

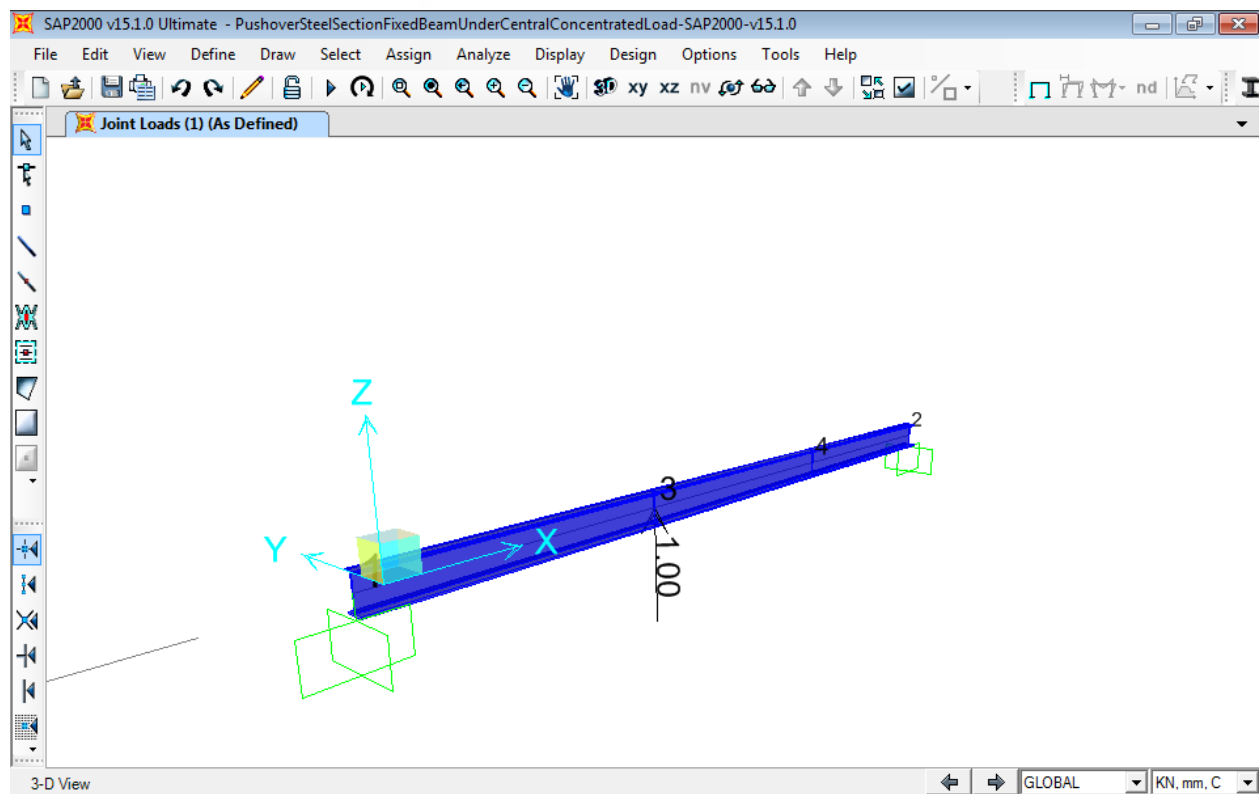
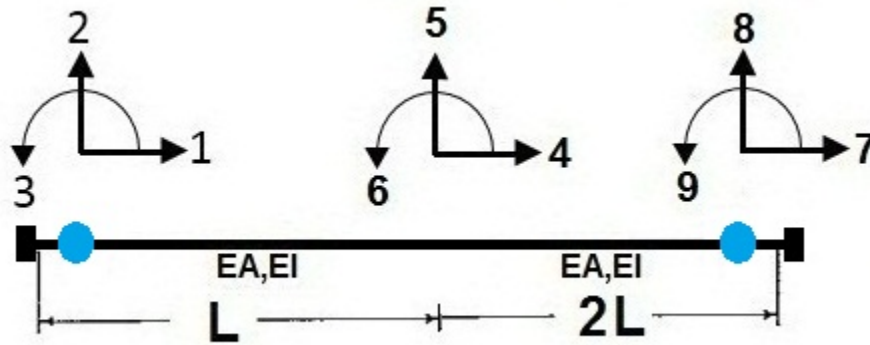
>> IN THE NAME OF GOD <<

## Pushover analysis of steel section beam subjected to incremental vertical load base on plastic hinge concept in MATLAB and SAP2000

The MATLAB Program is Verified by SAP2000 v.15.1.0 (Linear and Nonlinear Structural Analysis Program)

This MATLAB program is written by Salar Delavar Ghashghaei - Date of Publication: April/15/2016

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Fixed support beam model in SAP2000

### Define Parameters:

```
% Define Parameters in unit: mm,kN
```

```
P4=0.0; % [kN]
```

```
P5=5.0; % [kN] [kN] Incremental Loading [DOF (5)]
```

```
P6=0.0; % [kN.mm]
```

```
tf=9.2;% [mm] I section thickness on flange
```

```

bf=110;% [mm] I section width on flange
tw=5.9;% [mm] I section thickness of Web
hw=201.6;% [mm] Height of web
L=200;% [mm] length of Beam
d=2*tf+hw;
Ie=((tw*hw^3)/12)+((bf*tf^3)/12)+2*((bf*tf)*(0.5*(d-tf))^2);
EI= Es*Ie; % [kN.mm^2]
EA = Es*(2*(tf*bf)+(tw*hw)); % [kN]

```

#### Plastic Hinge Properties:

```

ty=0.004; % Yeild rotation
tu=0.025; % Ultimate rotation
My=(fy*Ie)/(0.5*d); % [kN.mm] Yeild moment
Mu=fy*((bf*tf*(d-tf)+tw*(0.5*d-tw)^2)); % [kN.mm] Ultimate moment

```

#### Analysis Report:

```

(+)It is converged in 2 iterations for increment 1
(+)It is converged in 2 iterations for increment 2
(+)It is converged in 3 iterations for increment 3
(+)It is converged in 3 iterations for increment 4
(+)It is converged in 3 iterations for increment 5
(+)It is converged in 4 iterations for increment 6
(+)It is converged in 4 iterations for increment 7
(+)It is converged in 5 iterations for increment 8
(+)It is converged in 6 iterations for increment 9
(+)It is converged in 8 iterations for increment 10
(+)It is converged in 12 iterations for increment 11
(+)It is converged in 21 iterations for increment 12
(+)It is converged in 77 iterations for increment 13
(-)For increment 14 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
(-)For increment 15 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
(-)For increment 16 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
(-)For increment 17 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
(-)For increment 18 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
(-)For increment 19 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
  ## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 20 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
  ## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 21 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
  Mechanism:      ||O-----O||
  Mechanism:      ||O---O-----O||
  ## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 22 trail iteration reached to Ultimate 100
  ## The solution for this step is not converged ##
  Mechanism:      ||O-----||
  Mechanism:      ||O-----O||
  Mechanism:      ||O---O-----O||
  ## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 23 trail iteration reached to Ultimate 100

