

Tutorial

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

Civil

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Summary

In the initial cable pretension analysis of a PC cable-stayed bridge, initial cable forces are calculated based on the composite section properties of girders and slabs.

If a large magnitude of cable pretension is introduced at once 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, excessive moments may occur and the slope of the girder may become large, which can cause cracking of the slab.

In order to reflect this kind of construction features in the model, it is necessary to perform construction stage analysis reflecting the section properties before and after the composite action and appropriately distributed cable tensions over 1st and 2nd 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.

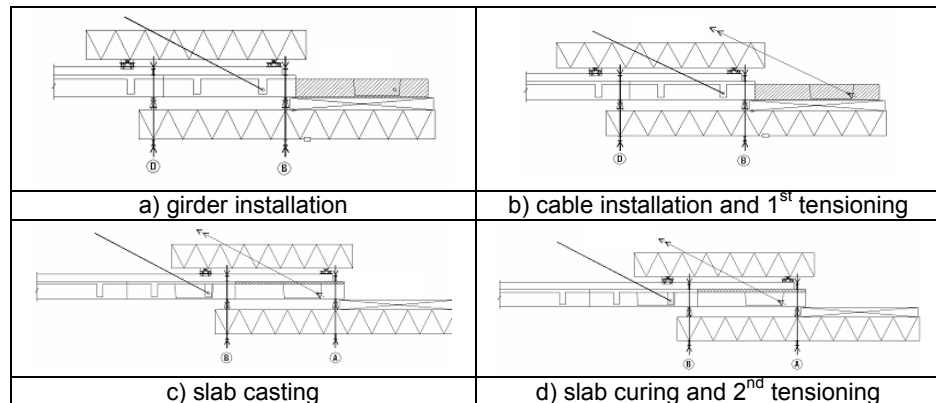


Figure 1. Construction Stage Cycle

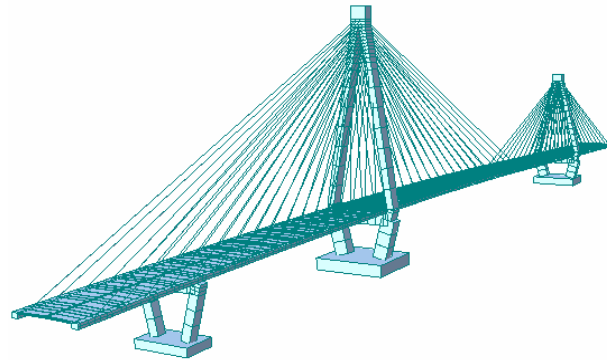


Figure 2. Analysis model

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 data for the bridge are as follows.

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

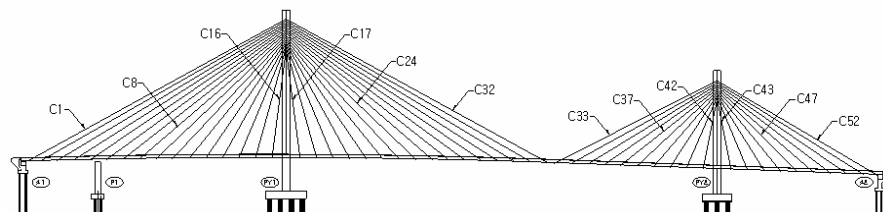


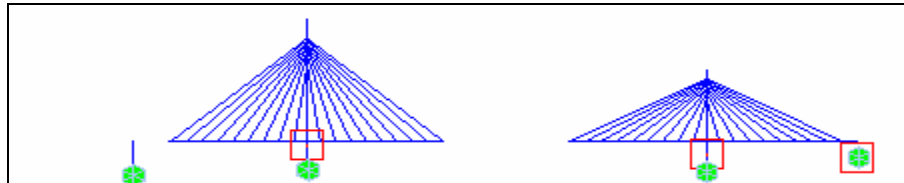
Figure 3. General Layout of Bridge Structure

Construction stages

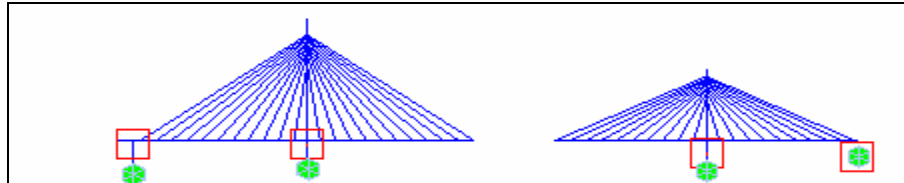
[CS10] Generating towers and piers



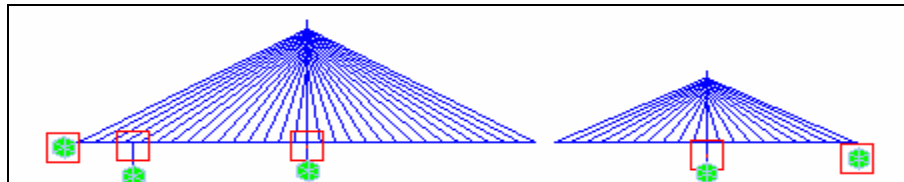
[CS11~CS64] Generating cantilever and support for abutment A2



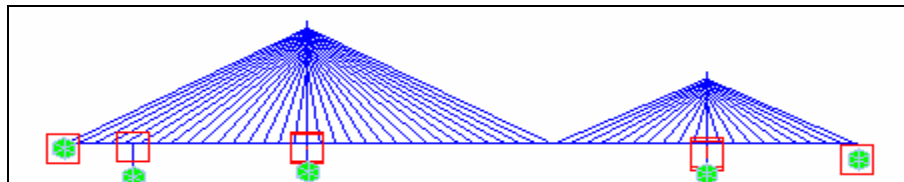
[CS65~CS78] Generating cantilever and support for piers



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



[Stage105~Stage114] Generating cantilever and key segment closure



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.

