>> IN THE NAME OF GOD <<

# Moment-Curvature Analysis of Unconfined Circular Concrete Pipe 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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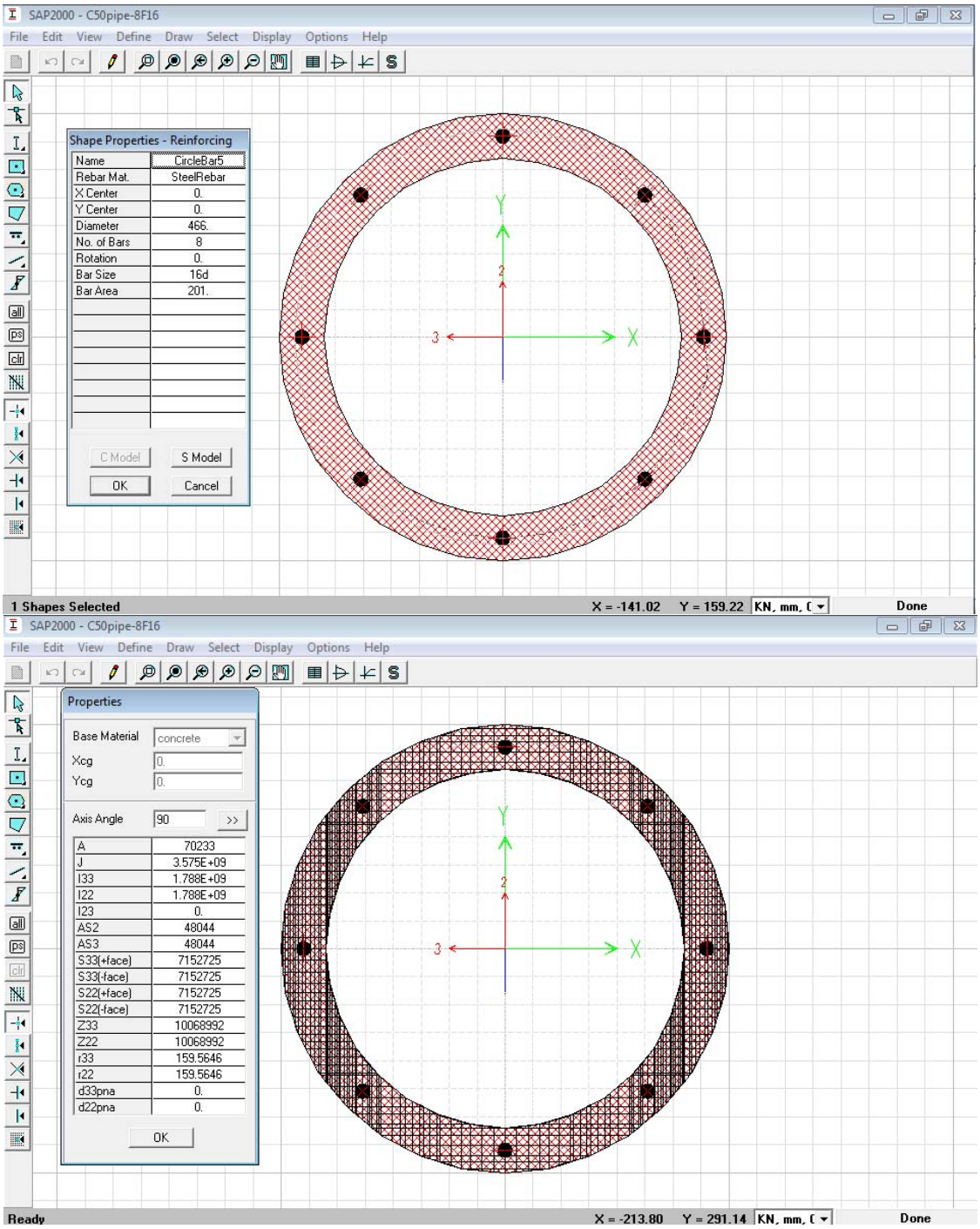
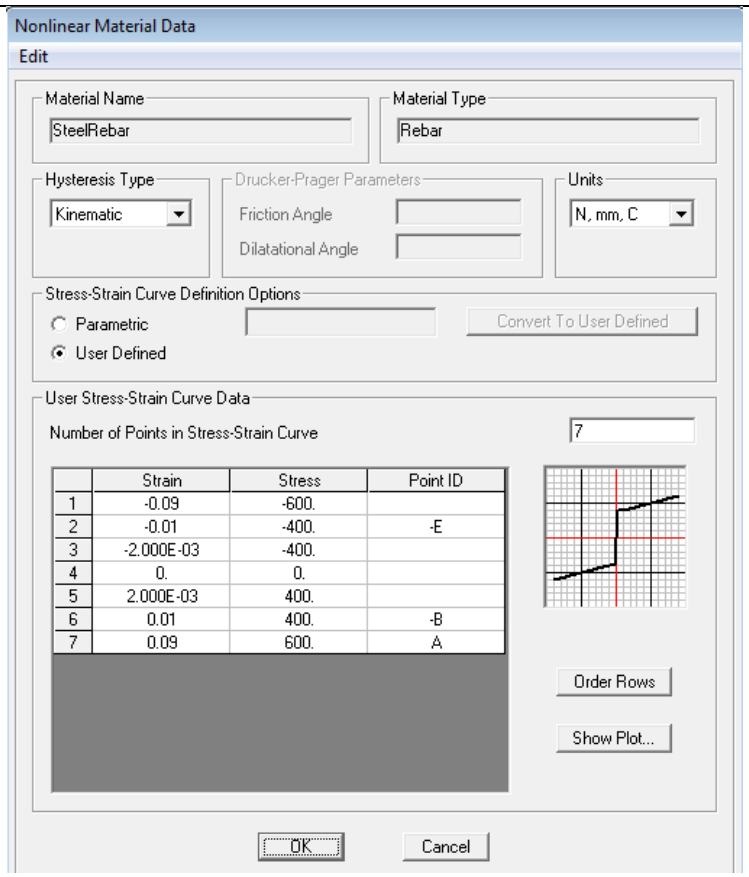
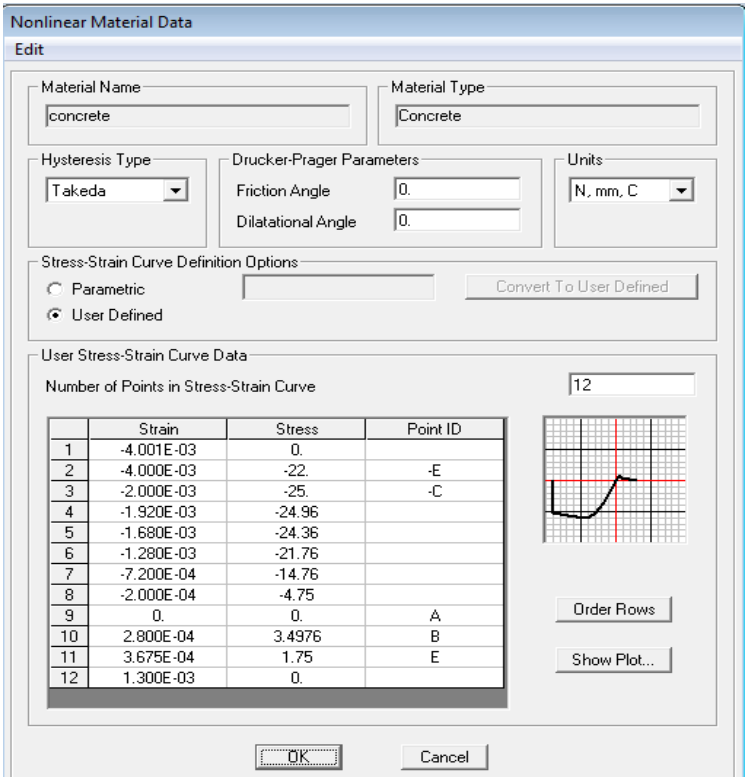



