Advanced Application 12

Final and Forward Construction Stage Analysis for a PC Cable-Stayed Bridge (Part II)

Civil

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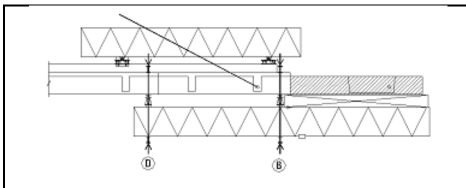
Summary

In an initial cable pretension analysis of PC cable-stayed bridge, initial cable forces are calculated based on the composite section properties of girder and slab.

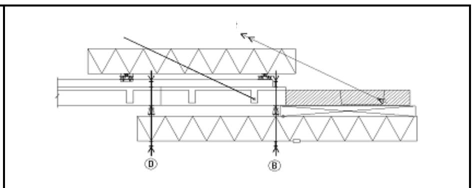
If a large amount of cable pretension is introduced at one time at the stage when only the girder is installed in construction stage analysis, the cable forces can be controlled effectively because the cable pretension at the 2nd stage of tensioning is quite small. However, extreme moments may occur and the slope of girder may become large, which can cause cracking of the casting slab.

In order to consider this kind of construction feature in the model, it is necessary to perform construction stage analysis reflecting the section properties before and after the composite action and multiple cable tensioning.

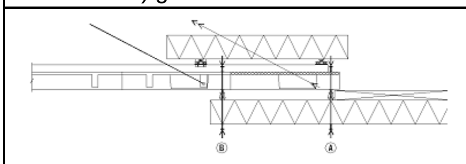
This tutorial shows the construction stage analysis process considering the section properties before and after the composite action, by using the “Composite Section for Construction Stage” function.



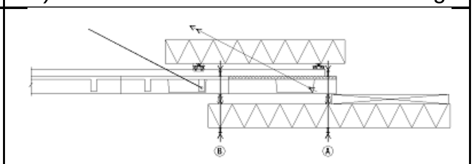
a) girder installment



b) cable installment and 1st tensioning



c) slab casting



d) slab hardening and 2nd tensioning

Figure 1. Construction Stage Cycle

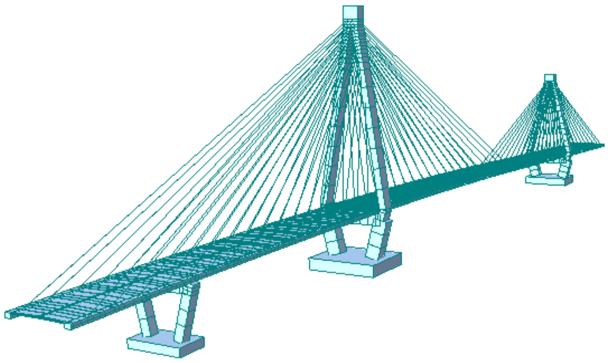


Figure 2. Analysis model

Bridge dimensions

This tutorial has been based on a real project of a PC cable-stayed bridge, and has been simplified. We are going to review the main features of MIDAS/Civil for the construction stage analysis with the cable pretension forces calculated in an initial cable forces analysis.

The figures for the bridge are as follows

Bridge type: PC cable-stayed bridges
Bridge length: L = 46.5+113.5+260.0+100.0 = 520.0 m
2 pair of cables, diamond shape tower
Main girder: Beam and Slab type concrete section
Tower: concrete section
Number of cables: 52×2 pair = 104
Install 4 Key blocks in 1,2,3,4 spans
Install 2 elastic bearings on PY1, PY2

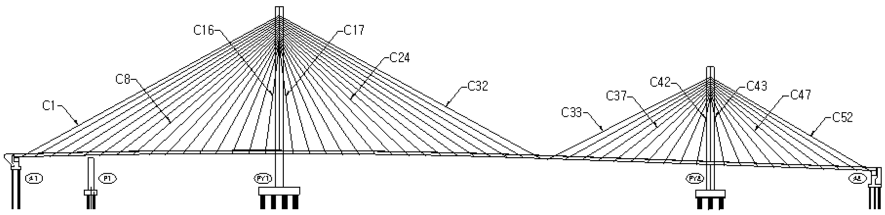
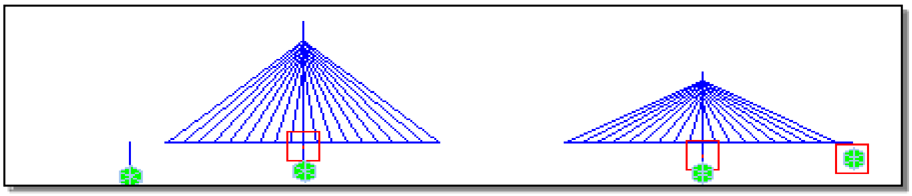


Figure 3. General Layout of Bridge Structure

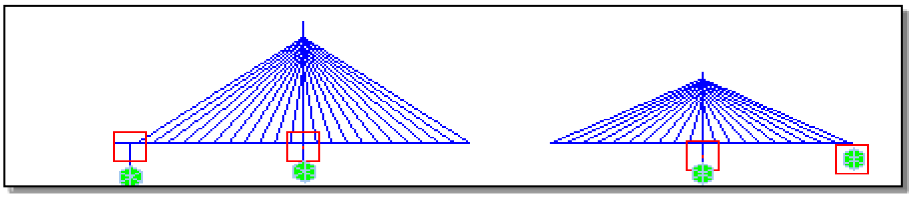
Construction stages

[CS10] Generating towers and piers

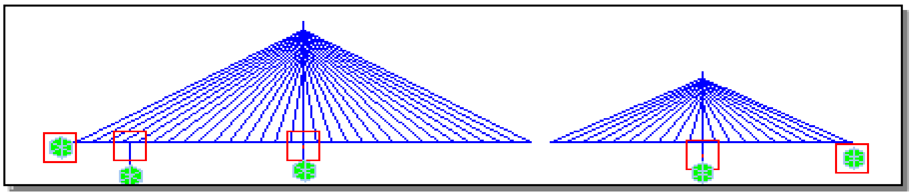
[CS11~CS64] Generating cantilever and support for abutment A2



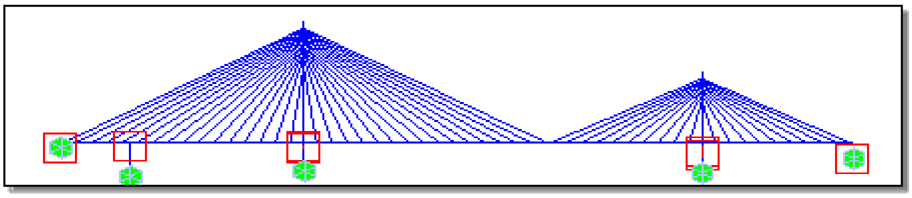
[CS65~CS78] Generating cantilever and support for piers



[Stage79~Stage104] Generating cantilever and support for abutment A1



[Stage105~Stage114] Generating cantilever and closing key segment



Definition of Properties

Definition of Material Properties

Input additional material properties for the construction stage analysis.

[Unit : kN, m]

ID	Name	Type of Design	Standard	Modulus of Elasticity	Poisson's Ratio	Thermal Coeff.	Weight Density
4	Tendon	User Defined	None	1.9613e8	0.0	0.0	76.98
5	Main w/o weight	Concrete	None	3.7e7	0.2103	1e-5	0.0

Input zero for the weight density of slab because the self-weight of the slab will be assigned using beam loads.

