Software for the Analysis of Concrete Column Sections Reinforced with GFRP Bars

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Introduction

- GFRP reinforced concrete application has matured from emerging technology to standard practice.
- ACI 440 code is about to be released.
- Design tools are needed to guide the engineering work.
- GFRP bar prices are becoming comparable to steel bars

Objectives

- Develop a comprehensive analysis tool for concrete columns reinforced entirely with GFRP bars in both the longitudinal and transverse directions as a direct replacement for steel.
- The tool shall cover all the design aspects of concrete columns reinforced with GFRP.

Objectives

- Design Interaction Diagrams for short columns.
- Complete consideration of 2nd order effect for slender columns in sway and non-sway frames.

Challenges

- Considering the 2nd order effect due to biaxial bending moments in sway and non-sway frames (Note: moment magnification is not sufficient). [For a coming presentation]
- Construct the relationship between the angle of the applied moments α and the angle of the neutral axis γ. [The main scope of this presentation]

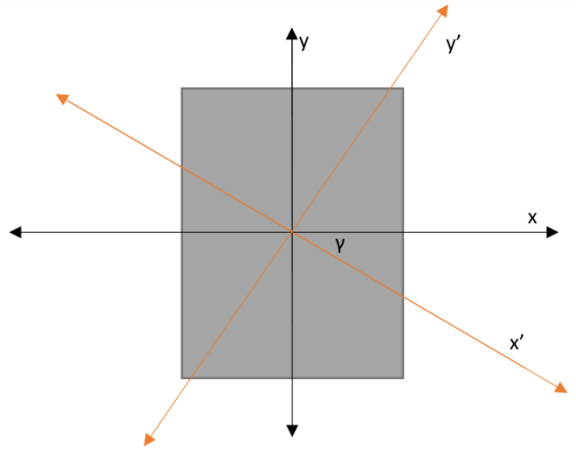
Theoretical Background

Problem Definition

- In the design process, the designer usually calculates the required reinforcement based on the applied moments.
- For a non-circular section with a bi-axial bending moment, the angle of the neutral axis γ is unknown.
- There is a need to construct a relationship between the angle of the applied moments α and the angle of the neutral axis γ for all applicable aspect ratios.

Commentary

- The angle of the applied moments α is defined as : $Tan(\alpha) = \frac{M_y}{M_x}$.
- The angle of the applied moments α and the angle of the neutral axis γ are not equal for any aspect ratio other than one, $\alpha \neq \gamma$.



Theoretical Background

Problem Definition

Commentary

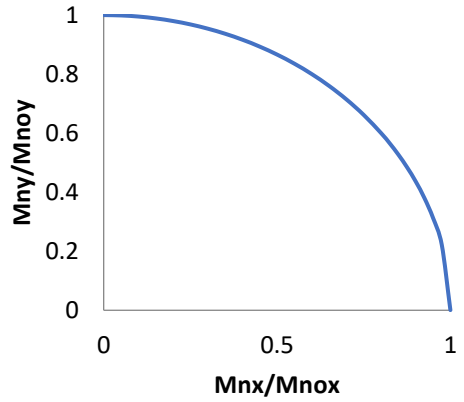
- The traditional way to account for the variation of the angle of loading α is by using the interaction expression at a constant P:

$$\left(\frac{M_{nx}}{M_{nox}}\right)^{\beta} + \left(\frac{M_{ny}}{M_{noy}}\right)^{\beta} = 1$$

Where,

M_{nox} and M_{noy} are the ultimate bending moment under uniaxial loading conditions in x and y respectively.

β is a given constant.



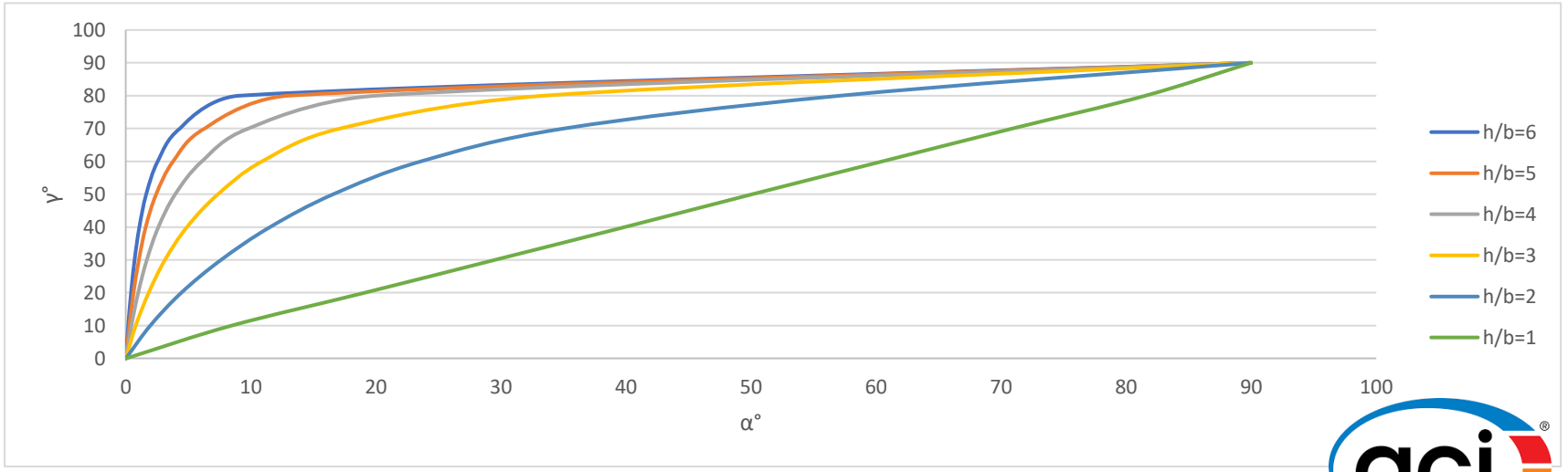
Theoretical Background

Analytical Approach

- Instead of the designer approach, we started our investigation by solving an analysis problem for different aspect ratios and different reinforcement ratios.
- By varying the angle of the neutral axis and calculating M_y and M_x for the section, the corresponding α's are evaluated.

