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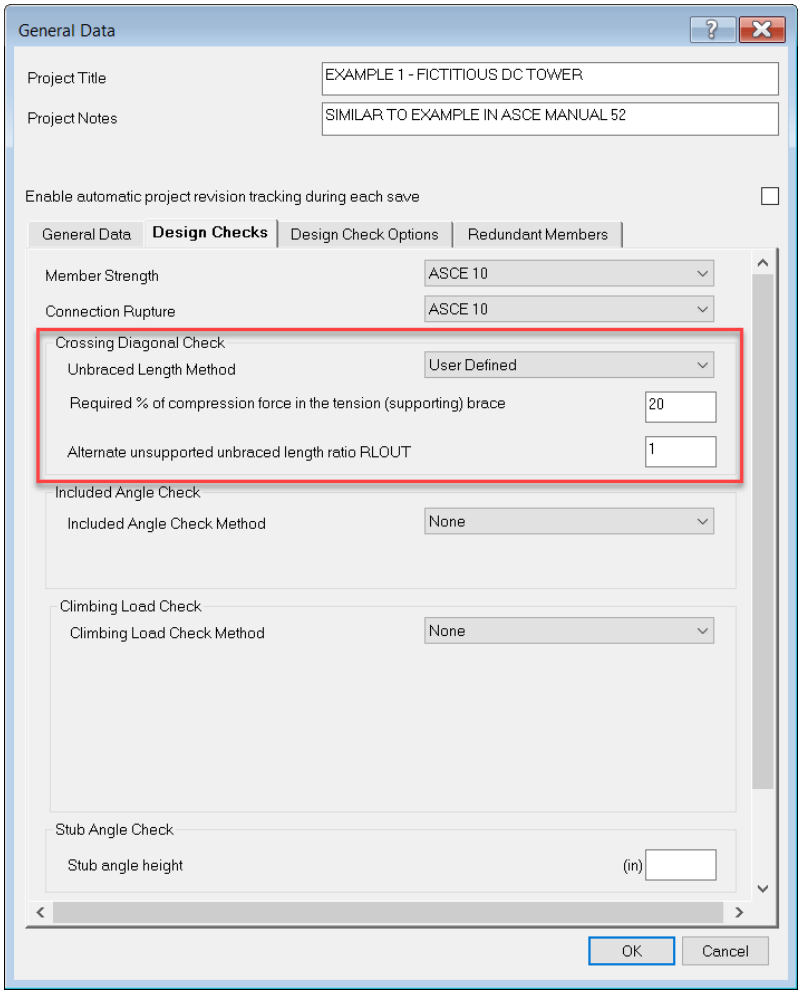
Crossing Diagonal Check in TOWER

Introduction

Crossing diagonals, also known as X-Braces, are one of the most common member configurations in lattice steel structures. For a traditional crossing diagonal pair, one member will have a tension force while the other member will have a compression force. It is generally recognized that the member in tension will provide some amount of support against out-of-plane buckling of the compression member. Most lattice tower design codes have specific criteria to determine the amount of out-of-plane buckling support and how the support varies based on the magnitude of the tensile and compressive forces in the members. TOWER can automate the process of determining how much support is provided to the compressed member of the crossing diagonal pair by the other member of the pair. This technote is intended to describe how to properly utilize the crossing diagonal check in TOWER.

Selecting the Design Code for the Crossing Diagonal Check

The first step to utilize the crossing diagonal check in TOWER is to select the design code to use in the *Design Checks* tab of the ***General/ General Data*** dialog box.



