>> 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)
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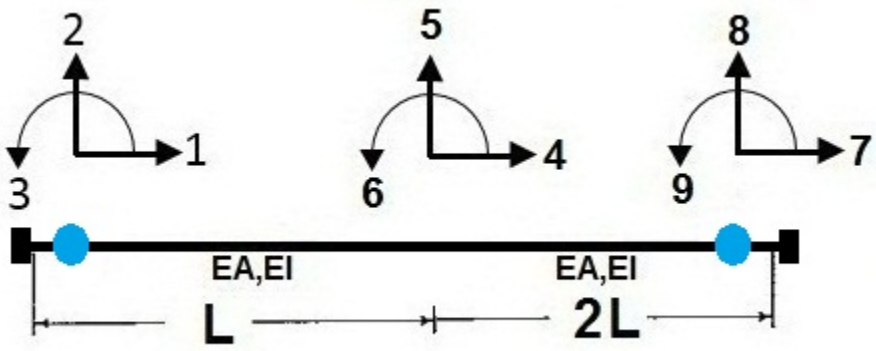
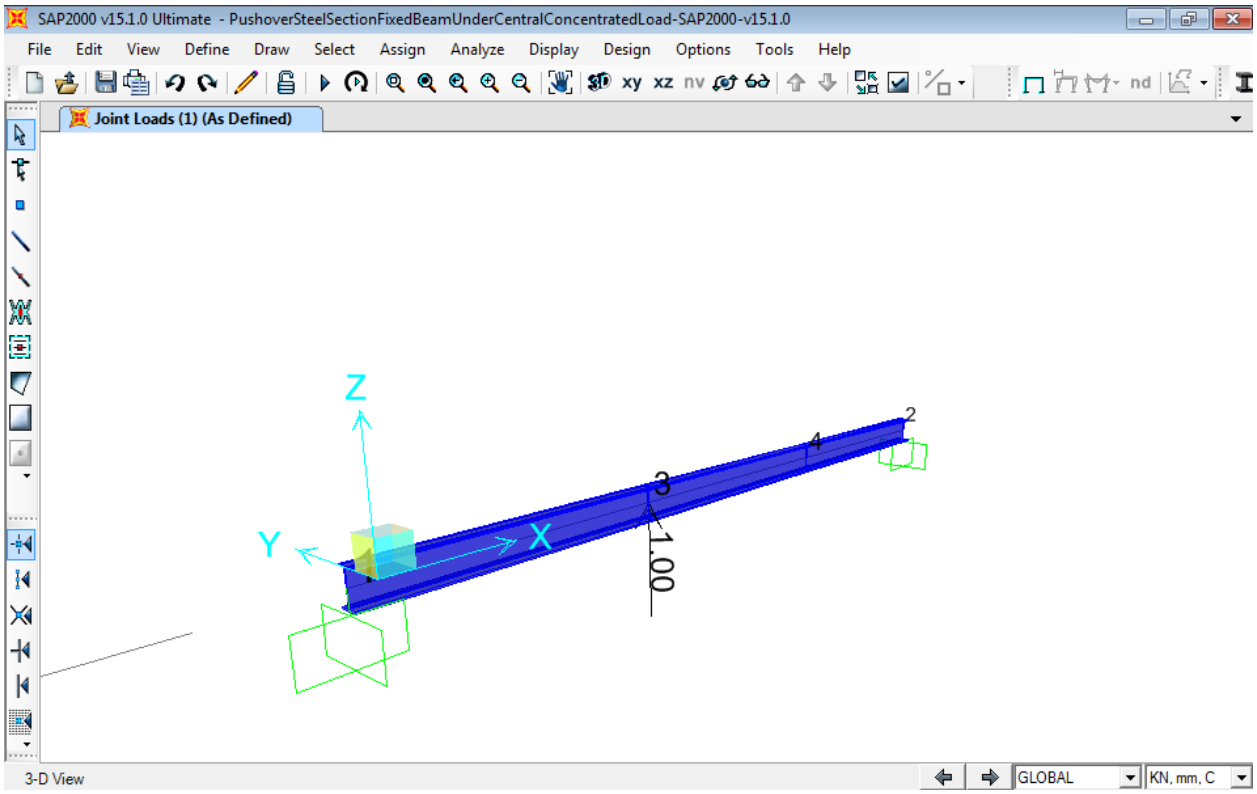




Fixed support beam model in SAP2000