Properties / ***Material Properties / Add***

Material ID>**(4)** ; Name>**(Tendon)** ; Type of Design> **User Defined**
Standard>**None** ; Modulus of Elasticity>**(1.9613e8)** ;
Poisson's Ratio> **(0)** ; Thermal Coeff.>**(0)** ; Weight Density> **(76.98)**
Material ID >**(5)** ; Name>**(Main w/o weight)** ; Type of Design> **Concrete**
Standard>**None** ; Modulus of Elasticity>**(3.7e7)** ;
Poisson's Ratio> **(0.2103)** ; Thermal Coeff.>**(1e-5)** ;
Weight Density> **(0.0)**

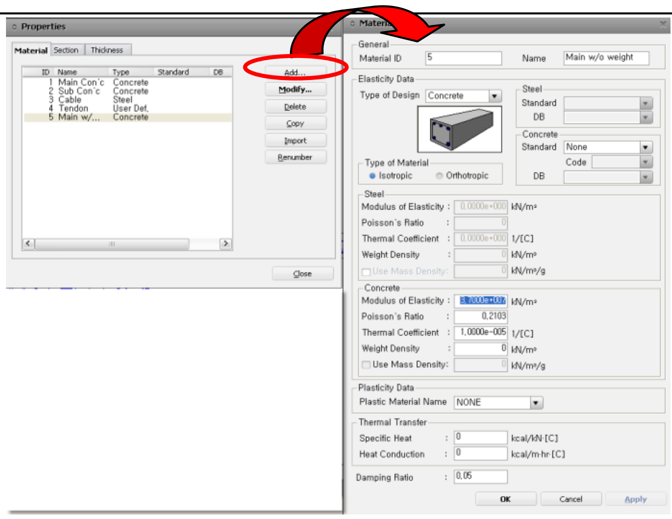


Figure 4. Material Property Input Dialog Box

Definition of time-dependent material properties

Define the time-dependent material properties of concrete to reflect creep and shrinkage for the construction stage.

Properties / *Time Dependent Material / Creep/Shrinkage / Add*

Name>**(Creep/Shrinkage)** ; Code> **CEB-FIP(1990)**

Compressive strength of concrete at the age of 28 days>**(40000)**

Relative Humidity of ambient environment (40~99)>**(70)**

Notational size of member>**(1.5)**

Type of cement>**Normal or rapid hardening cement (N, R)**

Age of concrete at the beginning of shrinkage>**(3)** ↵

Properties / *Time Dependent Material / Material Link*

Time Dependent Material Type>Creep/Shrinkage>**Creep/Shrinkage**

Select Material for Assign>Materials>**1:Main, 5:Main w/o weight** >

Operation> Add / Modify

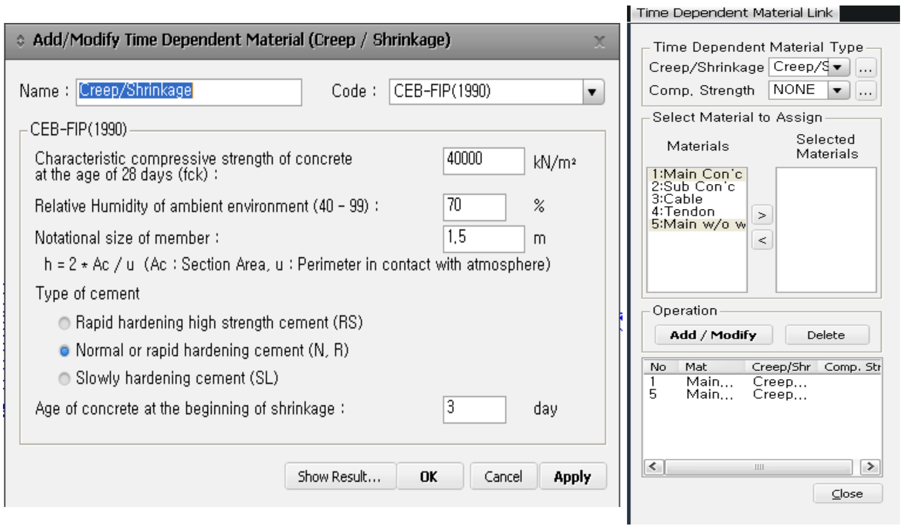


Figure 5. Input time-dependent material properties

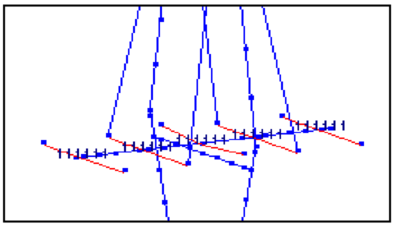
Definition of Structure Groups

Construction stages of the cantilever

The following figures show the repetitive process for generating the cantilevers. Define the Structure Groups as per construction process.

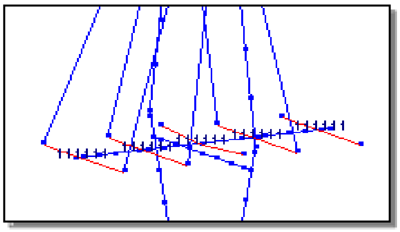
[Stage15]

Girder installment



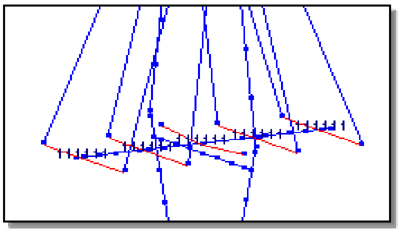
[Stage16]

Create side-span cable, 1st tensioning



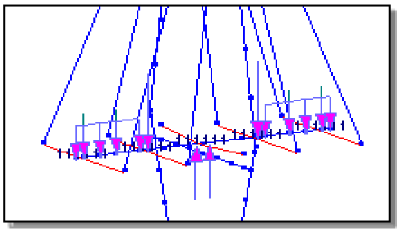
[Stage17]

Create mid-span cable, 1st tensioning



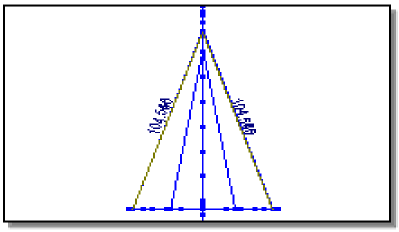
[Stage18]

Assign cross beam load and slab load



[Stage19]

2nd tensioning (mid-span, side-span)



[Stage20]

Move form-traveler load

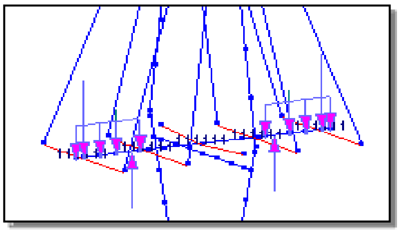


Figure 6. Typical cycle of segment

The user must activate the girder and rigid links simultaneously in stage 15, as shown below in Figure 7, Case B. If the rigid link is activated in the stage where the cables are activated, as shown below in Figure 7, Case A, a vertical distance will exist between the girder and cable anchorages. This is because the girder has a deflection due to its self-weight, whereas the cable anchorages are generated before the deflection occurs. Thus, it is important that the girder and rigid links are activated simultaneously in order for cable anchorages to be activated in the deformed position.

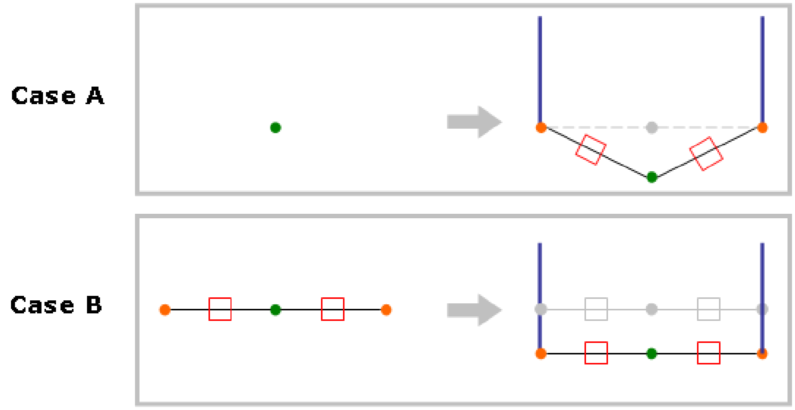


Figure 7. Activate girder and rigid links

Side-span cables and mid-span cables are activated and tensioned at stage 16 and stage 17. Assign different Structure Groups to the side-span and mid-span cables.

