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Issue #27

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# In this issue, we discuss recently developed features for FB-MultiPier v5.8.0

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 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 were largely motivated by YOUR suggestions:

- Prestressed carbon fiber reinforced polymer (CFRP) piles.
- Confined concrete in rectangular sections.
- Accumulated soil axial resistance reporting for use in downdrag calculations.
- Monitoring of soil axial reactions for deep foundation member design.

# Prestressed Carbon Fiber Reinforced Polymer (CFRP) 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 carbon fiber reinforced polymer (CFRP) piles. Cross-sections containing prestressed CFRP 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.

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An example database selection of the FDOT standard 12-in. prestressed CFRP pile crosssection is shown in Fig. 1.

Nile Turne Infe					
lie Type Into					
Pile Type	Segment Cross Section	on O	Prientation		
Type 1 V Add Del Pile Segments (Head to Tip) Custom	· · · · · · · · · · · · · · · · · · ·	· · · · · · · · · · · · · · · · · · ·	Column 2 3 2 Pile	1 Pier Cap 3 2 Xp Yp Zp	
Database Section Selection O Use Database Section O Customize Current Section	Custom Retrieve Section	Add To Datab	ase	Delete Section	
	H-Dile / Dine Dile	<b>9</b>		Delete Section	
ection Type	H-Pile / Pipe Pile Rectangular	<b>J</b>	>	12" Square FD(	) I Standard prestressed steel
ection Type O Circular O Pipe Pi	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile	e (Concrete Filled)	>	12" Square FD0	DT Standard prestressed steel
ection Type O Circular O Pipe Pi Rectangular O Pipe Pi	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled)	e (Concrete Filled)	> > >	12" Square FDC 14" Square FDC 18" Square FDC	DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel
ection Type O Circular O Pipe Pi Rectangular O Pipe Pi O H-Pile	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled)	e (Concrete Filled)	> > >	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC	DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel
ection Type O Circular O Pipe Pi Rectangular O Pipe Pi O H-Pile Edit Secti	H-Pile / Pipe Pile Rectangular Circular / Pipe Pil le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w)	>	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 24" Square FDC	DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel DT Standard prestressed steel
ection Type O Circular O Pipe Pi Rectangular O Pipe Pi H-Pile Edit Section	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w)	>	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 24" Square FDC 30" Square FDC	DT Standard prestressed steel DT Standard prestressed steel
ection Type O Circular O Pipe Pi Rectangular O Pipe Pi H-Pile Edit Section ection Constitutive Properties	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h)	24 24	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 24" Square FDC 30" Square FDC 30" Square FDC	DT Standard prestressed steel DT Standard prestressed high moment-capacity steel
ection Type O Circular O Pipe Pi Rectangular Pipe Pi H-Pile Edit Secti ection Constitutive Properties Default Stress Strain Curve	H-Pile / Pipe Pile Rectangular Circular / Pipe Pil le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h)	24 24	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 24" Square FDC 30" Square FDC 30" Square FDC 12" Square FDC	DT Standard prestressed steel DT Standard prestressed Righ moment-capacity steel DT Standard prestressed CFRP
ection Type Circular Pipe Pi Rectangular H-Pile Edit Section Constitutive Properties Default Stress Strain Curve User-Defined Stress Strain	H-Pile / Pipe Pile Rectangular Circular / Pipe Pil le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h) Unit Weight	24 24 150	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 24" Square FDC 30" Square FDC 30" Square FDC 12" Square FDC 14" Square FDC	DT Standard prestressed steel DT Standard prestressed high moment-capacity steel DT Standard prestressed CFRP DT Standard prestressed CFRP DT Standard prestressed CFRP
Ection Type     Oricular     Oricular	H-Pile / Pipe Pile Rectangular Circular / Pipe Pil le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h) Unit Weight	24 24 150	12" Square FDC 14" Square FDC 18" Square FDC 20" Square FDC 30" Square FDC 30" Square FDC 12" Square FDC 14" Square FDC 18" Square FDC 24" Square FDC	DT Standard prestressed steel DT Standard prestressed fCRP DT Standard prestressed CFRP DT Standard prestressed CFRP DT Standard prestressed CFRP DT Standard prestressed CFRP
ection Type Circular Pipe Pi Rectangular Pipe Pi H-Pile Edit Secti Ection Constitutive Properties Default Stress Strain Curve User-Defined Stress Strain C Edit Properties Plot Stress Strain	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h) Unit Weight Length	> > > > > > > > > > > > > > > > > > >	12" Square FDC 14" Square FDC 20" Square FDC 20" Square FDC 30" Square FDC 30" Square FDC 30" Square FDC 12" Square FDC 14" Square FDC 24" Square FDC 30" Square FDC	DT Standard prestressed steel DT Standard prestressed high moment-capacity steel DT Standard prestressed CFRP DT Standard prestressed CFRP
Section Type O Circular O Pipe Pi Rectangular O Pipe Pil H-Pile Edit Section Constitutive Properties Default Stress Strain Curve User-Defined Stress Strain C Edit Properties Plot Stress Strain	H-Pile / Pipe Pile Rectangular Circular / Pipe Pile le (Concrete Filled) ion Contents	e (Concrete Filled) Width (w) Depth (h) Unit Weight Length	> > > > > > > > > > > > > > > > > > >	12" Square FDC 14" Square FDC 20" Square FDC 20" Square FDC 30" Square FDC 30" Square FDC 12" Square FDC 18" Square FDC 30" Square FDC 30" Square FDC	DT Standard prestressed steel DT Standard prestressed high moment-capacity steel DT Standard prestressed CFRP DT Standard prestressed CFRP