Define Parameters:

```
% Define Parameters in unit: mm,kN
P4=0.0; % [kN]
P5=5.0; % [kN] [kN] Incremantal 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)/(.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

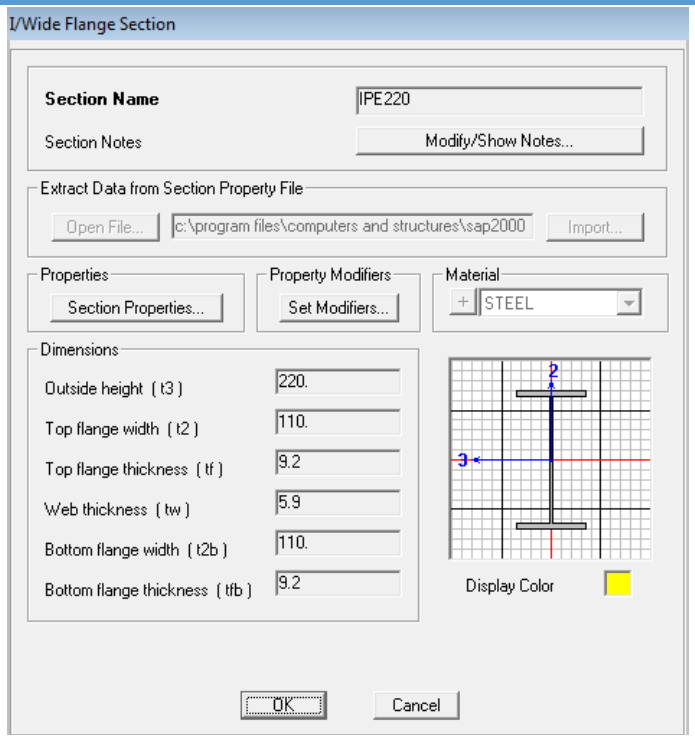
```
 -1.3330  -0.8891   0.8891   0.6667
 -1.3774  -0.9188   0.9188   0.6889
================================================
```

SAP2000 Analysis Report:

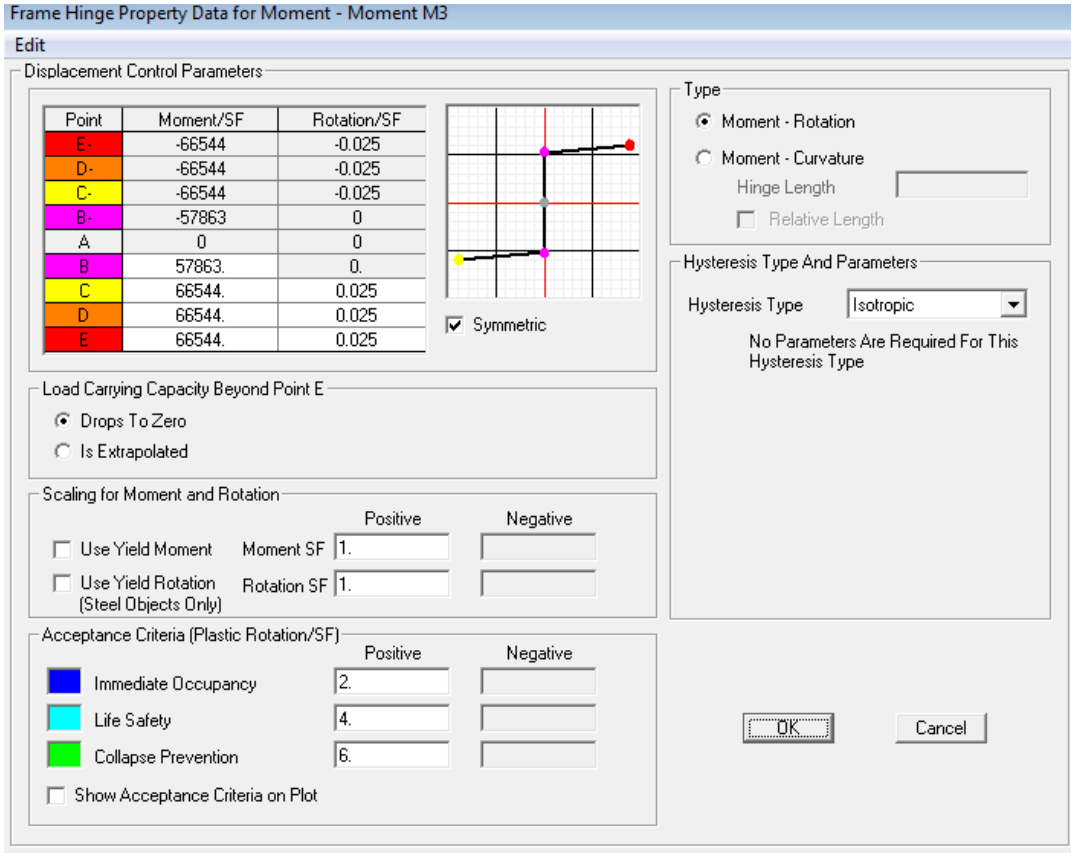
```
