>> IN THE NAME OF GOD <<

Moment-Curvature Analysis of Unconfined Concrete Section with MATLAB and SAP2000

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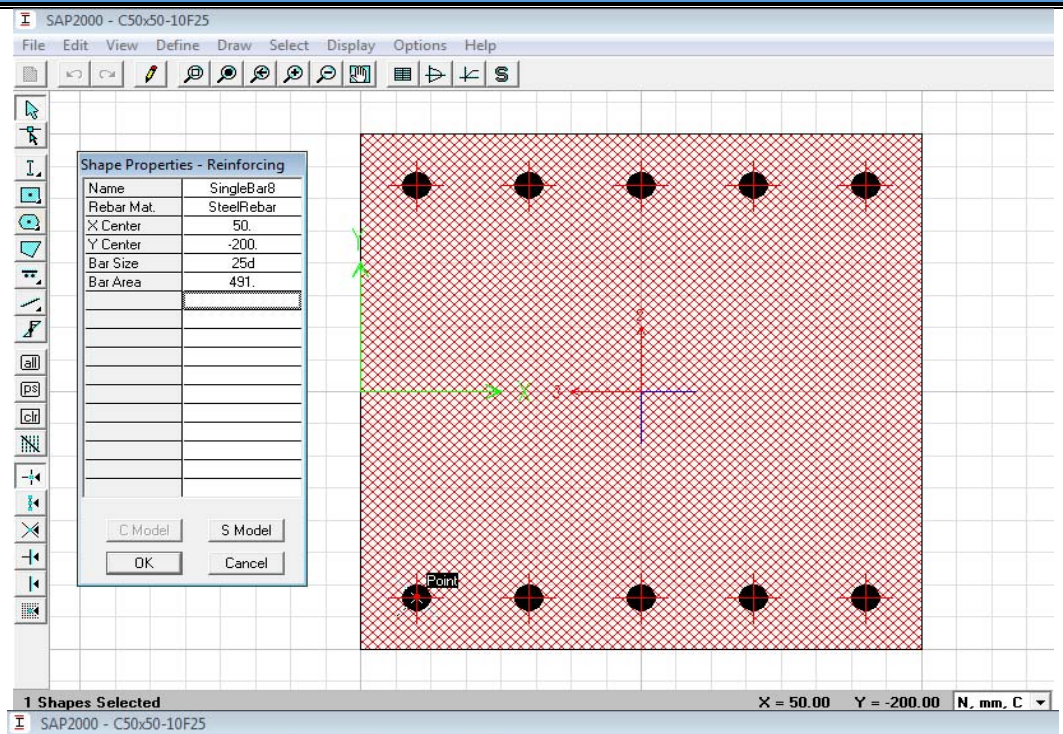
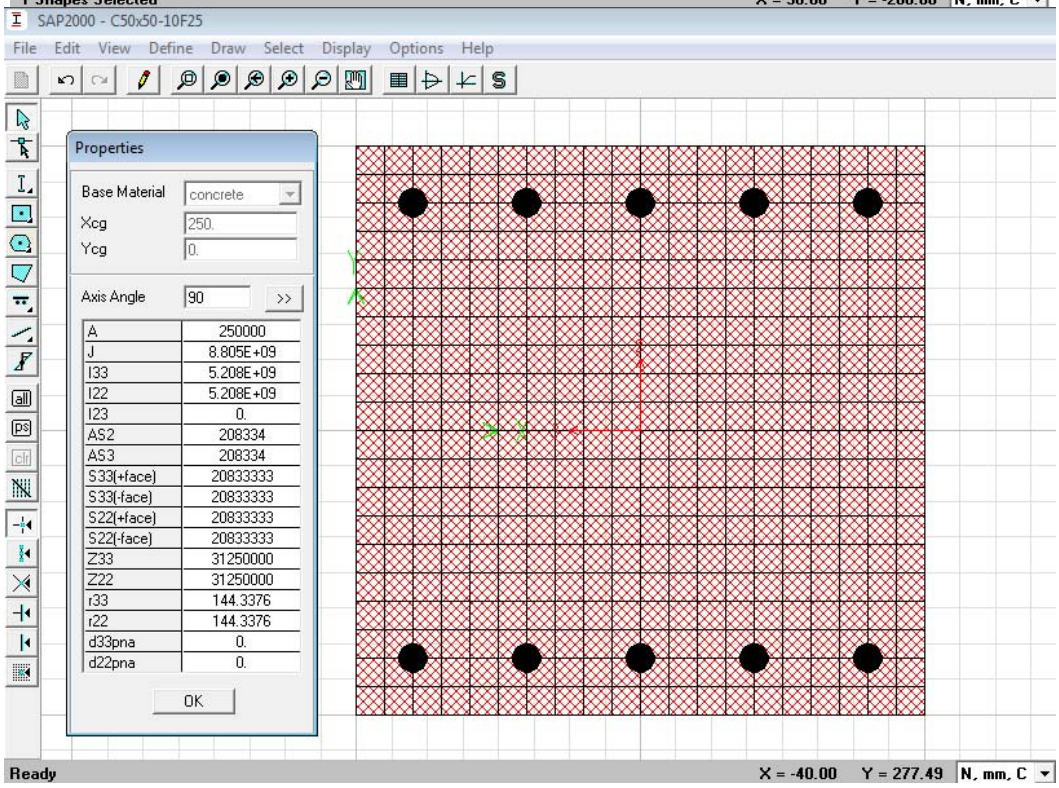
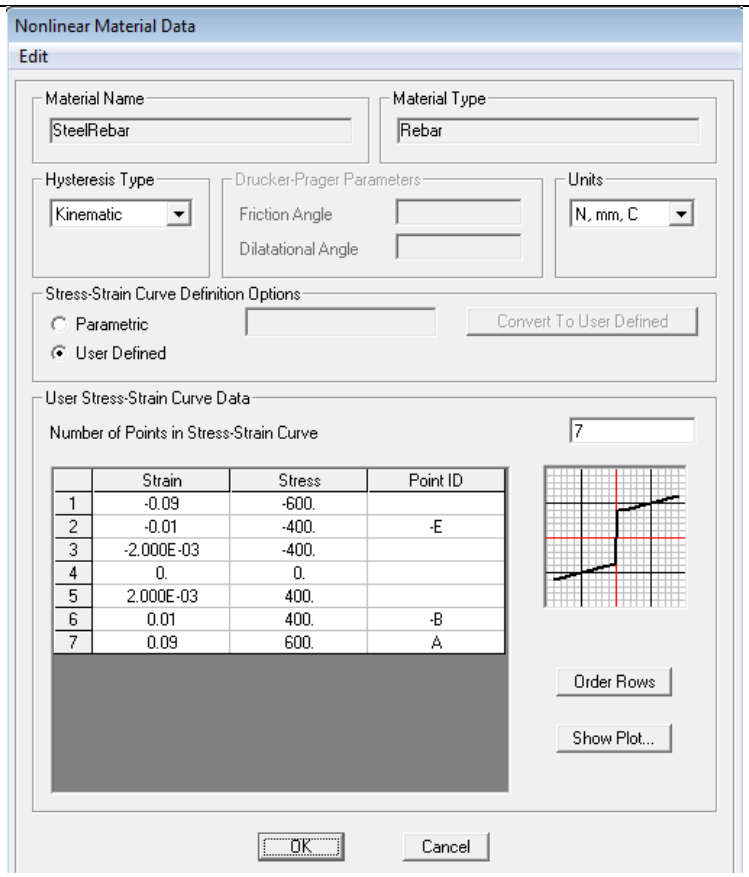
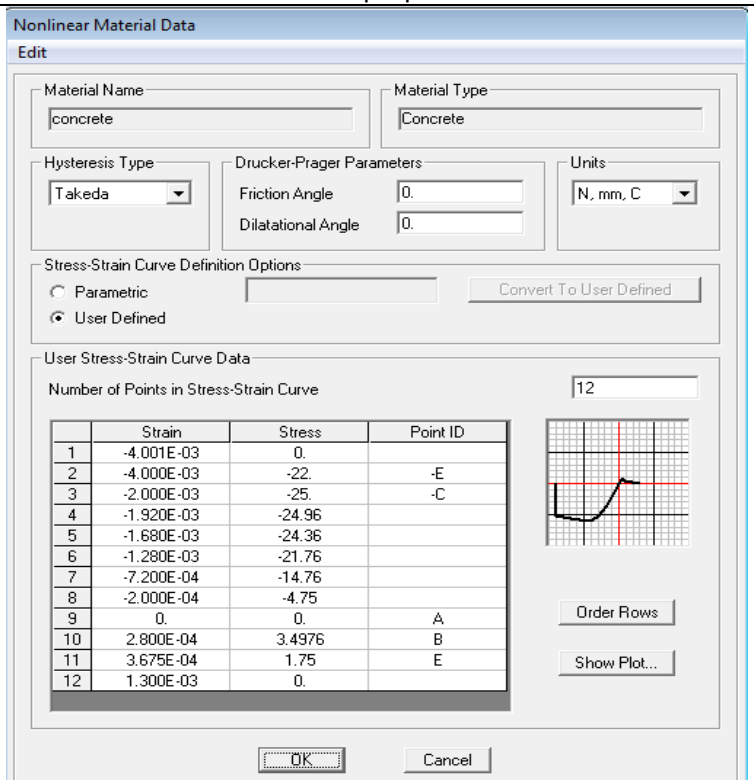




