LOAD ON BURIED PRESSURE CONDUITS WITH REFERENCE TO SELECTION OF ASBESTOS-CEMENT PIPES

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ABSTRACT

The use of asbestos-cement pressure conduits is becoming popular even in developing countries.

Asbestos-cement pipe can withstand internal pressure of up to 1.4 MPa and is unaffected by corrosion. Its other virtues are that it is light in weight, could be easily cut and filed, is not easily fractured if properly cradled, and can be joined without the need for expert skill.

However, due to faulty design it could be damaged and become out of service within a very short time.

This paper is an attempt to bring together the various design parameters used in determining internal and external pressures for proper selection of asbestos-cement pressure pipes using the Marston-Schlick combined loading theory, which lends itself to easy manipulation, compared to the traditional earth-pressure theory of Rankine-Coulomb.

STRENGTH AND DESIGN FACTORS

Absestos-cement water pipe should be strong enough to withstand the combined stresses resulting from internal hydrostatic pressure and external loads. Its ability to withstand these forces is however dependent upon the conditions under which the pipe is installed. Field performance of the pipe is enhanced if the bedding conditions, as well as the internal and external loads acting on the pipe are taken into consideration in selecting the class of pipe for a given job.

Adequate safety factors must be applied to ensure performance under severe loading conditions. Schlick's method of combined loading approach could be used as a basis for selecting asbestos-cement water pipes.

BEDDING CONDITION

Typical bedding conditions encountered in the field are shown in Table 1 and Fig. 1.

Table 1. Bedding Conditions

Class of Bedding	Description
A	Sand or gravel bed; backfill tamped
B	Sand or gravel bed; backfill untamped
C	Pipe barrel laid on flat trench bottom with backfill tamped
D	Pipe barrel laid on flat trench bottom with backfill untamped

Fig. 1(a) and (b) show class A bedding. Fig. 1(c) and (d) show class C bedding. The lightly dotted areas show approved backfill material. The heavily dotted areas in the lower portions show approved backfill tamped in 10cm layers. In Fig. 1(a) a depth of at least 5cm of sand is placed in a cradle under the pipe. In Fig. 1(b) the pipe is bedded in a gravel base. In Fig. 1(c) the pipe barrel rests on earth mounds. In Fig. 1(d) the pipe barrel rests on the bottom of the trench. Class B is the same as Class A and Class D is the same as Class C, except that the backfill is not tamped in classes B or D.

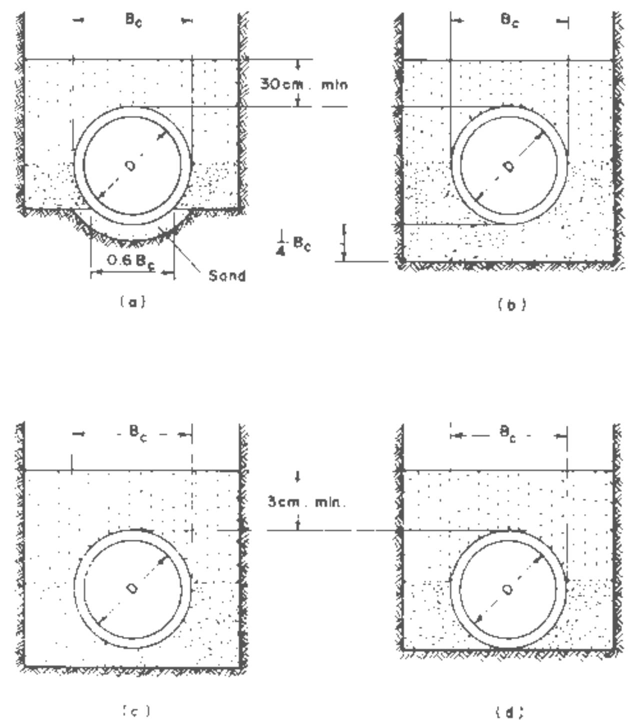


Fig.1 Bedding Conditions illustrated

COMBINED-LOADING THEORY

When asbestos-cement pipe is tested under various combinations of internal pressure and extern. : load by the 3-edge bearing, a relationship between these loads exists at the point of fracture. This relationship can be represented by a parabolic curve as shown in Fig. 2. The equation of the curve in Fig. 2 may be expressed as

$$\omega = W\sqrt{\frac{P-p}{p}} \qquad (1)$$

where

- W = external load per unit length in the 3-edge bearing that will crash the pipe when no internal pressure exists *(N/m)*
- P = intensity of internal pressure that will burst the pipe when no external load exists *(N/m^2)*
- p = intensity of internal pressure in combination with some external load, ω, applied in 3-edge bearing that will fracture the pipe *(N/m^2)*
- ω = external load in 3-edge bearing which, in combination with some internal pressure p, will fracture the pipe *(N/m)*

THE THREE-EDGE BEARING TEST

The three-edge bearing test (Fig. 3) is a method of testing the crushing strength of a conduit. Because the supporting strength of a conduit in a trench is affected by the bedding conditions and the lateral pressure acting against the sides of the conduit, it is necessary to apply a load factor to the three-edge bearing loads to simulate field loading conditions. This relationship can be expressed as

$$P_E = \text{L.F. } P_T \qquad (2)$$

where

- P_E = external load
- P_T = three-edge bearing load
- L.F. = Load Factor

Table 2 shows load factors values to be used for the bedding conditions shown in Table 1. In Fig. 3 the value of C, the clear space between wooden supports is 13mm for $\phi \leqslant$ 300mm 25mm for ϕ between 350-600mm; and 50mm for $\phi \geqslant$ 750mm.