You can choose from the following options:

Fixed	Unbraced lengths will not be modified by TOWER (this is the default for all TOWER models prior to version 7.32)
User Defined	The user is responsible for determining the required percentage of compression force and the alternate unsupported RLOUT
ASCE 10	The ability of the support to resist out-of-plane buckling will be evaluated as per the guidelines in ASCE 10-15, example 7.
ANSI/TIA 222-G	The ability of the support to resist out-of-plane buckling will be evaluated as Section 4.5.2.1a of 222-G.
EN50341-1:2001	The ability of the support to resist out-of-plane buckling will be evaluated as per Annex J.6.3.3 of EN50341-1:2001 (CENELEC)
ECCS	The ability of the support to resist out-of-plane buckling will be evaluated as per Section 7.3 of ECCS 39:1985.
AS 3995	The ability of the support to resist out-of-plane buckling will be evaluated as per Appendix H3 (simple cross bracing only) of AS 3995-1994.
CS S37-01	The ability of the support to resist out-of-plane buckling will be evaluated as per Section 6.2.3.3.1 of CSA S37-01.
EN50341-1:2012	The ability of the support to resist out-of-plane buckling will be evaluated as per Annex J.4.3.3 of EN50341-1:2012 (CENELEC) and Section H.3.3 of EN1993-1:2006.
EN50341-2-4:2016	The ability of the support to resist out-of-plane buckling will be evaluated as per Section J.4.3.3.3 DE.3 of EN50341-2-4:2016

The User Defined option requires an input value for the *Required % of compression force in the tension (supporting) brace*. This is a limiting ratio (%Ratio$_{LIM}$) for the ratio (%Ratio) of the absolute value of the tension force in the supporting diagonal (if any) divided by the force in the compressed diagonal being checked. For the ASCE 10 and TIA/EIA 222-G options this value is prescribed to be 20% and for the AS3995 option it is 60%. More complex provisions are used with the other options.

Some of these codes also require an input value for the *Alternate Unsupported Unbraced Length Ratio (RLOUT)*. The value may be used instead of the original unbraced length ratio RLX or RLY which is entered in the ***Geometry/ Angle Members*** table for the most compressed member being checked. Codes which do not have an option to enter RLOUT will have it automatically calculated based on the code requirements.

Selecting the Angle Groups for the Crossing Diagonal Check

The second step to utilize the crossing diagonal check in TOWER is to select which angle groups the check will be applied to. This is done by selecting the *Crossing Diagonal* group type in the Angle Groups Table (***Geometry/ Groups/ Table Edit***).

	Group Label	Group Description	Angle Type	Angle Size	Material Type	Element Type	Group Type	Optimize Group	Allow. Add. Angle Width For Optimize (in)
23	25	WB1-2	SAU	2.5X2X0.1875	A 36	Truss	Crossing Diagonal	Size + Type	12.000
24	26	WB3	SAU	2.5X2X0.1875	A 36	Truss	Crossing Diagonal	Size + Type	12.000
25	27	WB4	SAE	3X3X0.25	A 36	Truss	Crossing Diagonal	Size + Type	12.000
26	28	WB5	SAU	3X2.5X0.1875	A 36	Truss	Crossing Diagonal	Size + Type	12.000
27	29	WB6	SAU	3X2.5X0.1875	A 36	Truss	Crossing Diagonal	Size + Type	12.000
28	30	WB7	SAE	3X3X0.1875	A 36	Truss		Size + Type	12.000
29							Leg		NA
30							Other		NA
31							Redundant		NA
32							Fictitious		NA
33							Crossing Diagonal		NA
34							Redundant-AI		NA
							Corner Diagonal		

The Crossing Diagonal group type can only be used with element types of Truss or Beam and cannot be selected for element types T-Only or T-Only Beam. The compression capacity reduction from the crossing diagonal unbraced length check is not compatible with tension only analysis.

Application of RLX, RLY, RLZ and RLOUT

The compression capacity of any member in TOWER is based on the controlling RLX, RLY or RLZ value entered in the Angle Member Connectivity table (***Geometry/ Members/ Table Edit***). The RLX, RLY and RLZ values for crossing diagonals should be entered assuming maximum support is provided to the compressed diagonal from the other diagonal according to the selected code. When TOWER determines maximum support is not provided per the selected code provisions, it will automatically replace the entered RLX or RLY with the alternate unsupported value RLOUT. Tower will determine whether RLX or RLY is replaced based on the Connect Leg (Long only or Short only) selection in the Angle Member Connectivity table.

