AASHTOWare BrDR 7.5.0

Substructure Tutorial

Pier4 – BrDR Substructure Moment Magnification

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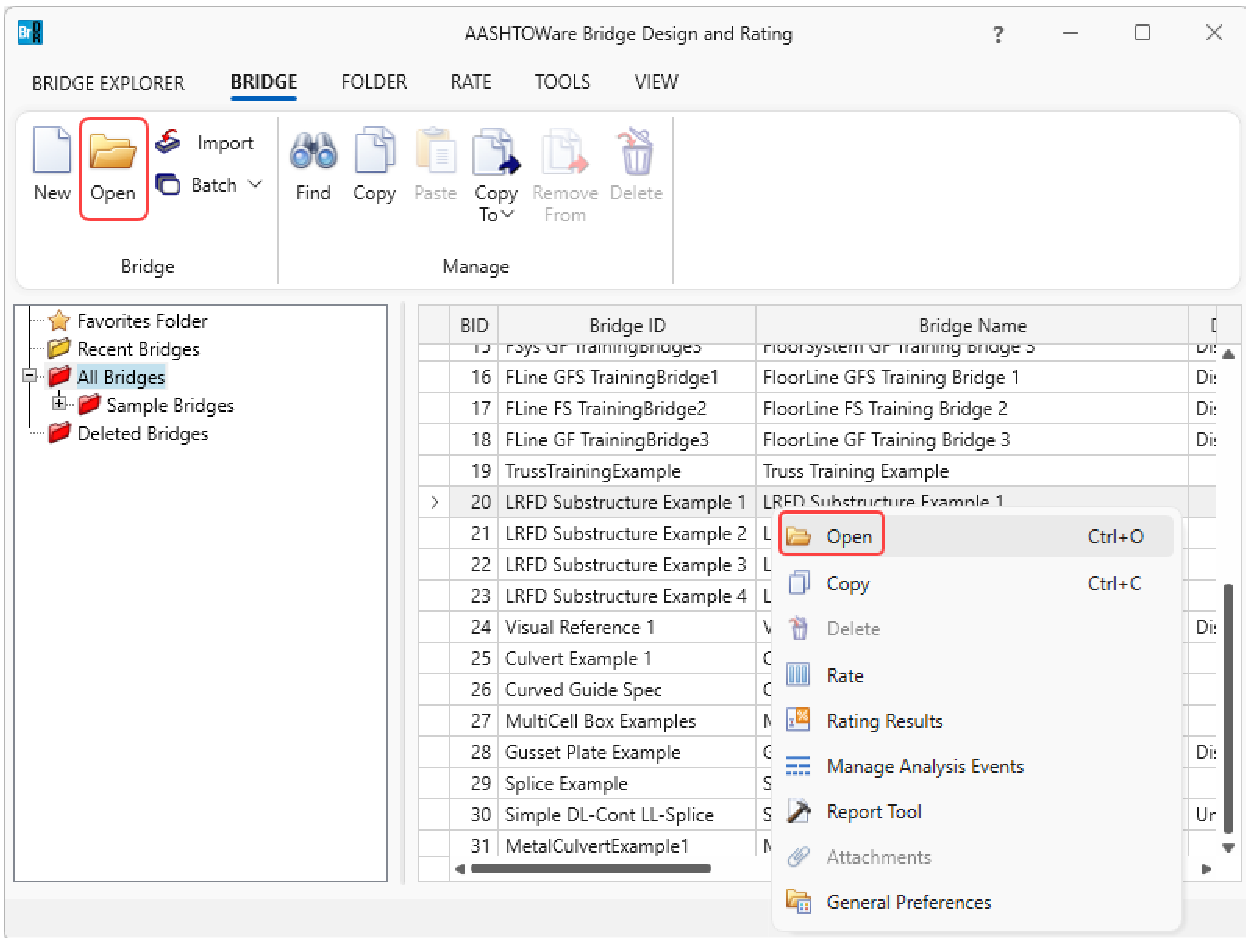
Topics Covered

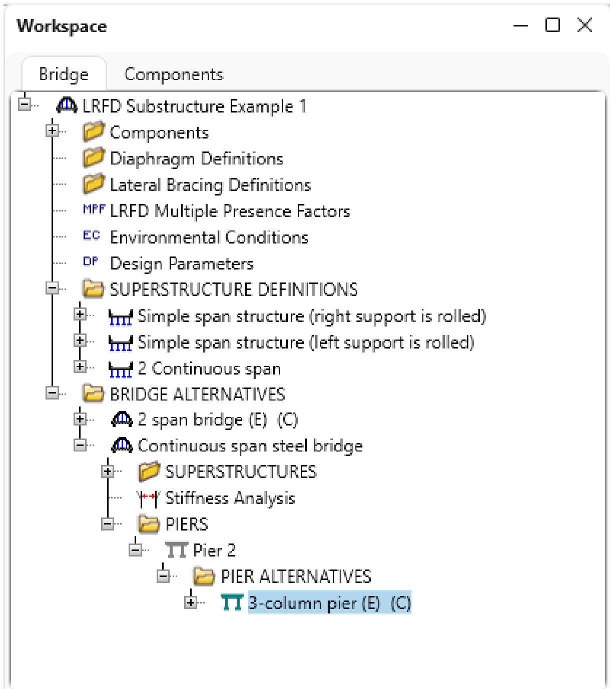
- 3 column frame pier
- Moment magnification analysis
- Using AASHTO LRFD Bridge Design Specifications, 9th Edition

3 column frame pier

This example uses the pier in **BID 20, LRFD Substructure Example 1** provided in the sample database delivered with the software. Double click on **BID 20** from the **Bridge Explorer** to open the bridge (or select **Open** from the **Bridge** group of the **BRIDGE** ribbon, or right click and select **Open**) as shown below.