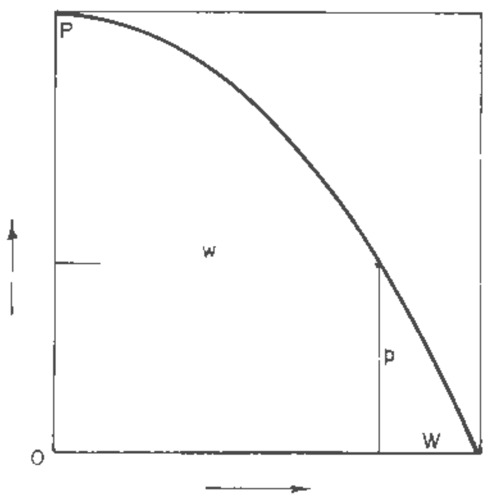


Fig. 2. Load-Pressure Cruve

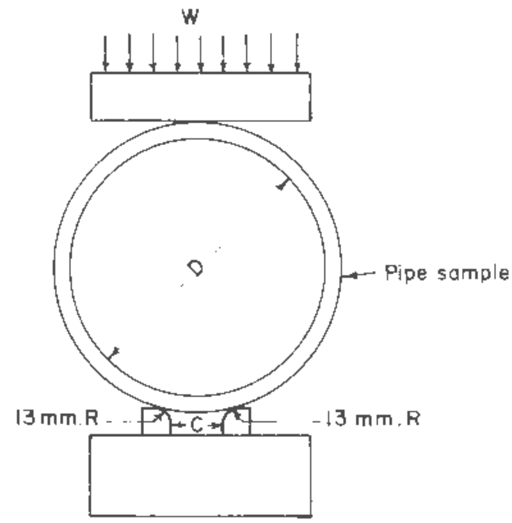


Fig. 3. Crushing Test Assembly (3-edge bearing)

Table 2. Relationship Between Pipe Size, Load Factor and Class of Bedding

Pipe Size (mm)	Load Factor	Class of Bedding
100 — 300	1.7	
350 — 500	1.8	A
600 — 900	2.0	
100 — 900	1.5	B
100 — 300	1.3	C
350 — 500	1.4	
600 — 900	1.5	D
100 — 900	1.1	

HYDROSTATIC PRESSURES

The internal hydrostatic pressures to be considered in designing pipelines are normal operating pressures which are dependent upon the service condition and water hammer pressure which arise as a result of sudden closure of a valve resulting in immediate build of pressure wave, called surge pressure. A factor of safety of 4.0 is normally used to cater for the normal internal hydrostatic pressure and water hammer pressure. Allowance for water hammer pressure is given by the equation

$$P_{h(\max)} = \psi \, v_p \, v_\omega \qquad (3)$$

where

$P_{h(\max)}$ = maximum build-up of water hammer pressure (N/m^2)

v_p = velocity of water wave

v_ω = velocity of water in conduit just before pipe closure (m/sec)

The velocity of the pressure wave, v_p may be expressed by the equation

$$v_p = \psi \sqrt{\frac{E_\omega}{\psi}} \cdot \frac{1}{\sqrt{1 + \frac{E_\omega}{E_A} \cdot \frac{d}{t}}} \qquad (4)$$

where

ψ = density of the water in the conduit (Kg/m^3)

E_ω = modulus of elasticity of asbestos-cement pipe (N/m^2)

d/t = ratio of internal diameter to shell thickness of pipe

In Eq. 4, $E_\omega = 2.06 \times 10^3$ MN/m^2 and $E_A = 2.34 \times 10^4$ MN/m^2.

EXTERNAL LOADS

External loads on conduits in trenches or those surrounded with earth are dead loads due to backfill and superimposed loads due to static or moving loads. Marston's theory states that the load on a buried conduit equals the weight of the backfill material directly over the conduit plus or minus the frictional or shearing forces transferred to that prism by the adjacent prisms of earth. The magnitude and direction of these frictional forces are functions of the amount of relative settlement occuring between the interior and adjacent earth prisms.

After intensive experimentation, Marston propounded the following set of approximate equations for computation of external loads.

For pipes on, or projecting above ground in cohesionless cover material

$$W = C \gamma D^2 \quad (5)$$

For flexible pipes in trenches and thoroughly compacted side fills

$$W = (C_o - C')\gamma BD \quad (6)$$

For rigid pipes in trenches, with ordinary bedding and $B < 1.5D$

$$W = (C_o - C')\gamma D^2 \quad (7)$$

In the above equations W is the load of cover material per unit length of pipe (N/m); γ is the unit weight of backfill (N/m^3); B is the trench width at the top of pipe (m); D is the external diameter of the conduit (m); C, C_o, C' are experimental coefficients. The general form of Marston's equation is,

$$W = C'' \gamma B^2 \quad (8)$$

In Eq. 8 the units of the parameters are as defined above. Any system of unit if applied consistently could be used with the above formulae. The coefficients C, C_o, C', C'' are dependent upon the ratio of depth of fill to width of conduit or trench; the shearing forces on the plane between the backfill and adjacent earth; for embankment condition, the amount of relative settlement between the backfill and adjacent earth; the rigidity of the conduit support under embankment loading.

