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STRENGTH AND DYNAMIC CHARACTERISTICS OF MECHANICALLY JOINTED CAST-IRON WATER PIPELINES

By

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16. Abstract (Limit: 200 words)

This report expands on the earlier Interim Grant Report IR-3, July 1977. Elastic and dynamic characteristics of both mechanical joints with rubber gaskets and cast-iron pipes are discussed. The main characteristics for pipe failure are the ultimate tension force and the ultimate bending moment M_u. Practical observations confirm that other modes of failure seldom occur, although some compression failures have occurred. Bolt failure, ultimate gasket friction, the longitudinal elastic constant of gasket, longitudinal periods of pipe due to gasket elasticity, longitudinal periods of pipe due to pipe elasticity, the rotational constant of gasket, periods of rotational motion due to gasket, and periods of vibration for vertical anti-symmetrical rotational modes of continuous elastic pipes are topics discussed. Some calculations are carried out as examples.

17. Document Analysis a. Descriptors

Dynamic characteristics	Bending moments	Pipe joints
Pipelines	Stress analysis	
Dynamic structural analysis	Elastic properties	

b. Identifiers/Open-Ended Terms

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I

1. Scope

The purpose of this interim report is to generalize and complement Section III-2 of the Interim Grant Report IR-3, "Strength Characteristics of Jointed Water Pipelines" by M.G. Salvadori and A. Singhal (July, 1977), and to obtain the elastic and dynamic characteristics of both the mechanical joints with rubber gaskets and the cast-iron pipes.

The example used in this report is the same as the example of Section III-2 of the Interim Grant Report IR-3. For completeness' sake the pages of sections III-2, III-3,i and III-3,ii of Report IR-3 are repeated as Sections 2, 3 and 4 of this report, with some corrections in Section 4.

2. Pipe Failure Data

The pipe of the present example is that defined in Sect. III d - "Typical Cast-iron Pipe Modeling Data." The mechanical joint with rubber gasket is defined in ANSI A21.11 - 1972 Fig. 11.1 (Fig. 6) with mechanical joints dimensions specified in Table 11.1, Table I here reproduced, and mechanical joint gasket dimensions specified in Table 11.2 (Table II) and Fig. 11.2 (Fig. 11), here reproduced.

Table III gives the ultimate stresses for the pipe itself under the indicated static conditions.

TABLE III

Loading condition	Ultimate stress (psi)
Axial tension	18,000
Axial compression	90,000
Bending Rupture	40,000
Torsion	27,000
Shear	32,000
Buckling	
local torsional	68,000 - 105,000
Euler	104,093
Internal pressure	18,000
Ring bending	40,000
Ring buckling (Euler)	19,600

TABLE I

Mechanical-Joint Dimensions—in.

