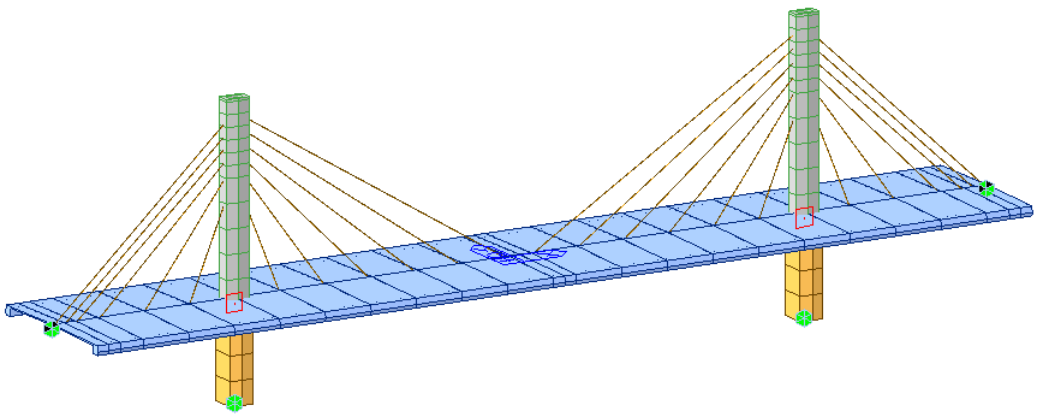
Calculation of initial pretension for a cable-stayed bridge using ‘Cable Force Tuning’ function in midas Civil



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00. Contents

01. Overview

A cable-stayed bridge is a structural system that effectively combines cables, girders and the pylon into an esthetically pleasing structure. It is a versatile bridge type since different pylon forms and cable layout forms can be adopted depending on the surrounding environment.

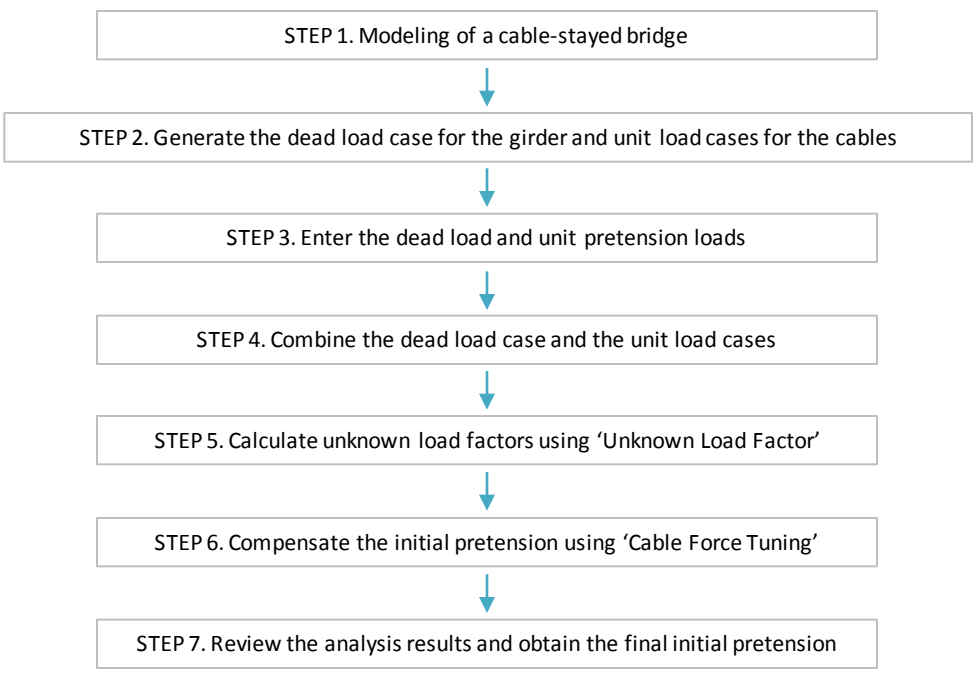
By inducing initial pretension to the cables, it can reduce the moments acting on the girders and make a light long span bridge possible. The calculation of the initial pretension of the cables can be difficult and complicated, and in the past the initial pretension was determined by the designer's discretion, experimental values, etc.

The 'Unknown Load Factor' function in midas Civil calculates the initial pretension that needs to be applied to the cables for a cable-stayed bridge. However, with the 'Unknown Load Factor' the designer cannot get the desired initial pretension in one go. The designer should do many iterations by fine-tuning the pretension using the influence matrix in order to get the initial pretension that produces the desired bending moments and deformations.

'Cable Force Tuning' in midas Civil is a function that makes the iteration process required for the design of the bridge easy.

'Cable Force Tuning' allows the user to adjust the cable force and to check the displacements of the girders or the pylon in real time, without reanalyzing.

This tutorial explains how to calculate the initial pretension for a three span cable-stayed bridge using the 'Unknown Load Factor' and 'Cable Force Tuning' functions.



| Flow Chart for calculating initial cable forces |

02. Example Model

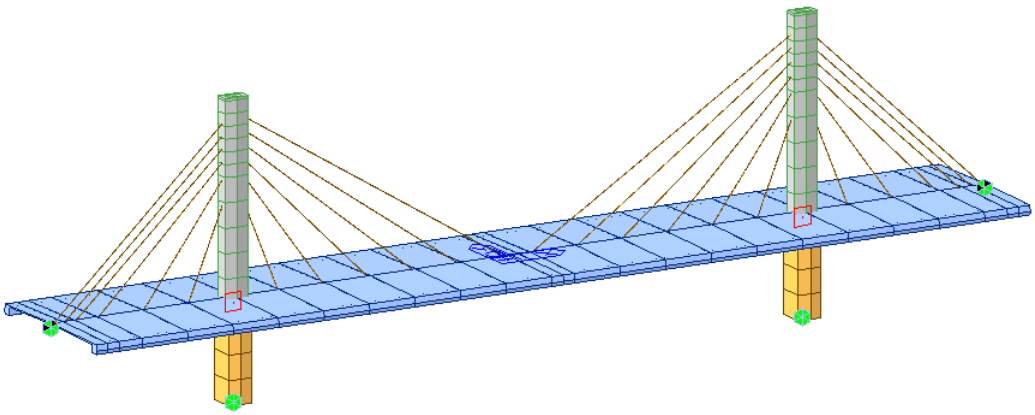
1. Open the example model

From the Main Menu > *Open Project*

1. Select 'Cable Force Tuning_Before.mcb' and click 'Open'.

2. Overview of the example model

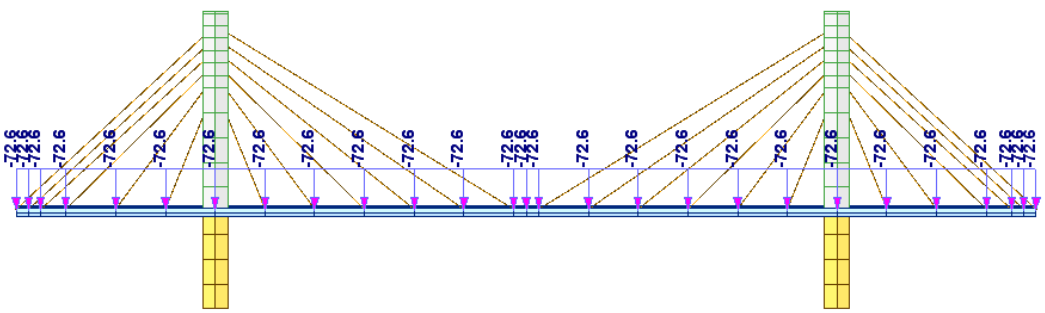
1. Type: 3 span concrete cable-stayed bridge
2. Span: 40m + 125m + 40m = 205m
3. Pylon: 20m (lower) + 40m (upper) = 60m
4. Elements: Girders and Pylons (Beam Element) , Cables (Truss Elements)
5. The cables are symmetrical about the centre of the main span. Both abutments are free to displace in the x-direction and rotate about the y-axis. The pylons are fully fixed at the base.
6. Bearing for the deck-pylon connection: Elastic Link-General Type



| example model – 3 span concrete cable stayed bridge |

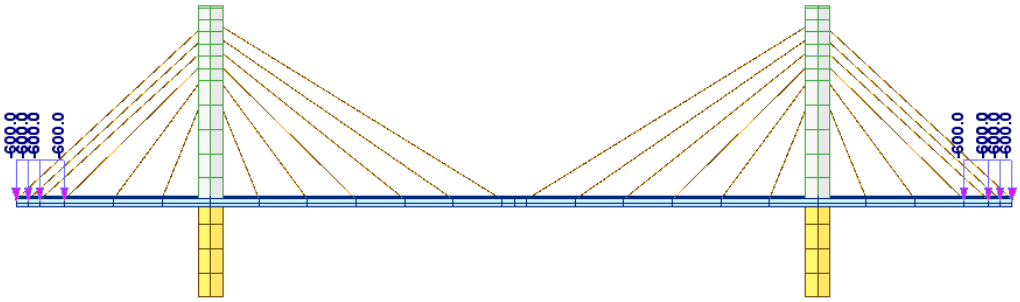
3. Loads

1. Dead load: Automatically calculated Self Weight
2. Secondary dead load: 72.57 kN/m uniform load in the Global (-Z) direction