Table 3. Selected values of C'' for use in Eq. 8

H/B	Sand and damp top soil	Saturated top soil	Damp Clay	Saturated Clay
1	0.85	0.86	0.88	0.90
2	1.46	1.50	1.56	1.62
3	1.90	1.98	2.08	2.20
4	2.22	2.33	2.49	2.66
5	2.45	2.59	2.80	3.03
6	2.61	2.78	3.04	3.33
7	2.73	2.93	3.22	3.57
8	2.81	3.03	3.37	3.76

The values of these coefficients may be determined from Fig. 4.

If a condition occurs where the width of the trench, B is less than two or three times the diameter of the conduit, D, then Marston's formula for trench condition could be used to determine W.

$$W = C_d \gamma B_d^2 \quad (9)$$

C_d, which is a load coefficient may be determined from Fig. 5 for various values of H/B_d.

When very heavy superimposed or impact loads are encountered in the field, their magnitude may be computed on the basis of either a concentrated load such as wheel load or on the basis of distributed load. Ordinarily axle loads and accompanying impact loads are neglected if the depth of cover is greater than about 1.80m. Superimposed load produced by heavy concentrated load (Fig. 6) could be determined by the formula

$$W_{sc} = \frac{C_s P F}{L} \quad (10)$$

where

W_{sc} = superimposed concentrated load on the conduit *(N/m)*

P = concentrated load *(N)*

F = impact factor (Table 4)

C_s = load coefficient dependent upon $B_{c/2H}$ and $L/2H$ (Tables 5 and 6)

B_c = External diameter or width of conduit *(m)*

H = depth of back fill from crown (top of conduit) to ground surface *(m)*

L = effective length of conduit *(m)*

Table 4. Impact factor caused by moving vehicles

Type of Traffic	Impact Factor, F
Highway	1.50
Railway	1.75
Airfields, taxiways, aprons, etc.	1.25

