midas Civil Advanced Tutorial

Nonlinear time history analysis of a bridge with seismic isolators

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Since this example focuses on the procedure for performing nonlinear boundary time history analysis, the modeling process will be omitted, and a completed model file will be opened.

The procedure for performing nonlinear boundary time history analysis with MIDAS/Civil is as follows:

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1. Define the properties of Nonlinear Links
2. Input Nonlinear Links
3. Enter the analysis conditions for Time History Analysis
4. Perform Nonlinear Time History Analysis.
5. Check the analysis results

For the definition of LRB, refer to the analysis manual.

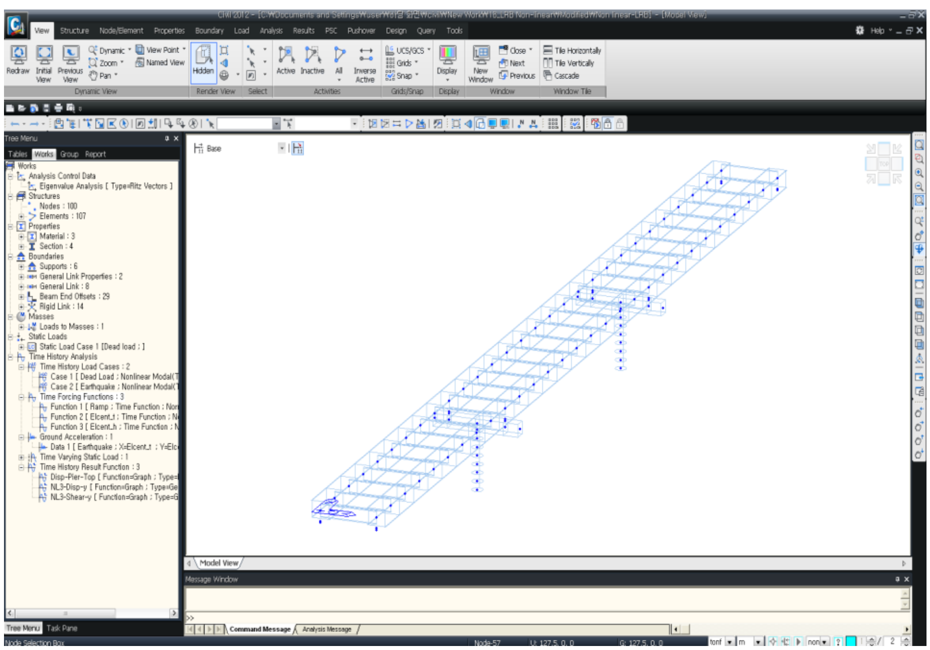


Figure 1. 3-D Bridge Model

Bridge Specifications

Bridge Spans: 45 m + 50 m + 45 m = 140 m

Bridge Width: 11.4 m

Bridge Type: Steel Box Girder

Lanes: Three lanes

Nonlinear analysis of a bridge with LRB Isolator elements

Modeling

Open a new file (***New Project***) and save (***Save***) the file as **'Non linear-LRB'**.
Assign the unit system as '**tonf**' and '**m**'. The unit system can be changed any time during the input process depending on the types of data entries.

/ ***New Project***
/ ***Save*** **(Non linear-LRB)**

Tools / ***Unit System***
Length> **m**; Force>**tonf** ↵

Model Import

In this tutorial, we will import a model (Structural Model.mct) completed with geometry and material/section data.

/ Import / ***MIDAS/Civil MCT File***
open>**Structural Model.mct** ↵

Non linear link definition

Nonlinear Link (LRB) properties

Abutment (LRB-A)

	Vertical	Longitudinal	Transverse
Direction	Dz	Dx	Dy
Nonlinear	No	Yes	Yes
Linear Properties			
Effective Stiffness	479100(design)	336.1(iteration)	336.1(iteration)
Effective Damping	0	0	0
Nonlinear Properties			
Stiffness	-	1099	1099
Yield Strength	-	15.69	15.69
Post yield Stiffness ratio	-	0.08917	0.08917

Pier (LRB-P)

	Vertical	Longitudinal	Transverse
Direction	Dz	Dx	Dy
Nonlinear	No	Yes	Yes
Linear Properties			
Effective Stiffness	1289000(design)	702.2(iteration)	702.2(iteration)
Effective Damping	0	0	0
Nonlinear Properties			
Stiffness	-	2204	2204
Yield Strength	-	33.63	33.63
Post yield Stiffness ratio	-	0.0862	0.0862

Nonlinear Link (LRB) property input

Input the properties of Lead Rubber Bearing isolators.

Boundary > General Link > ***General Link Properties***

Define General Link Properties> Add

Name **(LRB-A)**; Application type> **Force**; Property Type>**Lead Rubber Bearing Isolator**

Self Weight>Total Weight **(0)**

Linear Properties

DOF>**Dx, Dy, Dz**(on) ; Effective Stiffness **(479100)**, **(336.1)**, **(336.1)**

Nonlinear Properties

DOF>**Dy**(on) ; Properties... Stiffness (k) **(1099)**

Yield Strength **(15.69)**; Post Yield Stiffness Ratio(r) **(0.08917)**

Hysteretic Loop Parameter (α) **(0.5)**

Hysteretic Loop Parameter (β) **(0.5)**↵

DOF > **Dz**(on) ; Properties... (The procedure is identical to that for **Dy)**

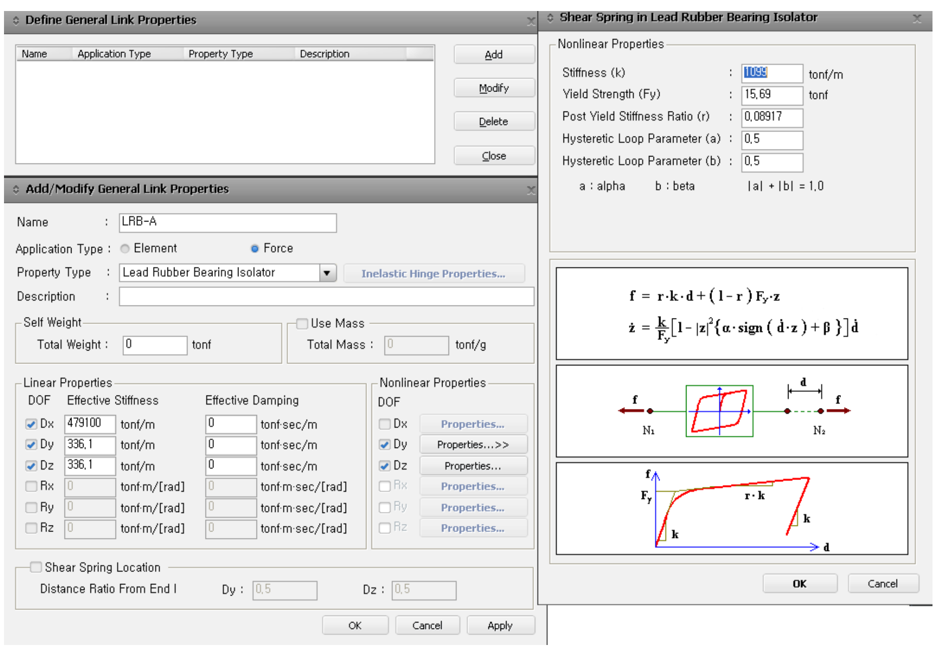


Figure 2. LRB properties Input for Abutment

Input the properties of LRB for Pier.