Slab and cross beams are cast in stage 18 after 1st tensioning of cables. As explained later, self-weight of the slab needs to be assigned as a uniform beam load. Therefore, we input zero value for the weight density of slab.

The stiffness of the composite section is automatically increased in the composite stage. In this tutorial, the cross beams are considered as loads, instead of assigning them as elements in the geometric modeling.

The 2nd tensioning of cables is introduced in stage 19, when the girder has the composite section properties after the slab concrete is cast. Form-traveler load is moved for installing the next segment in stage 20.

Repeat all the 6 stages mentioned above to install the other segments.

Structure / Group / Structure

Note that below is to only explain how to use the "define structure group" function. For our case, where massive amounts of input are required, we will use MCT command shell to import "structural group" data to facilitate the process, as described in the next page.

Girder_LS_2 Add ↲

815 867 157to160 (Select nodes and elements which will be assigned to the Structure Group defined above)

Select the Structure Group and assign a group by right-clicking the mouse and invoking the Context Menu.

Construction Stage	Group Name	Element No.	Node No.
Stage15	girder_LS_2	157to160	159,160,815, 867
	girder_LM_2	167to170	168,169,818, 870
	girder_RM_2	260to263	260 to 263, 841, 893
	girder_RS_2	270to273	271 to 274, 844, 896
Stage16	Cable_LS_2	1415, 1515	-
	Cable_RS_2	1444, 1544	-
Stage17	Cable_LM_2	1418, 1518	-
	Cable_RM_2	1441, 1541	-
Stage18, 19, 20	-	-	-

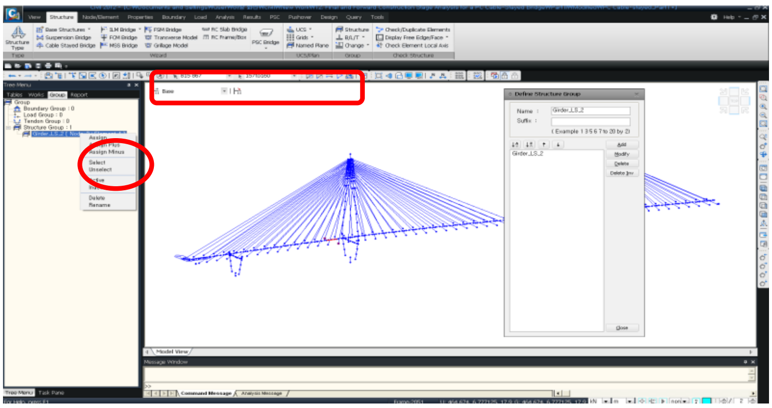


Figure 8. Assign the Structure Group to nodes and elements

Input all the Group information by using the *CS_info_Group.txt* file and MCT Command Shell.

Tool / MCT Command Shell

Copy the data from *CS_info_SGroup.txt* file and paste it to MCT Command Shell.

Click on 

↵

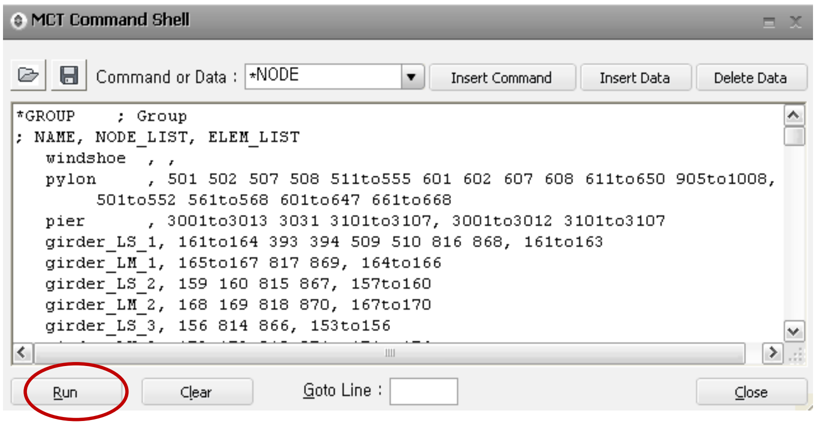


Figure 9. Input Group data by using MCT Command Shell

Definition of composite section for construction stage

It is necessary to tension the cables twice in order to exactly reflect the construction stages in a PC cable-stayed bridge. The girders become composite when the slab concrete is cast after 1st tensioning of cables. Creep/Shrinkage and composite section properties can be determined by using the “Composite Section for Construction Stage” command. It is necessary to assign section data before defining the composite section for construction stage. This section data is not used for calculating the composite section properties, but used for selecting elements, displaying hidden section, and defining the neutral axis for assigning tendon profiles.

By dividing the whole section into several parts based on construction stages, and then defining the stages to be activated, material properties, neutral axis, and section properties by parts, the analysis is performed based on composite section properties.

It is important to understand that “Composite Section for CS” can be defined by section IDs. Therefore, even though some elements could have the same section properties, their section IDs should be different in order to define “Composite Section for CS” for the elements which are activated at different construction stages. The 3 section types used in the completed stage model are stored separately. They are named after the activated stages.

Import section data from the *Section_info.mcb* file.

Properties / ***Section Properties***
Import ↵
Select *Section_info.mcb* file.
OK ↵

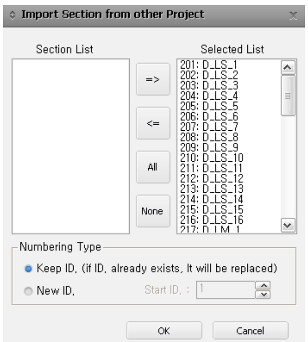
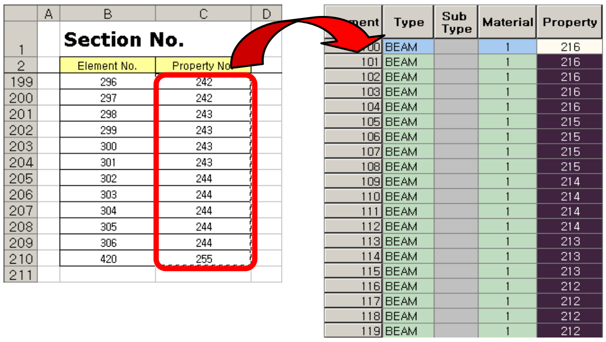


Figure 10. “Import Section from other project” dialog box

Change section property data of all the elements with the section data named after the activated stages. Copy section property data from the "1) Section No." tab of *CS_info.xls* file and paste it into the Property column in Elements Table. Make sure that the sorting order of element numbers is identical in the MS-Excel spreadsheet and Element Table. By default, the element table is sorted as per the element number.

Node/Element / ***Elements Table***



	A	B	C	D
1		Section No.		
2		Element No.	Property No	
199		296	242	
200		297	242	
201		298	243	
202		299	243	
203		300	243	
204		301	243	
205		302	244	
206		303	244	
207		304	244	
208		305	244	
209		306	244	
210		420	255	
211				

ment	Type	Sub Type	Material	Property
00	BEAM		1	216
101	BEAM		1	216
102	BEAM		1	216
103	BEAM		1	216
104	BEAM		1	216
105	BEAM		1	215
106	BEAM		1	215
107	BEAM		1	215
108	BEAM		1	215
109	BEAM		1	214
110	BEAM		1	214
111	BEAM		1	214
112	BEAM		1	214
113	BEAM		1	213
114	BEAM		1	213
115	BEAM		1	213
116	BEAM		1	212
117	BEAM		1	212
118	BEAM		1	212
119	BEAM		1	212

Figure 11. Change of the section assignment.

This process for defining 'Composite Section for Construction Stage' requires Construction Stage, and Construction Stage requires Boundary Group and Load Group, which are not defined yet. Therefore, we will revisit this page below after we complete all these processes.

We will proceed with the following steps
Defining Boundary Group > Load Group > Construction Stage > Composite Section for Construction Stage'

Go to Page 16 to define Boundary Group.

