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Analytical Investigation to Improve the Buckling Capacity of Hollow Circular Pipe Columns

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Abstract: Pipe columns subjected to high loads are prone to buckling and this is a cause of major concern for many industrial buildings, making it vital to find a solution to prevent buckling. Many industrial columns have been subjected to long-term stresses that leave the structure vulnerable to sudden loads or pressures. These sudden changes can cause deformations leaving the columns incapable of carrying their designed loads. This in turn leaves the whole structure at risk of failure. One solution is the pressurization of pipe column. The pressurization of pipes is a very cost-effective solution as there would be no extra materials needed. Thus, the aim of this was study was to analytically examine the effects of pressurization on hollow circular pipes. Analytical relationships between various parameters are presented. General results, show, that pressurization increases the buckling capacity of hollow circular pipe columns.

Keywords: Pressurization, Buckling, Hollow, Circular, Pipe, Columns

INTRODUCTION

Buckling of circular pipes has posed significant challenges to the stability and reliability of engineering structures for centuries due to its reduction of load-bearing capacity. The failure mode under the applied support load and circumferential pressure results in global buckling response [1,2]. In another study [3], circular pipes are structurally sound enough to support the surrounding soil and surcharge loads; however, they become functionally obsolete when they develop cracks or experience flooding. Further, circular pipes are known for the lack of a defined weak axis in the cross-section. This makes it difficult to conclusively determine the bending direction after loading [4]. The stability of circular pipes decreases as initial imperfections increase. Additionally, the effect of these initial geometric imperfections on the stability coefficient gradually lessens as slenderness increases [4].

Studies [5,6,7] discuss methods to enhance the buckling capacity of the pipes. The performance of both single and double-integral arrestors was evaluated. It was found that pipelines under external pressure have a tendency to collapse [5]. Theoretical analysis of pre and post buckled composite pipes were carried out. Closed form solutions were obtained [6]. A review on the performance of filament wound fiber-reinforced polymer (FRP) composite pipes was carried out. A lower hoop stress reduced buckling under various loads [7].

Several studies [8,9,10] have been carried out to enhance the buckling capacity of pipe columns through the application of internal pressure. However, these studies were restricted to thin circular pipes, and the researchers primarily focused on predicting the wrinkling effects in such pipes. Buckling is a critical concern in many structures where circular pipes serve as columns. Therefore, in this work an elastic buckling analysis of pressurized hollow circular pipe columns is presented.

METHODOLOGY

The approach taken in this work evaluates how strength of columns can be enhanced by pressurization. By taking Euler's equation and including pressure, a new strength is acquired. There are multiple variables that can change the load that columns can handle, of which length, width, thickness, and internal pressure are included. Each of these factors have been varied to see their behavior as they change. For our analysis purposes, the modulus of elasticity was taken as 2900 ksi. Figure 1 shows, the cross section of a hollow circular column here 'W' & 't' are respectively taken as width and thickness.

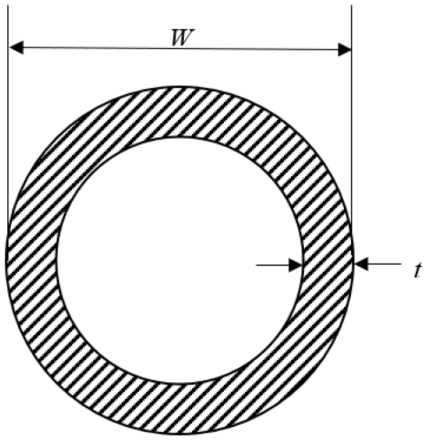

Figure 1: Cross -section of a hollow circular column

$$P_{cr} = \frac{\pi^2 E r^2 A}{L^2} \quad 1)$$

- Pcr = Maximum load carrying capacity of a column, kips
- $A = \text{Cross} - \text{sectional area of column, in}^2$
- $r = \text{Radius of gyration, in}$

$$\text{Shear flow x Pressurized area} = \frac{P r_p A_p}{4t} \quad 2)$$

- $P_{cr} = \text{ load carried by the material} + \text{load carried by the internal pressure, therefore}$

$$P_{cr} = \frac{\pi^2 E r^2 A_m}{L^2} + \frac{P r_p A_p}{4t} \quad 3)$$

- $P = \text{Internal pressure in the pipe, ksi}$
- $r = \text{Radius of gyration of the shaded area} \Rightarrow \sqrt{\frac{I_m}{A_m}}$
- $I_m = \text{Moment of inertia of the shaded area, in}^4$