Size	A Plain End	B	C	D	F	φ	X	J	K_1 Centrifugal Pipe	K_1 Pit Cast Pipe and Fittings	K_2	L*	M	N	O	P	S Centrifugal Pipe	S Pit Cast Pipe and Fittings	Y	Bolts No.	Bolts Size	Bolts Length
2	±0.05 2.50	2.50	±0.05 3.39	±0.05 3.50	±0.05 2.61	28°	+0.06−0.0 ¾	±0.05 4.75	−0.05 6.00	−0.10 6.25	−0.10 6.25	−0.05 0.56	−0.05 0.62	0.50	0.31	0.63	0.37	−0.07 0.44	0.08	2	⅝	2½
2¼	±0.05 2.75	2.50	±0.05 3.64	±0.05 3.75	±0.05 2.86	28°	+0.06−0.0 ¾	±0.05 5.00	−0.05 6.25	−0.10 6.50	−0.10 6.50	−0.05 0.56	−0.05 0.62	0.50	0.31	0.63	0.37	−0.07 0.44	0.08	2	⅝	2½
3	±0.06 3.96	2.50	±0.04 4.84	+0.06−0.04 4.94	+0.07−0.03 4.06	28°	+0.06−0.0 ¾	±0.06 6.19	−0.06 7.62	−0.12 7.69	−0.12 7.69	−0.06 0.94	−0.06 0.62	0.75	0.31	0.63	0.47	−0.10 0.52	0.12	4	⅝	3
4	±0.06 4.80	2.50	±0.04 5.92	+0.06−0.04 6.02	+0.07−0.03 4.90	28°	+0.06−0.0 ⅞	±0.06 7.50	−0.06 9.06	−0.12 9.12	−0.12 9.12	−0.06 1.00	−0.06 0.75	0.75	0.31	0.75	0.55	−0.10 0.65	0.12	4	¾	3½
6	±0.06 6.90	2.50	±0.04 8.02	+0.06−0.04 8.12	+0.07−0.03 7.00	28°	+0.06−0.0 ⅞	±0.06 9.50	−0.06 11.06	−0.12 11.12	−0.12 11.12	−0.06 1.06	−0.06 0.88	0.75	0.31	0.75	0.60	−0.10 0.70	0.12	6	¾	3½
8	±0.06 9.05	2.50	±0.04 10.17	+0.06−0.04 10.27	+0.07−0.03 9.15	28°	+0.06−0.0 ⅞	±0.06 11.75	−0.06 13.31	−0.12 13.37	−0.12 13.37	−0.08 1.12	−0.08 1.00	0.75	0.31	0.75	0.66	−0.12 0.75	0.12	6	¾	4
10	±0.06 11.10	2.50	+0.06−0.04 12.22	+0.06−0.04 12.34	+0.07−0.03 11.20	28°	+0.06−0.0 ⅞	±0.06 14.00	−0.06 15.62	−0.12 15.69	−0.12 15.62	−0.08 1.19	−0.08 1.00	0.75	0.31	0.75	0.72	−0.12 0.80	0.12	8	¾	4
12	±0.06 13.20	2.50	+0.06−0.04 14.32	+0.06−0.04 14.44	+0.07−0.03 13.30	28°	+0.06−0.0 ⅞	±0.06 16.25	−0.06 17.88	−0.12 17.94	−0.12 17.88	−0.08 1.25	−0.08 1.00	0.75	0.31	0.75	0.79	−0.12 0.85	0.12	8	¾	4
14	+0.05−0.08 15.30	3.50	+0.07−0.05 16.40	+0.07−0.05 16.54	+0.06−0.07 15.44	28°	+0.06−0.0 ⅞	±0.06 18.75	−0.08 20.25	−0.12 20.31	−0.12 20.25	−0.12 1.31	−0.12 1.25	0.75	0.31	0.75	0.85	−0.12 0.89	0.12	10	¾	4½
16	+0.05−0.08 17.40	3.50	+0.07−0.05 18.50	+0.07−0.05 18.64	+0.06 0.07 17.54	28°	+0.06−0.0 ⅞	±0.06 21.00	−0.08 22.50	−0.12 22.56	−0.12 22.50	−0.12 1.38	−0.12 1.31	0.75	0.31	0.75	0.91	−0.12 0.97	0.12	12	¾	4½
18	+0.05−0.08 19.50	3.50	+0.07−0.05 20.60	+0.07−0.05 20.74	+0.06−0.07 19.64	28°	+0.06−0.0 ⅞	±0.06 23.25	−0.08 24.75	−0.15 24.83	−0.15 24.75	−0.12 1.44	−0.12 1.38	0.75	0.31	0.75	0.97	−0.15 1.05	0.12	12	¾	4½
20	+0.05−0.08 21.60	3.50	+0.07−0.05 22.70	+0.07−0.05 22.84	+0.06−0.07 21.74	28°	+0.06−0.0 ⅞	±0.06 25.50	−0.08 27.00	−0.15 27.08	−0.15 27.00	−0.12 1.50	−0.12 1.44	0.75	0.31	0.75	1.03	−0.15 1.12	0.12	14	¾	4½
24	+0.05−0.08 25.80	3.50	+0.07−0.05 26.90	+0.07−0.05 27.04	+0.06−0.07 25.94	28°	+0.06−0.0 ⅞	±0.06 30.00	−0.08 31.50	−0.15 31.58	−0.15 31.50	−0.12 1.62	−0.12 1.56	0.75	0.31	0.75	1.08	−0.15 1.22	0.12	16	¾	5
30	+0.08−0.06 32.00	4.00	+0.08−0.06 33.29	+0.08−0.06 33.46	+0.08−0.06 32.17	20°	+0.06−0.0 1⅛	±0.06 36.88	−0.12 39.12	−0.18 39.12	−0.18 39.12	−0.12 1.81	−0.12 2.00	0.75	0.38	1.00	1.20	−0.15 1.50	0.12	20	1	6
36	+0.08−0.06 38.30	4.00	+0.08−0.06 39.59	+0.08−0.06 39.76	+0.08−0.06 38.47	20°	+0.06−0.0 1⅛	±0.06 43.75	−0.12 46.00	−0.18 46.00	−0.18 46.00	−0.12 2.00	−0.12 2.00	0.75	0.38	1.00	1.35	−0.15 1.80	0.12	24	1	6
42	+0.08−0.06 44.50	4.00	+0.08−0.06 45.79	+0.08−0.06 45.96	+0.08−0.06 44.67	20°	+0.06−0.0 1⅜	±0.06 50.62	−0.12 53.12	−0.18 53.12	−0.18 53.12	−0.12 2.00	−0.12 2.00	0.75	0.38	1.00	1.48	−0.15 1.95	0.12	28	1¼	6
48	+0.08−0.06 50.80	4.00	+0.08−0.06 52.09	+0.08−0.06 52.26	+0.08−0.06 50.97	20°	+0.06−0.0 1⅜	±0.06 57.50	−0.12 60.00	−0.18 60.00	−0.18 60.00	−0.12 2.00	−0.12 2.00	0.75	0.38	1.00	1.61	−0.15 2.20	0.12	32	1¼	6