Following steps show the procedure for defining "Composite Section for Construction Stage" in Stage 15. Below explains, for the purpose of learning, how to define "Composite Section for Construction Stage". Do not apply these as we will import all data at once.

The girder becomes composite in Stage19 when the curing of the slab is completed.

Refer to Figure 11 and Input the stiffness by parts.

Load / Construction Stage Load Type/ ***Composite Section for Construction Stage***

Active Stage>**Stage_15** ; Section> **CEB-FIP202:D_LS_2**
Composite Type>**User** ; Part Number> **(2)**
Construction Sequence
Part>**(1)** ; Material Type>**(Material)**
Material>**1:Main Con'c** ; Composite Stage>**Active Stage**
Age>**(7)** ; Cy>**(12.12)** ; Cz>**(0.8)**; h>**(1.5)**
Stiff> ... (Copy the data from *CS_info.xls* and paste.)

Part>**(2)** ; Material Type>**(Material)**
Material>**5:Main_w/o weight** ; Composite Stage>**Stage19**

Age>**(7)** ; Cy>**(12.12)**; Cz>**(1.474);** h>**(1.5)**
Stiff> ... (Copy the data from *CS_info.xls* and paste.)

Girder (Part 1) is activated in Stage 15, slab concrete is poured at Stage 18 and after 7 days, slab (Part 2) is activated in Stage 19. This indicates that the girder has composite section properties in Stage 19. Assign material data in which the weight density is zero, and assign self weight of slab using beam element loads.

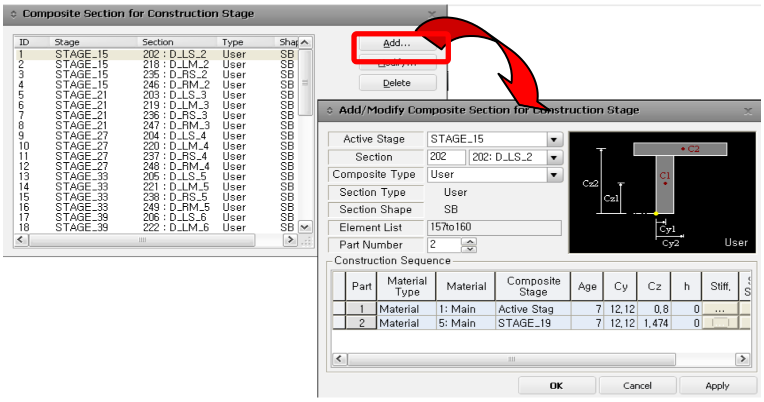


Figure 12. Composite Section for Construction Stage dialog box

Input the stiffness data of the girder and slab before composite action occurs, by using the data in the “2) Composite Stiff” tab of *CS_info.xls* file.

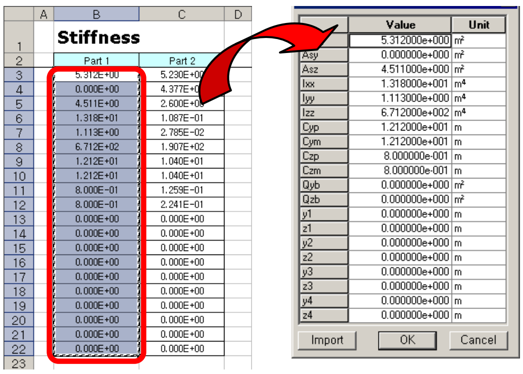


Figure 13. User Stiffness dialog box

Input the stiffness data of the girder after composite action occurs, by using the MCT Command Shell as follows:

Tool / MCT Command Shell

Copy data from *CS_info_Composite.txt* file and paste into MCT Command Shell.
Click on Run ↵

Definition of Boundary Groups

Boundary conditions to be used in construction stages

All the boundary groups are shown in Figure 14, 15 and 16 by the boundary types such as Rigid Link, Elastic Link and Support. Some groups (*_dis_const) of Elastic Links are activated and deactivated during construction stages. All the groups, except these, are also used in the completed stage.

Rigid Link is used in connecting the centroid of the girder/tower and the anchorage of cables. It is also used in modeling the towers and piers.

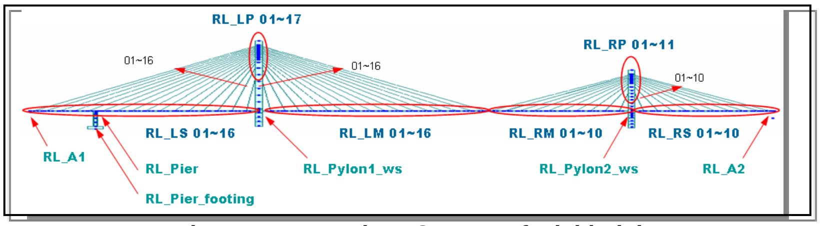


Figure 14. Boundary Groups of Rigid Link

Elastic Link is used in modeling the bearings. The boundary groups whose name is of the order *_dis_const", are activated and deactivated during the construction stages in order to restrain the rotation of the structure.

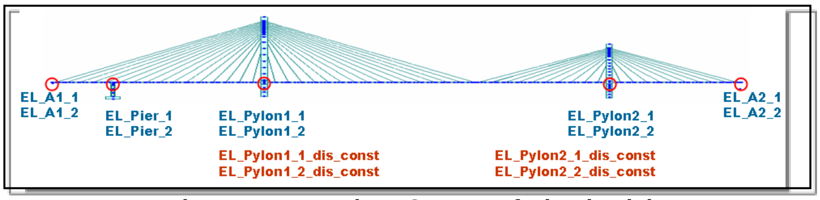


Figure 15. Boundary Groups of Elastic Link

"Support" command is used for assigning supports.

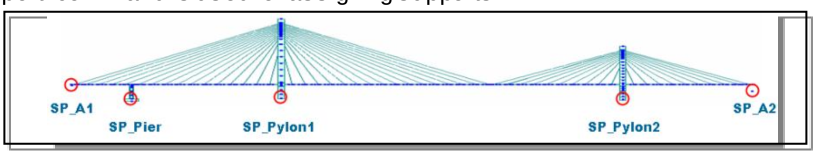


Figure 16. Boundary Groups of Support

Input Boundary Group

Define boundary groups and assign boundary conditions into the group as per construction stages. Copy data from *CS_info_BGroup.txt* file and paste it into MCT Command Shell in order to define the Boundary groups.

Tool / MCT Command Shell

Copy data from *CS_info_BGroup.txt* file and paste into MCT Command Shell.

Click on Run ↵

Assign boundary conditions to the boundary groups by using the tables. Refer to construction stages and Figure 14, 15 and 16 to assign the appropriate group.

Boundary > Boundary Tables > Elastic Link or Support or Rigid Link

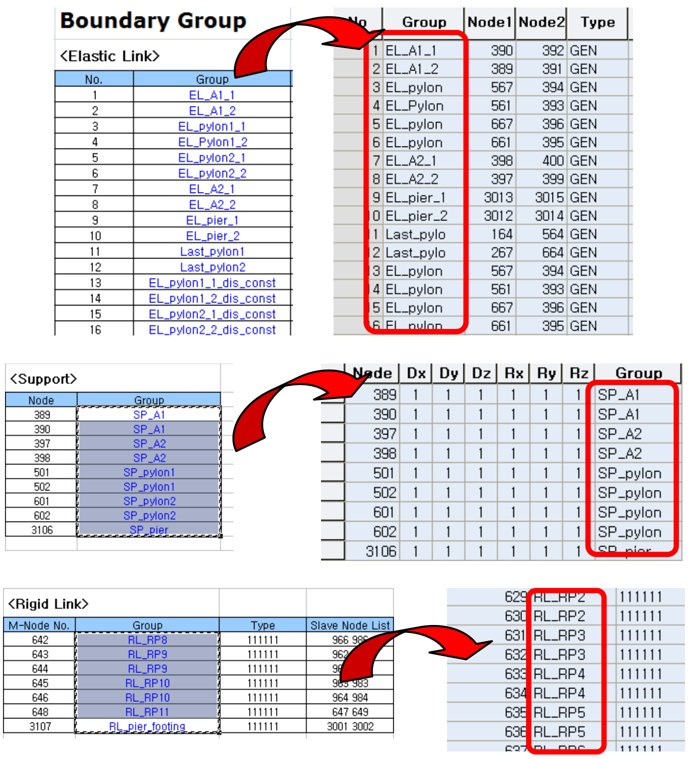


Figure 17. Assign Boundary Group

Check temporary boundary conditions

Check additional temporary boundary conditions to restrain the rotation of the girders.