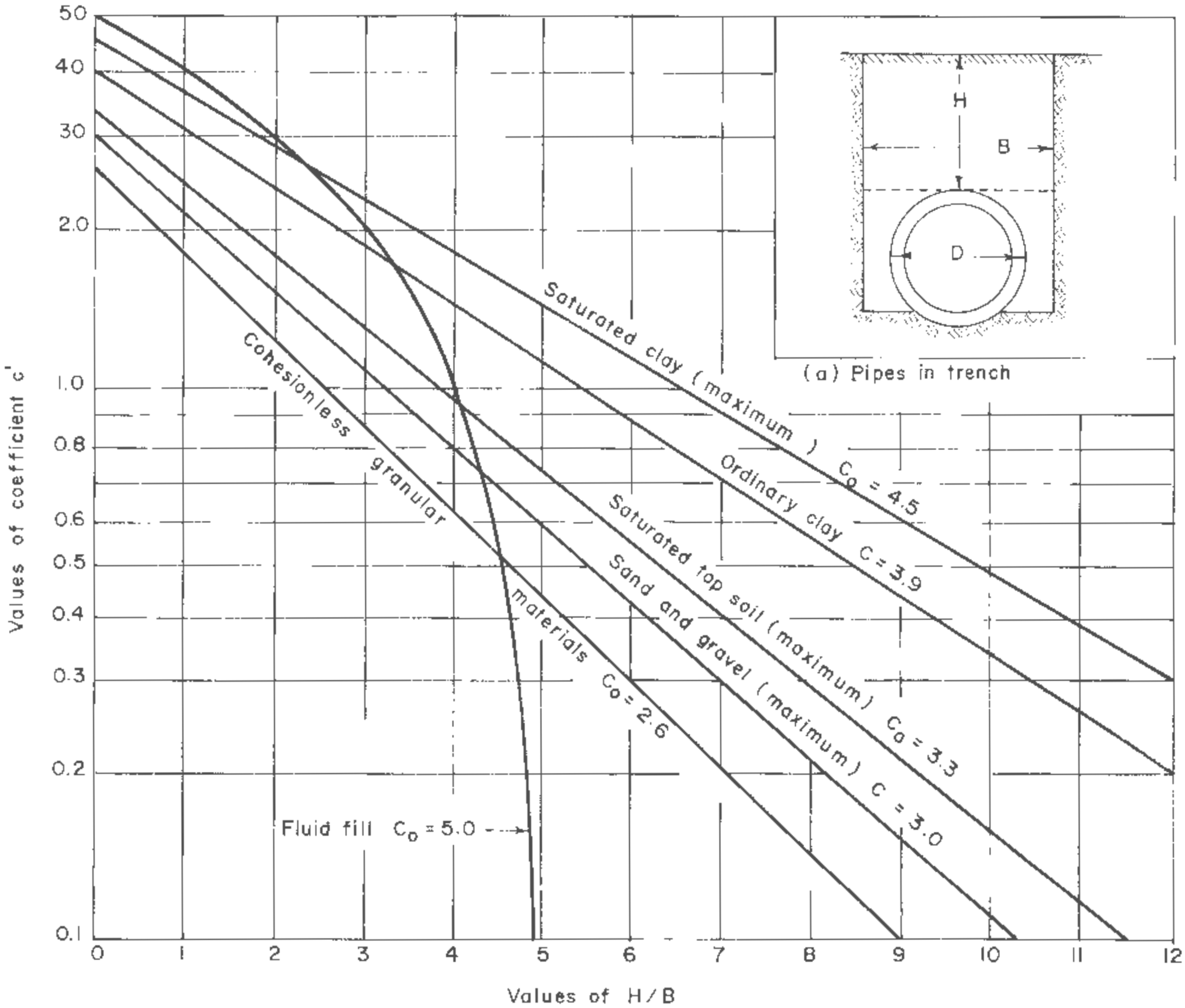


Fig. 4. Vertical External Loads on Circular Conduits

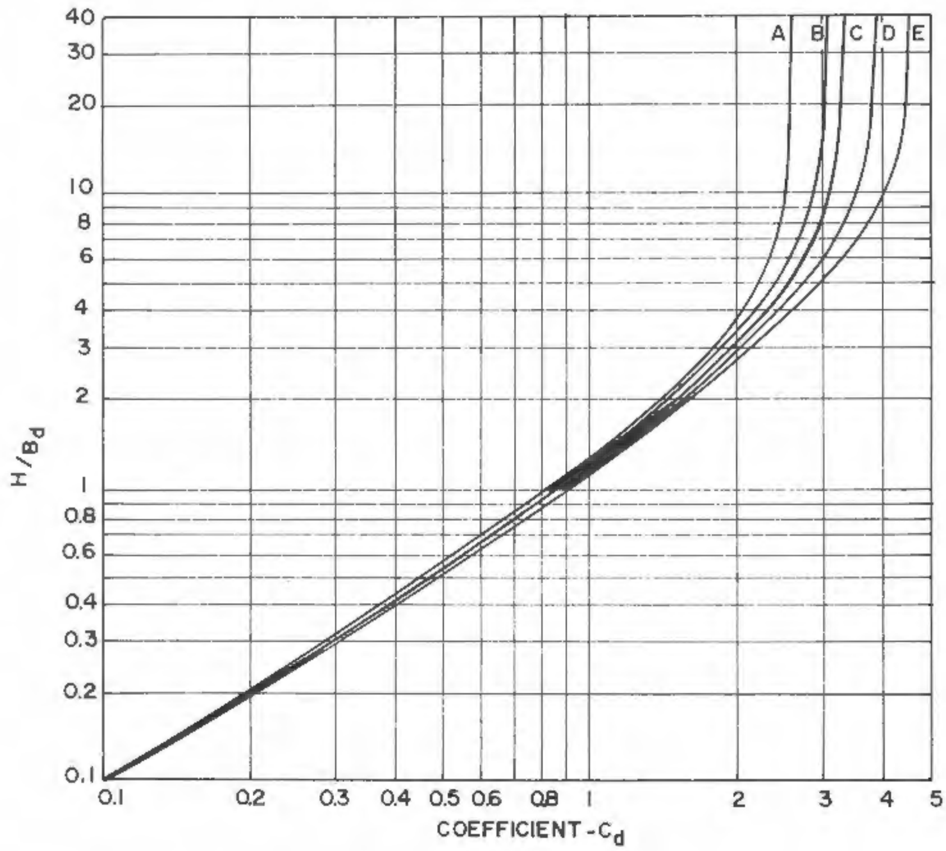


Fig. 5. Graph for determining C_d coefficients

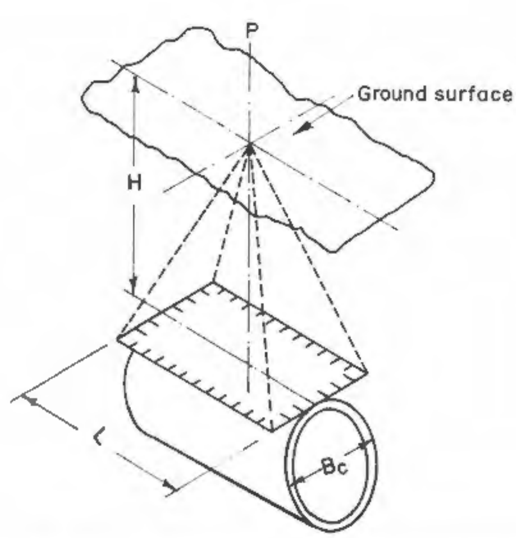


Fig. 6. Concentrated superimposed load

Table 5. Values of C_s for concentrated and distributed superimposed loads centered vertically over conduits

$D/2H$ or $B_c/2H$	$M/_{2H}$ or $L/_{2H}$						
	0.1	0.3	0.5	0.7	0.9	1.2	1.5
0.1	0.019	0.053	0.079	0.097	0.108	0.117	0.121
0.3	0.053	0.149	0.224	0.274	0.306	0.333	0.345
0.5	0.079	0.224	0.336	0.414	0.463	0.505	0.525
0.7	0.097	0.274	0.414	0.511	0.584	0.628	0.650
0.9	0.108	0.306	0.463	0.574	0.647	0.711	0.742
1.2	0.117	0.333	0.505	0.628	0.711	0.783	0.820
1.5	0.121	0.345	0.525	0.650	0.742	0.820	0.861

Table 6. Values of C_s for concentrated superimposed loads centered vertically over a few selected cricular conduits

External Dia of Pipe (mm)	Dept of Cover (m)							
	0.75	0.90	1.20	1.50	1.80	2.40	3.00	3.60
150	0.106	0.078	0.046	0.031	0.023	0.013	0.008	0.006
200	0.137	0.102	0.051	0.011	0.029	0.017	0.010	0.008
250	0.174	0.129	0.078	0.052	0.037	0.022	0.013	0.009
300	0.202	0.153	0.092	0.062	0.44	0.025	0.016	0.011
400	0.259	0.197	0.136	0.081	0.057	0.034	0.021	0.015
500	0.316	0.241	0.150	0.102	0.073	0.042	0.027	0.019
900	0.470	0.375	0.248	0.171	0.124	0.073	0.049	0.035