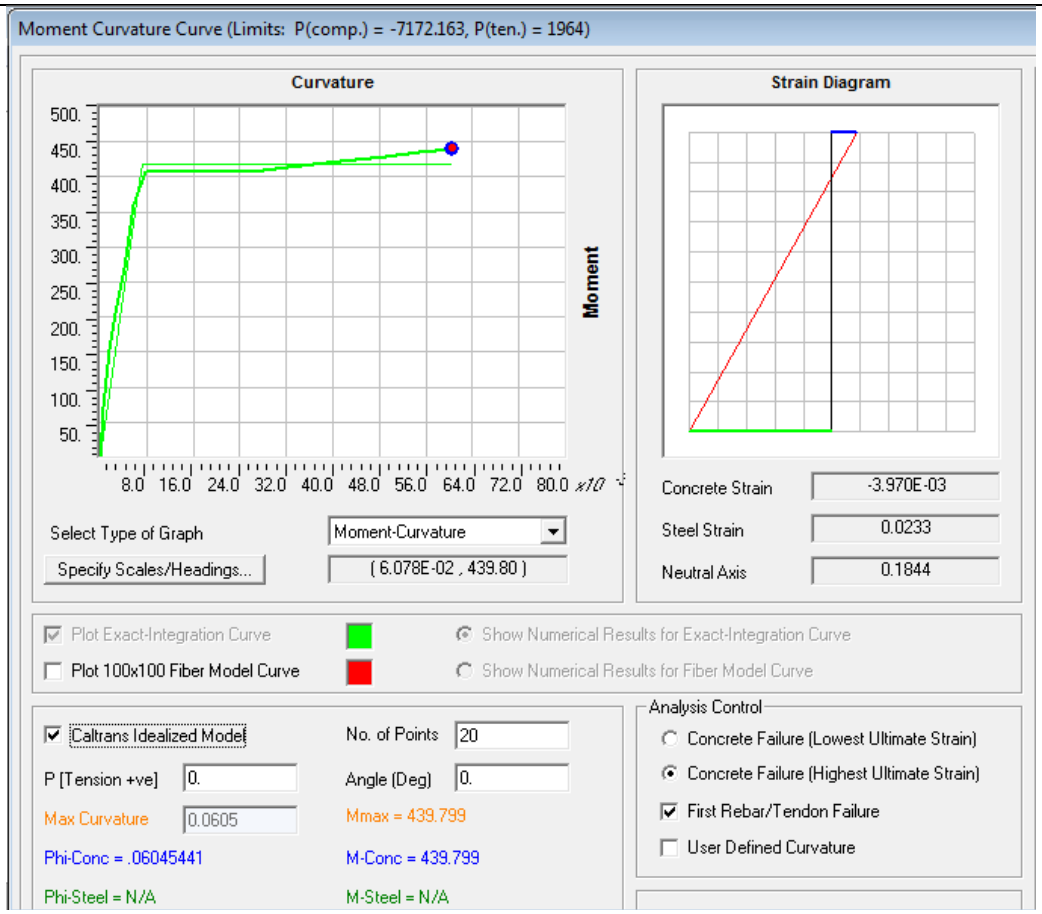
Unconfined concrete section properties in SAP2000



Steel rebar material properties in SAP2000



Unconfined concrete material properties in SAP2000



Moment curvature analysis in SAP2000

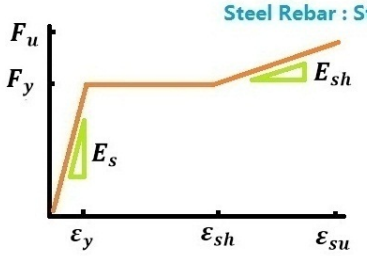
```
%*************************************************************%
%    _     _____________________________________              %
%    |    |                                     |             %
%         |     #     #     #     #     #     #   |           %
%         |     #                             #   |           %
%    b    |    As1   As2   As3   As4   As5   As6  |           %
%         |     #                             #   |           %
%    |    |     #     #     #     #     #     #   |           %
%    _    |_____________________________________|             %
%         |<-                 h                ->|           %
%         |<-d1->|                                            %
%         |<-  d2   ->|                                       %
%         |<-     d3      ->|                                 %
%         |<-        d4          ->|                          %
%         |<-            d5          ->|                      %
%         |<-               d6            >|                 %
%      X                                                      %
%      ^                                                      %
%      |             (Moment - Curvature along X axis)        %
%      |                                                      %
%      +----> Y                                               %
%*************************************************************%
```