- A_m = Area of the shaded material, in^2
- r_p = Radius of gyration of the pressurized area $\Rightarrow \sqrt{\frac{I_p}{A_p}}$
- I_p = Moment of inertia of the pressurized area, in^4
- A_p = Area of the pressurized material, in^2
- t = Thickness of the column, in
- L = Column length, in

By substituting the equations for area of a circle the following equation is given:

$$Pcr = \frac{\pi^2 E r^2}{L^2}[\frac{1}{4}\pi w^2 - \frac{1}{4}\pi(w-t)^2] + \frac{p r_p}{4t}[\frac{1}{4}\pi(w-t)^2] \qquad 4)$$

CALCULATIONS AND COMPARISON OF RESULTS

Figures 2 through 4 below display the relationships between critical column loads and varying widths for a particular column thickness in a logarithmic scale for a better understanding of results. The column thicknesses used were 0.125, 0.25, and 0.5 inches. Three column lengths of 12, 15, and 18 feet were used in the study. Additionally, each column length was subjected to 0, 2, and 4 ksi internal pressure. It was found that for a particular column thickness and length with increasing internal pressure, the load carrying capacity of the column was increased. It was also found, that everything being equal, a shorter column had much increased load carrying capacity.

Figure 5 shows below shows a relationship between critical column and aspect ratio (L/t) for a width of 10 inches. A greater aspect ratio produced a lower critical load carrying capacity at all lengths and internal pressure.