**Figure(1)** Unconfined circular concrete pipe section properties in SAP2000



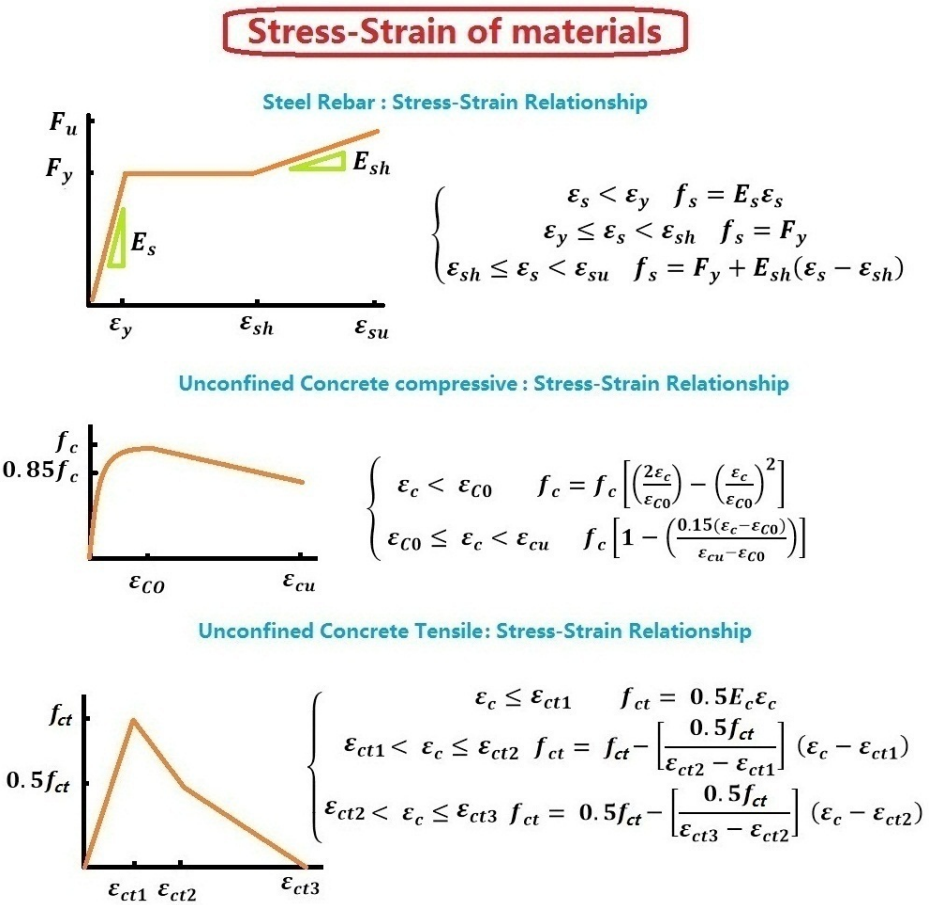

**Figure(2)** Steel rebar material properties in SAP2000




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

**Section Properties:**

```
D1=500;% [mm]
D2=400;% [mm]
%As:  As1      As2     As3     As4    As5      As6
As=[200.96 401.92 401.92 401.92 0 200.96]; % NOTE: As1 & As6 = 8fi16
%d:d1  d2  d3  d4  d5  d6
d=[25 90.9 250 409.1 0 475];
```