Section Properties:

```
b=500;% [mm]
h=500;% [mm]
%As:  As1      As2     As3     As4    As5      As6
As=[2454.296 0 0 0 0 2454.296]; % NOTE: As1 & As6 = 5fi25
%d:d1  d2  d3  d4  d5  d6
d=[50 0 0 0 0 450];
```

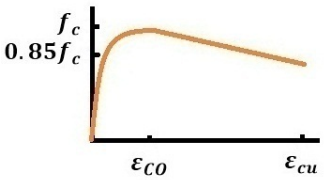
Stress-Strain of materials

Steel Rebar : Stress-Strain Relationship



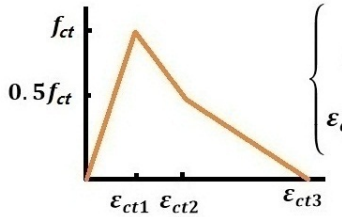
$$\begin{cases} \varepsilon_s < \varepsilon_y & f_s = E_s\varepsilon_s \\ \varepsilon_y \le \varepsilon_s < \varepsilon_{sh} & f_s = F_y \\ \varepsilon_{sh} \le \varepsilon_s < \varepsilon_{su} & f_s = F_y + E_{sh}(\varepsilon_s - \varepsilon_{sh}) \end{cases}$$

Unconfined Concrete compressive : Stress-Strain Relationship



$$\begin{cases} \varepsilon_c < \varepsilon_{C0} & f_c = f_c\left[\left(\frac{2\varepsilon_c}{\varepsilon_{C0}}\right) - \left(\frac{\varepsilon_c}{\varepsilon_{C0}}\right)^2\right] \\ \varepsilon_{C0} \le \varepsilon_c < \varepsilon_{cu} & f_c\left[1 - \left(\frac{0.15(\varepsilon_c - \varepsilon_{C0})}{\varepsilon_{cu} - \varepsilon_{C0}}\right)\right] \end{cases}$$

Unconfined Concrete Tensile: Stress-Strain Relationship



$$\begin{cases} \varepsilon_c \le \varepsilon_{ct1} & f_{ct} = 0.5E_c\varepsilon_c \\ \varepsilon_{ct1} < \varepsilon_c \le \varepsilon_{ct2} & f_{ct} = f_{ct} - \left[\frac{0.5f_{ct}}{\varepsilon_{ct2} - \varepsilon_{ct1}}\right](\varepsilon_c - \varepsilon_{ct1}) \\ \varepsilon_{ct2} < \varepsilon_c \le \varepsilon_{ct3} & f_{ct} = 0.5f_{ct} - \left[\frac{0.5f_{ct}}{\varepsilon_{ct3} - \varepsilon_{ct2}}\right](\varepsilon_c - \varepsilon_{ct2}) \end{cases}$$

Concrete Properties:

```
fc =25;% [N/mm^2] Unconfined concrete strength
ecu=0.004;% Ultimate concrete strain
Ec=5000*sqrt(fc);
ec0=(2*fc)/Ec;
fct=-0.7*sqrt(fc);% Concrete tension stress
ect1=(2*fct)/Ec;ect2=(2.625*fct)/Ec;ect3=(9.292*fct)/Ec;% Concrete tension
strain
```

Steel Reinforcing Properties:

```
fy =400;% [N/mm^2] Yield strength of reinforcing steel
Es =2e5;% [N/mm^2] Modulus of elasticity of steel
fu=1.5*fy;% Ultimate steel stress
ey=fy/Es;% Yeild steel strain
esh=0.01;% Strain at steel strain-hardening
esu=0.09;% Ultimate steel strain
Esh=(fu-fy)/(esu-esh);
```

Analysis Report:

```
############################
# Moment-Curvature Analysis  #
############################
(+)Increment 1 : It is converged in 8 iterations - strain: 0.000042 - x: 215.24 - Phi: 0.00020 - Moment: 25.33
(+)Increment 2 : It is converged in 7 iterations - strain: 0.000092 - x: 215.69 - Phi: 0.00043 - Moment: 55.44
(+)Increment 3 : It is converged in 8 iterations - strain: 0.000188 - x: 216.55 - Phi: 0.00087 - Moment: 111.47
(+)Increment 4 : It is converged in 10 iterations - strain: 0.000280 - x: 206.02 - Phi: 0.00136 - Moment: 148.54
(+)Increment 5 : It is converged in 11 iterations - strain: 0.000367 - x: 186.41 - Phi: 0.00197 - Moment: 178.59
(+)Increment 6 : It is converged in 11 iterations - strain: 0.000429 - x: 176.63 - Phi: 0.00243 - Moment: 198.90
(+)Increment 7 : It is converged in 14 iterations - strain: 0.000872 - x: 150.32 - Phi: 0.00580 - Moment: 360.53
(+)Increment 8 : It is converged in 23 iterations - strain: 0.001041 - x: 140.67 - Phi: 0.00740 - Moment: 406.06
(+)Increment 9 : It is converged in 24 iterations - strain: 0.001171 - x: 122.57 - Phi: 0.00955 - Moment: 404.72
(+)Increment 10 : It is converged in 24 iterations - strain: 0.001301 - x: 109.75 - Phi: 0.01185 - Moment: 404.59
(+)Increment 11 : It is converged in 26 iterations - strain: 0.001600 - x: 91.37 - Phi: 0.01751 - Moment: 405.41
(+)Increment 12 : It is converged in 27 iterations - strain: 0.002000 - x: 78.58 - Phi: 0.02545 - Moment: 406.51
(+)Increment 13 : It is converged in 28 iterations - strain: 0.002400 - x: 72.61 - Phi: 0.03305 - Moment: 412.98
(+)Increment 14 : It is converged in 29 iterations - strain: 0.002800 - x: 69.24 - Phi: 0.04044 - Moment: 420.19
(+)Increment 15 : It is converged in 30 iterations - strain: 0.003200 - x: 67.04 - Phi: 0.04773 - Moment: 427.13
(+)Increment 16 : It is converged in 31 iterations - strain: 0.003600 - x: 65.52 - Phi: 0.05495 - Moment: 433.91
(+)Increment 17 : It is converged in 32 iterations - strain: 0.004000 - x: 64.40 - Phi: 0.06211 - Moment: 440.58

    ## Unconfined Concrete Strain Reached to Ultimate Strain: 0.0040 ##
```