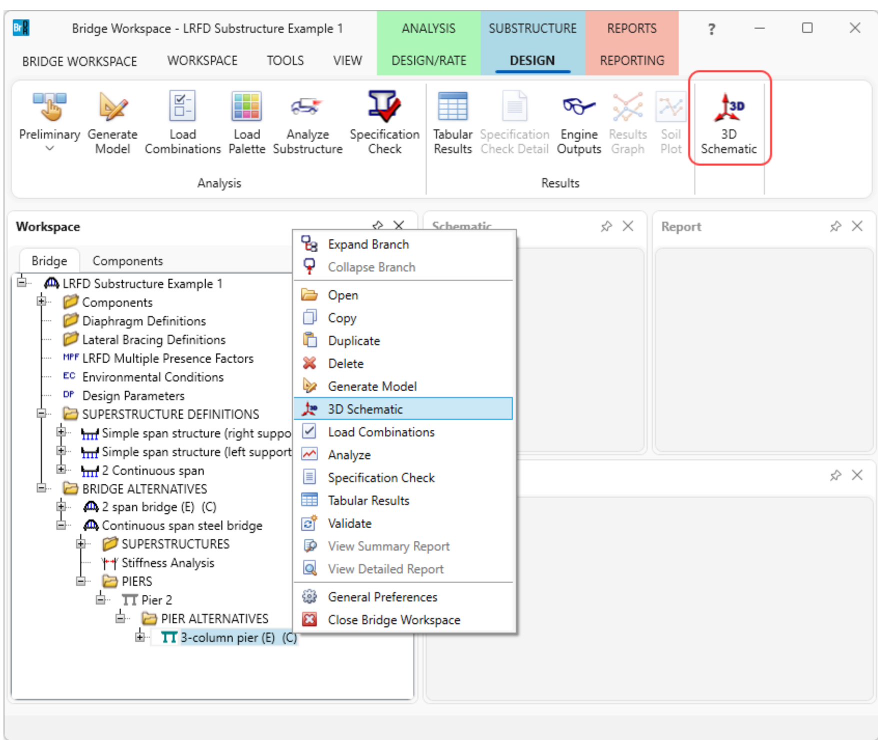


Expand the **Bridge Workspace** tree to show the pier alternative.



3D Schematic - Pier Alternative

With pier alternative **3-column pier** selected in the **BWS** tree, click on the **3D Schematic** button from the **SUBSTRUCTURE DESIGN** ribbon (or right click and select **3D Schematic**) to open the schematic as shown below.



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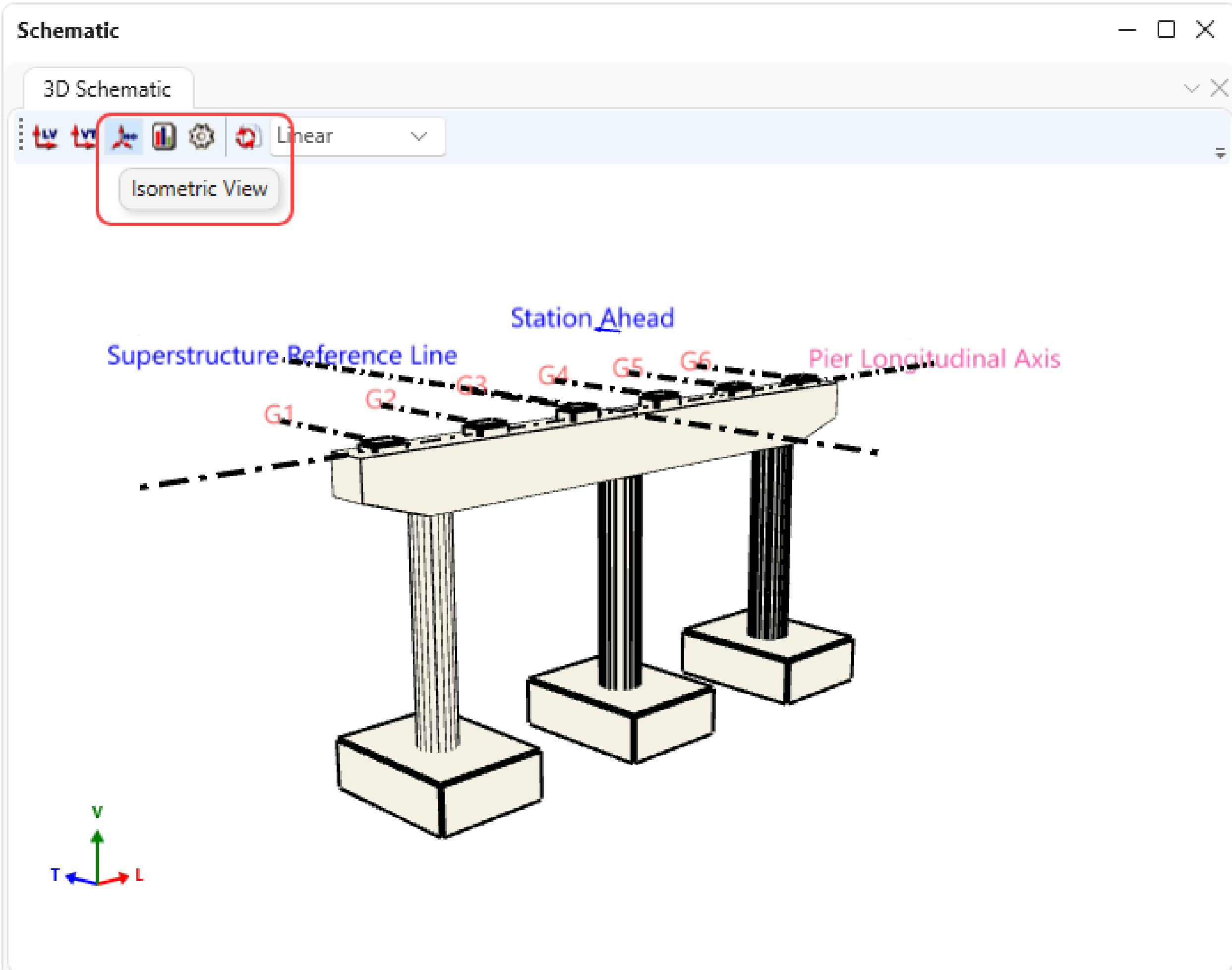
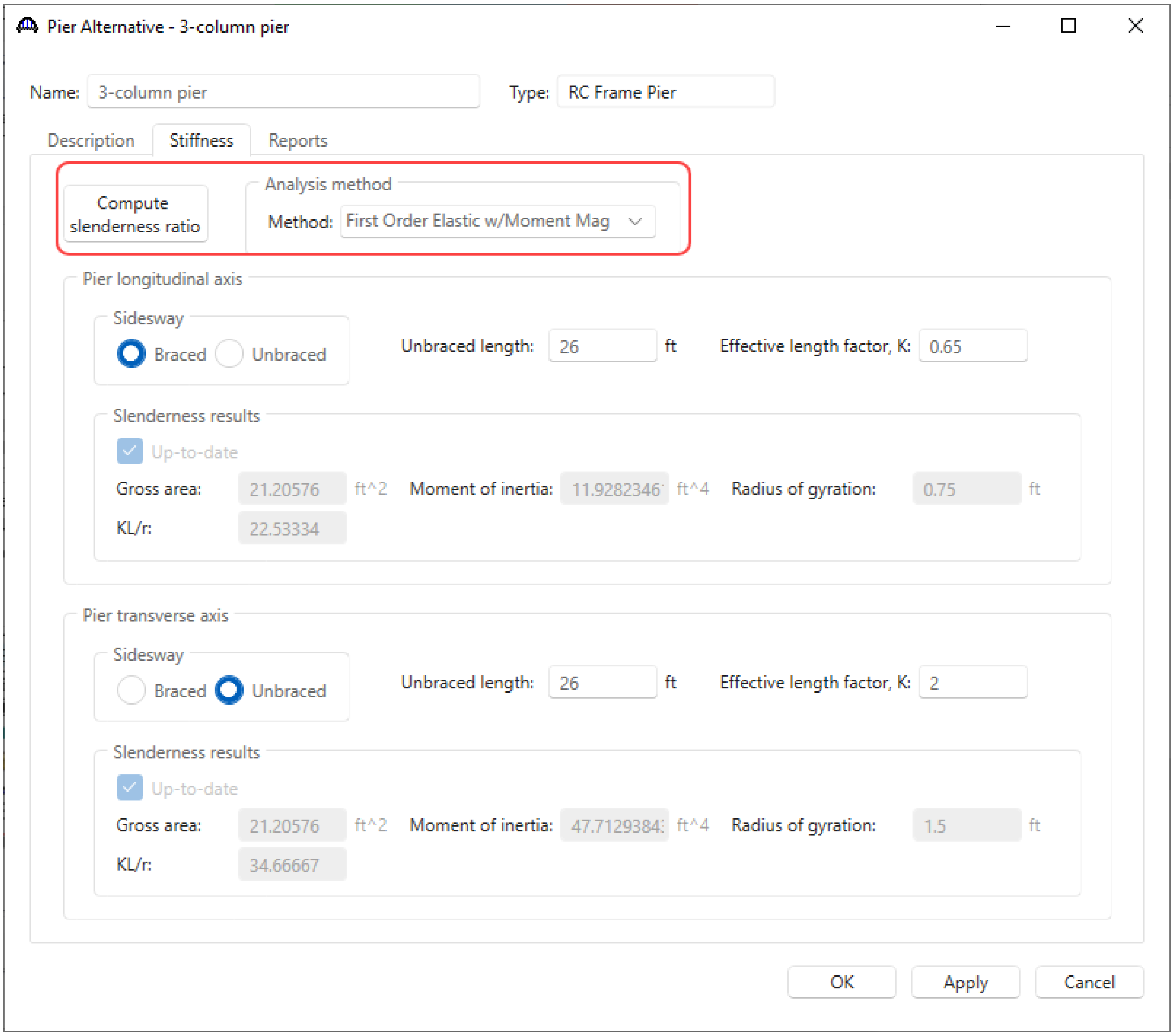
The isometric schematic of this pier is shown below after pressing the Isometric button as shown below.