Commentary

- The angle of the neutral axis ranged from 0-90 degrees, while the aspect ratios ranged from h/b=1 up to h/b=6.



Theoretical Background

Analytical Approach

- By studying the presented graph, a strong resemblance is observed between the recovered curves and Ramberg-Osgood equations.
- For each aspect ratio h/b, a similar equation is adopted:

$$\alpha = \frac{\gamma}{E} + K\left(\frac{\gamma}{E}\right)^{n}$$

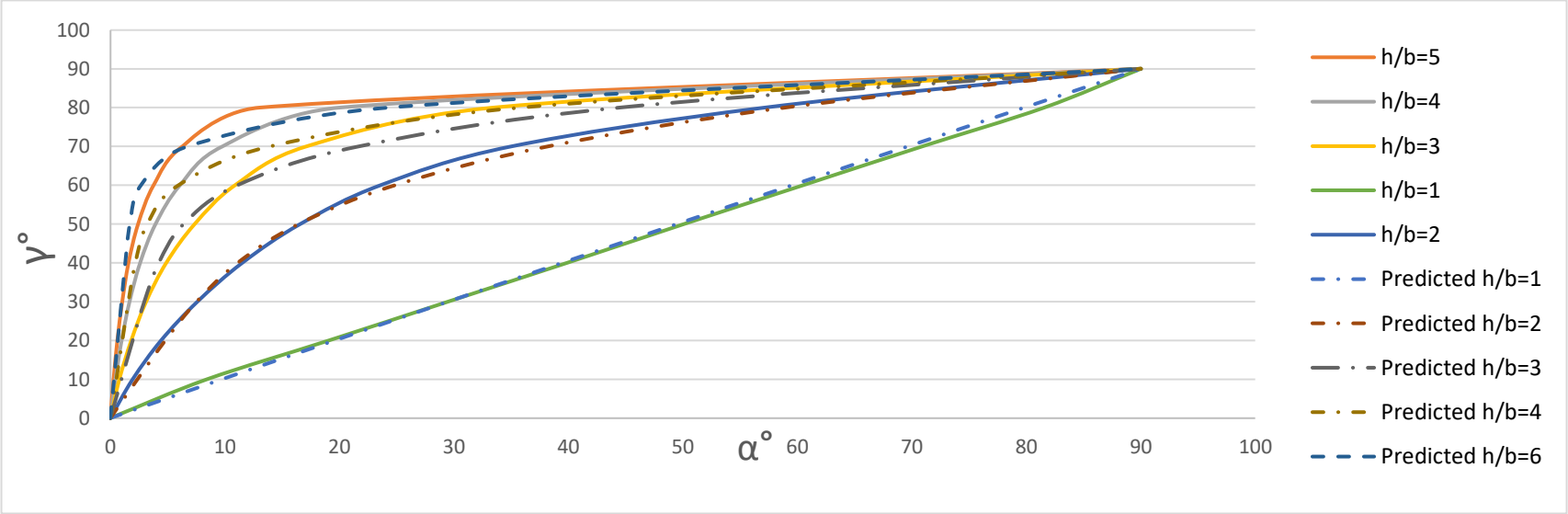
Commentary

The Ramberg–Osgood equation was created to describe the non-linear relationship between stress and strain in metals including their yield points.

$$\varepsilon = \frac{\sigma}{E} + K\left(\frac{\sigma}{E}\right)^{n}$$

Where,

ε is strain, σ is stress, E is the initial slope and K and n are material constants.



Theoretical Background

Analytical Approach

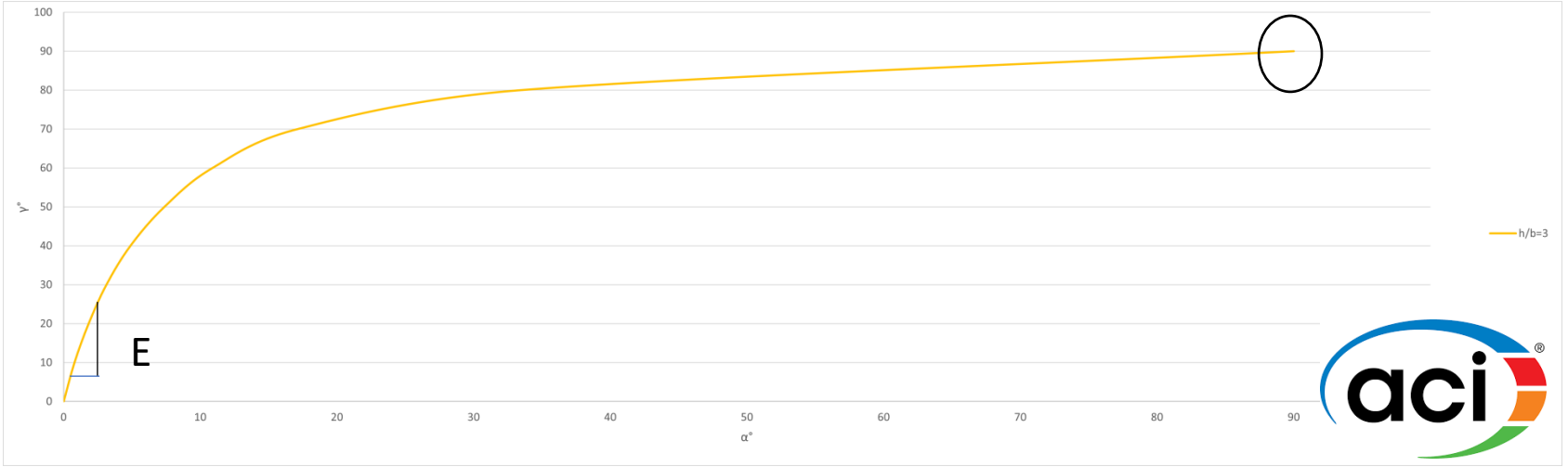
- For each aspect ratio h/b, a similar equation is adopted:

$$\alpha = \frac{\gamma}{E} + K\left(\frac{\gamma}{E}\right)^{n}$$

Where,
α is applied moment angle
γ is neutral axis angle
E is the initial slope
K and n are constants based on the aspect ratio

Commentary

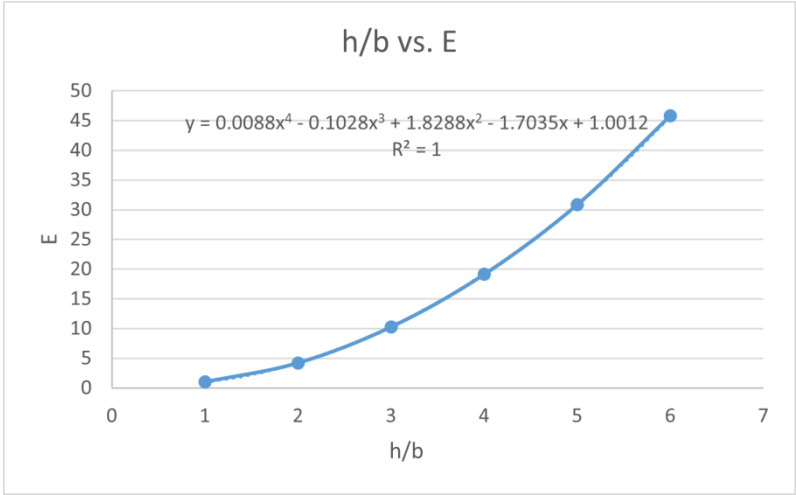
- It is important to note that α and γ are equal at 0° and 90°. This boundary condition is used to calculate one of our three unknowns n, K, and E.
- E and n could be estimated based on curve-fitting of the calculated analysis problem with an $R^2 = 1\ and\ 0.99, respectively.$



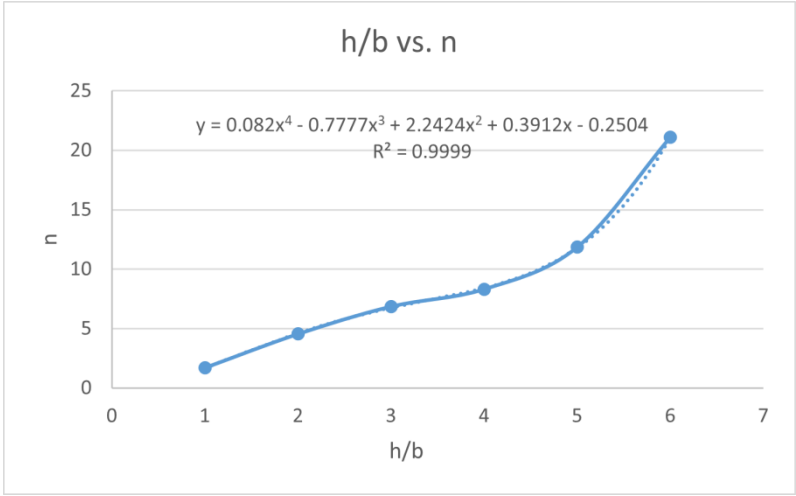
Theoretical Background

Analytical Approach

- The relationship between the aspect ration h/b and the initial slope E, with an $R^2 = 1$.



- The relationship between the aspect ration h/b and n, with an $R^2 = 0.99$.