Angle Type	Connect Leg	RLOUT Replaces
Single Angle	Long only	RLY
	Short only	RLX
Double Angle LBB	Long only	RLY
	Short only	RLX
Double Angle SBB	Long only	RLX
	Short only	RLY

The entered value for RLZ will not be changed by TOWER.

The compression capacity, C_{Cap}, is defined in Eq. 3-3 of the TOWER manual and is based on the following assumptions:

Fixed

C_{Cap} based on RLX, RLY and RLZ

User Defined

C_{Cap} based on RLX, RLY and RLZ if %Ratio ≥ $\%Ratio_{LIM}$

C_{Cap} based on RLOUT, RLX or RLY (whichever was not replaced by RLOUT) and RLZ if %Ratio ≤ $\%Ratio_{LIM}$

ASCE 10 or TIA/EIA 222-G-1

C_{Cap} based on RLX, RLY and RLZ if %Ratio ≥ 20%

C_{Cap} based on RLOUT, RLX or RLY (whichever was not replaced by RLOUT) and RLZ if %Ratio ≤ 20%

CSA S37-01

The user input value, RLOUT, has no effect on Ccap (RLOUT is calculated as needed).

C_{Cap} based on RLX, RLY and RLZ if %Ratio > 100%

C_{Cap} based on code specified formula when %Ratio ≥ 0% and < 100%

When supporting member is in compression (both members in compression, %Ratio < 0) then ADL = DL1 + DL2 (i.e. RLX = 1)

EN50341-1:2001

C_{Cap} based on RLY, RLZ and code specified formula for unbraced length ratio.

RLX and RLOUT have no effect on Ccap

RLZ must be input to equate to L1 inFigs J.4 and J.5 to satisfy J.6.3.3 part 2 (case where tension and $|S_d|/|N_d|>2/3$)

ECCS

C_{Cap} based on RLX, RLY and RLZ if %Ratio ≥ 50%

C_{Cap} based on RLX = 1 is modified by the factor $2(F_C/(F_C+F_T))$, where FC is the compressive force in the compression member (counted positive) and FT is the force in the other member (positive if compression and negative if tension).

This implements the intent of ECCS 7.3 "The sum of the load carrying capacities of both bars in compression must be at least equal to the algebraic sum of the loads in the two bars" by rewriting it in a manner compatible with the way TOWER handles capacities.

AS3995

C_{Cap} based on RLX, RLY and RLZ if %Ratio ≥ 60%

C_{Cap} based on RLOUT = 1, RLX or RLY (whichever is not replaced by RLOUT) and RLZ if %Ratio ≤ 60%

EN50341-1:2012

Same as ECCS except triggered at %Ratio < 66.67%

EN50341-2-4:2016

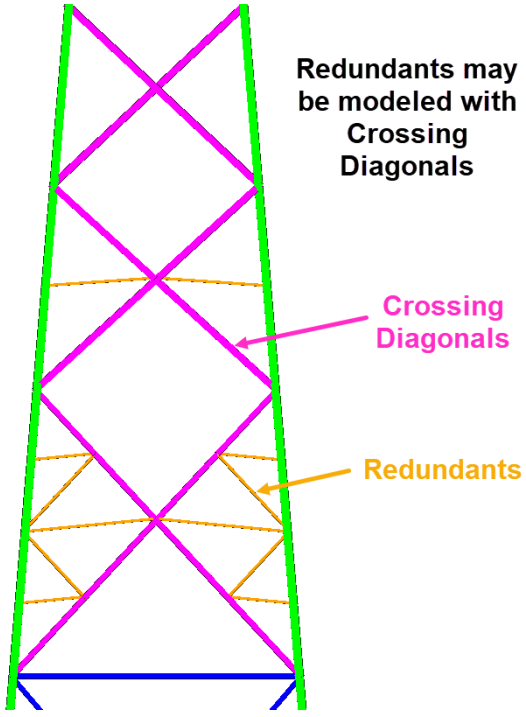
Same as EN50341-1:2001.

For all methods, the calculated compression capacity shown in ***Geometry/ Member Capacities and Overrides*** is based on the entered values of RLX, RLY and RLZ and do not reflect any code-based crossing diagonal adjustments.