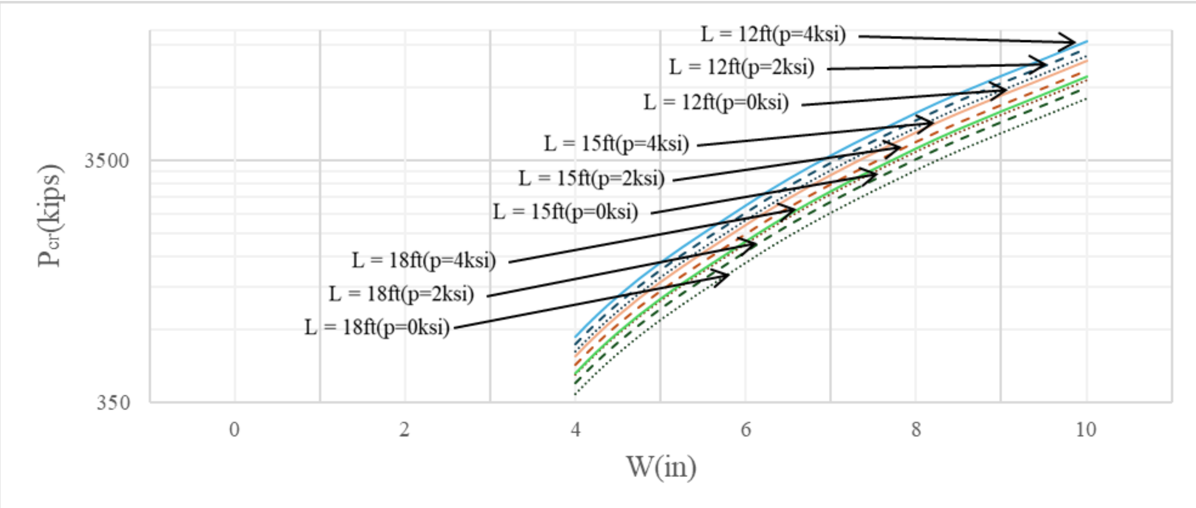

Figure 2: Critical Load vs. Width, t = 0.125 in

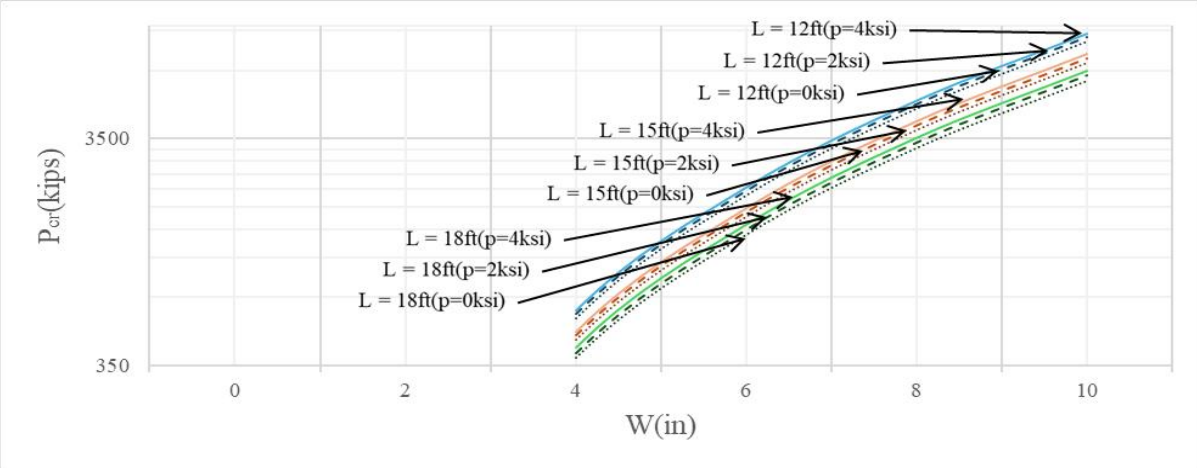

Figure 3: **Critical Load vs. Width, t = 0.25 in**

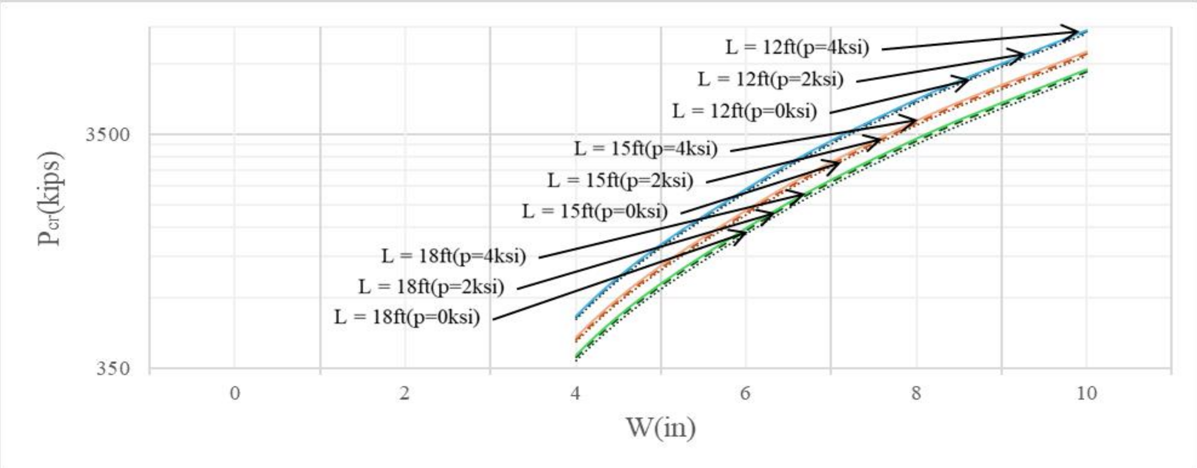

Figure 4: **Critical Load vs. Width, t = 0.5 in**

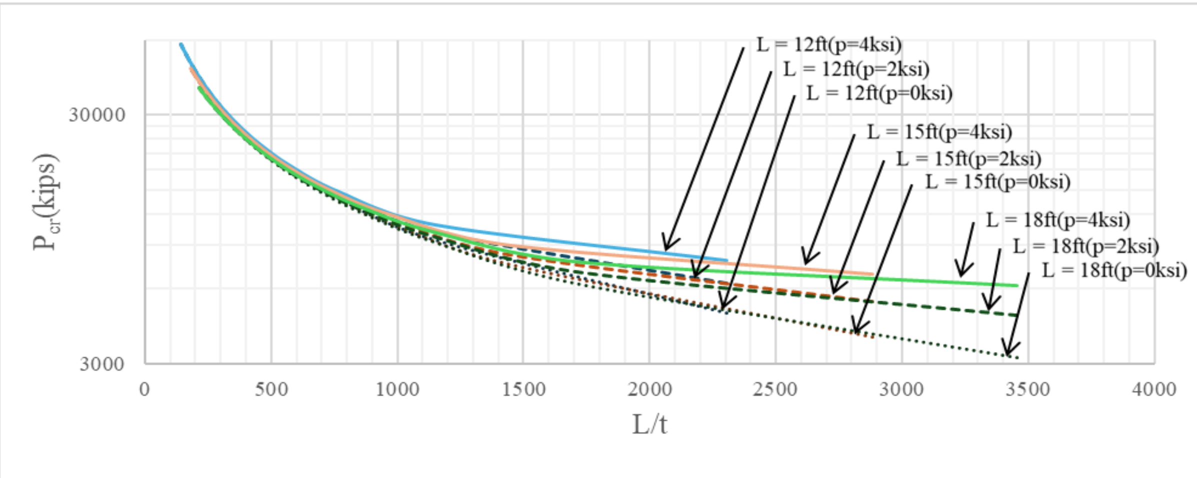

Figure 5: **Critical Load vs. L/t, W = 10 in**

Tables 1 and 2 below show the variation of strength for a particular width and a particular internal pressure for varying column lengths. For example, in Table 1 for a width of 2 inches, and lengths of 12, 15, and 18 ft, respective increase in critical loads were found to be 7, 8, and 10% at 2 ksi internal pressure. For 10 inches, an 8, 10, and 12% increase in critical loads were observed. Table 2 shows, a similar pattern. Tables 3 and 4 show the variation of strength with respect to a particular aspect ratio and an internal pressure. For example, for L/t = 2000, a 24, 30, and 36% increase in critical loads was observed respectively for column lengths of 12, and 18 ft at 2 ksi internal pressure. For L/t = 100, the strength gain was not significant after round off. This could be attributed to less available area for internal pressure. A similar trend was found in Table 4.

Table 1: Variation of strengths for a particular width and a 2ksi pressure

Width (Inches)		(P_{crw}/P_{cro})	
	L = 12ft	L = 15ft	L = 18ft