Theoretical Background

Analytical Approach

1

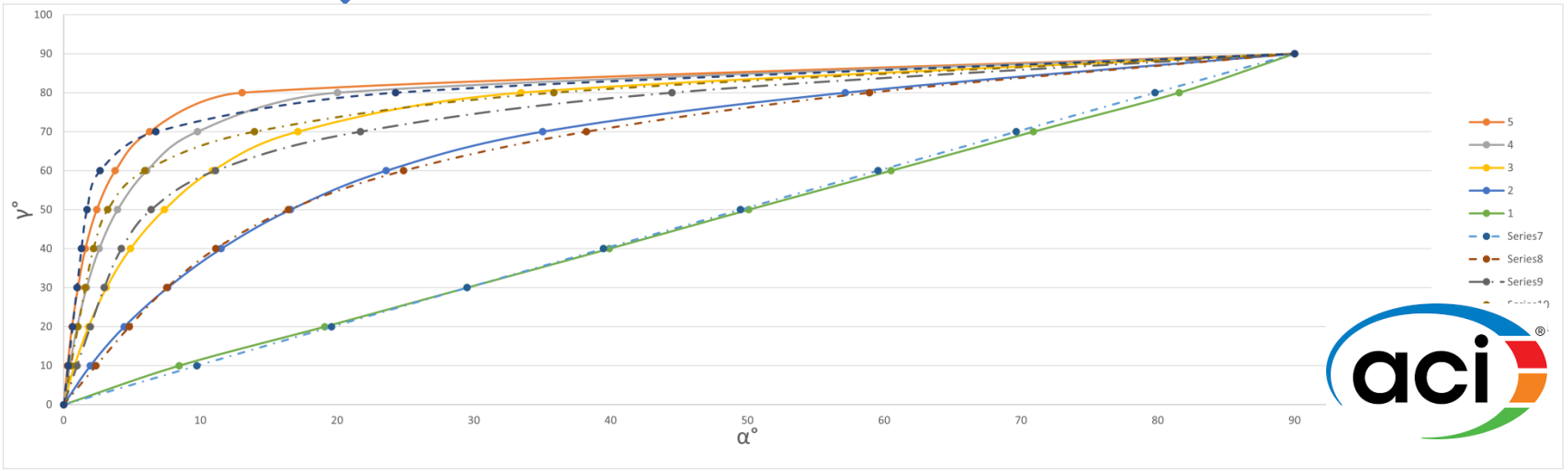
- For a given h/b, M_x and M_y.
- Calculate $\alpha = tan^{-1}(\frac{M_y}{M_x})$

2

- Calculate n and E from the following equations:
- $E = 0.0088\left(\frac{h}{b}\right)^4 - 0.103\left(\frac{h}{b}\right)^3 + 1.83\left(\frac{h}{b}\right)^2 - 1.7\left(\frac{h}{b}\right)+1$
- $n = 0.082\left(\frac{h}{b}\right)^4 - 0.78\left(\frac{h}{b}\right)^3 + 2.24\left(\frac{h}{b}\right)^2 + 0.39\left(\frac{h}{b}\right) - 0.25$

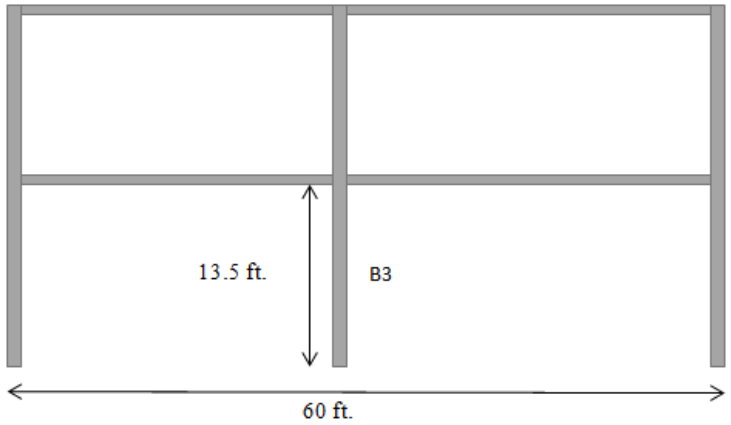
3

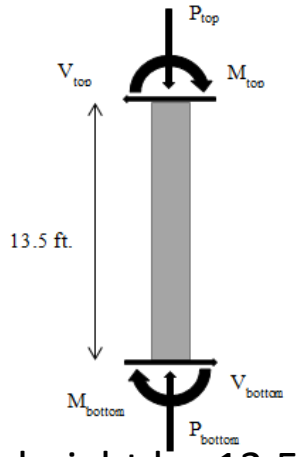
- Calculate k from the boundary condition $\alpha=\gamma=90$
- Calculate the angle of the neutral axis numerically using $\alpha = \frac{\gamma}{E} + K\left(\frac{\gamma}{E}\right)^n$

