>> IN THE NAME OF GOD <<

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

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

**This program is written by Salar Delavar Ghashghaei - Date of Publication: June/23/2016**

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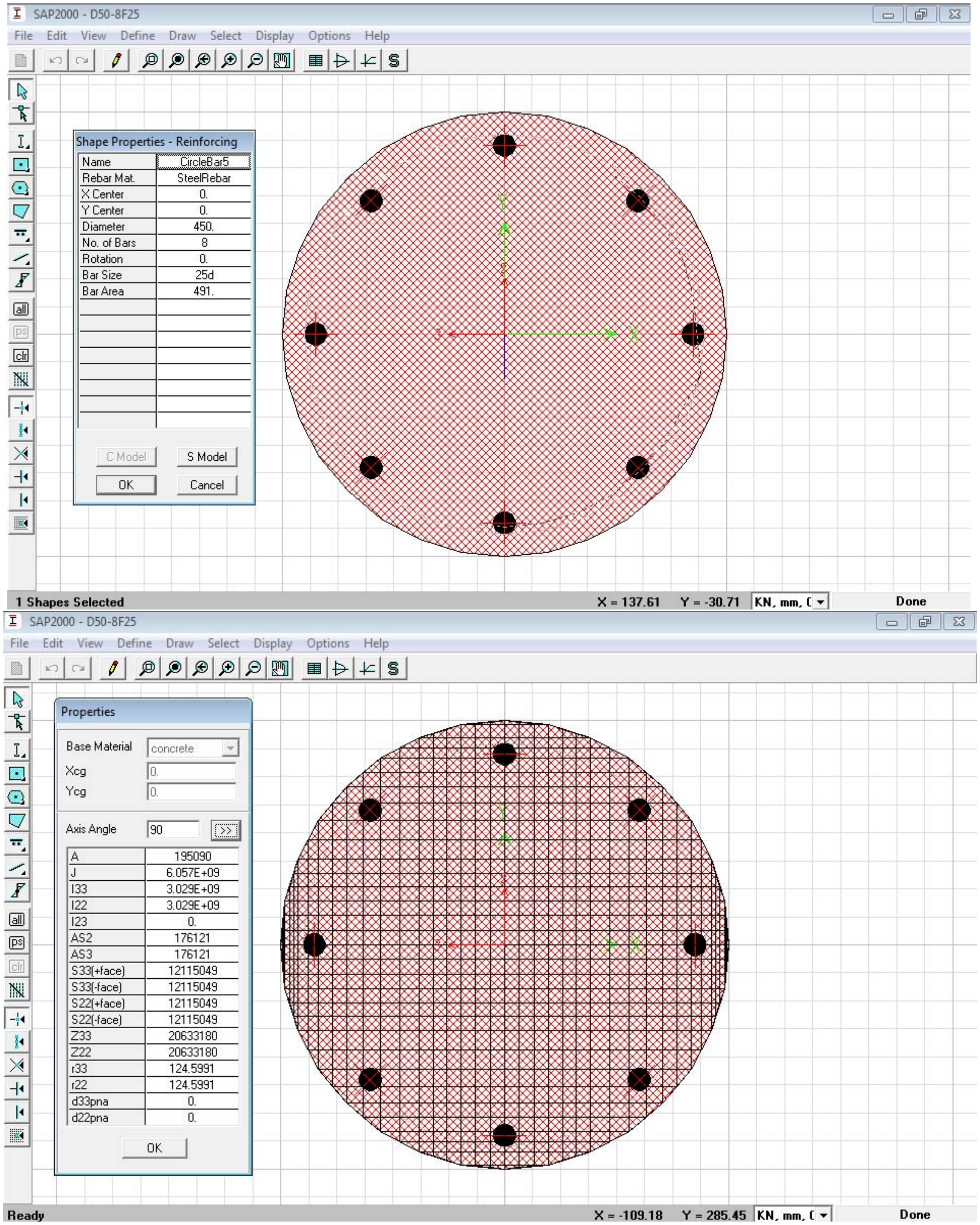
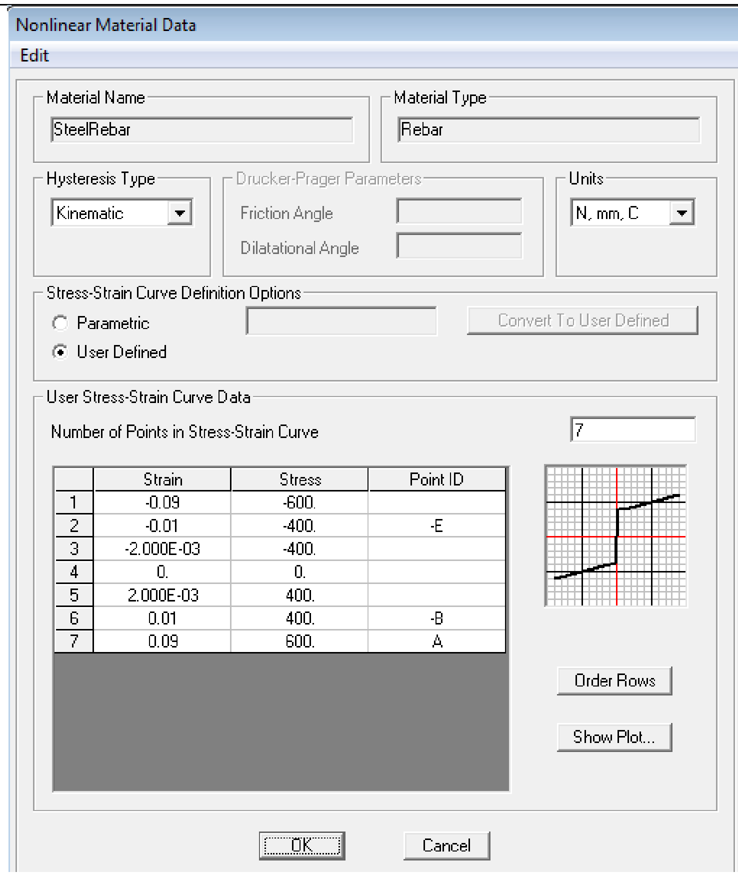



