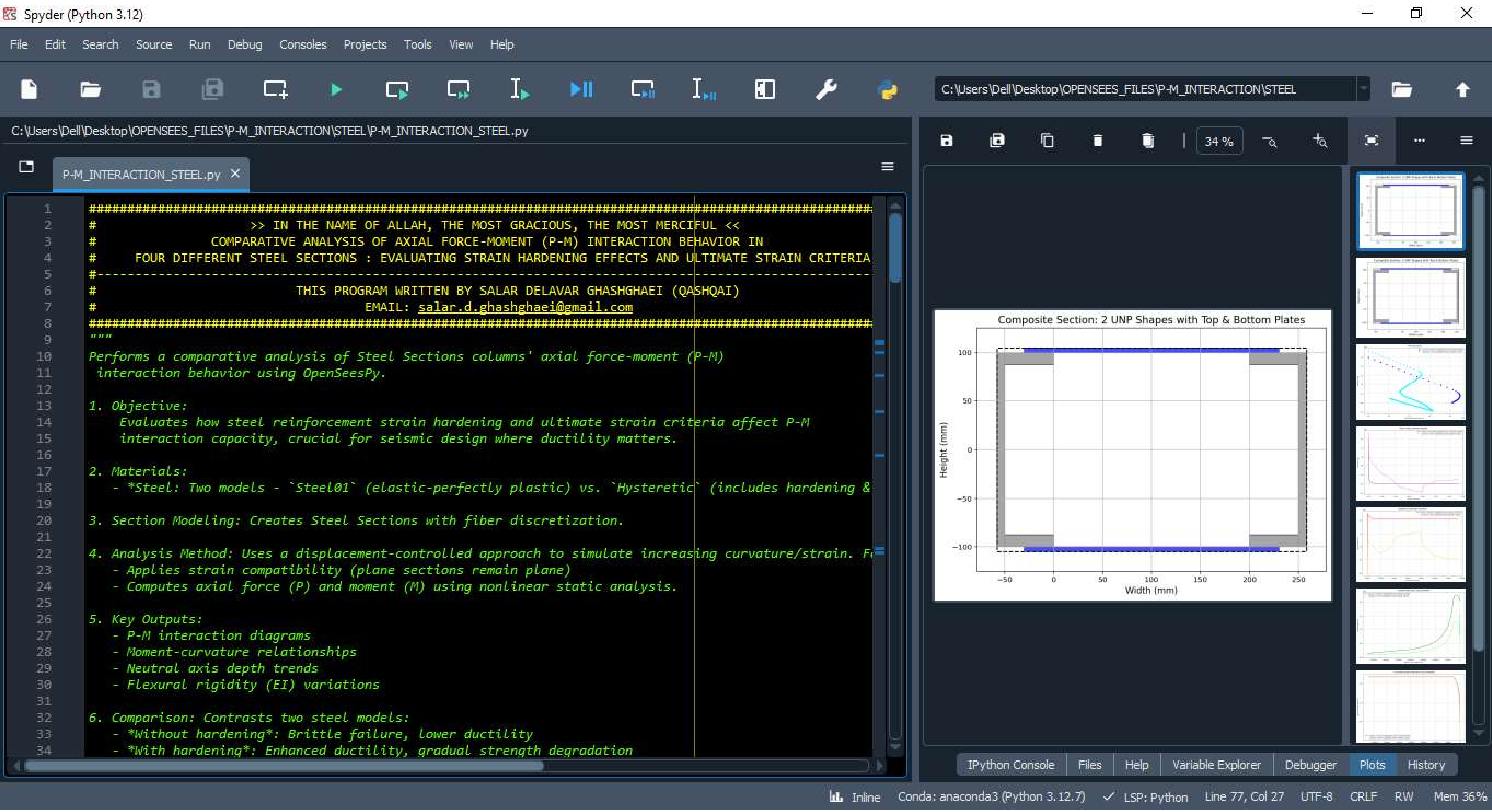
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

COMPARATIVE ANALYSIS OF AXIAL FORCE-MOMENT (P-M) INTERACTION BEHAVIOR IN FOUR DIFFERENT STEEL SECTIONS : EVALUATING STRAIN HARDENING EFFECTS AND ULTIMATE STRAIN CRITERIA

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)