In like manner, a heavy distributed superimposed load could be reckoned from the expression (Fig. 7)

$$W_{sd} = C_s \, p \, F \, B_c \qquad (11)$$

where

W_{sd} = superimposed distributed load on the conduit *(N/m)*

p = intensity of distributed load *(N/m^2)*

F = impact factor (Table 3)

B_c = external diameter or width of conduit *(m)*

H = depth of backfill from crown of conduit to ground surface *(m)*

D and M = width and length, respectively of the area over which the distributed load acts *(m)*

SAFETY FACTOR

On the basis of the foregoing, a limited number of nomograms in the frequently used ranges of pipe sizes and loading conditions are made for asbestos-cement pipes using a factor of safety of 4.0 for internal pressures and 2.5 for external loads. Since the probability of water-hammer pressure occuring simultaneously with external impact load is very small, pipes selected from the curve are therefore given a factor of safety of only 2.5 for resisting external loads, consisting of backfill load plus a 5 ton wheel load and impact load.

NOMOGRAMIC CURVES

The nomograms in Figs. 8 to 11 are made for five pipe sizes in the frequently used range of ϕ 150mm — ϕ900mm. The curves may be used by entering them through the depth of cover and bedding condition scales. The scales are correlated to the 3-edge bearing equivalents of the design external loads with a factor of safety of 2.5 where there is an external loading condition different from that due only to depth of cover, however, or where conditions warrant a change in the factor of safety, the equivalent external load should be determined and the selection curves entered at the proper value on the design external load scale.

The application of the curves to design is shown in the following examples.

Example 1.

A ϕ 900mm pipe is to operate at a pressure of 0.9 MN/m^2 at a depth of 2.40m. The available bedding condition is class B. Select the class of pipe for this job.

Solution

Enter the nomogramic curve for ϕ 900mm pipe at bedding condition for class B and 2.40m cover. The intersection of the 2.40 cover line with 0.9 MN/m^2 operating pressure line falls between pipe classes 150 and 200. Hence use ϕ 900mm class 200 pipe. The intersection of the 2.40m cover line with class 200 curve is at 1.1 MN/m^2 operating pressure or 4.4 MN/m^2 design pressure. Therefore, the pressure safety factor is

$$\frac{4.4}{09} = 4.9$$

with a factor of safety of 2.5 for external loads.

Table 7 shows how w, the design external load is determined on the basis of the 3-edge bearing test for five commonly encountered pipe sizes and three frequently used cover depths.

Example 2

A ϕ 500mm asbestos-cement pipe; length 2km; shell thickness 5cm; time of closure of valve, T = 2sec; velocity of water before closure of valve = 0.9m/sec; backfill depth, H = 2.40m trench width = 1.20m; backfill is sandy soil γ = 15kN/m^3 bedding condition class A. Make necessary calculations neglecting normal pressure in the pipeline.

Solution

Water hammer pressure

$$P_{h(max)} = \psi \, v_p \, v_w \quad \text{but } v_p =$$

$$= \sqrt{\frac{E_w}{\psi}} \cdot \frac{1}{\sqrt{1 + \frac{E_w}{E_A} \cdot \frac{d}{t}}}$$

$$v_p = \sqrt{\frac{2.06 \times 10^9}{1000}} \cdot \frac{1}{\sqrt{\frac{2.06 \times 10^6}{23.4 \times 10^6} \cdot \frac{0.5}{0.05}}}$$

Therefore $V_p = 1048$ m/sec

The critical time, $T_c = \frac{2L}{V_p} = \frac{2 \times 2000}{1048}$

$= 3.82$ sec

Therefore, time of closure of value, $T < T_c$

Hence, full water-hammer pressure is developed

$$P_{h(\max)} = \psi\, v_p\, v_w = 1000 \times 1048 \times 0.8$$

$$= 0.84 \text{ MN/m}^2$$

:xternal Load

Using Marston's general formula

$$W = C''\gamma B^2$$

Therefore $C'' = 1.46$

Therefore, $W = 1.46 \times 15 \times (1.20)^2$

$= 31.54$ kN/m

Selection of Pipe

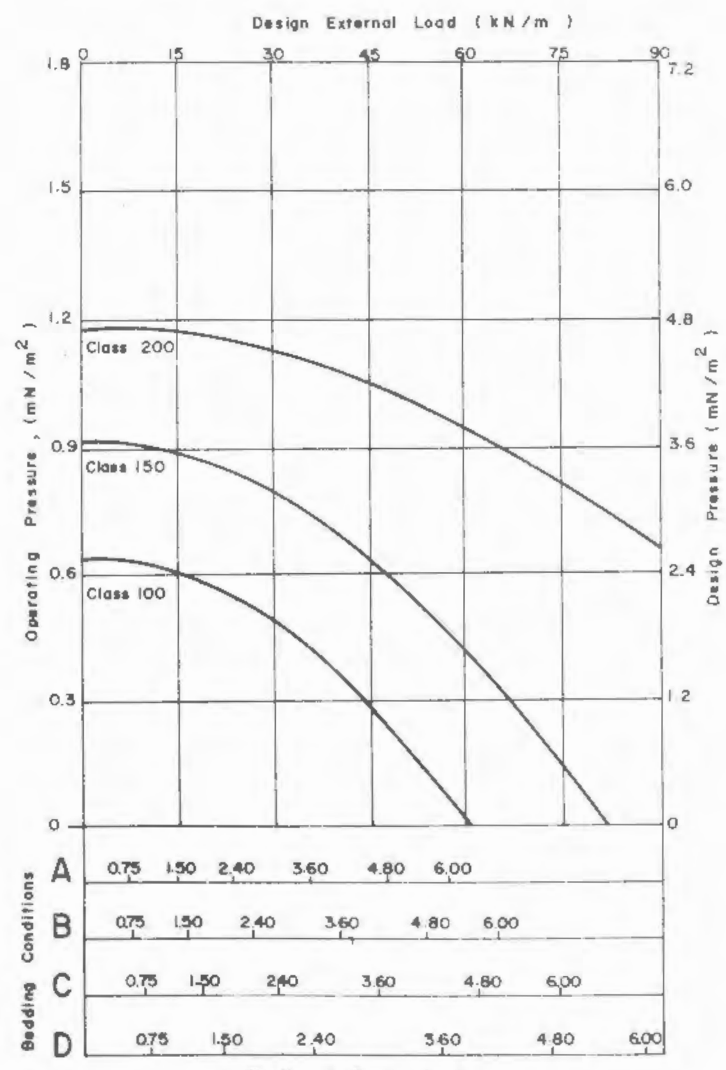
Enter selection pipe for ϕ 500mm at bedding condition class A, 2.40m cover. The intersection of 2.40m cover line with 0.84 MN/m² operating pressure line falls exactly on class 150 pipe.