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

The default stress-strain relationship implemented for CFRP strands in FB-MultiPier is schematically illustrated in Fig. 2. Considerations are given for both tensile and compressive strains, where the contribution of CFRP strands in compression is conservatively neglected. Under tensile strains, CFRP strands are assumed to behave in a linear manner up to rupture. For tensile 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 in tension, a warning message is issued as part of the program output, which includes the model location where the rupture has occurred.

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

All built-in cross-sections for prestressed CFRP piles are defined with utilization of 7-wire 0.6-in. diameter CFRP strands. Accordingly, the default modulus for CFRP strands is defined as 22,500 ksi. Further, the default rupture stress is defined as 369 ksi. These parameters correspond to a strand tensile rupture strain of 0.0164 in./in.

In the event that other variants of prestressed CFRP strands are to be utilized in a given pile cross section, the engineer can specify associated values of elastic modulus and rupture stress. However, for such instances, compression contributions to cross-section stiffness and resistance remain neglected during analysis. Alternatively, a user-defined stress-strain relationship can be supplied, as illustrated in Fig. 3. When user-defined relationships are employed, the engineer can define constitutive behaviors under both tension and compression.

The state of current practice is such that a single-valued resistance factor ( $\phi$ ) is applicable to prestressed CFRP member cross-sections when forming load-moment strength interaction diagrams. A resistance factor 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.

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Full Cross-Section Pile Properties	User-Defined Stress/Strain	Х
Pile Type Info	Custom	
Type 1 V Add Del	Segment 1	
	Material Types Strain Stress	
Pile Segments	2 O Concrete (ksi)	_
(Head to Tip)	Mild Steel -0.001647 -0.0004	
Custom	-0.000824 -0.0004	
<b>~</b>	0.00000 0.0000	
	0.016473 369.0000	
₹	Casing 0.016575 0.0004	
Add Del	0.018121 0.0004	
Database Section Selection O Use Database Section O Use Database Section O Customize Current Section	Defaults Plot	
Section Type	Clear	-
O Circular     O Pipe Pile       Image: Rectangular     O Pipe Pile (Column Column)       Image: O H-Pile     Edit Section Column)	<ol> <li>Notes</li> <li>Grayed values are not applicable for the defined material and can be activated by editing the section properties.</li> <li>If the first curve point is (0,0), then the curve will be assumed to be</li> </ol>	
Section Constitutive Properties O Default Stress Strain Curve User-Defined Stress Strain Curve Edit Properties	<ul> <li>symmetric about the origin. Otherwise, enter values from negative to positive.</li> <li>Clicking the 'Defaults' button will generate a Stress/Strain curve. This curve is based on the user-inputted material properties shown on the Cross Section Details dialog.</li> <li>If during the analysis, the inputted strain levels are exceeded, then</li> </ul>	
Plot Stress Strain Cross Section Details	Inear extrapolation will be performed to calculate stresses.       OK     Cancel   Excel	

Figure 3. Analysis output print options on the Analysis Settings page

When forming load-moment interaction diagrams for prestressed CFRP cross-sections, an environmental factor is also applied (i.e., compounded on the resistance factors). In FB-MultiPier, the environmental factor is set at a value of 1.0 by default. When of interest though, the engineer can specify a custom value on the Analysis Settings page (Fig. 4).