Spyder (Python 3.12)
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P-M_INTERACTION_STEEL.py
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
COMPARATIVE ANALYSIS OF AXIAL FORCE-MOMENT (P-M) INTERACTION BEHAVIOR IN
FOUR DIFFERENT STEEL SECTIONS : EVALUATING STRAIN HARDENING EFFECTS AND ULTIMATE STRAIN CRITERIA
THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
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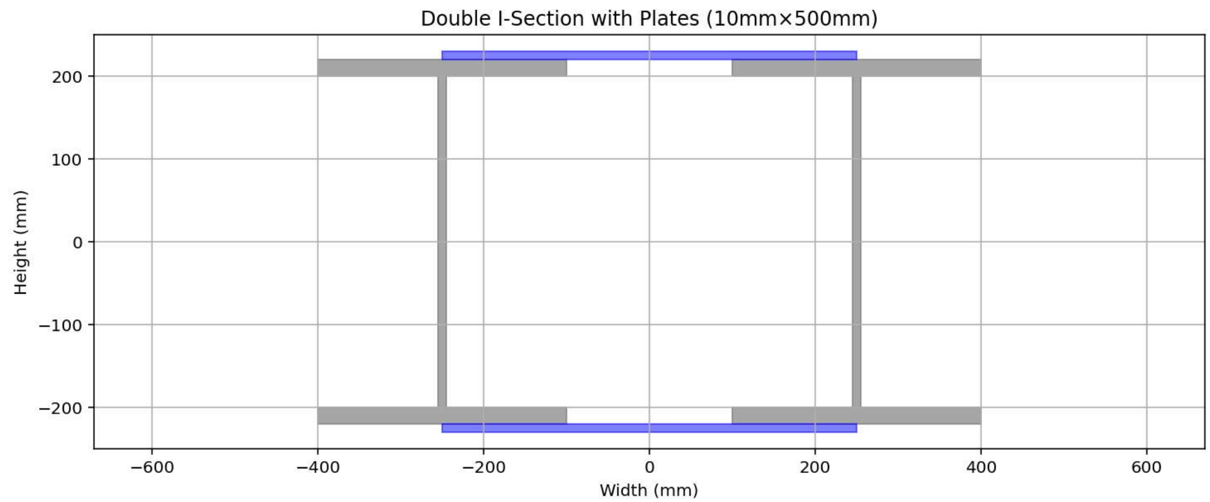
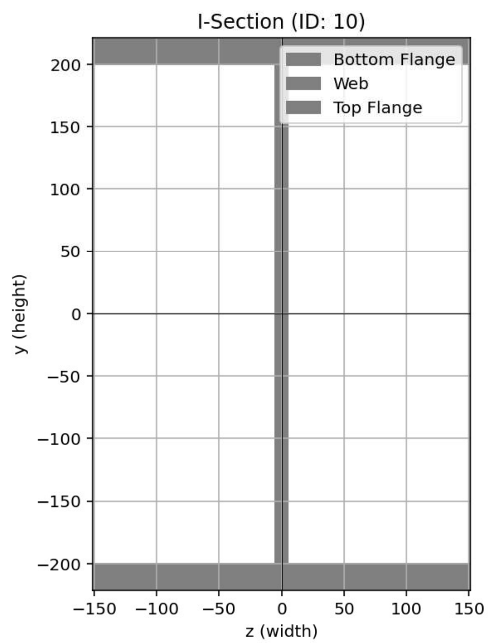
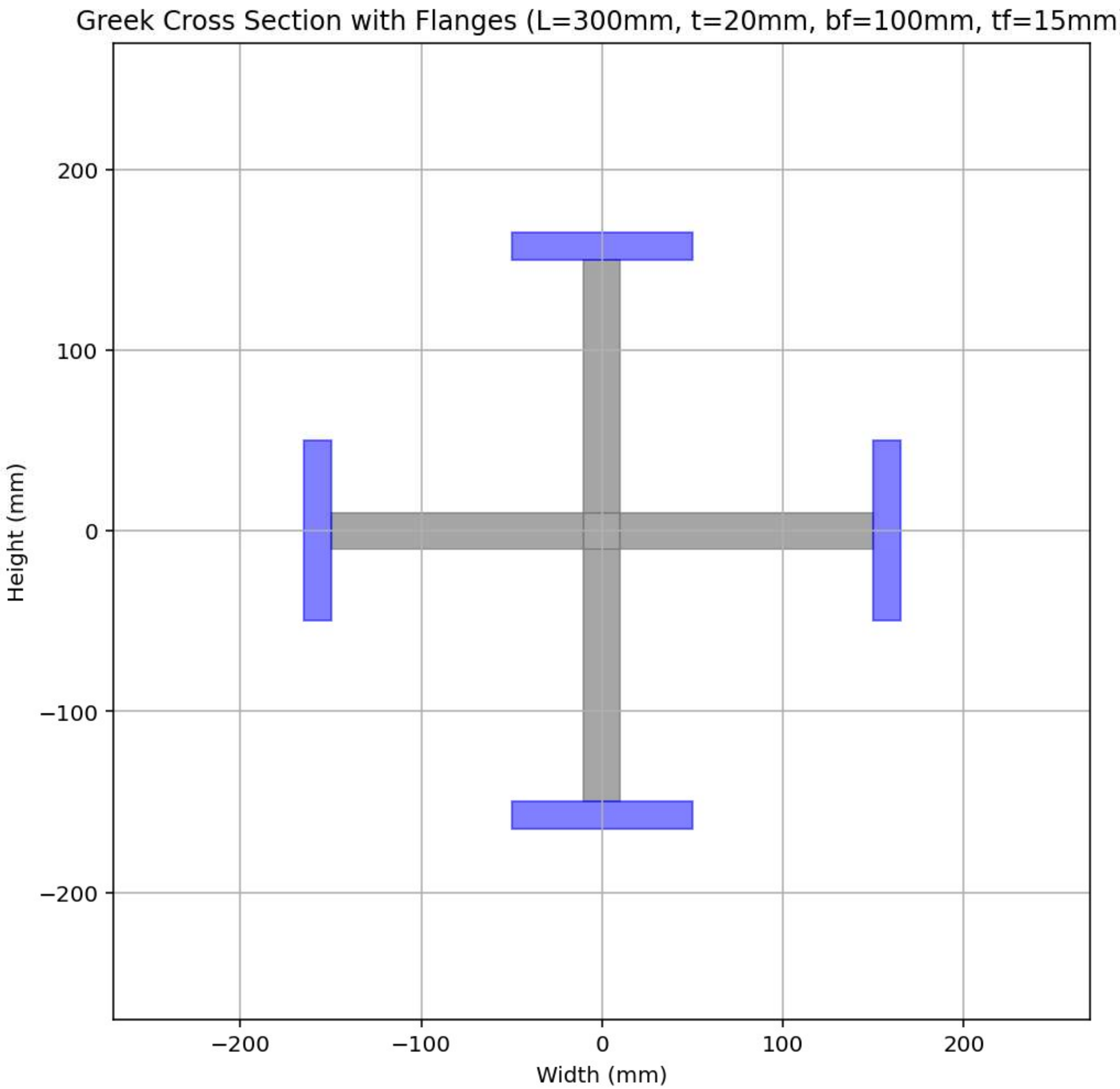
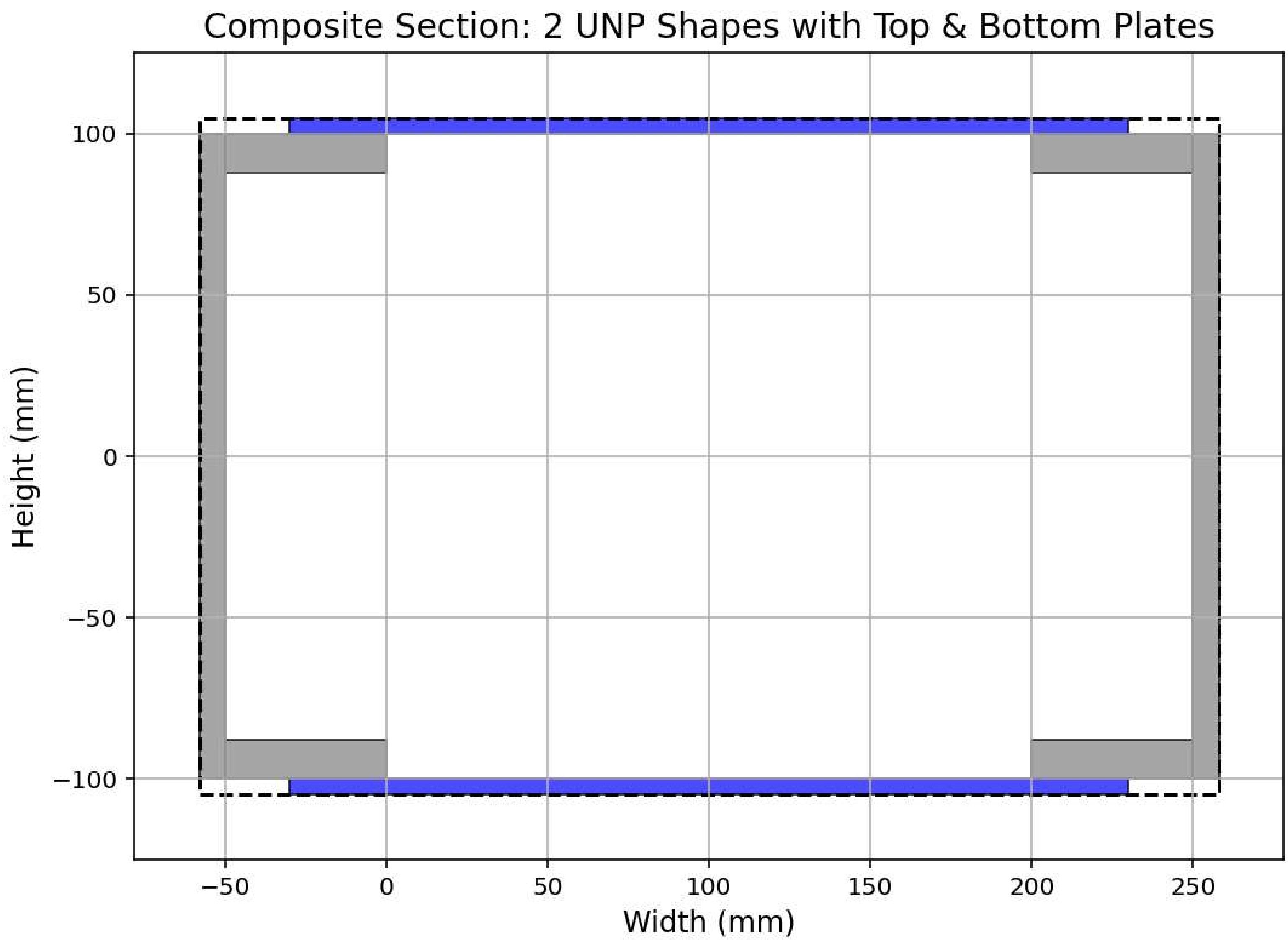
"""
Performs a comparative analysis of Steel Sections columns' axial force-moment (P-M)
interaction behavior using OpenSeesPy.
1. Objective:
Evaluates how steel reinforcement strain hardening and ultimate strain criteria affect P-M
interaction capacity, crucial for seismic design where ductility matters.
2. Materials:
- *Steel: Two models - `Steel01` (elastic-perfectly plastic) vs. `Hysteretic` (includes hardening &
3. Section Modeling: Creates Steel Sections with fiber discretization.
4. Analysis Method: Uses a displacement-controlled approach to simulate increasing curvature/strain. F
- Applies strain compatibility (plane sections remain plane)
- Computes axial force (P) and moment (M) using nonlinear static analysis.
5. Key Outputs:
- P-M interaction diagrams
- Moment-curvature relationships
- Neutral axis depth trends
- Flexural rigidity (EI) variations
6. Comparison: Contrasts two steel models:
- *Without hardening*: Brittle failure, lower ductility
- *With hardening*: Enhanced ductility, gradual strength degradation
34 %
Composite Section: 2 UNP Shapes with Top & Bottom Plates
Height (mm)
Width (mm)
IPython Console Files Help Variable Explorer Debugger Plots History
Inline Conda: anaconda3 (Python 3.12.7) LSP: Python Line 77, Col 27 UTF-8 CRLF RW Mem 36%