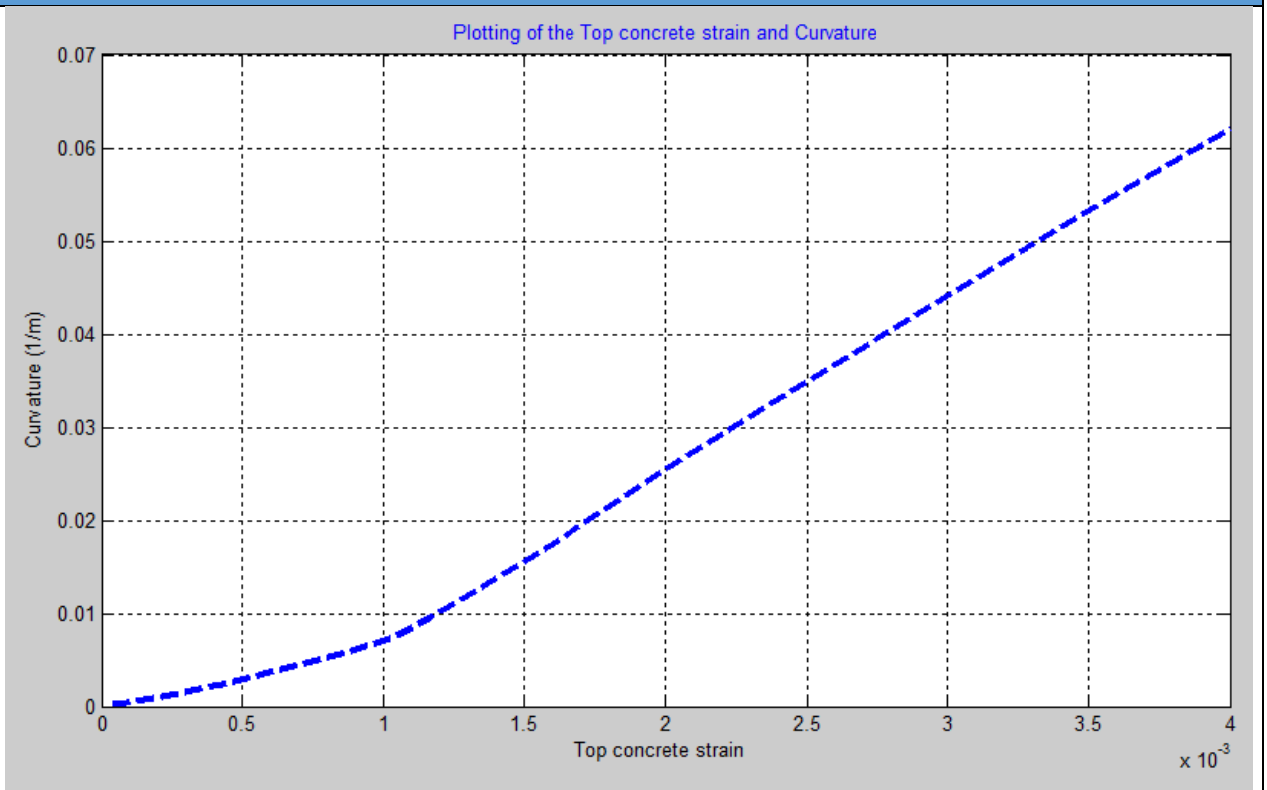
Increment (i)	Top strain (1)	Neuteral axis(x) (mm)	Curvature (1/m)	Flextural Rigidity(EI) (kN.m^2)
1	0.00004	215.24	0.000195	129810.90
2	0.00009	215.69	0.000428	129088.35
3	0.00019	216.55	0.000866	127932.72
4	0.00028	206.02	0.001359	75237.02
5	0.00037	186.41	0.001971	49070.30
6	0.00043	176.63	0.002430	44243.12
7	0.00087	150.32	0.005798	47994.07
8	0.00104	140.67	0.007398	28455.69
9	0.00117	122.57	0.009552	-617.77
10	0.00130	109.75	0.011853	-59.35
11	0.00160	91.37	0.017512	145.02
12	0.00200	78.58	0.025452	138.27
13	0.00240	72.61	0.033052	851.86
14	0.00280	69.24	0.040441	975.49
15	0.00320	67.04	0.047731	951.88
16	0.00360	65.52	0.054948	939.15
17	0.00400	64.40	0.062112	931.47