Model / Properties /  **Material**

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)

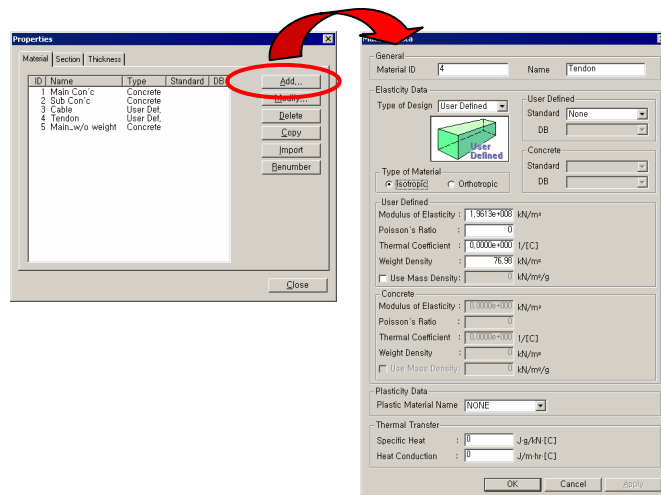


Figure 4. Material Property Input Dialog Box

Definition of time-dependent material properties

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

Model / Properties /  **Time Dependent Material (Creep/Shrinkage)**

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

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)**

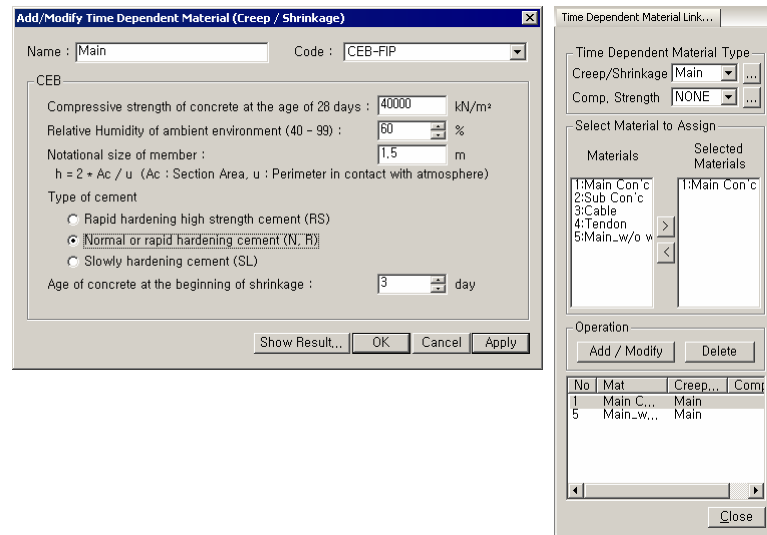
Age of concrete at the beginning of shrinkage>**(3)** ↵

Model / Properties /  **Time Dependent Material Link**

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

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

Operation> 



The figure shows two overlapping windows from a software application. The primary window is titled 'Add/Modify Time Dependent Material (Creep / Shrinkage)'. It contains several input fields: 'Name' is set to 'Main', 'Code' is 'CEB-FIP'. Under the 'CEB' section, 'Compressive strength of concrete at the age of 28 days' is 40000 kN/m², 'Relative Humidity of ambient environment (40 - 99)' is 60%, and 'Notational size of member' is 1.5 m. The 'Type of cement' section has three radio buttons: 'Rapid hardening high strength cement (RS)', 'Normal or rapid hardening cement (N, R)' (which is selected), and 'Slowly hardening cement (SL)'. The 'Age of concrete at the beginning of shrinkage' is set to 3 days. At the bottom are buttons for 'Show Result...', 'OK', 'Cancel', and 'Apply'. The secondary window, titled 'Time Dependent Material Link...', is partially visible on the right. It shows 'Time Dependent Material Type' as 'Creep/Shrinkage' and 'Comp. Strength' as 'NONE'. It has a 'Select Material to Assign' section with two lists: 'Materials' (1:Main Con'c, 2:Sub Con'c, 3:Cable, 4:Tendon, 5:Main_w/o w) and 'Selected Materials' (1:Main Con'c). At the bottom is a table with columns 'No', 'Mat', 'Creep...', and 'Comt'. The table contains two rows: row 1 with 'Main C...' and row 5 with 'Main_w...'. Below the table are 'Add / Modify' and 'Delete' buttons, and a 'Close' button at the very bottom.

Figure 5. Input time-dependent material properties

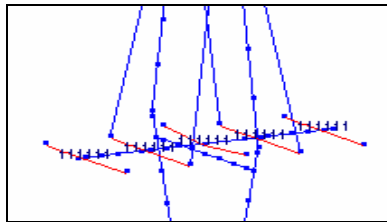
Definition of Structure Groups

Construction stages of the cantilevers

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

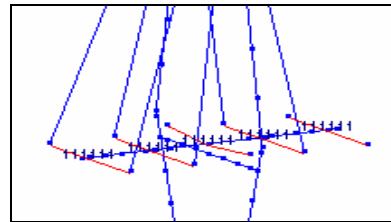
[Stage15]

Girder installation



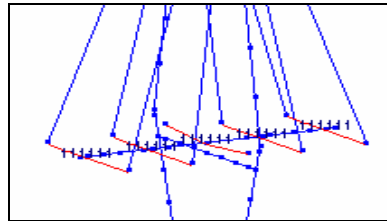
[Stage16]

Create side-span cables, 1st tensioning



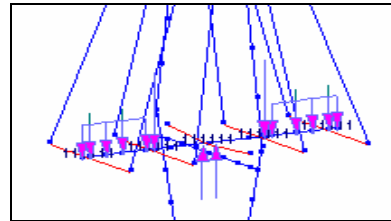
[Stage17]

Create mid-span cables, 1st tensioning



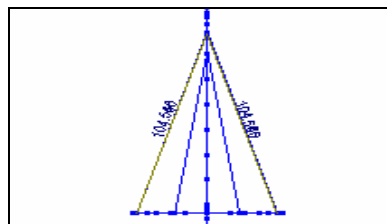
[Stage18]

Assign cross beam load and slab loads



[Stage19]

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



[Stage20]

Move form-traveler load

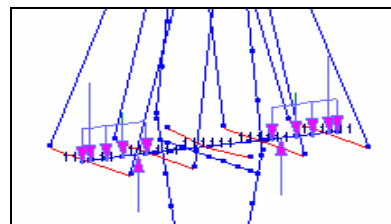


Figure 6. Typical cycle of segment installation

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 takes place. 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.