Running the Crossing Diagonal Check

Once you have selected a code for the crossing diagonal check in ***General/ General Data*** and specified which angle groups are Crossing Diagonals in the ***Geometry/ Groups*** table, TOWER will do the following during each analysis.

1) Automatically find crossing diagonal pairs. To be considered a pair, both members must be a Crossing Diagonal group type and must intersect. In versions prior to 16.50, the diagonals must be continuous (no joints between the origin and end) to be considered as a pair. In versions 16.50 and later, TOWER will identify crossing diagonal pairs even if the intersection joint or other joints along the diagonals are modeled; provided the diagonal members are collinear (they lie in a perfectly straight line). This allows the crossing diagonal check to work when redundant members are connected to the crossing diagonals.



2) For diagonals with intermediate joints between the origin and end, coalesce the diagonal segments into a single diagonal.
3) For each load case determine the compression capacity C_{Cap} as described above.
4) Whenever the crossing diagonal check is triggered, change the member end conditions based on the Member Strength code (not the Crossing Diagonal Check code) in effect for all codes except CENELEC-Conservative, RTE-RESAL, PN-90/B-03200, BS 8100, and SP 16.13330.2001 (SNiP) which do not use conventional member end condition concepts. For all other codes, if the eccentricity code is 2 then promote to it to 3. For all ASCE 10 compatible codes (ASCE 10, AS 3995, CSA S37, IS 802, RTE-ASCE, TIA/EIA 222-F, ANSI/TIA 222-G-1) if the restraint code is 5 then promote it to 6. For all ECCS compatible codes (ECCS, CENELEC, RTE-ECCS, NGT-ECCS) if the restraint code is 5 promote it to 7 and if the restraint code is 6 promote it to 8.
5) For every load case with at least one diagonal pair where RLOUT controls the compression capacity instead of the input RLX, RLY and RLZ, create a Crossing Diagonal Check for Load Case "Load Case" (RLOUT Controls) in the *Analysis Results* report as shown below. If RLOUT does not control any diagonal pairs, the report will not be generated for that load case.

Crossing Diagonal Check for Load Case "WIND FACE" (RLOUT controls):

Comp. Member Label	Tens. Member Label	Connect Leg for Comp. Member	Force In Comp. Member (kips)	Force In Tens. Member (kips)	Original Supported L/R Cap. (kips)	RLX	RLY	RLZ	L/R	KL/R	Curve No.	Alternate Unsupported L/R Cap. (kips)	RLOUT	L/R	KL/R	Curve No.
D8P	D8Y	Short only	-5.59	-5.59	22.08	0.550	0.780	0.550	107.86	110.89	2	21.09	1.000	109.56	114.78	3
D8Y	D8P	Short only	-5.59	-5.59	22.08	0.550	0.780	0.550	107.86	110.89	2	21.09	1.000	109.56	114.78	3
D10P	D10Y	Short only	-3.41	-3.41	38.82	0.750	0.500	0.500	79.16	89.37	2	31.98	1.000	100.78	110.39	3
D10Y	D10P	Short only	-3.41	-3.41	38.82	0.750	0.500	0.500	79.16	89.37	2	31.98	1.000	100.78	110.39	3
D12P	D12Y	Short only	-0.88	-0.88	17.59	0.750	0.500	0.500	109.75	112.31	2	16.15	1.000	118.19	119.09	3
D12X	D12XY	Short only	-0.12	-0.12	17.59	0.750	0.500	0.500	109.75	112.31	2	16.15	1.000	118.19	119.09	3
D12XY	D12X	Short only	-0.12	-0.12	17.59	0.750	0.500	0.500	109.75	112.31	2	16.15	1.000	118.19	119.09	3
D12Y	D12P	Short only	-0.88	-0.88	17.59	0.750	0.500	0.500	109.75	112.31	2	16.15	1.000	118.19	119.09	3

6) Whenever the highest usage for an angle group is from a member where RLOUT controls the compression capacity instead of the input RLX, RLY and RLZ, use the term 'Cross' for the Usage Control in the *Group Summary (Compression Portion)* report as shown below.