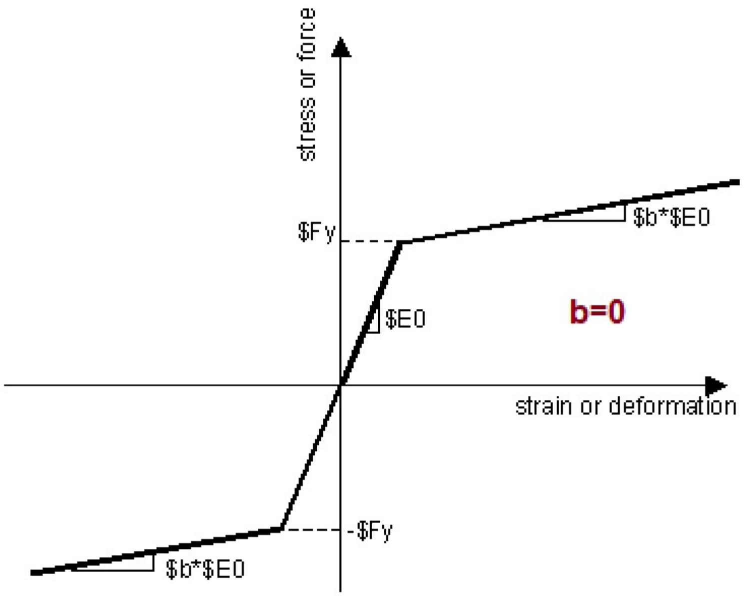

Double I-Section with Plates (10mm×500mm)
Height (mm)
Width (mm)


I-Section (ID: 10)
Bottom Flange
Web
Top Flange
y (height)
z (width)

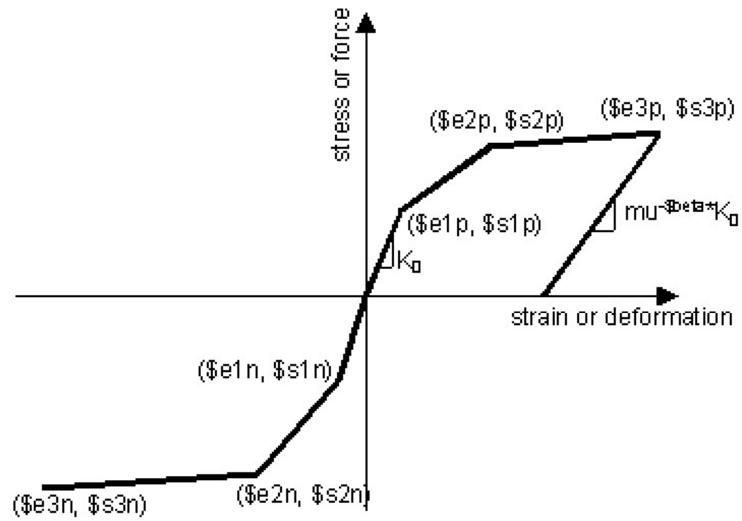

Greek Cross Section with Flanges (L=300mm, t=20mm, bf=100mm, tf=15mm)
Height (mm)
Width (mm)
200
100
0
−100
−200
−200
−100
0
100
200



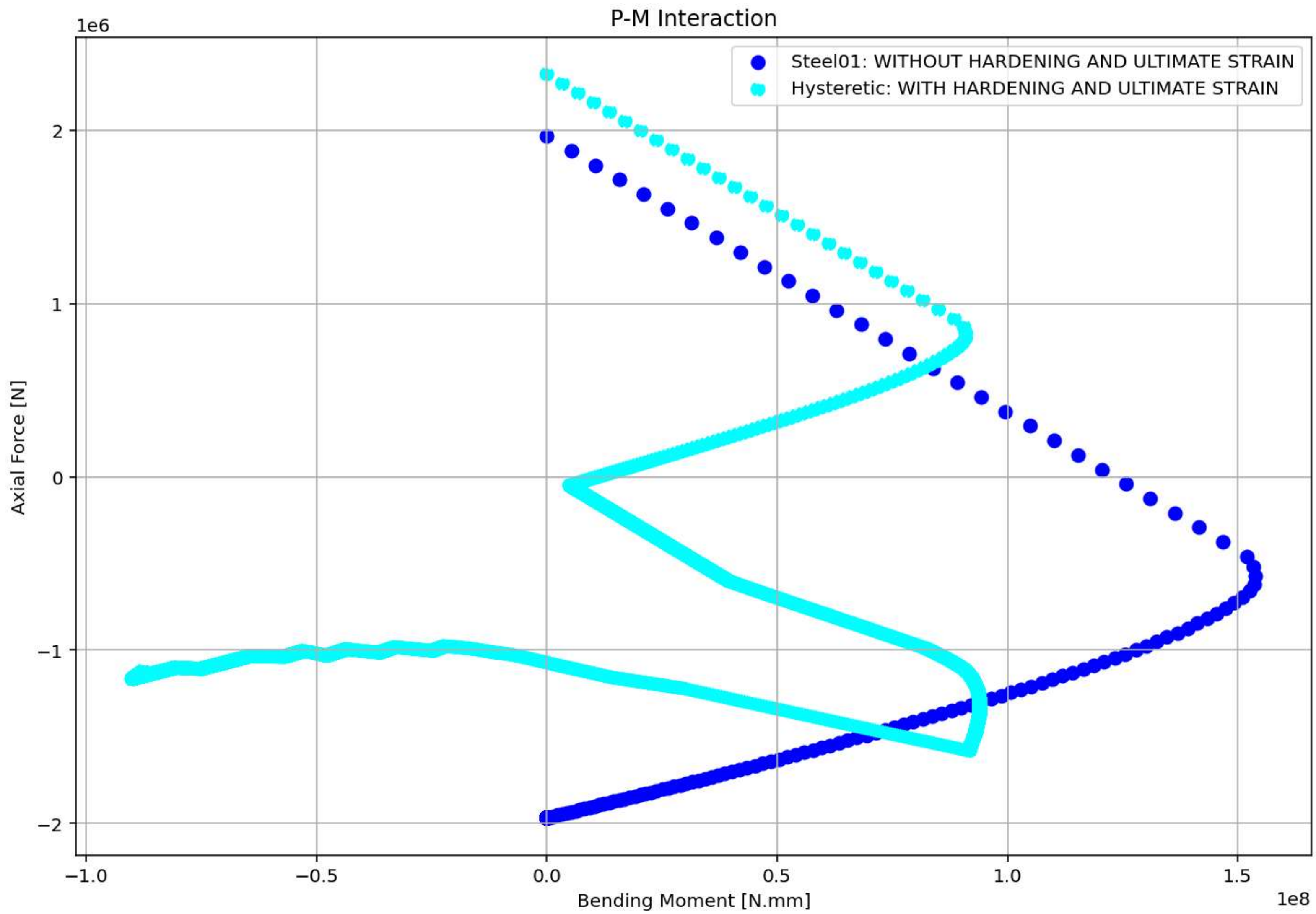
Composite Section: 2 UNP Shapes with Top & Bottom Plates
Height (mm)
Width (mm)
100
50
0
−50
−100
−50
0
50
100
150
200
250