**Figure(1)** Unconfined concrete circular section properties in SAP2000



Nonlinear Material Data

Edit

Material Name: SteelRebar

Material Type: Rebar

Hysteresis Type: Kinematic

Drucker-Prager Parameters

Friction Angle

Dilatational Angle

Units: N, mm, C

Stress-Strain Curve Definition Options

Parametric

User Defined

Convert To User Defined

User Stress-Strain Curve Data

Number of Points in Stress-Strain Curve: 7

| | Strain | Stress | Point ID |
|---|---|---|---|
| 1 | -0.09 | -600. | |
| 2 | -0.01 | -400. | -E |
| 3 | -2.000E-03 | -400. | |
| 4 | 0. | 0. | |
| 5 | 2.000E-03 | 400. | |
| 6 | 0.01 | 400. | -B |
| 7 | 0.09 | 600. | A |

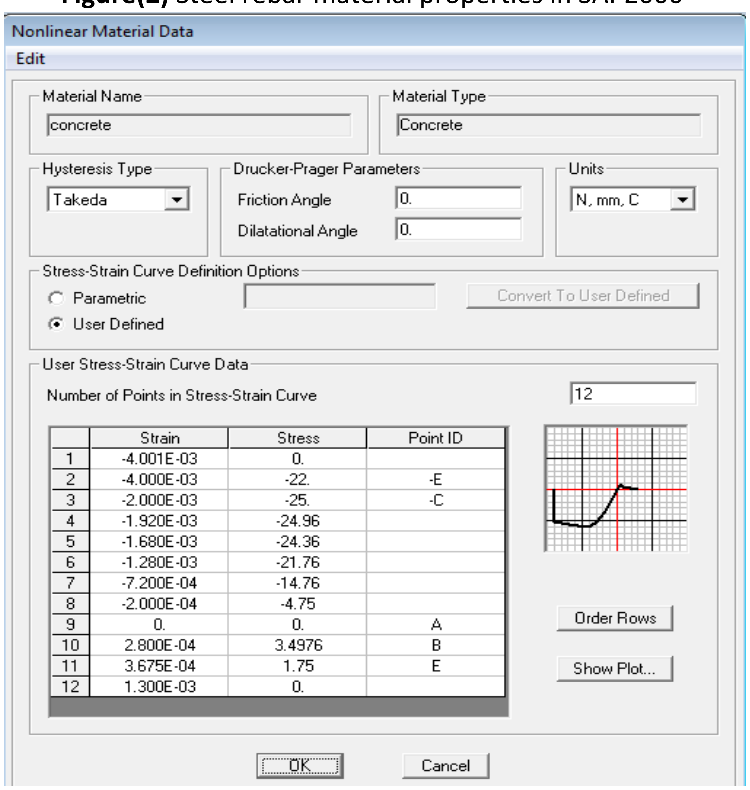
Order Rows

Show Plot...

OK

Cancel

**Figure(2)** Steel rebar material properties in SAP2000



Nonlinear Material Data

Edit

Material Name: concrete

Material Type: Concrete

Hysteresis Type: Takeda

Drucker-Prager Parameters

Friction Angle: 0.

Dilatational Angle: 0.

Units: N, mm, C

Stress-Strain Curve Definition Options

Parametric

User Defined

Convert To User Defined

User Stress-Strain Curve Data

Number of Points in Stress-Strain Curve: 12

| | Strain | Stress | Point ID |
|---|---|---|---|
| 1 | -4.001E-03 | 0. | |
| 2 | -4.000E-03 | -22. | -E |
| 3 | -2.000E-03 | -25. | -C |
| 4 | -1.920E-03 | -24.96 | |
| 5 | -1.680E-03 | -24.36 | |
| 6 | -1.280E-03 | -21.76 | |
| 7 | -7.200E-04 | -14.76 | |
| 8 | -2.000E-04 | -4.75 | |
| 9 | 0. | 0. | A |
| 10 | 2.800E-04 | 3.4976 | B |
| 11 | 3.675E-04 | 1.75 | E |
| 12 | 1.300E-03 | 0. | |

Order Rows

Show Plot...

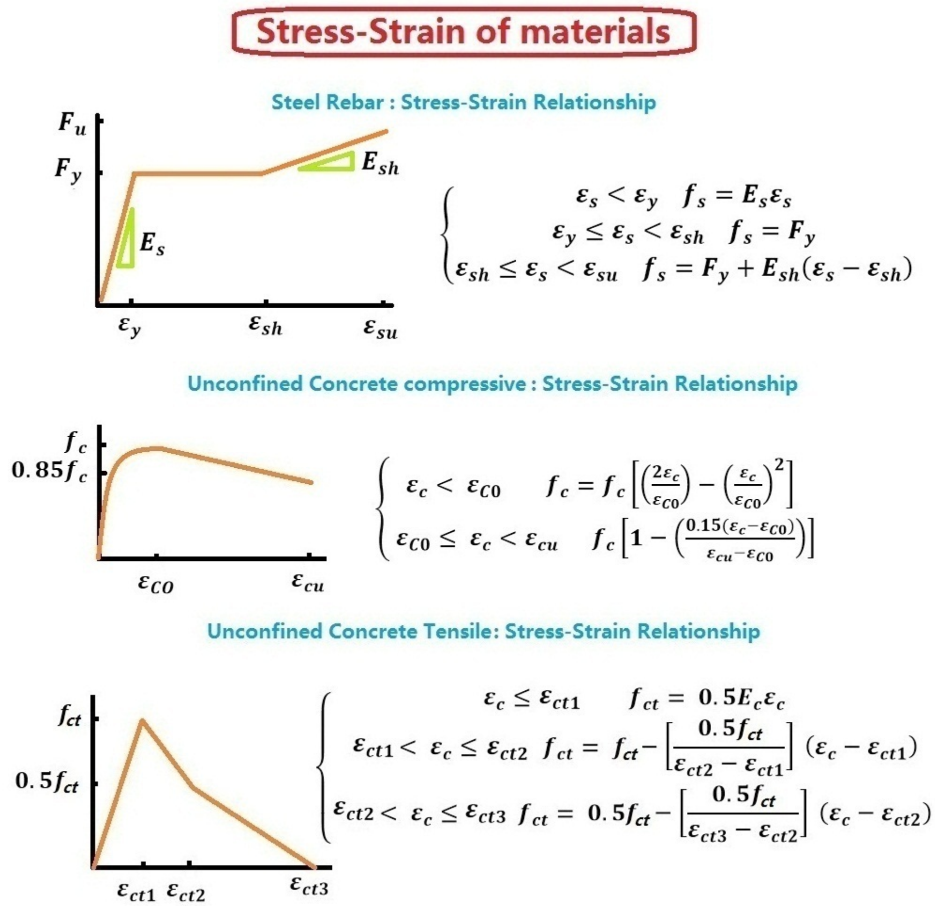
OK

Cancel

**Figure(3)** Unconfined concrete material properties in SAP2000

**Section Properties:**

```
%% Section Properties
D=500;% [mm]
%As:  As1      As2     As3     As4    As5      As6
As=[490.8594 981.7188 981.7188 981.7188 0 490.8594]; % NOTE: As1 & As6 =
8fi25
%d:d1  d2  d3  d4  d5  d6
d=[37.5 99.74 250 400.26 0 462.26];
```




