confined concrete core within the member cross-section.

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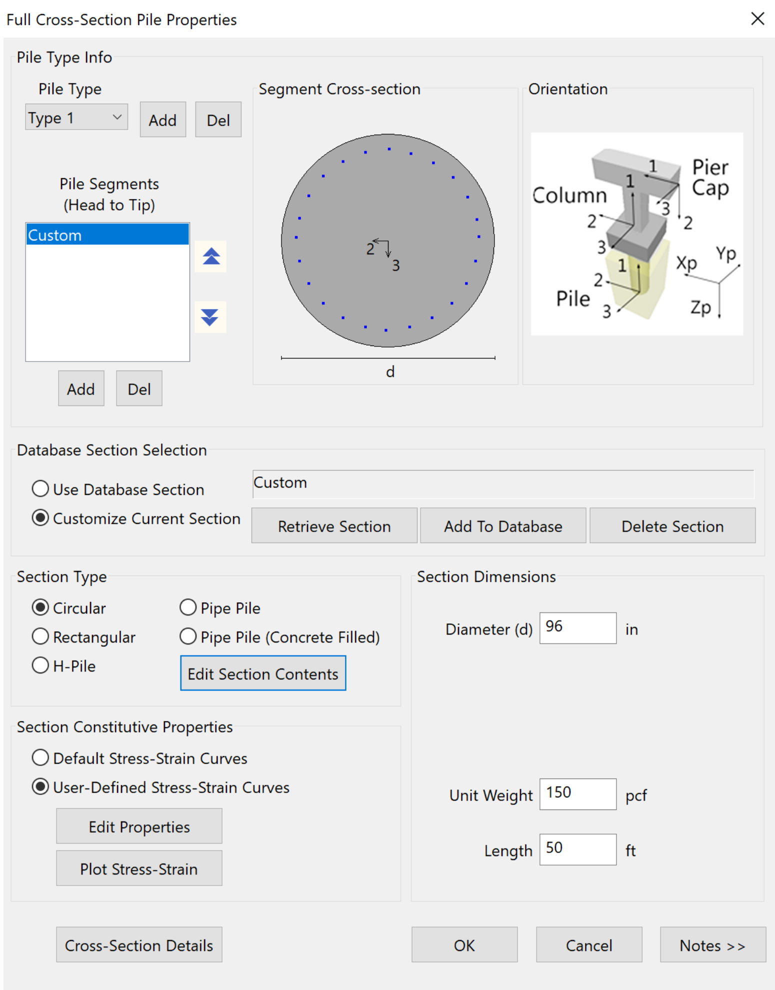

Figure 16. Full Cross-Section Pile Properties dialog

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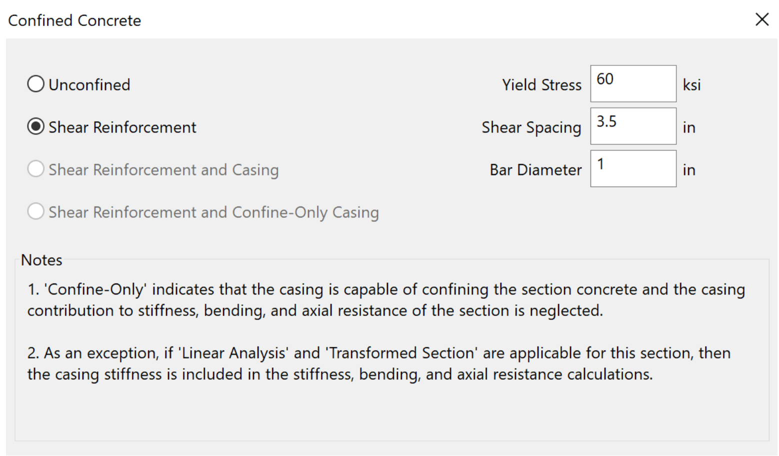

Figure 17. Confined Concrete dialog with illustrative input

After specifying the required input within the Confined Concrete dialog (Fig. 17), and navigating back to the Full Cross-Section Pile Properties dialog (Fig. 16), the abscissa and ordinate values of the user defined stress-strain curves can be specified. Clicking the "Edit Properties" button (Fig. 16) opens the User-Defined Stress-Strain dialog. Shown in Fig. 18 is an illustrative input set of stress-strain values for the unconfined portion (i.e., the "cover" concrete, or, the annular region outside of the confined core) of the 96-in. circular cross-section.