```

```

## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 24 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 25 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 26 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 27 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 28 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 29 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at support [DOF (1)] reached to Ultimate Moment ##
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 30 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at support [DOF (1)] reached to Ultimate Moment ##
## Moment at L [DOF (5)] reached to Ultimate Moment ##
(-)For increment 31 trail iteration reached to Ultimate 100
## The solution for this step is not converged ##
Mechanism:      ||O-----||
Mechanism:      ||O-----O||
Mechanism:      ||O--O-----O||
## Moment at support [DOF (1)] reached to Ultimate Moment ##
## Rotation at support [DOF (1)] reached to Ultimate Rotation ##
===== Nonlinear =====
rotation(D3) X-displacement(D4) Y-displacement(D5) rotation(D6) rotation(D9)
-----
0      0  0.7785  0.0003  0
0.0001  0  1.5569  0.0006  0
0.0001  0  2.3354  0.0009  0
0.0001  0  3.1139  0.0011 -0.0001
0.0002  0  3.8923  0.0014 -0.0001
0.0002  0  4.6708  0.0017 -0.0001
0.0002  0  5.4493  0.0020 -0.0001

```

0.0002	0	6.2280	0.0023	-0.0001
0.0003	0	7.0070	0.0026	-0.0001
0.0003	0	7.7871	0.0028	-0.0002
0.0003	0	8.5698	0.0031	-0.0002
0.0004	0	9.3601	0.0034	-0.0002
0.0005	0	10.1867	0.0037	-0.0002
0.0012	0	11.5888	0.0040	-0.0002
0.0023	0	13.3303	0.0043	-0.0003
0.0034	0	15.0982	0.0046	-0.0003
0.0046	0	16.8690	0.0049	-0.0003
0.0057	0	18.6428	0.0051	-0.0003
0.0069	0	20.4243	0.0054	-0.0004
0.0080	0	22.2446	0.0057	-0.0005
0.0094	0	24.5603	0.0063	-0.0013
0.0110	0	27.2872	0.0070	-0.0025
0.0127	0	30.1234	0.0077	-0.0038
0.0144	0	32.9847	0.0084	-0.0051
0.0162	0	35.8517	0.0091	-0.0065
0.0179	0	38.7199	0.0099	-0.0078
0.0196	0	41.5884	0.0106	-0.0091
0.0213	0	44.4570	0.0113	-0.0105
0.0230	0	47.3256	0.0120	-0.0118
0.0248	0	50.1942	0.0128	-0.0131
0.0265	0	53.0628	0.0135	-0.0145

===== Linear =====  
rotation(D3) X-displacement(D4) Y-displacement(D5) rotation(D6) rotation(D9)

0	0	0.7453	0.0003	0
0	0	1.4906	0.0006	0
0	0	2.2359	0.0008	0
0	0	2.9813	0.0011	0
0	0	3.7266	0.0014	0
0	0	4.4719	0.0017	0
0	0	5.2172	0.0020	0
0	0	5.9625	0.0022	0
0	0	6.7078	0.0025	0
0	0	7.4532	0.0028	0
0	0	8.1985	0.0031	0
0	0	8.9438	0.0034	0
0	0	9.6891	0.0036	0
0	0	10.4344	0.0039	0
0	0	11.1797	0.0042	0
0	0	11.9250	0.0045	0
0	0	12.6704	0.0047	0
0	0	13.4157	0.0050	0
0	0	14.1610	0.0053	0
0	0	14.9063	0.0056	0
0	0	15.6516	0.0059	0
0	0	16.3969	0.0061	0
0	0	17.1422	0.0064	0
0	0	17.8876	0.0067	0
0	0	18.6329	0.0070	0
0	0	19.3782	0.0073	0
0	0	20.1235	0.0075	0
0	0	20.8688	0.0078	0
0	0	21.6141	0.0081	0
0	0	22.3595	0.0084	0
0	0	23.1048	0.0087	0

===== Internal Force =====

+ ===== Nonlinear ===== +

(f3)	(f6-L)	(f6-R)	(f9)
------	--------	--------	------

-----  
1.0e+005 \*

-0.0436	-0.0302	0.0302	0.0222
-0.0873	-0.0603	0.0603	0.0444
-0.1309	-0.0905	0.0905	0.0666
-0.1746	-0.1207	0.1207	0.0889
-0.2182	-0.1508	0.1508	0.1111
-0.2619	-0.1810	0.1810	0.1333
-0.3055	-0.2111	0.2111	0.1555
-0.3492	-0.2413	0.2413	0.1777
-0.3928	-0.2715	0.2715	0.1999
-0.4364	-0.3017	0.3017	0.2222
-0.4799	-0.3319	0.3319	0.2445
-0.5231	-0.3623	0.3623	0.2669
-0.5648	-0.3934	0.3934	0.2901
-0.5840	-0.4359	0.4359	0.3243
-0.5898	-0.4851	0.4851	0.3651
-0.5945	-0.5349	0.5349	0.4064
-0.5993	-0.5846	0.5846	0.4476
-0.6040	-0.6344	0.6344	0.4888
-0.6087	-0.6843	0.6843	0.5297
-0.6138	-0.7345	0.7345	0.5691
-0.6230	-0.7885	0.7885	0.5885
-0.6319	-0.8467	0.8467	0.5961
-0.6394	-0.9064	0.9064	0.6020
-0.6466	-0.9664	0.9664	0.6076
-0.6538	-1.0264	1.0264	0.6131
-0.6609	-1.0865	1.0865	0.6187
-0.6680	-1.1466	1.1466	0.6242
-0.6751	-1.2067	1.2067	0.6297
-0.6822	-1.2668	1.2668	0.6352
-0.6894	-1.3269	1.3269	0.6407
-0.6965	-1.3869	1.3869	0.6462

+ ===== Linear ===== +  
 (f3) (f6-L) (f6-R) (f9)