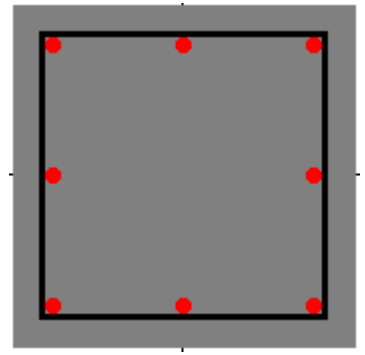


Results and Discussion

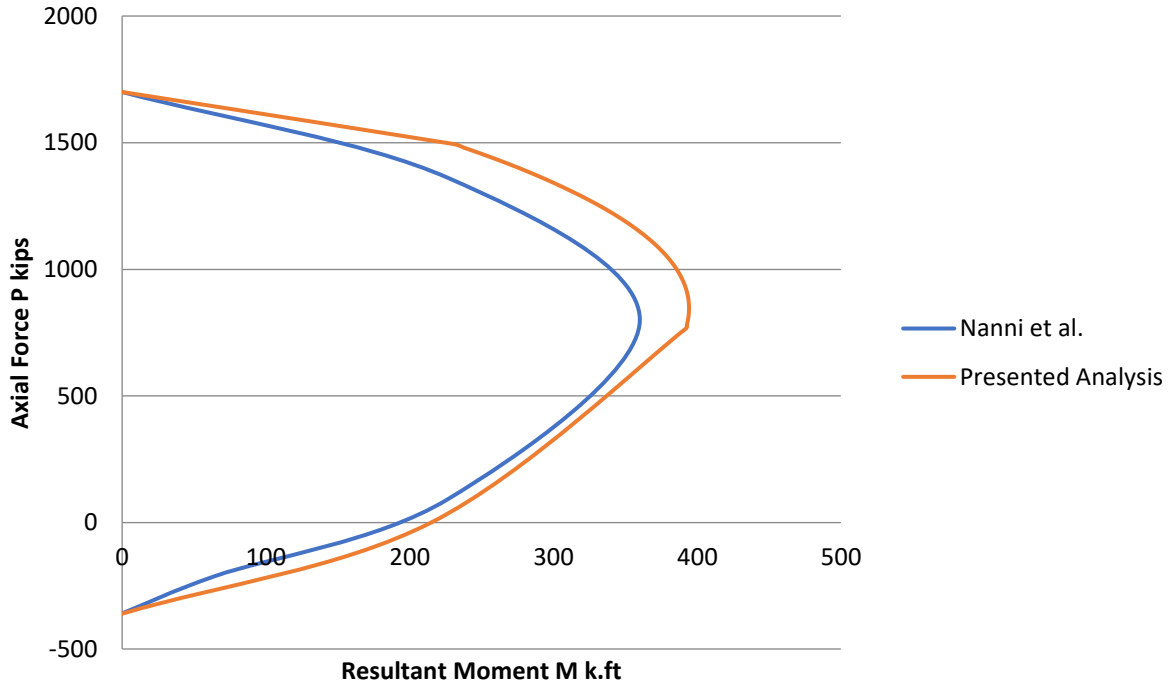
Nanni et al. 2021







- Non-sway Frame.
- Uniaxial loading.
- Column clear height l_u= 13.5 ft.
- Interior exposure



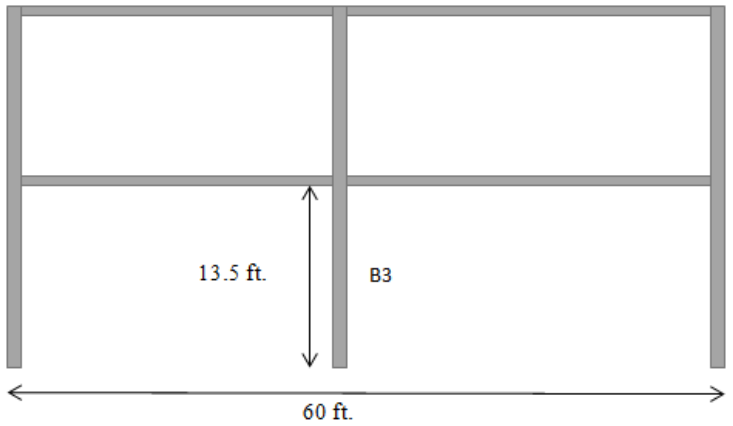
Geometry:
- 20 in.*20 in.
- Cover=2.5 in.

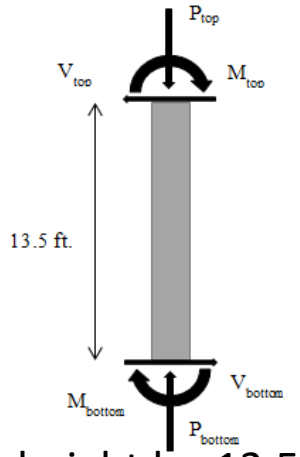
GFRP:
- 8 #8 bar.
- $\varepsilon_{fu} = 0.01$
- $E_f = 5700\ ksi$

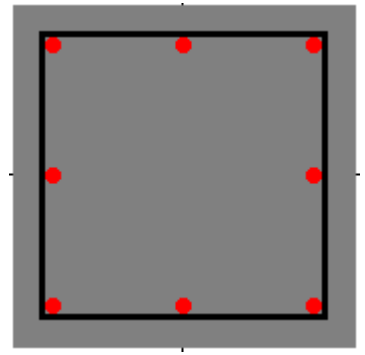
Concrete:
- $f'_c = 5\ ksi$
- $E_c = 4074\ ksi$
- $\varepsilon_{cu} = 0.003$

Results and Discussion

Uniaxial vs 45° loading







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- 45° loading
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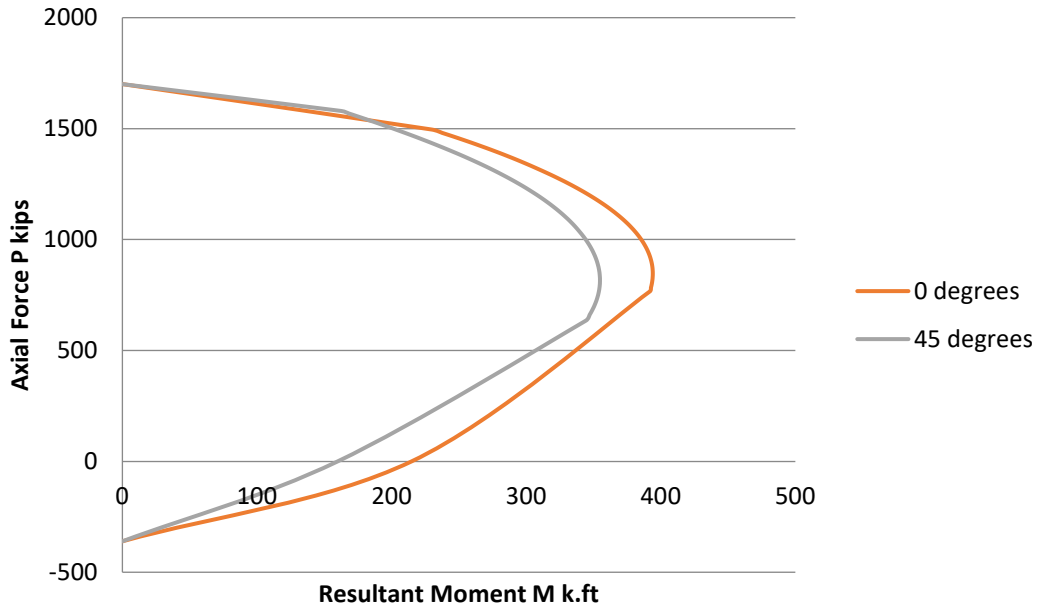

