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BSI Newsletter

Bridge Software Institute

In this issue, we discuss recently developed features for FB-MultiPier v5.3.

The Bridge Software Institute (BSI) encourages all of our clients to communicate suggestions for improvements to our software. These suggestions may be general or very specific to project needs. We firmly believe that you are in the best position to know what those needs are!

In this release of FB-MultiPier, the enhancements listed below were all a result of YOUR suggestions:
a) Lateral stability analysis for determining minimum pile tip embedment.
b) Lateral soil resistance (p-y) models for Weak Rock and Strong Rock.
c) Tip resistance (q-z) models for Driven Piles in Sand and Driven Piles in Clay.
d) An option for coupling axial and lateral soil resistance.
e) A pre-analysis option for ensuring uniform bearing reactions due to span self-weight.
f) Print of max/min strains and corresponding stresses for nonlinear frame elements.

Several of the enhancements are highlighted below.

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Program Enhancements

Lateral Stability Analysis for Minimum Pile Tip Embedment

It is necessary to list minimum pile penetration (embedment lengths) in bridge plan documents so as to satisfy lateral loading requirements. However, assessing lateral stability involves modeling, analyzing, and post-processing numerous structural configurations to find optimal pile embedment lengths. To streamline this process, the “Minimum Pile Tip Embedment” (MPTE) feature in FB-MultiPier v5.3 automates incremental modification of pile lengths and post-processing of lateral load analysis results. The MPTE feature is accessible from the “Lateral Stability” page (Fig. 1), and is complementary to other lateral-load analysis modes, such as “Pushover” analysis.

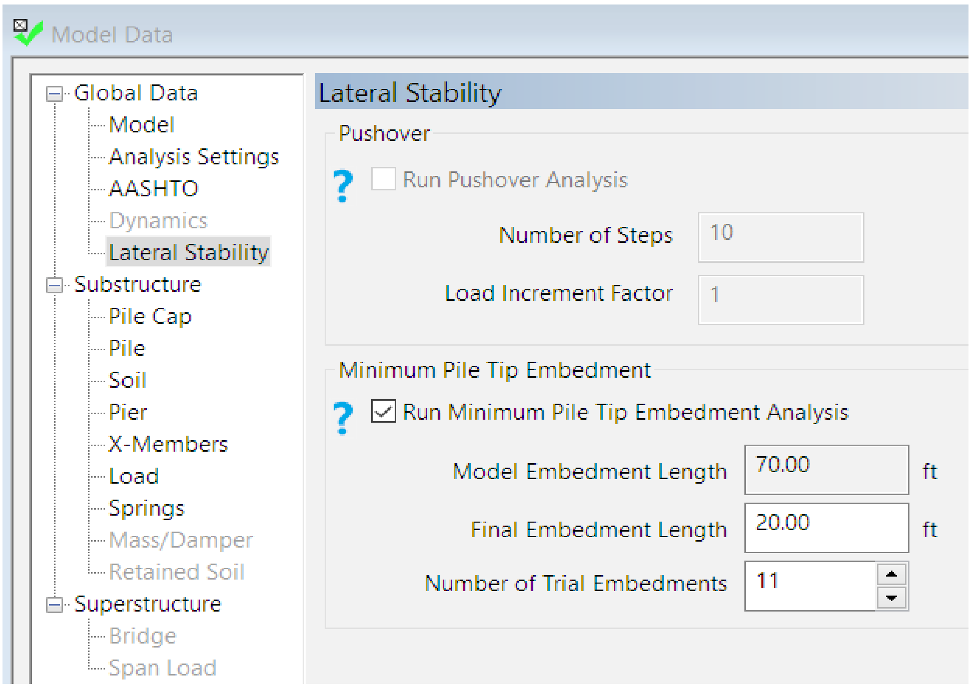

Figure 1. Lateral Stability page for specifying Minimum Pile Tip Embedment analysis

When the MPTE feature is enabled, pile lengths are automatically incremented and analyzed over a specified range of candidate embedment lengths. The determination of minimum pile tip embedment is applicable for numerous conditions of loading and soil support. One typical case is demonstrated below.

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FB-MultiPier v5.3
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Atlas v7.0

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Demonstration Case

In the following demonstration case, minimum pile embedment length will be determined to satisfy lateral stability under AASHTO Extreme II loading (Fig. 2). For the structural configuration considered (Fig. 3), it is assumed that the contractor will drive the piles so that the required axial capacity is attained. Therefore, soil tip resistance (q-z) in the model is increased to a magnitude that will not allow compressive failure at the already-attained ultimate axial soil capacity.

Load Combination Preview

		DC	DW	LL1	IM1	BR1	WA	CV
EXTREME-II	Comb. 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 2. Load Combination Preview table, indicating Load Factors associated with AASHTO Extreme II

AASHTO vessel collision (CV) loading is taken as 2500 kips, applied at the waterline footing (Fig. 3). To mimic the presence of superstructure resistance, an opposing lateral load of -200 kips is applied at the pier cap level. As context, the opposing lateral load (-200 kips) was previously determined to be the maximum loading permitted to be shed at the substructure-superstructure interface. For this configuration, embedment lengths ranging from 20 ft to 70 ft are investigated over eleven unique trial embedment depths (recall Fig. 1).