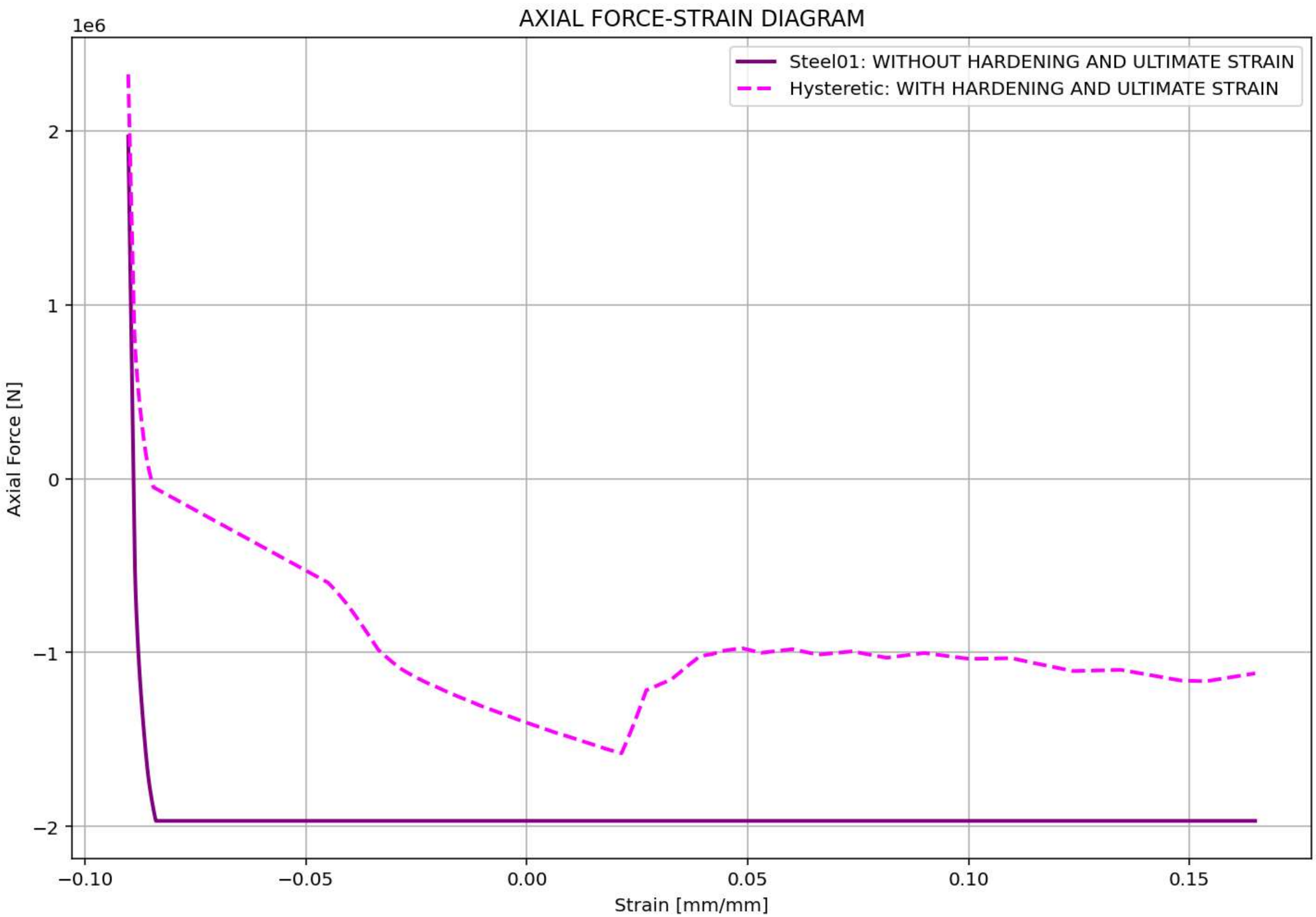


WITHOUT HARDENING AND ULTIMATE STRAIN

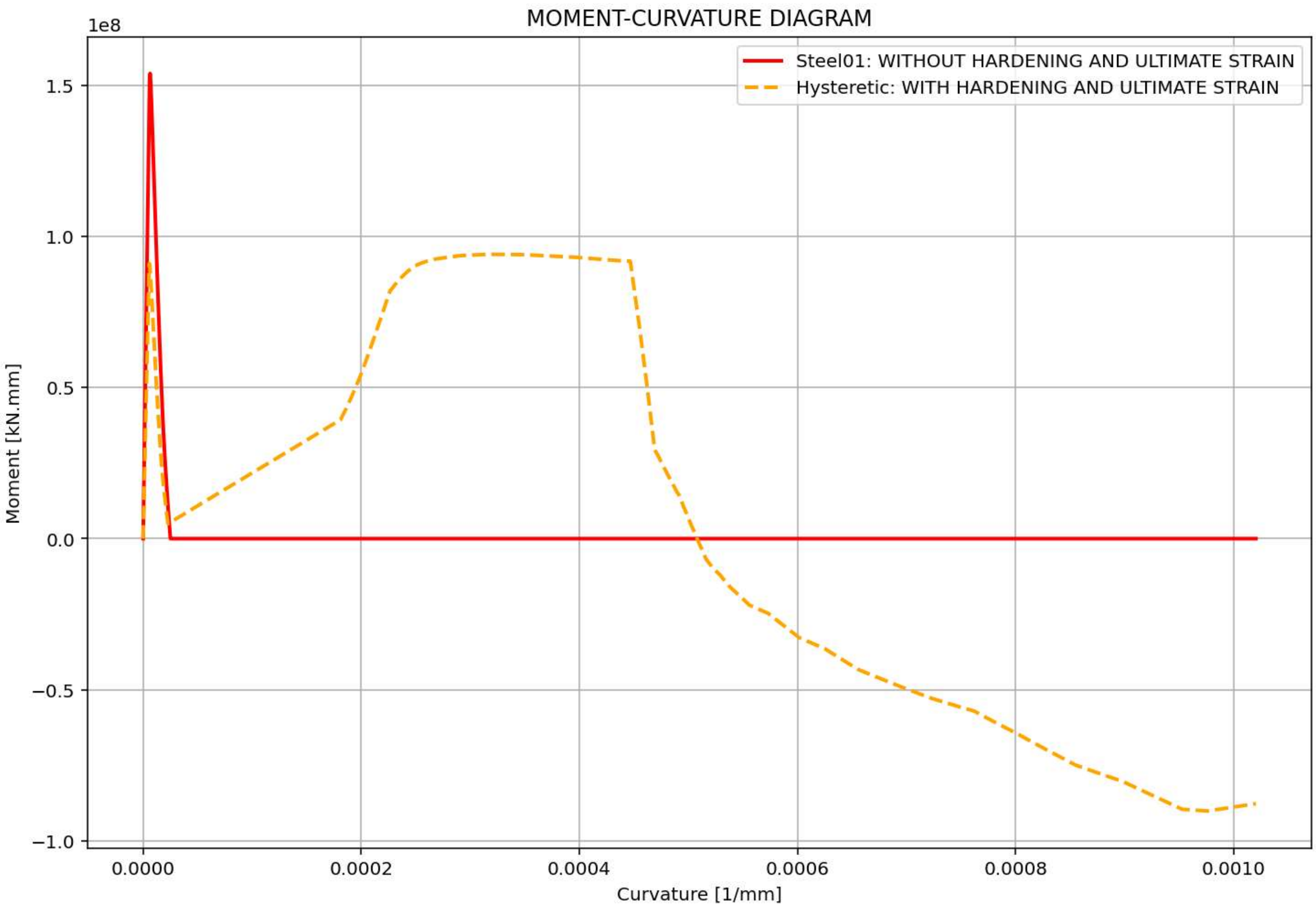


WITH HARDENING AND ULTIMATE STRAIN

