Rinker MATERIALS

DESIGN METHODOLOGY FOR NON-REINFORCED CONCRETE PIPE

The design of non-reinforced concrete pipe (NRCP) follows the exact same procedures and methodology as for reinforced pipe:

1. Determine live loads and dead loads acting on the pipe.
2. Based on the type of installation, determine the appropriate bedding factor.
3. For the pipe diameter being considered, determine the required D-Load test strength.

$$\text{D-Load}_{\text{ult.}} = \frac{S.F.}{D}\left(\frac{W_1}{B_{fLL}} + \frac{W_e}{B_{fDL}}\right)$$

W_e = Earth Load
W_1 = Live Load
B_{fDL} = Bedding Factor (dead load)
B_{fLL} = Bedding Factor (live load)
D = Pipe Diameter, feet
SF = Safety Factor

The above calculated D-Load establishes the required strength and the three edge bearing test confirms that strength is being furnished.

Some engineers may require an analysis to verify the proposed wall thickness is sufficient for the anticipated design load.

Such an analysis can be readily provided by determining the tensile stress in the extreme fibers. This stress must be less than the modulus of rupture stress. The modulus of rupture stress is defined as the empirically derived ultimate tensile stress at the outer surface of the concrete based on a triangular stress distribution with the neutral axis being in the center of the wall.

Stress (S) = MC/I
M = Bending Moment, in-lbs/lf
C = Distance to Extreme Fiber from Neutral Axis
(For solid wall C = t/2, t = wall thickness in inches)
I = Moment of Inertia = $bt^3/12$, for b = 12",
= t^3
Therefore: S = $M/(2t^2)$

Since MOR = Stress at the extreme surface and the design bending moment (M) equals the ultimate moment ($M_{ult.}$) developed in the pipe wall, the equation can be expressed as:

$$MOR = M_{ult.}/(2t^2) \text{ or}$$
$$M_{ult.} = MOR(2t^2)$$

Experience has shown the empirically derived modulus of rupture values typically range from 1000 for 12" pipe to 600 for 36" pipe and larger. Listed below are the MOR values used for 5000 psi concrete for 12" - 36" NRCP:

Pipe Dia.	MOR (psi)
12"	1000
15"	950
18"	900
21"	850
24"	800
27"	750
30"	700
33"	650
36" & Larger	600

Unlike reinforced concrete pipe which can be designed for either the 0.01" crack D-Load and/or for the ultimate D-load, NRCP is always designed for the ultimate D-load since it does not crack at lessor loads. Using the equation shown above and the moment developed in the 3-Edge-Bearing (3EB) test, the pipe's ultimate D-load can be determined:

$$M = 0.159QD_m$$

M = Moment Developed in 3EB Test, in/lbs
0.159 = Moment Coefficient
Q = Load, (D-Load *D), lbs
D_m = Mean Pipe Diameter, inches
D = Pipe Diameter, feet

Therefore:

$$0.159QD_m = MOR(2t^2)$$
Since Q = D-Load * D
$$\text{D-Load} = (2(MOR)t^2)/(0.159DD_m)$$

Normally, NRCP is designed using a standard wall thickness and the maximum load the pipe will carry is determined. This allows for the use of existing standard equipment and maintains uniformity of the pipe wall for the various diameters. For loads beyond the strength capacity of standard wall thickness special wall thickness or high strength concrete would be required. In determining allowable fill heights, the weight of the pipe should be taken into consideration.

As mentioned above, NRCP bedding factors, earth loads and live loads are the same as for RCP. This means that provided the D-Load requirements are met, NRCP can be substituted for RCP. It should be noted that for NRCP design, a test load safety factor of 1.5 is used. The AASHTO Standard Installations (Section 17 AASHTO Standard Specifications for Highway Bridges) can be used for NRCP. The American Concrete Pipe Association's Design Data 40 explains the four types of standard installations and the applicable bedding factors.

Listed below are two tables that show the maximum fill heights allowed for the four standard installation types and maximum fill heights allowed for various D-Loads using the four standard installations.

Table I

NRCP TYPICAL MAX. FILL HT. (TYPE 1-4 INSTALLATIONS)

		FILL HTS. (FT) INSTALLATION TYPE			
DIA. (Inches)	**WALL (Inches)**	**1**	**2**	**3**	**4**
12"	2	48	37	29	19
	2-3/4	87	67	52	34
15"	2-1/4	36	27	22	14
	3	63	47	38	25
18"	2-1/2	30	22	18	12
	3-1/4	50	37	30	20
21"	2-3/4	25	19	15	10
	3-1/2	40	30	24	16
24"	3	21	16	12	8
	3-3/4	33	25	20	13
27"	3-1/4	17	13	10	6
	4	26	20	16	11
30"	3-1/2	15	11	9	5
	4-1/4	22	17	13	9
33"	3-3/4	12	9	7	-
	4-1/2	18	14	11	7
36"	4	11	7	5	-
	4-3/4	16	12	9	5

SAFETY FACTOR - 1.5

NOTE:
This table is to show the significance of wall thickness in determining maximum fill heights. Design fill heights are shown as a function of D-Load strength in Table II.

Table II

D-LOAD VS. MAX. FILL HT.(TYPE 1-4 INSTALLATIONS)

		MAX. FILL HEIGHT (FT) - INSTALLATION TYPE			
D-Load		**TYPE 1**	**TYPE 2**	**TYPE 3**	**TYPE 4**
	600	10	6	-	-
*	800	13	10	7	-
*	1000	17	13	10	6
	1200	21	16	12	8
*	1350	23	18	14	9
	1400	24	18	14	10
	1600	28	21	17	11
	1800	32	24	19	13
*	2000	35	27	21	15
	2200	39	30	23	16
	2400	43	33	26	18
	2600	46	35	28	19
	2800	50	38	30	21
*	3000	54	41	32	23
	3200	57	44	35	24
	3400	61	47	37	26
	3600	65	50	39	27
	3800	68	52	41	29
	4000	72	55	43	31

* **STANDARD ASTM C76 STRENGTH CLASSIFICATIONS.**

FOR TYPE 1 INSTALLATIONS, FILL HEIGHTS LESS THAN 3 FT. REQUIRE A MIN. STRENGTH OF 660D FOR 12", 15" & 18"

FOR TYPE 2 INSTALLATIONS, FILL HEIGHTS LESS THAN 3 FT REQUIRE A MIN. STRENGTH OF 700D FOR 12", 15", 18", 24" & 27".

While the above information primarily addresses D-Load pipe, NRCP can be furnished using the direct design methodology which designs pipe specifically for the anticipated field calculated bending moments, thrust, and shear forces.

Non-reinforced concrete pipe has a long established history of performance. With state of the art manufacturing and proper engineering design, NRCP will provide the Engineer with an economical, structurally sound piping material that will perform and meet or exceed the project requirements.