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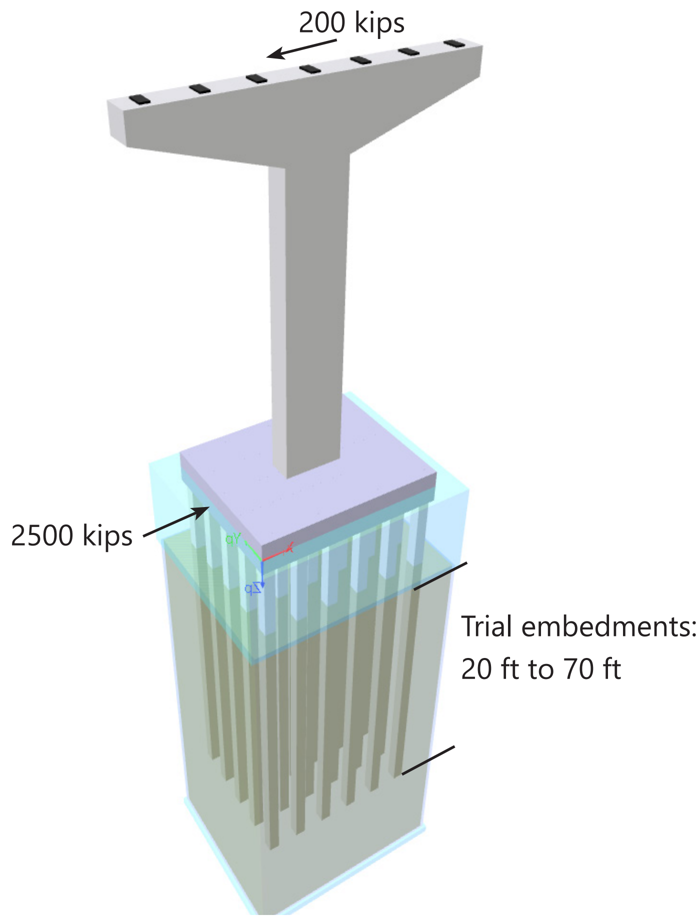

Figure 3. Isometric view of the substructure numerical model with applied lateral loads

Pertinent results from the Minimum Pile Tip Embedment Analysis are viewable from within the Design Table Generator menu (Fig. 4). Specifically, plots of maximum pile-head Lateral X (and Y) displacements are viewable across all embedment lengths and Load Combinations (Fig. 5). Further, maximum and minimum axial forces throughout the piles can be viewed. Using the controlling displacements and axial forces, trends in nonlinear soil response (with respect to pile embedment length) can be conveniently reviewed, and a minimum pile tip embedment length selected.

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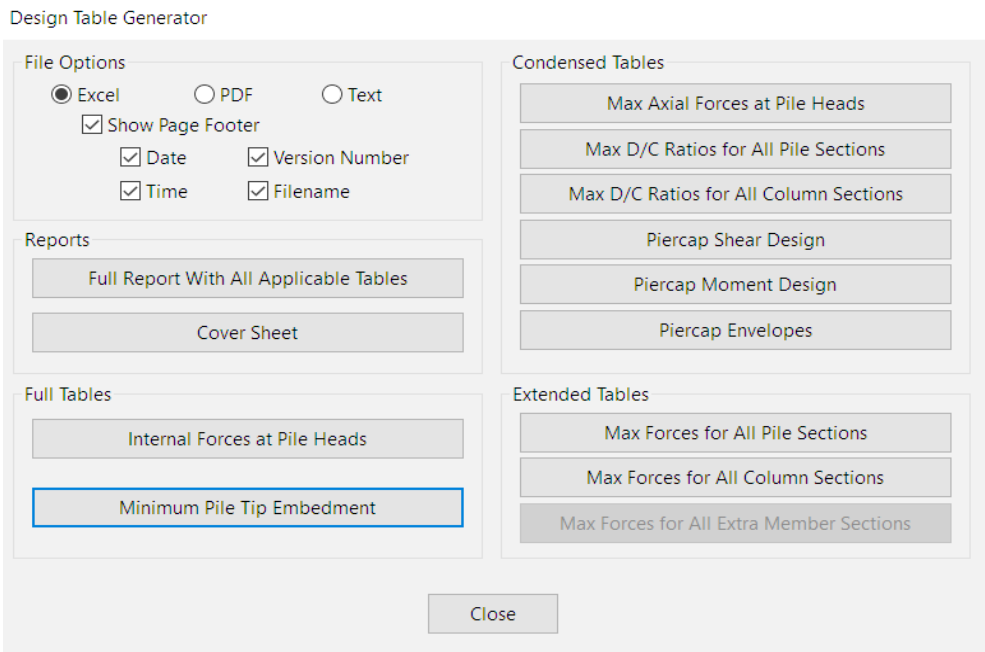

Figure 4. Design Table Generator menu for viewing Minimum Pile Tip Embedment results