Boundary > General Link > ***General Link Properties***

Define General Link Properties> Add

Name **(LRB-P)**; Application type> **Force**; Property Type>**Lead Rubber Bearing Isolator**

Self Weight>Total Weight **(0)**

Linear Properties

DOF>**Dx, Dy, Dz**(on) ; Effective Stiffness **(1289000)**, **(702.2)**, **(702.2)**

Nonlinear Properties

DOF>**Dy**(on) ; Properties... Stiffness (k) **(2204)**

Yield Strength **(33.63)** ; Post Yield Stiffness Ratio(r) **(0.0862)**

Hysteretic Loop Parameter (α) **(0.5)**

Hysteretic Loop Parameter (β) **(0.5)**↵

DOF>**Dz**(on) ; Properties... **(**The procedure is identical to that for **Dy)**

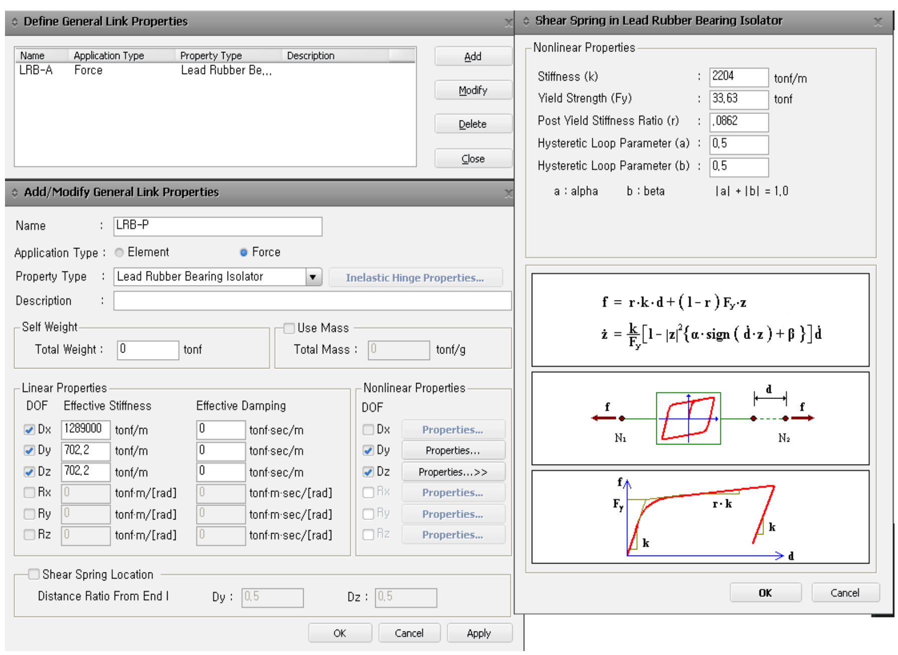


Figure 3. LRB properties Input for Pier

Create Nonlinear Links (LRB)

Create Nonlinear Link (LRB) elements on the supports.
There are a total of 8 locations to input LRB. The order in which the input takes place is from the left abutment to the left pier, the right pier and the right abutment.

Create nonlinear links at the left Abutment.

Boundary / ***General Link***

General Link Property>**LRB-A**

Zoom Window (Zoom in the left abutment where LRB-A is to be created)

2 Nodes **(93, 95)**

2 Nodes **(94, 96)**

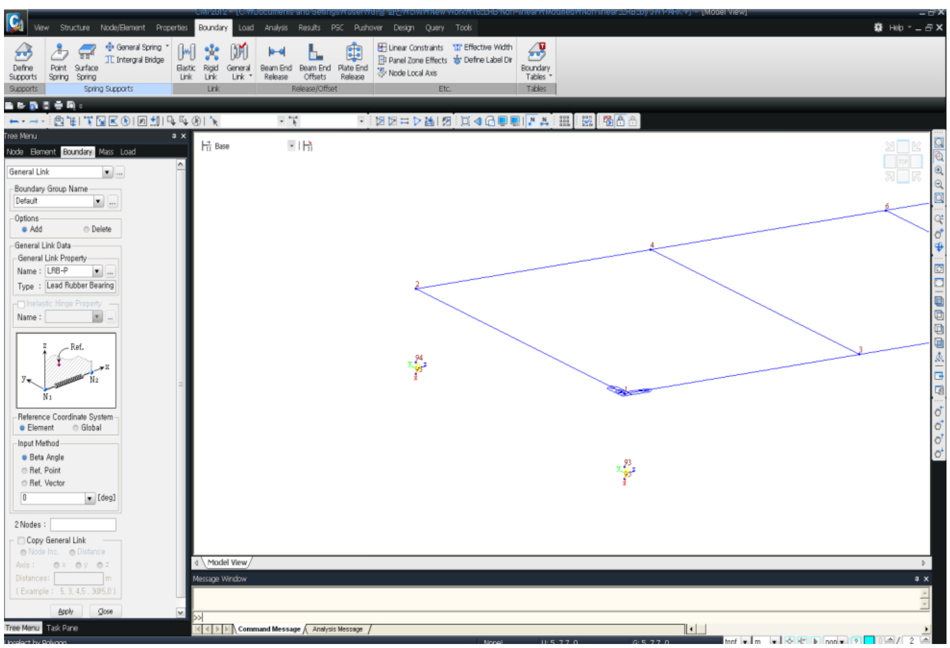


Figure 4. Nonlinear link Input at the left Abutment

Create nonlinear links at the left Pier

Boundary / ***General Link***

General Link Property>**LRB-P**

Zoom Window (Zoom in the left Pier where LRB-P is to be created)

