New England District, U.S. Army Corps of Engineers, Regulatory Division
Openness Ratio Spreadsheet

● Openness Ratio (OR) is calculated by dividing a culvert's cross-sectional area by its length: OR = x-sec area ÷ length
● Along with other criteria, the MA PGP, General Condition 21, states that to qualify for the Category 1 (non-reporting):
   1. New permanent stream crossings must have an OR ≥.25

$$\text{OR} =.25 = \frac{\text{(x-sec area)}}{\text{culvert length}} \quad \text{or} \quad \text{OR} =.25 = \frac{\text{[(x-sec culvert area pre-embed) - embedded area]}}{\text{culvert length}}$$

    2. Round culverts must be embedded at least 25%
● The chart below provides the diameter needed to meet the .25 OR for various culvert lengths, accounting for the
  embedded area, when embedding 25%. All calculations must be done in meters. The conversion to feet is provided.
● The Corps uses the .25 OR as a guide for Category 2 projects reviews.

Required Diameter for .25 OR & 25% Embedment					
Length		Required Open Area		Required Diameter	
(FT)	(M)	(FT^2)	(M^2)	(FT)	(M)
6	1.83	4.92	0.46	2.79	0.85
8	2.44	6.56	0.61	3.23	0.98
10	3.05	8.20	0.76	3.61	1.10
12	3.66	9.84	0.91	3.95	1.21
14	4.27	11.48	1.07	4.27	1.30
16	4.88	13.12	1.22	4.56	1.39
18	5.49	14.76	1.37	4.84	1.48
20	6.10	16.40	1.52	5.10	1.56
22	6.71	18.04	1.68	5.35	1.63
24	7.32	19.68	1.83	5.59	1.70
26	7.93	21.32	1.98	5.82	1.77
28	8.54	22.96	2.13	6.04	1.84
30	9.15	24.60	2.29	6.25	1.91
32	9.76	26.24	2.44	6.45	1.97
34	10.37	27.88	2.59	6.65	2.03
36	10.98	29.52	2.74	6.85	2.09
38	11.59	31.16	2.90	7.03	2.14
40	12.20	32.80	3.05	7.22	2.20
42	12.80	34.44	3.20	7.39	2.25
44	13.41	36.08	3.35	7.57	2.31
46	14.02	37.72	3.51	7.74	2.36
48	14.63	39.36	3.66	7.90	2.41
50	15.24	41.00	3.81	8.07	2.46

Derivation
1. The MA PGP, Category 1 requires:
   * 25% culvert embedment (=.25 x culvert diameter)
   * .25 openness ratio

2. Embedded area calculated as follows:

$$A_1 = \frac{D^2}{4} \left[a - \frac{\sin(2a)}{2} \right]$$

$$a = \cos^{-1}(1 - h/r)$$
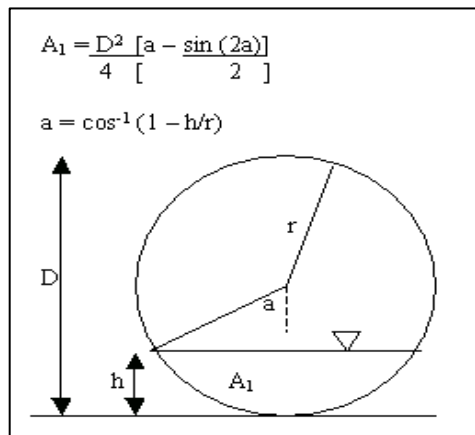
Notes:
   * a is in radians
   * a = 60° = 1.05 radians, if h =.25D
   * A$_1$ = embedded area

3. OR =.25 = $\frac{\text{[(x-sec culvert area pre-embed) - embedded area]}}{\text{culvert length}}$

where:
   * x-sec area = $\Pi D^2 / 4$
   * embedded area for 25% embed = $.62D^2/4 = (A_1)$
   * culvert length = L

Therefore:
$$.25 = \frac{\Pi D^2/4 \ - \ .62D^2/4}{L}$$
or

$$D = .63L^{1/2}$$