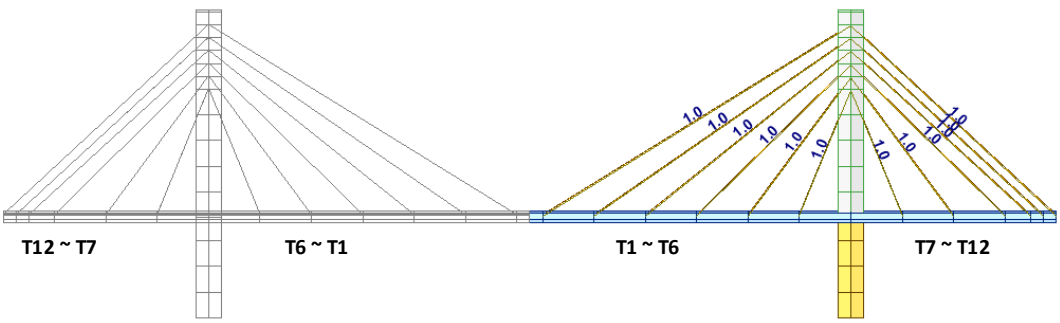
| secondary dead load |

3. Counter Weight : apply a 600 kN/m uniform load in the Global (-Z) direction as shown below



| Counter Weight Load |

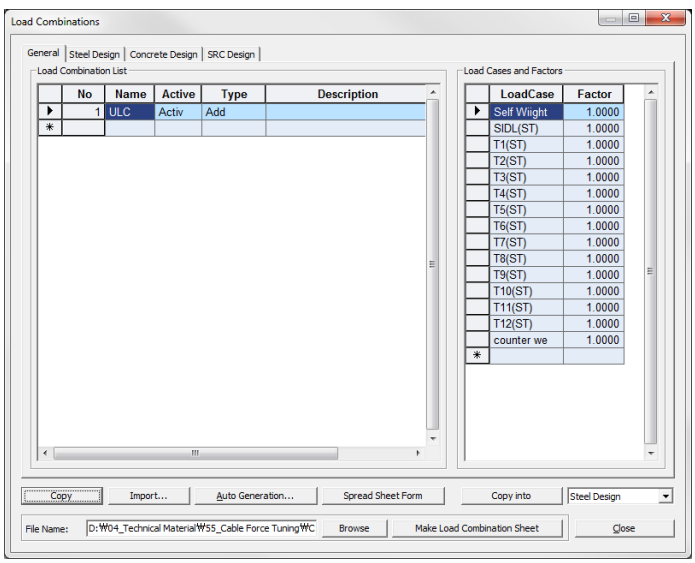
4. Cable Pretension Load : apply Unit Pretension Load to all cables



| Cable Pretension Load |

4. Unit Load Combination

Make a load combination of the twelve unit pretension load cases , the two dead load cases and the Counter Weight load case as shown below.



| Generate a Unit Load Combination |

03. Unknown Load Factor

For the unit load combination created in the previous page, calculate the unknown load factors using 'Unknown Load Factor'.

Set the constraint conditions for ULF load combination by limiting the moment (My) in the deck on the right hand side from 5000 kN·m to -5000 kN·m. In order to use 'Unknown Load Factor' the analysis should be performed.

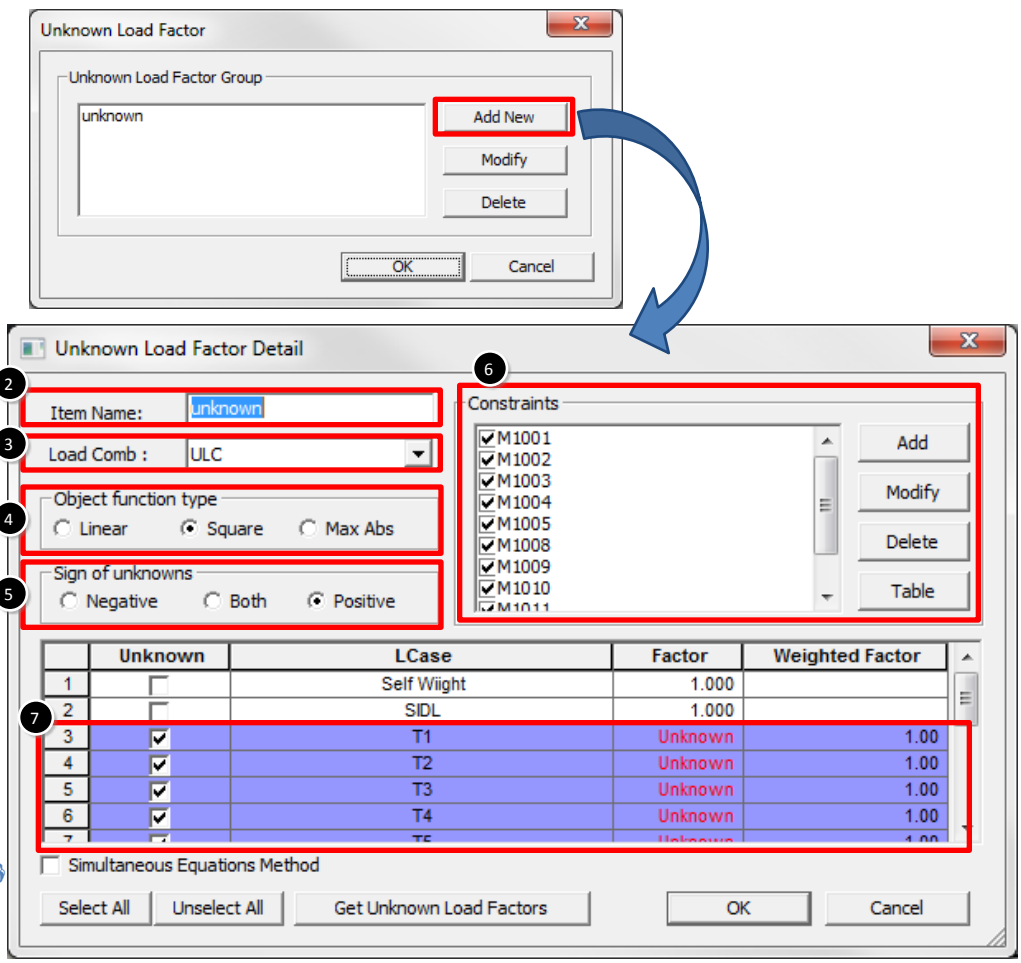
1. Set Unknown Load Factor Details

Main Menu>*Results> Cable Control >Unknown Load Factor*

1. Click Add New
2. Item Name : **unknown**
3. Load Comb. : **ULC**
4. Objective function type : **Square**
5. Sign of unknowns : **Positive**
6. Two ways of entering Constraints ('Add' or 'Table') are explained on the next page
7. Check the cable pretension Load Cases (**T1 ~ T12**) as Unknowns.

Sign of unknowns : Define the sign for the unknown load factors.