2 Nodes **(59, 63)**

2 Nodes **(60, 64)**

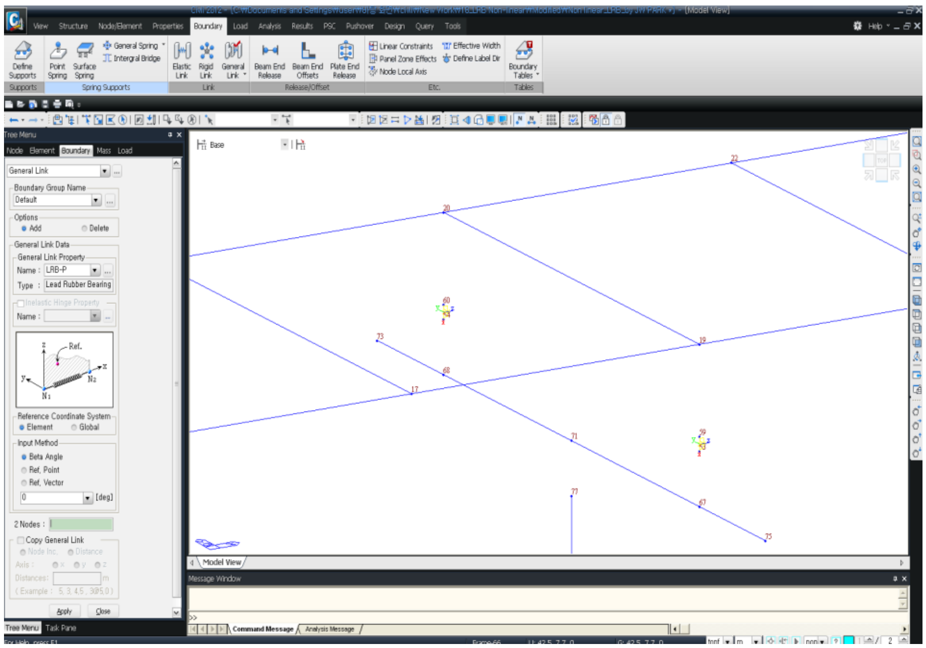


Figure 5. Nonlinear link Input at the left Pier

Create nonlinear links at the right Pier

Boundary / ***General Link***

General Link Property>**LRB-P**

Zoom Window (Zoom in the right Pier where LRB-P is to be created)

2 Nodes **(61, 65)**

2 Nodes **(62, 66)**

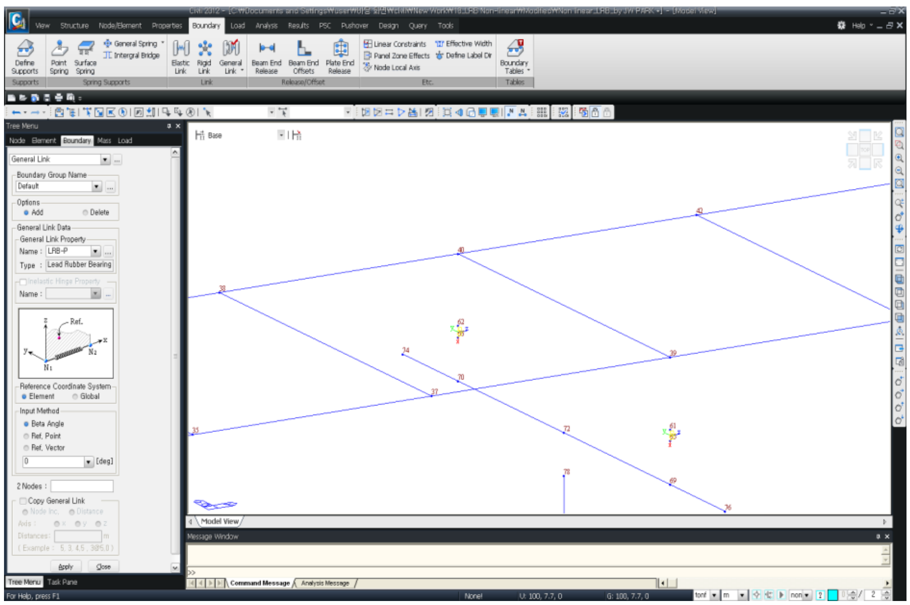


Figure 6. Nonlinear link Input at the right Pier

Create nonlinear links at the right Abutment.

Boundary / ***General Link***

General Link Property>**LRB-A**

Zoom Window (Zoom in the right abutment where LRB-A is to be created)

2 Nodes **(97, 99)**

2 Nodes **(98, 100)**

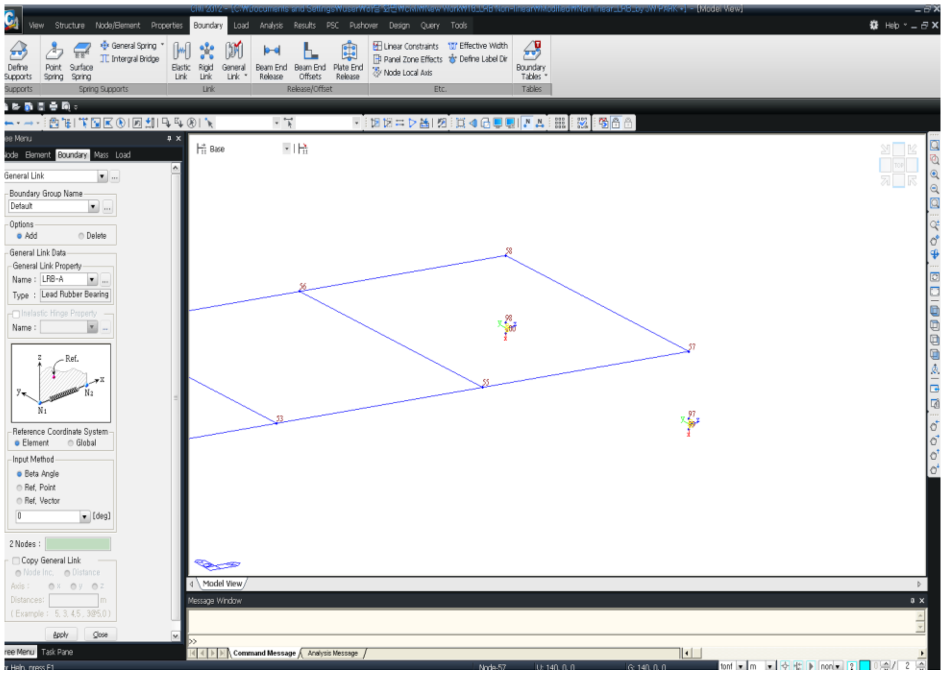


Figure 7. Nonlinear link Input at the right Abutment

Mass input

Three types of masses can be defined, which are Structure Mass, Nodal Mass and Load to Mass. Detailed applications for each type of mass are explained in the online manual.
When nonlinear modal time history analysis with general link is performed, mass should be assigned to all nodes to which the general links are connected. In this example, Structure Mass and Load to Mass are used.

Structure Mass

Convert the self-weight of the elements modeled in the structure into masses.