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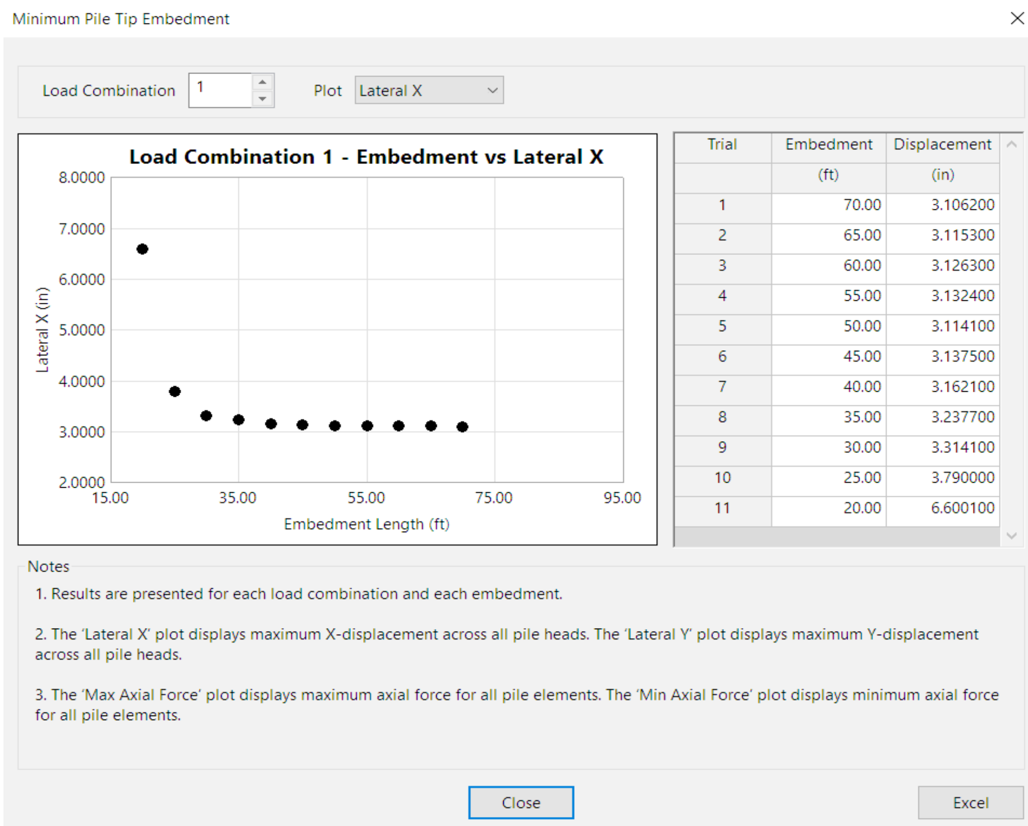

Figure 5. Minimum Pile Tip Embedment results plotting and tabulation

New Lateral Resistance and Tip Resistance Curves

To better characterize lateral resistance of deep foundations in weak rock and strong rock, two new p-y curves have been added to FB-MultiPier v5.3. Contingent upon structural configuration and loading conditions, the weak rock p-y curves (Fig. 6a) might be suitable for use in modeling layers exhibiting unconfined compressive strengths in the range of 10,440 psf to 104,400 psf. For layers exhibiting unconfined compressive strengths in excess of 144,100 psf, the strong rock p-y curves (Fig. 6b) may be found to be suitable.

In addition to the enhancements for lateral soil resistance modeling, two new tip resistance curves (q-z) have also been implemented. Namely, Mosher (1984) and Skempton (1951) curves can be used to model tip resistance for piles that are tipped in sand (Fig. 6c) or clay (Fig. 6d), respectively.