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Global Data	Analysis Settings				
- Model - Analysis Settings - Design Specs. - Dynamics - Lateral Stability Substructure - Pile - Soil - Pier - Soil - Pier - X-Members - Load - Springs - Mass/Damper - Retained Soil Superstructure - Bridge - Span Load	Pile Behavior Uinear - Gross Uinear Pier Behavior Uinear - Gross Uinear Pier Behavior Cuinear - Gross Uinear Section Properties Transformed Section Iteration Control Iterations 100 Tolerance 0.5 kips Analysis Type © Static	Soil Behavior       Print Control         Include Soil       Pile Displacem         Tip Stiffness       0         Additional Options       Pile Displacem         Interaction Diagram Phi Factors       Piler Properties         AASHTO       Environmental Factor       Piler Properties         A AREMA       Flexure Phi Factor       0.75         Besign Specification Options       Cap Stresses/N       Stiffness Options         Stiffness Node       0       0	ents rrces ents rrces Forces ayer lie Node Curves rrces foments urves ta All   None	~	
	O Dynamic	Coordinate System Export N	Iodal Coordinates		

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

Nonlinear frame elements in FB-MultiPier are formulated based on a discrete fiberintegrated 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 crosssections containing prestressed CFRP 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 tensile rupture of any prestressed CFRP 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 under tension. 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. Rupture of the strands is taken as the ratio of the input values of strand rupture stress and elastic modulus (e.g., a rupture stress of 369 ksi and modulus of 22,500 ksi corresponds to a rupture strain of 0.0164 in./in.).

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As a benefit of implementing the approach described above when forming load-moment interaction surfaces, capacities of prestressed CFRP 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 CFRP 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 CFRP pile cross-sections. For example, shown in Fig. 5 is a comparison of two sets of points along an interaction diagram for a 12-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 <u>Consolazio et al. (2004)</u> and computed using FB-MultiPier for a 12-in. standard FDOT prestressed CFRP pile cross-section

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# **Confined Concrete in Rectangular** Sections

Hoops or ties placed in rectangular reinforced concrete cross-sections can act to establish and confine a concrete core, thus increasing the concrete compressive strength of the core. This increase in compressive strength is a function of the quantity of confinement reinforcement and geometry of the reinforced section. The phenomenon of concrete confinement is particularly important and useful when designing for seismic forces and other forms of extreme event loading, especially for scenarios where hinges may form in reinforced concrete structural members.

A widely adopted empirical model for analyzing confined concrete sections is based on the work of <u>Mander et al. (1988)</u>, and is often referred to as the "Mander model". Accordingly, the Mander model serves as the basis for modeling of confinement effects in FB-MultiPier. Based on the cross section geometry, longitudinal reinforcement layout, and transverse reinforcement properties, unique stress-strain relationships are generated for the confined and unconfined section portions (Fig. 6). The stressstrain relationship for the confined section portions possesses a relatively larger peak compressive stress (f'cc), as compared to that of the unconfined section portions (f'c). Further, the stress-strain relationship associated with confined concrete degrades less rapidly to zero-valued stress as compared to that associated with the unconfined portions. Under tensile loads, both the confined and unconfined stress-strain relationships exhibit linear behavior up to the cracking stress (ft), and zero-valued stress beyond cracking.



# Figure 6. Stress-strain relationships for modeling of confined and unconfined concrete portions of cross-sections.

For modeling of circular cross sections in FB-MultiPier, the ability to incorporate confinement effects into the analysis has been available and maintained for many years. Accompanying the release of FB-MultiPier v5.8.0, a complementary feature set has been implemented for rectangular concrete cross sections as well.

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Figure 7. Rectangular Confined Concrete dialog

The Rectangular Confined Concrete dialog is shown in Fig. 7. Input controls contained within this dialog correspond to required parameters for modeling rectangular cross-sections per the Mander model. These include the spiral (or tie) shear reinforcement yield stress, longitudinal (shear) spacing, and bar diameter. Further, the dimensions of the confined core (bc, dc) can be directly specified. For each overall core dimension (bc, dc), the number of confined "cells" created by the transverse reinforcement scheme (wi', wi''), and the length of each cell dimension, are then supplied. As a convenience, only the wi' spacings along one side of the confined core are required (likewise for the wi' spacings). Based on the values supplied for these parameters, stress-strain relationships for both the confined and unconfined portions of rectangular sections are formed and assigned to the appropriate cross-section portions during analysis.