Structure / ***Structure Type***

Conversion of Structure Self weight into Masses

Convert to X, Y, Z ↵

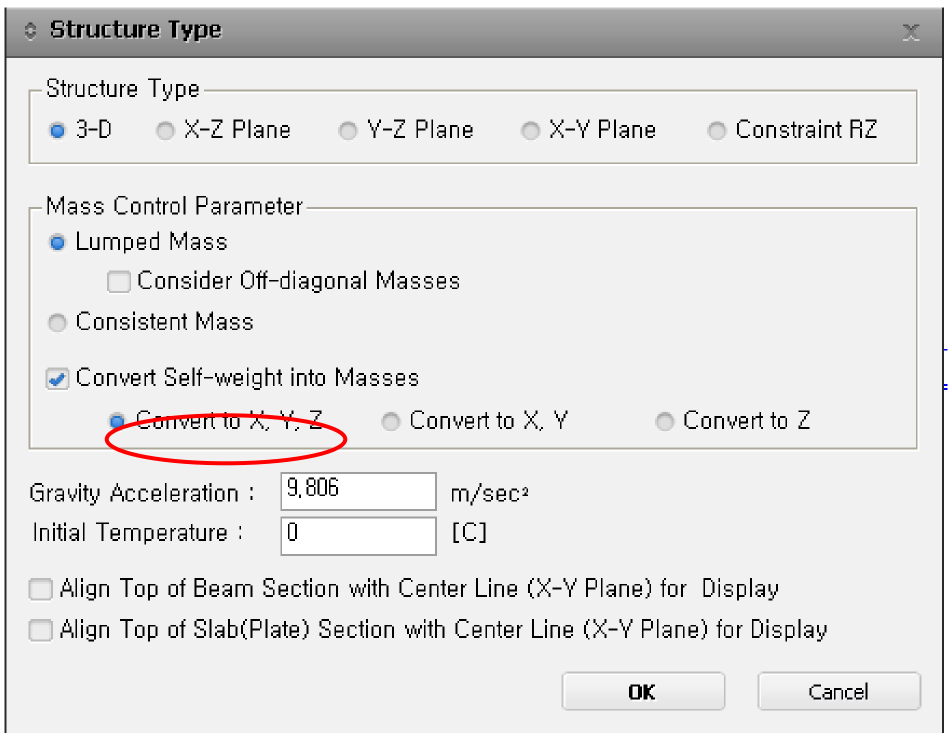


Figure 8. Automatic conversion of the self-weight of the structure into Mass

Load to Mass

This converts beam loads to masses.

Load / Static Loads Load Type / ***Loads to Masses***

Mass Direction>**X, Y, Z**

Load Type for Converting>**Beam Load (Line, Typical)** (on)

Gravity **(9.806)**; Load Case>**Deadload**

Scale Factor **(1)**; **Add** ↵

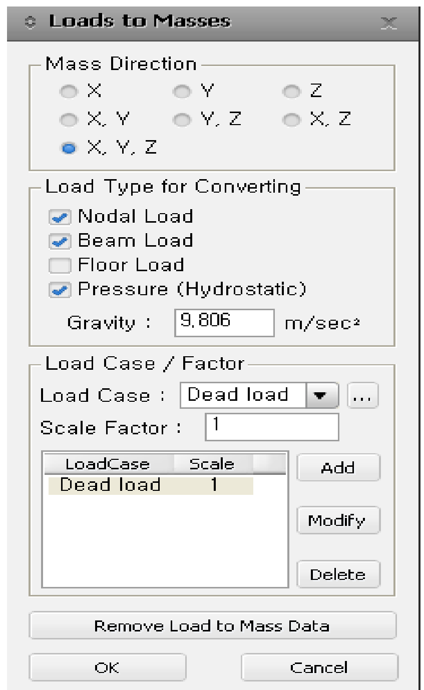


Figure 9. Mass Input using Loads to Masses function

Input for Time History Analysis Data

Time History Function

Unlike linear analysis, the principle of superposition does not apply to nonlinear analysis. This example pertains to analysis for both dead load and seismic load. But it is not correct to linearly combine the separate results due to each load afterwards. For time history analysis, we need to consider both loads acting simultaneously.

In order to reflect the dead load in time history analysis, the ***Time Varying Static Load*** function is used. This function basically creates a condition in which the dead load is in place at the time of performing time history analysis for seismic load. A 'Ramp' function is assigned to the static dead load and the El Centro data is used for the seismic load.

We first define a ramp Time Forcing Function to represent the dead load.

Load / Seismic Load Type / Time History Analysis Data / ***Time History Functions***

Add Time Function

Function Name **(Ramp)**

Enter the data as shown in Figure 10.

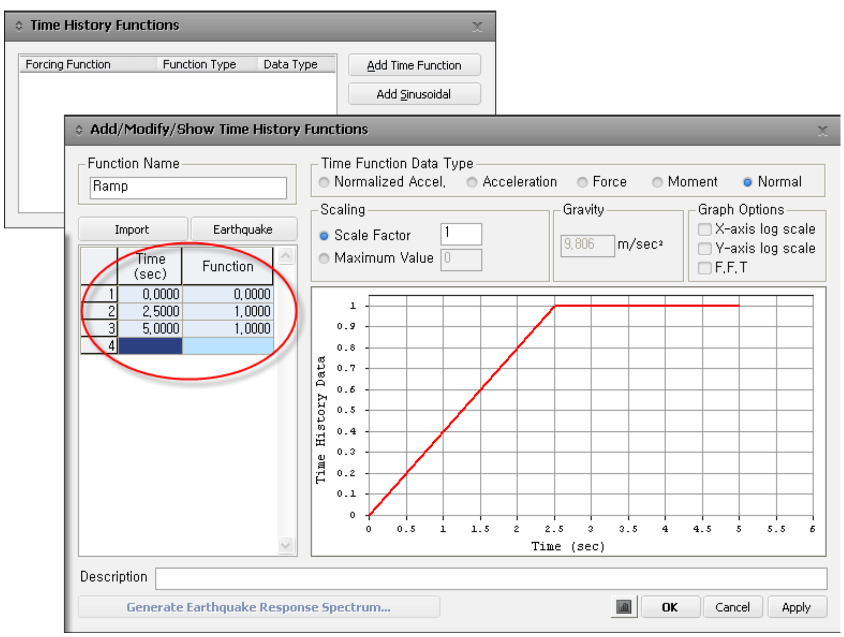


Figure 10. Definition of Time Forcing Function for static dead load

The seismic load data is created using the El Centro seismic data.

Load / Seismic Load Type / Time History Analysis Data / ***Time History Functions***