**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:

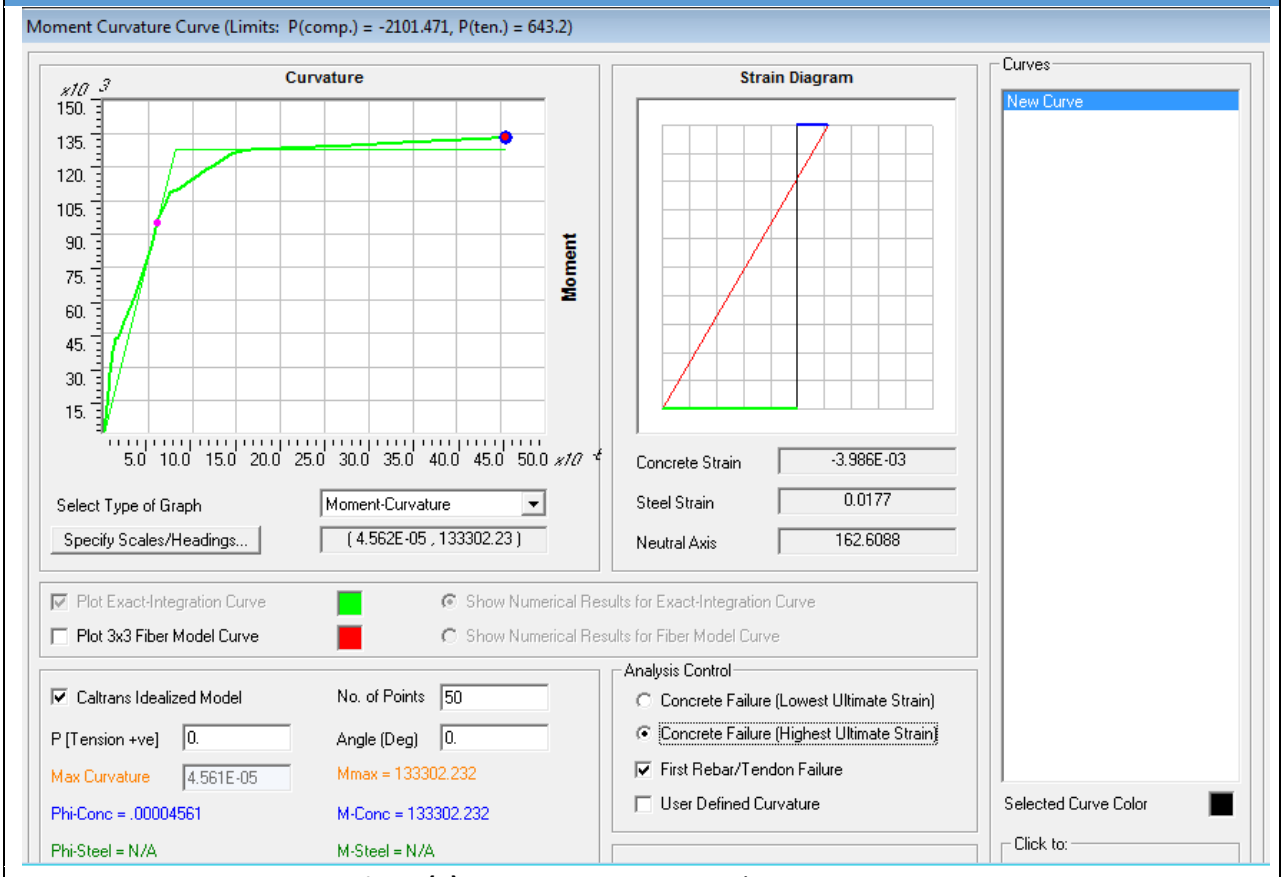
```
############################
# Moment-Curvature Analysis  #
############################
(+)Increment 1 : It is converged in 7 iterations - strain: 0.000042 - x: 213.32 - Phi: 0.00020 - Moment: 6.85
(+)Increment 2 : It is converged in 6 iterations - strain: 0.000092 - x: 213.84 - Phi: 0.00043 - Moment: 14.97
(+)Increment 3 : It is converged in 7 iterations - strain: 0.000188 - x: 214.83 - Phi: 0.00087 - Moment: 30.05
(+)Increment 4 : It is converged in 10 iterations - strain: 0.000280 - x: 194.32 - Phi: 0.00144 - Moment: 38.21
(+)Increment 5 : It is converged in 10 iterations - strain: 0.000367 - x: 176.70 - Phi: 0.00208 - Moment: 45.49
(+)Increment 6 : It is converged in 10 iterations - strain: 0.000429 - x: 168.52 - Phi: 0.00255 - Moment: 50.55
(+)Increment 7 : It is converged in 11 iterations - strain: 0.000872 - x: 150.19 - Phi: 0.00580 - Moment: 89.63
(+)Increment 8 : It is converged in 13 iterations - strain: 0.001041 - x: 147.51 - Phi: 0.00706 - Moment: 102.68
(+)Increment 9 : It is converged in 17 iterations - strain: 0.001171 - x: 142.56 - Phi: 0.00821 - Moment: 109.25
(+)Increment 10 : It is converged in 17 iterations - strain: 0.001301 - x: 135.58 - Phi: 0.00959 - Moment: 112.61
(+)Increment 11 : It is converged in 19 iterations - strain: 0.001600 - x: 126.12 - Phi: 0.01269 - Moment: 120.27
(+)Increment 12 : It is converged in 30 iterations - strain: 0.002000 - x: 116.52 - Phi: 0.01717 - Moment: 127.61
(+)Increment 13 : It is converged in 33 iterations - strain: 0.002400 - x: 104.05 - Phi: 0.02307 - Moment: 128.71
(+)Increment 14 : It is converged in 37 iterations - strain: 0.002800 - x: 97.95 - Phi: 0.02859 - Moment: 129.47
(+)Increment 15 : It is converged in 38 iterations - strain: 0.003200 - x: 96.14 - Phi: 0.03328 - Moment: 129.97
(+)Increment 16 : It is converged in 38 iterations - strain: 0.003600 - x: 95.62 - Phi: 0.03765 - Moment: 130.61
(+)Increment 17 : It is converged in 35 iterations - strain: 0.004000 - x: 95.66 - Phi: 0.04182 - Moment: 131.11

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

+-----------------------------------------+
 Elastic EI : 34768.63 (kN.m^2)
 Plastic EI : 573.17 (kN.m^2)
 Unconfined Section Ductility Rito : 13.35
+-----------------------------------------+
```

| Analysis | |
|---|---|
| Curvature (1/m) | Moment (kN.m) |
| 0.00000 | 0.000 |
| 0.00020 | 6.846 |
| 0.00043 | 14.971 |
| 0.00087 | 30.051 |
| 0.00144 | 38.209 |
| 0.00208 | 45.487 |
| 0.00255 | 50.546 |
| 0.00580 | 89.632 |
| 0.00706 | 102.680 |
| 0.00821 | 109.247 |
| 0.00959 | 112.605 |
| 0.01269 | 120.269 |
| 0.01717 | 127.611 |
| 0.02307 | 128.715 |
| 0.02859 | 129.472 |
| 0.03328 | 129.966 |
| 0.03765 | 130.607 |
| 0.04182 | 131.112 |