**Figure(4)** Material properties in MATLAB

**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);
```

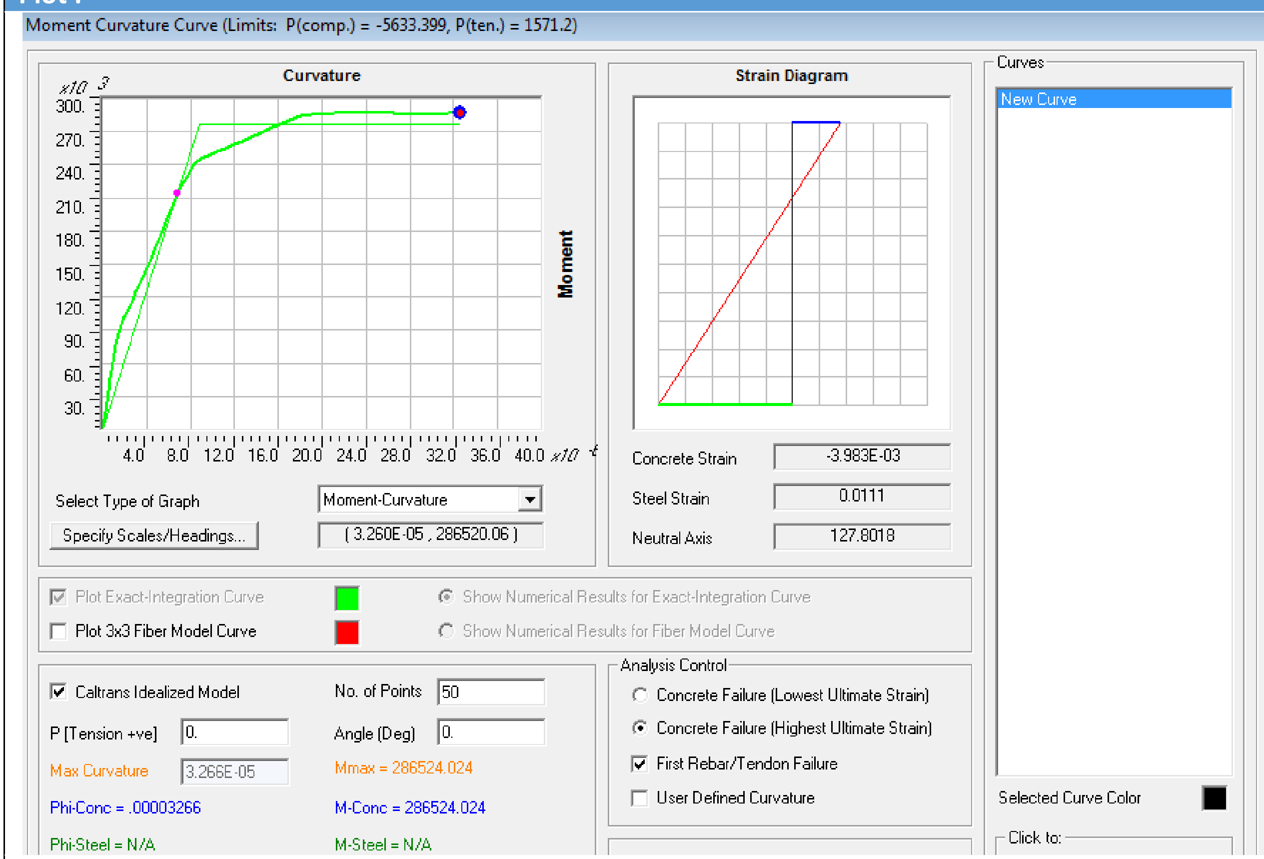
## Analysis Report:

```
############################
# Moment-Curvature Analysis   #
############################
(+)Increment 1 : It is converged in 8 iterations - strain: 0.000042 - x: 220.50 - Phi: 0.00019 - Moment: 13.57
(+)Increment 2 : It is converged in 7 iterations - strain: 0.000092 - x: 220.84 - Phi: 0.00042 - Moment: 29.71
(+)Increment 3 : It is converged in 8 iterations - strain: 0.000188 - x: 221.48 - Phi: 0.00085 - Moment: 59.80
(+)Increment 4 : It is converged in 9 iterations - strain: 0.000280 - x: 219.50 - Phi: 0.00128 - Moment: 85.15
(+)Increment 5 : It is converged in 11 iterations - strain: 0.000367 - x: 207.72 - Phi: 0.00177 - Moment: 98.11
(+)Increment 6 : It is converged in 12 iterations - strain: 0.000429 - x: 199.69 - Phi: 0.00215 - Moment: 107.96
(+)Increment 7 : It is converged in 15 iterations - strain: 0.000872 - x: 170.40 - Phi: 0.00512 - Moment: 173.08
(+)Increment 8 : It is converged in 15 iterations - strain: 0.001041 - x: 167.16 - Phi: 0.00623 - Moment: 201.17
(+)Increment 9 : It is converged in 17 iterations - strain: 0.001171 - x: 165.11 - Phi: 0.00709 - Moment: 220.93
(+)Increment 10 : It is converged in 18 iterations - strain: 0.001301 - x: 162.61 - Phi: 0.00800 - Moment: 236.93
(+)Increment 11 : It is converged in 24 iterations - strain: 0.001600 - x: 151.68 - Phi: 0.01055 - Moment: 252.61
(+)Increment 12 : It is converged in 26 iterations - strain: 0.002000 - x: 142.55 - Phi: 0.01403 - Moment: 268.20
(+)Increment 13 : It is converged in 28 iterations - strain: 0.002400 - x: 138.07 - Phi: 0.01738 - Moment: 283.03
(+)Increment 14 : It is converged in 44 iterations - strain: 0.002800 - x: 129.63 - Phi: 0.02160 - Moment: 286.24
(+)Increment 15 : It is converged in 49 iterations - strain: 0.003200 - x: 124.89 - Phi: 0.02562 - Moment: 286.23
(+)Increment 16 : It is converged in 52 iterations - strain: 0.003600 - x: 121.66 - Phi: 0.02959 - Moment: 286.07
(+)Increment 17 : It is converged in 55 iterations - strain: 0.004000 - x: 119.43 - Phi: 0.03349 - Moment: 286.41