- Negative : Limit the range of the factors to negative (-).
- Both : Do not limit the sign of the factors.
- Positive : Limit the range of the factors to positive (+).



| Unknown Load Factor Detail dialog box |

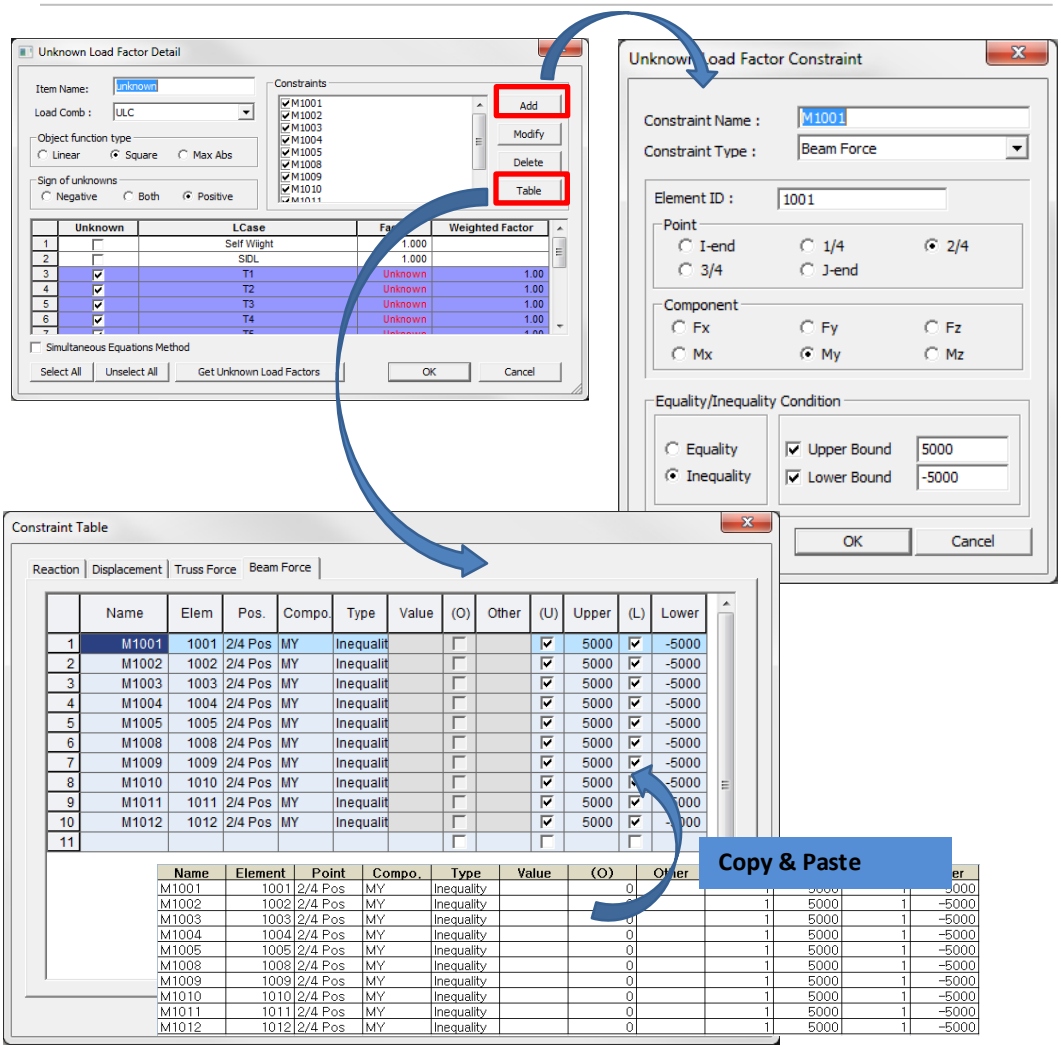
Simultaneous Equations Method :

When the selected constraints are all Equality Type, and the number of unknown loads is the same as that of constraints, this option can be checked. Then the program uses simultaneous equations method rather than optimization technique to find the unknown load factors.

03. Unknown Load Factor

2. Set Constraints

1. Click Add
2. Constraint Name **: M1001**
3. Constraint Type : **Beam Force**
4. Element ID : **1001**
5. Point : **2/4**
6. Component : **My**
7. Equality/Inequality Condition : **Inequality**
8. Upper Bound : **5000** , Lower Bound : **-5000**
9. Click 'OK'
10. Enter the same value for **M1002 , M1003 , M1004 , M1005, M1008 , M1009 , M1010 , M1011 , M1012** by changing the Name and Element ID
11. For easier input of constraints, Copy&Paste using Excel is possible (refer to Unknown Load Factor Detail.xls)

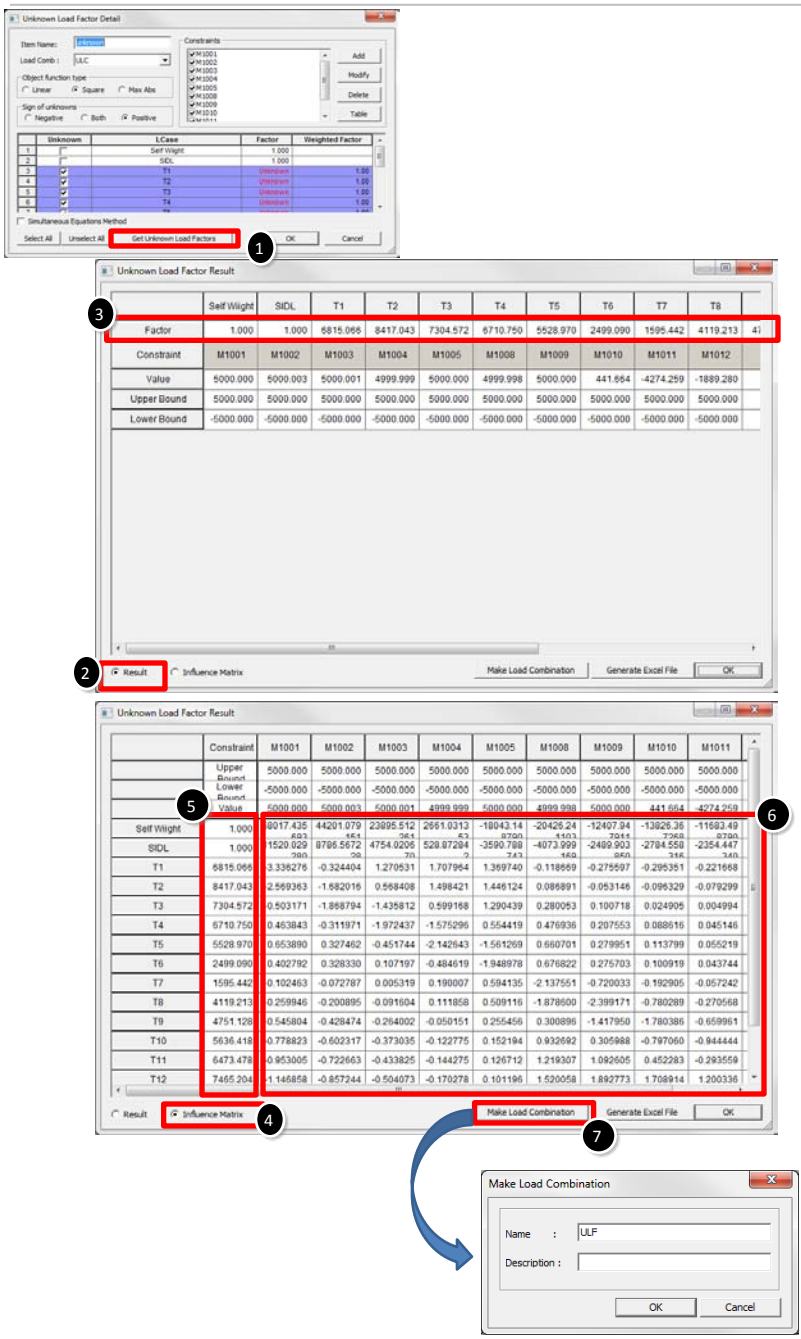


| Set Constraints |

03. Unknown Load Factor

3. Get Unknown Load Factors

1. Click Get Unknown Load Factors
2. Select '**Result**'
3. Check the unknown load factors to be applied to the cables
4. Select '**Influence Matrix**'
5. Check the unknown load factors in the Influence Matrix
6. Check the influence matrix
7. Generate a Load Combination (Name: **ULF**) where the unknown load factors are applied to the unit pretension load cases.



| Check the Unknown Load Factor Result and generate a Load Combination |

04. Cable Force Tuning

The user may not find the desired unknown load factors from 'Unknown Load Factor' when there are many constraints or the structural system is complicated.

Using the 'Cable Force Tuning' function, the user can find the desired pretension.

In this section the 'Cable Force Tuning' function and how to calculate the initial pretension for a cable-stayed bridge are explained.