 B E G I N   A N A L Y S I S                              2016/04/15  19:48:37


 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    Null   Total  Iteration   Relative  Curr Step   Curr Sum    Max Sum
 Steps   Steps   Steps  this Step  Unbalance       Size   of Steps   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
```

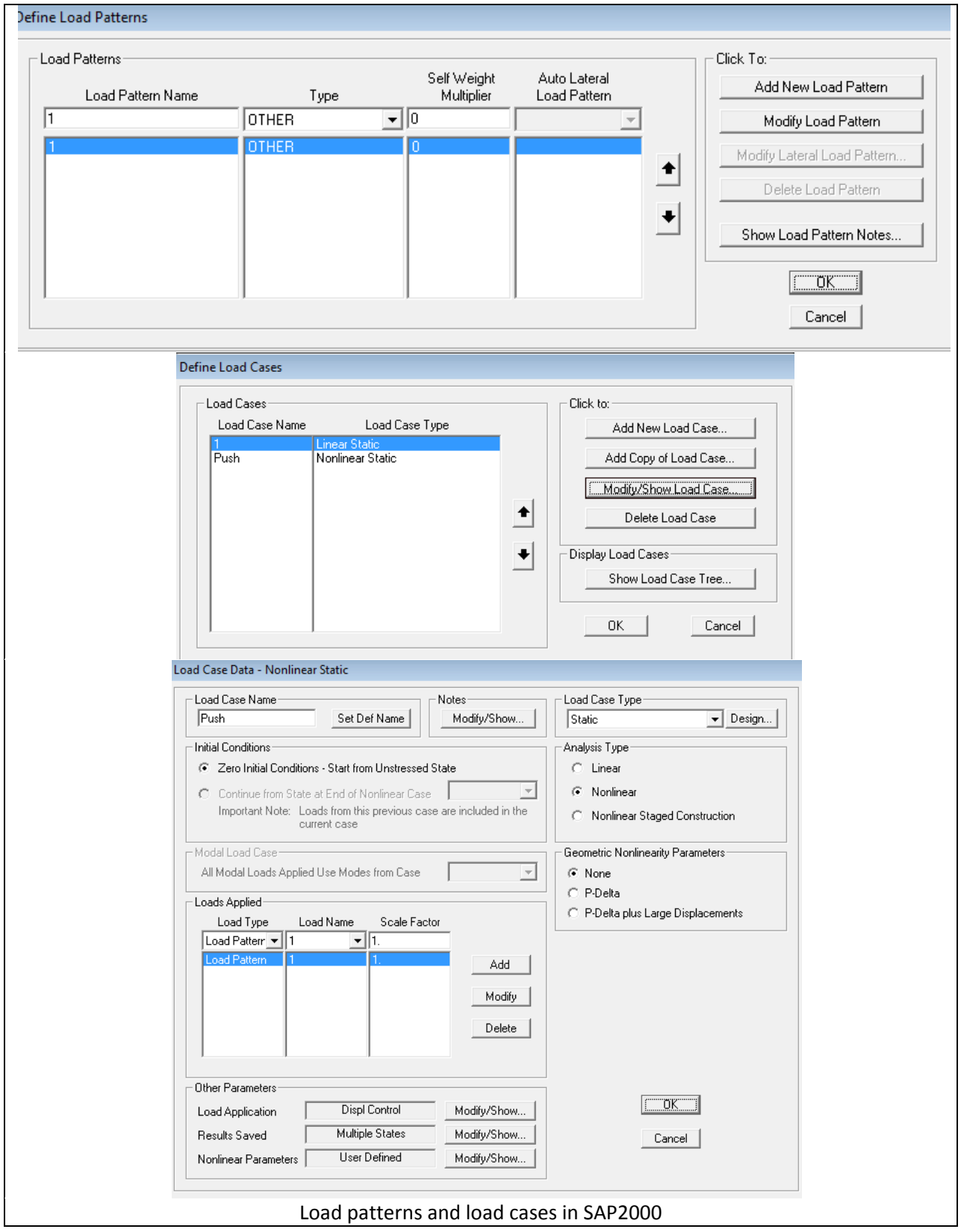
Plot :



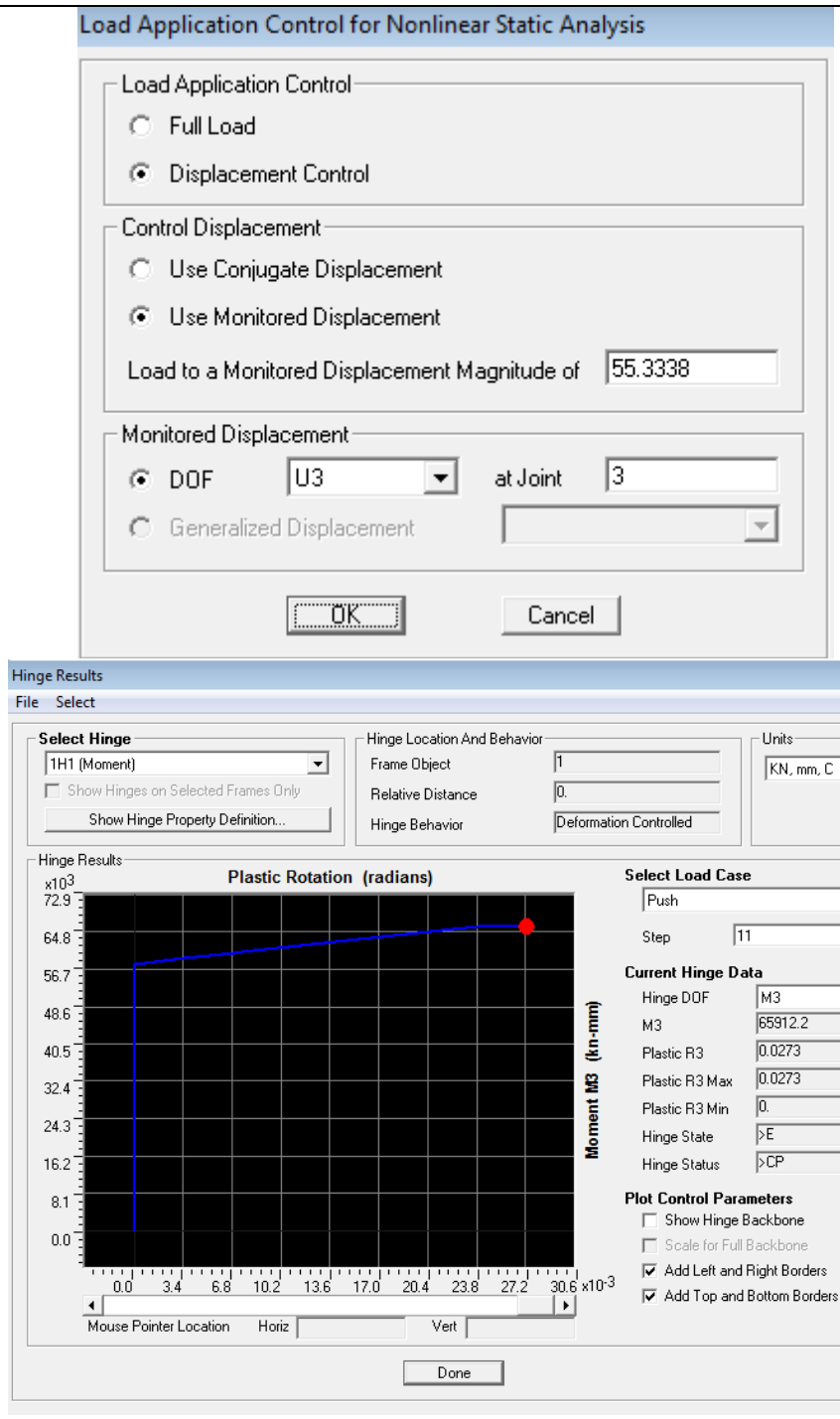
Steel section (IPE220) in SAP2000