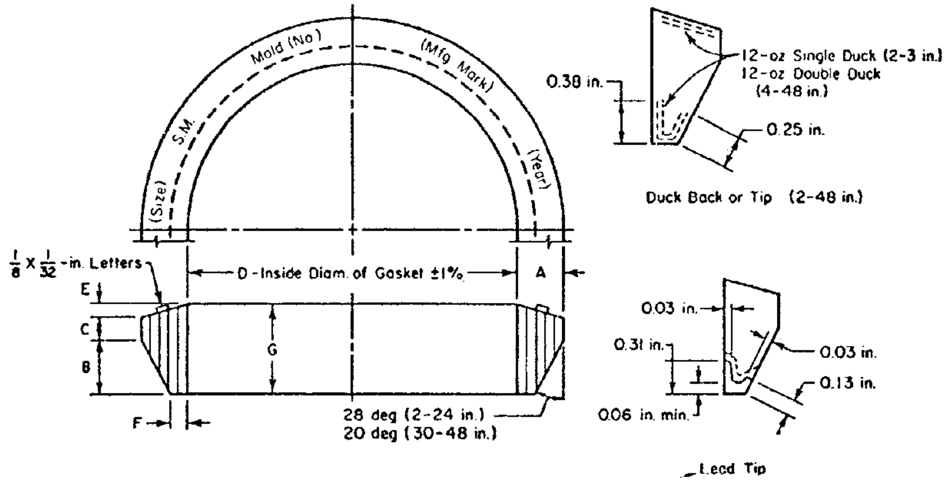

Fig. 11

Mechanical - joint gasket, 2-48 in (see table II and notes;

Notes

1. Tipped or backed gaskets may be made in the same mold as plain rubber gaskets, but the inside diameter of such reinforced portions shall not exceed the "pipe OD."
2. The duck for tips and backs shall be frictioned before molding.