-----  
 1.0e+005 \*

-0.0444	-0.0296	0.0296	0.0222
-0.0889	-0.0593	0.0593	0.0444
-0.1333	-0.0889	0.0889	0.0667
-0.1777	-0.1185	0.1185	0.0889
-0.2222	-0.1482	0.1482	0.1111
-0.2666	-0.1778	0.1778	0.1333
-0.3110	-0.2075	0.2075	0.1556
-0.3555	-0.2371	0.2371	0.1778
-0.3999	-0.2667	0.2667	0.2000
-0.4443	-0.2964	0.2964	0.2222
-0.4888	-0.3260	0.3260	0.2444
-0.5332	-0.3556	0.3556	0.2667
-0.5776	-0.3853	0.3853	0.2889
-0.6221	-0.4149	0.4149	0.3111
-0.6665	-0.4446	0.4446	0.3333
-0.7109	-0.4742	0.4742	0.3556
-0.7554	-0.5038	0.5038	0.3778
-0.7998	-0.5335	0.5335	0.4000
-0.8442	-0.5631	0.5631	0.4222
-0.8887	-0.5927	0.5927	0.4444
-0.9331	-0.6224	0.6224	0.4667
-0.9775	-0.6520	0.6520	0.4889
-1.0220	-0.6817	0.6817	0.5111
-1.0664	-0.7113	0.7113	0.5333
-1.1108	-0.7409	0.7409	0.5556
-1.1552	-0.7706	0.7706	0.5778
-1.1997	-0.8002	0.8002	0.6000
-1.2441	-0.8298	0.8298	0.6222
-1.2885	-0.8595	0.8595	0.6444

-1.3330 -0.8891 0.8891 0.6667  
-1.3774 -0.9188 0.9188 0.6889  
=====

## SAP2000 Analysis Report:

B E G I N   A N A L Y S I S

2016/04/15 19:48:37

RUNNING ANALYSIS WITHIN THE GUI PROCESS  
USING THE ADVANCED SOLVER (PROVIDES LIMITED INSTABILITY INFORMATION)

NUMBER OF JOINTS	=	2
WITH RESTRAINTS	=	1
NUMBER OF FRAME/CABLE/TENDON ELEMENTS	=	1
NUMBER OF LOAD PATTERNS	=	1
NUMBER OF ACCELERATION LOADS	=	6
NUMBER OF LOAD CASES	=	2

E L E M E N T   F O R M A T I O N

19:48:37

L I N E A R   E Q U A T I O N   S O L U T I O N

19:48:37

FORMING STIFFNESS AT ZERO (UNSTRESSED) INITIAL CONDITIONS

TOTAL NUMBER OF EQUILIBRIUM EQUATIONS	=	3
NUMBER OF NON-ZERO STIFFNESS TERMS	=	6
NUMBER OF EIGENVALUES BELOW SHIFT	=	0

B E G I N   A N A L Y S I S

2016/04/15 19:48:36

RUNNING ANALYSIS WITHIN THE GUI PROCESS  
USING THE ADVANCED SOLVER (PROVIDES LIMITED INSTABILITY INFORMATION)

NUMBER OF JOINTS	=	4
WITH RESTRAINTS	=	2
NUMBER OF FRAME/CABLE/TENDON ELEMENTS	=	3
NUMBER OF LOAD PATTERNS	=	1
NUMBER OF ACCELERATION LOADS	=	6
NUMBER OF LOAD CASES	=	2

E L E M E N T   F O R M A T I O N

19:48:36

L I N E A R   E Q U A T I O N   S O L U T I O N

19:48:36

FORMING STIFFNESS AT ZERO (UNSTRESSED) INITIAL CONDITIONS

TOTAL NUMBER OF EQUILIBRIUM EQUATIONS	=	6
NUMBER OF NON-ZERO STIFFNESS TERMS	=	21
NUMBER OF EIGENVALUES BELOW SHIFT	=	0

L I N E A R   S T A T I C   C A S E S

19:48:36

USING STIFFNESS AT ZERO (UNSTRESSED) INITIAL CONDITIONS

TOTAL NUMBER OF CASES TO SOLVE	=	1
NUMBER OF CASES TO SOLVE PER BLOCK	=	1

LINEAR STATIC CASES TO BE SOLVED:

CASE: 1

N O N L I N E A R   S T A T I C   A N A L Y S I S

19:48:36

CASE: PUSH  
 STARTING FROM ZERO (UNSTRESSED) INITIAL CONDITIONS  
 LOAD CONTROL TYPE = DISPLACEMENT  
 NUMBER OF STAGES = 0  
 TYPE OF GEOMETRIC NONLINEARITY = NONE  
 INCLUDE ELASTIC MATERIAL NONLINEARITY = YES  
 INCLUDE INELASTIC MATERIAL NONLINEARITY = YES  
 METHOD TO USE WHEN HINGES DROP LOAD = UNLOAD ENTIRE STRUCTURE  
 SAVE POSITIVE INCREMENTS ONLY = NO  
 RELATIVE FORCE CONVERGENCE TOLERANCE = 0.000100  
 RELATIVE EVENT TOLERANCE = 0.010000

Saved Steps	Null Steps	Total Steps	Iteration this Step	Relative Unbalance	Curr Step Size	Curr Sum of Steps	Max Sum of Steps
( 20	50	200	10/10	1.000000	0.100000	1.000000	1.000000)
1	0	1	Conv 1	5.54E-12	0.100000	0.100000	0.100000
2	0	2	Conv 1	6.64E-12	0.084591	0.184591	0.184591
3	0	3	Conv 1	5.00E-12	0.100000	0.284591	0.284591
4	0	4	Conv 1	3.95E-12	0.100000	0.384591	0.384591
5	0	5	Conv 1	3.31E-12	0.014527	0.399118	0.399118
6	0	6	Conv 1	6.62E-12	0.100000	0.499118	0.499118
7	0	7	Conv 1	4.39E-12	0.100000	0.599118	0.599118
8	0	8	Conv 1	4.26E-12	0.100000	0.699118	0.699118
9	0	9	Conv 1	5.48E-12	0.100000	0.799118	0.799118
10	0	10	Conv 1	9.41E-12	0.100000	0.899118	0.899118
11	0	11	Conv 1	8.85E-12	0.036081	0.935200	0.935200
11	0	12	Conv 1	0.000199	1.00E-08	0.935200	0.935200
11	0	13	Conv 1	0.000373	1.00E-08	0.935200	0.935200
11	0	14	Conv 1	0.000359	0.064800	1.000000	1.000000

TIME FOR INITIALIZING ANALYSIS = 0.02  
 TIME FOR CONTROLLING ANALYSIS = 0.00  
 TIME FOR UPDATING LOADS AND STATE = 0.01  
 TIME FOR FORMING STIFFNESS MATRIX = 0.04  
 TIME FOR SOLVING STIFFNESS MATRIX = 0.49  
 TIME FOR CALCULATING DISPLACEMENTS = 0.09  
 TIME FOR DETERMINING EVENTS = 0.01  
 TIME FOR SAVING RESULTS = 0.15  
 -----  
 TOTAL TIME FOR THIS ANALYSIS = 0.81

A N A L Y S I S C O M P L E T E

2016/04/15 19:48:37

Plot :

**I/Wide Flange Section**

**Section Name** IPE220

Section Notes [Modify/Show Notes...](#)

Extract Data from Section Property File

[Open File...](#) c:\program files\computers and structures\sap2000 [Import...](#)

**Properties** [Section Properties...](#)

**Property Modifiers** [Set Modifiers...](#)

**Material** + STEEL

**Dimensions**

Outside height ( t3 ) 220.