Extend the 2.40m cover line upwards until it intersects the Design External Load line at 55 kN/m.

Thus, the chosen pipe is capable of handling 55 kN/m with an external load safety factor of

$$2.5 \times \frac{55}{31.54} = 4.36.$$

Fig. 7.



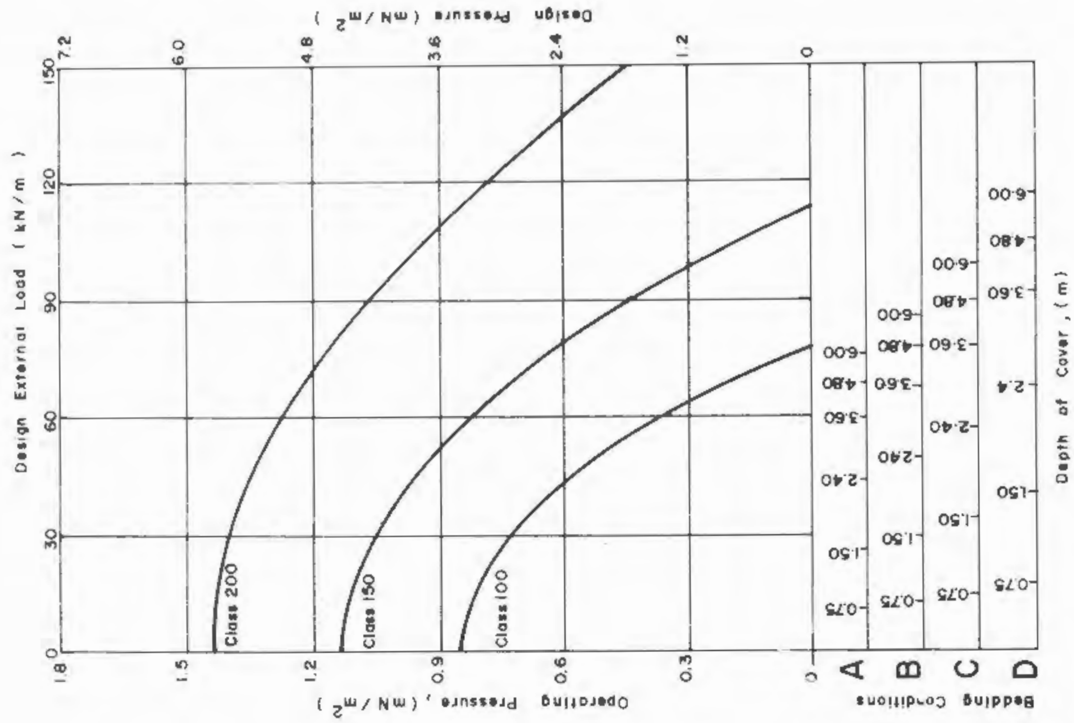

Design External Load (kN / m)
Design Pressure (mN / m2)
Operating Pressure , (mN / m2)
Bedding Conditions
A
B
C
D
Class 100
Class 150
Class 200
Depth of Cover , (m)

Fig. 9.