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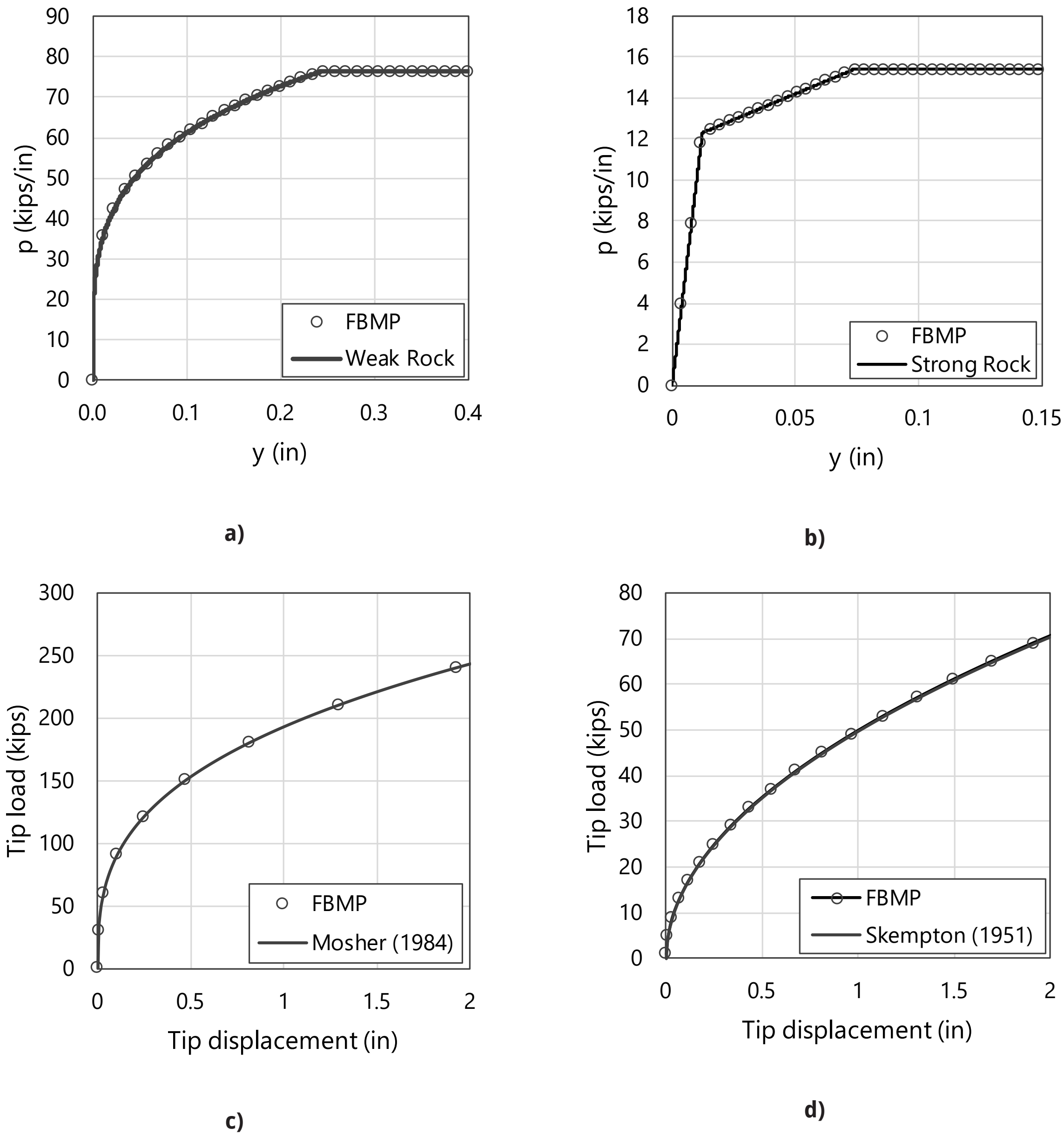

Figure 6. Lateral and tip resistance curves: a) p-y curve for weak rock with q_u = 80,000 psf ; b) p-y curve for strong rock with q_u = 145,000 psf; c) Mosher (1984) q-z curve for medium-dense sand with $\varphi = 33^{\circ}$; d) Skempton (1951) q-z curve for medium-stiff clay with C_u=1,462 psf

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Coupled Axial and Lateral Soil Resistance

Beam on nonlinear Winkler foundation models are typically formulated such that pile loads are transferred to the soil through distributed t-z, p-y, and q-z springs. In turn, the distributed springs are attached to the centerline of frame elements (representing the pile). However, in the field, loads are transferred to the soil at the pile and soil interface. In the case of lateral loading of a pile, this leads to the transfer of moment due to the mobilization of side shear in addition to that transferred through p-y springs. This necessitates considerations for coupled axial and lateral resistance analysis.

Conducting coupled analysis is found to reduce computed pile bending moment and deflection, especially when analyzing large-diameter drilled shafts. Coupling between axial and lateral resistance can be enabled in FB-MultiPier by checking the “Coupled Axial and Lateral Soil Resistance” option from the “Analysis Settings” page (Fig. 7).

