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E = modulus of Elasticity

I = Moment of Inertia

k = effective length

L = column length

$$P_{cr} = \frac{\pi^2 EI}{(kL)^2}$$

$$f(P) = P - P_{cr}\cos\left(\frac{P}{P_{cr}}\right) = 0$$

~~Calc~~ Given:

$E = 210 \times 10^9$ Pa

$I = 8.1 \times 10^{-6}\ m^4$

$L = 3m$

$k = 1.0$

$$P_{cr} = \frac{\pi^2 (210 \times 10^9)(8.1 \times 10^{-6})}{(1 \cdot 3.0)^2}$$

$$= 9.8696 \times \frac{(210 \times 10^9)(8.1 \times 10^{-6})}{9} = \underline{\underline{1.87 \times 10^6 N}}$$

$$f(P) = P - P_{cr}\cos\left(\frac{P}{P_{cr}}\right) \rightarrow P = P_{cr}\cos\left(\frac{P}{P_{cr}}\right)$$

$$\frac{d}{dP}[P] = 1$$

$$\frac{d}{dP}\left[-P_{cr}\cos\left(\frac{P}{P_{cr}}\right)\right] = -P_{cr}\left[-\sin\left(\frac{P}{P_{cr}}\right)\right] \times \frac{1}{P_{cr}} = \sin\left(\frac{P}{P_{cr}}\right) \therefore \underline{f'(P) = 1 + \sin\left(\frac{P}{P_{cr}}\right)}$$

~~New~~ ~~R~~ Newton Raphson Method

$$P_{new} = P_{old} - \frac{f(P_{old})}{f'(P_{old})}$$

initial guess $\rightarrow$ $P_0 = 0.5 P_{cr} = 0.5 \times (1.87 \cdot 10^6)$

$P_0 = 9.35 \times 10^5$

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Iteration 1:

$$f(P_0) = (9.35\times10^5) - (1.87\times10^6)\cos\left(\frac{9.35\times10^5}{1.87\times10^6}\right) = -705{,}000$$

$$f'(P_0) = 1 + \sin\left(\frac{9.35\times10^5}{1.87\times10^6}\right) = 1.4794$$

$$P_1 = P_0 - \left(\frac{f(P_0)}{f'(P_0)}\right) \qquad P_1 = 935000 - \frac{-705000}{1.4794} \approx \underline{1.412\times10^6}$$

Iteration 2:

$$f(P_1) = (1.412\times10^6) - (1.87\times10^6)\cos\left(\frac{1.412\times10^6}{1.87\times10^6}\right) = 52{,}000$$

$$f'(P_1) = 1 + \sin\left(\frac{1.412\times10^6}{1.87\times10^6}\right) = 1.684$$

$$P_2 = P_1 - \frac{f(P_1)}{f'(P_1)} = 1.412\times10^6 - \frac{52000}{1.684} \approx \underline{1.381\times10^6}$$

Iteration 3:

$$f(P_2) = (1.381\times10^6) - (1.87\times10^6)\cos\left(\frac{1.381\times10^6}{1.87\times10^6}\right) = -3000$$

$$f'(P_2) = 1 + \sin(0.739) = 1.673$$

$$P_3 = 1.381\times10^6 - \frac{-3000}{1.673} \approx 1.383\times10^6$$

Iteration 4:

$$f(P_3) = (1.383\times10^6) - (1.87\times10^6)\cos\left(\frac{1.383\times10^6}{1.87\times10^6}\right) = -10$$

$$f'(P_3) = 1 + \sin(0.740) = 1.673$$

$$P_4 = 1.383\times10^6 - \frac{-10}{1.673} \approx 1.383\times10^6$$

∴ The critical buckling load considering nonlinear effects is 1.383×10^6 N or 1.38 MN.