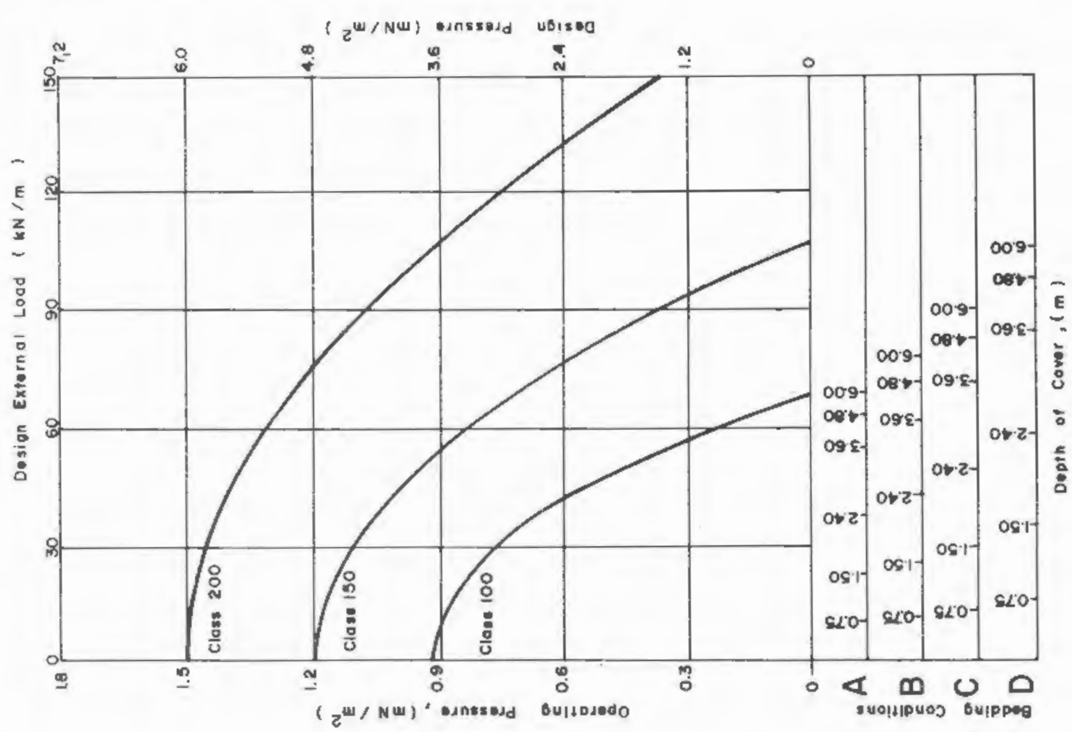

Design External Load (kN / m)
Design Pressure (mN / m2)
Operating Pressure , (mN / m2)
Bedding Conditions
A
B
C
D
Class 100
Class 150
Class 200
Depth of Cover , (m)

Fig. 8.

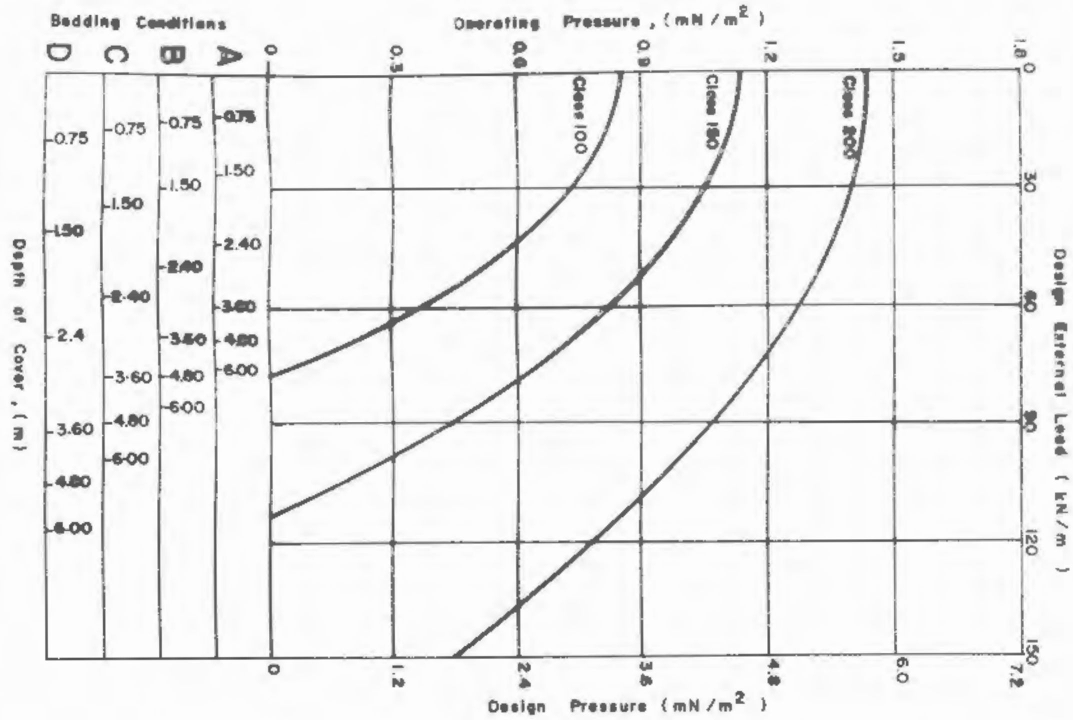

Bedding Conditions
D C B A
Operating Pressure , (mN / m^2)
Class 100
Class 150
Class 200
Depth of Cover , (m)
Design External Load (kN / m)
Design Pressure (mN / m^2)

Fig. 10.

