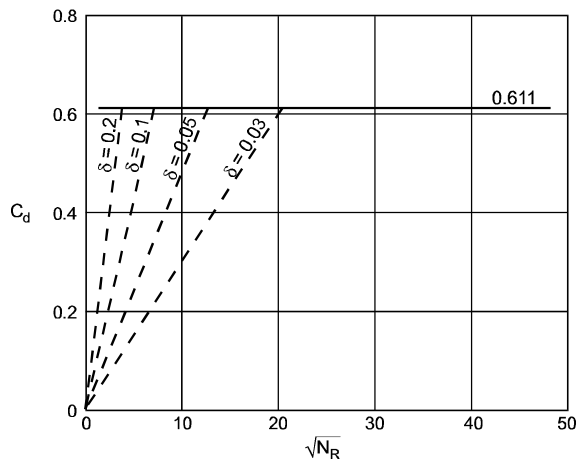


Figure 2-10. Asymptotic Approximation of Discharge Coefficient.

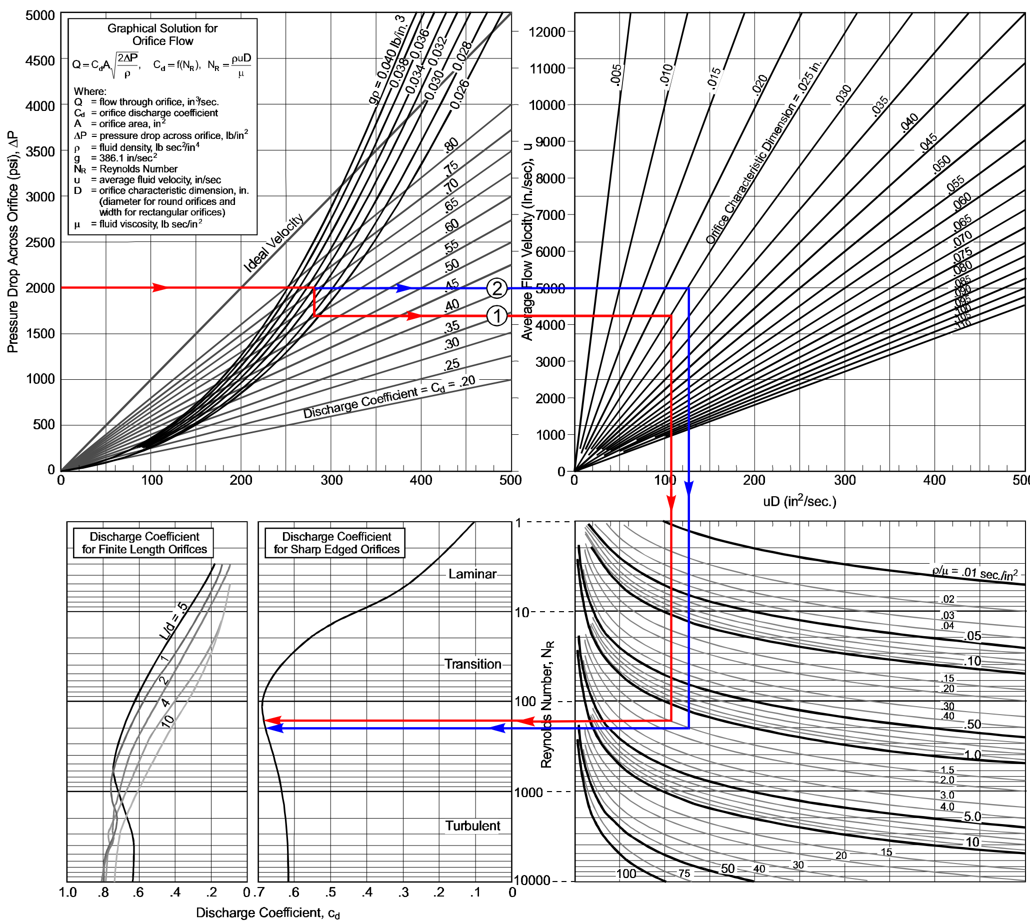


Figure 2-11. FPRC/OSU Orifice Flow Nomograph.