Pier Alternative – Stiffness tab

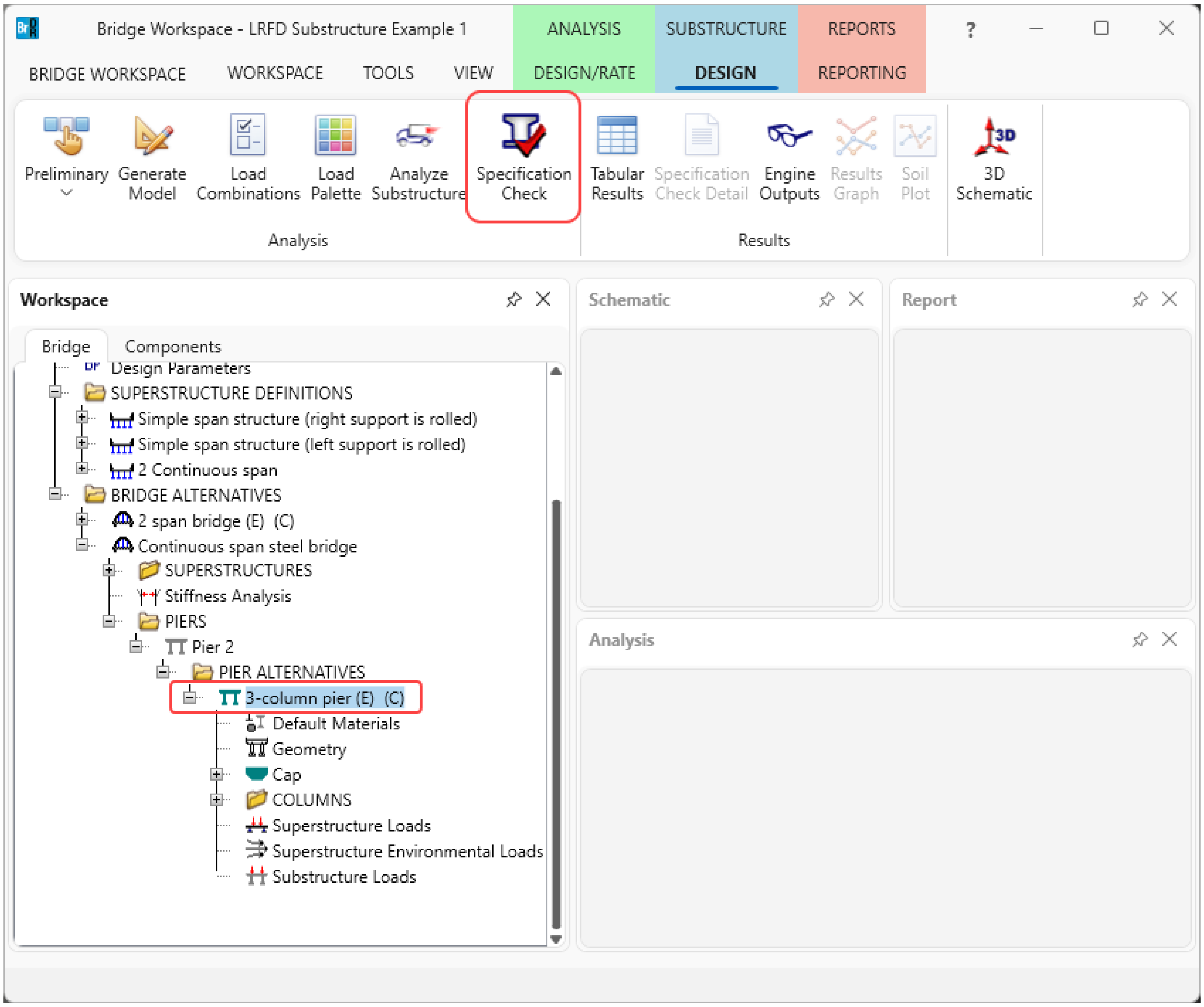
Double click on the **3-column pier** node in the **BWS** tree to open the **Pier Alternative** window and navigate to the **Stiffness** tab. Click on the **Compute Slenderness Ratio** button and BrDR will compute the KL/r ratios that can be used to determine the effect of slenderness as per AASHTO LRFD Article 5.7.4.3.