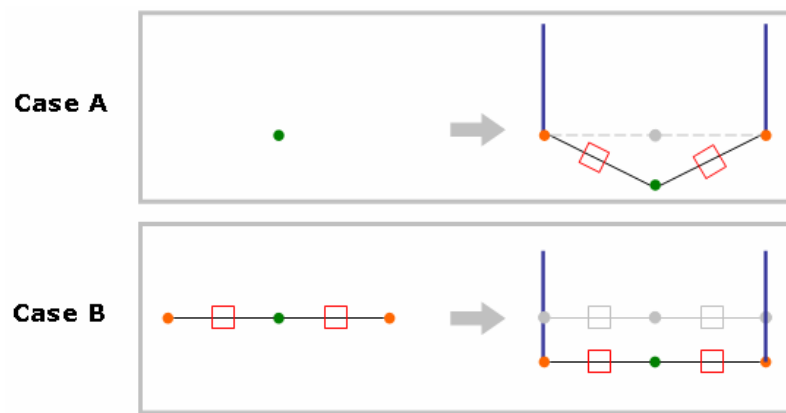


Figure 7. Activate girders and rigid links

The 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, the self weight of the slab needs to be assigned as a uniform beam load. Therefore, we input zero value for the weight density of the 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 girders retain the composite section properties after the slab concrete is cast. The 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.

Model / Group /  **Define Structure Group**

Girder_LS_2 

 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	815, 867
	girder_LM_2	167to170	818, 870
	girder_RM_2	260to263	841, 893
	girder_RS_2	270to273	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	-	-	-

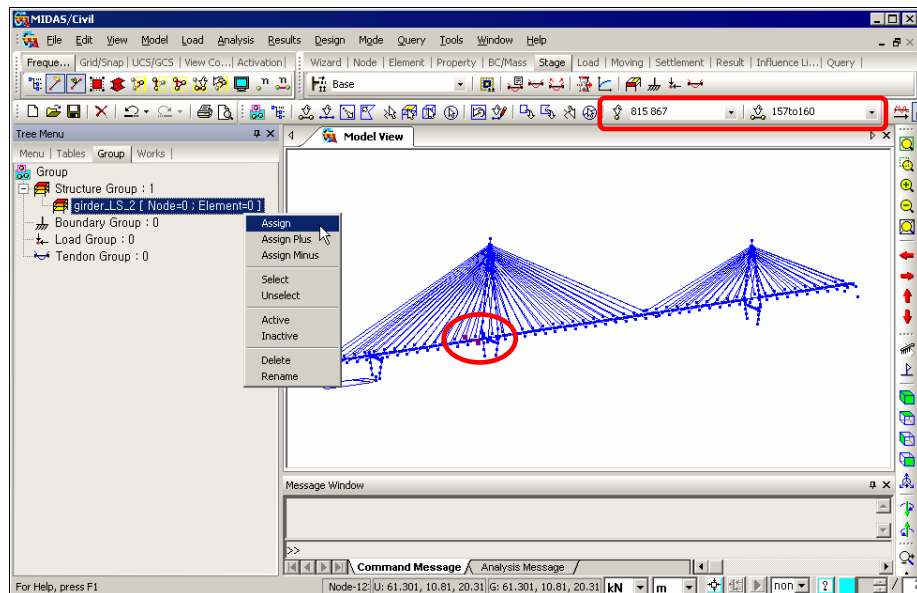


Figure 8. Assign the Structure Groups to nodes and elements

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 into MCT Command Shell.

Click on  ↵

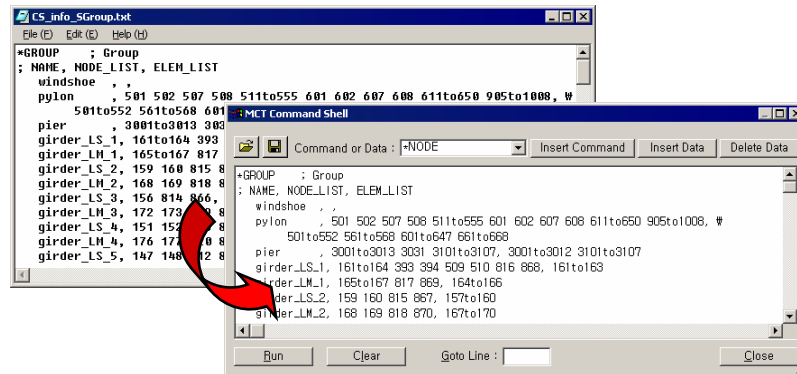


Figure 9. Input Group data by using MCT Command Shell

Definition of composite section for construction stage

It is necessary to tension the cables over two stages 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 sections for construction stages. This section data is not used for calculating the composite section properties, but used for selecting elements, displaying hidden sections, and defining the neutral axis for assigning tendon profiles.

By dividing the entire 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 the 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.