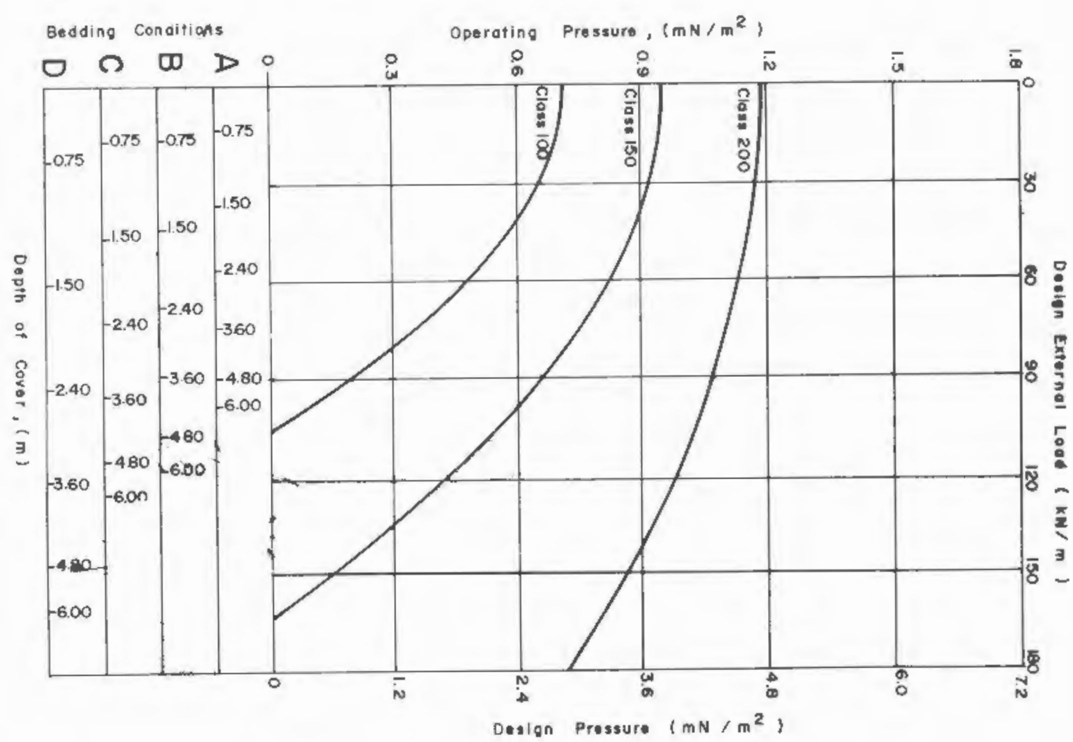

Bedding Conditions
D C B A
Operating Pressure , (mN / m^2)
Class 100
Class 150
Class 200
Depth of Cover , (m)
Design External Load (kN / m)
Design Pressure (mN / m^2)

Fig. 11.

Table 7(a). Determination of design external load *(w)* applied in three-edge bearing

1 Pipe Size (mm)	2 External Load (N)	3 Equivalent 3-Edge Bearing (N) (Col. 1) / L.F.	4 External Load Applied in 3-Edge Bearing (N) (Col. 3 × F.S. of 2.5)
	CLASS A BEDDING 0.75m COVER		
150	1321	778	1945
250	2002	1174	2935
300	2255	1326	3315
500	2980	1655	4138
900	4341	2171	5428
	CLASS A BEDDING 1.50m COVER		
150	2820	1659	4150
250	4501	2647	6618
300	5222	3074	7685
500	7912	4397	10993
900	11351	5676	14190
	CLASS A BEDDING 2.40m COVER		
150	4630	2722	6805
250	7508	4417	11043
300	8785	5169	12923
500	12063	6699	16748
900	17748	8874	22185

Table 7(b). Determination of design external load *(w)* applied in three-edge bearing

1 Pipe Size (mm)	2 External Load (N)	3 Equivalent 3-Edge Bearing (N) (Col. 1) / L.F.	4 External Load Applied in 3-Edge Bearing (N) (Col. 3 × F.S. of 2.5)
	CLASS B BEDDING 0.75m COVER		
150	1321	881	2203
250	2002	1334	3335
300	2255	1503	3758
500	2980	1988	4970
900	4341	2896	7240
	CLASS B BEDDING 1.50m COVER		
150	2820	1882	4705
250	4501	2988	7470
300	5222	3483	8722
500	7912	5275	13188
900	11351	7566	18915
	CLASS B BENDDING 2.40m COVER		
150	4630	3087	7718
250	7508	5008	12520
300	8785	5858	14645
500	12063	8042	20105
900	17748	11832	29580

Table 7(c). Determination of design external load (w) applied in three-edge bearing

1 Pipe Size (mm)	2 External Load (N)	3 Equivalent 3-Edge Bearing (N) (Col. 2) / L.F.	4 External Load Applied in 3-Edge Bearing (N) (Col. 3 × F.S. of 2.5)
CLASS C BEDDING 0.75m COVER			
150	1321	1014	2535
250	2002	1539	3848
300	2255	1734	4335
500	2980	2130	5325
900	4341	2896	2740
CLASS C BEDDING 1.50m COVER			
150	2820	2171	5428
250	4501	3461	8643
300	5222	4017	10043
500	7912	5649	14123
900	11351	7566	18915
CLASS C BEDDING 2.40m COVER			
150	4630	3563	8908
250	7508	5758	14445
300	8785	6757	16893
500	12063	8617	21543
900	17748	11832	29580

Table 7(d). Determination of design external load (w) applied in three-edge bearing

1 Pipe Size (mm)	2 External Load (N)	3 Equivalent 3-Edge Bearing (kN) (Col. 2) / L.F.	4 External Load Applied in 3-Edge Bearing (kN) (Col. 3 × F.S. of 2.5)
CLASS D BEDDING 0.75m COVER			
150	1331	1201	3003
250	2002	1819	4548
300	2255	2051	5128
500	2980	2713	6783
900	4341	3945	9863
CLASS D BEDDING 1.50m COVER			
150	2820	2566	6415
250	4501	4092	10230
300	5222	4750	11875
500	7912	7192	17980
900	11351	10319	25798
CLASS D BEDDING 2.40m COVER			
150	4630	4208	10520
250	7508	6828	17070
300	8785	7984	19960
500	12063	10964	27410
900	17748	16133	40333

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