TABLE II

2-48-in. Mechanical-Joint Gasket Dimensions—in.

Pipe Size	Pipe OD	Dimensions of Plain Rubber Gaskets						
		A ±0.01 in.	*B*	*C*	*D* +1 per cent −1 per cent	*E*	*F* ±0.01 in.	*G* ±0.02 in.
2	2.50	0.48	0.62	0.31	2.48	0.12	0.15	1.05
2¼	2.75	0.48	0.62	0.31	2.72	0.12	0.15	1.05
3	3.96	0.48	0.62	0.31	3.86	0.12	0.15	1.05
4	4.80	0.62	0.75	0.31	4.68	0.16	0.22	1.22
6	6.90	0.62	0.75	0.31	6.73	0.16	0.22	1.22
8	9.05	0.62	0.75	0.31	8.85	0.16	0.22	1.22
10	11.10	0.62	0.75	0.31	10.87	0.16	0.22	1.22
12	13.20	0.62	0.75	0.31	12.95	0.16	0.22	1.22
14	15.30	0.62	0.75	0.31	14.99	0.16	0.22	1.22
16	17.40	0.62	0.75	0.31	17.07	0.16	0.22	1.22
18	19.50	0.62	0.75	0.31	19.13	0.16	0.22	1.22
20	21.60	0.62	0.75	0.31	21.20	0.16	0.22	1.22
24	25.80	0.62	0.75	0.31	25.34	0.16	0.22	1.22
30	32.00	0.73	1.00	0.38	31.47	0.16	0.37	1.54
36	38.30	0.73	1.00	0.38	37.67	0.16	0.37	1.54
42	44.50	0.73	1.00	0.38	43.78	0.16	0.37	1.54
48	50.80	0.73	1.00	0.38	49.98	0.16	0.37	1.54

The main characteristics for pipe failure are the ultimate tension force and the ultimate bending moment M_u:

$$P_{u,p} = 18{,}000\ [\pi(19.50 - .63)] \times .63 = 672{,}256 \text{ lbs.}$$

$$M_{u,p} = RS_x = R\frac{\pi}{4}D^2t = 40{,}000 \times \frac{\pi}{4}\ (19.50 - .63)^2 \times .63 = 7{,}047{,}500 \text{ lb-in.}$$

It is confirmed by practical observations that other modes of failure seldom occur (additional verbal confirmation from Dr. S. Takada), although some compression failures have occurred.

3. Bolt Failure

From Table I, 12 bolts of 3/4 in. diameters (area = .3345 in^2), must be used with a minimum yield strength of 45,000 psi. The ultimate tensile force P_u and ultimate bending moment M_u developed by the bolts are:

$$P_{u,b} = 12 \times .3345 \times 45{,}000 = 180{,}630 \text{ lbs.}$$

$$M_{u,b} = .3345 \times 45{,}000 \times \left(\frac{19.50 - .63}{2}\right)^2 \quad [2+4 \times .866^2 + 4 \times .5^2]$$
$$= 6{,}834{,}000 \text{ lbs. in.}$$

For a working stress of 0.6 x 45,000 = 27,000 psi, the allowable tensile force developed by the bolt is:

$$P_{a,b} = 180{,}630 \times 27{,}000/45{,}000 = 108{,}378 \text{ lbs.}$$

4. Ultimate Gasket Friction

With the symbols of Fig. 1, Table I and Table II, let:

t_g = (A+F)/2 = average thickness of gasket

w_g = G = gasket base width

D = outside diameter of pipe

$A_g = \pi\ (D+t_g) \times t_g$ = circumferential cross-section area of gasket

$t_b = \sigma_t \, NA_b$ = allowable total bolt tension

σ_t = allowable bolt tensile stress

N = number of bolts

A_b = cross-section area of one bolt.