Click **OK** to apply the data and close the window.

Specification Check

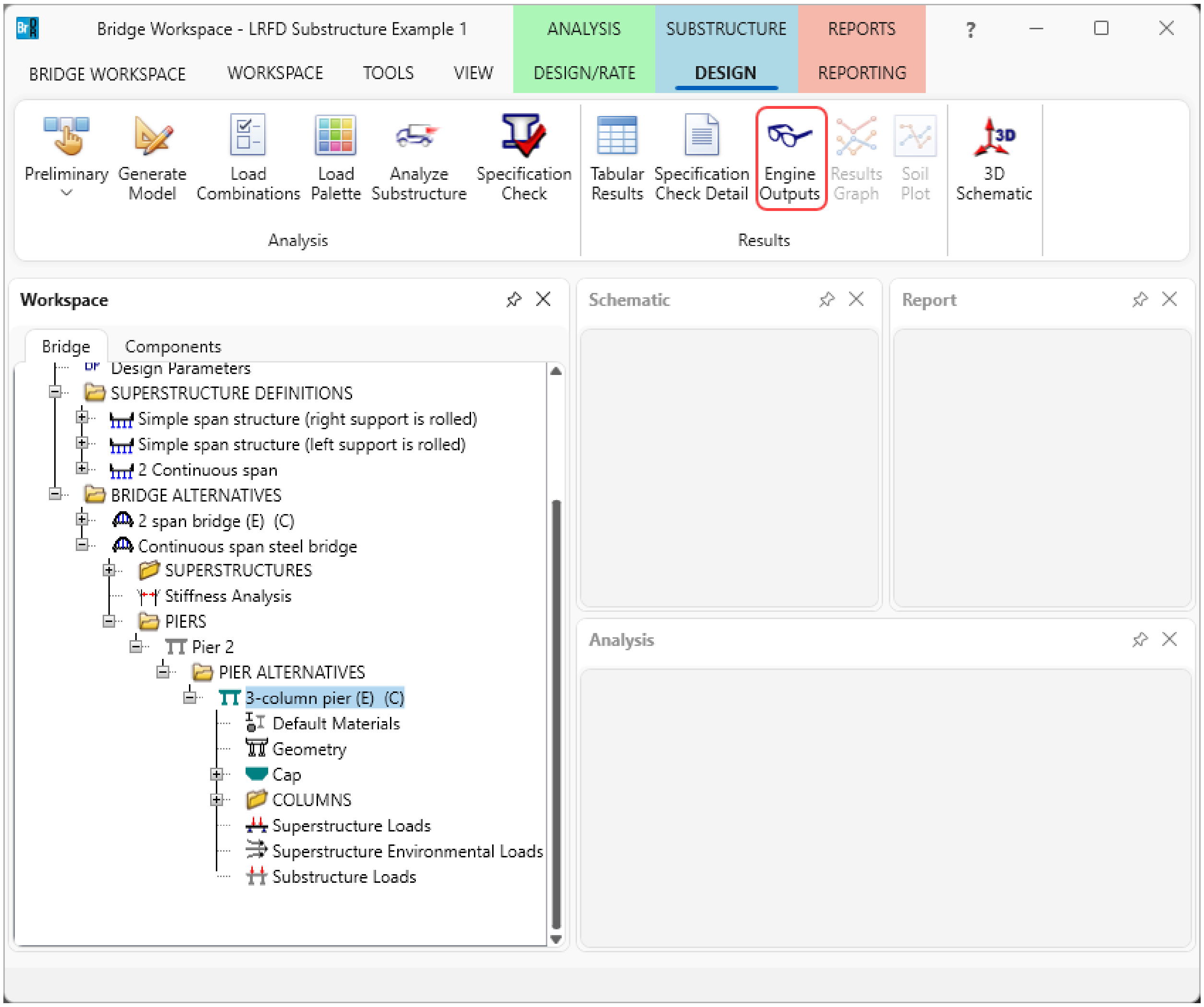
In this example, moment magnification should be considered to account for the effects of slenderness. Launch a specification check of the pier by clicking on the **Specification Check** button from the **Analysis** group of the **SUBSTRUCTURE DESIGN** ribbon as shown below