Solely to maintain general consistency with widely utilized empirical models (e.g., the Mander model), the maximum magnitude of compressive stress is set equal to 5 ksi in the user-defined curve, which is equal to the given value of f'c for the concrete material. However, the user-defined feature set is robust to input of stress-strain curve values that deviate (if judged to be appropriate by the engineer) from that of widely used empirical models. A plot of the user-defined stress strain curve for the unconfined (cover) concrete can be viewed by clicking the "Plot" button from within the User-Defined Stress-Strain dialog, as shown in Fig. 19.

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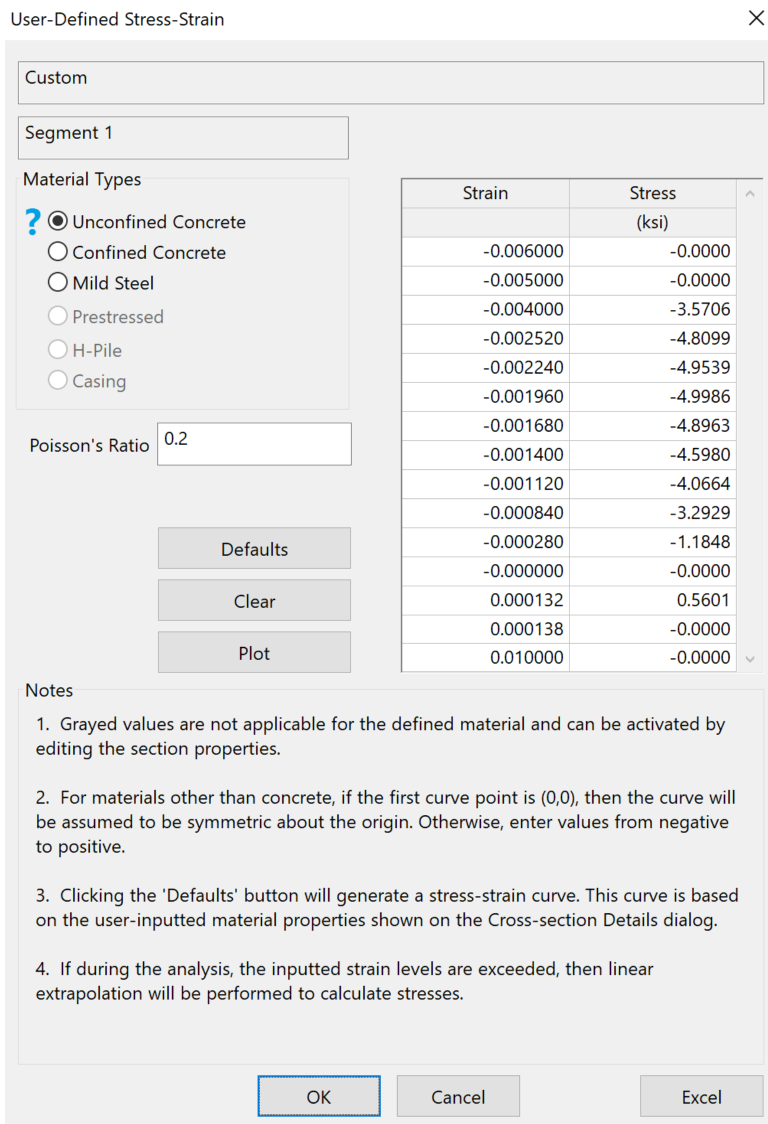

Figure 18. User-Defined Stress-Strain dialog with illustrative input for Unconfined Concrete