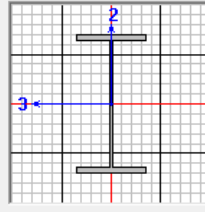
Top flange width ( t2 ) 110.


Top flange thickness ( tf ) 9.2

Web thickness ( tw ) 5.9

Bottom flange width ( t2b ) 110.

Bottom flange thickness ( tfb ) 9.2



Display Color 

[OK](#) [Cancel](#)

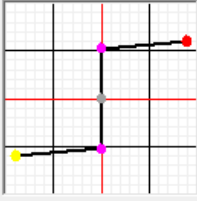
Steel section (IPE220) in SAP2000

**Frame Hinge Property Data for Moment - Moment M3**

Edit

**Displacement Control Parameters**

Point	Moment/SF	Rotation/SF
E-	-66544	-0.025
D-	-66544	-0.025
C-	-66544	-0.025
B-	-57863	0
A	0	0
B	57863	0.
C	66544.	0.025
D	66544.	0.025
E	66544.	0.025



☒ Symmetric

**Load Carrying Capacity Beyond Point E**

☒ Drops To Zero

☐ Is Extrapolated

**Scaling for Moment and Rotation**

☐ Use Yield Moment Moment SF Positive 1. Negative

☐ Use Yield Rotation Rotation SF Positive 1. Negative (Steel Objects Only)

**Acceptance Criteria (Plastic Rotation/SF)**

☒ Immediate Occupancy Positive 2. Negative

☒ Life Safety Positive 4. Negative

☒ Collapse Prevention Positive 6. Negative

☐ Show Acceptance Criteria on Plot

**Type**

☒ Moment - Rotation

☐ Moment - Curvature Hinge Length

☐ Relative Length

**Hysteresis Type And Parameters**

Hysteresis Type Isotropic

No Parameters Are Required For This Hysteresis Type

[OK](#) [Cancel](#)

Plastic hinge (M3) in SAP2000



Define Load Patterns

Load Patterns

Load Pattern Name	Type	Self Weight Multiplier	Auto Lateral Load Pattern
1	OTHER	0	
1	OTHER	0	

↑

↓

Click To:

Add New Load Pattern

Modify Load Pattern

Modify Lateral Load Pattern...

Delete Load Pattern

Show Load Pattern Notes...

OK

Cancel

Define Load Cases

Load Cases

Load Case Name	Load Case Type
1	Linear Static
Push	Nonlinear Static

↑

↓

Click to:

Add New Load Case...

Add Copy of Load Case...

Modify/Show Load Case...

Delete Load Case

Display Load Cases

Show Load Case Tree...

OK

Cancel

Load Case Data - Nonlinear Static

Load Case Name

Push

Set Def Name

Notes

Modify/Show...

Load Case Type

Static

Design...

Initial Conditions

☒ Zero Initial Conditions - Start from Unstressed State
 ☐ Continue from State at End of Nonlinear Case

Important Note: Loads from this previous case are included in the current case

Modal Load Case

All Modal Loads Applied Use Modes from Case

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	1	1.
Load Pattern	1	1.

Add

Modify

Delete

Analysis Type

☐ Linear
 ☒ Nonlinear
 ☐ Nonlinear Staged Construction

Geometric Nonlinearity Parameters

☒ None
 ☐ P-Delta
 ☐ P-Delta plus Large Displacements

Other Parameters

Load Application

Displ Control

Modify/Show...

Results Saved

Multiple States

Modify/Show...

Nonlinear Parameters

User Defined

Modify/Show...