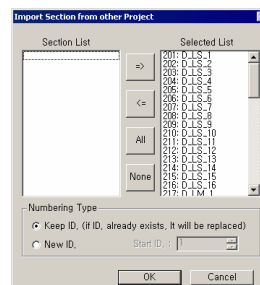
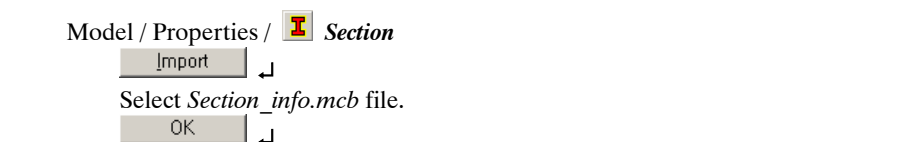
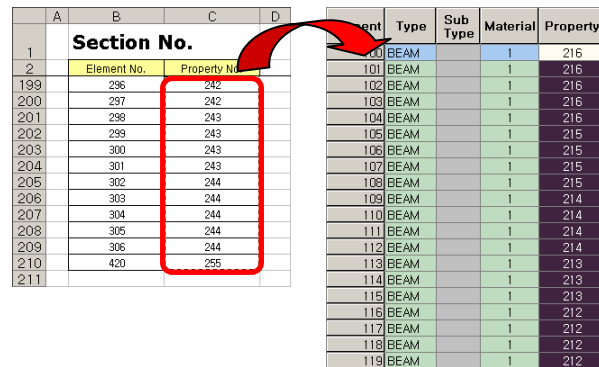


Figure 10. “Import Section from other project” dialog box

Change section property data of all the elements with the section data named after the activated stages. Copy section property data from the “2) 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.

Model / Properties /  **Elements Table**



Section No.				Element	Type	Sub Type	Material	Property
	Element No.	Property No.						
1				100	BEAM		1	215
2				101	BEAM		1	216
199	296	242		102	BEAM		1	216
200	297	242		103	BEAM		1	216
201	298	243		104	BEAM		1	216
202	299	243		105	BEAM		1	215
203	300	243		106	BEAM		1	215
204	301	243		107	BEAM		1	215
205	302	244		108	BEAM		1	215
206	303	244		109	BEAM		1	214
207	304	244		110	BEAM		1	214
208	305	244		111	BEAM		1	214
209	306	244		112	BEAM		1	214
210	420	255		113	BEAM		1	213
211				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.

The following steps show the procedure for defining “Composite Section for Construction Stage” in Stage 15.

Load/Construction Stage Analysis Data/  **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)**


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)**

Stiff>  (Copy the data from *CS_info.xls* and paste.)

 The girder becomes composite in Stage19 when the slab is cured.

 Refer to Figure 11 and input the stiffness by parts.

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

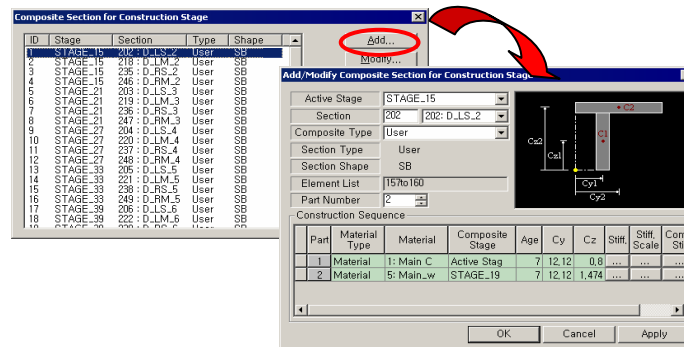


Figure 12. Composite Section for Construction Stage dialog box

Input the stiffness data of the girder and slab before composite action takes place, by using the data in the "2) Composite Stiff" tab of CS_info.xls file.

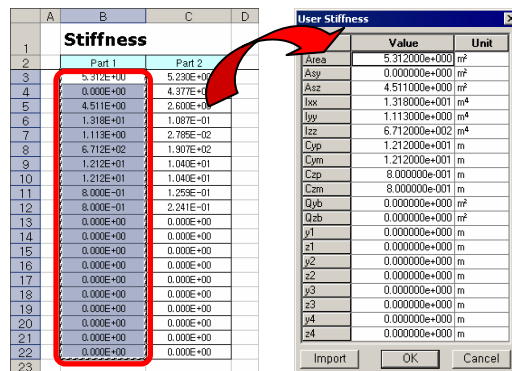


Figure 13. User Stiffness dialog box

Input the stiffness data of the girder after composite action takes place, 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  

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 the 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 anchorages of the cables. It is also used for modeling the towers and piers.

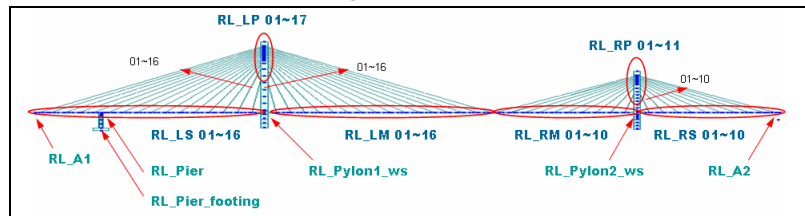


Figure 14. Boundary Groups of Rigid Link

Elastic Link is used for 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.

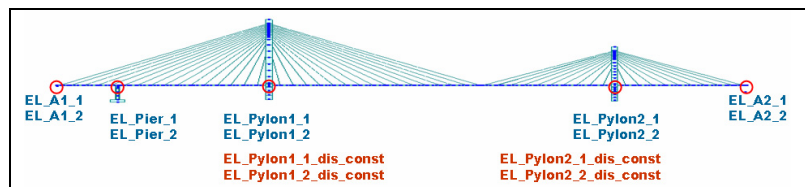


Figure 15. Boundary Groups of Elastic Link

"Support" command is used for assigning supports.