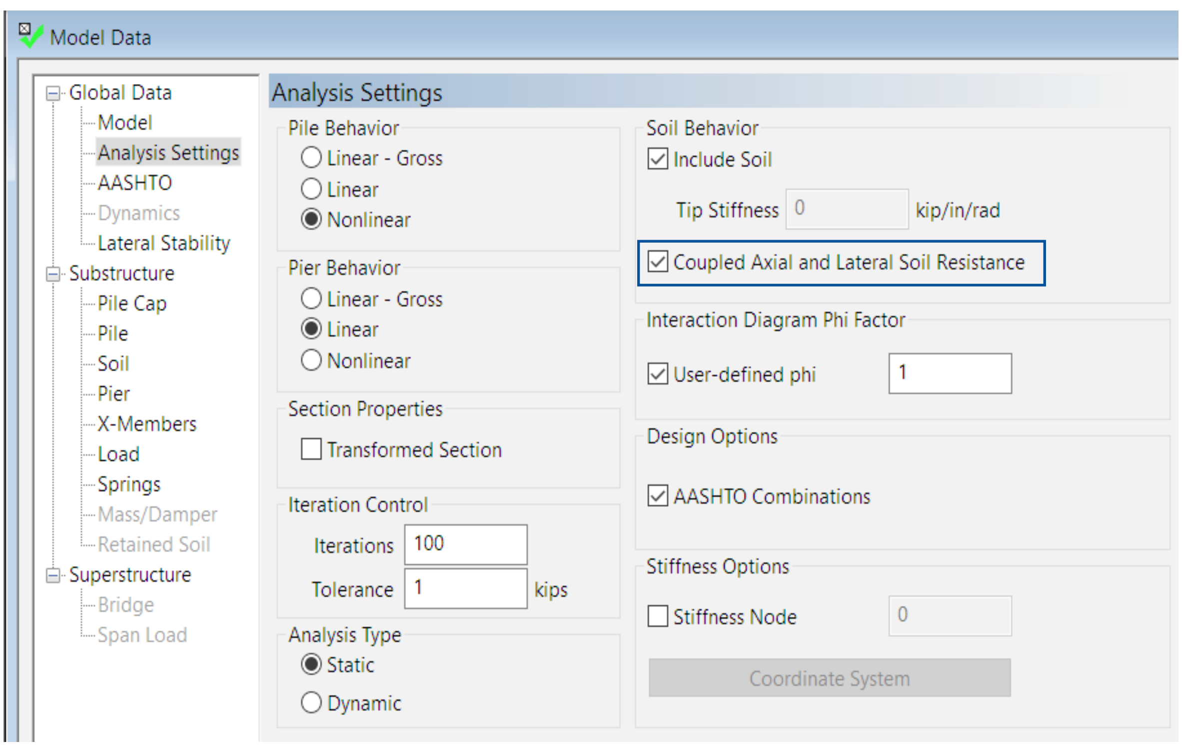

Figure 7. Analysis Settings menu

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This feature has been demonstrated to accurately capture physically measured lateral load responses of large-diameter drilled shafts. For example, as documented in McVay et al. (2006), computed versus measured results are shown in Fig. 8 for lateral loading of a 9 ft diameter shaft, subjected to 650 kips of lateral load at the shaft-head.

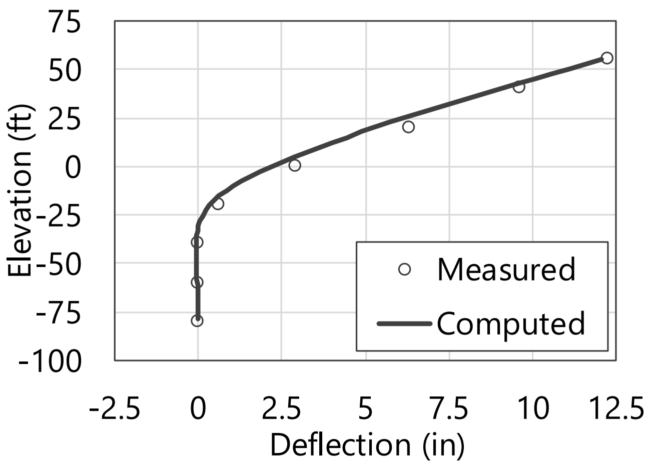

Figure 8. Measured and computed response of a 9 ft diameter drilled shaft in limestone under lateral loading (650 kips applied at shaft-head)

Uniform Distribution of Program Generated Superstructure Self-Weight

The construction sequence for most bridges results in uniform, or nearly uniform, distribution of self-weight to the bearings atop each bridge pier. A pre-analysis feature has been added in FB-MultiPier v5.3 to distribute superstructure self-weight uniformly to the bearings at each bridge pier while satisfying system equilibrium, accounting for span stiffness, and accounting for span continuity. This feature can be toggled from within the Program Settings dialog (Fig. 9). Note that this feature is not intended for simultaneous use with the special analysis feature for forming one-pier two span models.

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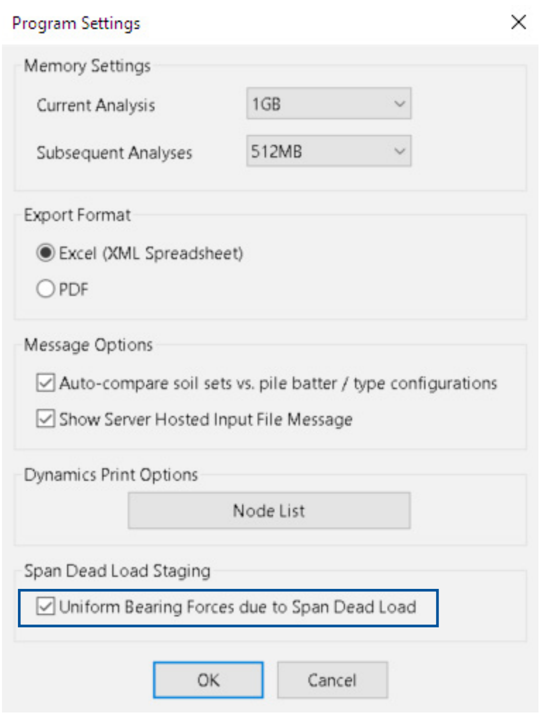

Figure 9. Program Settings dialog

In the "spine" model approach, adopted in FB-MultiPier, each span of the superstructure is represented by resultant frame elements connected end-to-end. The FB-MultiPier implementation additionally includes an assemblage of intermediate superstructure elements (Fig. 10). Namely, the span (or deck) elements terminate at a "Vertical link", the bottom of which attaches to the "Transfer beam". In turn, the "Transfer beam" runs parallel to the pier cap, and attaches to the top of each bearing location.