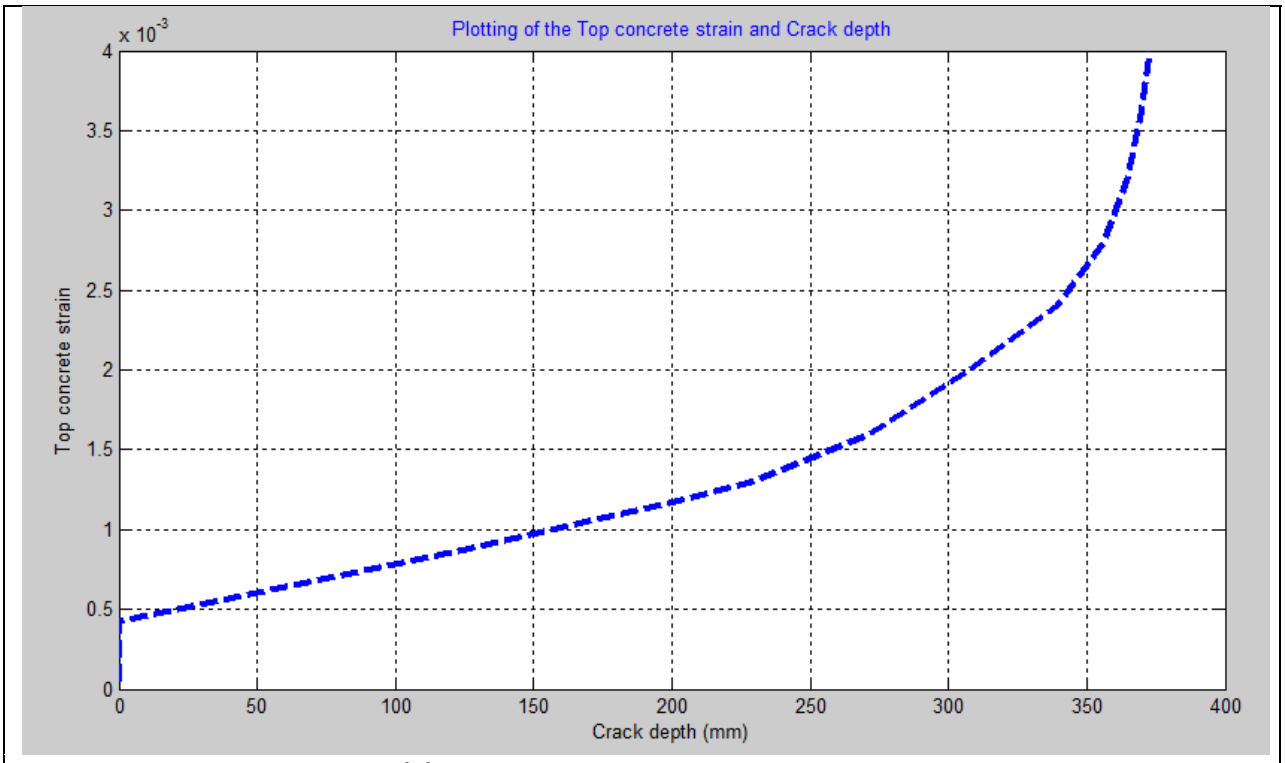
| Analysis curve fitted | |
|---|---|
| Curvature (1/m) | Moment (kN.m) |
| 0.00000 | 0.000 |
| 0.00313 | 108.941 |
| 0.04182 | 131.112 |

| Increment (i) | Top strain (1) | Neuteral axis(x) (mm) | Curvature (1/m) | Flextural Rigidity(EI) (kN.m^2) |
|---|---|---|---|---|
| 1 | 0.00004 | 213.32 | 0.000197 | 34768.63 |
| 2 | 0.00009 | 213.84 | 0.000432 | 34646.11 |
| 3 | 0.00019 | 214.83 | 0.000873 | 34412.17 |
| 4 | 0.00028 | 194.32 | 0.001441 | 26517.05 |
| 5 | 0.00037 | 176.70 | 0.002080 | 21870.48 |
| 6 | 0.00043 | 168.52 | 0.002547 | 19841.91 |
| 7 | 0.00087 | 150.19 | 0.005803 | 15445.63 |
| 8 | 0.00104 | 147.51 | 0.007055 | 14553.72 |
| 9 | 0.00117 | 142.56 | 0.008213 | 13302.53 |
| 10 | 0.00130 | 135.58 | 0.009595 | 11736.07 |
| 11 | 0.00160 | 126.12 | 0.012687 | 9479.88 |
| 12 | 0.00200 | 116.52 | 0.017165 | 7434.35 |
| 13 | 0.00240 | 104.05 | 0.023067 | 5580.11 |
| 14 | 0.00280 | 97.95 | 0.028586 | 4529.23 |
| 15 | 0.00320 | 96.14 | 0.033285 | 3904.68 |
| 16 | 0.00360 | 95.62 | 0.037650 | 3469.02 |
| 17 | 0.00400 | 95.66 | 0.041816 | 3135.48 |