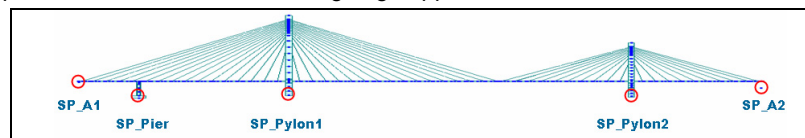


Figure 16. Boundary Groups of Support

Input Boundary Group

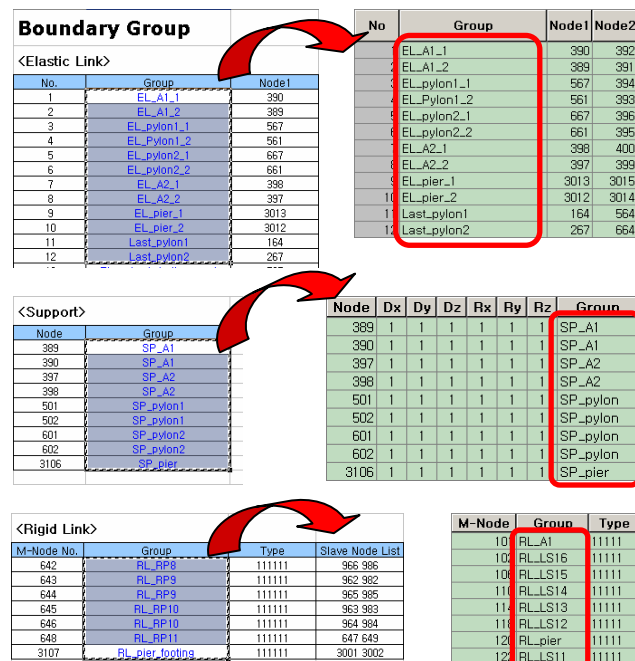
Define boundary groups and assign boundary conditions into the groups as per the construction stages. Copy data from *CS_info_BGroup.txt* file and paste it into MCT Command Shell in order to define the Boundary groups.

Tool / MCT Command Shell

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

Click on  ↵

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



Boundary Group		
<Elastic Link>		
No.	Group	Node1
1	EL_A1_1	390
2	EL_A1_2	389
3	EL_pylon1_1	567
4	EL_pylon1_2	561
5	EL_pylon2_1	667
6	EL_pylon2_2	661
7	EL_A2_1	398
8	EL_A2_2	397
9	EL_pier_1	3013
10	EL_pier_2	3012
11	Last_pylon1	164
12	Last_pylon2	267

No	Group	Node1	Node2
1	EL_A1_1	390	392
2	EL_A1_2	389	391
3	EL_pylon1_1	567	394
4	EL_pylon1_2	561	393
5	EL_pylon2_1	667	396
6	EL_pylon2_2	661	395
7	EL_A2_1	398	400
8	EL_A2_2	397	399
9	EL_pier_1	3013	3015
10	EL_pier_2	3012	3014
11	Last_pylon1	164	564
12	Last_pylon2	267	664

<Support>	
Node	Group
389	SP_A1
390	SP_A1
397	SP_A2
398	SP_A2
501	SP_pylon1
502	SP_pylon1
601	SP_pylon2
602	SP_pylon2
3106	SP_pier

Node	Dx	Dy	Dz	Rx	Ry	Rz	Group
389	1	1	1	1	1	1	SP_A1
390	1	1	1	1	1	1	SP_A1
397	1	1	1	1	1	1	SP_A2
398	1	1	1	1	1	1	SP_A2
501	1	1	1	1	1	1	SP_pylon
502	1	1	1	1	1	1	SP_pylon
601	1	1	1	1	1	1	SP_pylon
602	1	1	1	1	1	1	SP_pylon
3106	1	1	1	1	1	1	SP_pier

<Rigid Link>			
M-Node No.	Group	Type	Slave Node List
642	RL_RP8	111111	966 986
643	RL_RP9	111111	962 982
644	RL_RP9	111111	965 985
645	RL_RP10	111111	963 983
646	RL_RP10	111111	964 984
648	RL_RP11	111111	647 649
3107	RL_pier_topting	111111	3001 3002

M-Node	Group	Type
10	RL_A1	11111
102	RL_LS16	11111
106	RL_LS15	11111
110	RL_LS14	11111
112	RL_LS13	11111
116	RL_LS12	11111
120	RL_pier	11111
122	RL_LS11	11111

Figure 17. Assign Boundary Groups

Input temporary boundary conditions

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

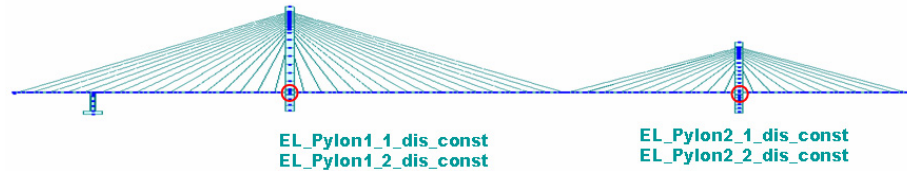

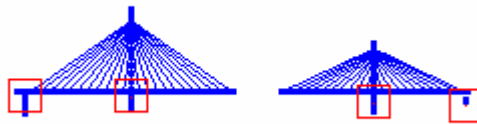
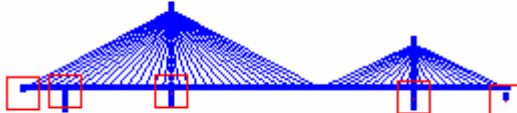


Figure 18. Positions of temporary restraints


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

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

Refer to the table below and input the 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