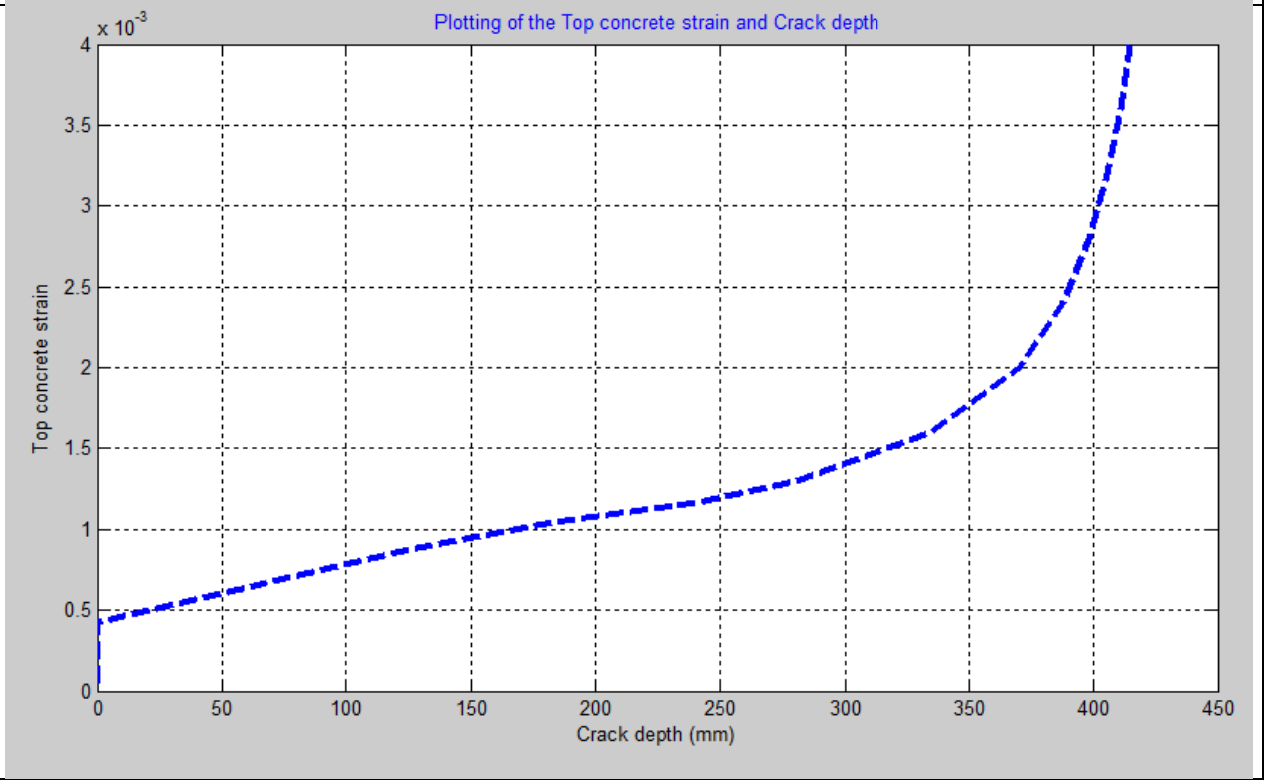
Analysis curve fitted

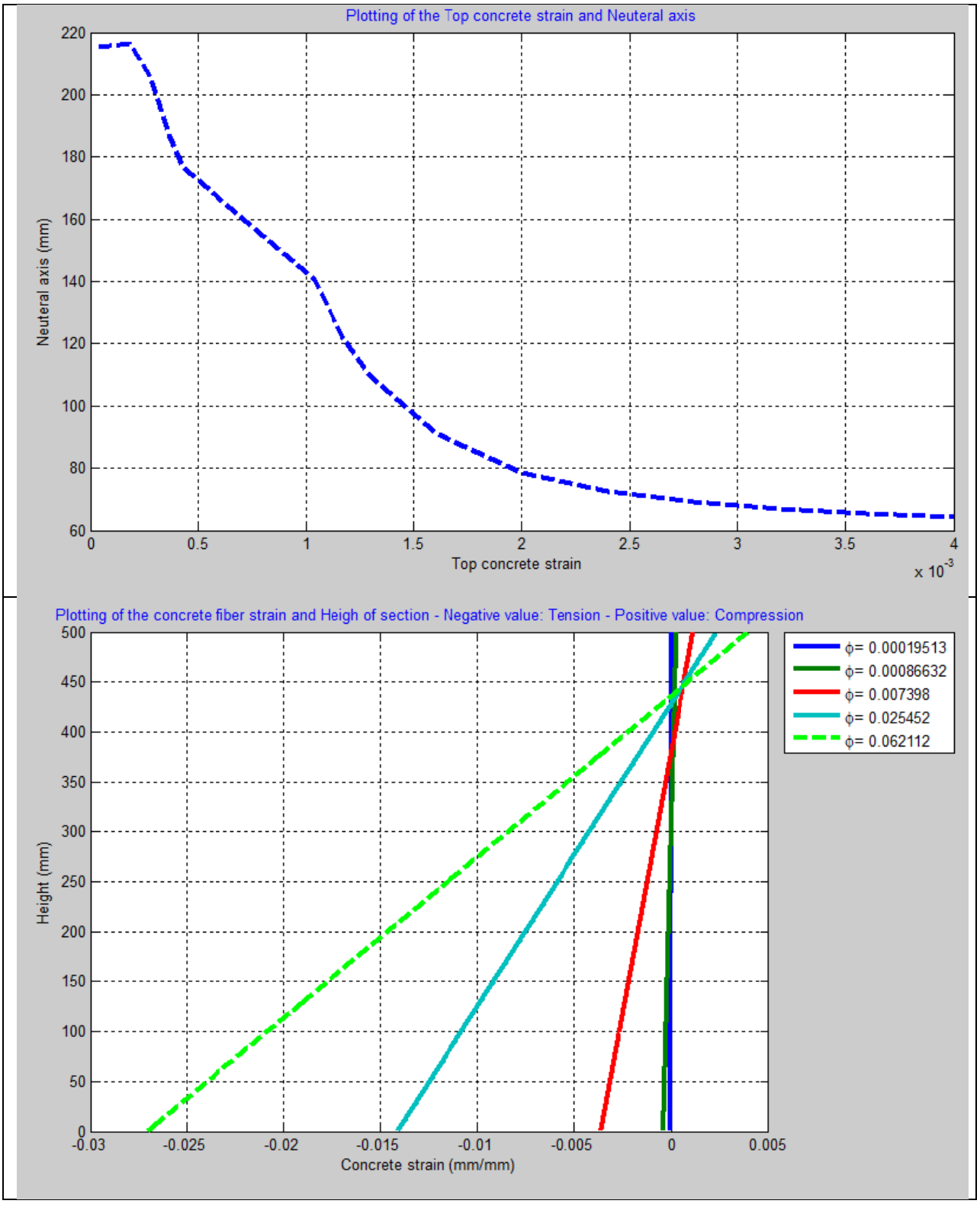
Curvature (1/m)	Moment (kN.m)
0	0
0.0029	375.0638
0.0621	440.5788

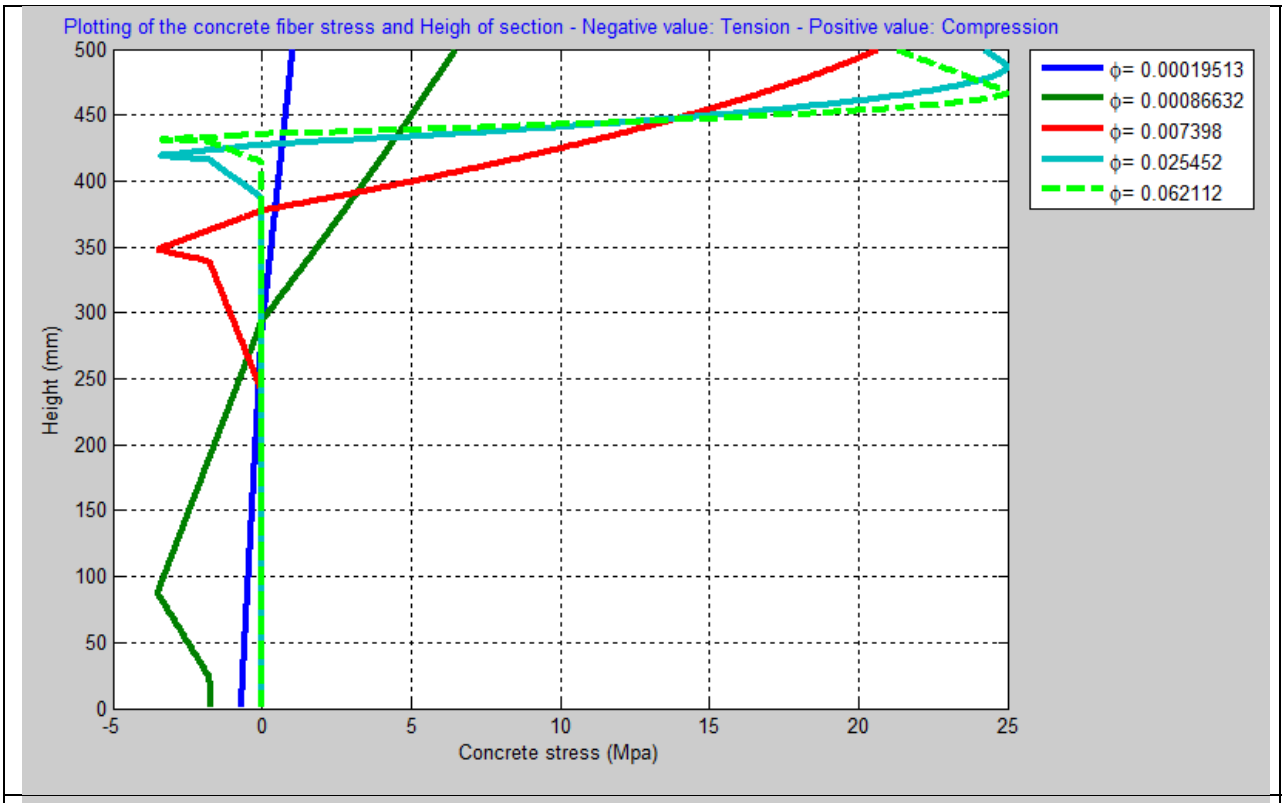
```
Elastic EI : 129810.90 (kN.m^2)
Plastic EI : 1106.25 (kN.m^2)
Unconfined Section Ductility Rito : 21.50
```