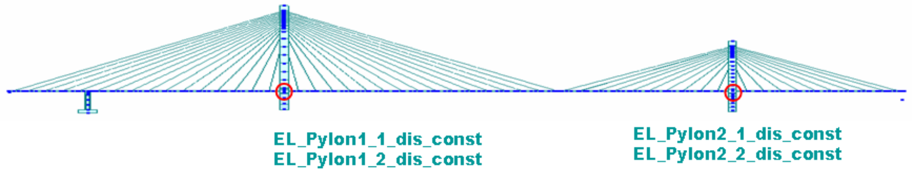
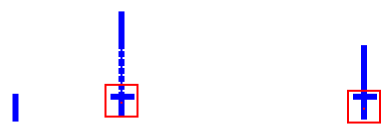
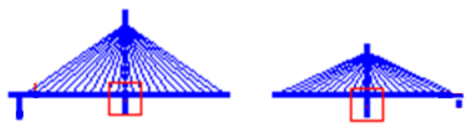
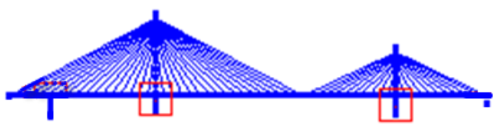


Figure 18. Positions of temporary restraint

These boundary groups are activated to restrain the rotation of the girder at an early stage when it is a cantilever. They are deactivated when the cantilevers on both sides are connected to the piers, and the key segment of main span is installed.

[Stage11] Activate Pier Table 	Activate EL_Pylon1_1_dis_const Activate EL_Pylon1_2_dis_const Activate EL_Pylon2_1_dis_const Activate EL_Pylon2_2_dis_const
[Stage77-2] Connect cantilever and pier 	Deactivate EL_Pylon1_1_dis_const Deactivate EL_Pylon1_2_dis_const
[Stage111-2] Install key segment on man span 	Deactivate EL_Pylon2_1_dis_const Deactivate EL_Pylon2_1_dis_const

Boundary > Boundary Tales > Elastic Link Table

Check below data in the Elastic Link Table, which will be used as temporary boundary conditions.

[Unit : kN, m]

Node1	Node2	Type	SDx	SDy	SDz	SRx	SRy	SRz	Group
567	394	Gen	0	0	0	1e11	0	1e11	EL_pylon1_1_dis_const
561	393	Gen	0	0	0	1e11	0	1e11	EL_pylon1_2_dis_const
667	396	Gen	0	0	0	1e11	0	1e11	EL_pylon2_1_dis_const
661	395	Gen	0	0	0	1e11	0	1e11	EL_pylon2_2_dis_const

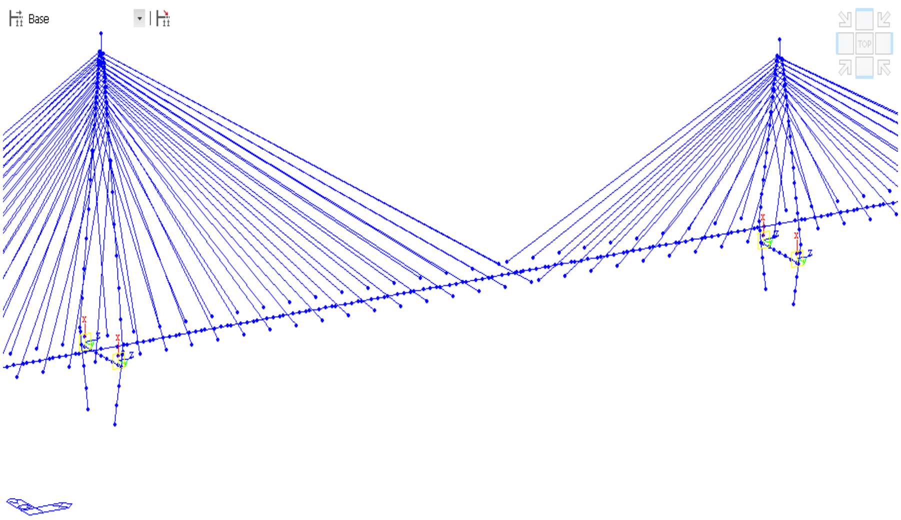


Figure 19. Temporary restraints

Definition of Load Groups

Load cases to be used in construction stages

Load cases in this tutorial are as follows.

Load Case Name	Description	Remarks
Self Weight	Self weight.	Auto calculation by the program.
Ten_*	1st tensioning before composite.	Cable Pretension. 10 to 20% of initial cable force.
Ten2_*	2nd tensioning after composite.	Cable Pretension. 80 to 90% of initial cable force.
3rd Tension	Cable force adjustment after closing key segment.	Cable Pretension.
FT	Form traveler load.	Nodal load. Move as per construction stages
Cross&Slab	Self weight of cross beam and slab.	-
Counter Weight	-	-
Tendon Prestress	Prestress by tendon.	-
2nd Dead	Superimposed dead loads.	-

Self weight of the structure and superimposed dead load are already inputted in the completed stage model. Load groups for the loadings have to be defined and activated at the respective construction stages. FT load case, which is the form-traveler load, is activated only during the construction stages. Creep and Shrinkage are reflected when calculating the prestress losses. Initial cable pretensions are calculated based on the composite section properties of the girder. If large pretension forces are introduced at one time before the composite action occurs, it will not only be difficult to control the member forces, it will also cause cracking of concrete. Therefore, 10 to 20% of initial cable pretension is applied before the composite action occurs, and the balance pretension is applied separately after pouring the concrete slab.

Define Load Groups using the *CS_info_LGroup.txt* file.

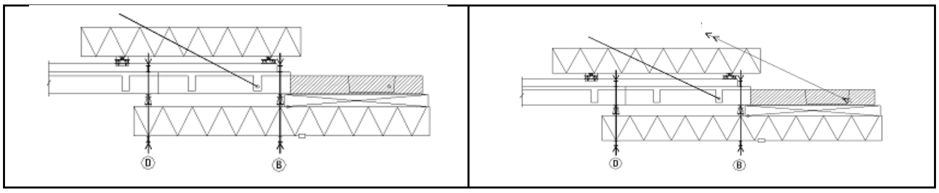
Tool / MCT Command Shell

Copy data from *CS_info_LGroup.txt* file and paste it into MCT Command Shell.

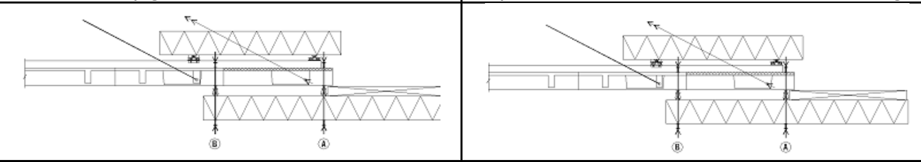
Click on Run ↵

Input loadings considering construction stages.

Figure 20 shows the procedure for constructing one segment of the PC cable-stayed bridge using the cantilever method.



a) girder installment	b) cable installment and 1st tensioning



c) slab casting	d) slab hardening and 2nd tensioning

Figure 20. Construction Stage Cycle

For example, Stage15 to Stage20 are typical stages in which a segment is installed.