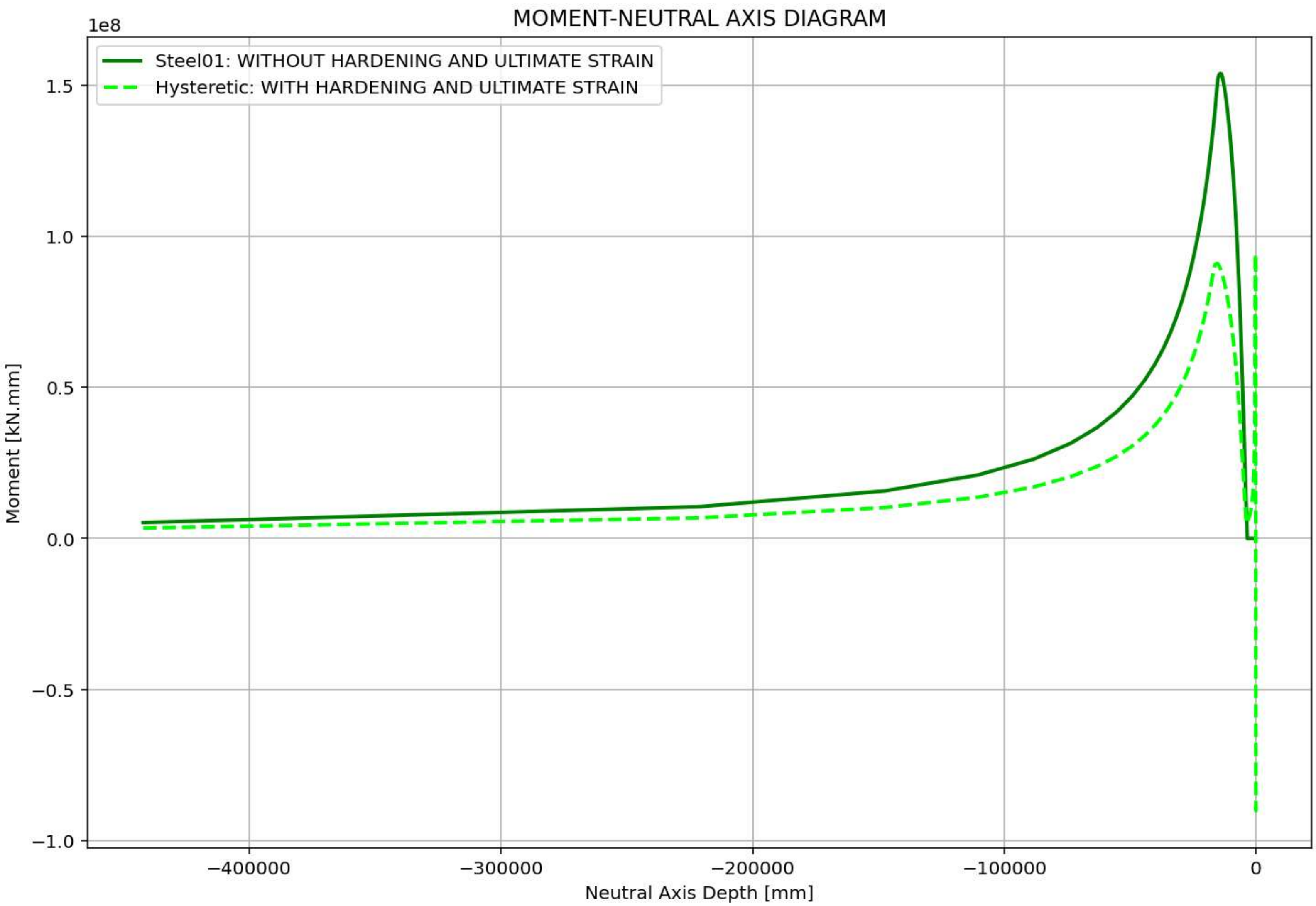

P-M Interaction
1e6
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN
2
1
0
−1
−2
Axial Force [N]
−1.0
−0.5
0.0
0.5
1.0
1.5
1e8
Bending Moment [N.mm]