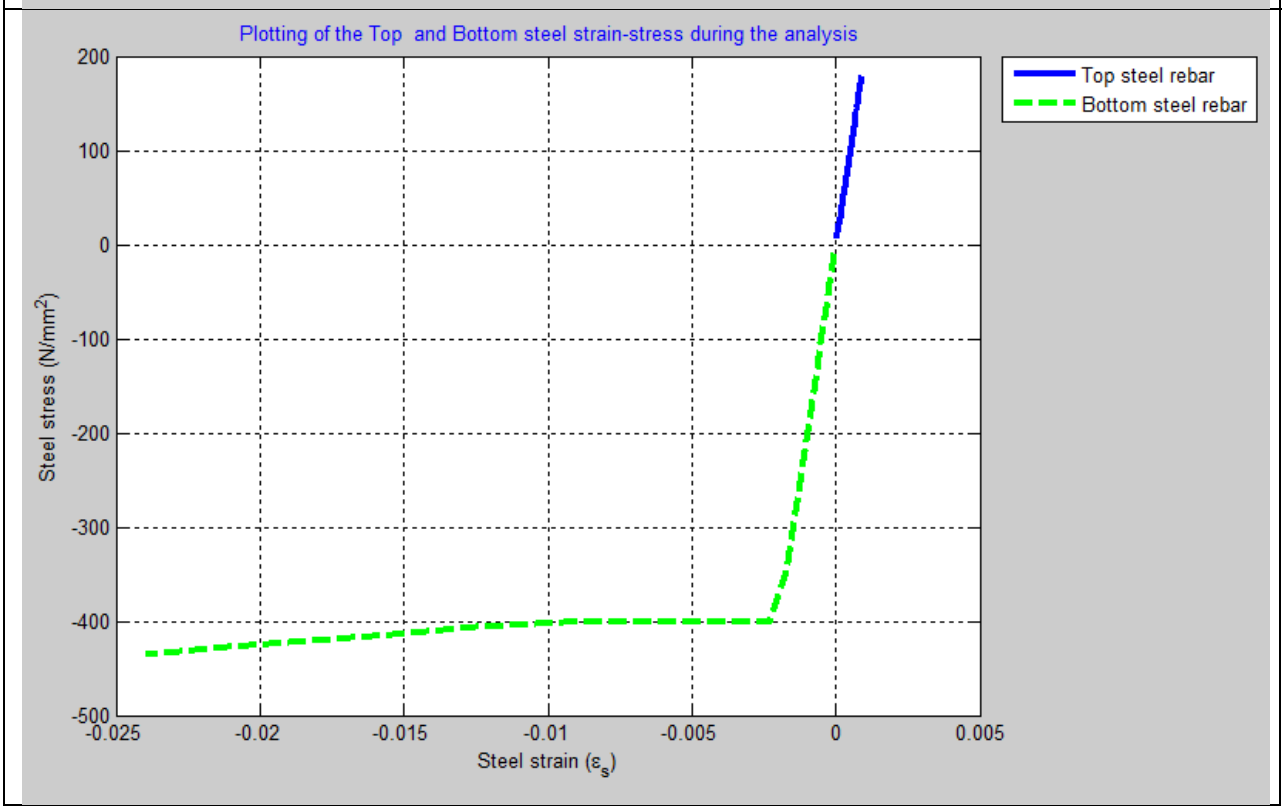
Plot :