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# Accumulated Soil Axial Resistance Reporting for use in Downdrag Calculations

For design of deep foundation members, particularly driven piles, the phenomenon of "downdrag" may play a significant role. Downdrag denotes negative skin friction, or the accumulated negative soil axial resistance along the pile length as the pile undergoes downward motions. The <u>AASHTO LRFD Bridge Design Specifications</u> contain an explicit approach for considering negative skin friction, but also allow for use of the neutral plane method.

This latter method is conceptually illustrated in Fig. 8, where the neutral plane is the elevation at which the negative skin friction has dissipated. Here, the results of an analysis involving axial loading of a deep foundation member are utilized to build up two sets of through-depth soil force reaction curves. More specifically, a "top-down" curve is generated by accumulating soil axial resistance from top to bottom along the embedded pile length. The initial value of the top-down curve is assigned the sustained load (i.e., the axial force developed in the pile itself at the ground surface elevation).



Figure 8. Conceptual illustration of accumulated soil resistance plotting used in downdrag calculations for design of deep foundation members



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Either one or a family of bottom-up curves are also generated as part of the neutral plane method. Namely, some portion of the computed soil-pile tip reaction is used to initialize the bottommost curve value (e.g., 0%, 25%, 50%, 75%, or 100% of the soil reaction at the pile tip). Then, from bottom to top, the soil axial reaction is accumulated to produce this second type of through-depth curve. The intersections of the two types of curves are taken, with respect to a given profile of free-field settlement values, as candidates for establishing the neutral plane.

FB-MultiPier provides an aid for determining the position of the neutral plane by accumulating the positive soil resistance (top-down) and negative soil resistance (bottom-up), as could otherwise be obtained from a given set of analysis results. As a convenience to the engineer, accumulated soil force results are automatically computed for each pile and every substructure in a bridge model when the Soil Response Forces print option is enabled in the Print Control menu on the Analysis Settings page (Fig. 9).

Global Data Model Analysis Settings Design Specs. Dynamics Lateral Stability	Analysis Sett	ings								
	Pile Behavior Dinear - Gross Linear Pier Behavior Linear - Gross Linear Dinear Nonlinear			Soil Behavior Include Soil Tip Stiffness		/rad	Print Control			
Substructure					Additional Options			Pier Displacements		
-Pile Cap -Pile -Soil				Interaction Diagram Phi Factors AASHTO Environmental Factor			Pier Element Forces  Pier Properties  Soil Response Forces			
X-Members	Section Prop	erties		O AREMA Flexue		Flexure Phi	Factor	0	Soil Data per Layer	
-Load Springs	Transfor	med Section		O User-defined Axial Phi Factor 0			Soil Data per Pile Node			
-Mass/Damper	Iteration Control			Design Specification Options				Unbalanced Forces Cap Stresses/Moments Stress-Strain Curves Spring Forces		
Retained Soil	Iterations 100 Tolerance 0.5 kips									
Bridge										
Span Load	Analysis Type			Stiffness Options				Interaction Data		
	Static		Stiffness Node		0			All   None		
	Opynamic				Cod	ordinate Syster	n		Export Nodal Coordinates	

Figure 9. Analysis Settings print option for reporting accumulated soil axial reactions



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An illustrative set of output pertaining to accumulated soil-axial resistance is listed in Table 1. For each embedded pile node (e.g., 1 through 16 from top to bottom), five accumulated axial reactions are calculated. These include the cumulative top-down soil axial force (plus the sustained load at the top of the pile), and five variations on the cumulative bottom-up soil axial force. In particular, the five curves reflect (in turn), no contribution from the pile tip as well as 25%, 50%, 75%, and 100% contributions. Plotting of the values listed in Table 1 produces curves resembling those illustrated schematically in Fig. 8 above, and facilitates determination of the neutral plane.

# Table 1. Example tabulated output of accumulated soil resistance (top-down, bottom-up)used in downdrag calculations for design of deep foundation members

		Bottom-up with percentage of tip resistance				nce (kip)
Node	Top-down (kip)	0%	25%	50%	75%	100%
1	63.8	72.6	75.0	77.5	79.9	82.4
2	67.2	71.0	73.5	75.9	78.4	80.8
3	70.8	67.7	70.1	72.6	75.0	77.5
4	74.6	64.1	66.6	69.0	71.4	73.9
5	78.7	60.3	62.7	65.2	67.6	70.1
6	82.9	56.2	58.7	61.1	63.6	66.0
7	87.5	51.9	54.4	56.8	59.3	61.7
8	92.2	47.4	49.9	52.3	54.7	57.2
9	97.2	42.7	45.1	47.6	50.0	52.5
10	102.4	37.7	40.1	42.6	45.0	47.5
11	107.8	32.5	35.0	37.4	39.9	42.3
12	113.4	27.1	29.6	32.0	34.5	36.9
13	119.2	21.5	23.9	26.4	28.8	31.3
14	125.3	15.6	18.1	20.5	23.0	25.4
15	131.6	9.6	12.0	14.5	16.9	19.4
16	144.7	3.3	5.7	8.2	10.6	13.1