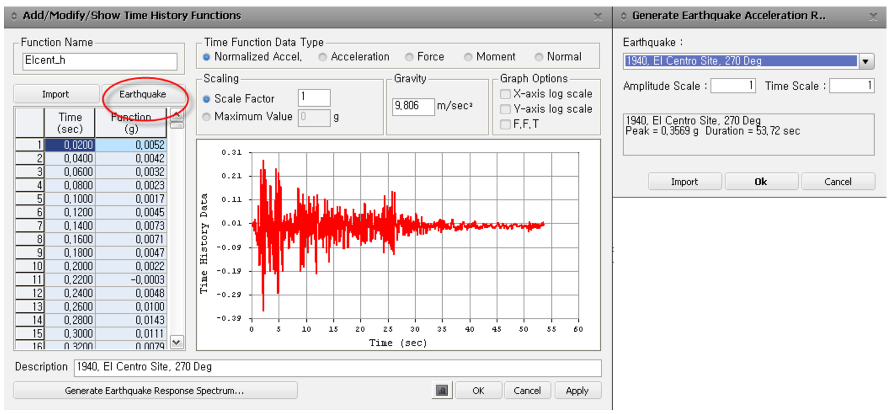
Add Time Function

Earthquake

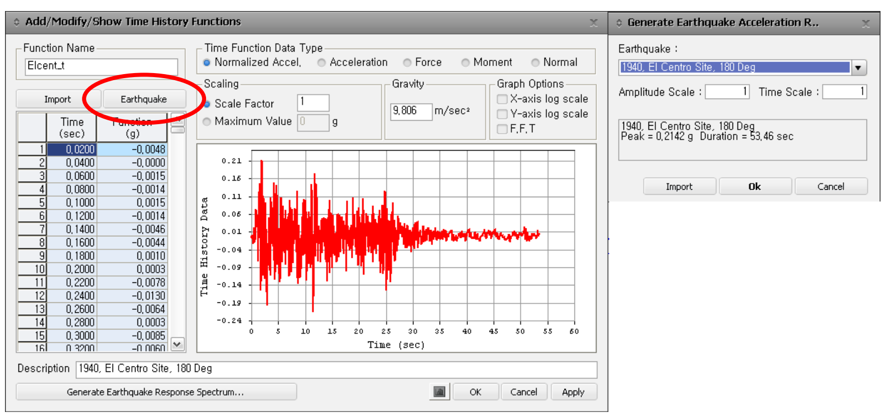
Earthquake>**1940 EL Centro Site, 270 Deg > OK > Apply**

Earthquake

Earthquake>**1940 EL Centro Site, 180 Deg > OK > OK**



(a) El Centro Site 270Deg (Peak: 0.3569g)



(b) El Centro Site 180Deg (Peak: 0.2142g)

Figure 11. El Centro seismic data Input

Eigenvalue Analysis Data Input

There are two methods for performing time history analysis, which are Modal Superposition method and Direct Integration method. In this example, we will use the Modal Superposition method. Eigenvalue analysis control data are specified before defining Time History Load Cases. For eigenvalue analysis, MIDAS/Civil provides the Eigen Vectors method and Ritz Vectors method. Ritz Vectors method is strongly recommended when nonlinear modal time history analysis is performed with general links. In this case, general link force vectors must be included in the starting load vectors in order to include the deformations of general link to calculate the starting load vectors. In this example, we will use the Ritz Vectors method with checking on "Include GL-link Force Vector" option.

Load / Seismic / Time History Analysis Data / ***Load Cases*** Eigenvalue Analysis Control...

(or Analysis>***Eigenvalue Analysis Control***)

Ritz Vectors

Starting Load Vectors

Load Case>**Deadload**; Number of Generations>**1** Add

Load Case>**Ground Acc X**; Number of Generations>**8** Add

Load Case>**Ground Acc Y**; Number of Generations>**8** Add ↵

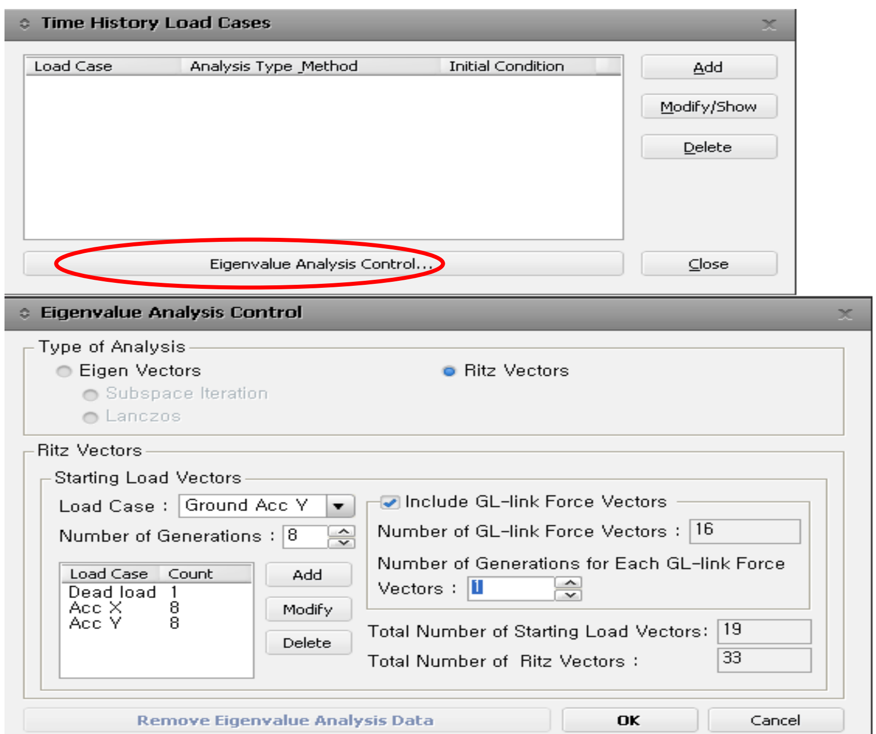


Figure 12. Eigenvalue Analysis Control data input

Time History Load Cases

Dead load and seismic load are separately entered in Time History Load Cases.

Defining Dead Load in Time History Load Case

Load / Seismic / Time History Analysis Data / ***Load Cases***

ADD

Load Case Name **(Dead Load)**

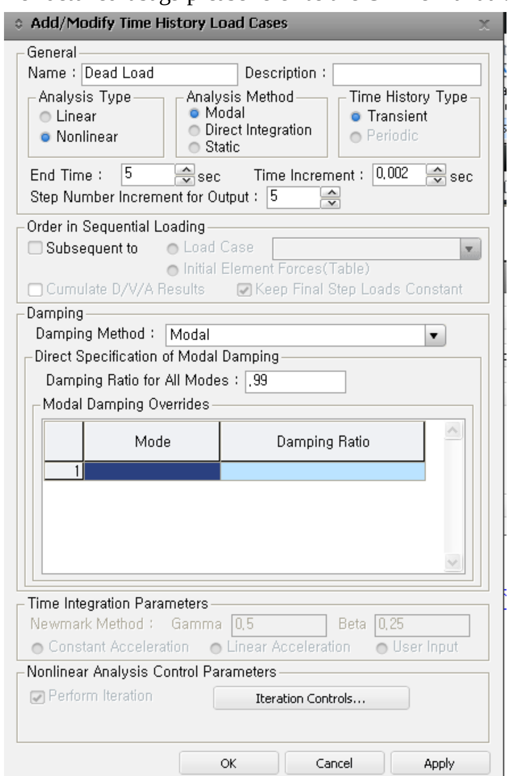
End Time **(5)**; Time Increment **(0.002)**

Step Number Increment for Output **(5)**

Analysis Type>**Nonlinear**; Analysis Method>**Modal**

Damping>**Direct Specification of Modal Damping – Damping Ration for All Modes**>Damping Ratio for All Modes **(0.99)** ↵

For detailed usage please refer to the Online manual.