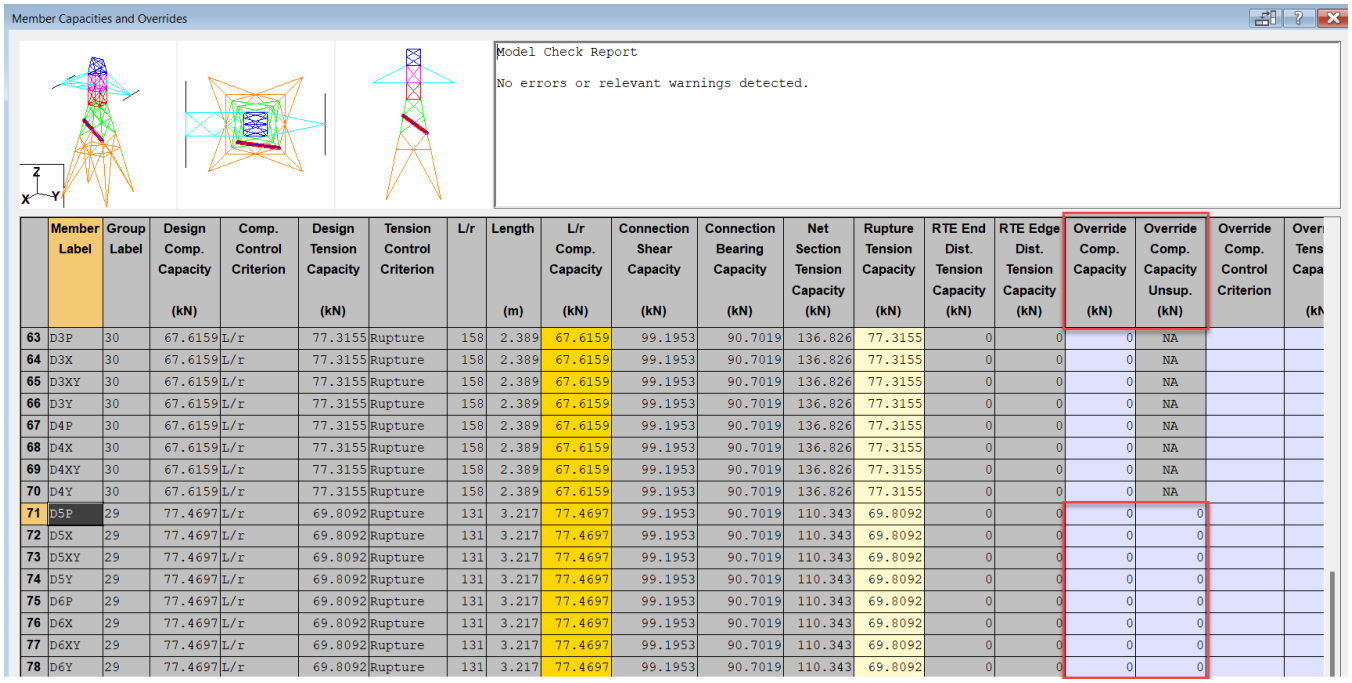
Group Summary (Compression Portion):