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

+===================+
=   Analysis curve fitted =
  Curvature    Moment
    (1/m)      (kN.m)
---------------------------
        0        0
   0.0033  231.9855
   0.0335  286.4053

+===================+
+----------------------------------------------------+
 Elastic EI : 71223.50 (kN.m^2)
 Plastic EI : 1799.95 (kN.m^2)
 Unconfined Section Ductility Rito : 10.28
+----------------------------------------------------+
+================+
 =        Analysis           =
  Curvature    Moment
    (1/m)      (kN.m)
----------------------------
  0.00000     0.000
  0.00019    13.566
  0.00042    29.711
  0.00085    59.803
  0.00128    85.148
  0.00177    98.113
  0.00215   107.956
  0.00512   173.076
  0.00623   201.168
  0.00709   220.926
  0.00800   236.925
  0.01055   252.614
  0.01403   268.203
  0.01738   283.027
  0.02160   286.242
  0.02562   286.233
  0.02959   286.068
  0.03349   286.405
+===================+
 =  Analysis curve fitted  =
```

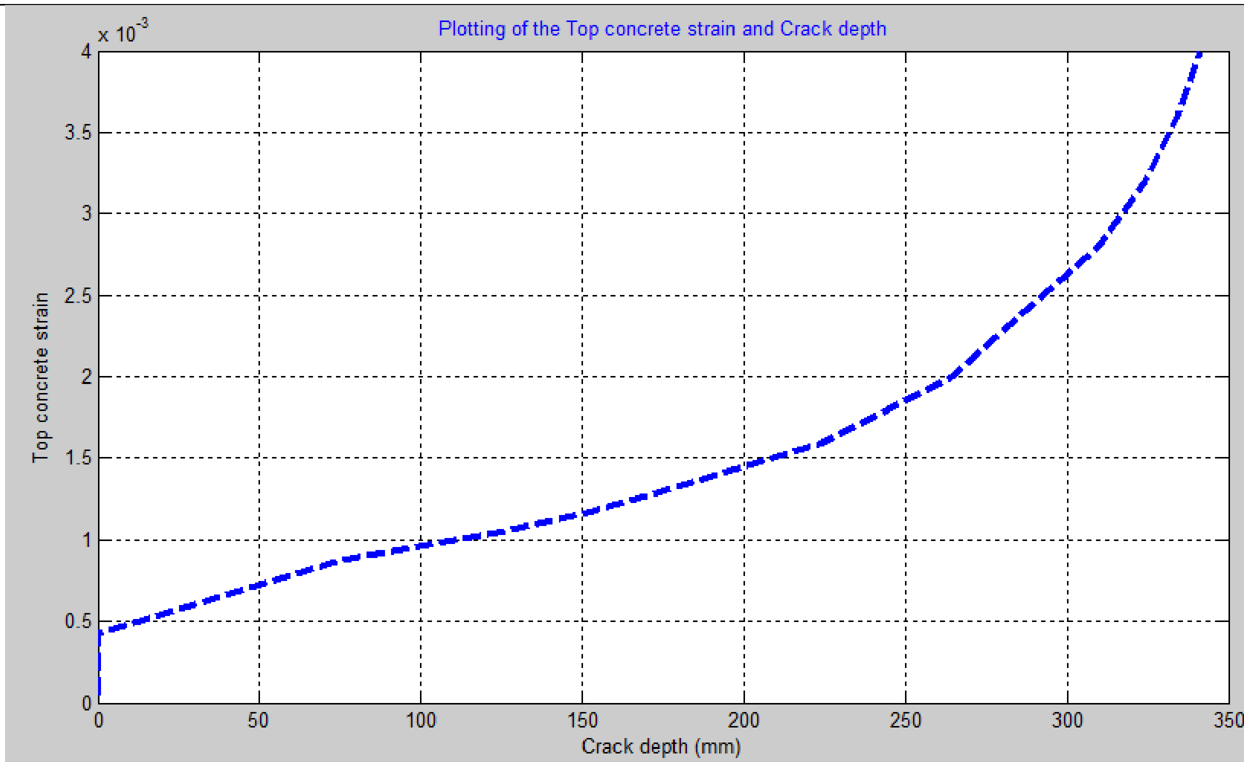
| Curvature (1/m) | Moment (kN.m) |
|---|---|
| 0.00000 | 0.000 |
| 0.00326 | 231.985 |
| 0.03349 | 286.405 |