OK

Cancel

Load patterns and load cases in SAP2000

### Load Application Control for Nonlinear Static Analysis

**Load Application Control**

☐ Full Load

☒ Displacement Control

**Control Displacement**

☐ Use Conjugate Displacement

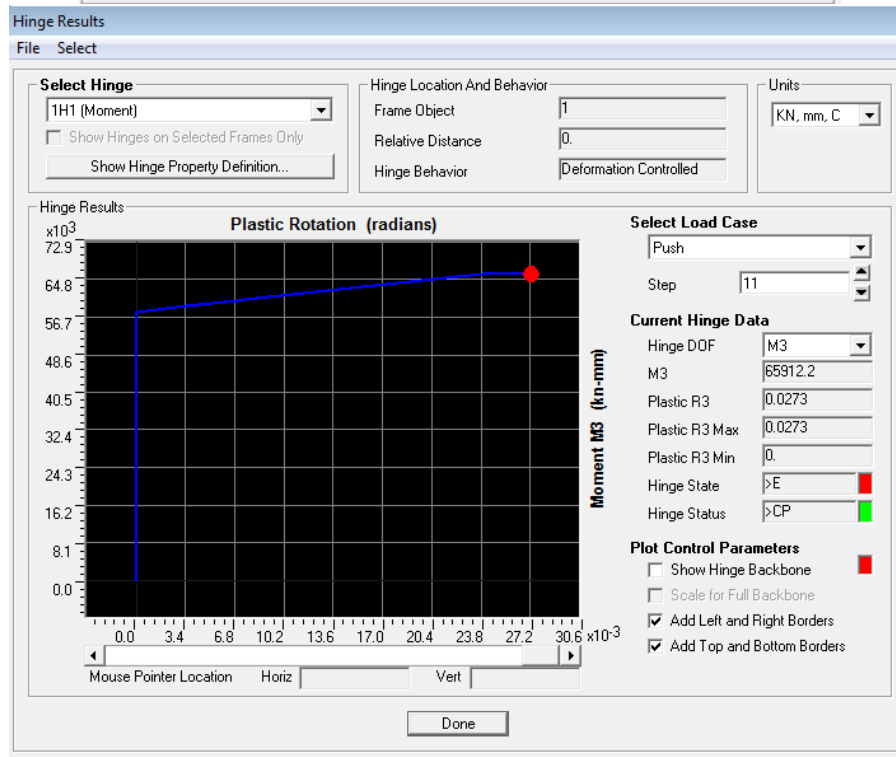
☒ Use Monitored Displacement