Stage	Description	Load
Stage15	Girder installment	Self weight of girder
Stage16	Side-span cable installment	1st tensioning
Stage17	Mid-span cable installment	1st tensioning
Stage18	Slab and cross beam casting	Self weight of slab and cross beam
Stage19	Composite section properties	2nd tensioning
Stage20	Movement of Form Traveler	Deactivate/Activate FT load

Stage	Load Type	Load Groups activated	Load Groups deactivated
Stage15	Self Weight	Input Self Weight at 1st stage	-
Stage16	Pretension	Ten_sc_L2_1, Ten_sc_R2_1	-
Stage17	Pretension	Ten_mc_L2_1, Ten_mc_R2_1	-
Stage18	Nodal Load Beam Load	Cross&slab_LS_2 Cross&slab_LM_2 Cross&slab_RS_2 Cross&slab_RM_2	-
Stage19	Pretension	Ten_sc_L2_2, Ten_mc_L2_2 Ten_sc_R2_2, Ten_sc_R2_2	-
Stage20	Nodal Load	FT_LS_2, FT_LM_2 FT_RM_2, FT_RS_2	FT_LS_1, FT_LM_1 FT_RS_1, FT_RM_1

In this tutorial, the loading data is inputted using tables. The input method of loadings during Stage15 to Stage20 (described above) is given below.

Self-Weight is calculated automatically based on the material and section data.

Load / Static Loads / ***Self Weight***

Load Case Name>**Self Weight** ; Load Case Group> **Self Weight**

X>**(0)** ; Y>**(0)** ; Z>**(-1)** Add ↵

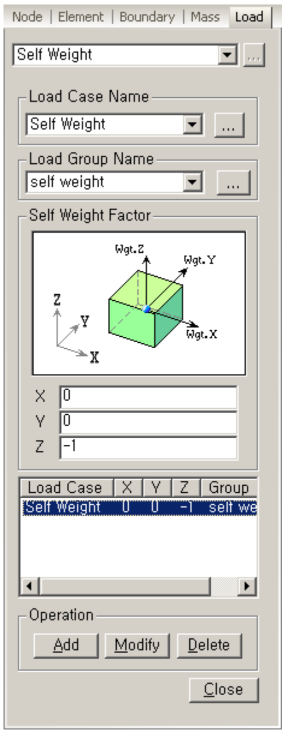


Figure 21. Self-Weight dialog box

Input cable pretension forces using the “Pretension Loads” command.

Load / Temp./Prestress / Prestress Loads / ***Pretension Loads***

Select by Window **(Elem. 1415, 1515)**

Load Case Name>**Ten_15** ; Load Case Group> **Ten_sc_L2_1**

Pretension Load>**(1025.29)** [Add] ↵

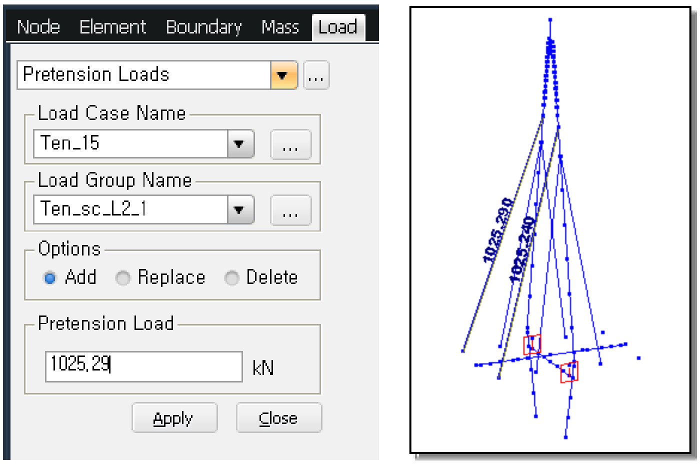
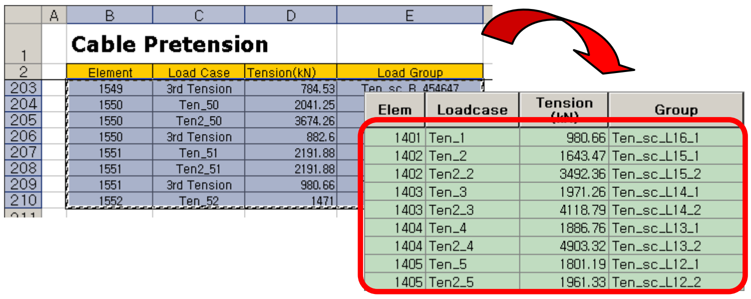


Figure 22. Input cable pretension forces

Input cable pretension forces using the data in “4) Pretension” tab of CS_*info.xls* file.

Load / Load Tables / Prestress Load / ***Pretension Loads***



	Element	Load Case	Tension(kN)	Load Group
203	1549	3rd Tension	784.53	Ten_sc_R_454647
204	1550	Ten_50	2041.25	
205	1550	Ten2_50	3674.26	
206	1550	3rd Tension	882.6	
207	1551	Ten_51	2191.88	
208	1551	Ten2_51	2191.88	
209	1551	3rd Tension	980.66	
210	1552	Ten_52	1471	

Elem	Loadcase	Tension (kN)	Group
1401	Ten_1	980.66	Ten_sc_L16_1
1402	Ten_2	1643.47	Ten_sc_L15_1
1402	Ten2_2	3492.36	Ten_sc_L15_2
1403	Ten_3	1971.26	Ten_sc_L14_1
1403	Ten2_3	4118.79	Ten_sc_L14_2
1404	Ten_4	1886.76	Ten_sc_L13_1
1404	Ten2_4	4903.32	Ten_sc_L13_2
1405	Ten_5	1801.19	Ten_sc_L12_1
1405	Ten2_5	1961.33	Ten_sc_L12_2

Figure 23. Input cable pretension forces

Input self-weight of cross beams and slab using “Nodal Loads” and “Beam Loads” commands. Below is to show how to manually input nodal loads and beam loads.
For the purpose of this tutorial, all data will be imported with using the provided excel file

---

Load / Static Loads / ***Nodal Loads***

Select by Window **(Node. 158, 160)**

Load Case Name>**cross&slab** ; Load Case Group> **Cross&slab_LS_02**

X>**(0)** ; Y>**(0)** ; Z>**(-254.973)**

Do not press “Apply” button. We will import all data at once.

Load / Static Loads / ***Element Loads***

Select by Window **(Elem. 157to160)**

Load Case Name> **Cross&Slab** ; Load Case Group> **Cross&slab_LS_02**

Direction>**Global Z**

Value

x1>**(0)** ; x2>**(1)** ; w>**(-127.486)**

Do not press “Apply” button. We will import all data at once.

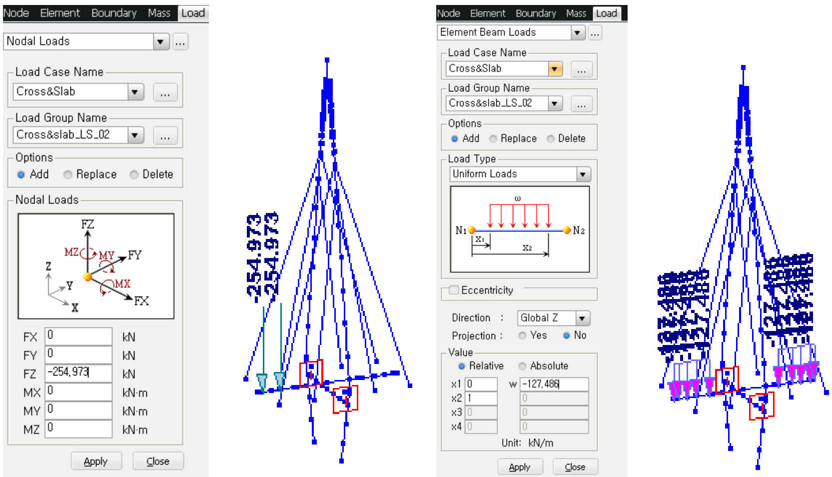


Figure 24. Input self weight of cross beam and slab

Input Nodal Loads and Beam Loads using the data in “5) Nodal” and “6) Beam” tabs of *CS_info.xls* file.

Load / Load Tables / ***Nodal Loads***

Load / Load Tables / ***Beam Loads***

Construction Stage Analysis

Define construction stages.