| Increment (i) | Top strain (1) | Neuteral axis(x) (mm) | Curvature (1/m) | Flextural Rigidity(EI) (kN.m^2) |
|---|---|---|---|---|
| 1 | 0.00004 | 220.50 | 0.000190 | NaN |
| 2 | 0.00009 | 220.84 | 0.000418 | 71223.50 |
| 3 | 0.00019 | 221.48 | 0.000847 | 71009.85 |
| 4 | 0.00028 | 219.50 | 0.001276 | 70602.84 |
| 5 | 0.00037 | 207.72 | 0.001769 | 66749.47 |
| 6 | 0.00043 | 199.69 | 0.002150 | 55455.19 |
| 7 | 0.00087 | 170.40 | 0.005115 | 50217.54 |
| 8 | 0.00104 | 167.16 | 0.006226 | 33836.75 |
| 9 | 0.00117 | 165.11 | 0.007091 | 32312.64 |
| 10 | 0.00130 | 162.61 | 0.008000 | 31155.83 |
| 11 | 0.00160 | 151.68 | 0.010548 | 29615.00 |
| 12 | 0.00200 | 142.55 | 0.014030 | 23948.02 |
| 13 | 0.00240 | 138.07 | 0.017382 | 19116.36 |
| 14 | 0.00280 | 129.63 | 0.021600 | 16282.67 |
| 15 | 0.00320 | 124.89 | 0.025623 | 13252.04 |
| 16 | 0.00360 | 121.66 | 0.029592 | 11170.88 |
| 17 | 0.00400 | 119.43 | 0.033491 | 9667.15 |

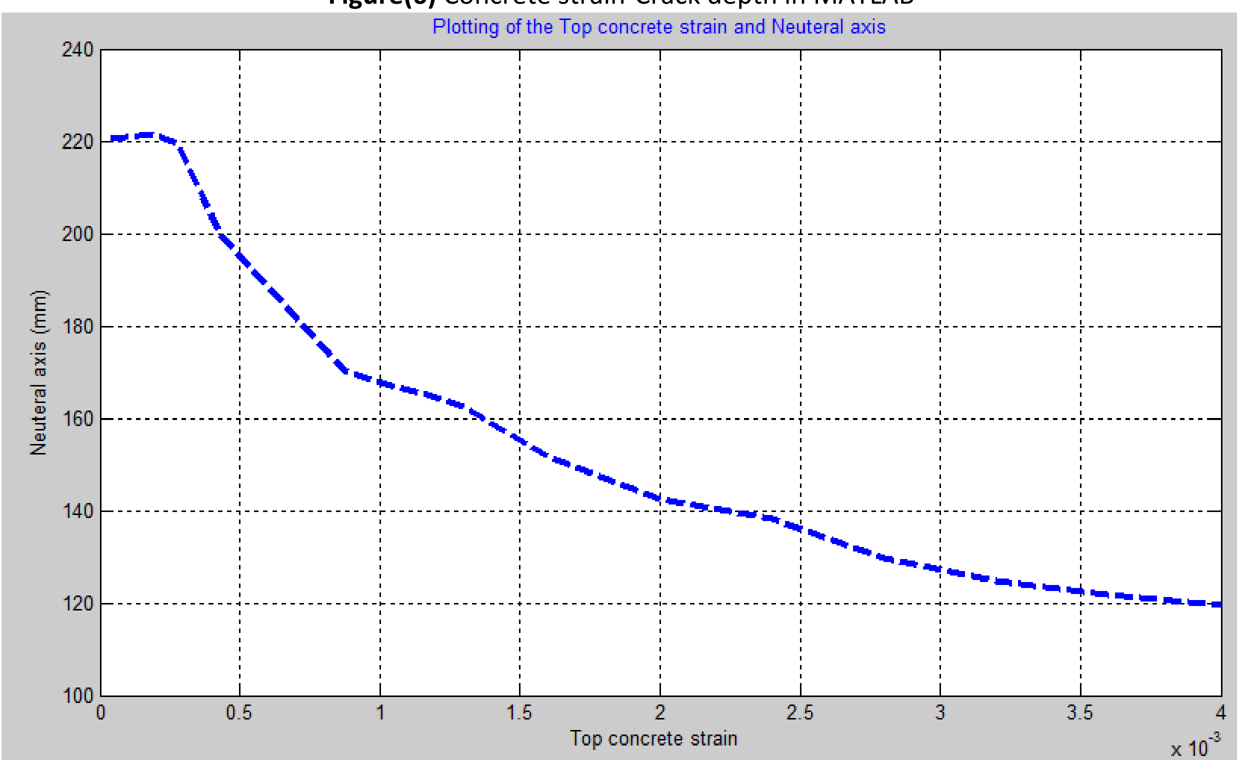
## Plot :



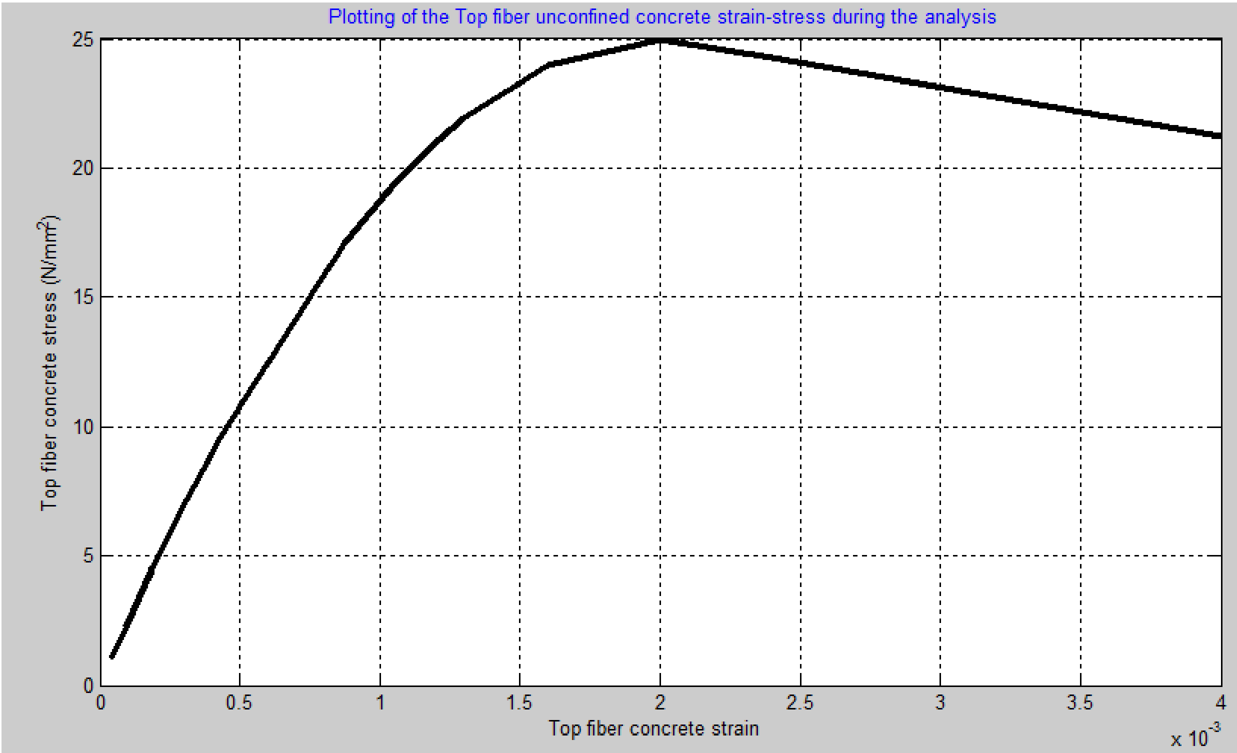

**Figure(5)** Moment curvature analysis in SAP2000



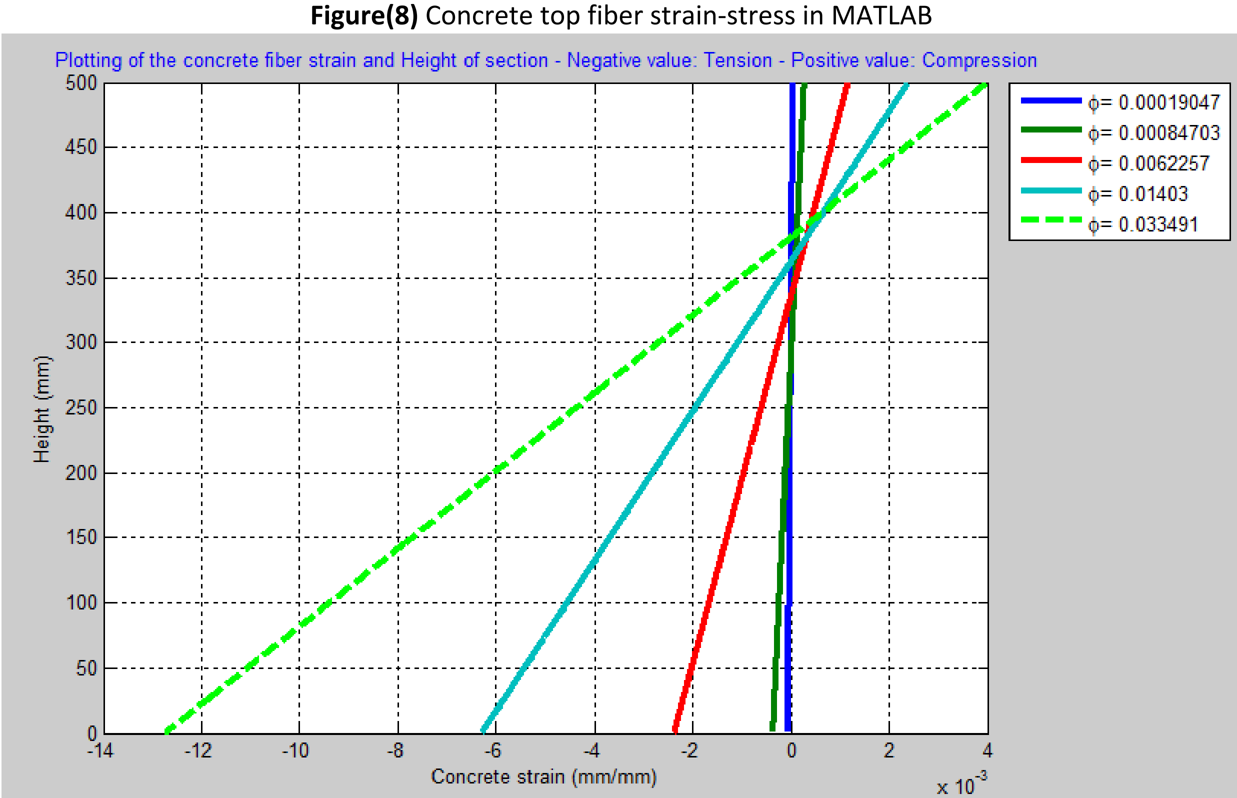

**Figure(6)** Concrete strain-Crack depth in MATLAB



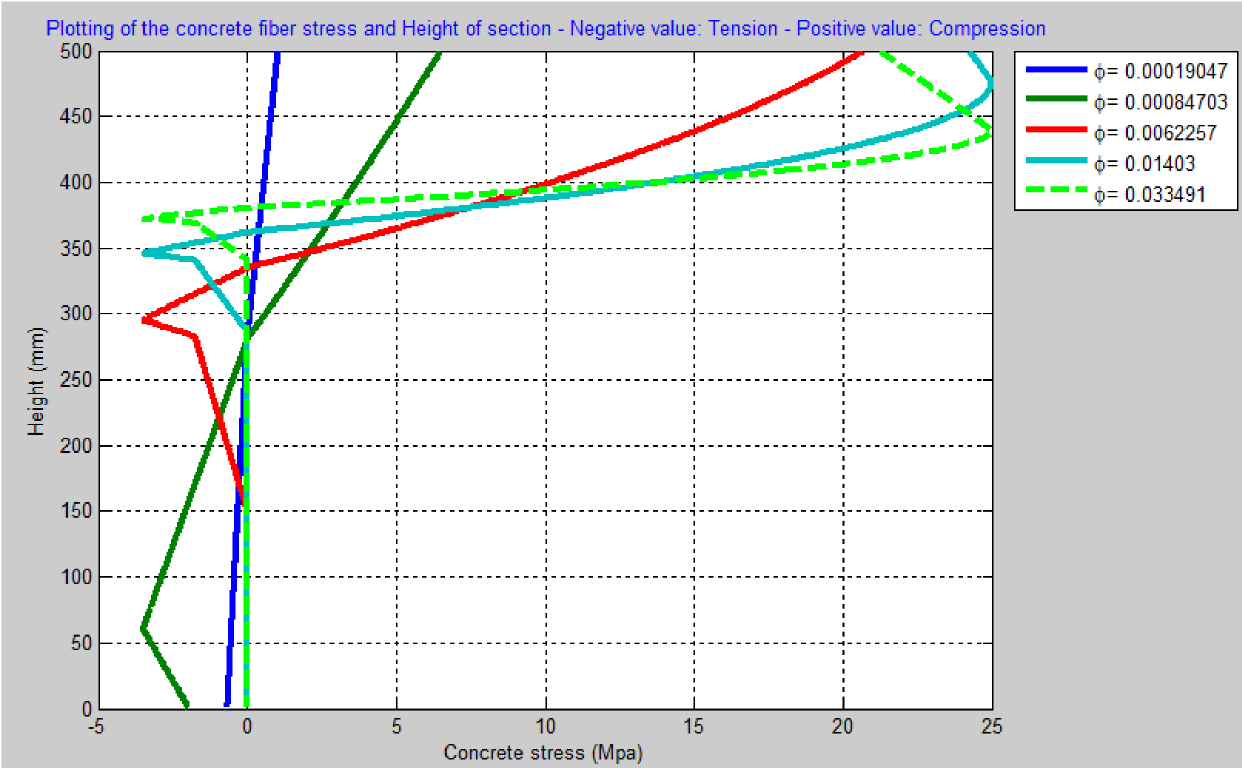

**Figure(7)** Concrete strain-Neuteral axis in MATLAB



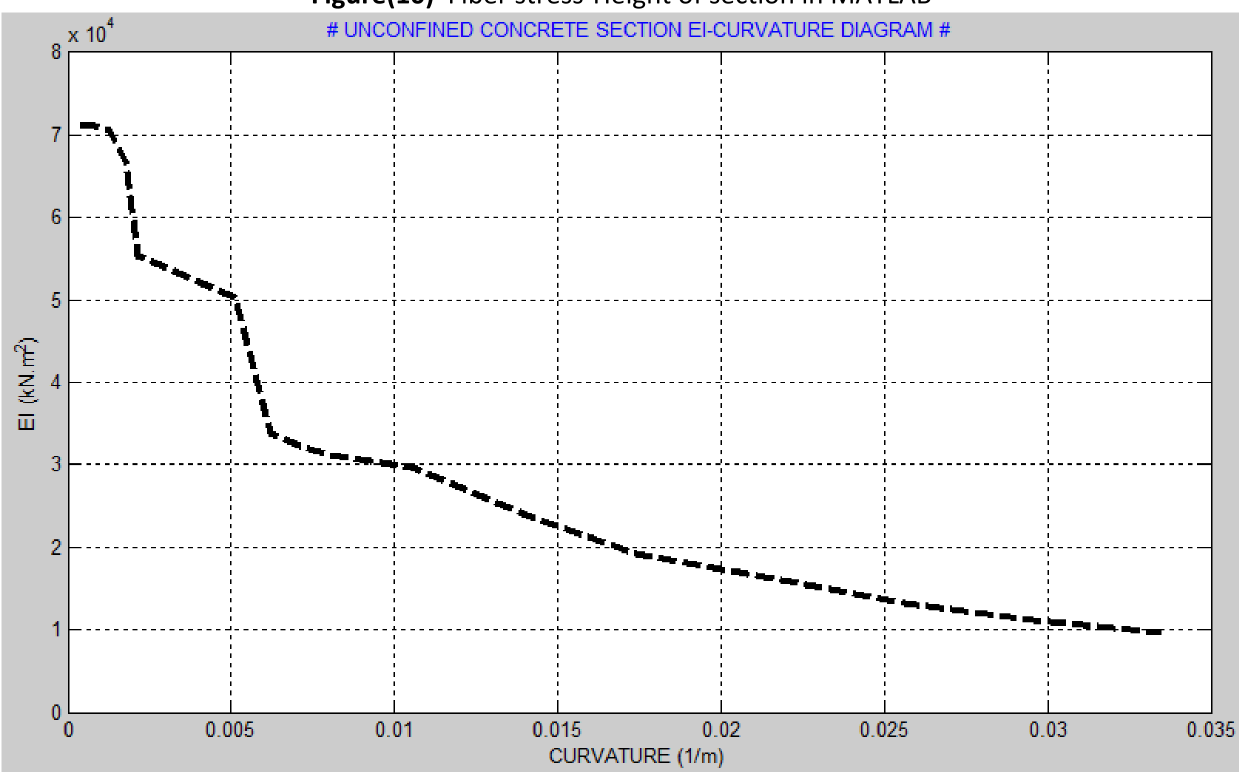