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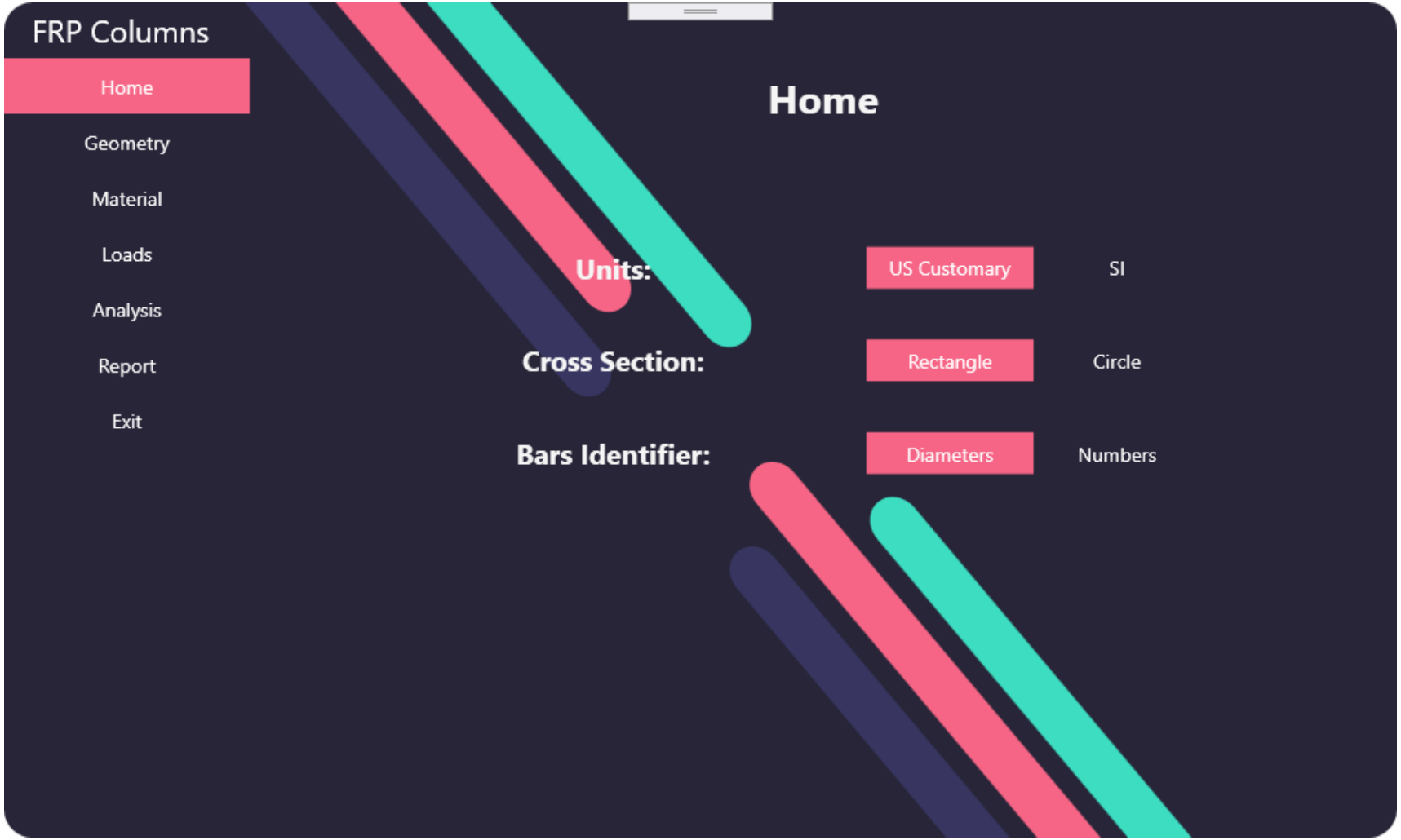
Software Development