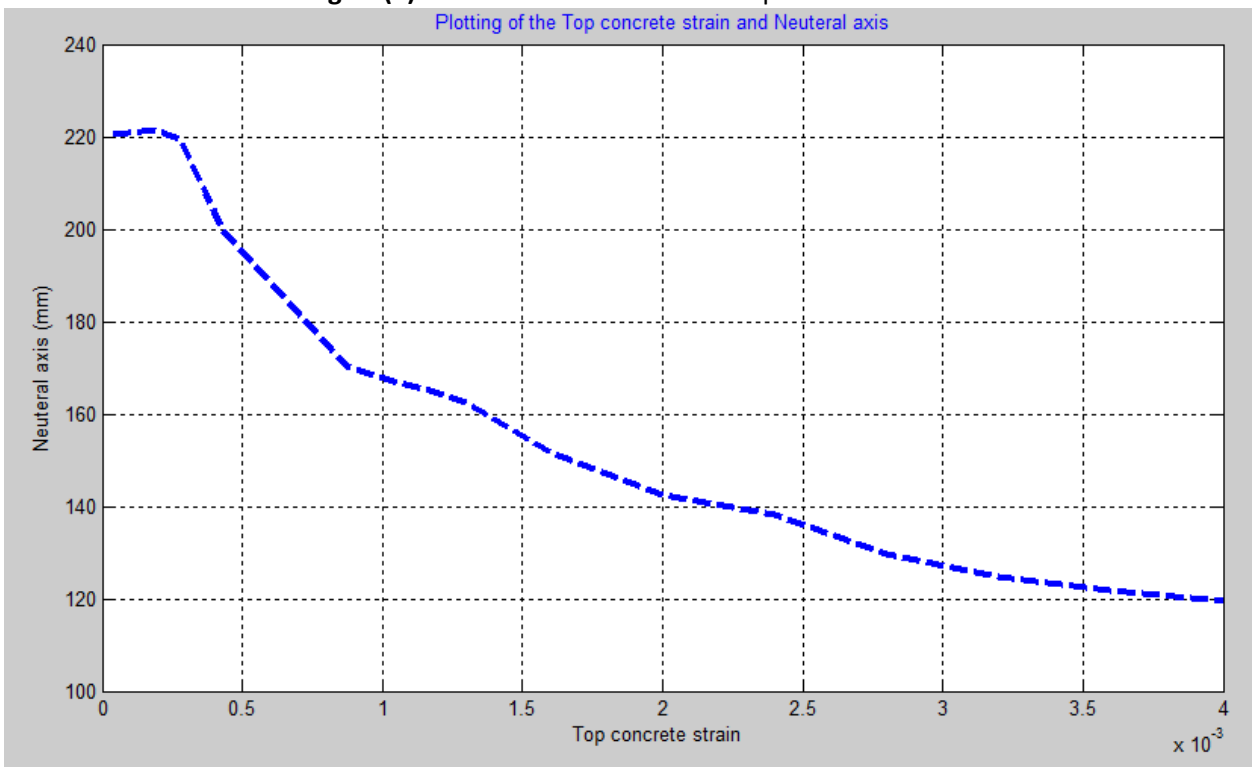
**Plot :**



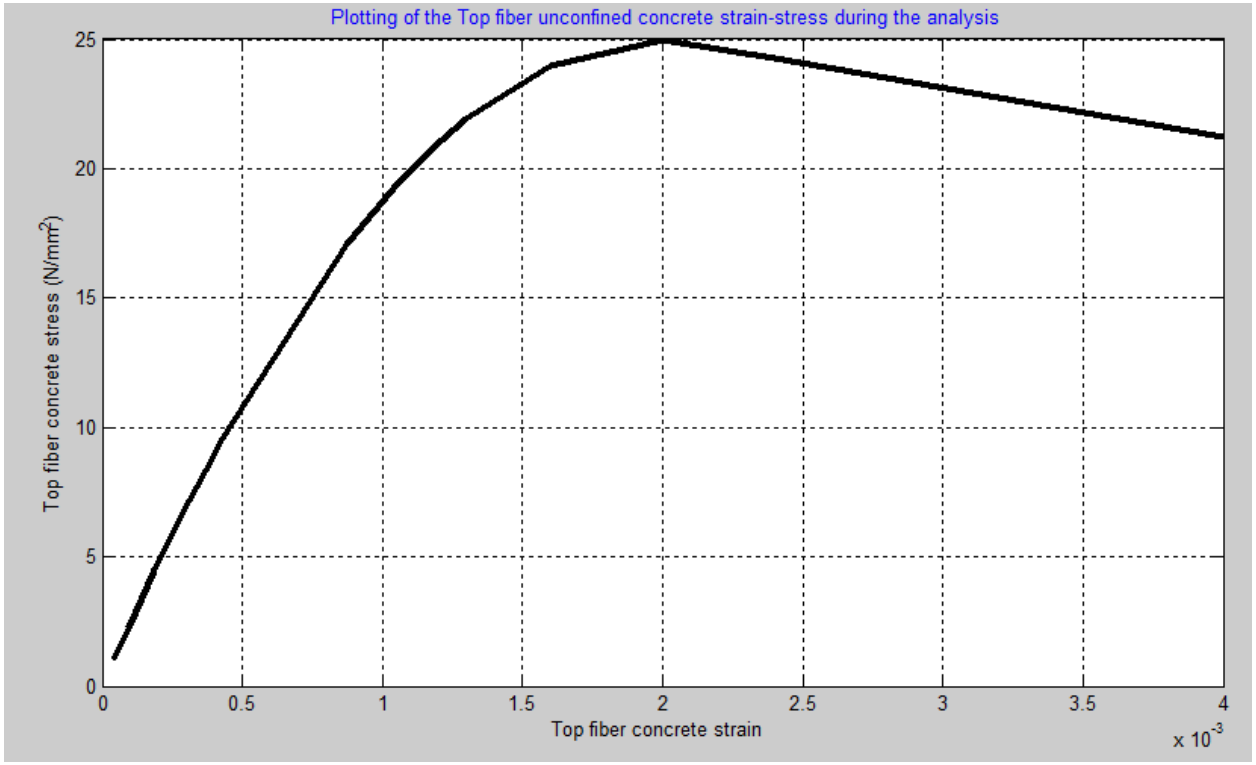

**Figure(5)** Moment curvature analysis in SAP2000



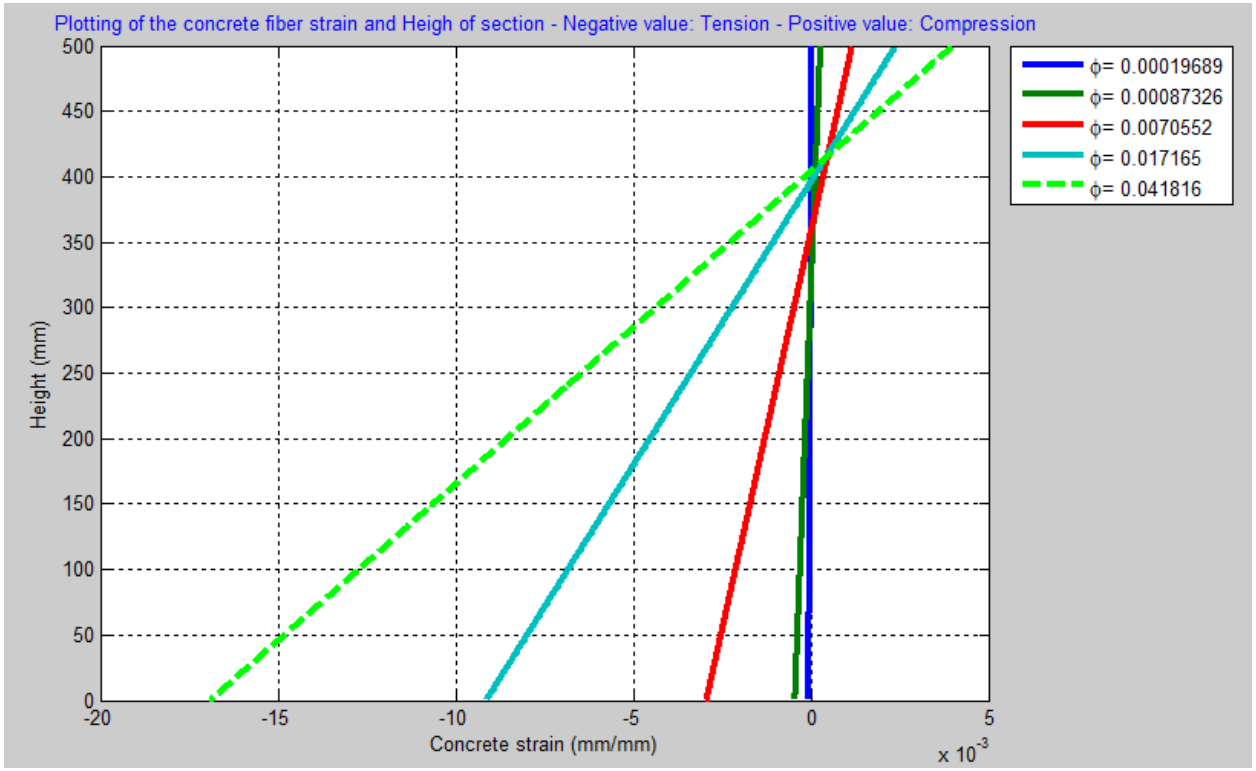

**Figure(6)** Concrete strain and crack depth in MATLAB



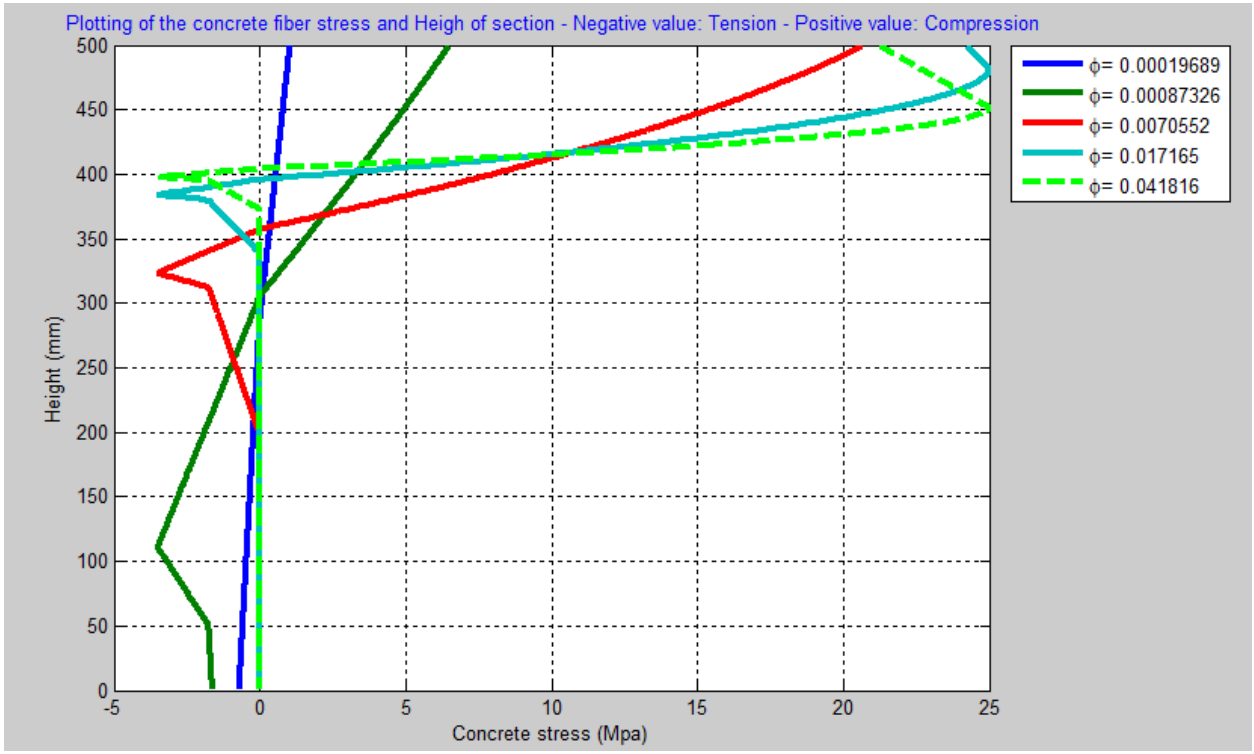