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# Monitoring of Soil Axial Reactions for Deep Foundation Member Design

Nominal (unfactored) soil resistance parameters contained within FB-MultiPier models are utilized to generate and apply distributed non-linear soil springs, which mimic various forms of physical soil resistance. As the intention is to describe soil-pile stiffness as realistically as possible, the force-displacement (or moment-rotation) relationships generated in this manner are typically not intended to be modified beyond consideration of group effects (e.g., p-multipliers). Consequently, through use of the as-formed soil force-deformation relationships, equilibrium states can be converged upon that exceed design-level soil resistance limits, such as limiting axial forces that incorporate LRFD resistance ( $\phi$ ) factors.

Bearing		Uplift
Nominal Side and Tip Resistance	e 150 kips	Nominal Side Resistance 135 k
Service Resistance Facto	r 1.0	Service Resistance Factor 1.0
Strength Resistance Facto	r 0.6	Strength Resistance Factor 0.6
Extreme Resistance Facto	r 1.0	Extreme Resistance Factor 0.8
2. During analysis, the factored axial res	sistance is compared ag	ainst mobilized soil axial forces and if the factored resista
	aniong the analysis res	
3 For AASHTO LRED analysis unique re	sistance factors can be i	nout with respect to Service Strength and Extreme limit
3. For AASHTO LRFD analysis, unique re states. The appropriate comparisons be	sistance factors can be i tween mobilized forces	nput with respect to Service, Strength, and Extreme limit and factored axial resistance are made during analysis.
3. For AASHTO LRFD analysis, unique re states. The appropriate comparisons be	sistance factors can be i tween mobilized forces	input with respect to Service, Strength, and Extreme limit and factored axial resistance are made during analysis.

Figure 10. Deep foundation member Axial Design dialog

A new feature in FB-MultiPier facilitates monitoring for exceedance of code-prescribed soil resistance forces. Namely, the Engineer can now input limiting compression (bearing) and tension (uplift) axial forces and associated LRFD resistance factors (Fig. 10).



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These input values of limiting axial force are then compared against summed soil-axial resistance forces obtained from the equilibrium solution. Comparisons are made on a per-pile basis and across each load case (or load combination). For any instances where equilibrium forces attributed to axial soil resistance exceed the respective limiting forces, a notification is subsequently issued and included among the analysis output so as to alert the Engineer of the offending pile and associated load case (Fig. 11).

Pile Tip Spring Force	=	12.327	
Mobilized Side plus Tip Force	=	97.000	
User-Defined Nominal Resistance	=	150.000	
User-Defined Phi Factor	=	0.600	
Factored Side plus Tip Resistance	=	90.000	
	_		
WARNING : Factored bearing (Side p	plus	Tip) resistance	exceeded.
Load Case = 2			
Substructure = 1			
Pile = 9			

Figure 11. Example output for soil-axial design of piles and drilled shafts

This form of accumulated soil reaction monitoring can be carried out for any unique pile(s) within a pile group and across any number of pier/bent substructures contained within a bridge model. Typically, the Engineer will supply previously computed nominal pile/shaft axial bearing (combined skin and tip resistance) and uplift (skin only) forces obtained from other software, such as FB-Deep. When AASHTO load combinations are analyzed, the Engineer may additionally input LRFD resistance ( $\phi$ ) factors specific to Service, Strength, and Extreme limit states (e.g., those indicated in Fig. 10) as applicable to downward (skin and tip resistance) or upward (skin resistance only) motions. FB-MultiPier will then monitor the analysis results obtained from the equilibrium solution and make the appropriate comparison to a limiting force depending on the limit state associated with a given load combination. Overall, this new feature is provided to assist the Engineer in locating the controlling load case or combination, particularly for foundations containing a relatively large number of deep foundation members.

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#### FB-MultiPier v5.8.0 Download a FREE demo today!

Released Jan 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 <u>Download a FREE demo today!</u>

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 twopoint attachments systems. For more information about Atlas, click here.





GeoStat

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