Configuration



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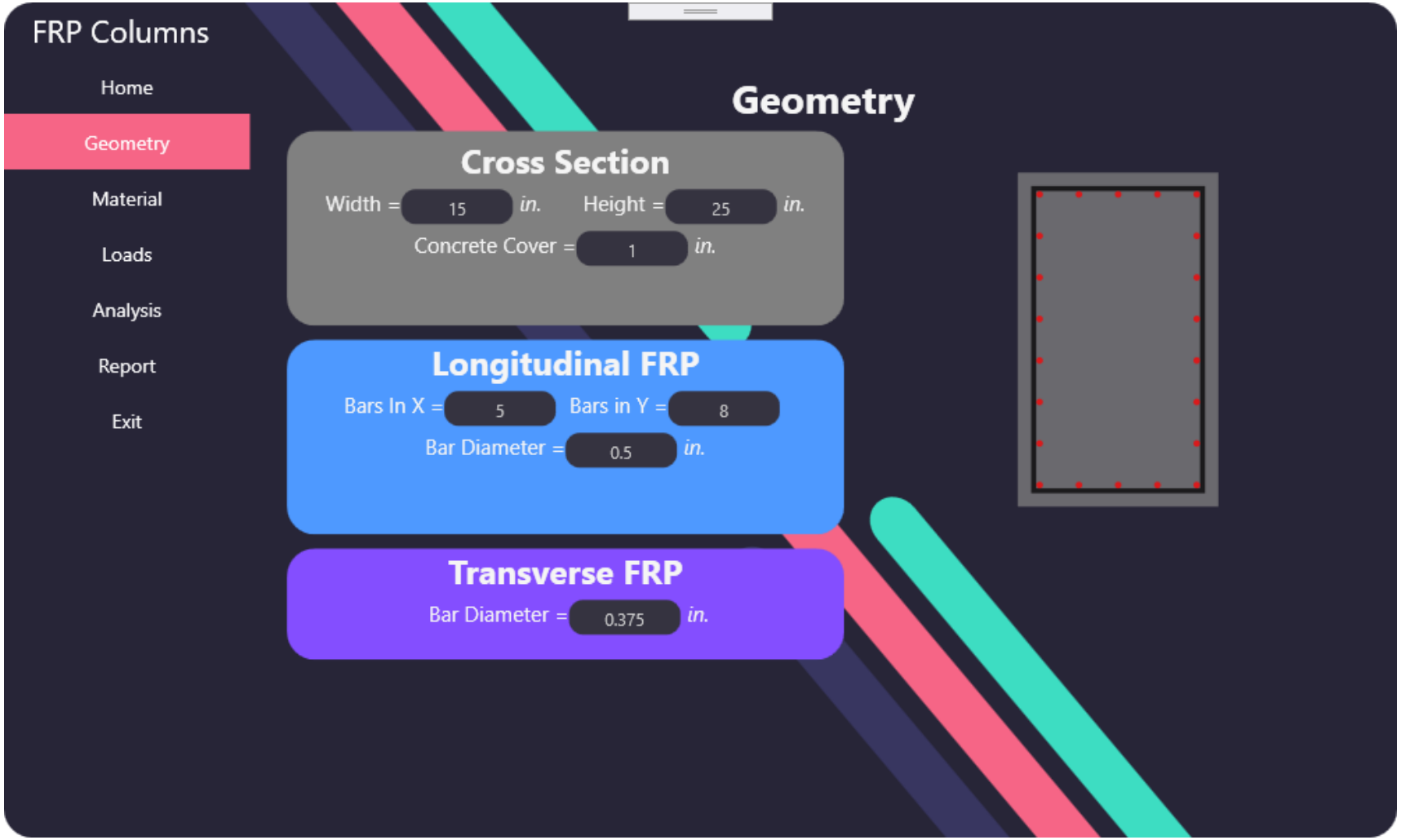
Software Development

Geometry



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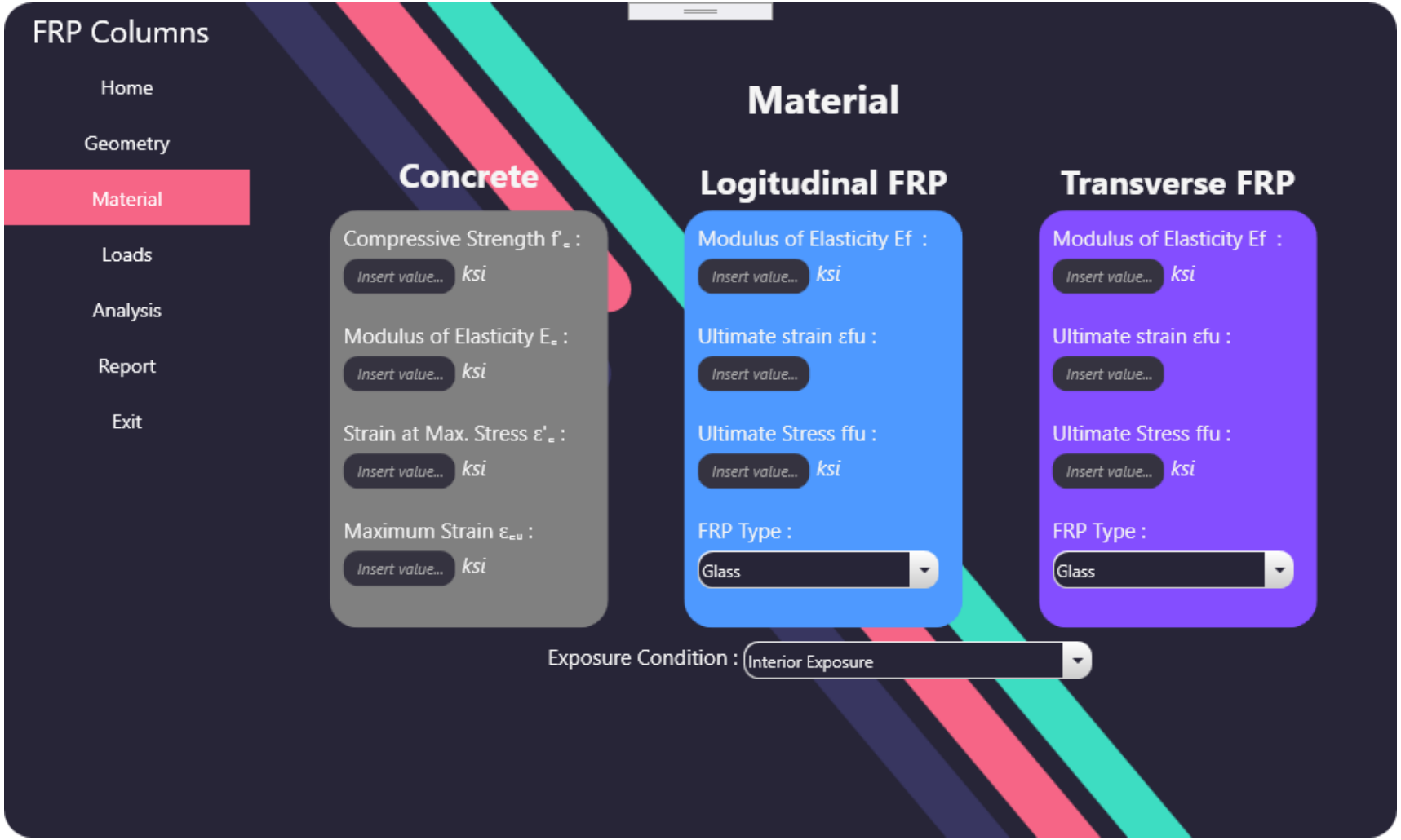
Software Development