Load to a Monitored Displacement Magnitude of

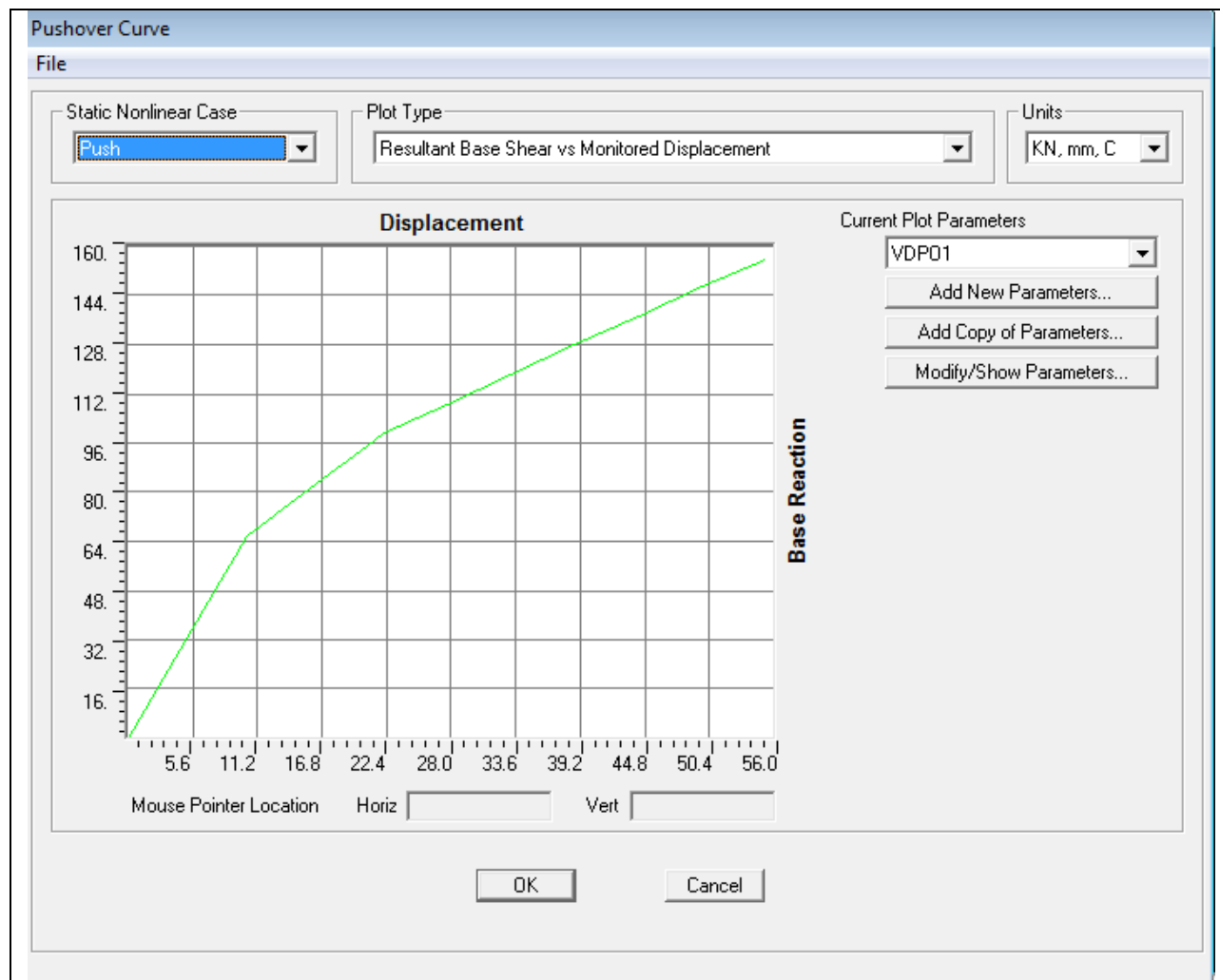
**Monitored Displacement**

☒ DOF  at Joint

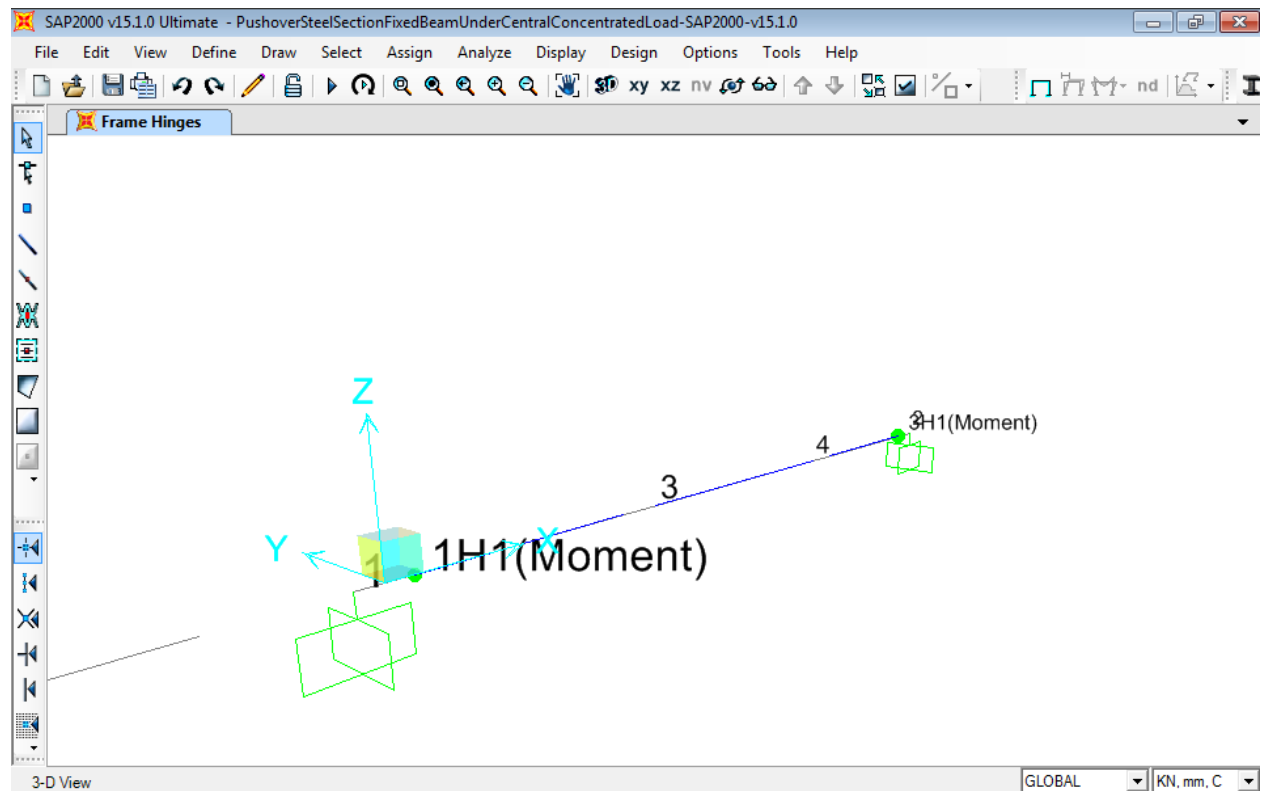
☐ Generalized Displacement



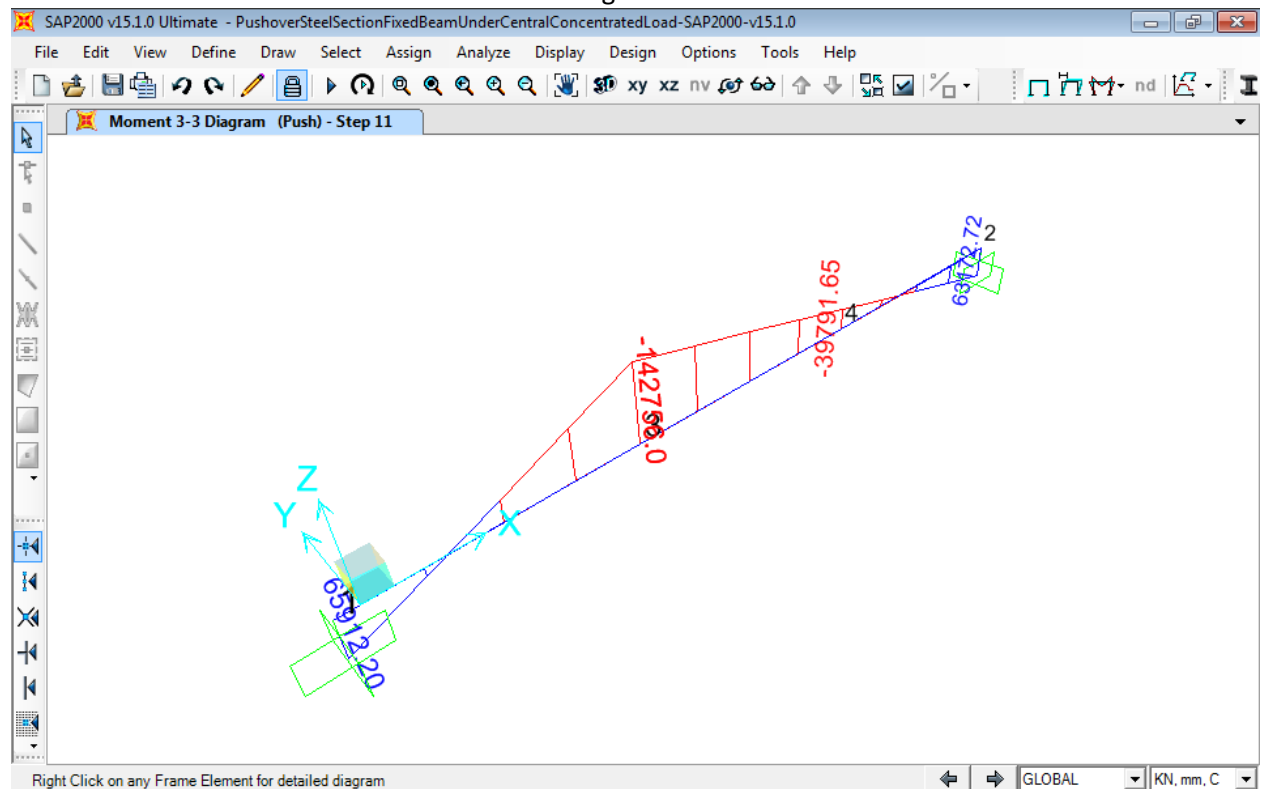
Plastic hinge (1H1) result in SAP2000