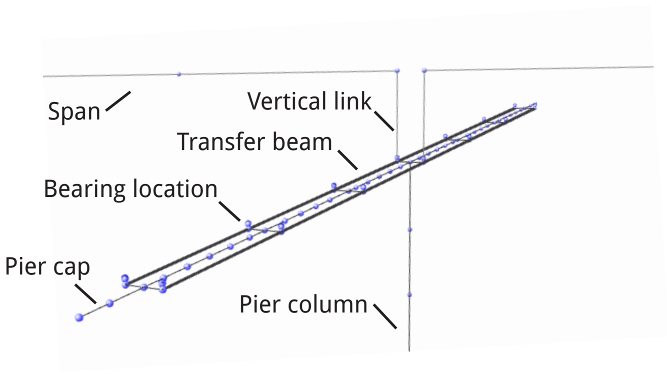

Figure 10. Intermediate superstructure elements

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Collectively, the intermediate superstructure elements transfer loads (such as span self-weight) between superstructure and substructure. However, distribution of span self-weight across the bearing locations is influenced (in part) by bearing stiffness, relative stiffness of the transfer beam, and the stiffness of the pier cap. The demonstration case below highlights the utility of the pre-analysis feature in bringing about uniform bearing reactions due to span self-weight.

Consider the bridge model shown in Fig. 11, with a typical pier shown in Fig. 12. The bridge model consists of simple spans (rollers on the left bearing rows; pins on the right bearing rows), seven concrete girders per span, and a cast in place deck. Loading for this models consists of self-weight and buoyancy effects.

Two analyses are conducted, one with use of the pre-analysis feature (recall Fig. 9), and one without use of the pre-analysis feature. Bearing reactions generated to the interior piers from the two analyses are shown in Fig. 13. As expected, use of the pre-analysis feature brings about uniform bearing reactions (Fig. 13a) as compared to results computed without use of the pre-analysis feature (Fig. 13b) where the reactions are larger near the stiffer column/cap connection. Importantly, the sum of the bearing reactions are equal in both cases, indicating that the pre-analysis feature acts only to more evenly distribute bearing reactions due to the program generated span self-weight.

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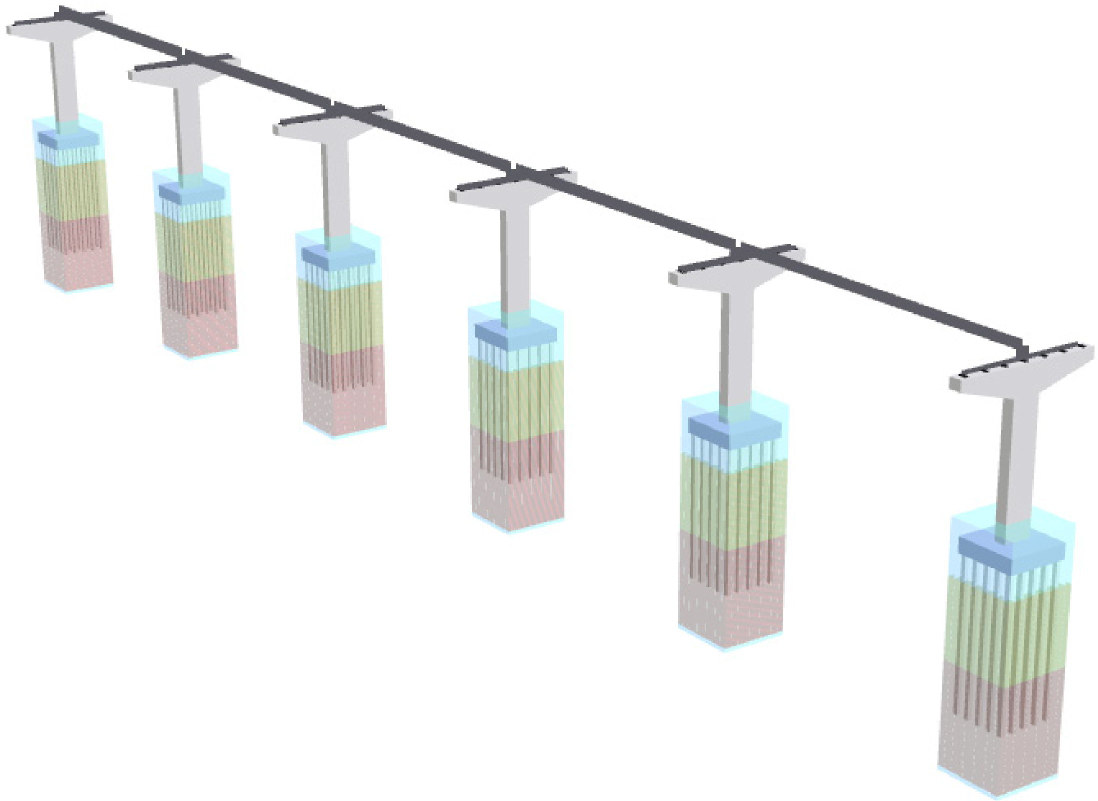