Construction stages are composed by defining the activation and deactivation of Structure Groups, Boundary Groups and Load Groups.

Following steps show the method for defining construction stage in Stage15.
For the purpose of this tutorial, all data will be imported with the following steps in the next page.

Load / Construction Stage Load Type / ***Define C.S (Construction Stage)***

Add

Stage

Name> **Stage_15** ; Duration> **14**

Element Tab

Active Group> **girder_LS/LM_2, girder_RM/RS_2** **;** Age> **7**

Boundary Tab

Active Group> **RL_LS2, RL_LM2, RL_RM2, RL_RS2**

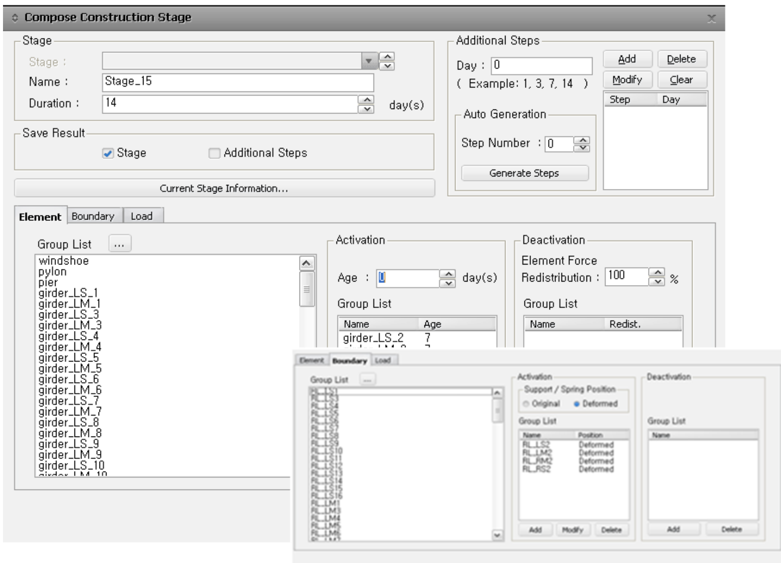


Figure 25. Compose Construction Stage dialog box

The whole construction schedule is summarized in "7) Stage" tab of *CS_info.xls* file.

Construction Stage

NAME	Duration	Element		Boundary		Load	
		active	deactive	active	deactive	active	deactive
STAGE_15	14	girder_LS_2(7), girder_LM_2(7), girder_RM_2(7), girder_RS_2(7)		RL_LS2(D), RL_RS2(D), RL_LM2(D), RL_RM2(D)			
STAGE_16	14	Cable_LS_2(0), Cable_RS_2(0)				Ten_sc_L2_1(F), Ten_sc_R2_1(F)	
STAGE_17	14	Cable_LM_2(0), Cable_RM_2(0)				Ten_mc_L2_1(F), Ten_mc_R2_1(F)	
STAGE_18	5					Cross&slab_LS_2(F), Cross&slab_LM_2(F), Cross&slab_RS_2(F), Cross&slab_RM_2(F)	
STAGE_19	5					Ten_sc_L2_2(F), Ten_mc_L2_2(F), Ten_mc_R2_2(F), Ten_sc_R2_2(F)	
STAGE_20	14					FT_LS_2(F), FT_LM_2(F), FT_RM_2(F), FT_RS_2(F)	FT_LS_1(F), FT_LM_1(F), FT_RM_1(F),
STAGE_21	14	girder_LS_3(7), girder_LM_3(7), girder_RM_3(7), girder_RS_3(7)		RL_LS3(D), RL_RS3(D), RL_LM3(D), RL_RM3(D)			
STAGE_22	14	Cable_LS_3(0), Cable_RS_3(0)				Ten_sc_L3_1(F), Ten_sc_R3_1(F)	
STAGE_23	14	Cable_LM_3(0), Cable_RM_3(0)				Ten_mc_L3_1(F), Ten_mc_R3_1(F)	

Figure 26. Construction schedule Stage15 to Stage23

Input construction stage data using the *CS_info_Stage.txt* file.

Tool / MCT Command Shell

Copy data from *CS_info_Stage.txt* file and paste it into MCT Command Shell.

Click on Run ↵

Go back to Page 13 to complete the process of defining 'Composite Section for Construction Stage'.

Construction stage analysis

In the PC cable-stayed bridge, iterative analysis is required to obtain the optimal cable pretension forces through forward construction stage analysis.

As mentioned above, 10 to 20% of initial cable pretension is applied at the time of 1st tensioning, and 80 to 90% is applied at the time of 2nd tensioning. Iterative calculations are performed until the optimal member forces are obtained for reviewing the analysis results.

In this tutorial, we have already input the cable pretension loads that are calculated by performing iterative analysis.

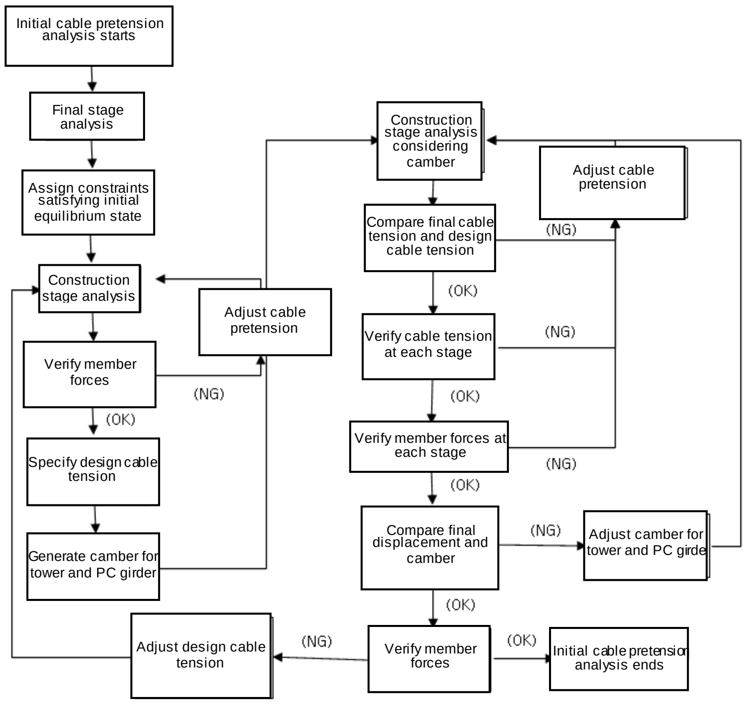


Figure 27. Iterative analysis procedure to obtain the optimal cable pretension

Perform Analysis and Review Results

Click Perform Analysis

Review deformed shapes

Review horizontal displacements of towers and vertical displacements of main girders.