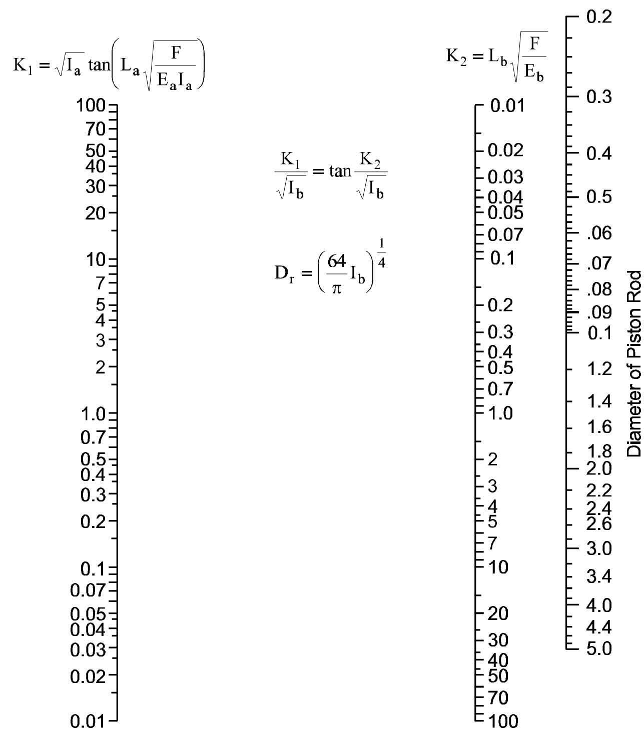
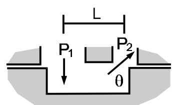
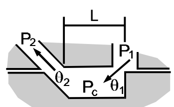
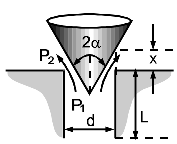
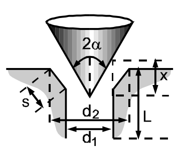
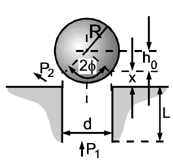
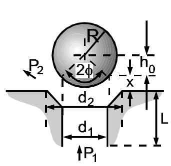


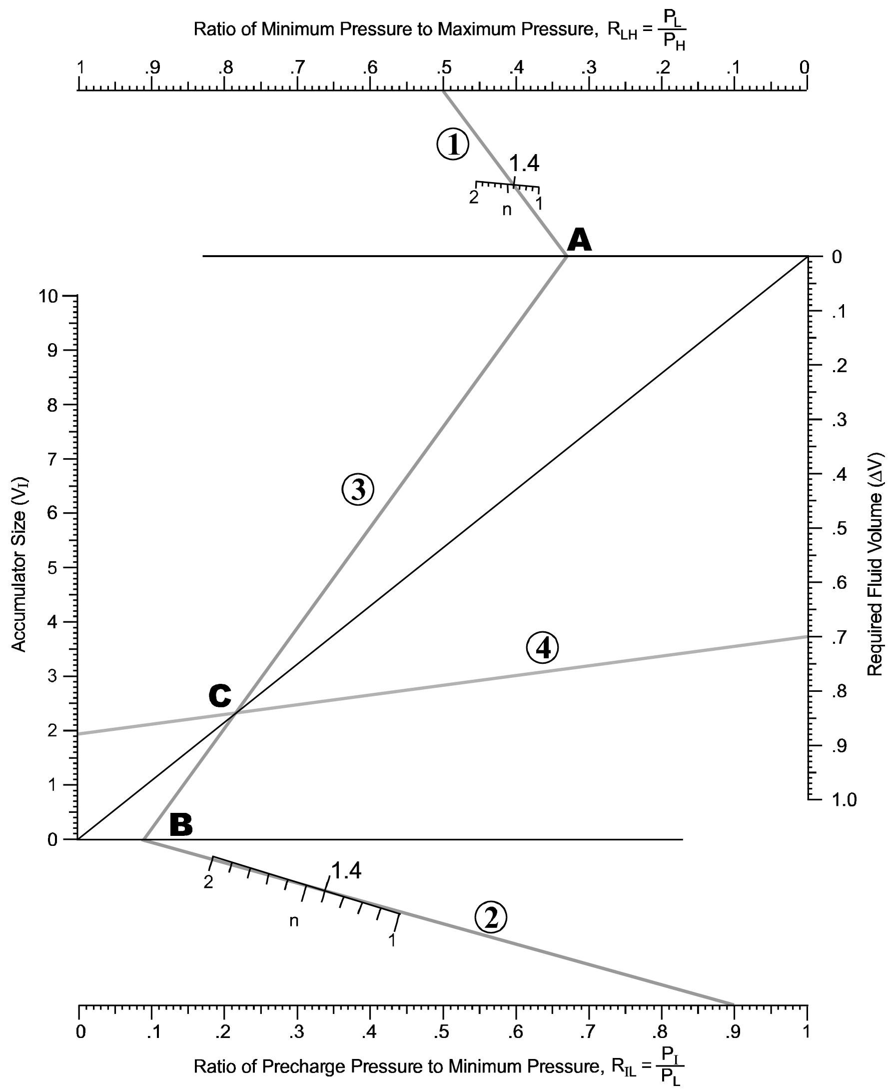
Figure 3-29. Piston-rod Nomograph using Swage Column Formula.

