Notes and assumptions

- The average existing concrete strength is taken as 5000 psi.
- The calculations were performed according to ACI-440.2R-08, Chapter 12.
- The calculations show only the increase in the axial load carrying capacity due to confinement of the pier. Calculations for the moment-axial force interaction are not provided.
- The increase in the axial load carrying capacity of the pier is achieved by increasing the average compressive strength of the concrete through confinement.
- Two cases of confinement are provided; the first case considers the confinement of th pier with FRP materials applied directly to the surface without any shape modificatio while the second case considers the confinement of he pier with FRP wraps after modifying the shape to a near-circular using steel plates and pipes.
- The analysis was performed based on the material properties of a uni-axial carbon fiber fabric (Replark). However, the analysis can be adjusted for other types of FRP fabric as well.

Notations:

A_{ec}	"Ratio between confined and total concrete cross sectional areas"
A_g	"Gross area of concrete section"
A_{st}	"Total area of longitudinal reinforcement"
b	"Width of compression face of pier"
D	"Diameter of compression member"
E_2	"Slope of linear portion of stress-strain model for confined concrete"
E_c	"Modulus of elasticity of concrete"
E_f	"Tensile modulus of elasticity of FRP"
f_c	"Concrete compressive strength"
f_{cc}	"Theoretical compressive strength of confined concrete"
f_{cc_mod}	"Actual compressive strength of confined concrete "
f_l	"Maimum confinement pressure fue to FRP jacket"
f_y	"Yield strength of longitudinal reinforcement"
h	"Depth of the compression face of the pier"
k_a	"Efficiency factor for FRP reinforcement in determining fcc"
k_b	"Efficiency factor for FRP in determining εcc"
k_ε	"Efficieny factor taken as 0.58"
n	"Number of plies of FRP"
P_n	"Nominal axial compressive strength of unconfined concrete section"
P_{nc}	"Nominal Axial compressive strength of confined concrete section"
ΔP_n	"% increase in the axial compressive strength due to confinement"
r_c	"Radius of edges of the cross section"
t_f	"Nominal thickness of one ply of FRP"
ε_{ccu}	"Theoretical ultimate axial compressive strain of confined concrete"
ε_{ccu_mod}	"Actual ultimate axial compressive strain of confined concrete"
ε_{fe}	"Effective strain level in FRP"
ε_u	"Design rupture strain of FRP renforcement"
ρ_g	"Ratio of area of longitudinal reinforcement to gross sectional area"
σ_u	"Design ultimate strength of FRP"

Properties of FRP materials

$E_f := 23 \cdot 10^6 \cdot \frac{lb}{in^2}$

$\sigma_u := 340 \cdot 10^3 \cdot \frac{lb}{in^2}$

$\varepsilon_u := .0147$

$t_f := .04 \cdot in$

Calculate the axial load carrying capacity of the pier:

$b := 42 \cdot in$

$h := 84 \cdot in$

$A_{st} := 34.36 \cdot in^2$

$A_g := b \cdot h = 3.528 \times 10^3 \cdot in^2$

$f_y := 60000 \cdot \frac{lb}{in^2}$

Calculate the axial load carrying capacity of the unstrengthened pier:

$f_c := 5000 \cdot \frac{lb}{in^2}$

$P_n := 0.8 \cdot \left[0.85 \cdot f_c \cdot \left(A_g - A_{st}\right) + f_y \cdot A_{st}\right]$

$P_n = 1.353 \times 10^7 \, lb$

Calculate the axial load carrying capacity of the pier when strengthened with layers of FRP materials directly applied to the sides of the pier with no shape modification:

$D := \left(b^2 + h^2\right)^{0.5} = 93.915 \cdot in$

$\rho_g := \frac{A_{st}}{A_g} = 9.739 \times 10^{-3}$

$r_c := 0 \cdot in$

$n := 5$

$$A_{ec} := \frac{1 - \left[\frac{\frac{b}{h}\cdot\left(h - 2\cdot r_c\right)^2 + \frac{h}{b}\cdot\left(b - 2\cdot r_c\right)^2}{3\cdot A_g}\right] - \rho_g}{1 - \rho_g} = 0.327$$

$$k_a := A_{ec}\cdot\left(\frac{b}{h}\right)^2 = 0.082$$

$$k_b := A_{ec}\cdot\left(\frac{h}{b}\right)^{0.5} = 0.462$$

$$k_\varepsilon := 0.58$$

$$\varepsilon_{fe} := k_\varepsilon\cdot\varepsilon_u = 8.526\times 10^{-3}$$

$$f_l := \frac{2\cdot E_f\cdot n\cdot t_f\cdot\varepsilon_{fe}}{D} = 835.216\cdot\frac{lb}{in^2}$$