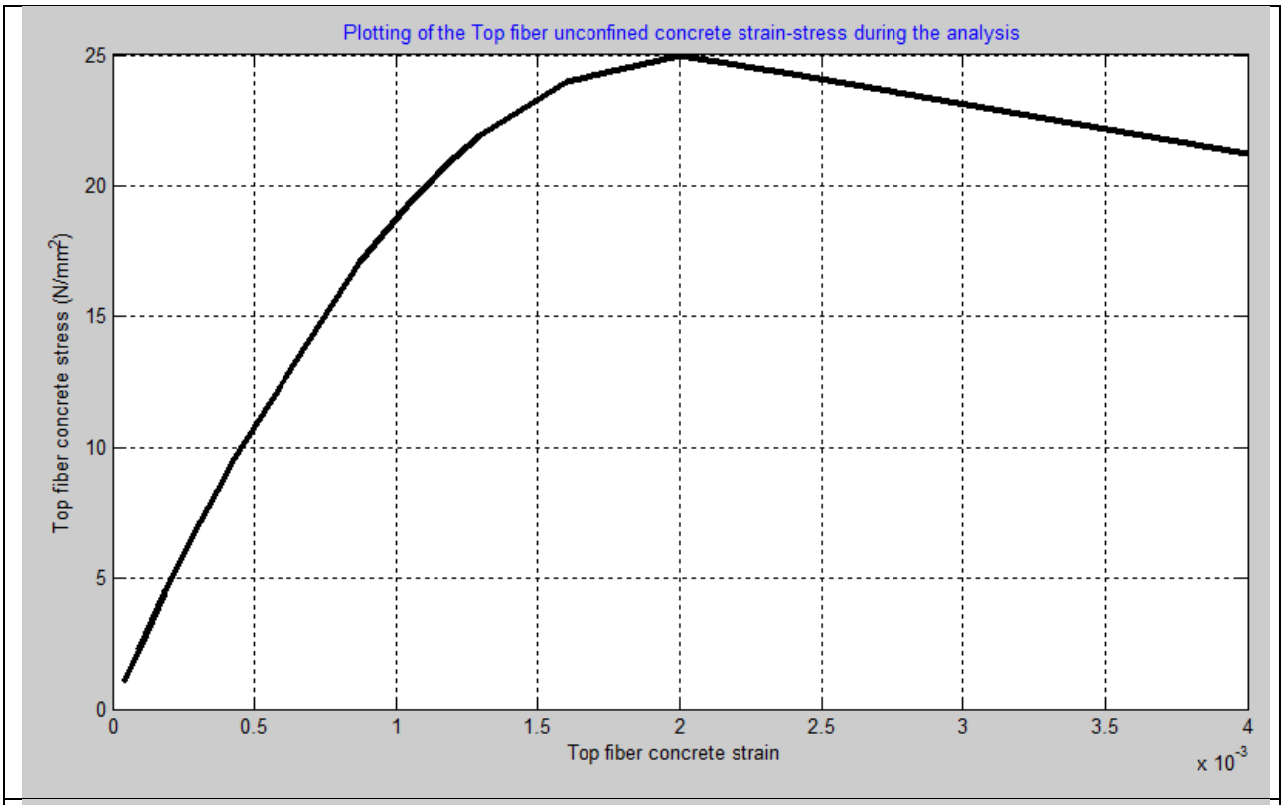

Plotting of the Top concrete strain and Curvature
Curvature (1/m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Top concrete strain
x 10^-3

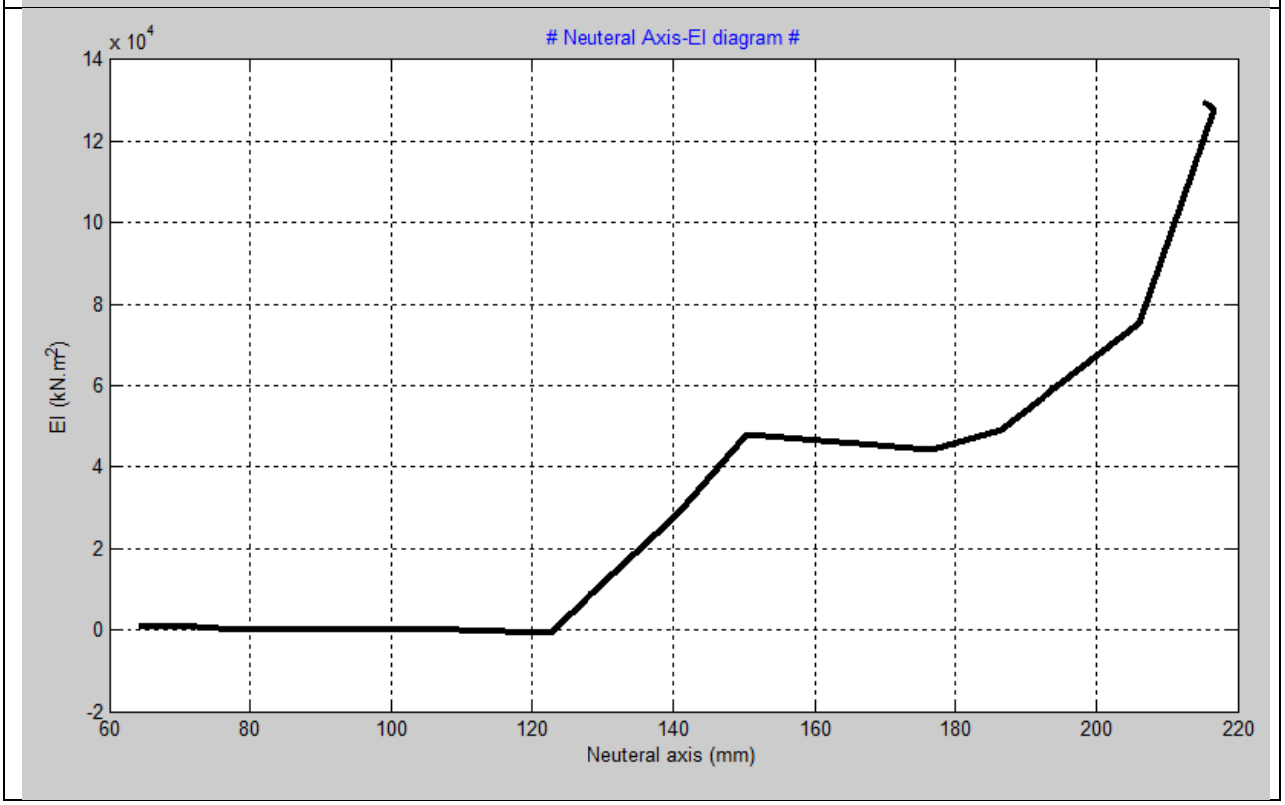

Plotting of the Top concrete strain and Crack depth
x 10^-3
Top concrete strain
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
400
450
Crack depth (mm)

