OPTIMIZATION OF PLATE THICKNESS WITH COMPARATIVE ANALYSIS OF AXIAL FORCE–MOMENT (P–M) INTERACTION IN CONFINED REINFORCED CONCRETE WITH PLATE COMPOSITE SECTIONS: EVALUATING STRAIN HARDENING AND ULTIMATE STRAIN CRITERIA USING OPENSEES
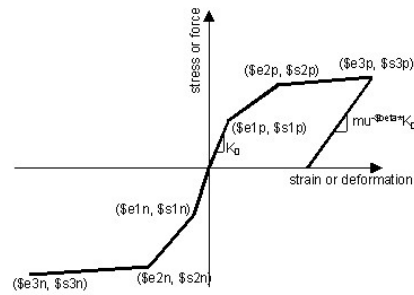
WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
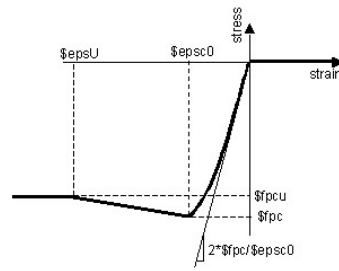
CORE AND COVER CONCRETE RELATION
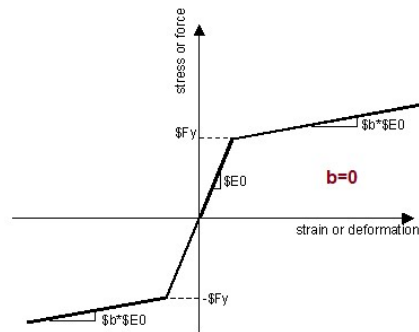
$epsU $epsc0

stress

strain

$fpcu

$fpc

2*$fpc/$epsc0

WITHOUT HARDENING AND ULTIMATE STRAIN

stress or force

$Fy

$b*$E0

$E0

b=0

strain or deformation

-$Fy

$b*$E0

WITH HARDENING AND ULTIMATE STRAIN

stress or force

($e2p, $s2p)

($e3p, $s3p)

($e1p, $s1p)

mu$^{-\beta}*K_0$

K_0

strain or deformation

($e1n, $s1n)

($e3n, $s3n)

($e2n, $s2n)

RC Rectangular Section with Steel Plates (ID: 10)

Core Concrete
Cover Concrete
Steel Plate
Top Steel
Bottom Steel
Skin Steel

Height (Y)

Width (Z)
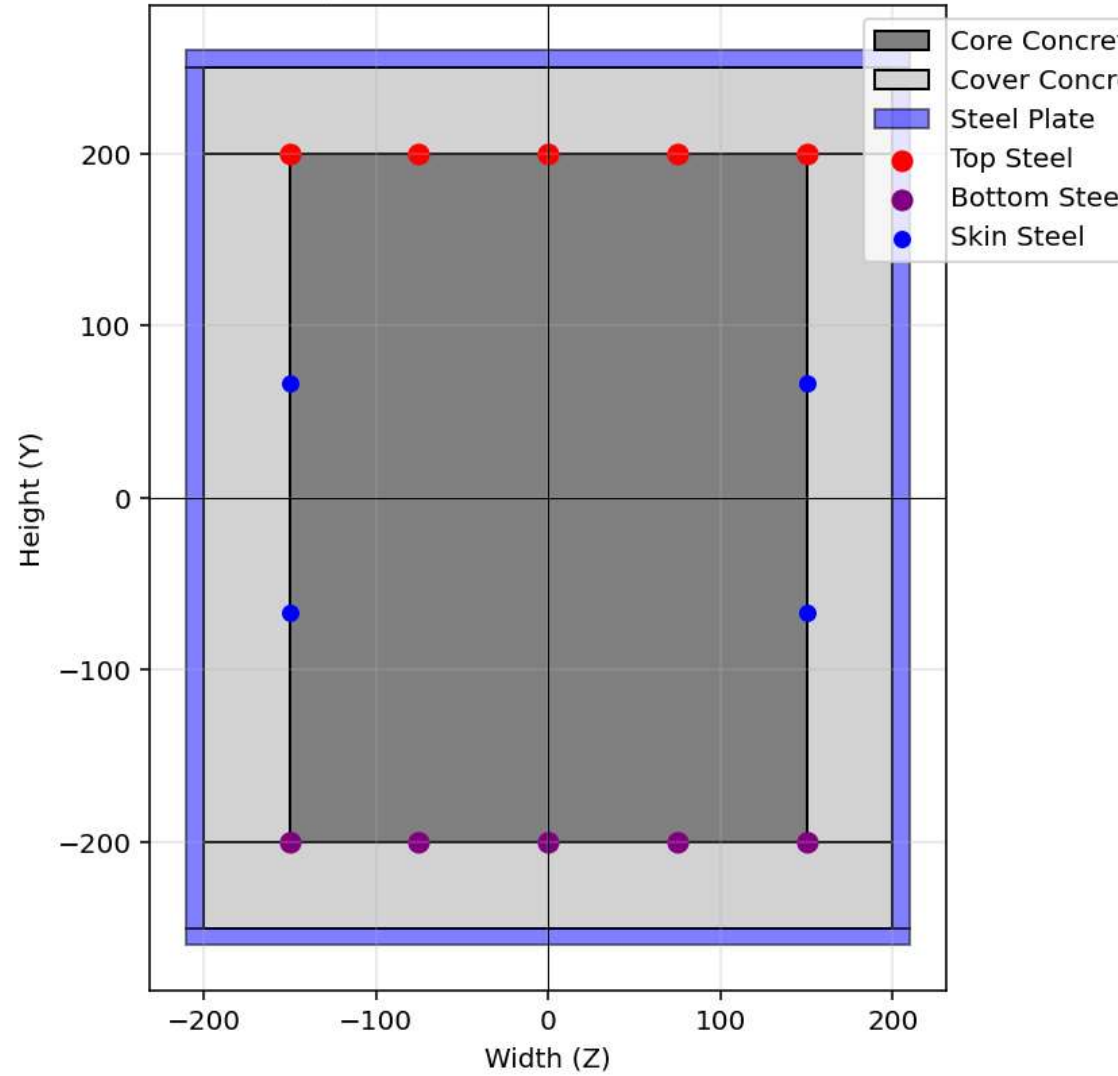
Spyder (Python 3.12)