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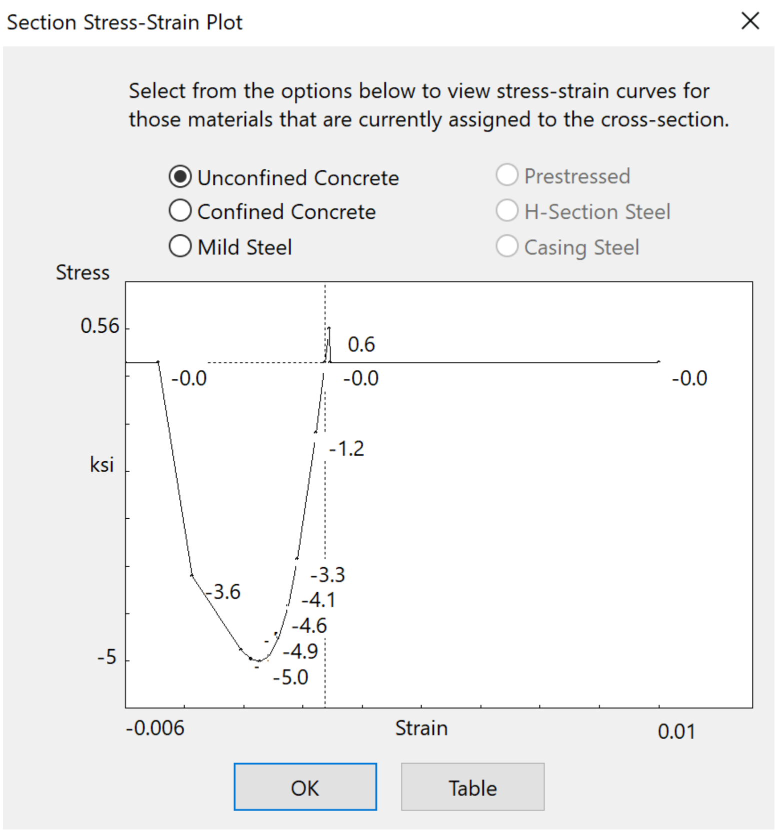

Figure 19. Stress-Strain Plot dialog for Unconfined Concrete

User-defined stress-strain values can be input for the confined concrete core in a similar manner. The abscissa and ordinate values are defined via tabulated input (Fig. 20) from within the User-Defined Stress-Strain dialog, but with selection of the "Confined Concrete" radio button. As listed in Fig. 20, the stress-strain values approximately adhere to those that would be obtained with use of the Mander model. As examples, the maximum magnitude confined compressive stress (6.9 ksi) exceeds the maximum compressive stress associated with the unconfined concrete portions of the cross-section; and, the confined stress strain curve exhibits ductility, whereas the unconfined concrete stress-strain curve (Fig. 19) exhibits diminishing stress carrying capacity for strains that are associated with post-peak compressive stresses.

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As with the unconfined concrete stress-strain curve (Fig. 18, Fig. 19), user-defined values of stress and strain defined for the confined concrete core can be input as judged appropriate by the engineer, even if such values happen to deviate from those associated with widely accepted empirical models. Subsequent to defining the stress and strain values, a plot of the user defined stress strain curve for the confined (core) concrete can be viewed by clicking the "Plot" button from within the User-Defined Stress-Strain dialog, as shown in Fig. 21.