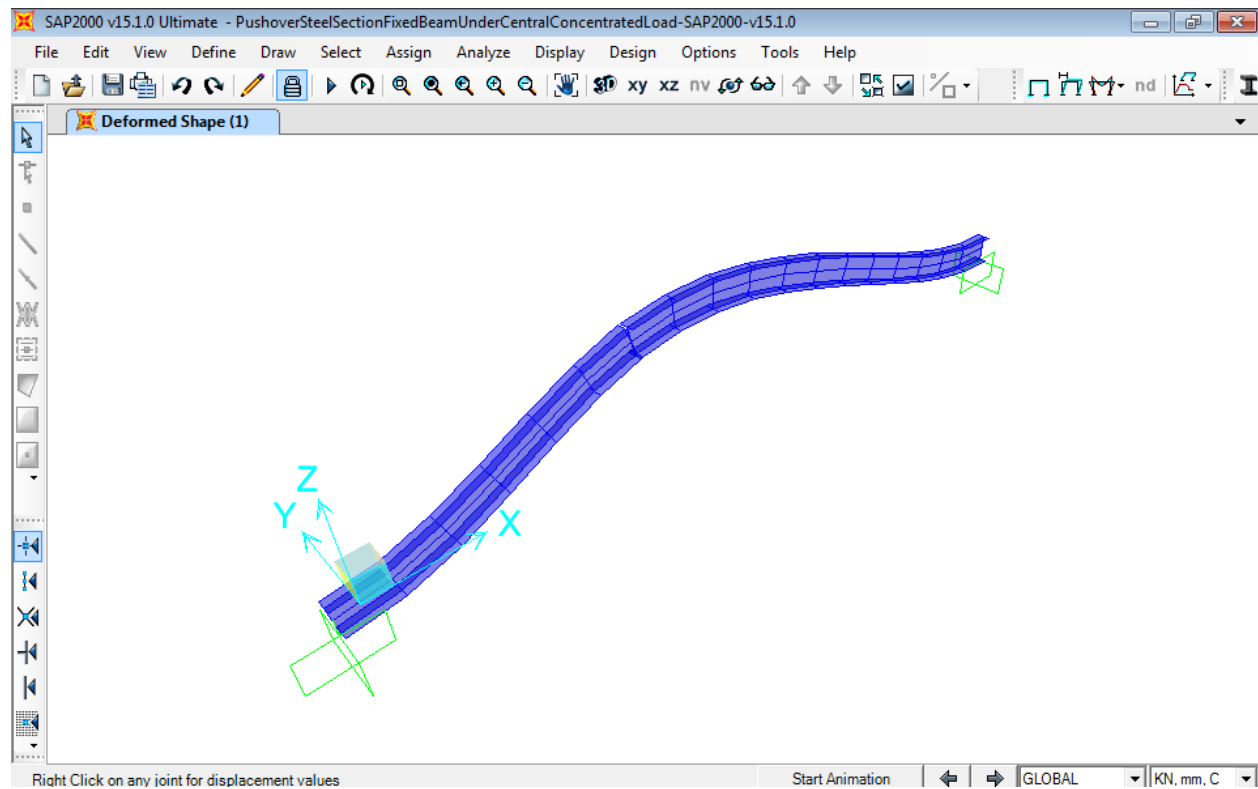
Pushover analysis result in SAP2000



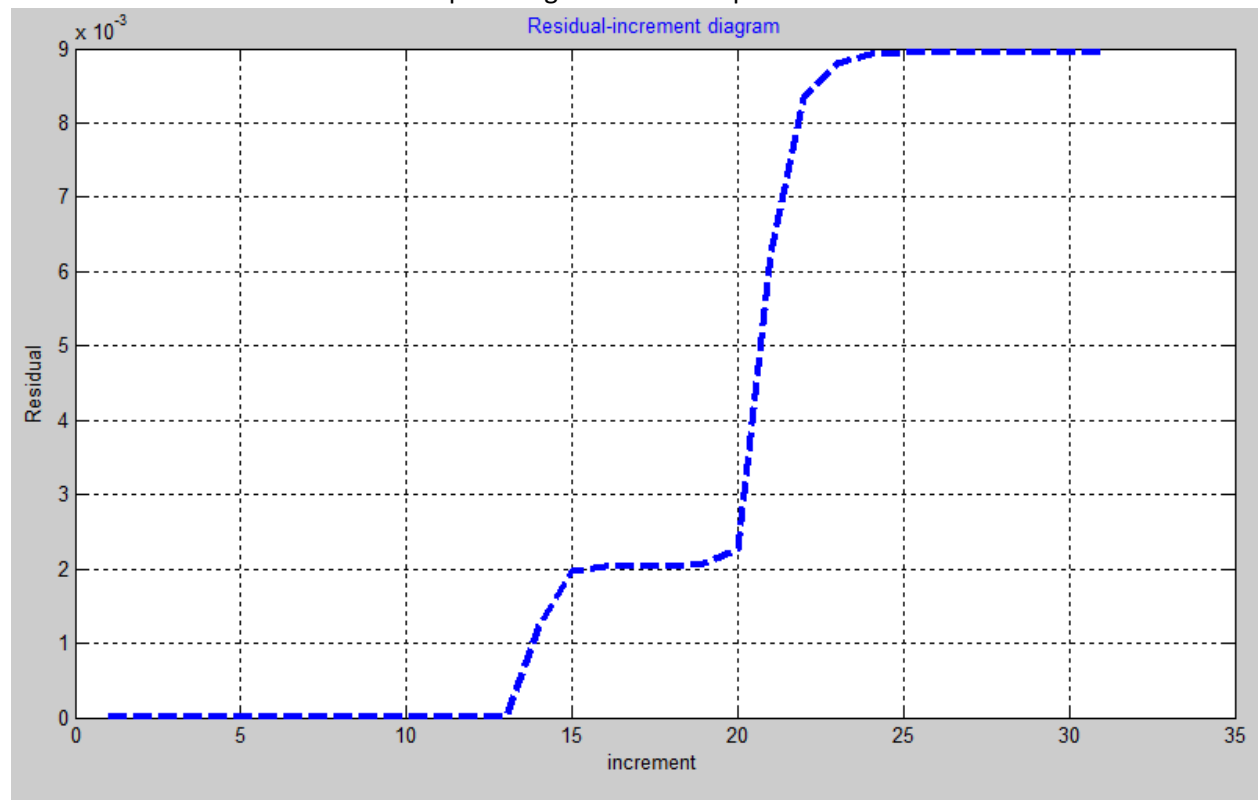
Define hinges in SAP2000



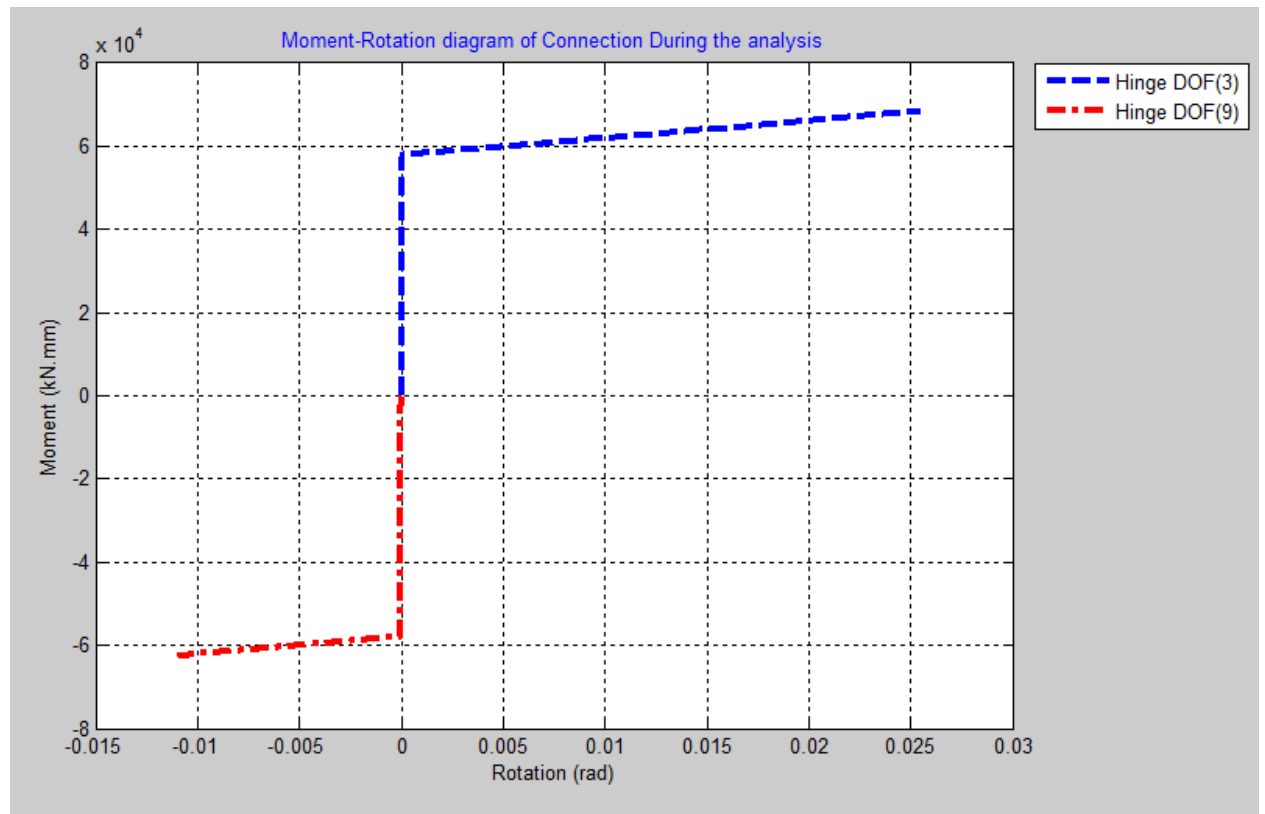
Moment diagram in SAP2000



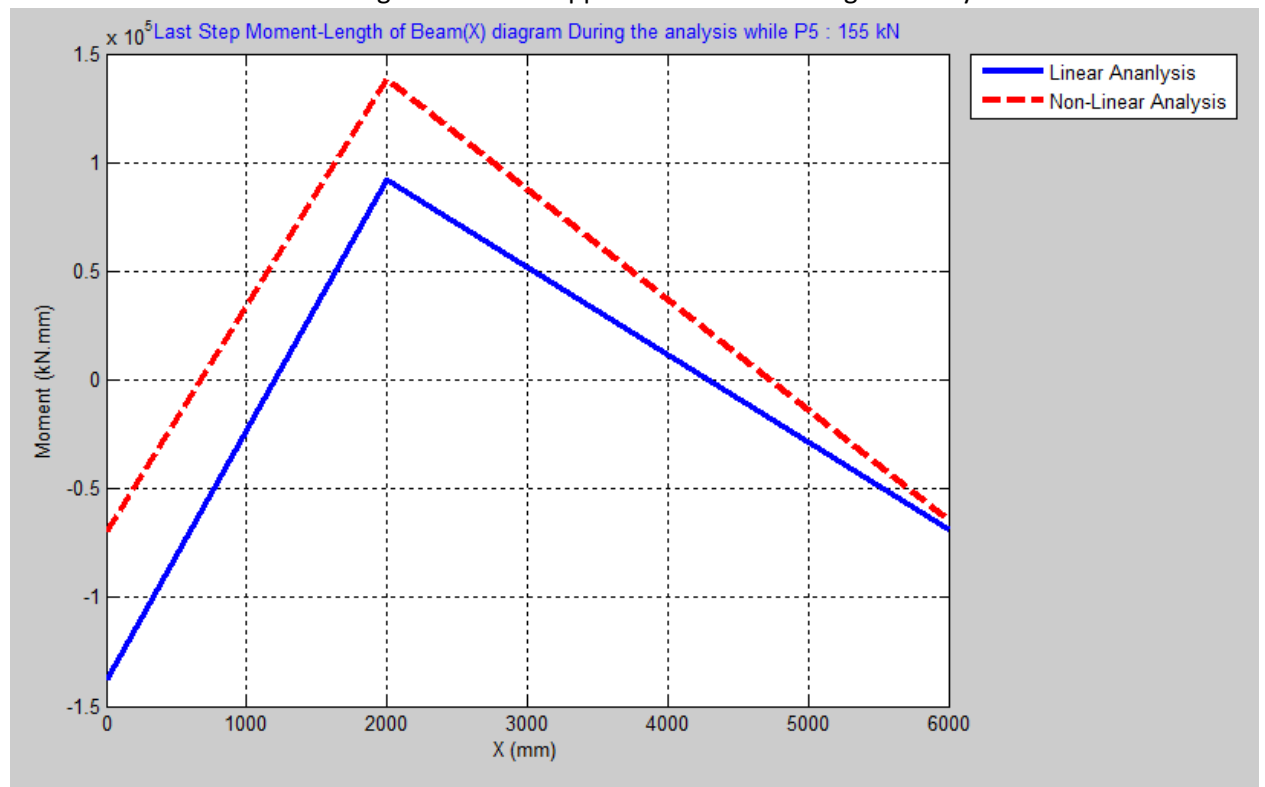
Last step loading deflection shape in SAP2000