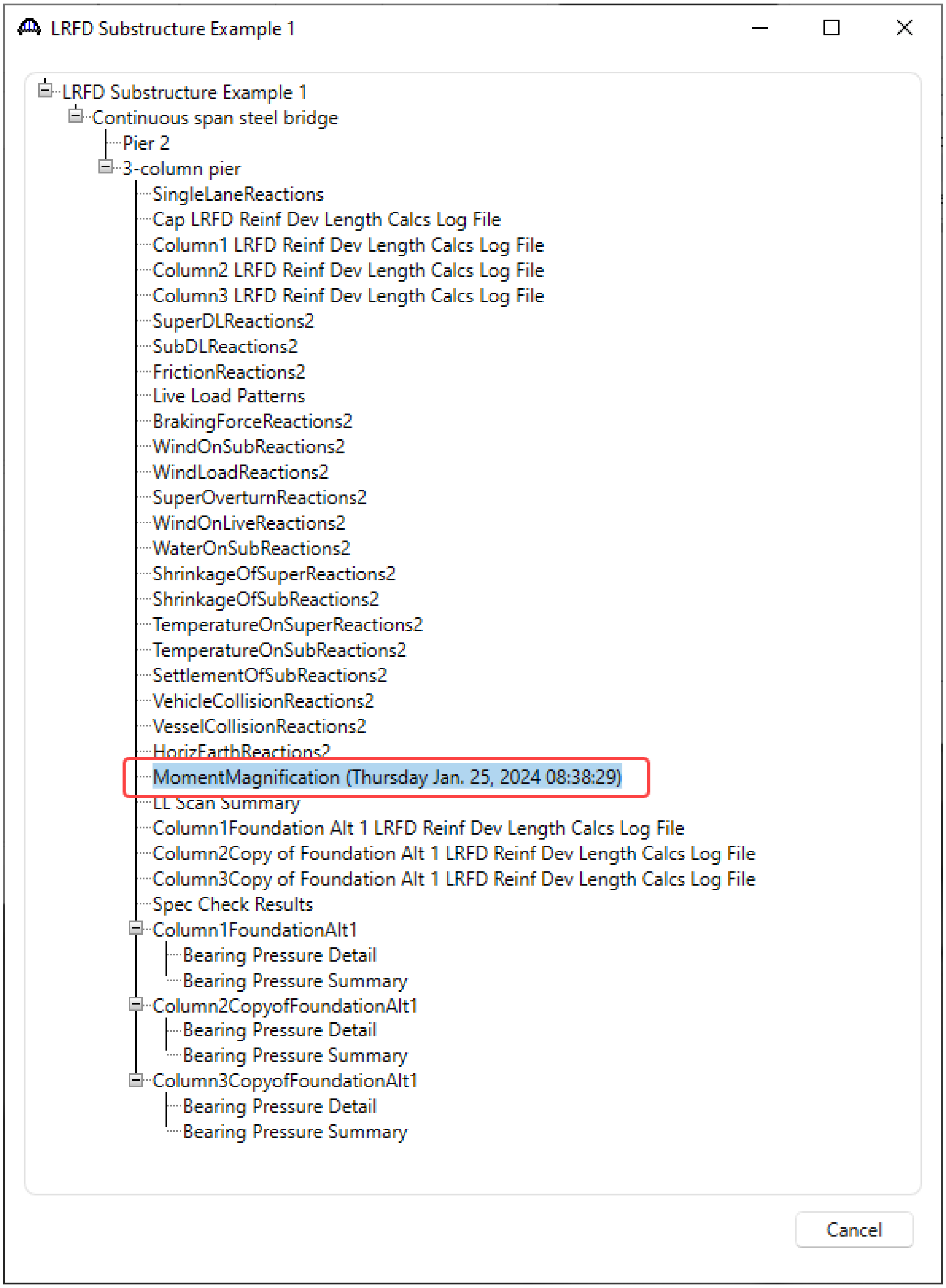


The program will first compute the elastic moments on the pier, then compute moment magnification factors and then compute the magnified moments. The magnified moments are then used in specification articles.

Engine Outputs

A report showing the moment magnification calculations can be found in the **Engine Outputs** window as shown below.




LRFD Substructure Example 1
LRFD Substructure Example 1
Continuous span steel bridge
Pier 2
3-column pier
SingleLaneReactions
Cap LRFD Reinf Dev Length Calcs Log File
Column1 LRFD Reinf Dev Length Calcs Log File
Column2 LRFD Reinf Dev Length Calcs Log File
Column3 LRFD Reinf Dev Length Calcs Log File
SuperDLReactions2
SubDLReactions2
FrictionReactions2
Live Load Patterns
BrakingForceReactions2
WindOnSubReactions2
WindLoadReactions2
SuperOverturnReactions2
WindOnLiveReactions2
WaterOnSubReactions2
ShrinkageOfSuperReactions2
ShrinkageOfSubReactions2
TemperatureOnSuperReactions2
TemperatureOnSubReactions2
SettlementOfSubReactions2
VehicleCollisionReactions2
VesselCollisionReactions2
HorizEarthReactions2
MomentMagnification (Thursday Jan. 25, 2024 08:38:29)
LL Scan Summary
Column1Foundation Alt 1 LRFD Reinf Dev Length Calcs Log File
Column2Copy of Foundation Alt 1 LRFD Reinf Dev Length Calcs Log File
Column3Copy of Foundation Alt 1 LRFD Reinf Dev Length Calcs Log File
Spec Check Results
Column1FoundationAlt1
Bearing Pressure Detail
Bearing Pressure Summary
Column2CopyofFoundationAlt1
Bearing Pressure Detail
Bearing Pressure Summary
Column3CopyofFoundationAlt1
Bearing Pressure Detail
Bearing Pressure Summary
Cancel

Pier4 – BrDR Substructure Moment Magnification

This report contains the elastic moments, the moment magnification factors and the resulting magnified moments for each load combination. Load Combination 1 is composed of the following load cases.