1. Function Overview

Overview of 'Cable Force Tuning':

1. Adjust the cable force (or load factor) using the table input or bar graph.
2. Select the desired result item to check along with the change in cable force.
3. The result item selected in 2. is displayed as Line Type or Bar Type. The influence of the adjusted cable force (or load factor) is reflected in real time.
4. The current load combination is updated with the adjusted load factors ('Save Load Combination') or the cable pretension loads are updated with the adjusted cable forces (Update to Present Model').

| Cable Force Tuning dialog box |

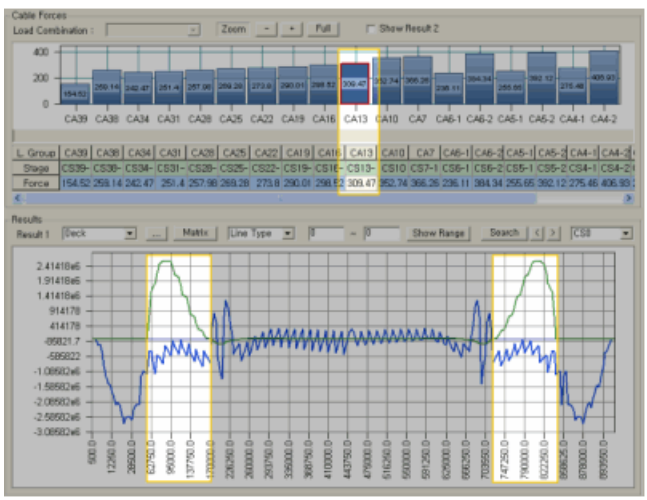
2. 'Cable Force Tuning' function

1. Adjust the cable force by the Influence Matrix Factor

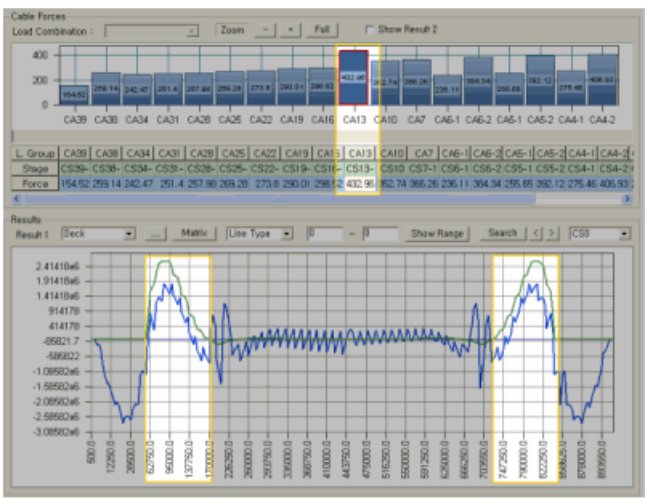
Select Cable 13, as in the figure below, and the **Relative Influence Value Line (green)** that is unique for Cable 13 is drawn. With the help of the Relative Influence Value Line, adjust the result.

When Relative Influence Value Line: (+) -> T (cable force) increases -> Result increases
When Relative Influence Value Line: (-) -> T (cable force) increases -> Result decreases

Check if the Relative Influence Value Line (green) is positive (+) or negative (-). As shown in the figure below, if the Relative Influence Value Line is positive, increasing T (cable force) will increase (+) the result. On the contrary, if the Relative Influence Value Line is negative (-), increasing T (cable force) will decrease (-) the result. This method is useful when the result is fine-tuned through a single cable force.



| Influence Matrix Factor Line when Cable 13 is selected |



| The result when the cable force of Cable 13 was increased |

Check whether the Relative Influence Value Line is positive or negative
: positive (+)

↓

Change T (cable force)
: Considering (+,-) of the Relative Influence Value Line, change the cable force so that the result will change to the desired direction

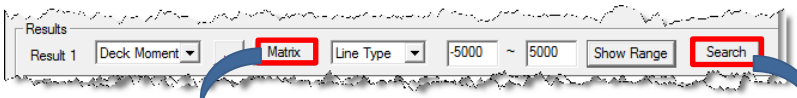
↓

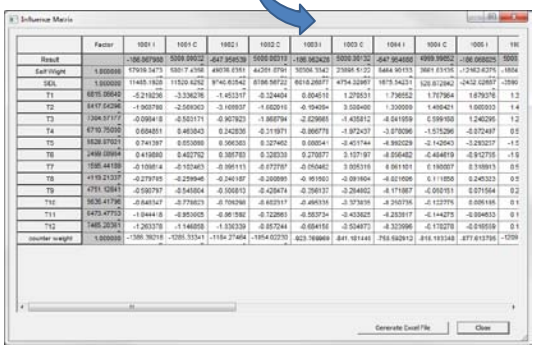
Check the Result graph
: Increasing the cable force increases the result since the Relative Influence Value Line is positive (+).

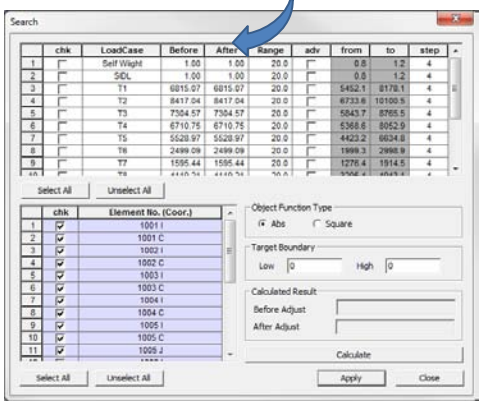
In this page, a different model is used for the explanation.

04. Cable Force Tuning

2) Find the optimal pretension using 'Search' option







STEP 1. Matrix & Search
Confirm the pretension from the Influence Matrix that affects the elements at the greatest degree and then use 'Search'

↓

STEP 2. Load Case
Pretension Load Case

↓

STEP 3. Range
Set the range for the pretension factor.
The initial range is -20~20%

↓

STEP 4. Element No.
Select the elements whose pretensions will be adjusted within the target range

↓

STEP 5. Object Function Type
Select the type of object function

↓

STEP 6. Boundary
Set the upper and lower limits within which the solution for the object function will be found

↓

STEP 7. Calculate & Apply
The pretension that satisfies the given conditions is found and applied

↓

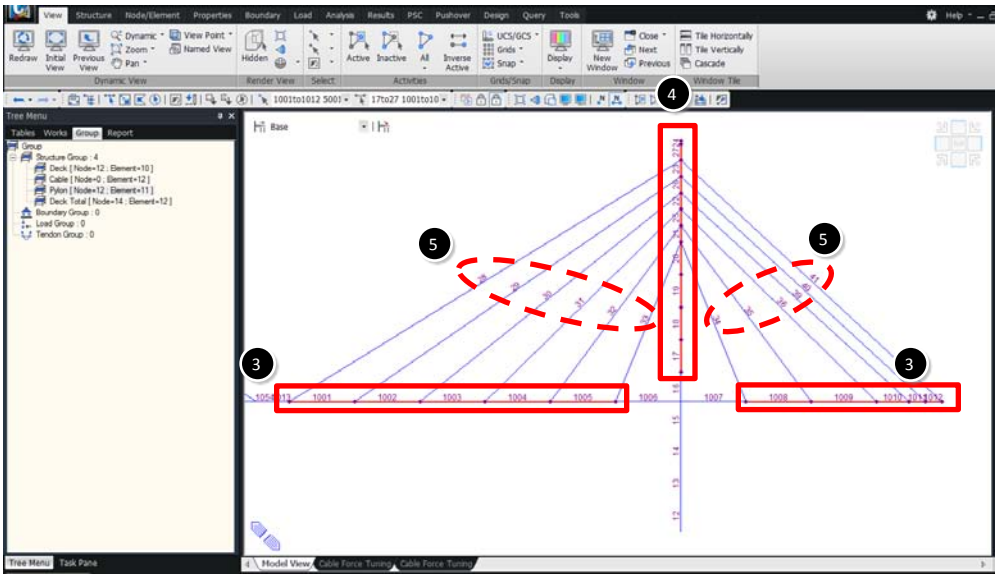
STEP 8. Close

🎧 Iteration is necessary to find the solution for the object function by using 'Search'.

When the result for 'Before Adjust' becomes the same as 'After Adjust', the result has converged and the pretension does not change any more.