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...esktop\OPENSEES_FILES\P-M_INTERACTION\COMPOSITE_OPTIMIZATION

C:\Users\Dell\Desktop\OPENSEES_FILES\P-M_INTERACT...-M_INTERACTION_COMPOSITE_CONCRETE_OPTIMIZATION.py

P-M_INTERACTION_CO...TE_OPTIMIZATION.py

```python
1  ###################################################################################################
2  #                    >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<             #
3  #            OPTIMIZATION OF PLATE THICKNESS WITH COMPARATIVE ANALYSIS OF AXIAL FORCE-MOMENT (P-M) #
4  #                    INTERACTION IN CONFINED REINFORCED CONCRETE WITH PLATE                        #
5  #        COMPOSITE SECTIONS: EVALUATING STRAIN HARDENING AND ULTIMATE STRAIN CRITERIA USING OPENSEES #
6  #-------------------------------------------------------------------------------------------------#
7  #                           OPTIMIZATION ALGORITHM : NEWTON-RAPHSON METHOD                         #
8  #-------------------------------------------------------------------------------------------------#
9  #                    THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)                    #
10 #                            EMAIL: salar.d.ghashghaei@gmail.com                                   #
11 ###################################################################################################
12 """
13 Performs a comparative analysis of reinforced concrete columns' axial force-moment (P-M)
14  interaction behavior using OpenSeesPy.
15
16 1. Objective:
17    Evaluates how steel plate , rebar reinforcement strain hardening and ultimate strain criteria affect P-M
18    interaction capacity, crucial for seismic design where ductility matters.
19
20 2. Materials:
21    - Concrete: Confined (core) and unconfined (cover) modeled with `Concrete01` material laws.
22    - *Steel: Two models - `Steel01` (elastic-perfectly plastic) vs. `Hysteretic` (includes hardening & fracture).
23
24 3. Section Modeling: Creates a rectangular RC cross-section with fiber discretization. Core concrete is confined,
25  cover concrete unconfined, with rebars placed at edges and mid-depth.
26
27 4. Analysis Method: Uses a displacement-controlled approach to simulate increasing curvature/strain. For each str
28    - Applies strain compatibility (plane sections remain plane)
29    - Computes axial force (P) and moment (M) using nonlinear static analysis.
30
31 5. Key Outputs:
32    - P-M interaction diagrams
33    - Moment-curvature relationships
34    - Neutral axis depth trends
```

Help | Variable Explorer | Debugger | Plots | Files

Console 1/A

```
THICKNESS:  7.761015561219099

        Optimum Plate Thickness:      7.761016e+00
        Iteration Counts:             4
        Convergence Residual:         1.2095905152e-14

Total time (s): 27.6250


In [5]:
```

IPython Console | History

Inline   Conda: anaconda3 (Python 3.12.7)   ✓ LSP: Python   Line 1, Col 1   UTF-8   CRLF   RW   ...lem 36%

PLATE THICKNESS: 1.00000000e+01
F: 1036871.385868473
Fmin: 1036866.7435809877
Fmax: 1036876.0281560402
DF: 464228.75262796873
DX: 2.2335354714649007
IT: 1 - RESIDUAL: 2.2335354714649007 - PLATE THICKNESS: 10

PLATE THICKNESS: 7.76646453e+00
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DF: 461974.6848940849
DX: 0.005448934883253633
IT: 2 - RESIDUAL: 0.005448934883253633 - PLATE THICKNESS: 7.766464528535099

PLATE THICKNESS: 7.76101559e+00
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Fmax: 4.63467482291162
DF: 461969.1848754882
DX: 3.2432746477001504e-08
IT: 3 - RESIDUAL: 3.2432746477001504e-08 - PLATE THICKNESS: 7.7610155936518455

PLATE THICKNESS: 7.76101556e+00
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Fmin: -4.619691805914044
Fmax: 4.619691899046302
DF: 461969.18524801725
DX: 1.2095905151537061e-14
IT: 4 - RESIDUAL: 1.2095905151537061e-14 - PLATE THICKNESS: 7.761015561219099

Optimum Plate Thickness: <mark>7.761016e+00</mark>
Iteration Counts: 4
Convergence Residual: 1.2095905152e-14

Total time (s): 27.6250

P-M Interaction

AXIAL FORCE-STRAIN DIAGRAM

MOMENT-CURVATURE DIAGRAM

MOMENT-NEUTRAL AXIS DIAGRAM

FLEXURAL RIGIDITY-NEUTRAL AXIS DIAGRAM

Flexural Rigidity [N/mm²]

Neutral Axis Depth [mm]

Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN

FLEXURAL RIGIDITY-AXIAL RIGIDITY DIAGRAM