Results / Deformation / ***Deformed Shape***

Stage_114

Load Cases/Combination>**CS:Summation**

Components> **DX**

Stage_114

Load Cases/Combination>**CS:Summation**

Components> **DZ**

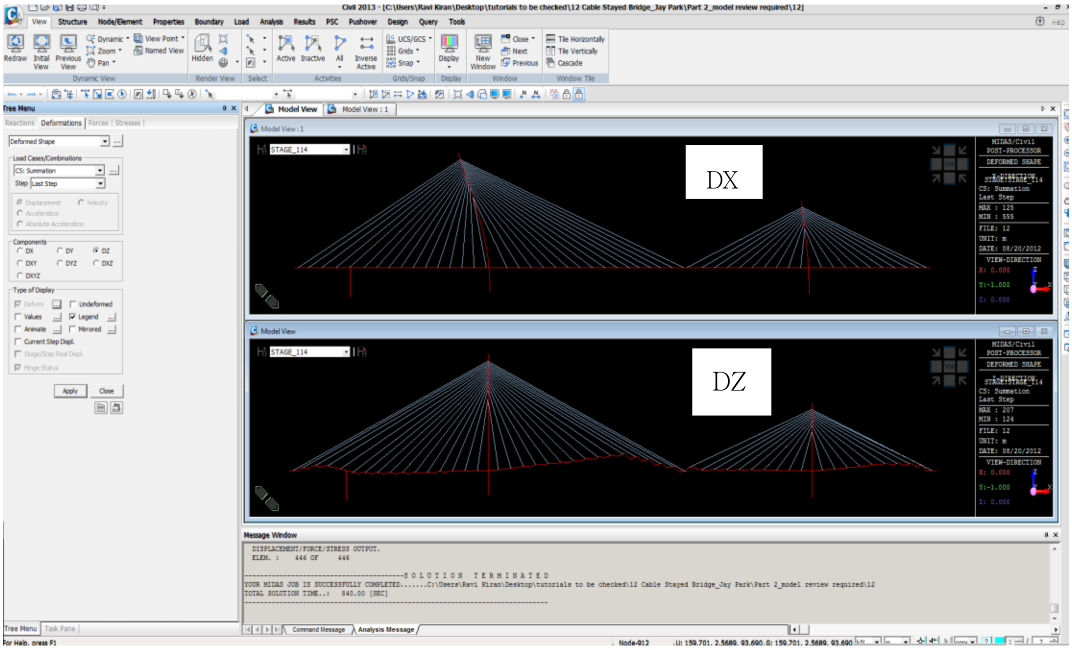


Figure 28. Deformed shapes

Review member forces

Review member forces in towers and main girders.

Results / Deformation / ***Beam Diagrams***

Stage_114

Load Cases/Combination>**CS:Summation**

Components> **My**

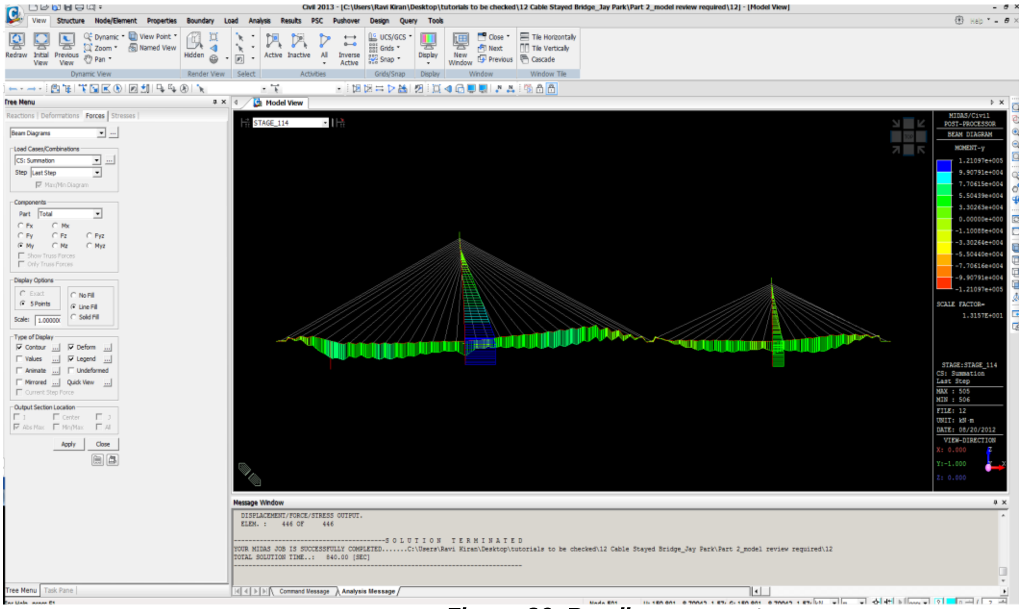


Figure 29. Bending moments

Review analysis results of composite girders

Review member forces/stresses by section parts of the composite section.

Results / Result Tables / Composite Section for C.S. / Beam Force

---

Member forces by section parts

Elem	Load	Section Part	Part	Axial (kN)	Moment-y (kN·m)	Moment-z (kN·m)
105	Com	1	I	-28064,57	1261,84	0,09
105	Com	2	I	-20965,01	20,87	0,02
106	Com	1	I	-34346,54	754,15	0,16
106	Com	2	I	-24006,20	12,47	0,03
107	Com	1	I	-32597,25	1889,23	0,20
107	Com	2	I	-25236,47	31,24	0,03
108	Com	1	I	-32184,69	1845,41	0,23
108	Com	2	I	-24875,44	30,52	0,04
109	Com	1	I	-34278,76	-354,49	0,27
109	Com	2	I	-21644,59	-5,86	0,05
110	Com	1	I	-41571,90	-1299,88	0,02
110	Com	2	I	-24431,23	-21,50	0,00
111	Com	1	I	-39017,37	367,92	0,05
111	Com	2	I	-26249,15	6,08	0,01
112	Com	1	I	-37971,58	848,20	0,09
112	Com	2	I	-26570,10	14,03	0,02

Stresses by section parts

						Bend(-y) (kN/m²)	Bend(+z) (kN/m²)	Bend(-z) (kN/m²)	Cb(min/max) (kN/m²)	Cb1(-y+z) (kN/m²)	Cb2(+y+z) (kN/m²)	Cb3(+y-z) (kN/m²)	Cb4(-y-z) (kN/m²)
						0,0	-640,1	640,1	-3747,9	-3747,9	-3747,9	-3747,9	-3747,9
						0,0	-100,8	179,2	-4287,3	-4287,3	-4287,3	-4287,3	-4287,3
						0,0	-382,6	382,6	-4586,9	-4586,9	-4586,9	-4586,9	-4586,9
						0,0	-60,3	107,1	-4909,2	-4909,2	-4909,2	-4909,2	-4909,2
						0,0	-958,4	958,4	-4353,3	-4353,3	-4353,3	-4353,3	-4353,3
						0,0	-150,9	268,4	-5160,8	-5160,8	-5160,8	-5160,8	-5160,8
						0,0	-936,2	936,2	-4298,2	-4298,2	-4298,2	-4298,2	-4298,2
						0,0	-147,4	262,1	-5087,0	-5087,0	-5087,0	-5087,0	-5087,0
						0,0	179,8	-179,8	-4577,8	-4577,8	-4577,8	-4577,8	-4577,8
						0,0	28,3	-50,4	-4426,3	-4426,3	-4426,3	-4426,3	-4426,3
						0,0	659,4	-659,4	-5551,8	-5551,8	-5551,8	-5551,8	-5551,8
110	Com	2	I	-4996,2	-0,0	0,0	103,9	-184,6	-4996,2	-4996,2	-4996,2	-4996,2	-4996,2
111	Com	1	I	-5210,7	-0,0	0,0	-186,6	186,6	-5210,7	-5210,7	-5210,7	-5210,7	-5210,7
111	Com	2	I	-5367,9	-0,0	0,0	-29,4	52,3	-5367,9	-5367,9	-5367,9	-5367,9	-5367,9
112	Com	1	I	-5071,0	-0,0	0,0	-430,3	430,3	-5071,0	-5071,0	-5071,0	-5071,0	-5071,0
112	Com	2	I	-5433,6	-0,0	0,0	-67,8	120,5	-5433,6	-5433,6	-5433,6	-5433,6	-5433,6
113	Com	1	I	-5258,7	-0,0	0,0	316,1	-316,1	-5258,7	-5258,7	-5258,7	-5258,7	-5258,7
113	Com	2	I	-4992,3	-0,0	0,0	49,8	-88,5	-4992,3	-4992,3	-4992,3	-4992,3	-4992,3
114	Com	1	I	-6285,9	-0,0	0,0	673,5	-673,5	-6285,9	-6285,9	-6285,9	-6285,9	-6285,9
114	Com	2	I	-5718,4	-0,0	0,0	106,1	-188,6	-5718,4	-5718,4	-5718,4	-5718,4	-5718,4
115	Com	1	I	-5660,4	-0,0	0,0	-1096,0	1096,0	-5660,4	-5660,4	-5660,4	-5660,4	-5660,4
115	Com	2	I	-6583,9	-0,0	0,0	-172,6	306,9	-6583,9	-6583,9	-6583,9	-6583,9	-6583,9

Figure 30. Result tables of the composite section