3. Define Groups

1. Select **Group Tree**
2. **Structure Group Add** (Deck , Cable , Pylon)
3. Deck (Element : **1001to1005** , **1008to1012** , Node : **1001to1012**) assign by **Drag&Drop**
4. Pylon (Element : **17to27** , Node : **5001to5012**) assign by **Drag&Drop**
5. Cable (Element : **28to41**) assign by **Drag&Drop**



| Define Groups |

4. Define Result Items

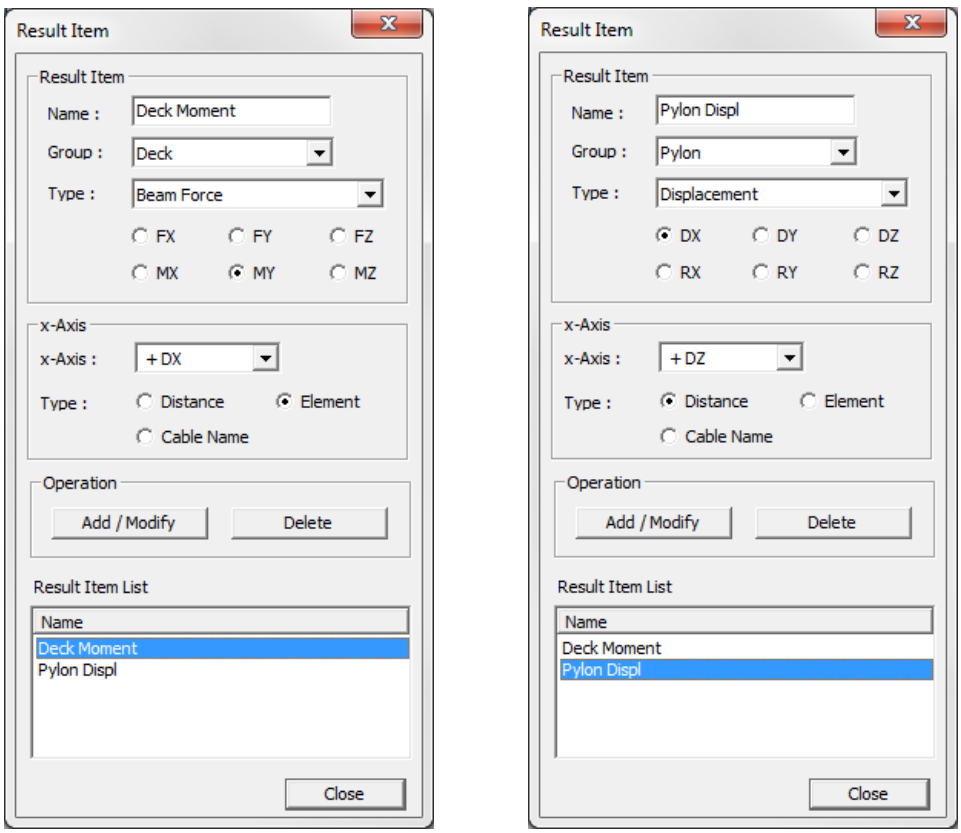
From 'Result Item' define the result items to be checked through cable force tuning.
Beam Force , Truss Force , Displacement or Beam Stress can be checked.

Main Menu>*Results> Cable Control> Cable Force Tuning*

1. Load Combination : **ULF**
2. Click [...] of Results
3. Name : **Deck Moment**
4. Group : **Deck**
5. Type : **Beam Force (MY)**
6. X-Axis **: + DX** , Type **: Element**
7. Click [Add / Modify]
8. Name : **Pylon Displacement**
9. Group : **Pylon**
10. Type : **Displacement (DX)**
11. X-Axis : **+ DZ** , Type : **Distance**
12. Click [Add / Modify]
13. Click [Close]

Type : the Type of x-Axis for the Results

- **Distance** : the values on the x-Axis are represented using the absolute length of the elements in the group.
- **Element** : x-Axis is represented by Element number.
- **Cable Name** : x-Axis is represented by Cable location.



| Result Item dialog box |

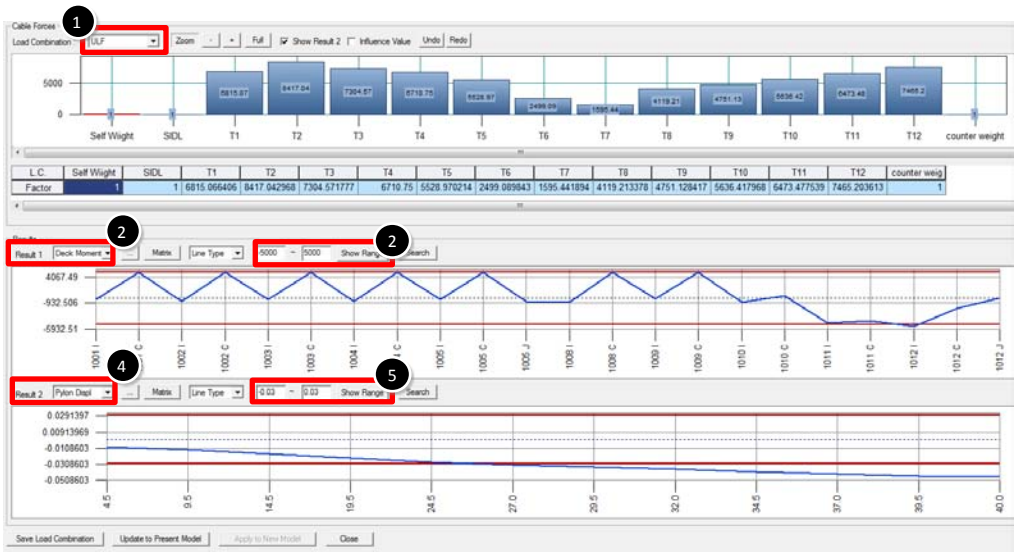
5. Cable force tuning

Main Menu>*Results> Cable Control> Cable Force Tuning*

1. Check '**Show Result2**'
2. Results 1 of Result: **Deck Moment**
3. Show Range : enter **-5000 ~ 5000**, click Show Range
4. Results 2 of Result: **Pylon Displacement**
5. Show Range : enter **-0.03 ~ 0.03** , click Show Range

The graph below shows the moments in the girder for the current pretension values.

Using 'Cable Force Tuning', adjust the pretension so that the moments fall within the defined range (-5000kN·m ~ 5000kN·m). Also, the displacements of the pylons should fall within the set range of -0.03m ~ 0.03 m.



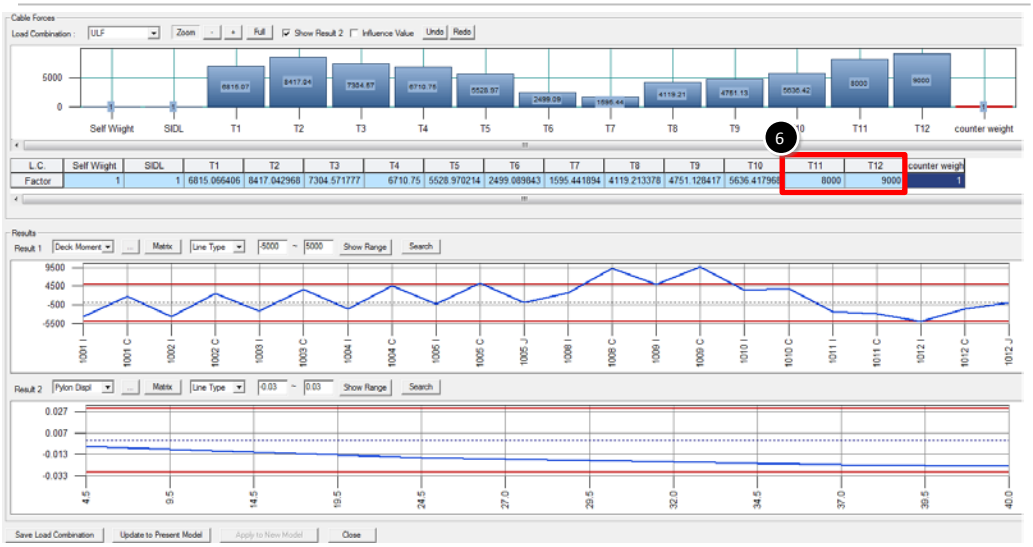
| Distribution of the girder moments obtained by Unknown Load Factor |

04. Cable Force Tuning

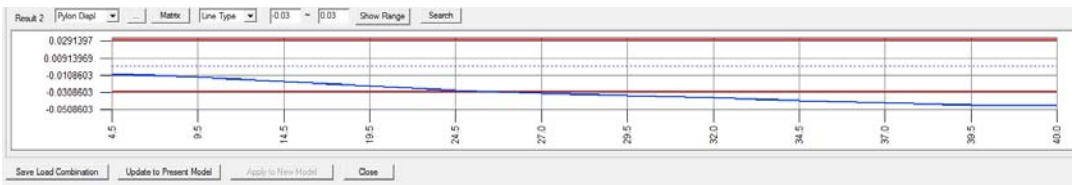
In order the meet the target displacements AND the target moment distribution, one must understand the correlation between the displacement graph of the pylons and the moment graph of the girders. Use the procedure 'Adjust the cable force by the Influence Matrix Factor' on page 10.