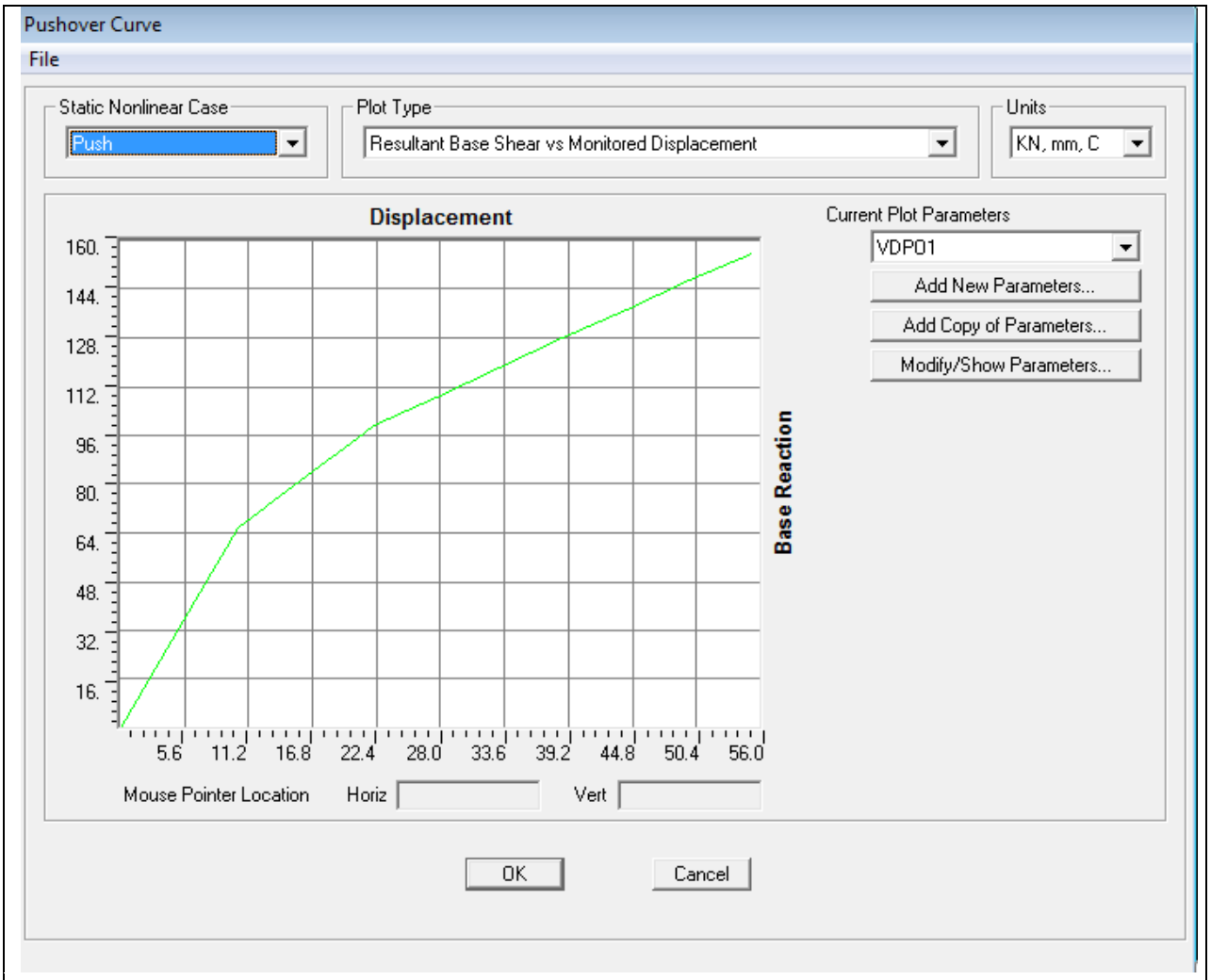
Plastic hinge (M3) in SAP2000



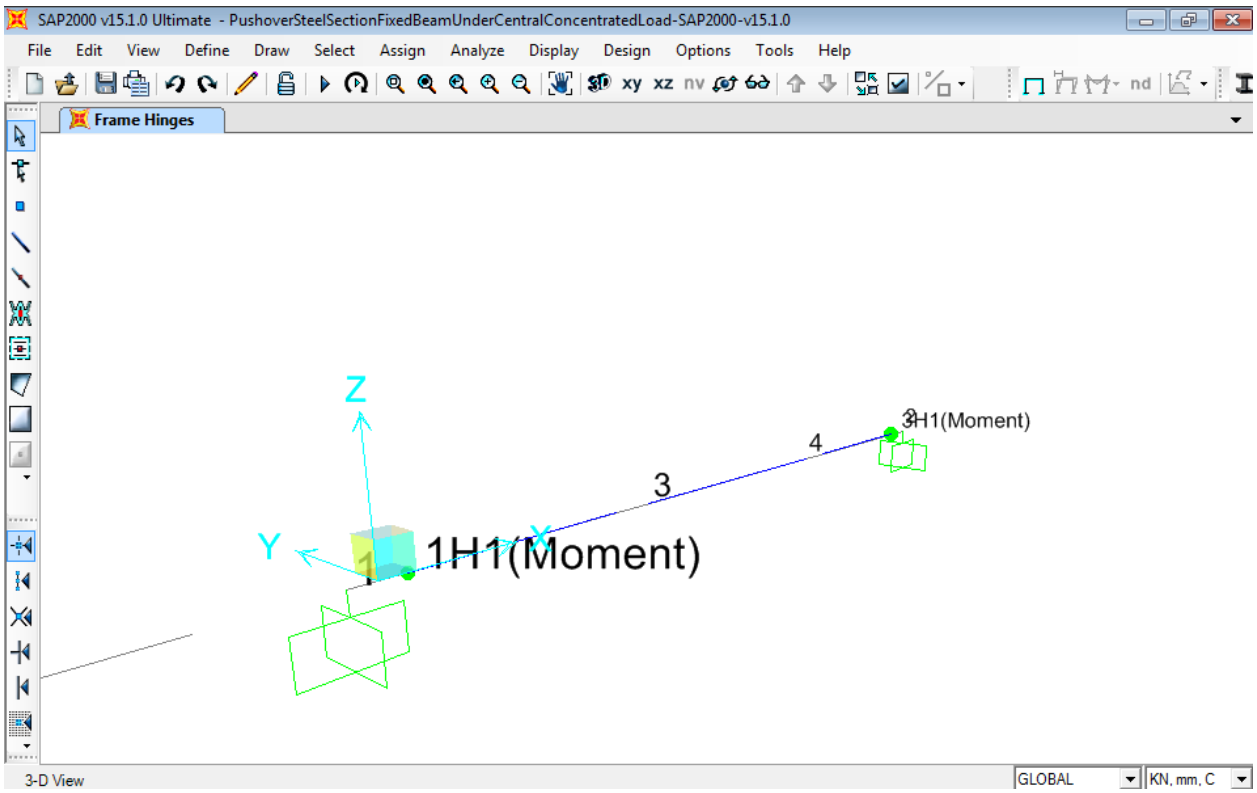
Load patterns and load cases in SAP2000



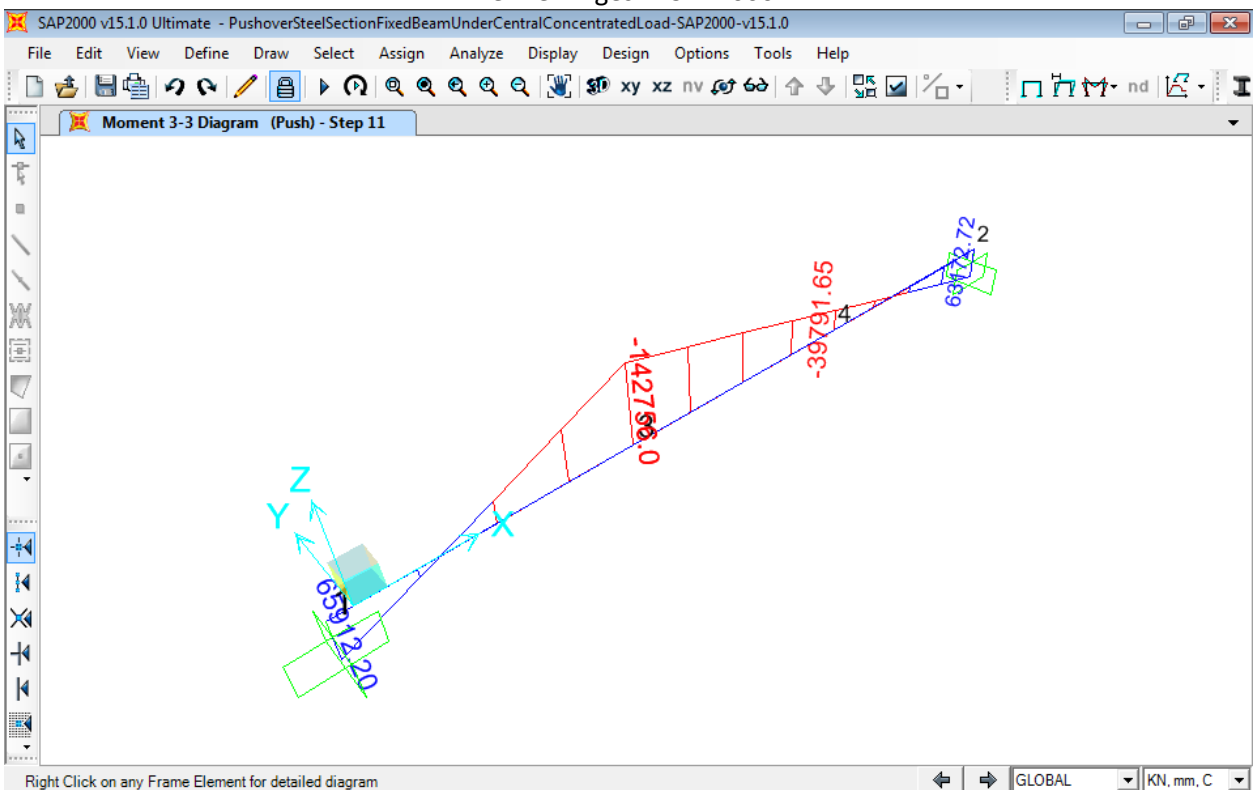
Plastic hinge (1H1) result in SAP2000