Figure 11. Isometric view of bridge model

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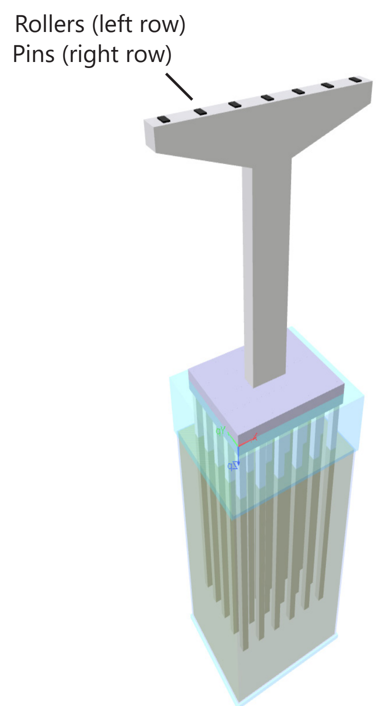

Figure 12. Isometric view of typical pier from bridge model

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LOC	L/R	CASE	FX kips	FY kips	FZ kips	MXX kip-ft	MYY kip-ft	MZZ kip-ft
1	L	1	-0.0	-0.0	-170.5	0.0	0.0	-0.0
2	L	1	-0.0	-0.0	-170.8	0.0	-0.0	-0.0
3	L	1	-0.0	-0.0	-170.7	0.0	0.0	-0.0
4	L	1	0.0	-0.0	-170.8	0.0	-0.0	0.0
5	L	1	0.0	-0.0	-170.7	0.0	-0.0	0.0
6	L	1	0.0	-0.0	-170.8	0.0	0.0	0.0
7	L	1	0.0	-0.0	-170.5	0.0	-0.0	0.0
1	R	1	0.0	0.0	-170.5	-0.0	0.0	-0.0
2	R	1	0.0	0.0	-170.8	-0.0	-0.0	-0.0
3	R	1	0.0	0.0	-170.7	-0.0	0.0	0.0
4	R	1	-0.0	0.0	-170.8	-0.0	0.0	0.0
5	R	1	-0.0	0.0	-170.7	-0.0	-0.0	-0.0
6	R	1	-0.0	0.0	-170.8	-0.0	0.0	0.0
7	R	1	-0.0	0.0	-170.5	-0.0	-0.0	0.0

a)

LOC	L/R	CASE	FX kips	FY kips	FZ kips	MXX kip-ft	MYY kip-ft	MZZ kip-ft
1	L	1	-0.0	-0.0	-88.0	0.0	0.0	0.0
2	L	1	-0.0	-0.0	-197.8	0.0	-0.0	0.0
3	L	1	-0.0	-0.0	-186.8	0.0	-0.0	0.0
4	L	1	-0.0	-0.0	-249.6	0.0	0.0	0.0
5	L	1	0.0	-0.0	-186.8	0.0	0.0	0.0
6	L	1	0.0	-0.0	-197.8	0.0	0.0	0.0
7	L	1	0.0	-0.0	-88.0	0.0	-0.0	0.0
1	R	1	0.0	0.0	-88.0	-0.0	0.0	0.0
2	R	1	0.0	0.0	-197.8	-0.0	-0.0	0.0
3	R	1	0.0	0.0	-186.8	-0.0	-0.0	0.0
4	R	1	0.0	0.0	-249.6	-0.0	0.0	-0.0
5	R	1	-0.0	0.0	-186.8	-0.0	0.0	-0.0
6	R	1	-0.0	0.0	-197.8	-0.0	0.0	-0.0
7	R	1	-0.0	0.0	-88.0	-0.0	-0.0	-0.0

b)

Figure 13. Bearing reactions typical to interior piers: a) with pre-analysis; b) without pre-analysis

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Prints of Maximum / Minimum Strains and Corresponding Stresses

Controlling stresses and corresponding strains are now among the output print options available in FB-MultiPier. Strain (and corresponding stress) prints are integral to carrying out design-service checks. Additionally, such data may be of use when assessing strains and corresponding stresses in failed (plastic hinge) regions of pier members.

As a demonstration, consider the reinforced concrete pier in Fig. 14. Lateral resistance at the superstructure level is provided by a pier-top spring. Lateral loading (1800 kips) is applied at the interface between the pier columns and piles (Fig. 14b). In response to the lateral load, several plastic hinges form throughout the pier, where Element 9 develops maximum compressive demands and Element 37 develops maximum tensile demands. Correspondingly, prints of maximum and minimum strains (and corresponding stresses) in the pier columns are captured in the summary region of the analysis output file (Fig. 15).