🎧 The summation of the cable forces (T1~T6) is greater than the sum of cable forces (T7~T12). Therefore, the pylon is deflected to the Global Dx (-) direction. Adjust the cable forces of T11 and T12 to meet the target displacement of the pylons.

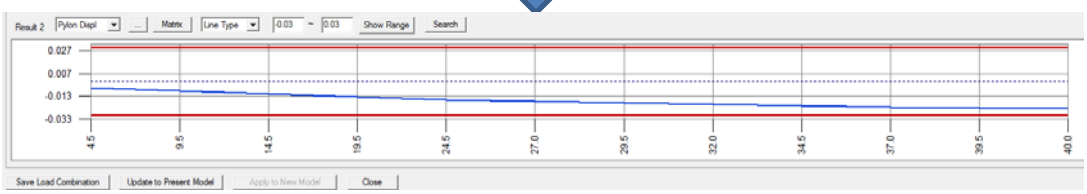
6. T11 : **8000** , T12 : **9000** 🎧



| Adjust the cable forces considering the displacements of the pylons |



| Displacement of the pylon when T11 : 6471.79 and T12 : 7467.89 |

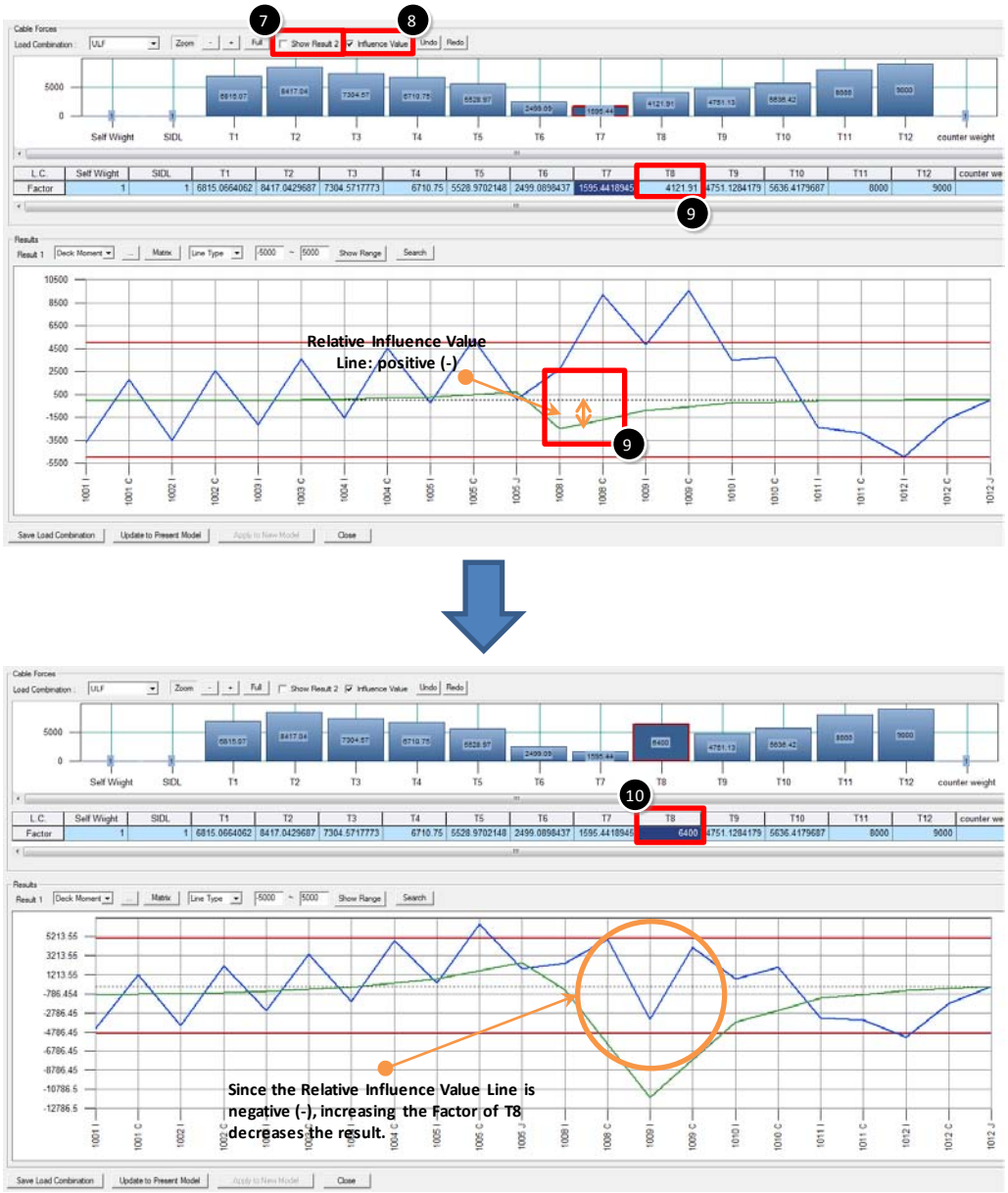


| Displacement of the pylon when T11 : 8000 and T12 : 9000 |

04. Cable Force Tuning

In order to meet the target moment distribution in the girders, use the Relative Influence Value Line and adjust the cable force of T8.

7. Check off '**Show Result2**'
8. Check '**Show Influence Value**'
9. Select **T8** and check Influence Value Line
10. T8 : **6400**



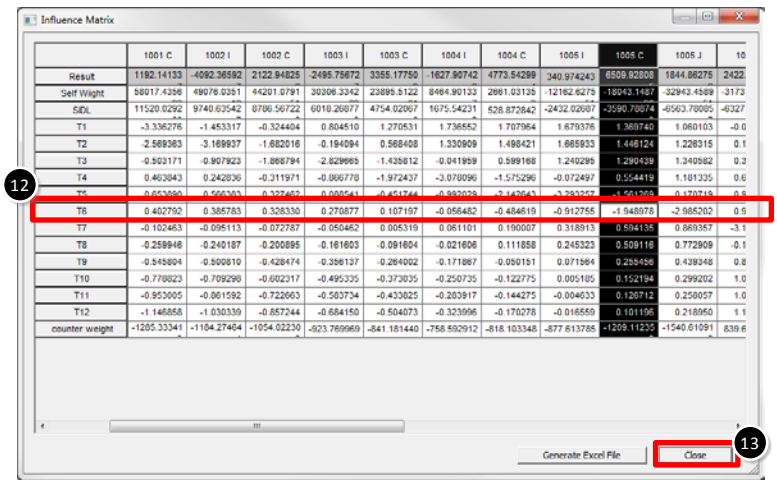
| Adjust the cable force using the Relative Influence Value Line |

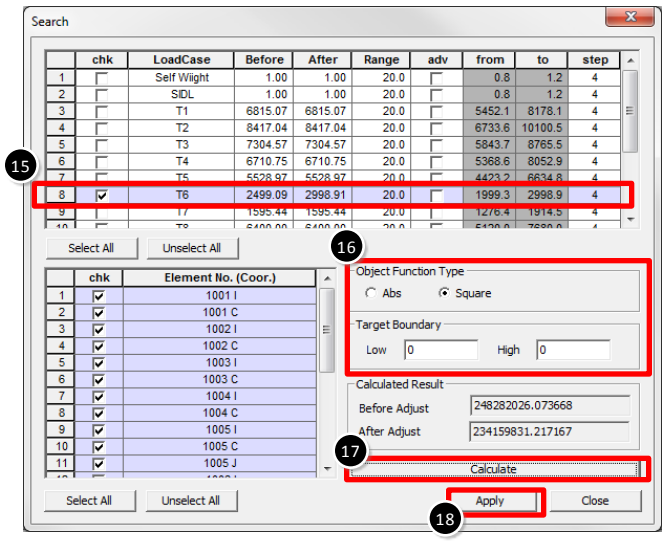
04. Cable Force Tuning

The value of My for element 1005 exceeds the set range. Select the cable that has the greatest influence on Element 1005C and adjust the cable force Factor using 'Search'.