2	1.07	1.08	1.10
10	1.08	1.10	1.12

P_{crw}/P_{cro} = critical loads with pressurization/critical loads without pressurization

Table 2: Variation of strengths for a particular width and a 4ksi pressure

Width (Inches)		(P_{crw}/P_{cro})	
	L = 12ft	L = 15ft	L = 18ft
2	1.13	1.16	1.20
10	1.15	1.19	1.23

Table 3: Variation of strengths for a particular L/t ratio and a 2ksi pressure

L/t		(P_{crw}/P_{cro})	
	L = 12ft	L = 15ft	L = 18ft
	t_1 = 0.072in	t_3 = 0.09in	t_5 = 0.108in
	t_2 = 1.44in	t_4 = 1.8in	t_6 = 2.16in
2000	1.24	1.30	1.36
100	1.00	1.00	1.00

Table 4: Variation of strengths for a particular L/t ratio and a 4ksi pressure

L/t		(P_{crw}/P_{cro})	
	L = 12ft	L = 15ft	L = 18ft
	t_1 = 0.072in	t_3 = 0.09in	t_5 = 0.108in
	t_2 = 1.44in	t_4 = 1.8in	t_6 = 2.16in
2000	1.47	1.59	1.71
100	1.00	1.00	1.00

CONCLUSIONS

The main goal of this work was to analytically study the effectiveness of pressurizing hollow circular columns as a means of increasing their critical load carrying capacity. The overall results show that pressurizing hollow circular columns increase the load carrying capacity of the structure. Additionally, thinner pressurized pipes tend to produce better load carrying capacity.

FUTURE RESEARCH

Further research is possible in this basic topic by using different shapes, thickness and lengths to gain further insights.

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