MomentMagnification - Notepad

File Edit Format View Help

```
Bridge ID: LRFD Substructure Example 1       NBI Structure ID: LRFD_EX1_sub
Bridge: LRFD Substructure Example 1       Bridge Alt: Continuous span steel bridge
Substructure: Pier 2 Substructure Alt: 3-column pier
Date: Thursday, January 25, 2024 8:37:13 AM

Report Filename: C:\Users\SharanyaRao\Documents\AASHTOWare\BrDR75[illegible]RFDSubstructureExample1\Continuousspansteelbridge\Pier2\3-columnpier\MomentMagnification.txt

Axis convention:  x = abo[illegible] the pier transverse axis, y = about the pier longitudinal axis
```

Load case 2 - Substructure DC

Load case 1 - Superstructure DC

Load case 631 - Substructure Temperature Fall

Load case 3 - LL1 T DV:1

Load case 619 - Braking 1 Lane Sta Back Dir

Load Combination:LC 1 = 1.000 (1.25DC(1) + 1.25DC(2) + 1.75LL(3) + 1.75BR(619) + 1.20TU(631))

					First-Order Elastic M2b (kip-ft)				First-Order Elastic M2s (kip-ft)		Magnified Moments (kip-ft)	
Column No	ElementID	NodeID	DeltaBx	DeltaBy	Mux	Muy	DeltaSx	DeltaSy	Mux	Muy	Mcx	Mcy
1	35	36	1.697	[illegible]	[illegible]	[illegible]	1.437	1.000	0.00	288.23	87.22	288.23
		37	1.697	[illegible]	[illegible]	[illegible]	1.437	[illegible]	[illegible]	[illegible]	[illegible]	-67.55
2	37	38	1.391	[illegible]	[illegible]	[illegible]	1.437	[illegible]	[illegible]	[illegible]	[illegible]	289.98
		39	1.391	1.031	-8.23	0.00	1.437	[illegible]	[illegible]	[illegible]	[illegible]	-66.85
3	39	40	1.283	1.041	-61.89	0.00	1.437	[illegible]	[illegible]	[illegible]	[illegible]	288.23
		41	1.283	1.041	-40.70	0.00	1.437	1.000	0.00	-67.55	-52.20	-67.55

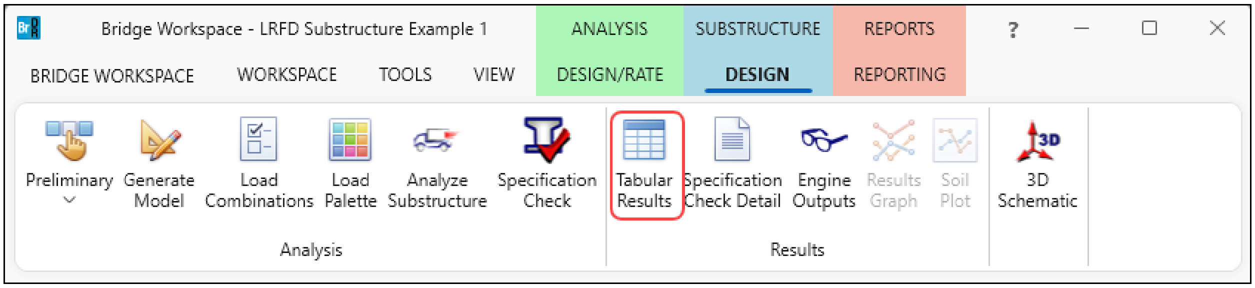
Load Combination:LC 2 = 1.000 (1.25DC(1) + 1.25DC(2) + 1.75LL(3) + 1.75BR(619) + 1.20TU(632))

					First-Order Elastic M2b (kip-ft)				First-Order Elastic M2s (kip-ft)		Magnified Moments (kip-ft)	
Column No	ElementID	NodeID	DeltaBx	DeltaBy	Mux	Muy	DeltaSx	DeltaSy	Mux	Muy	Mcx	Mcy
1	35	36	1.732	1.054	-269.73	0.00	1.437	1.000	0.00	288.23	-467.26	288.23
		37	1.732	1.054	-210.22	0.00	1.437	1.000	0.00	-67.55	-364.17	-67.55
2	37	38	1.346	1.028	-21.00	0.00	1.437	1.000	0.00	289.98	-28.28	289.98
		39	1.346	1.028	-8.23	0.00	1.437	1.000	0.00	-66.85	-11.07	-66.85
3	39	40	1.303	1.028	259.23	0.00	1.437	1.000	0.00	288.23	337.71	288.23
		41	1.303	1.028	249.95	0.00	1.437	1.000	0.00	-67.55	325.61	-67.55

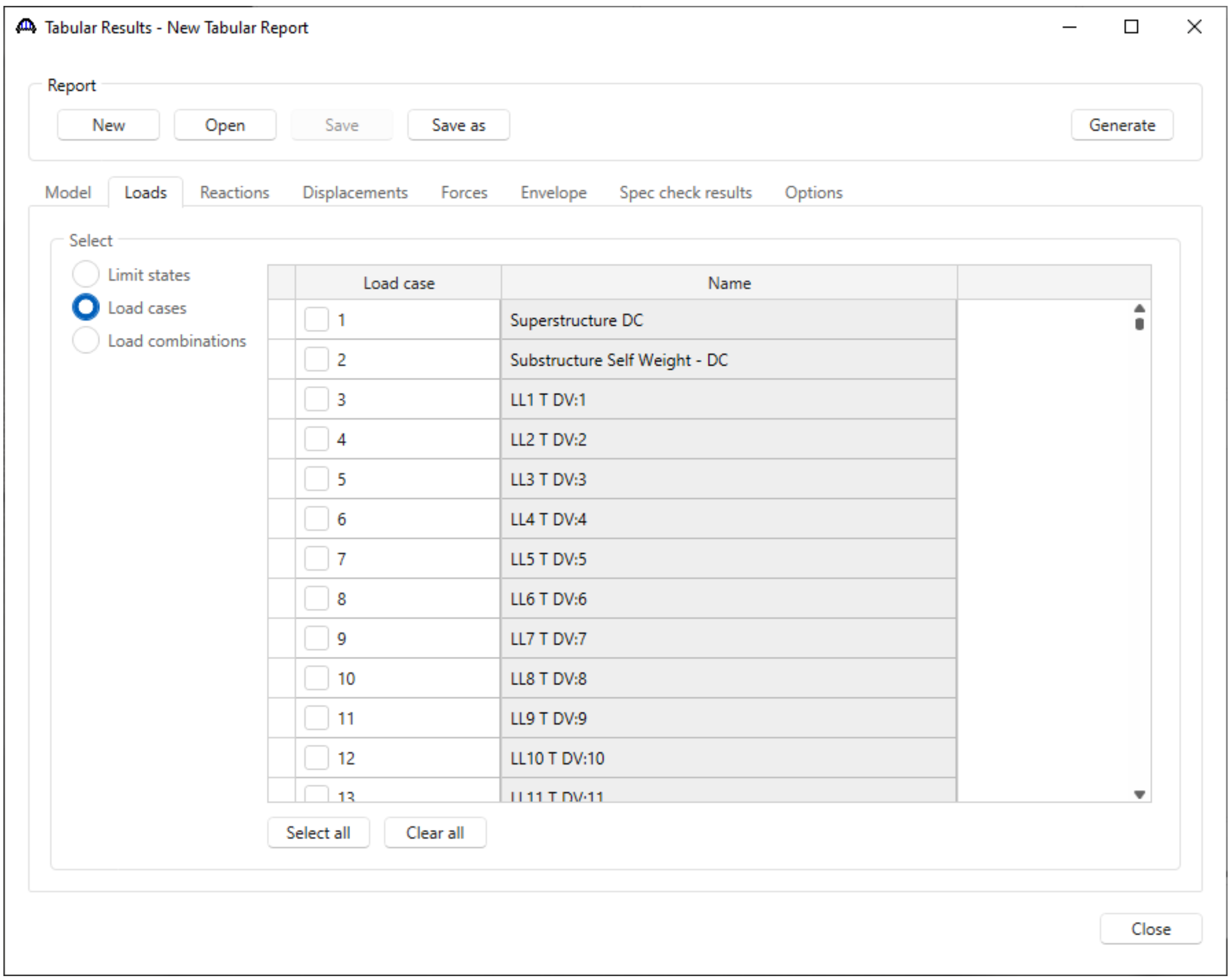
Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8