11. Click Matrix
12. Confirm that the cable force (**T6**) has the greatest influence on **Element 1005C** from the **Influence Matrix** window
13. Click Close
14. Click Search
15. Check : **T6 ,** Range : **20** , Step : **4**
16. Object Function Type : **Square** , Boundary : Low **(0)** , High **(0)**
17. Click Calculate
18. Click Apply
19. Repeat steps **15. ~ 18.** 🎧

🎧 Repeat the procedure to find the solution that converges the object function of 'Search'.



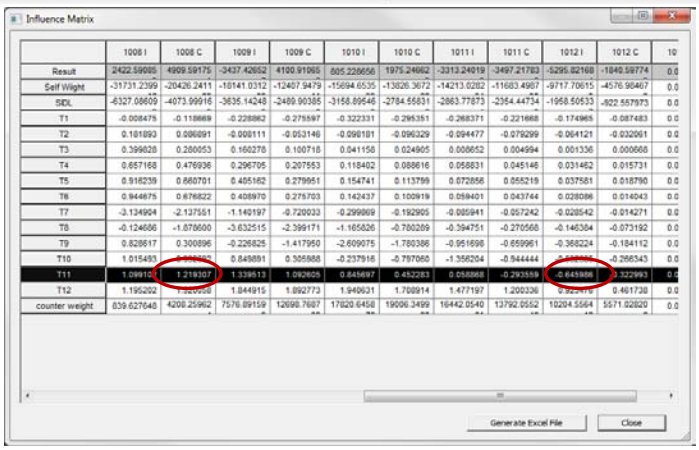


| Find the cable force that has the greatest influence and adjust it |

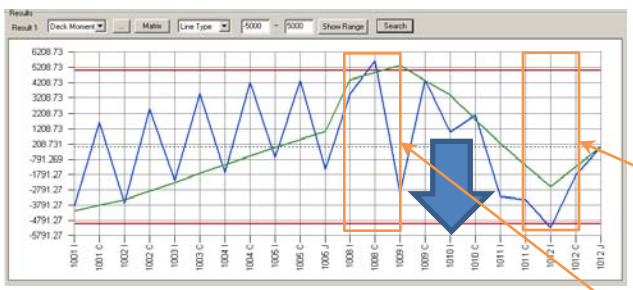
04. Cable Force Tuning

Adjust the cable force Factor (T11) following the procedure ‘Adjust the cable force by the Influence Matrix Factor’ on page 10 to meet the target moment for the i-end of Element 1012.

20. **T11 : 7000**



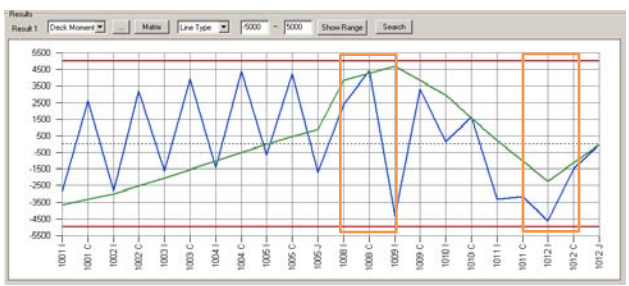
| Moment of the girder when T11 : 8000 |



| Moment of the girder when T11 : 8000 |

Since the Relative Influence Value Line is negative (-), decreasing T11 Factor increases the result.

Since the Relative Influence Value Line is positive (+), decreasing T11 Factor decreases the result.

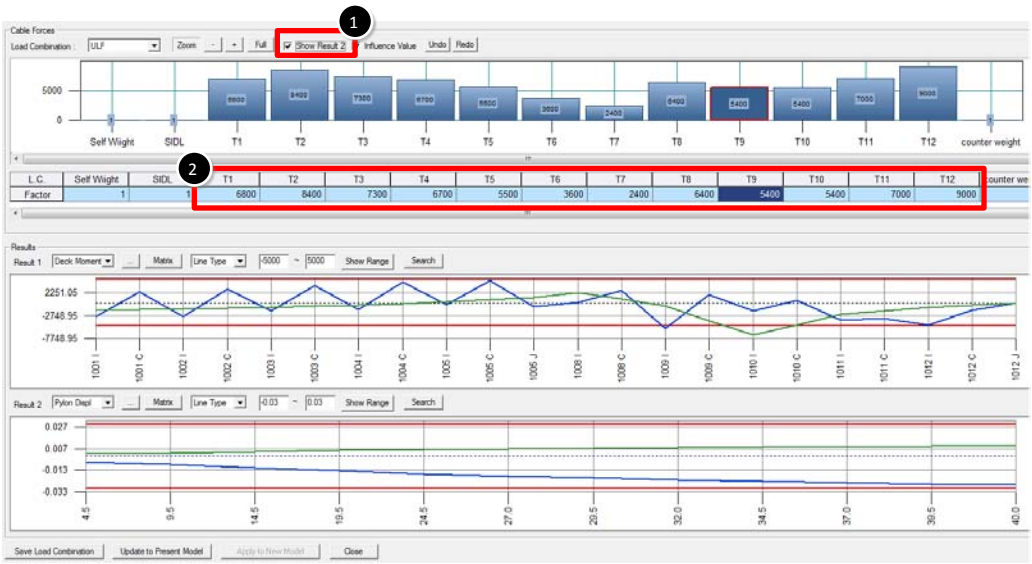


| Moment of the girder when T11 : 7000 |

6. Grouping through Cable Force Tuning

Fine-tune or group cable forces, while keeping the girder moment and the pylon displacement within the target range, in order to simplify construction and erection.

1. Check '**Show Result2**'
2. T1 : **6800** , T2 : **8400** , T3 : **7300** , T4 : **6700** , T5 : **5500** , T6 : **3600** , T7 : **2400** , T8 : **5400** , T9 : **5400** , T10 : **5400**