Group Label	Group Desc.	Angle Type	Angle Size	Steel Strength (ksi)	Max Usage %	Usage Control	Max Use In Comp. %	Comp. Control Member	Comp. Force (kips)	Comp. Control Load Case	L/r Capacity (kips)	Comp. Connect. Shear Capacity (kips)	Comp. Connect. Bearing Capacity (kips)	RLX	RLY	RLZ	L/r	KL/r	Length Comp. Member (ft)	Curve No.	No. Of Bolts Comp.
24	LBRA	SAE	3X3X0.1875	36.0	20.98	Comp	20.98	D1P	-3.609	WIND FAC	17.202	33.450	30.586	0.333	0.333	0.333	139.20	134.67	20.762	5	3
25	WB1-2	SAU	2.5X2X0.1875	36.0	10.46	Tens	9.30	D14P	-0.949	WIND FAC	21.256	11.150	10.195	0.750	0.500	0.500	83.80	92.85	5.963	2	1
26	WB3	SAU	2.5X2X0.1875	36.0	7.45	Comp	7.45	D11P	-1.311	WIND FAC	17.594	22.300	20.391	0.750	0.500	0.500	109.75	112.31	7.810	2	2
27	WB4	SAE	3X3X0.25	36.0	22.14	Comp	22.14	D9P	-8.595	WIND FAC	38.821	66.900	81.562	0.750	0.500	0.500	79.16	89.37	7.810	2	6
28	WB5	SAU	3X2.5X0.1875	36.0	26.53	Cross	26.53	D8Y	-5.594	WIND FAC	21.086	44.600	40.781	1.000	0.780	0.550	109.56	114.78	8.710	3	4
29	WB6	SAU	3X2.5X0.1875	36.0	22.98	Tens	17.11	D6X	-2.981	WIND FAC	17.416	22.300	20.391	0.550	0.780	0.550	130.70	128.20	10.555	5	2
30	WB7	SAE	3X3X0.1875	36.0	23.44	Comp	23.44	D4P	-3.563	WIND FAC	15.201	22.300	20.391	1.000	1.000	1.000	157.82	143.26	7.839	6	2

Note that the "Alternate Unsupported L/r Cap" (C_{Cap} from above) is used when checking the compression member. If that load case and member happen to control the group usage, the values from the "Alternate Unsupported" columns will be shown in the Groups Summary table. Please note that it is normal that these values do not match those printed in ***Geometry/ Member Capacities and Overrides*** which assume that the compression member is always supported and the C_{Cap} is based on RLX, RLY and RLZ. In the event that you find a lower than expected capacity for a compression member in the *Groups Summary* table, you should check the *Crossing Diagonal Check for Load Case* section in the Analysis Results report to confirm that the *Crossing Diagonal Check* is responsible for the reduced capacity.

Miscellaneous Notes

1) The Crossing Diagonal Check will use the overridden compression capacities if entered in the ***Geometry/ Members/ Capacities and Overrides*** table so long as both the supported and unsupported compression capacities are input. Note that the unsupported compression override capacity is only applicable for Crossing Diagonal members.



	Member Label	Group Label	Design Comp. Capacity (kN)	Comp. Control Criterion	Design Tension Capacity (kN)	Tension Control Criterion	L/r	Length (m)	L/r Comp. Capacity (kN)	Connection Shear Capacity (kN)	Connection Bearing Capacity (kN)	Net Section Tension Capacity (kN)	Rupture Tension Capacity (kN)	RTE End Dist. Tension Capacity (kN)	RTE Edge Dist. Tension Capacity (kN)	Override Comp. Capacity (kN)	Override Comp. Capacity Unsup. (kN)	Override Comp. Control Criterion	Over Tens Capa (kN
63	D3P	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
64	D3X	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
65	D3XY	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
66	D3Y	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
67	D4P	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
68	D4X	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
69	D4XY	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
70	D4Y	30	67.6159	L/r	77.3155	Rupture	158	2.389	67.6159	99.1953	90.7019	136.826	77.3155	0	0	0	NA		
71	D5P	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
72	D5X	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
73	D5XY	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
74	D5Y	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
75	D6P	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
76	D6X	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
77	D6XY	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		
78	D6Y	29	77.4697	L/r	69.8092	Rupture	131	3.217	77.4697	99.1953	90.7019	110.343	69.8092	0	0	0	0		

2) The Crossing Diagonal Check settings you input into ***General/ General Data*** can be applied to many other models using the ***File/ Batch Modify*** command.

3) The *Crossing Diagonal Unbraced Length Method* is considered when optimizing a tower.

4) When using the Crossing Diagonal Check, be aware that it is possible that the member with the highest usage may not necessarily be the member with the largest force. Since the Groups Summary and Groups Summary Super Set tables report on the member that controls the group (highest usage), the force which is reported is that which causes the highest usage. If this is a concern, you can make two runs: one with the Crossing Diagonal Check turned on (which will show you the highest usage) and one with it turned off (set to Fixed – which will show you the largest force in the Group).