**Figure(8)** Concrete top fiber strain-stress in MATLAB



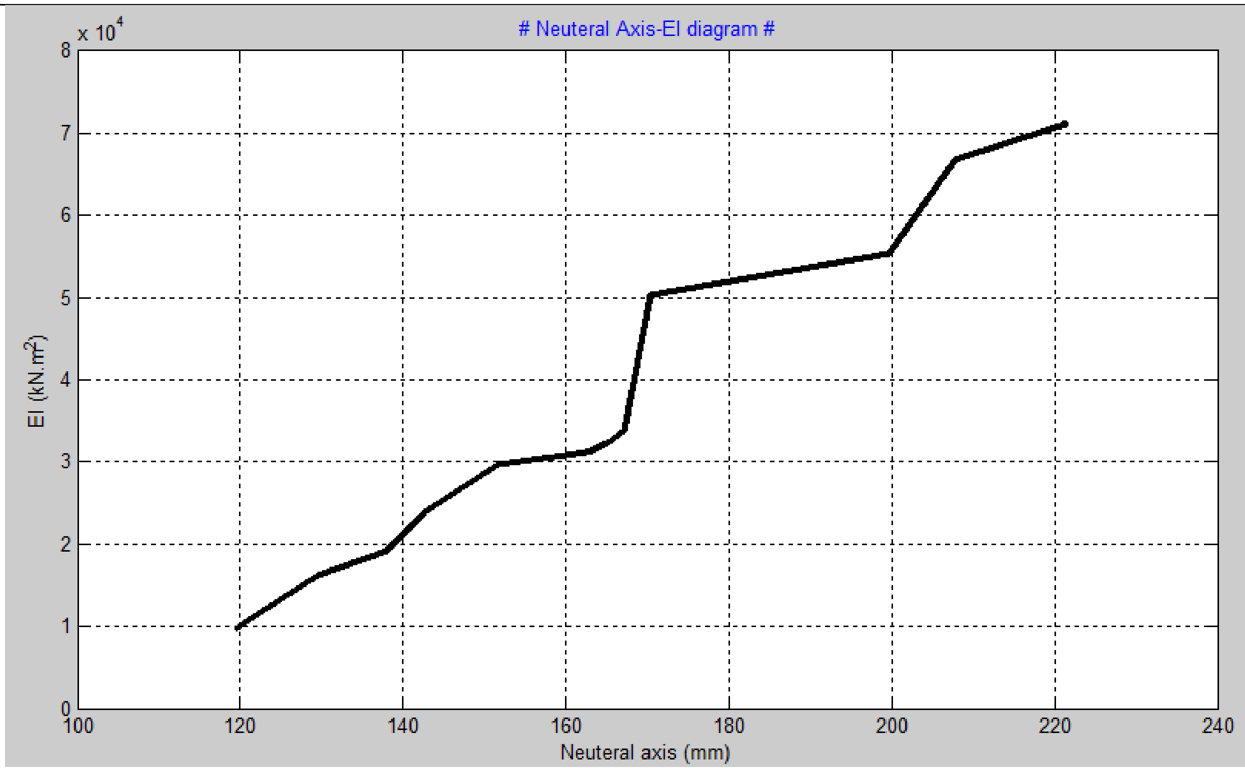

**Figure(9)** Fiber strain-Height of section in MATLAB



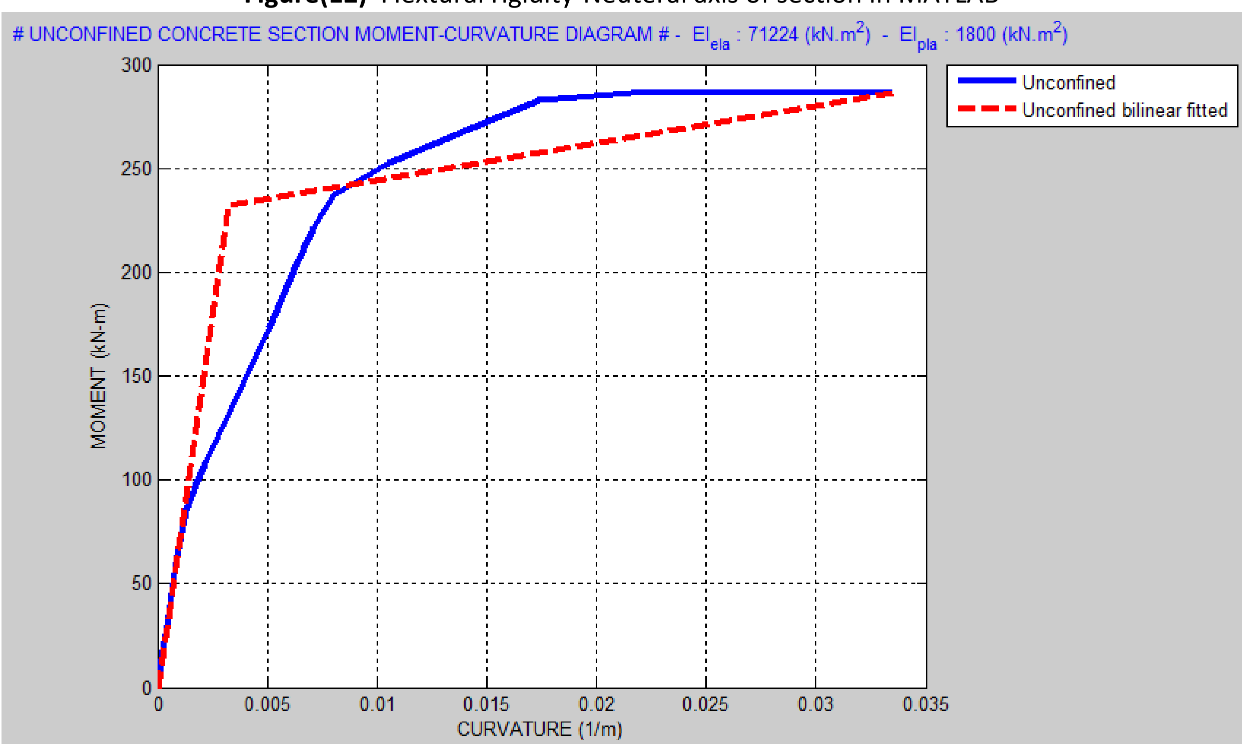

**Figure(10)** Fiber stress-Height of section in MATLAB



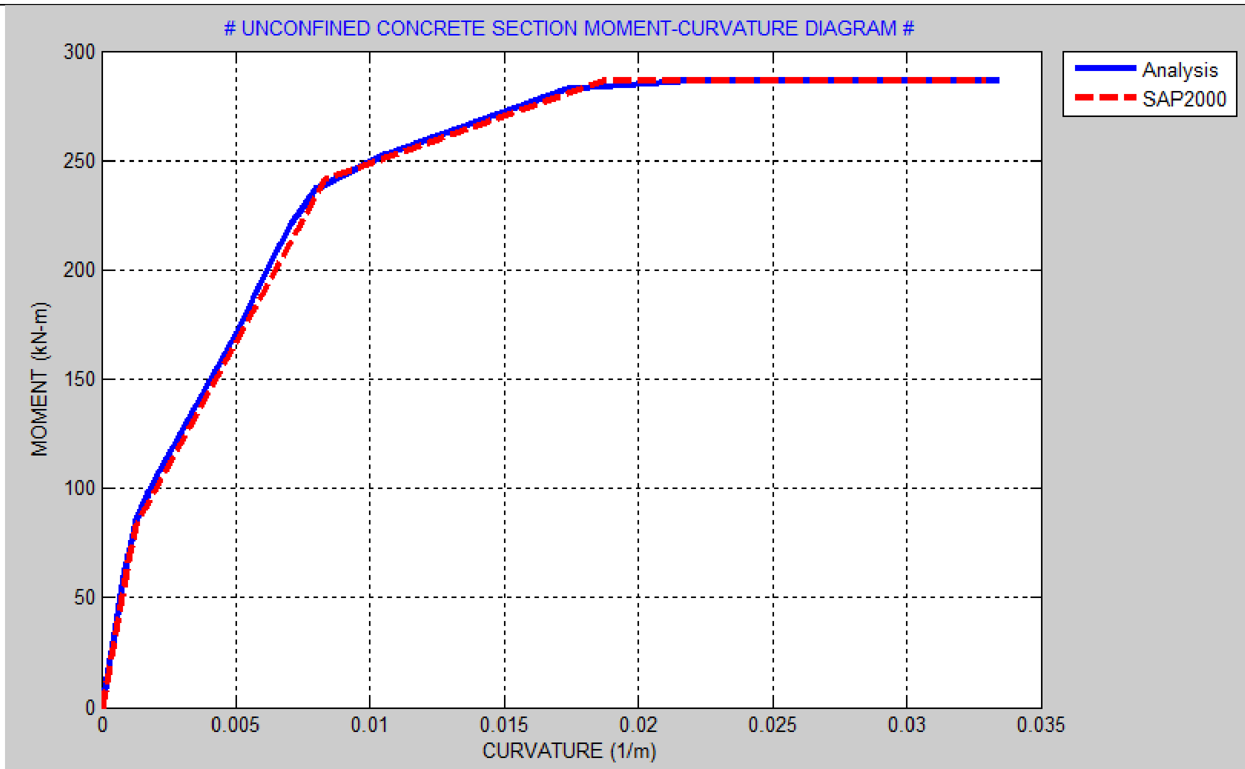

**Figure(11)** Flextural rigidity-Curvature of section in MATLAB



**Figure(12)** Flextural rigidity-Neuteral axis of section in MATLAB



**Figure(13)** Moment-Curvature of section in MATLAB




**Figure(14)** Moment-Curvature of section in MATLAB and SAP2000