Material



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Loads

Software Development

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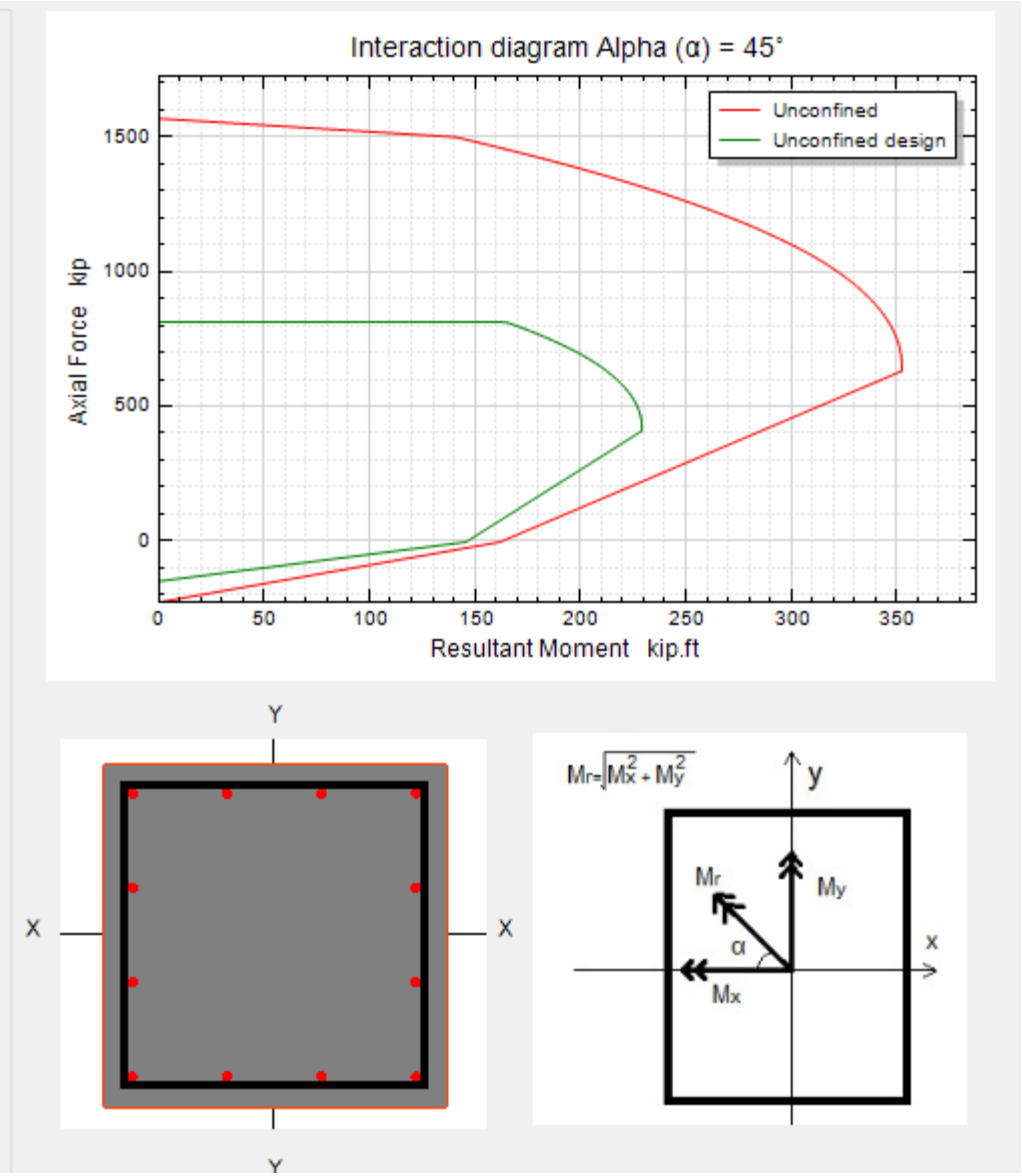
Software Development

Results



Software Development

Report

AEDA LLC
Advanced Engineering Design Apps

AEDA LLC
FRP BUILDINGS (FRP Bar Universal Internal Link Design In New Girders and Slabs)
Tuesday, 23 March 2021

Design of flexural members reinforced with FRP bars by AEDA LLC
Case name: P1.pdf

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Conclusions

- An accurate relationship between the angle of the applied moments α and the angle of the neutral axis γ is constructed for rectangular columns under bi-axial bending moment.
- The constructed technique is applicable for FRP, steel, stainless steel,…etc.
- A similar approach is used for elliptical columns based on the ratio of the major axis to the minor axis.
- A comprehensive software is almost fully developed to design and analyze concrete columns reinforced with FRP bars as a direct replacement of steel based on the new ACI440.1 code under balloting.
- The developed software considers the 2nd order effects due to biaxial bending moments in sway and non-sway frames using a rational analysis.