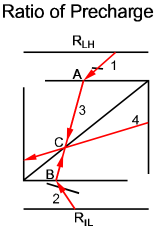
Since the swage column analysis is based on the assumption that the joint between the rod and cylinder body is rigid, a question to consider is “Where will failure occur in the actual cylinder?” One would expect the cylinder to fail either at the joint or somewhere along the rod. It does not seem reasonable that the cylinder body will be first to fail. The same condition exists in a swaged column. The column would be expected to fail in the swaged section or near the transition. Thus while a hydraulic cylinder is not a true swaged column, it may be possible to model it as such based on the expected point of failure. If this is true, the swaged column theory presents a simple, easy to apply modeling approach. A comprehensive study on the comparison of various buckling models with manufacturer’s rating was carried out at FPRC/OSU. It found that the results obtained from the swaged column formula (Eq. (3-67)) bears a similar curve to the manufacturer’s rating curve. Furthermore, by giving a safety factor of four (of the buckling or critical load), both curves show a high degree of agreement as shown in Fig. 3-30. A reasonable explanation for this high degree of agreement can be drawn from the fact that the pined end condition used in deriving the swage column formula is similar to the cap-end pivoted, rod-end pivoted and guided mounting configuration that has a C value of 1 (see Fig. 3-31). Note that C ranges from 0.25 to 4. In addition, Eq. (3-71) indicates that the maximum critical load allowed before cylinder buckling occurs is proportional to C. In other words, a mounting configuration has a C of 0.25 can only sustain one-fourth of

Table 5-4. Flow Forces In Hydraulic Valves.

Valve Type	Flow Force	
Spool conventional	Steady State	$F_{fs} = \left[2C_dC_v w(P_1 - P_2)\cos\theta\right]x$
	Unsteady	$F_{fu} = LC_d w\sqrt{2\rho(P_1 - P_2)}\frac{dx}{dt} + \frac{C_dLwx}{\sqrt{\frac{2}{\rho}(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}$
Spool	Steady State	$F_{fs} = 2C_dC_v\left[w_1(P_1 - P_c)\cos\theta_1 - w_2(P_c - P_2)\cos\theta_2\right]x$
	Unsteady	$F_{fu} = LC_d w_1\sqrt{2\rho(P_1 - P_2)}\frac{dx}{dt} + \frac{C_dLw_1x}{\sqrt{\frac{2}{\rho}(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}$
Poppet–sharp edged seat	Steady State	$\pi dC_dC_v\sin 2\alpha(P_1 - P_2)\left(1 - \frac{x\sin 2\alpha}{d}\right)x$
	Unsteady	$F_{fu} = \pi\rho LC_d\sin\alpha\left[(d - x\sin 2\alpha)\frac{dx}{dt} + \frac{x(d - 0.5x\sin 2\alpha)}{\sqrt{2\rho(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}\right]$
Poppet–conical seat	Steady State	$\pi d_mC_dC_v\sin 2\alpha(P_1 - P_2)\left(1 - \frac{x\sin 2\alpha}{d_m}\right)x$
	Unsteady	$F_{fu} = \pi\rho LC_d\sin\alpha\left[(d_m - x\sin 2\alpha)\frac{dx}{dt} + \frac{x(d_m - 0.5x\sin 2\alpha)}{\sqrt{2\rho(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}\right]$ $d_m = 0.5(d_1 + d_2)$
Ball–sharp edged seat	Steady State	$F_{fs} = \left[2\pi C_dC_vR(P_1 - P_2)\sin\phi\sin 2\phi\right]x$
	Unsteady	$F_{fu} = \pi LC_dR\sin 2\phi\left[\sqrt{2\rho(P_1 - P_2)}\frac{dx}{dt} + \frac{x}{\sqrt{\frac{2}{\rho}(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}\right]$
Ball– conical seat	Steady State	$F_{fs} = \left[2\pi C_dC_vR(P_1 - P_2)\sin\phi\sin 2\phi\right]x$
	Unsteady	$F_{fu} = \pi LC_dR\sin 2\phi\left[\sqrt{2\rho(P_1 - P_2)}\frac{dx}{dt} + \frac{x}{\sqrt{\frac{2}{\rho}(P_1 - P_2)}}\frac{d(P_1 - P_2)}{dt}\right]$

Note: F_{fs} = Steady state flow force; F_{fu} = Unsteady flow force; ρ = Fluid density; θ = jet angle; α = poppet half angle; C_d = discharge coefficient; C_v = velocity coefficient; P_1 = up stream pressure; P_2 = down pressure; P_c = chamber pressure; w = peripheral length of spool; x = spool displacement; L = damping length; ϕ = half seat included angle





P_I = Precharged Pressure
P_H = Maximum Working Pressure
P_L = Minimum Working Pressure
n = Polytropic Exponent

Figure 10-11. Graphical Solution for Example 10-2.