**Figure(7)** Concrete strain-Neuteral axis in MATLAB



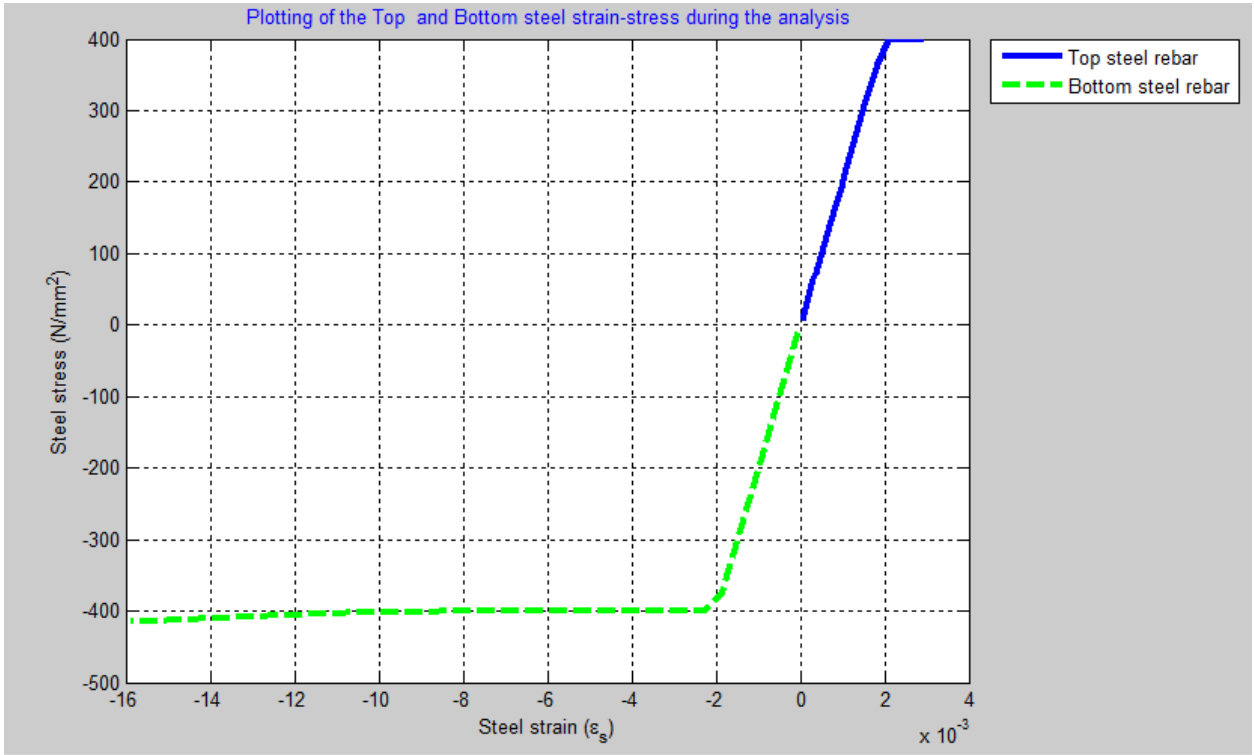

**Figure(8)** Concrete top fiber strain-stress in MATLAB



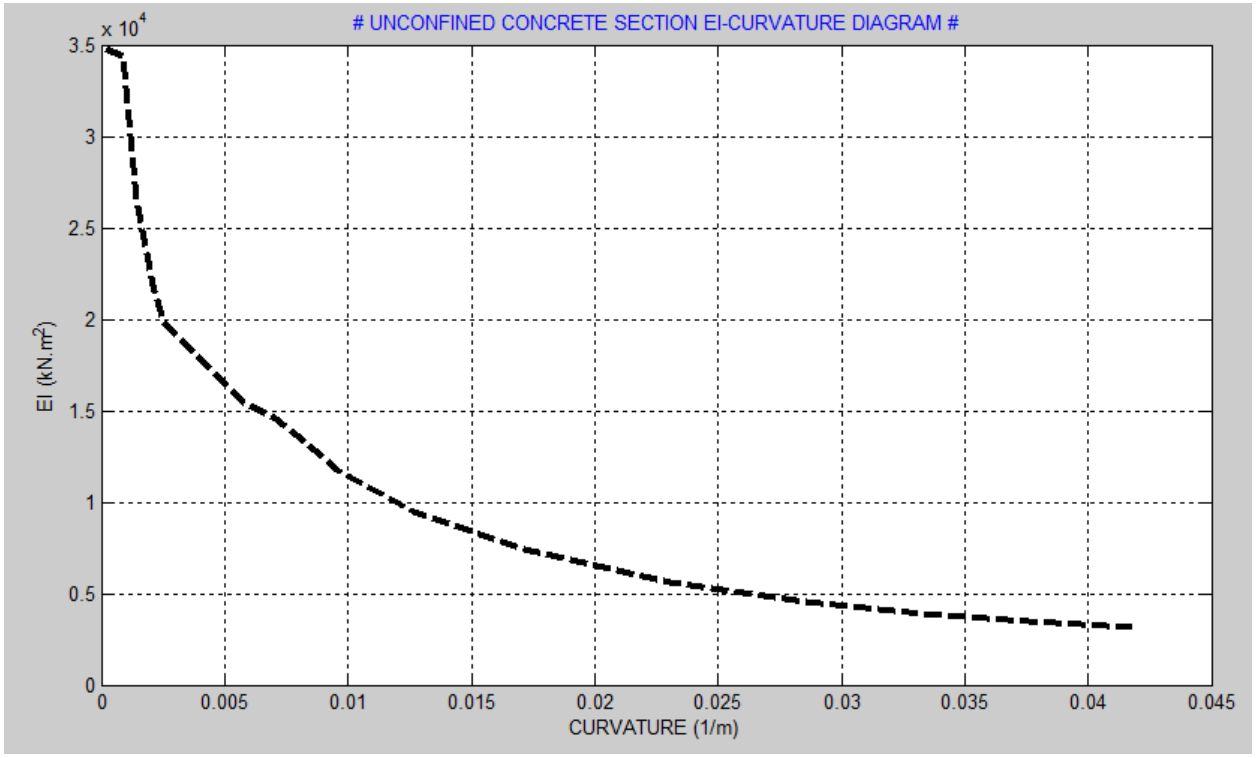

**Figure(9)** Fiber strain-Height of