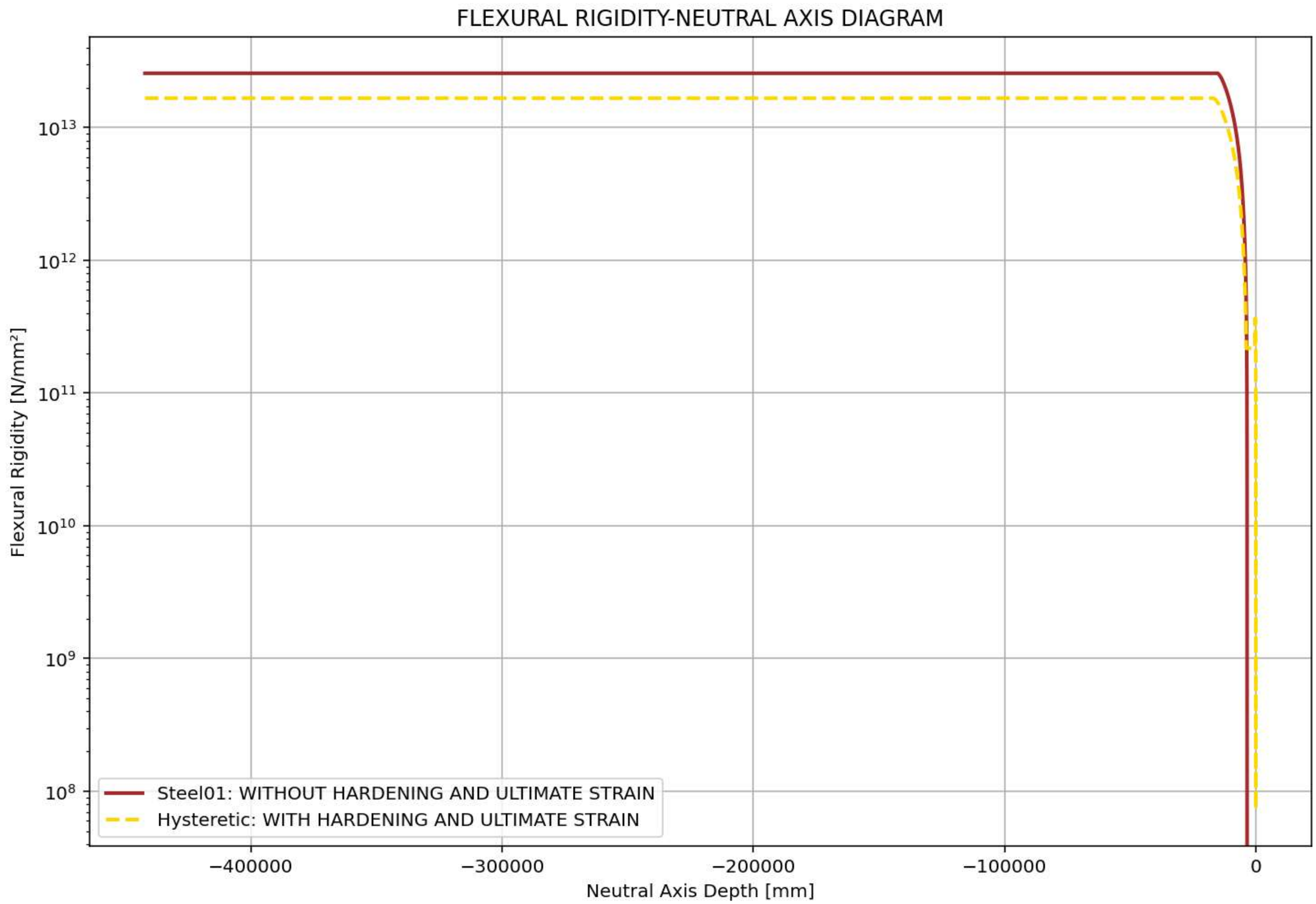


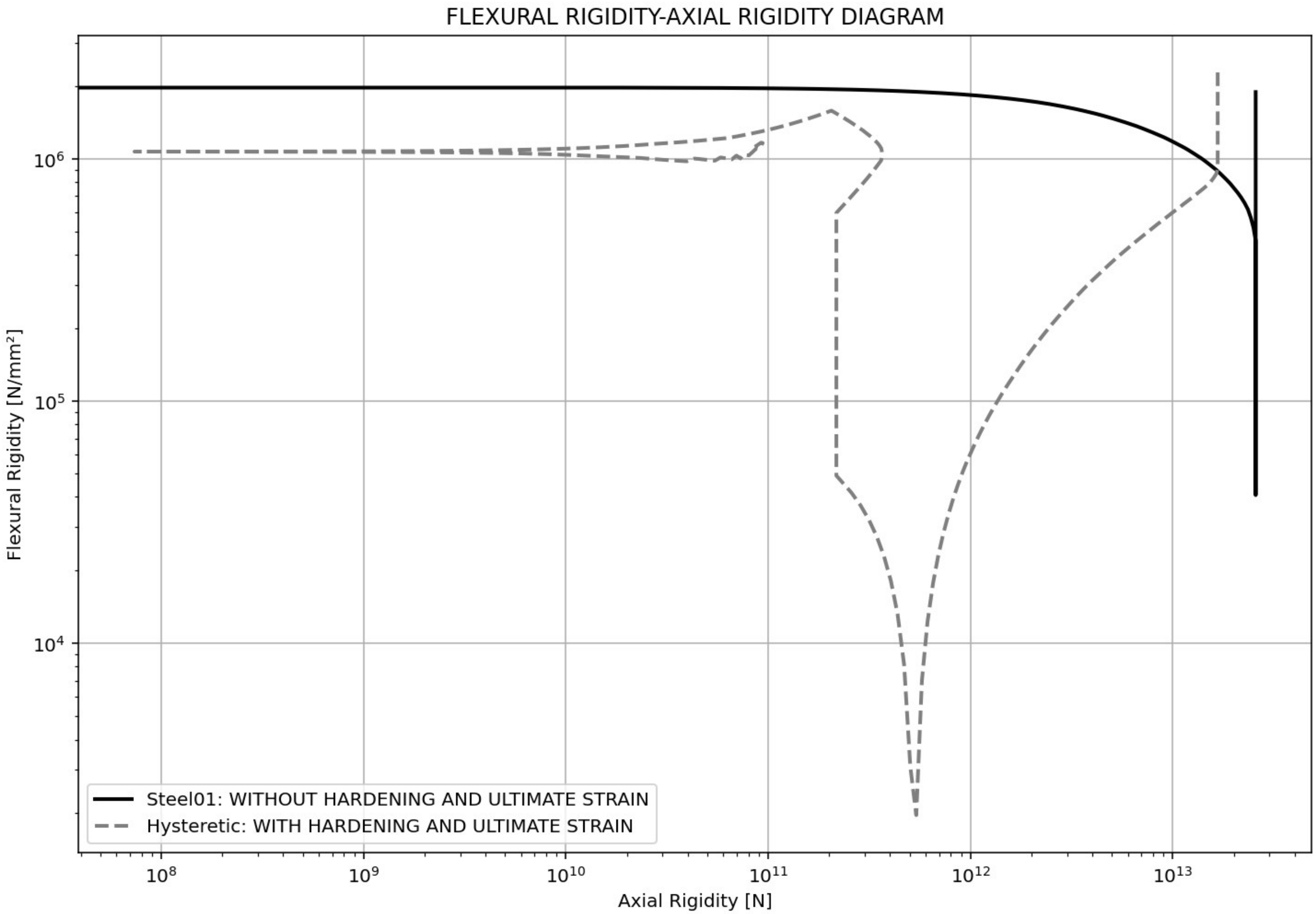
AXIAL FORCE-STRAIN DIAGRAM
1e6
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN
2
1
0
−1
−2
Axial Force [N]
−0.10
−0.05
0.00
0.05
0.10
0.15
Strain [mm/mm]



MOMENT-CURVATURE DIAGRAM
1e8
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN
1.5
1.0
0.5
0.0
−0.5
−1.0
Moment [kN.mm]
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
Curvature [1/mm]


MOMENT-NEUTRAL AXIS DIAGRAM
1e8
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN
1.5
1.0
0.5
0.0
−0.5
−1.0
Moment [kN.mm]
−400000
−300000
−200000
−100000
0
Neutral Axis Depth [mm]


FLEXURAL RIGIDITY-NEUTRAL AXIS DIAGRAM
Flexural Rigidity [N/mm²]
Neutral Axis Depth [mm]
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
−400000
−300000
−200000
−100000
0
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN


FLEXURAL RIGIDITY-AXIAL RIGIDITY DIAGRAM
Flexural Rigidity [N/mm²]
Axial Rigidity [N]
10^6
10^5
10^4
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
Steel01: WITHOUT HARDENING AND ULTIMATE STRAIN
Hysteretic: WITH HARDENING AND ULTIMATE STRAIN