Tabular Results

The load case descriptions can be found in the **Tabular Results** window for the Pier Alternative.

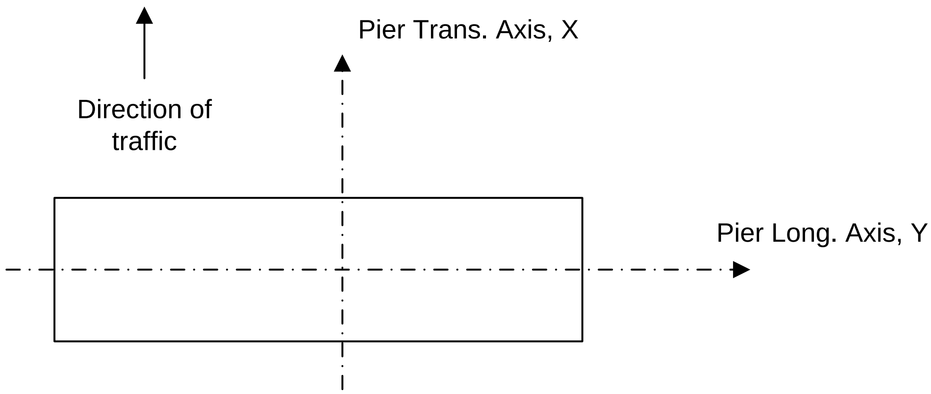


Navigate to the Loads tab. Click on the **New** button, and then click on the **Load Cases** button. By scrolling down the window, the many load cases can be reviewed.

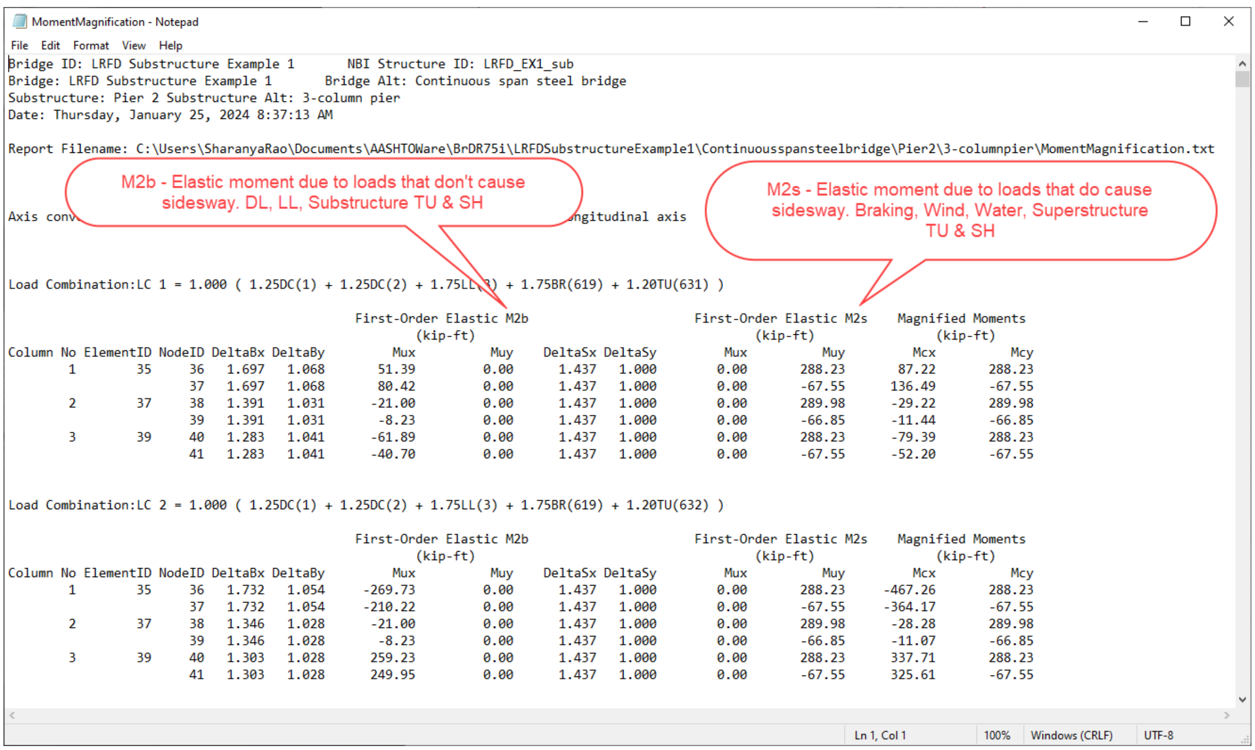


Pier4 – BrDR Substructure Moment Magnification

The following axis convention is used:



Plan View of Column



Bridge ID: LRFD Substructure Example 1   NBI Structure ID: LRFD_EX1_sub
Bridge: LRFD Substructure Example 1   Bridge Alt: Continuous span steel bridge
Substructure: Pier 2 Substructure Alt: 3-column pier
Date: Thursday, January 25, 2024 8:37:13 AM

Report Filename: C:\Users\SharanyaRao\Documents\AASHTOWare\BrDR75i\LRFDSubstructureExample1\Continuousspansteelbridge\Pier2\3-columnpier\MomentMagnification.txt

Axis conv ... ngitudinal axis

Load Combination:LC 1 = 1.000 (1.25DC(1) + 1.25DC(2) + 1.75LL(3) + 1.75BR(619) + 1.20TU(631))

					First-Order Elastic M2b (kip-ft)				First-Order Elastic M2s (kip-ft)		Magnified Moments (kip-ft)	
Column No	ElementID	NodeID	DeltaBx	DeltaBy	Mux	Muy	DeltaSx	DeltaSy	Mux	Muy	Mcx	Mcy
1	35	36	1.697	1.068	51.39	0.00	1.437	1.000	0.00	288.23	87.22	288.23
		37	1.697	1.068	80.42	0.00	1.437	1.000	0.00	-67.55	136.49	-67.55
2	37	38	1.391	1.031	-21.00	0.00	1.437	1.000	0.00	289.98	-29.22	289.98
		39	1.391	1.031	-8.23	0.00	1.437	1.000	0.00	-66.85	-11.44	-66.85
3	39	40	1.283	1.041	-61.89	0.00	1.437	1.000	0.00	288.23	-79.39	288.23
		41	1.283	1.041	-40.70	0.00	1.437	1.000	0.00	-67.55	-52.20	-67.55

Load Combination:LC 2 = 1.000 (1.25DC(1) + 1.25DC(2) + 1.75LL(3) + 1.75BR(619) + 1.20TU(632))

					First-Order Elastic M2b (kip-ft)				First-Order Elastic M2s (kip-ft)		Magnified Moments (kip-ft)	
Column No	ElementID	NodeID	DeltaBx	DeltaBy	Mux	Muy	DeltaSx	DeltaSy	Mux	Muy	Mcx	Mcy
1	35	36	1.732	1.054	-269.73	0.00	1.437	1.000	0.00	288.23	-467.26	288.23
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2	37	38	1.346	1.028	-21.00	0.00	1.437	1.000	0.00	289.98	-28.28	289.98
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3	39	40	1.303	1.028	259.23	0.00	1.437	1.000	0.00	288.23	337.71	288.23
		41	1.303	1.028	249.95	0.00	1.437	1.000	0.00	-67.55	325.61	-67.55

DeltaBx and **DeltaBy** are computed based on the braced/unbraced selections the user makes on the **Pier Alternative - Stiffness** tab.

The magnified moments, **Mcx** and **Mcy**, are then used in the specification checks.

The following is a detailed description of the moment magnification process excerpted from the BrDR Substructure Method of Solution manual:

First-Order Elastic Analysis using Moment-Magnification

Moment magnification takes into account the effects of deflection on force effects by using the approximate moment magnification adjustment method presented in AASHTO Article 4.5.3.2.2b. This method can be used for members with $K\ell_u/r$ less than 100.

$$M_c = \delta_b M_{2b} + \delta_s M_{2s} \qquad (4.5.3.2.2b\text{-}1)$$

M_{2b} is the moment on compression member due to factored gravity loads that result in no appreciable sidesway calculated by conventional first-order elastic analysis. BrD substructure will assume that the following loads contribute to the M_{2b} moment: DL of Superstructure, DL of Substructure, LL, Substructure Temperature, Substructure Shrinkage.

M_{2s} is the moment on compression member due to factored lateral or gravity loads that results in sidesway, Δ, greater than lu/1500, calculated by conventional first-order elastic frame analysis. BrD substructure will assume that the following loads contribute to the M_{2s} moment: Wind on Superstructure, Wind on Substructure, Water loads, Superstructure Temperature, Superstructure Shrinkage. The deflection produced by these loads will not be checked against the lu/1500 limit.

Moment magnification factors will be computed for both the longitudinal and transverse axes of the columns at each point of interest in the columns. Since the moment magnification factors are load dependent, they are computed for each load combination.

Article 4.5.3.2.2b gives equations to determine magnification factors, δ_b and δ_s. This article further states that δ_s shall be taken as 1.0 for members braced against sidesway.

The following equation is given for δ_b:

$$\delta_b = \frac{C_m}{1 - \frac{P_u}{\phi_K P_e}} \geq 1.0 \qquad (4.5.3.2.2b\text{-}3)$$

ϕ_K is the stiffness reduction factor equal to 0.75 for concrete.

Article 4.5.3.2.2b gives an equation for C_m for members braced against sidesway and without transverse loads between supports. For all other cases, C_m shall be taken as 1.0. Since the columns on a pier typically experience transverse loads, BrD Substructure will assume C_m is 1.0.

The following equation is given for δ_s:

$$\delta_s = \frac{1}{1 - \frac{\sum P_u}{\phi_K \sum P_e}} \qquad (4.5.3.2.2\mathrm{b} - 4)$$

P_e is the Euler buckling load for the column. It is taken as:

$$P_e = \frac{\pi^2 EI}{(K l_u)^2} \qquad (4.5.3.2.2b - 5)$$

For concrete compression members, Article 5.6.4.3 also applies. That article specifies that the EI to use in the Euler buckling load computation shall be the larger of:

$$EI = \frac{\frac{E_c I_g}{5} + E_S I_S}{1 + \beta_d} \qquad (5.6.4.3 - 1)$$

$$EI = \frac{\frac{E_c I_g}{2.5}}{1 + \beta_d} \qquad (5.6.4.3 - 2)$$

For columns that do not have a constant cross section over their length, a weighted average EI will be computed. BrD does not include the reinforcement in the computation of EI.

β_d is the ratio of maximum factored permanent load moments to maximum factored total load moment, always positive. This value will be computed at each point of interest by dividing the factored moment due to dead loads by the total factored moment at that point.

In this analysis, the order of load application does not affect the analysis results. Superposition can be used to determine the force effects due to the load combinations. The computation and application of the moment magnification factors occurs during the computation of the LRFD combinations within the substructure module.