The 99% Damping Ratio assumes that the total damping from the beginning (zero second) to the end time is 99%. This is to induce fast convergence of static load considered in nonlinear analysis using the Time Varying Static Load.

End Time: The finish time until which the time history analysis is required. Duration of seismic data should be considered to define End Time.

Time Increment: The time increment of a time history analysis significantly affects the accuracy of the analysis results. A common rule of thumb for determining the time increment is to use at least 1/10 of the smaller of the period of the time forcing function or the natural frequency of the structure. Since the period of the highest mode is 0.02, 0.002 is used here.

Step Number Increment for Output: Analysis time step required for producing results of the time history analysis. Results produced at the interval of (Number of Output Steps x Time Increment). If 1 is specified, analysis results are produced at every 0.002 sec. If 5 is specified, analysis results are produced at every 0.01 sec. For a reasonable analysis speed, 5 is used.

Figure 13. Time History Load Case dialog box

Define Time History Load Case for Earthquake Load.

Load / Time History Analysis Data / ***Load Cases***

Add

Load Case Name **(Earthquake)**

End Time **(50)**; Time Increment **(0.002)**

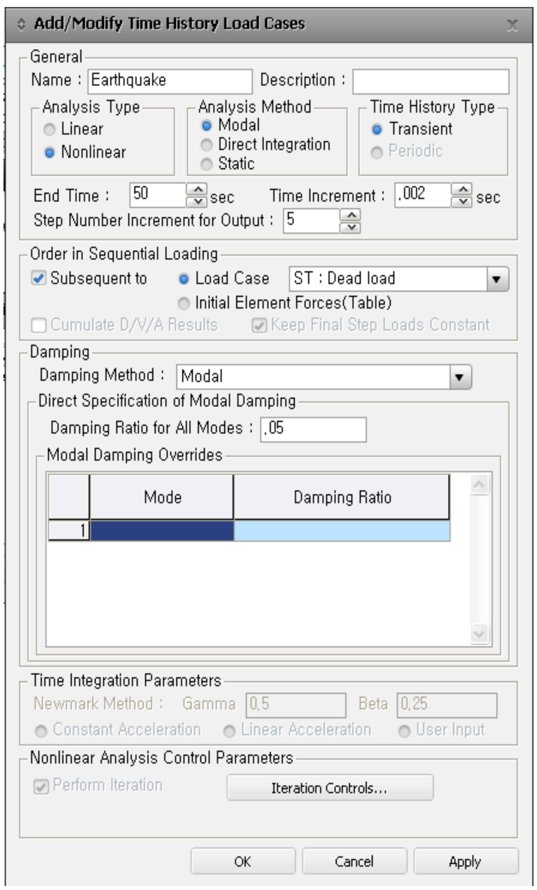
Step Number Increment for Output **(5)**

Analysis Type>**Nonlinear**; Analysis Method>**Modal**

Order in sequential Loading>Subsequent to>**Load Case**>**Dead Load**

Damping>Damping Method>**Modal**

Damping Ratio for All Modes **(0.05)** ↵



Order in Sequential Loading: Data related to a sequence of consecutively loaded multiple time history analysis conditions

Subsequent to:
Select a time history analysis condition previously defined, which precedes the time history analysis condition currently being defined. The Analysis Type and Analysis Method for the current time history analysis condition must be consistent with those for the preceding load condition. From the preceding analysis condition, displacement, velocity, acceleration, member forces, variables for the state of hinges and variables for the state of nonlinear link elements are obtained and used as the initial condition for analysis. However, in the case of loadings, the loading at the final state of the preceding analysis condition is assumed to constantly remain in the current analysis condition only when "Keep Final Step Loads Constant" is checked on.

Nonlinear direct integration method can be used in this example. It does not require Ritz vector analysis but it would take more analysis time and sensitive to the time increment.

Figure 14. Time History Load Case dialog box

Ground Acceleration

Assign the direction of the El Centro ground acceleration. The maximum accelerations of the two seismic data, Elcent_t and Elcent_h in Time History Function are 0.2142g and 0.3569g respectively. The seismic data, which pertains to the greater of the two maximum accelerations, is input in the direction of the 1st mode of vibration. For reference, the 1st vibration mode of this model is in the Y direction, which is in the transverse direction of the bridge. The greater acceleration data (Elcent_h) is thus applied in the Y direction.

Load / Seismics / Time History Analysis Data / ***Ground Acceleration***

Time History Load Case Name>**Earthquake**

Function for Direction-X

Function Name>**Elcent_t**

Function for Direction-Y

Function Name>**Elcent_h**

Operations>Add ↵

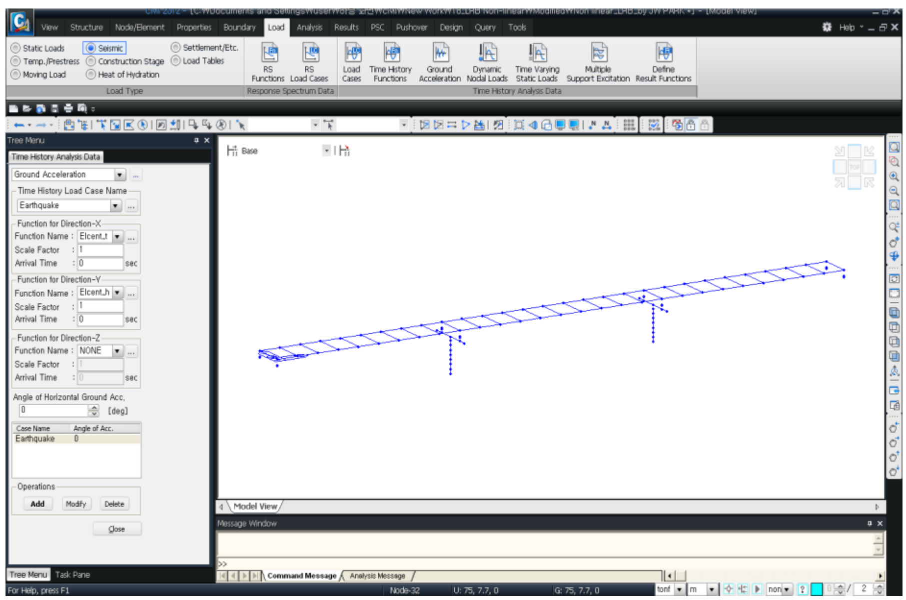


Figure 15. Definition of the directions of Earthquake data

Time Varying Static Loads

In order to apply dead load to Time History Analysis, Time Varying Static Load is entered.