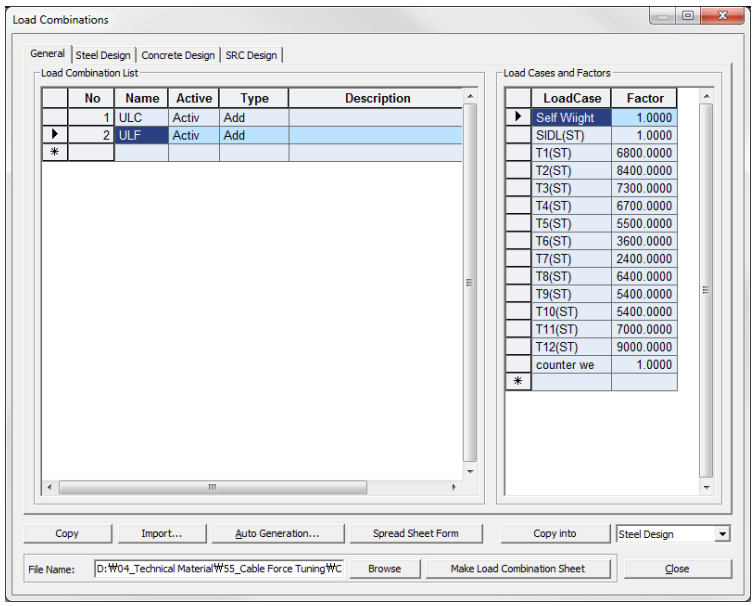


| Confirm the final cable forces |

7. Apply the final cable force

1) Save Load Combination

1. Click Save Load Combination
2. Main Menu > ***Result > Load Combinations***

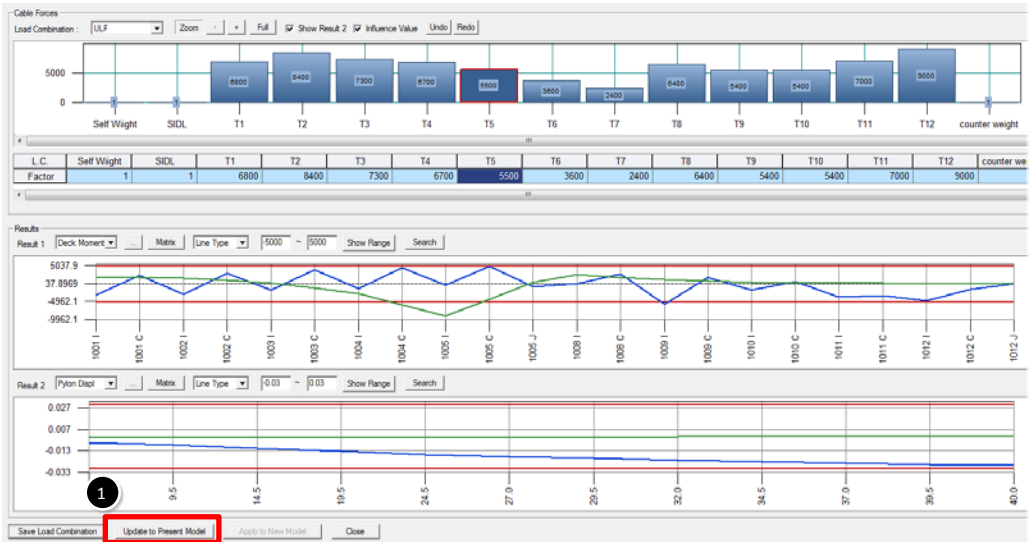


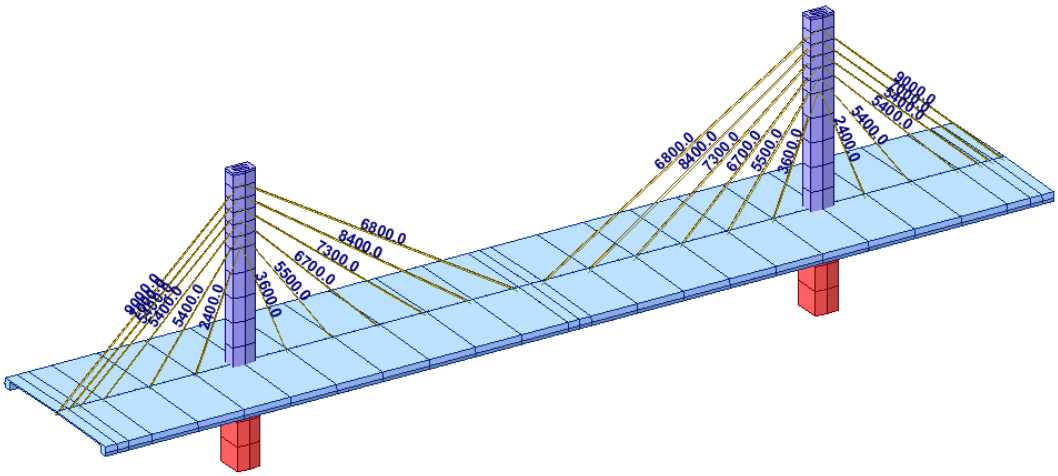
| ULF load combination updated with the tuned cable force factors |

04. Cable Force Tuning

2) Update to Present Model

1. Click Update to Present Model
2. Click **Perform Analysis**





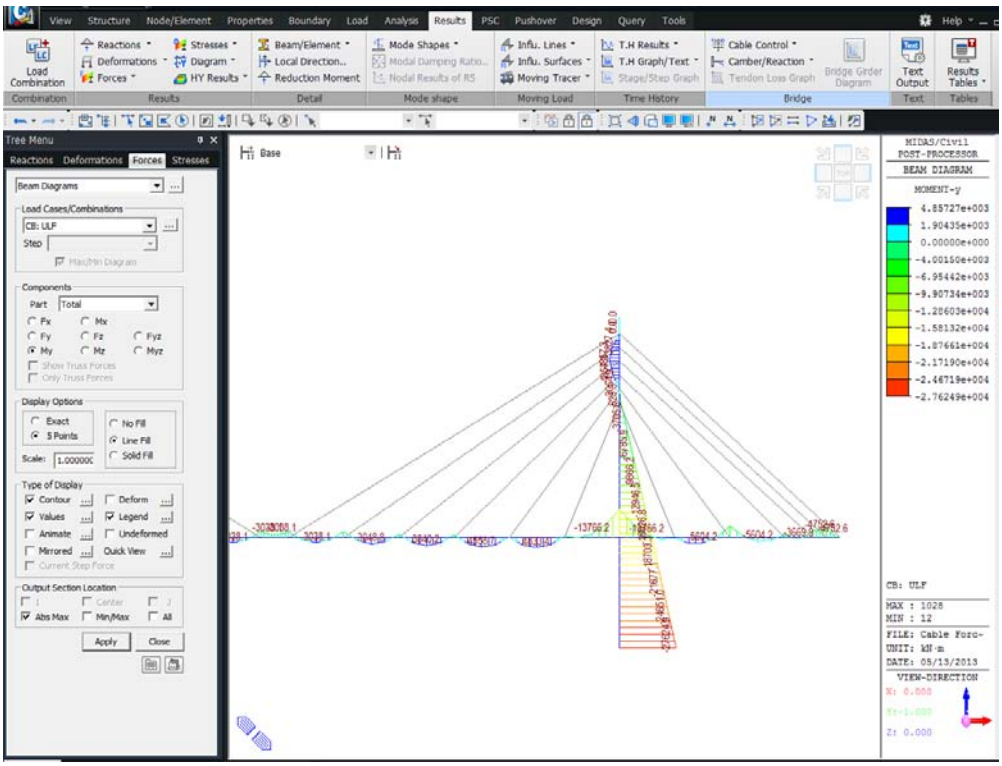
| Cable force factor is applied as the new Pretension Load |

04. Cable Force Tuning

3) Review the results

Check the target moments of the girders from **Beam Diagram**.

1. Select **Group Tree**
2. Select **Deck Total**
3. Click **Activate**
4. Main Menu>*Results>Force>Beam Diagrams*
5. Load Cases/Combinations : **CB: ULF**
6. Component : **My**
7. Type of Display : **Contour , Values** check
8. Output Section Location : **abs Max** off
9. Output Section Location : **Center** check
10. Click Apply

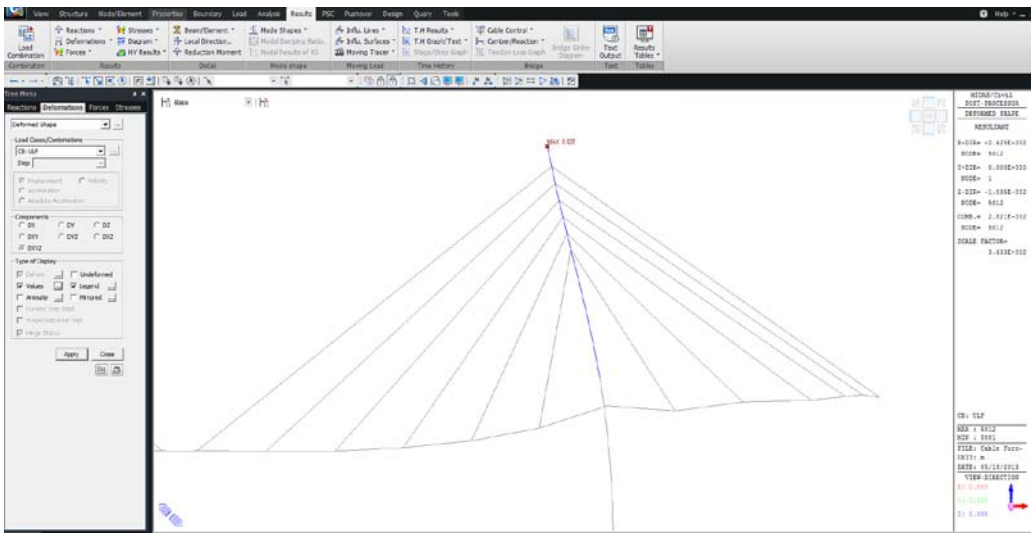


| My in the girder at the center of the elements |

04. Cable Force Tuning

Check the target displacements of the pylons from **Deformed Shape**.

1. Click **Activate All**
2. Select **Group Tree**
2. Select **Pylon**
3. Click **Activate**
4. Main Menu>*Results>Deformations>Deformed Shape*
5. Load Cases/Combinations : **CB: ULF**
6. Component : **DXYZ**
7. Type of Display : check **Values** and click ...
8. Check **MinMax Only** and select **Abs Max**
9. Click OK
10. Click Apply



| Check the displacement at the pylon |