Model / Boundaries /  **Elastic Link**

Boundary Group Name>**EL_pylon1_1_dis_const** ; Option> **Add**

Link Type>**General** ; Part Number> **(2)**

SDx>**(0)** ; SDy>**(0)** ; SDz>**(0)**

SRx>**(1e11)** ; SRy>**(0)** ; SRz>**(1e11)**

2 Nodes>**(567, 394)**

2 Nodes>**(561, 393)**

2 Nodes>**(667, 396)**

2 Nodes>**(561, 395)**

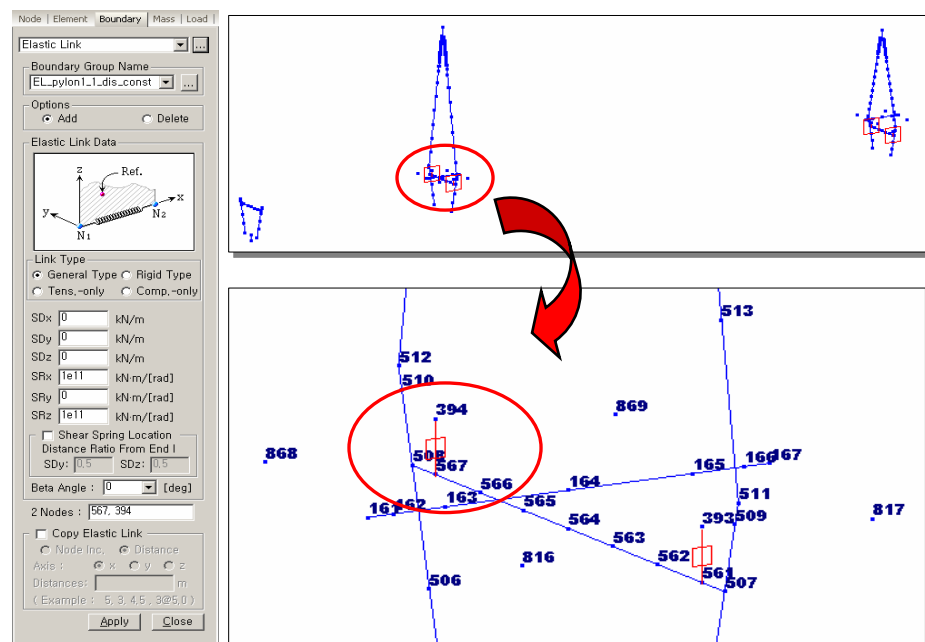


Figure 19. Temporary restraints

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_*	1 st tensioning before composite	Cable Pretension. 10 to 20% of initial cable force
Ten2_*	2 nd tensioning after composite	Cable Pretension. 80 to 90% of initial cable force
3rd Tension	Cable force adjustment after closure 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	-

The self weight of the structure and superimposed dead load are already inputted in the completed stage model. The 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 girders. If large pretension forces are introduced at one time before the composite action takes effect, not only will it be difficult to control the member forces, but it will also cause cracking of concrete. Therefore, 10 to 20% of the initial cable pretension is applied before the composite action takes place, 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  ↵

Input loadings considering construction stages

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

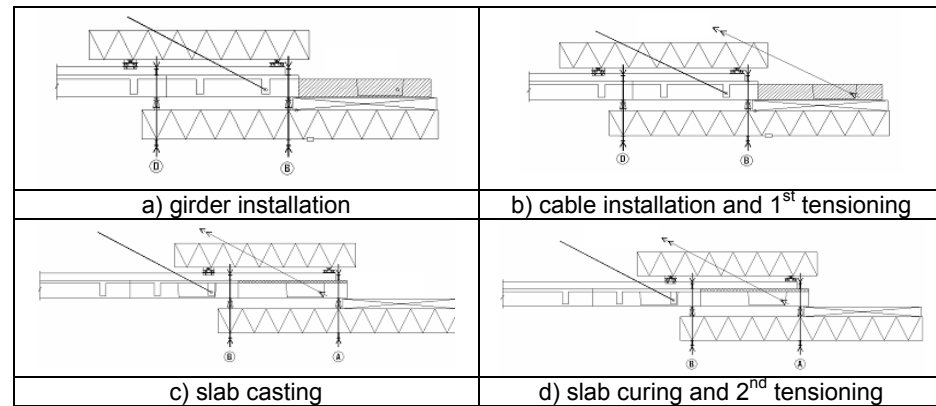


Figure 20. Construction Stage Cycle

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



Stage	Description	Load
Stage15	Girder installation	Self weight of girder
Stage16	Side-span cable installation	1 st tensioning
Stage17	Mid-span cable installation	1 st tensioning
Stage18	Slab and cross beam casting	Self weight of slab and cross beams
Stage19	Composite section properties	2 nd 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 1 st 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 the tables. The input method of loadings during Stage15 to Stage20 (described above) is given below.

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

Load /  **Self Weight**

Load Case Name>**Self Weight** ; Load Case Group> **Self Weight**
 X>(0) ; Y>(0) ; Z>(-1)  

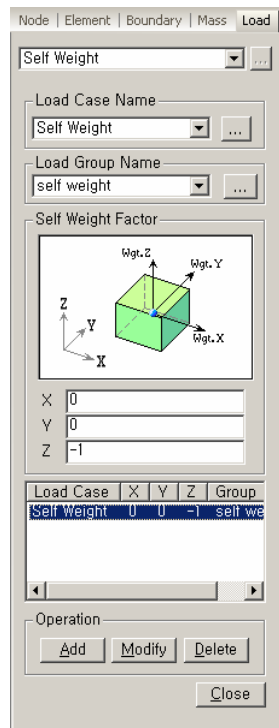






Figure 21. Self Weight dialog box

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

Load / 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)**  

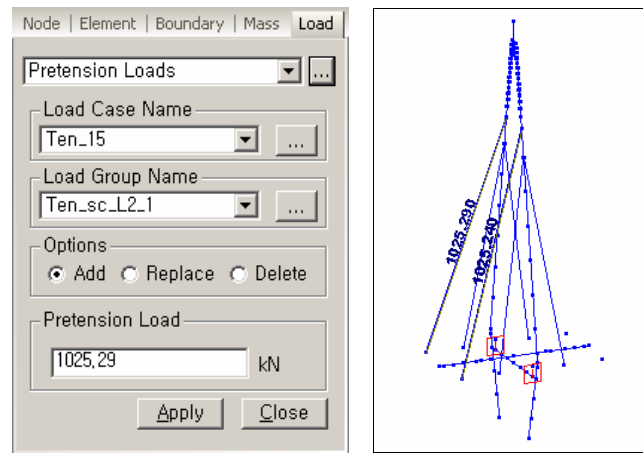


Figure 22. Input cable pretension forces

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


Load / Load Tables /  **Pretension Loads**


	A	B	C	D	E
1		Cable Pretension			
2		Element	Load Case	Tension(kN)	Load Group
203		1549	3rd Tension	784.53	Ten_sc_R_254647
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 the self weight of cross beams and slab using the “Nodal Loads” and “Beam Loads” commands.