$\sigma_c = T_b/A_g$ = axial compressive stress in gasket

$\sigma_r = \frac{\nu}{1-\nu}\,\sigma_c$ = radial compressive stress in gasket

ν = Poisson's ratio

$\sigma_f = \mu\sigma_r$ = axial frictional stress on gasket

μ = coefficient of friction

$A_f = \pi D w_g$ = frictional area of gasket

$R_{p-o} = \sigma_f \, A_f$ = pull-out frictional resistance of gasket

For the pipe of the present example we obtain:

$D_{nominal} = 18''$

$D = 19.50''$ (outside diameter)

$t_g = (.62 + .22)/2 = .42''$

$w_g = 1.22''$

$A_g = \pi(19.5 + .42) \times .42 = 26.28 \text{ in}^2$

$\sigma_t = .6 \times 45{,}000 = 27{,}000$ psi

$N = 12$

$A_b = .3345 \text{ in}^2$ (3/4" bolts)

$T_b = 27{,}000 \times 12 \times .3345 = 108{,}378$ lbs.

$\sigma_c = 108{,}378/26.28 = 4{,}124$ psi

$\nu = .4$

$\sigma_r = \frac{.4}{1-.4} (4,124) = 2,749$ psi

$\mu = .7$

$\sigma_f = .7 \times 2,749 = 1,925$ psi

$A_f = \pi \times 19.50 \times 1.22 = 74.24 \text{ in}^2$

$R_{p-o} = 1,925 \times 74.24 = 148,872$ lbs.

As an order-of-magnitude check on the maximum pull-out joint force, Dr. Takada found experimentally (Ref. 11, Fig. 8):

$\emptyset = 200$ mm. $\quad P_u = 30$ tons

$\emptyset = 300$ mm. $\quad P_u = 40$ tons

and a parabolic relationship between pull-out force and displacement. Assuming a linear relation between P_u and $\emptyset$, Dr. Takada's results would give for our example:

$\overline{D} = D-t = 19.50 - .63 = 18.87" = 479$ mm.

where t is the pipe thickness:

$P_u = 30 + (40-30) \times 279/100 = 57.9$ tons $= 127,300$ lbs.

which is of the same order of magnitude as R_{p-o}.

5. Longitudinal Elastic Constant of Gasket

Let:

$\gamma_{max} = \frac{d_{max}}{t_g}$ = maximum elastic shear strain of gasket

$d_{max} = \gamma_{max} t_g$ = maximum axial shear displacement of gasket

G_g = gasket shear modulus

$F_x = G_g \, A_f \, \gamma_{max}$ = maximum elastic longitudinal force due to gasket

$k_{x,g} = F_x/d_{max}$ = longitudinal spring constant of gasket.

For the present example:

$\gamma_{max} = .5$ (Ref. 1)

$d_{max} = .5 \times .42 = .21''$

$G_g = 1.1 \times 215$ psi (Ref. 1,2) (For 20° F)

$F_x = 1.1 \times 215 \times 74.74 \times .5 = 8{,}839$ lbs.

$k_{x,g} = 8{,}839/.21 = 42{,}088$ lbs/in

6. <u>Longitudinal Periods of Pipe Due to Gasket Elasticity</u>

Let:

w_p = weight of pipe per unit length

w_w = weight of water per unit length of pipe

L = length of pipe

$M_f = \left(\frac{w_p + w_w}{g}\right) \times L$ = mass of full pipe

g = acceleration of gravity

$M_e = \frac{w_p}{g} \times L$ = mass of empty pipe

$\omega_{f,g} = \sqrt{\frac{k_{x,g}}{M_f}}$ = longitudinal frequency of full pipe

$\omega_{e,g} = \sqrt{\frac{k_{x,g}}{M_e}}$ = longitudinal frequency of empty pipe