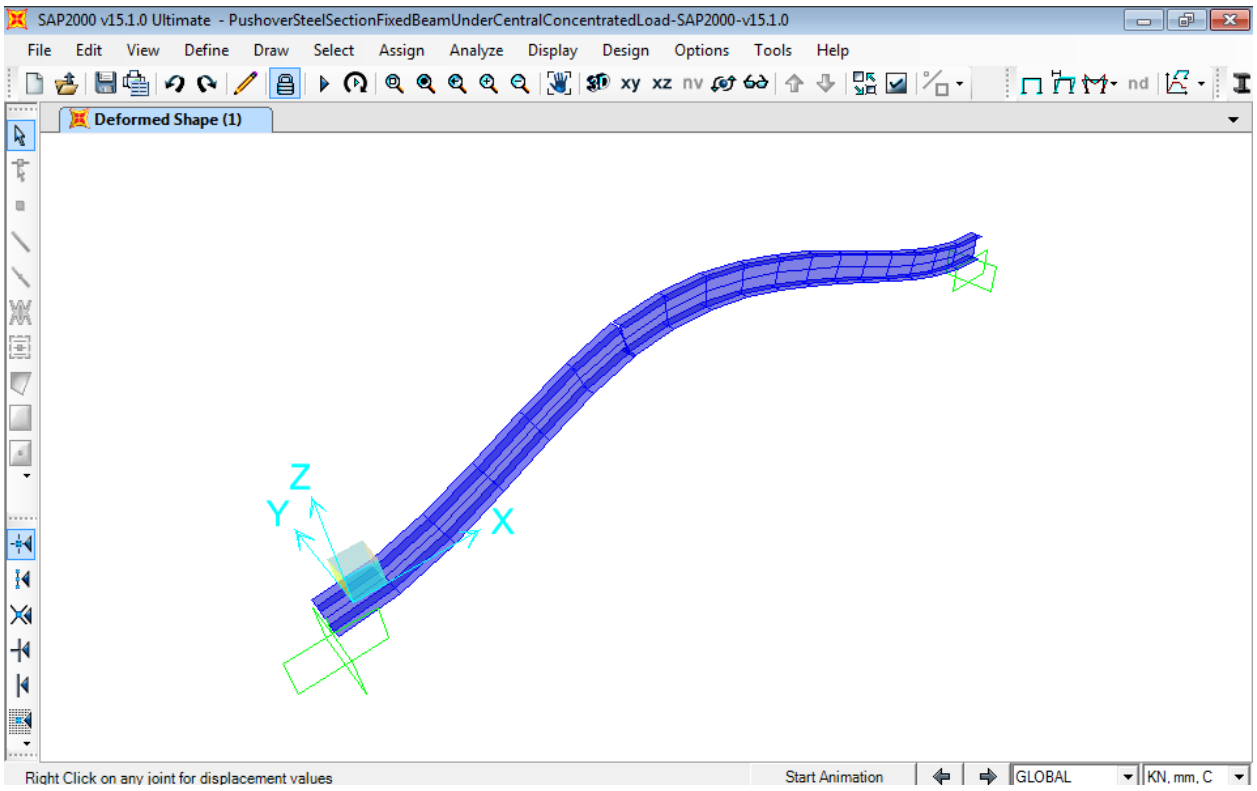
Pushover analysis result in SAP2000



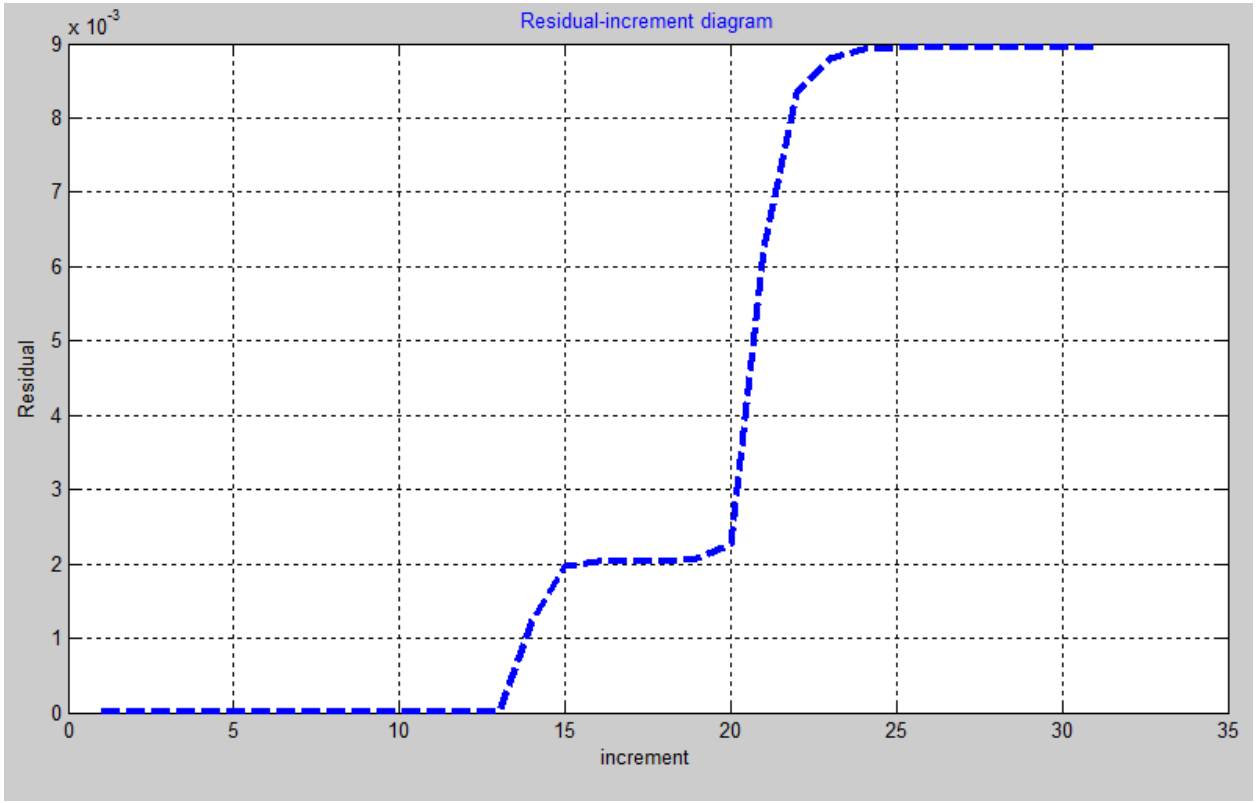
Define hinges in SAP2000



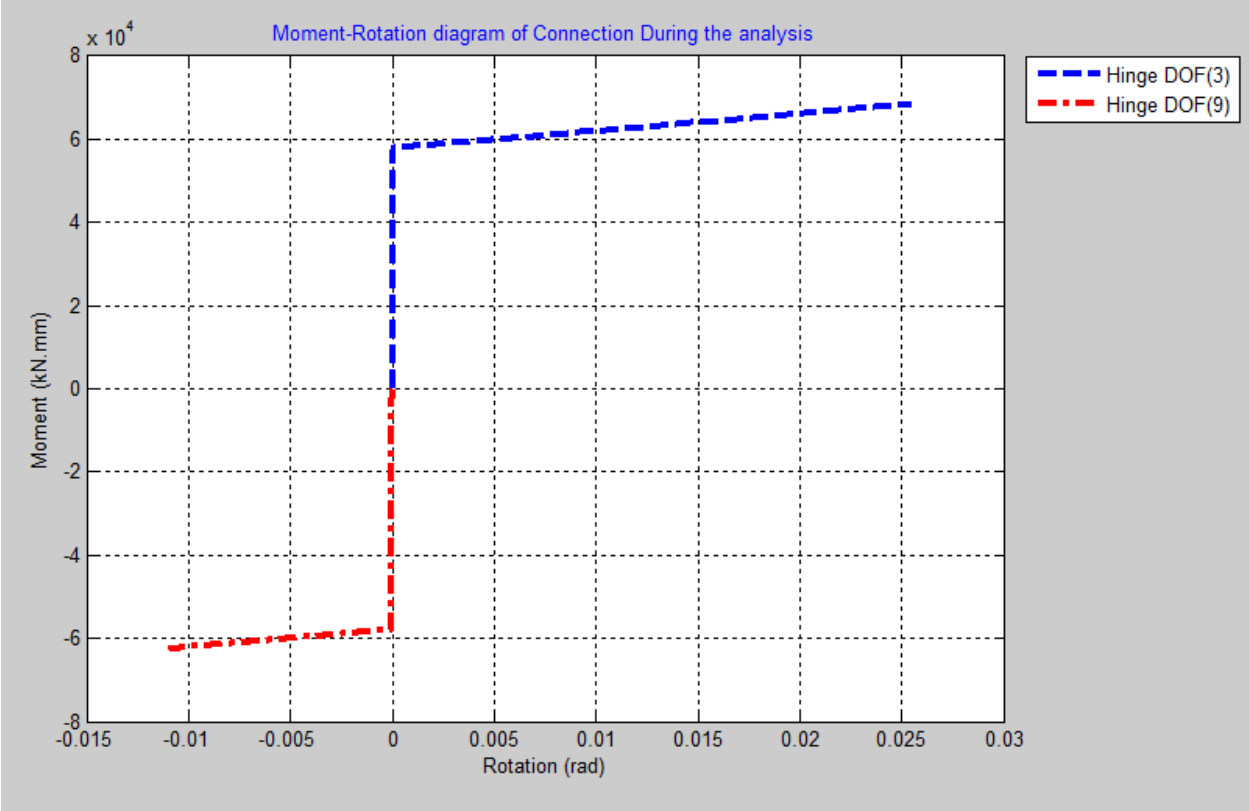
Moment diagram in SAP2000