$$\frac{f_l}{f_c} = 0.167$$

$$\text{Checkconfinement} := \begin{vmatrix} \text{"Okay"} & \text{if } \frac{f_l}{f_c} > .08 \\ \text{"Redesign"} & \text{otherwise} \end{vmatrix}$$

$$\text{Checkconfinement} = \text{"Okay"}$$

$$\varepsilon_c := 0.002$$

$$f_{cc} := f_c + 0.95\cdot 3.3\cdot k_a\cdot f_l = 5.214\times 10^3\cdot\frac{lb}{in^2}$$

$$\varepsilon_{ccu} := \varepsilon_c\cdot\left[1.5 + 12\cdot k_b\cdot\frac{f_l}{f_c}\cdot\left(\frac{\varepsilon_{fe}}{\varepsilon_c}\right)^{0.45}\right]$$

$$\varepsilon_{ccu} = 6.558\times 10^{-3}$$

$$\varepsilon_{ccu\_mod} := \begin{vmatrix} \varepsilon_{ccu} & \text{if } \varepsilon_{ccu} < .01 \\ .01 & \text{otherwise} \end{vmatrix}$$

$$\varepsilon_{ccu\_mod} = 6.558\times 10^{-3}$$

$$E_c := 33 \cdot 10^6 \cdot \frac{lb}{in^2} \cdot .145^{1.5} \cdot \left(\frac{f_c}{1000 \cdot \frac{lb}{in^2}} \right)^{.5} = 4.074 \times 10^6 \cdot \frac{lb}{in^2}$$

$$E_2 := \frac{f_{cc} - f_c}{\varepsilon_{ccu}} = 3.262 \times 10^4 \cdot \frac{lb}{in^2}$$

$$f_{cc\_mod} := f_c + E_2 \cdot \varepsilon_{ccu\_mod} = 5.214 \times 10^3 \cdot \frac{lb}{in^2}$$

$$P_{nc} := 0.8 \cdot \left[0.85 \cdot f_{cc\_mod} \cdot \left(A_g - A_{st} \right) + f_y \cdot A_{st} \right] = 1.404 \times 10^7 \, lb$$

$$\Delta P_n := \frac{P_{nc} - P_n}{P_n} = 3.757 \cdot \%$$

Calculate the axial load carrying capacity of the pier when strengthened with 5 layers of FRP materials applied to the modified shape (as shown in the attached drawing in the PDF files) of the pier:

$$D := \left(b^2 + h^2 \right)^{0.5} = 93.915 \cdot in$$

$$\rho_g := \frac{A_{st}}{A_g} = 9.739 \times 10^{-3}$$

$$n := 5$$

$$A_{ec} := 1.0$$

$$k_a := 1.0$$

$$k_b := 1.0$$

$$k_\varepsilon := 0.58$$

$$\varepsilon_{fe} := k_\varepsilon \cdot \varepsilon_u = 8.526 \times 10^{-3}$$

$$f_l := \frac{2 \cdot E_f \cdot n \cdot t_f \cdot \varepsilon_{fe}}{D} = 835.216 \cdot \frac{lb}{in^2}$$

$$\frac{f_l}{f_c} = 0.167$$

$$Checkconfinement := \begin{cases} \text{"Okay"} & \text{if } \frac{f_l}{f_c} > .08 \\ \text{"Redesign"} & \text{otherwise} \end{cases}$$

Checkconfinement = "Okay"

$$\varepsilon_c := 0.002$$

$$f_{cc} := f_c + 0.95 \cdot 3.3 \cdot k_a \cdot f_l = 7.618 \times 10^3 \cdot \frac{lb}{in^2}$$

$$\varepsilon_{ccu} := \varepsilon_c \cdot \left[1.5 + 12 \cdot k_b \cdot \frac{f_l}{f_c} \cdot \left(\frac{\varepsilon_{fe}}{\varepsilon_c} \right)^{0.45} \right]$$

$$\varepsilon_{ccu} = 0.011$$

$$\varepsilon_{ccu\_mod} := \begin{cases} \varepsilon_{ccu} & \text{if } \varepsilon_{ccu} < .01 \\ .01 & \text{otherwise} \end{cases}$$

$$\varepsilon_{ccu\_mod} = 0.01$$

$$E_2 := \frac{f_{cc} - f_c}{\varepsilon_{ccu}} = 2.447 \times 10^5 \cdot \frac{lb}{in^2}$$

$$f_{cc\_mod} := f_c + E_2 \cdot \varepsilon_{ccu\_mod} = 7.447 \times 10^3 \cdot \frac{lb}{in^2}$$

$$P_{nc} := 0.8 \cdot \left[0.85 \cdot f_{cc\_mod} \cdot \left(A_g - A_{st} \right) + f_y \cdot A_{st} \right] = 1.934 \times 10^7 \, lb$$

$$\Delta P_n := \frac{P_{nc} - P_n}{P_n} = 42.981 \cdot \%$$