$T_{f,g} = \frac{2\pi}{\omega_{f,g}}$ = longitudinal period of full pipe

$T_{e,g} = \frac{2\pi}{\omega_{e,g}}$ = longitudinal period of empty pipe

For the present example:

$w_p = 116.5$ lbs/ft

$w_w = 113.5$ lbs/ft

$L = 20$ ft.

$$M_f = \frac{(116.5+113.5)/12}{386.4}\ (20x12) = 11.905 \text{ lbs. sec}^2/\text{in}$$

$$M_e = \frac{116.5/12}{386.4}\ (20x12) = 6.03 \text{ lbs. sec}^2/\text{in}$$

$$\omega_{f,g} = \sqrt{\frac{42,088}{11.905}} = 59.46 \text{ sec}^{-1}$$

$$\omega_{e,g} = \sqrt{\frac{42,088}{6.03}} = 83.55 \text{ sec}^{-1}$$

$T_{f,g} = 2\pi/59.46 = .106$ sec

$T_{e,g} = 2\pi/83.55 = .075$ sec

7. Longitudinal Periods of Pipe Due to Pipe Elasticity

Let:

E = Elastic modulus of cast iron

A = Cross-section area of pipe

L = Pipe length

$k_{x,p} = EA/L$ = longitudinal spring constant of pipe

t = pipe thickness

D = outside pipe diameter

$\omega_{f,p};\omega_{e,p}$ = longitudinal frequencies of full and empty pipe.

For the present example:

$E = 20x10^6$ psi

$A = \pi(19.50 - .63) \text{ x } .63 = 37.35 \text{ in}^2$

$$k_{x,p} = \frac{20x10^6 x37.35}{20x12} = 3.11 \text{ x } 10^6 \text{ lbs/in}$$

$$\omega_{f,p} = \sqrt{\frac{3.11x10^6}{11.905}} = 511.11 \text{ sec}^{-1}$$

$$T_{f,p} = 2\pi/511.11 = .0123 \text{ sec}$$

$$\omega_{e,p} = \sqrt{\frac{3.11x10^6}{6.03}} = 718.16 \text{ sec}^{-1}$$

$$T_{e,p} = .0087 \text{ sec}$$

8. Rotational Elastic Constant of Gasket

Let d_{max} be the maximum shear displacement of the gasket at the top of the pipe. Under the assumption of a rigid pipe, the rotation of the pipe at a joint occurs around a horizontal axis tangent to the pipe at the bottom point of the joint and the shear displacement varies linearly across the depth of the pipe.* With the symbols of Fig.12 the displacement at the depth defined by the angle θ is:

$$d_\theta = (D_g/2)\ (1+\sin\theta)\ (d_{max}/D_g) = (1/2)(1+\sin\theta)\ d_{max},$$

where:

$D_g = D+t_g$, t_g = gasket thickness,

*This commonly accepted assumption concerning the pipe roation is derived from practical experience in the laboratory and in the field. No actual proof that the rotation always occurs about the assumed axis has been established.