Load / Nodal 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)  ↵

Load / Nodal Loads /  **Element Beam 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)  ↵

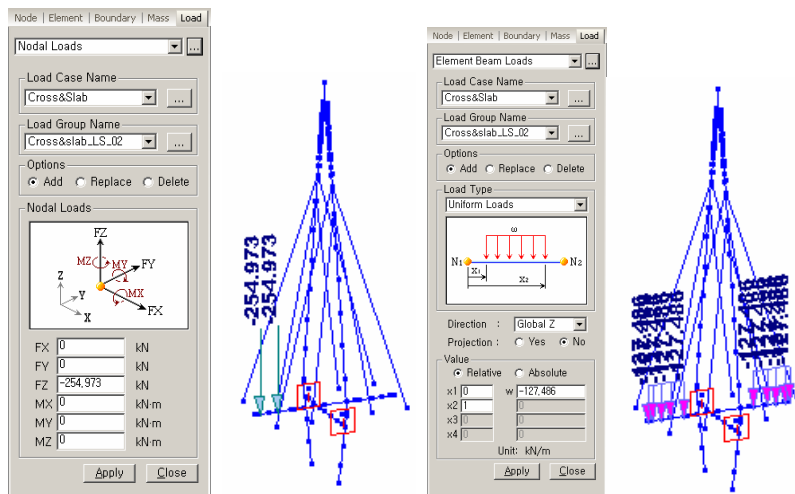




Figure 24. Input self weight of cross beams and slab

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 defined by the activation and deactivation of Structure Groups, Boundary Groups and Load Groups.

The following steps show the method for defining construction stage in Stage15.

Load / Construction Stage Analysis Data /  **Define Construction Stage**

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**

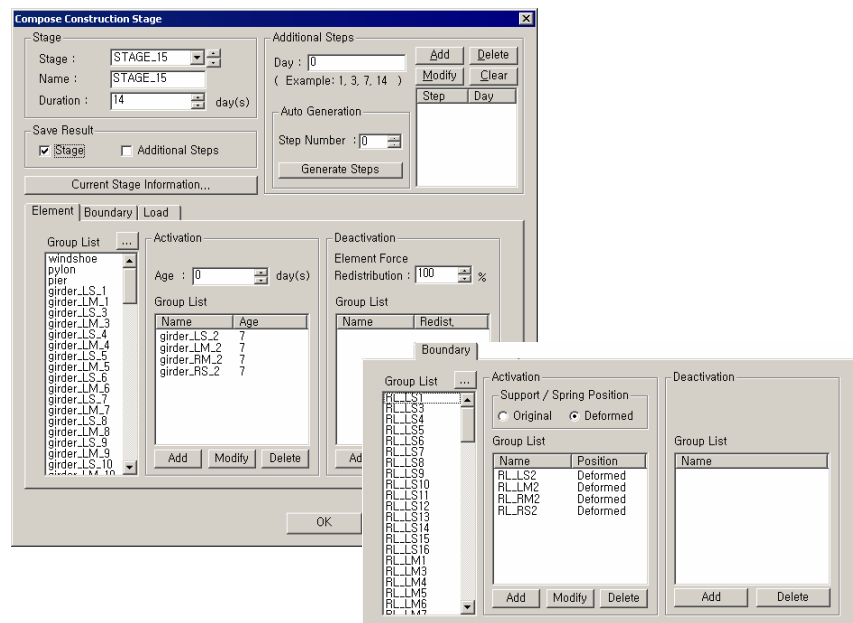


Figure 25. Compose Construction Stage dialog box

The entire 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)	
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  ↵

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 the 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.