Load / Seismic / Time History Analysis Data / ***Time Varying Static Load***

Time History Load Case Name>**Dead Load**

Static Load>**Dead Load**

Function>Function Name>**Ramp**

Operations>Add ↵

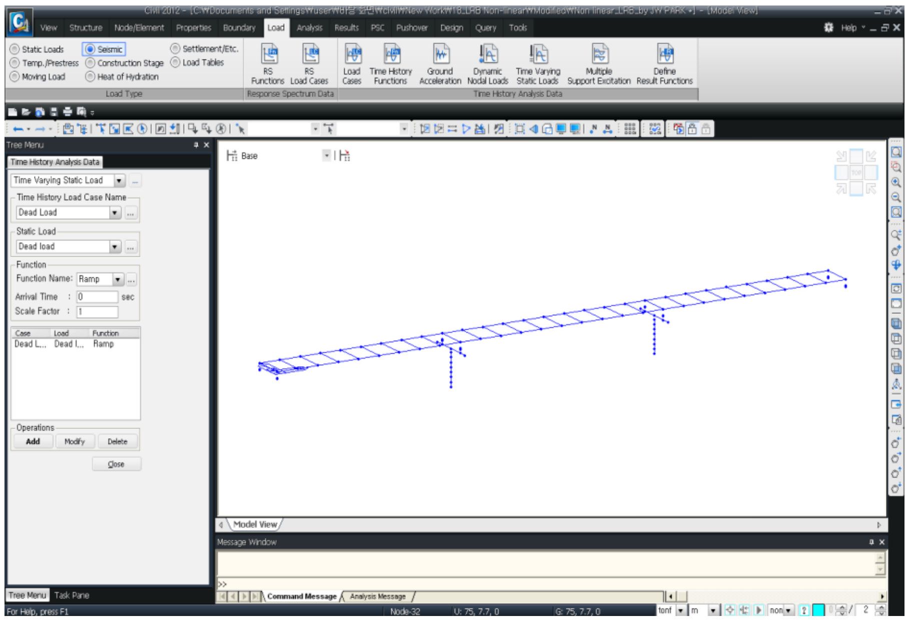


Figure 16. Varying Static Loads input

Analysis

Since the input for boundary nonlinear analysis is completed, analysis can be now performed.

Analysis / ***Perform Analysis***

Checking Results

Time history graph

Check the shear force acting on an LRB isolator and deformation of the upper part of a pier using the Time History Graph function.

Initial View
View / **Display** or **Display from the Icon Menu**
Boundary tab
General Link (on) ; **General Link Number** (on) ↵

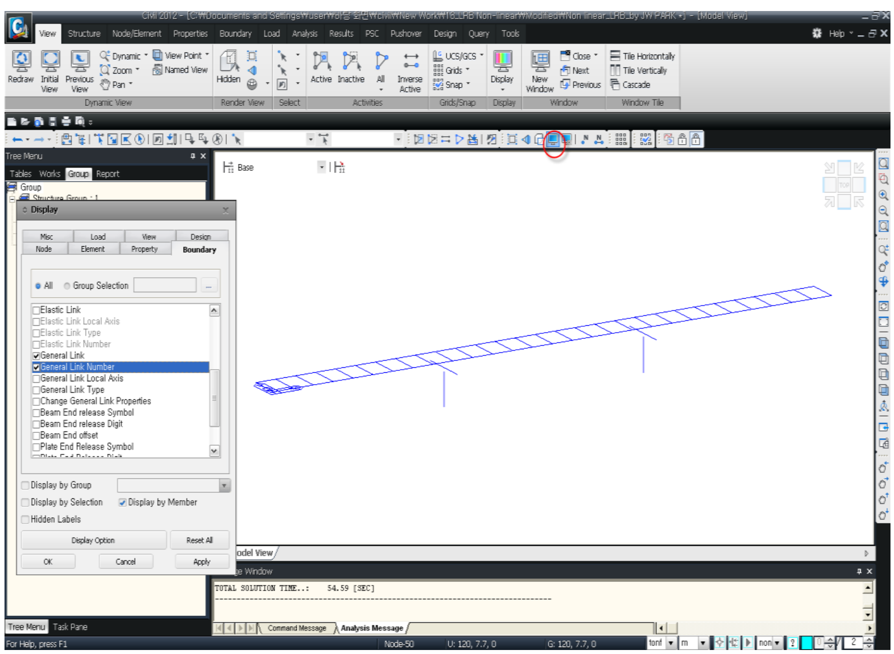


Figure 17. Initial Model View and Display of Nonlinear Link numbers

Check the horizontal force and deformation acting on General Link No.3 in the longitudinal direction.

Result / Time History Result / T.H Graph/Text / ***Time History Graph***

Define/Modify Function>**General Link Deform/Force**

Add New Function

Name **(NL3-Shear-y)**

NL-Link No>**5(nl:61,n2:65)** ; Type>**J-Node Force**

Components>**F-y** ; Time History Load Case>**Earthquake** ↵

Add New Function

Name **(NL3-Disp-y)**

NL-Link No>**3(nl:59,n2:63)** ; Type>**Deformation**

Components>**D-y** ; Time History Load Case>**Earthquake** ↵

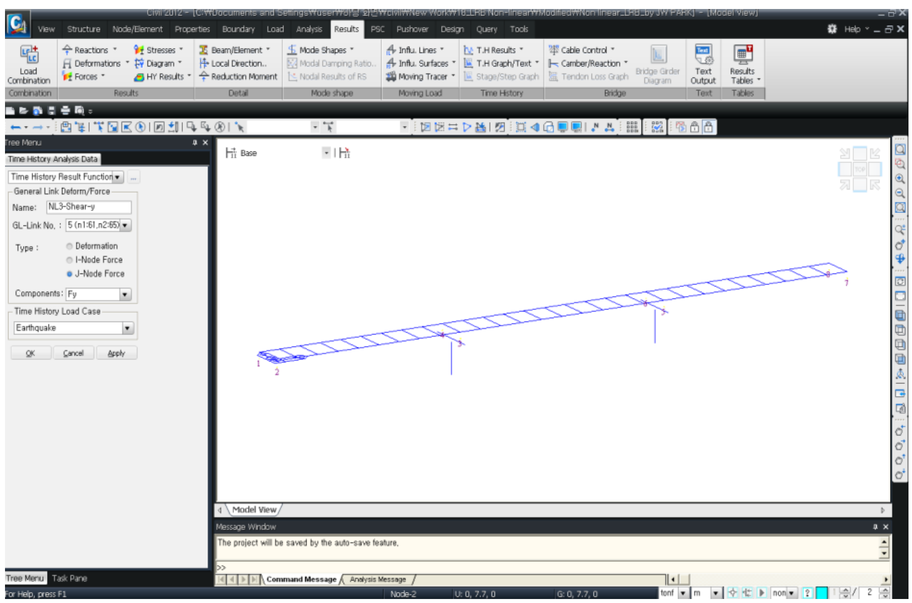


Figure 18. Horizontal force and deformation acting on General link No.3

Print the hysteresis Graph of the LRB isolator.