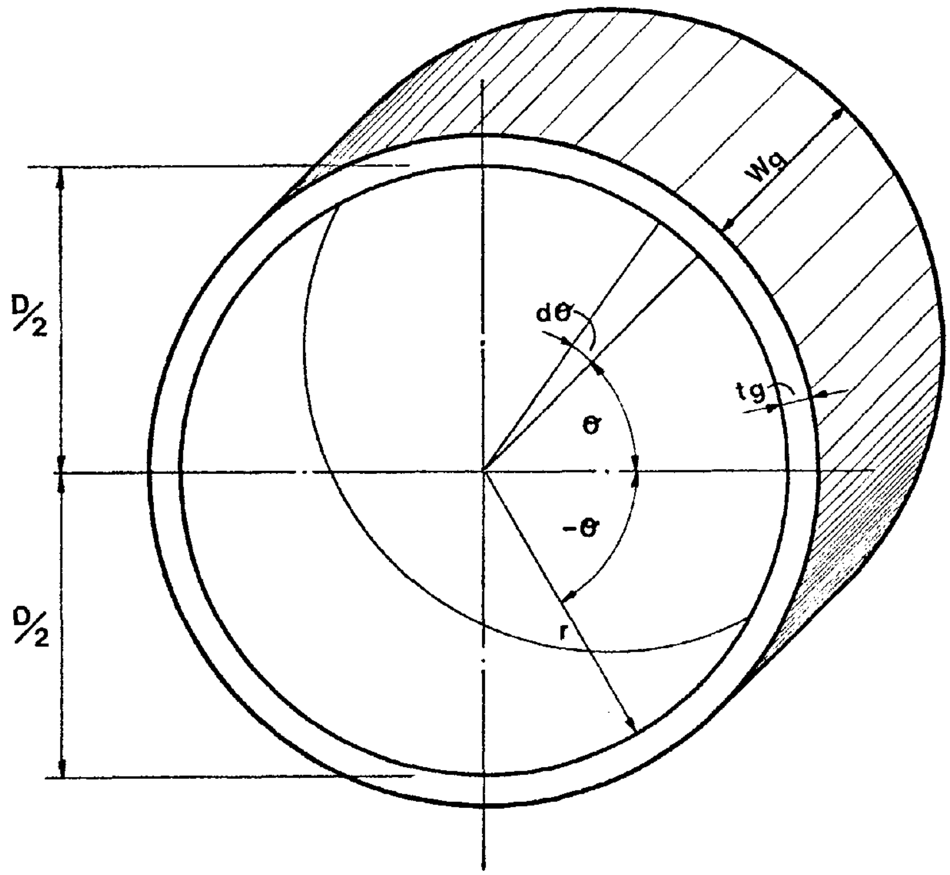

FIG. 12

and the shear strain in the gasket at the depth defined by the angle θ becomes:

$$\gamma_\theta = (1/2)\ (1+\sin\theta)\ (d_{max}/t_g) = (1/2)\ (1+\sin\theta)\ \gamma_{max}.$$

The corresponding shear stress is:

$$\tau_\theta = G_g\gamma_\theta = (1/2)\ G_g\ (1+\sin\theta)\ \gamma_{max}$$

and the moment of the τ_θ's about the horizontal axis tangent to the bottom of the pipe is:

$$M = 2\int_{-\pi/2}^{\pi/2} \tau_\theta\ w_g\ (D_g/2)\ d\theta\ (D_g/2)\ (1+\sin\theta)$$

$$= G_g\ (D_g/2)^2\ w_g\ \gamma_{max}\int_{-\pi/2}^{\pi/2}(1+\sin\theta)^2 d\theta$$

$$=(3/2)\pi G_g(D_g/2)^2\ w_g\gamma_{max}.$$

The pipe rotation at the joint, due to the elasticity of the gasket, is:

$$\alpha = \frac{d_{max}}{D_g}$$

and the rotational spring constant of the gasket is:

$$k_{\phi,g} = \frac{M}{\alpha} = \frac{3}{8}\pi G_g D_g^{\ 3}\ w_g/t_g$$

For the present example:

$G_g = 1.1 \times 215 = 236.5$ psi, $D_g = 19.50 + .42 = 19.92$ in.,

$w_g = 1.22$ in., $t_g = .42$ in.

$$k_{\phi,g} = \frac{3}{8}\pi \times 1.1 \times 215 \times (19.92)^3 \times 1.22/.42 = 6.398\text{x}10^6 \text{ lb-in/rad}.$$

9. Periods of Rotational Motion Due to Gasket

Letting:

$I_f, I_e = M_{f,e}[(1/3)L^2+(3/8)D^2]$ = mass moments of inertia of full and empty pipes of length L about axis of rotation at joint,

the rotational frequencies (in an antisymmetrical mode) of the pipe and its periods become:

$$\omega_{\substack{f,g\\e,g}} = \sqrt{\frac{k_{\phi,g}}{I_{\substack{f,g\\e,g}}}}, \quad T_{\substack{f,g\\e,g}} = \frac{2\pi}{\omega_{\substack{f,g\\e,g}}}$$

For the present example:

$$I_{f,g} = 11.950\ [(1/3)\ (20x12)^2 + (3/8)\ (19.50)^2] = 230{,}273\ \text{lbs.in.sec}^2$$

$$I_{e,g} = 6.03\ [(1/3)\ (20x12)^2 + (3/8)\ (19.50)^2] = 116{,}635\ \text{lbs.in.sec}^2$$

$$\omega_{f,g} = \sqrt{\frac{6.398x10^6}{.2302x10^6}} = 5.28\ \text{sec}^{-1}$$

$$\omega_{e,g} = \sqrt{\frac{6.938x10^6}{.1166x10^6}} = 7.40\ \text{sec}^{-1}$$

$$T_{f,g} = \frac{2\pi}{5.28} = 1.19\ \text{sec}$$

$$T_{e,g} = \frac{2\pi}{7.40} = 0.85\ \text{sec}$$

10. Periods of Vibration for Vertical Anti-symmetrical Rotational Modes of Continuous Elastic Pipes.

Letting:

$I = (\pi/8)\bar{D}^3 t$ = moment of inertia of pipe cross-section,

$\overline{D}$ = D-t = average pipe diameter,

the frequencies of the antisymmetrical mode of the full and empty pipe (Fig. 13) are:

$$\omega_{\substack{f,p \\ e,p}} = 14.0625\ (1/L^2) \sqrt{\frac{EIg}{w_{\substack{f,p \\ e,p}}}}\ ,$$

and the corresponding periods are:

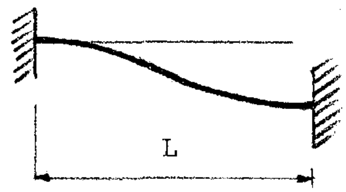

Fig. 13

$$T_{\substack{f,p \\ e,p}} = .4468\ L^2 \sqrt{\frac{w_{f,p};\ w_{e,p}}{EIg}}$$

In the present example:

$\overline{D} = 19.50 - .63 = 18.87$ in.

$I = (\pi/8) \times (18.87)^3 \times .63 = 1{,}662\ \text{in}^4$

$$\omega_{f,p} = 14.0625\ \frac{1}{(20\text{x}12)^2} \sqrt{\frac{20\text{x}10^6 \times 1{,}662 \times 386.4}{230/12}} = 200\ \text{sec}^{-1}$$

$$T_{f,p} = \frac{2\pi}{200} = .0314\ \text{sec.}$$

$$\omega_{e,p} = 14.0625\ \frac{1}{(20\text{x}12)^2} \sqrt{\frac{20\text{x}10^6 \times 1{,}662 \times 386.4}{116.5/12}} = 281\ \text{sec}^{-1}$$

$$T_{e,p} = \frac{2\pi}{281} = .0224\ \text{sec.}$$

$$\omega_{e,p} = \sqrt{\frac{k_{\phi,p}}{I_{e,p}}} = \sqrt{\frac{831\text{x}10^6}{.1160\text{x}10^6}} = 84.62 \text{ sec}^{-1}$$

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{84.62} = 0.074 \text{ sec}$$

11. Bibliography*

1. Design of neoprene bearing pads (Dupont, 1959)

2. Steel Pipe Design and Installation. American Water Works Association Manual M11.

*See also Bibliography in IR-3

13. Errata for Report IR-3

PAGE	LINE	READS	SHOULD READ
77	8	From Table XI	From Table I
77	4b	From Table XII	From Table II
77	5b	iii. Ultimate gasket friction	ii. Ultimate gasket friction
78	8	From Table Xi	From Table II

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