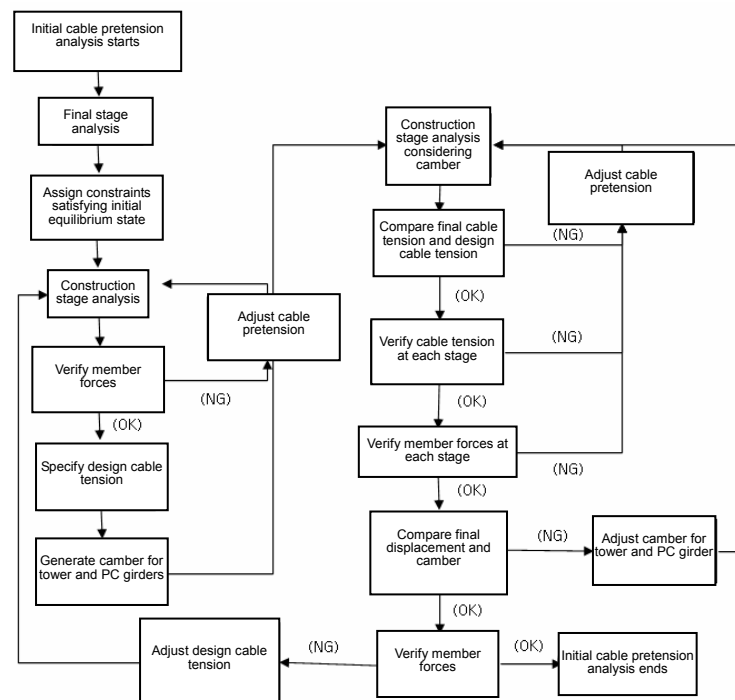



Figure 27. Iterative analysis procedure to obtain the optimal cable pretension

Review analysis results

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**

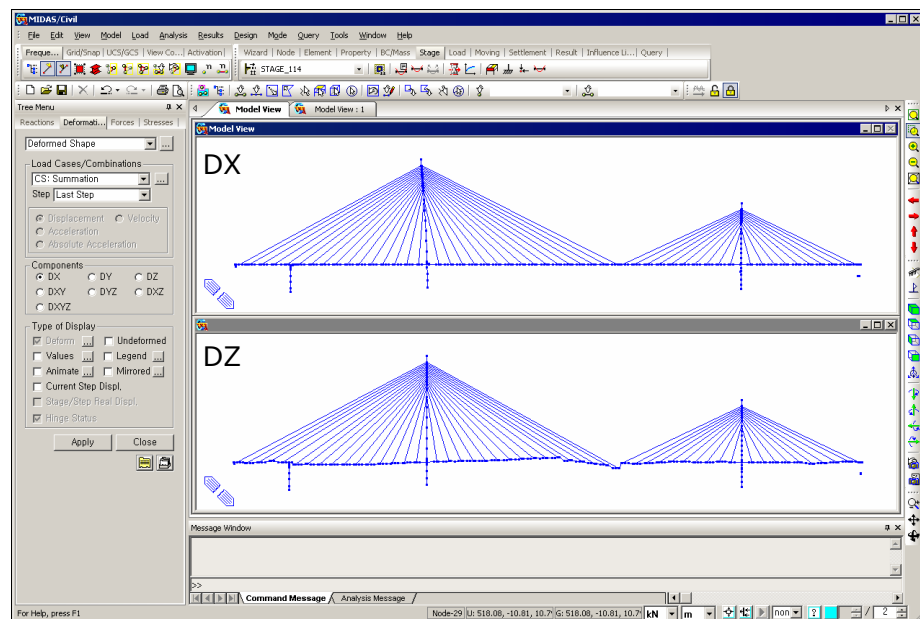



Figure 28. Deformed shapes

Review member forces

Review member forces in the towers and main girders.

Results / Deformation /  **Beam Diagrams**

Stage_114

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

Components> **My**

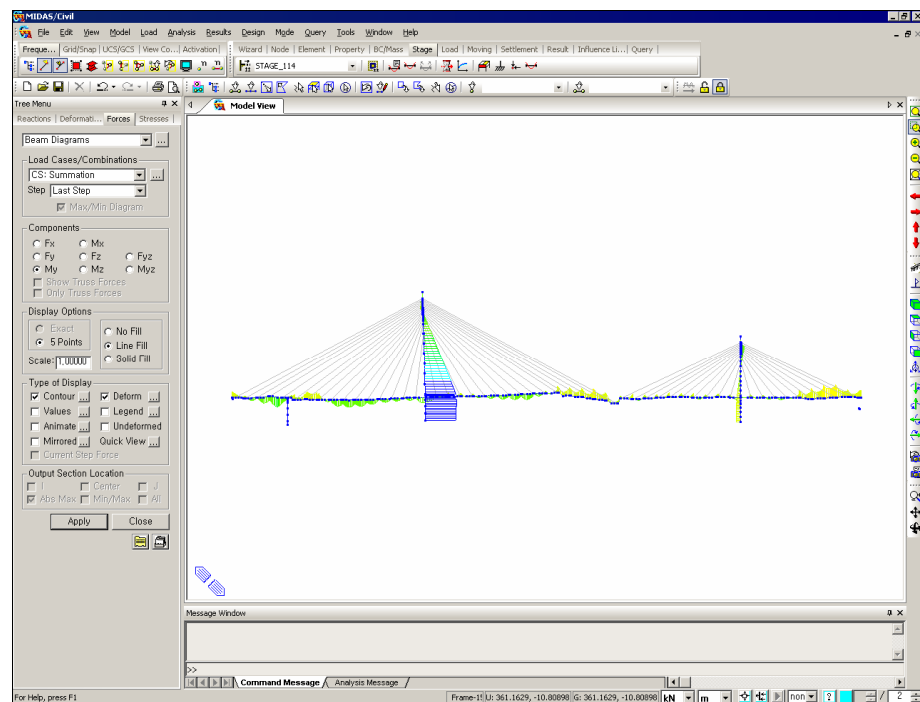


Figure 29. Bending moments

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	-28084.57	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	-32194.69	1845.41	0.23
108	Com	2	I	-24875.44	30.32	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	-950.4	950.4	-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
0.0	103.9	-184.6	-4996.2	-4996.2	-4996.2	-4996.2	-4996.2
0.0	-186.6	186.6	-5210.7	-5210.7	-5210.7	-5210.7	-5210.7
0.0	-29.4	52.3	-5367.9	-5367.9	-5367.9	-5367.9	-5367.9
0.0	-430.3	430.3	-5071.0	-5071.0	-5071.0	-5071.0	-5071.0
0.0	-67.8	120.5	-5433.6	-5433.6	-5433.6	-5433.6	-5433.6
0.0	316.1	-316.1	-5258.7	-5258.7	-5258.7	-5258.7	-5258.7
0.0	49.8	-88.5	-4992.3	-4992.3	-4992.3	-4992.3	-4992.3
0.0	673.5	-673.5	-6285.9	-6285.9	-6285.9	-6285.9	-6285.9
0.0	106.1	-188.6	-5718.4	-5718.4	-5718.4	-5718.4	-5718.4
0.0	-1096.0	1096.0	-5660.4	-5660.4	-5660.4	-5660.4	-5660.4
0.0	-172.6	306.9	-6583.9	-6583.9	-6583.9	-6583.9	-6583.9

Figure 30. Result tables of the composite section