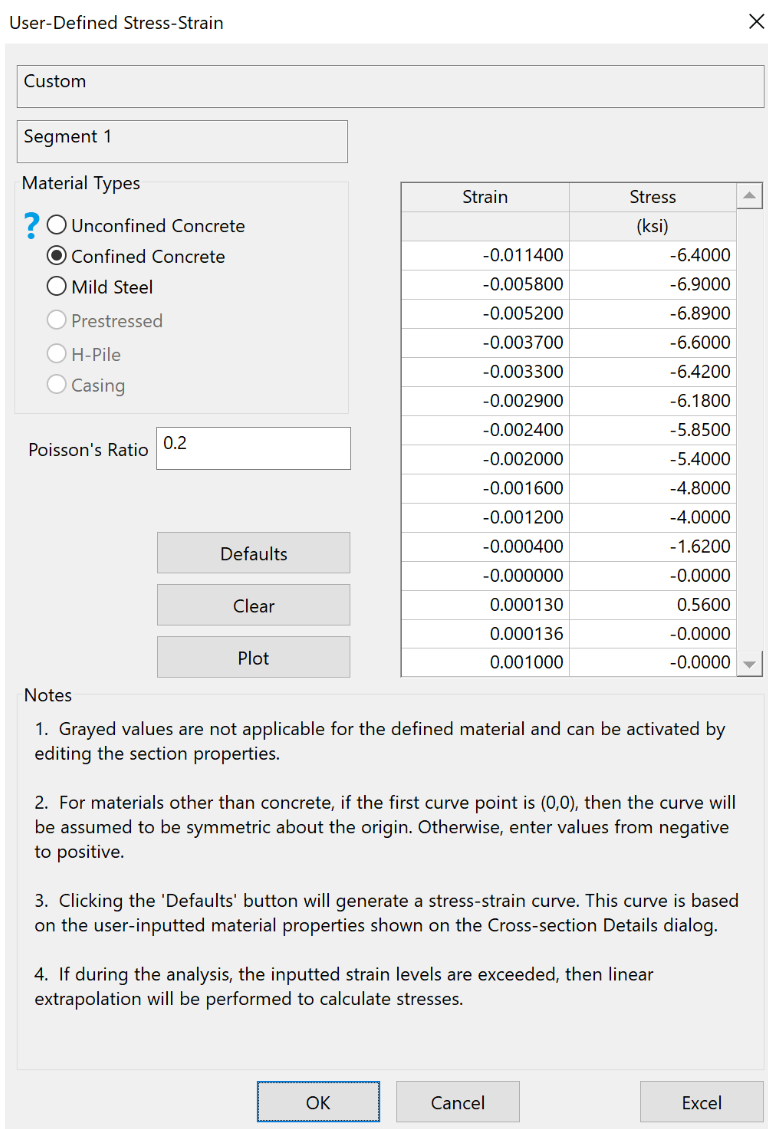

Figure 20. User-Defined Stress-Strain dialog with illustrative input for Confined Concrete

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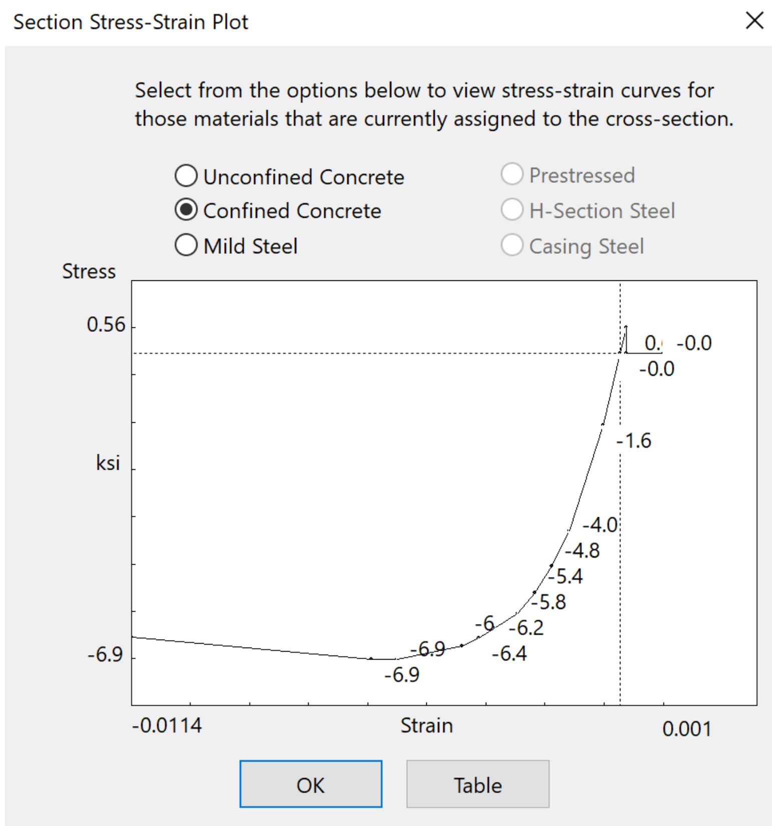

Figure 21. Stress-Strain Plot for Confined Concrete

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For models where user-defined stress-strain curves are assigned to the unconfined and confined cross-section portions of concrete members, and specific to scenarios where such curves deviate from widely accepted constitutive models, note that FB-MultiPier maintains the ability to solve for equilibrium of the associated model under a given set of loads. That is, the computed structural demands reflect the presence of the user-defined curves regardless of whether such curves adhere to formulations such as the Mander model. However, note that the bi-axial strength interaction diagrams computed for structural sections in FB-MultiPier adopt AASHTO LRFD strain limits. Therefore, even for scenarios where non-typical stress-strain curves are defined, the capacity portions of the load moment interaction calculations (i.e., the denominator components of the demand-capacity, D/C, ratios) reflect strain limits given in the AASHTO design provisions. Particularly for such scenarios, the maximum and minimum material strains that are computed for each cross-section, as included among the analysis output, should be reviewed by the design engineer.

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BSI Program Status

FB-MultiPier v6.0.0 Download a FREE demo today!

Released Oct 2023 - 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 v3.1.0 Download a FREE demo today!

Released Feb 2022 - 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 v7.2.0

Released Dec 2021 - 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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