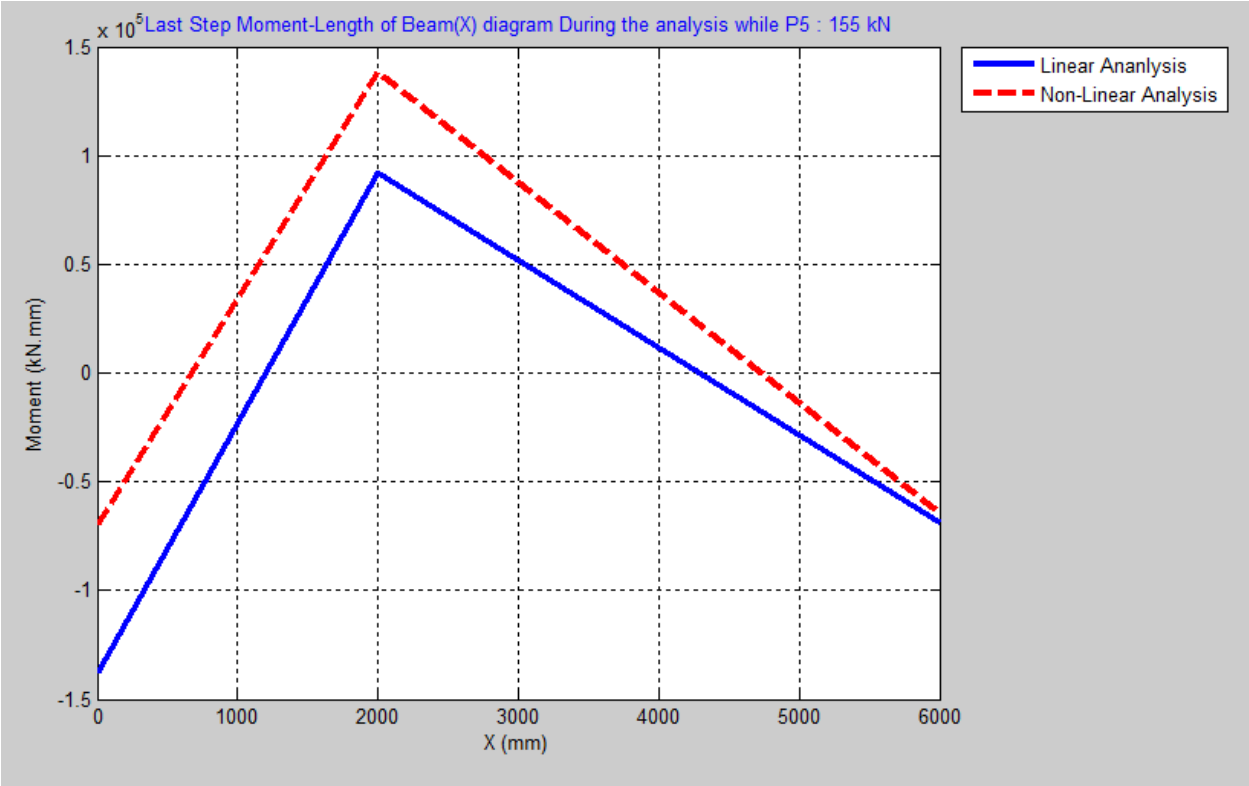
Last step loading deflection shape in SAP2000



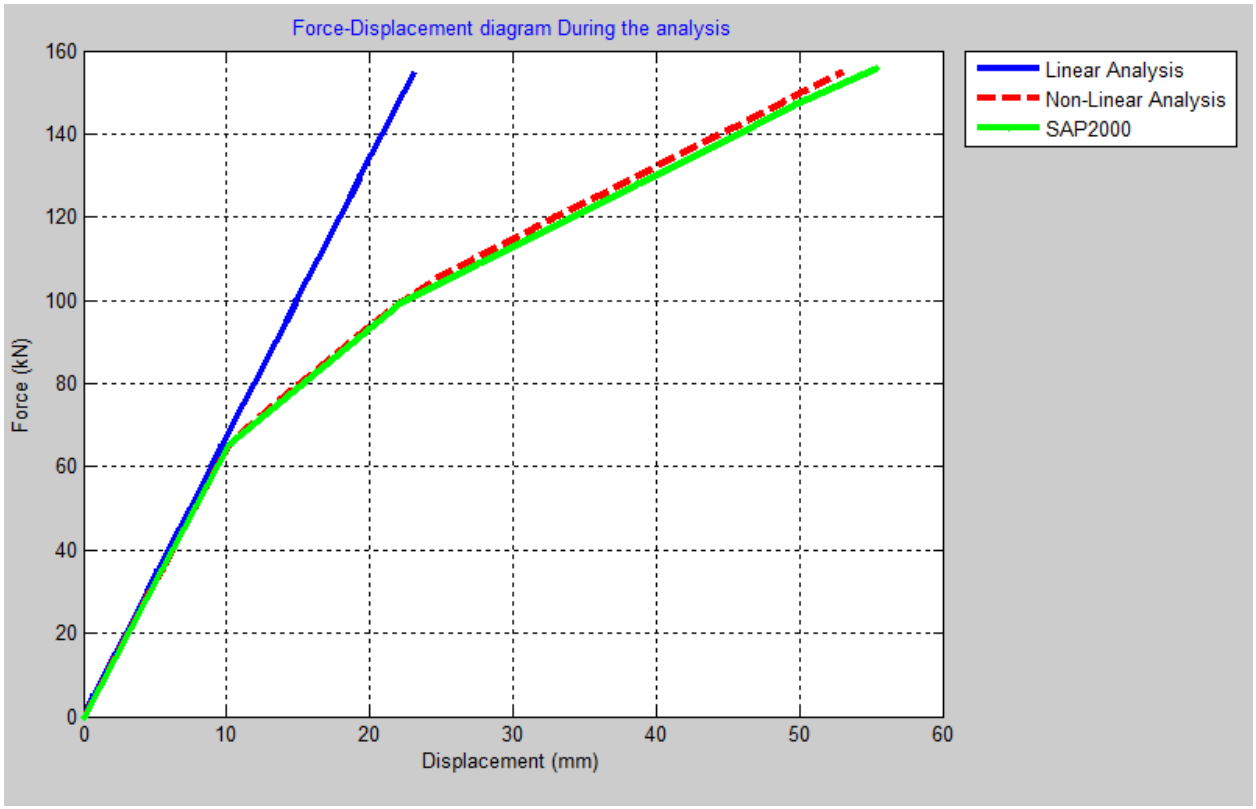
Increment-Residual diagram during the analysis in MATLAB



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