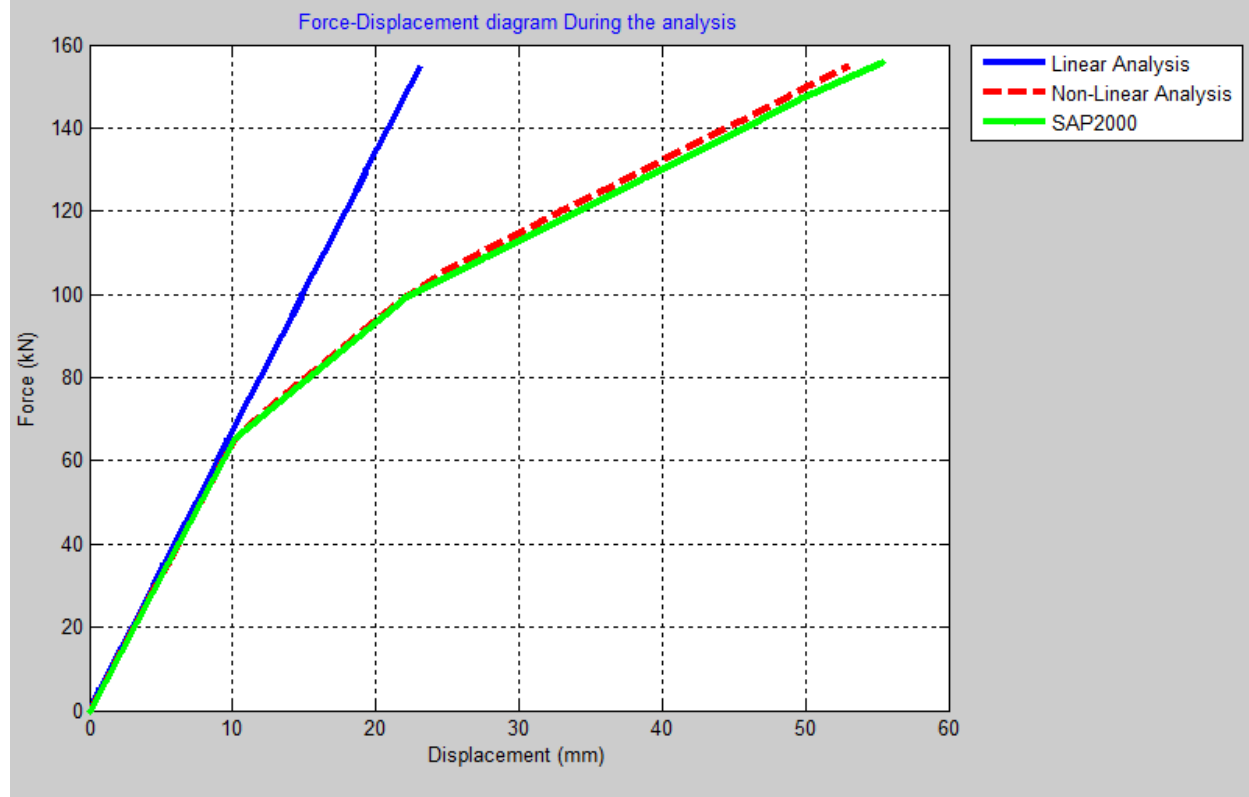
Increment-Residual diagram during the analysis in MATLAB



Moment-Rotation diagram of fixed support connection during the analysis in MATLAB



Last step loading diagram of Moment during the analysis in MATLAB



Force-Displacement diagram in SAP2000 and MATLAB