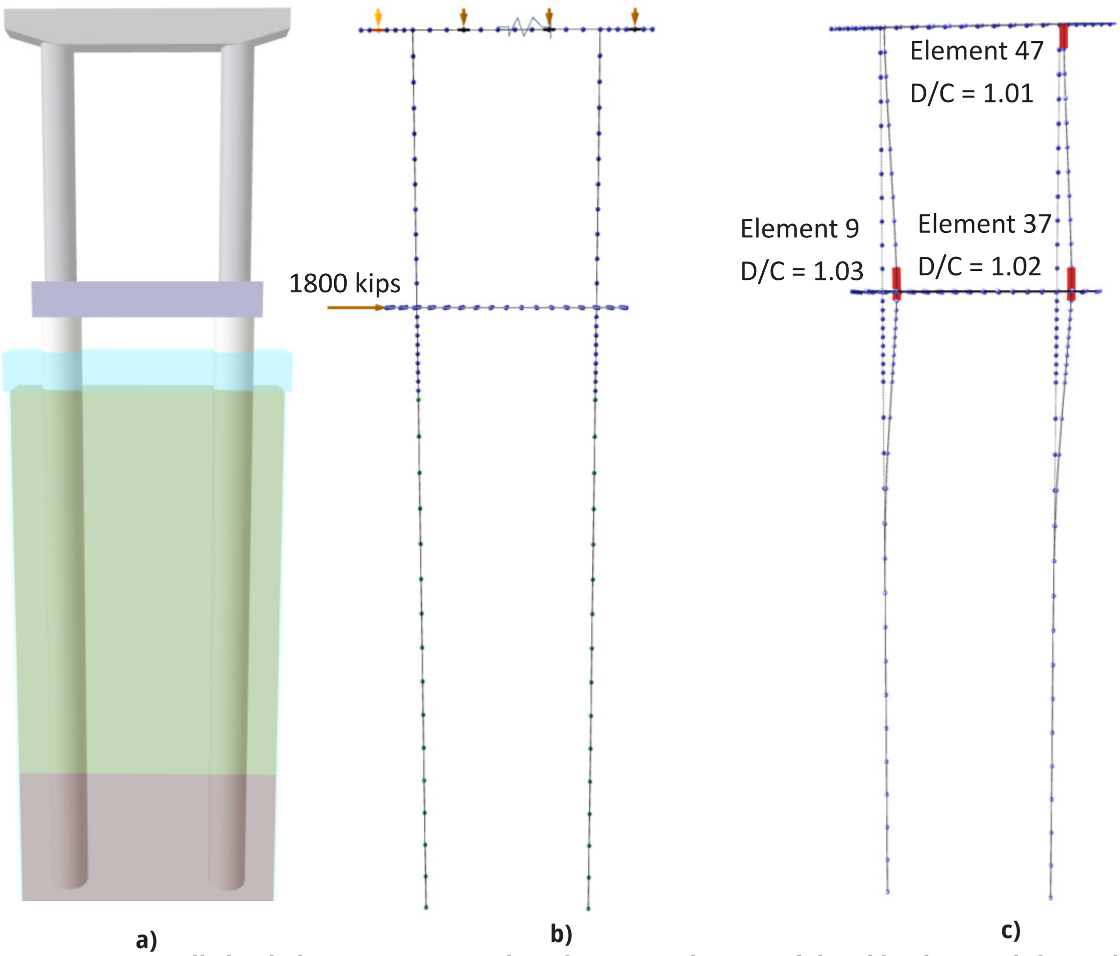

Figure 14. Laterally loaded pier: a) structural configuration; b) FE model and loading; c) deformed shape with plastic hinge locations

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```
Maximimum/Minimum Strains and Corresponding Stresses (ksi)
for Section   2

---------------------------------------------------------------
- Concrete                                                    -
---------------------------------------------------------------

Load Case                           =           1

Element No.                         =          37
Maximum Strain                      =  0.3362E-02
Corresponding Stress                =  0.0000E+00

Load Case                           =           1

Element No.                         =           9
Minimum Strain                      = -0.1248E-02
Corresponding Stress                = -0.3766E+01

WARNING : The concrete in at least one element of this
          section has cracked.


---------------------------------------------------------------
- Steel (mild longitudinal bars)                              -
---------------------------------------------------------------

Load Case                           =           1

Element No.                         =          37
Maximum Strain                      =  0.3329E-02
Corresponding Stress                =  0.6000E+02

Load Case                           =           1

Element No.                         =           9
Minimum Strain                      = -0.1217E-02
Corresponding Stress                = -0.3529E+02
```

Figure 15. Summary prints of controlling pier column strains and corresponding stresses

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For Technical Support

Cary Peterson
Technical Support, Bridge Software Institute

Location of model files: When running an analysis with FB-MultiPier, the input file should always be located on the local machine, and not on a network server. FB-MultiPier creates binary files during the analysis. Binary files are written to and read by FB-MultiPier. If an input file is located on a server, network latency can result in these binary files not being read and written fast enough to keep up with the engine during analysis. This can cause the program to crash when running the analysis. Thus, it is best practice to create a folder on the local machine, and save the input file to this location. Once the model has been analyzed, the input (.in) and output (.out) files can be copied back to the server location (for permanent storage, or for access by other end users).

License codes: Unlocking codes created by the license wizard to unlock a program license can only be used one time. Each time the license wizard is opened, it creates a new session. When the need arises to contact BSI for license unlocking codes, please provide the current “Session Code” and “MachineID” to receive new unlocking codes.

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BSI Program Status

FB-MultiPier v5.3 Download a FREE demo today!

Released: May 16, 2018 - 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 v2.05 Download a FREE demo today!

Released: January 31, 2018 - Continuing Development - Technical Support

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**.

Atlas v7.0

Released: June 13, 2017 - 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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