section in MATLAB



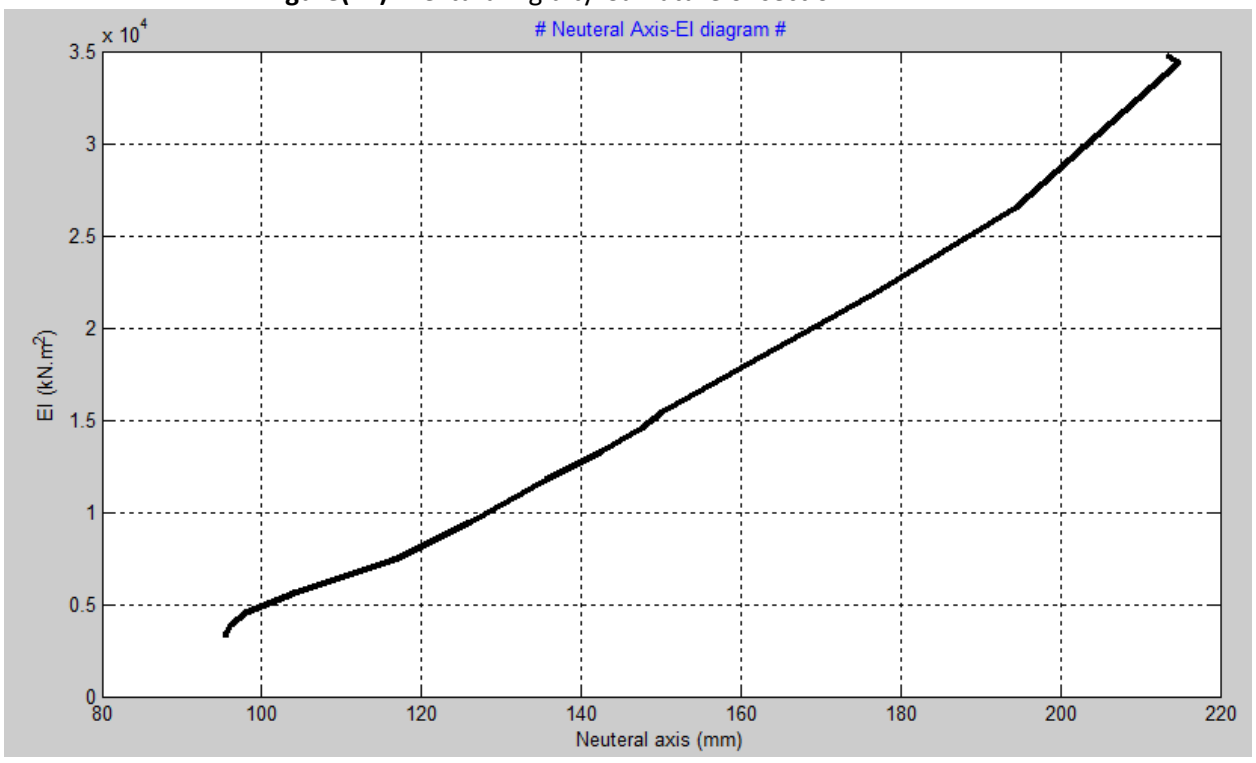

**Figure(10)** Fiber stress-Height of section in MATLAB



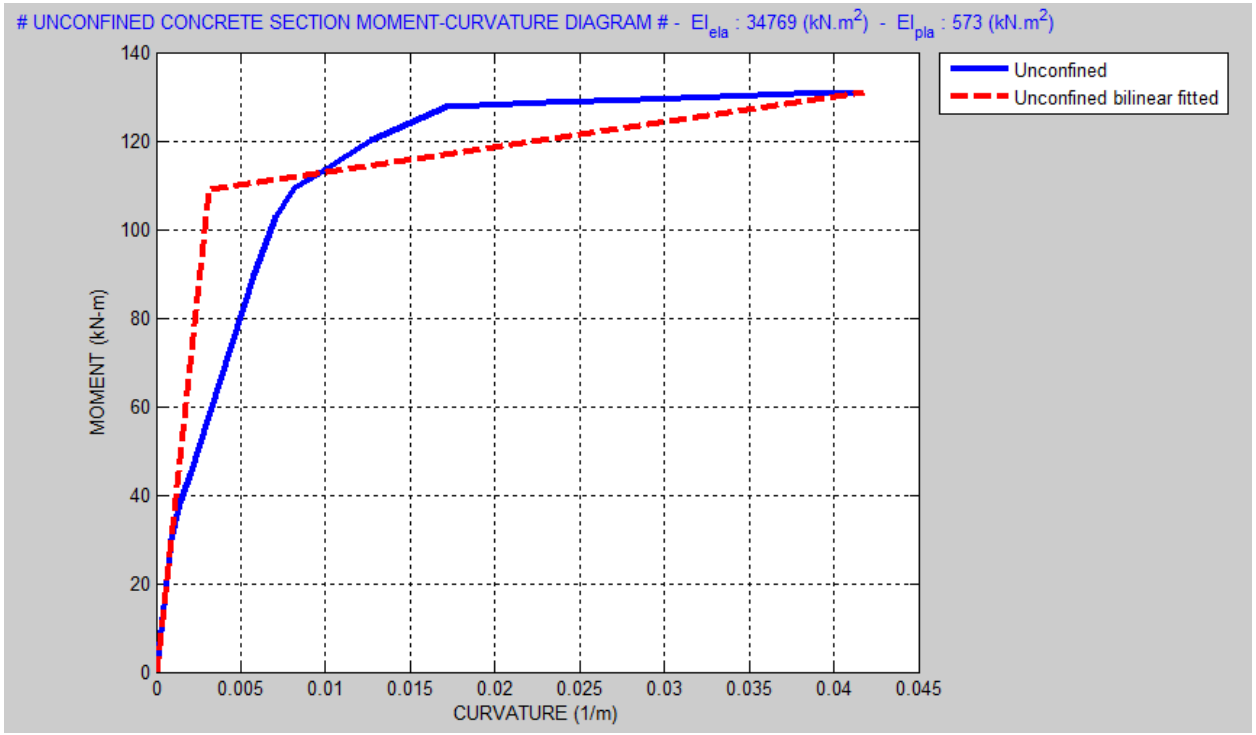

**Figure(11)** Top and bottom steel rebar strain-stress in MATLAB



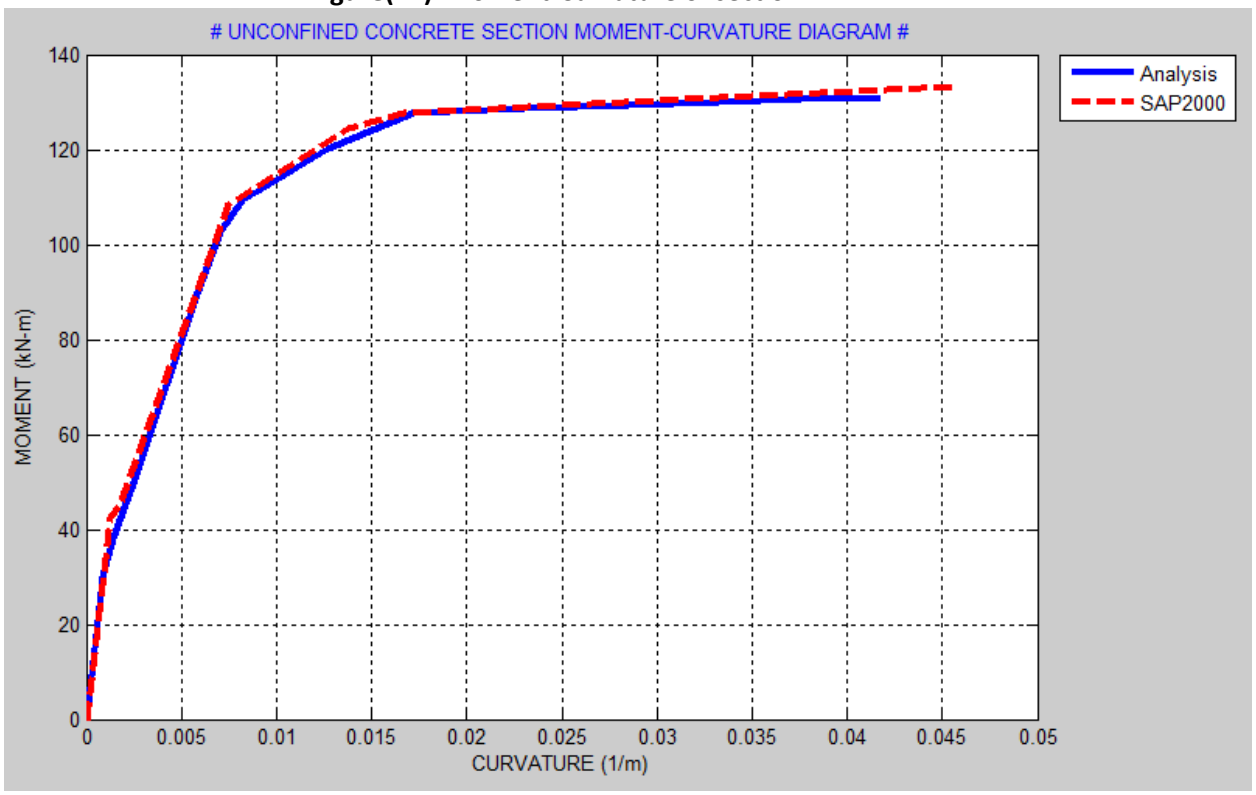

**Figure(12)** Flextural rigidity-Curvature of section in MATLAB




**Figure(13)** Flextural rigidity-Neuteral axis of section in MATLAB




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




**Figure(15)** Moment-Curvature of section in MATLAB and SAP2000