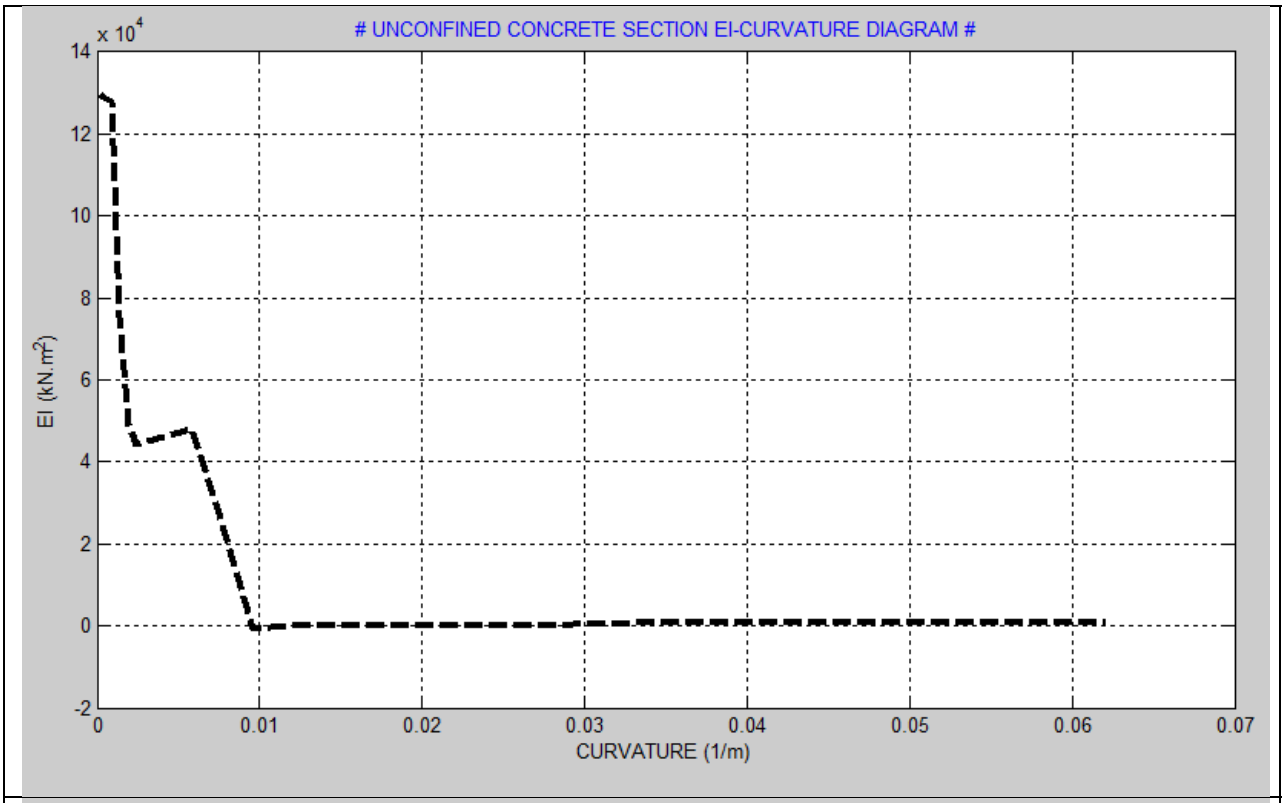

Plotting of the Top concrete strain and Neuteral axis
Neuteral axis (mm)
Top concrete strain
x 10^-3
Plotting of the concrete fiber strain and Heigh of section - Negative value: Tension - Positive value: Compression
Height (mm)
Concrete strain (mm/mm)
ϕ= 0.00019513
ϕ= 0.00086632
ϕ= 0.007398
ϕ= 0.025452
ϕ= 0.062112

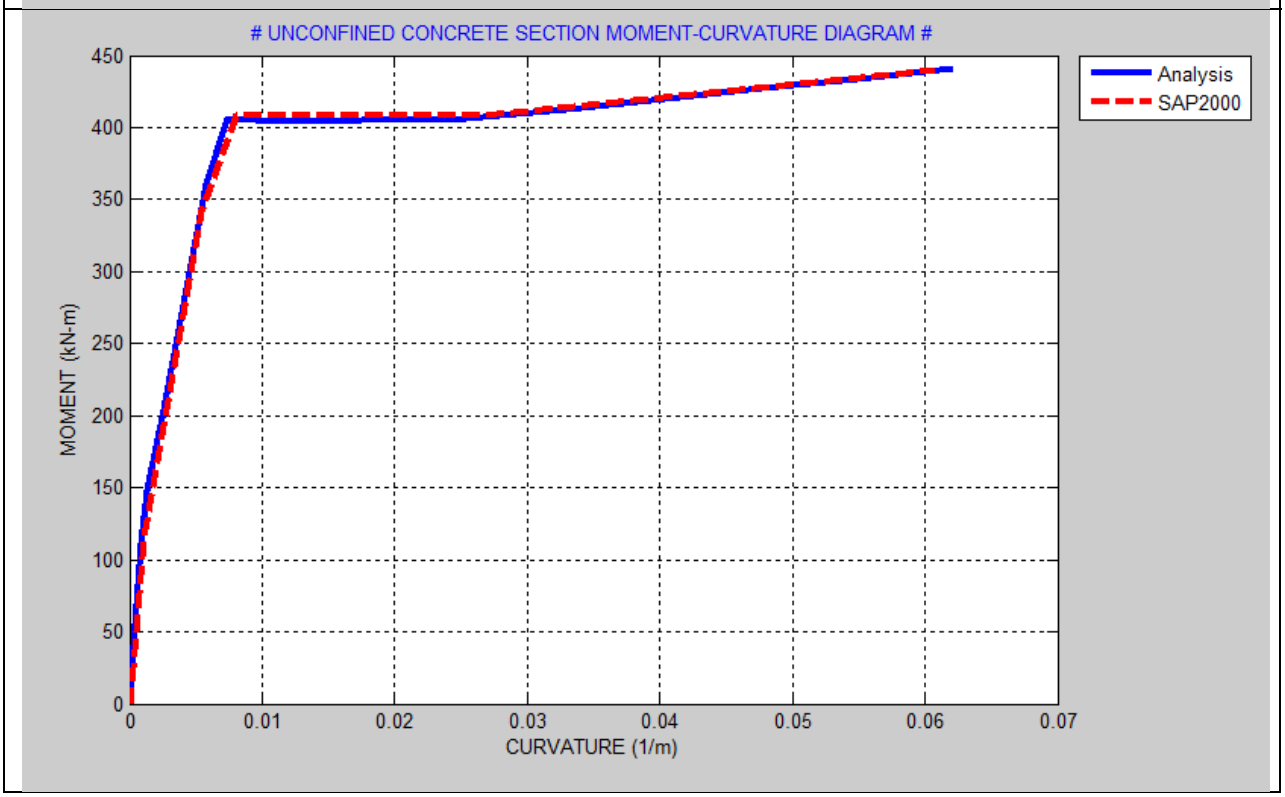

Plotting of the concrete fiber stress and Heigh of section - Negative value: Tension - Positive value: Compression
Height (mm)
Concrete stress (Mpa)
ϕ= 0.00019513
ϕ= 0.00086632
ϕ= 0.007398
ϕ= 0.025452
ϕ= 0.062112


Plotting of the Top and Bottom steel strain-stress during the analysis
Steel stress (N/mm2)
Steel strain (εs)
Top steel rebar
Bottom steel rebar


Plotting of the Top fiber unconfined concrete strain-stress during the analysis
Top fiber concrete stress (N/mm2)
Top fiber concrete strain
x 10-3
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5
4


Neuteral Axis-EI diagram
x 10^4
EI (kN.m2)
Neuteral axis (mm)
-2
0
2
4
6
8
10
12
14
60
80
100
120
140
160
180
200
220


UNCONFINED CONCRETE SECTION EI-CURVATURE DIAGRAM
x 10^4
EI (kN.m^2)
CURVATURE (1/m)
14
12
10
8
6
4
2
0
-2
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07


UNCONFINED CONCRETE SECTION MOMENT-CURVATURE DIAGRAM
Analysis
SAP2000
MOMENT (kN-m)
CURVATURE (1/m)
450
400
350
300
250
200
150
100
50
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07