Result / Time History Result / T.H Graph/Text / ***Time History Graph***

Check Function to Plot> **NL3-Shear-y** (on)

Click **Add from list**

Horizontal Axis> **NL3-Disp-y**

Type of Display

X Axis Decimal Pt. **(4)**; Y Axis Decimal Pt. **(1)**

Type>**Time History Graph** ↵

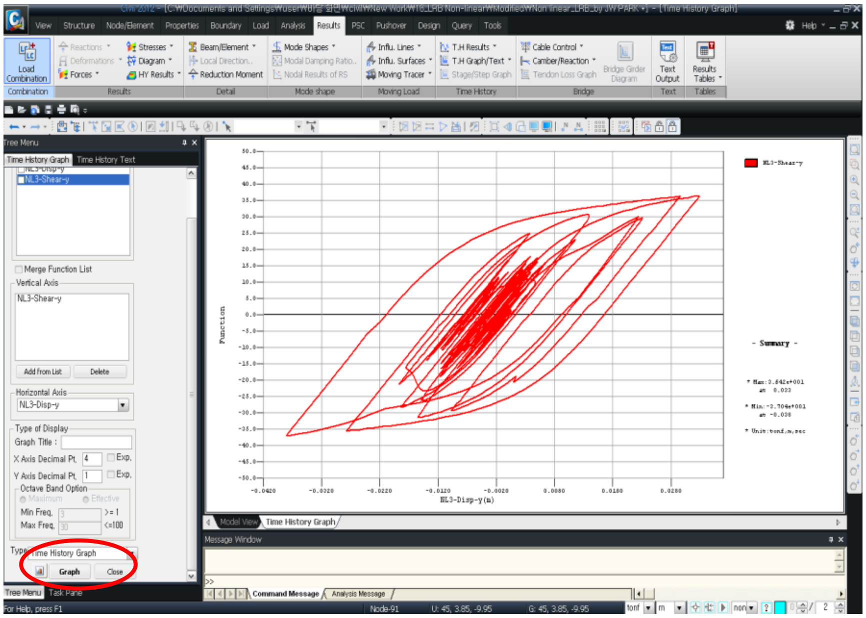


Figure 19. Hysteresis graph of LRB isolator

Check the displacement at the top of a pier by Time History Graph.

Result / Time History Result / T.H Graph/Text / ***Time History Graph***

Define/Modify Function>**Disp/Vel/Accel**

Add New Function

Name: **(Disp-Pier-Top)**

Node Number: **(77)**

Type of Result>**Displ.**

Components: >**DX**

Time History Load Case>**Earthquake**

Included Mode Number> **All** ↵

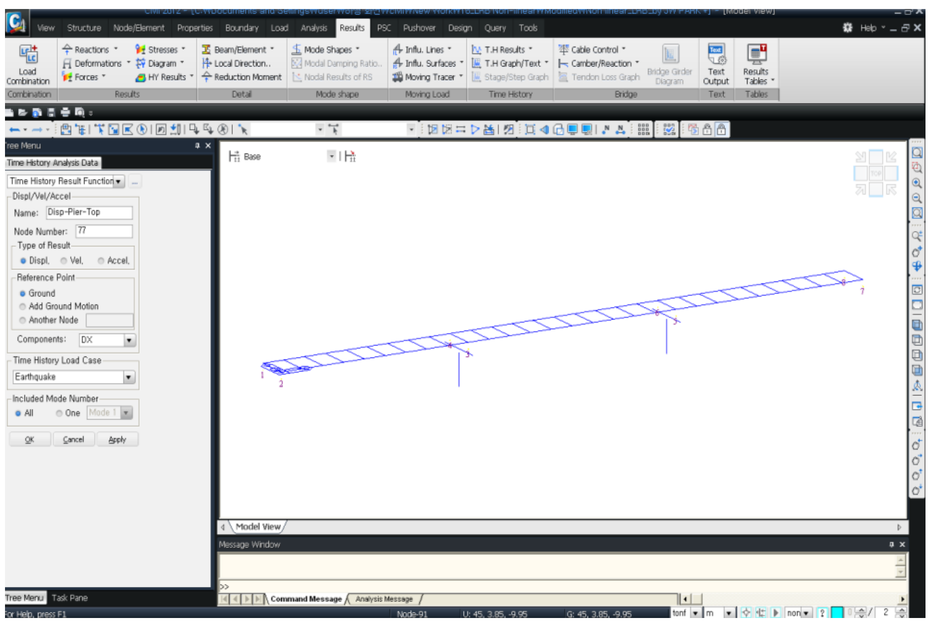


Figure 20. Assignment of parameters for display of deformation at pier top

Check the displacement result at the pier top by Time History Graph

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Result / Time History Result / T.H Graph/Text / ***Time History Graph***

Check Function to Plot> **Disp-Pier-Top** (on)

Click **Add from list**

Horizontal Axis> **Time**

Type of Display

X Axis Decimal Pt. **(1)** ; Y Axis Decimal Pt. **(4)**

Type:>**Time History Graph** ↵

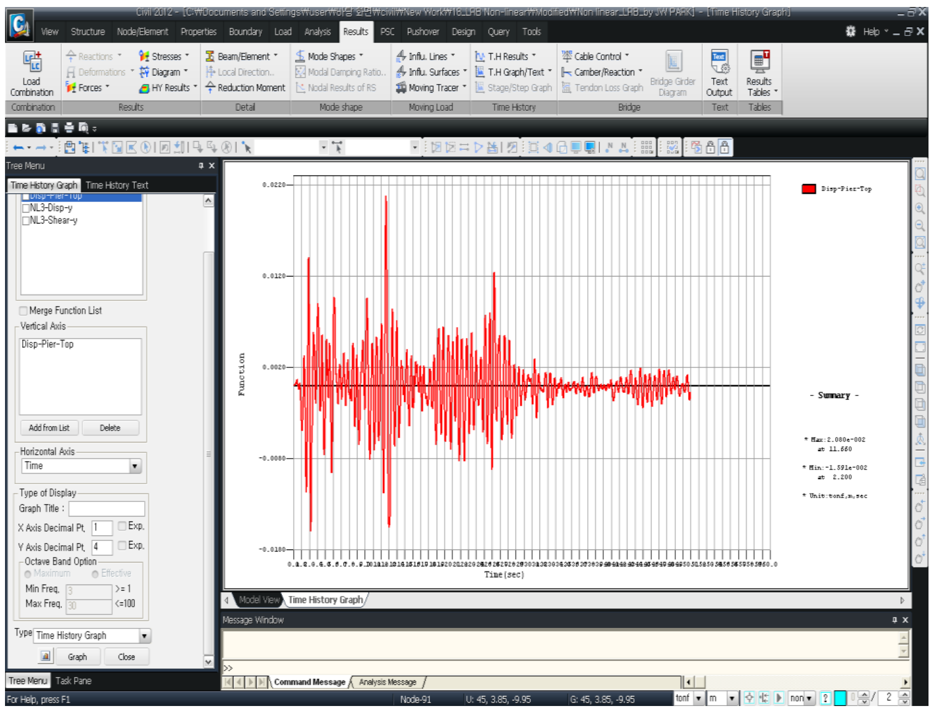

Figure 21. Displacement hysteresis graph at the pier top (node 77)