TECHNICAL INFORMATION

POLIPLEX® PE100

HYDRAULIC DESIGN

THRUST RESTRAINT AND ANCHORAGES

When a water distribution pipeline is under internal pressure, unbalanced forces develop at changes of size and direction in the pipeline. This applies to bends, tees, reducers, offsets, dead ends etc. Most POLIplex® jointing systems can develop the full axial strength of the pipe and do not require external support to resist these forces. However should the jointing system have no or insufficient axial strength capability such as where a plain rubber ring joint is in the vicinity, possibly due to a change of material of the pipe or fitting, unbalanced forces must be calculated so that provision can be made for them (Figure 1.1).

The notation used in equations of this section is as follows:-

A = cross-sectional area (m^2) of the inside of the joint socket – usually based in the outside diameter of the pipe D (m)
$= \pi \frac{D}{4}$
b_s = bearing capacity of soil (kPa)
c = soil cohesion strength (kPa)
D = outside diameter at unrestrained joint (m)
F of S = factor of safety
F_S = pipe/soil sliding resistance force (kN)
h = height of thrust block (m)
H = cover height (m)
K_p = lateral passive soil stress ratio
$= \tan^2(45 + \omega/2)$
L = length of pipe with harnessed joints on each side of the bend or elbow (m)
P = maximum internal pressure including any anticipated surge pressure or static test pressure if greater than operating pressure (kPa)
Q = flow rate (l/s)
R_S = soil bearing resistance (kN)
T = (unbalanced hydrostatic) thrust force (kN)
V = velocity (m/s)
w = width of thrust block (m)
W_e = weight of the prism of soil over the pipe (kN/m of pipe length)
$= \gamma HD$
W_p = weight of the pipe (kN/m)
W_w = weight of the contained water (kN/m)
α = bend deflection angle (degrees)
γ = specific weight of soil above the pipe (kN/m^3)
ω = soil friction angle (degrees)
ρ = density of fluid in the pipe (kg/m^3)
μ = coefficient of friction between the pipe and the soil

The magnitude of these thrust forces for tees and dead ends is equal to the product of the internal pressure and the cross-sectional area of the pipe, or branch pipe in the case of a tee:

$$T = PA \qquad \textit{Eqn. 1.1}$$

Similarly for a reducer where A_1 & A_2 are the pressure affected areas each side of the taper:

$$T = P(A_1 - A_2) \qquad \textit{Eqn. 1.2}$$

At elbows or bends, the resultant thrust force T is:

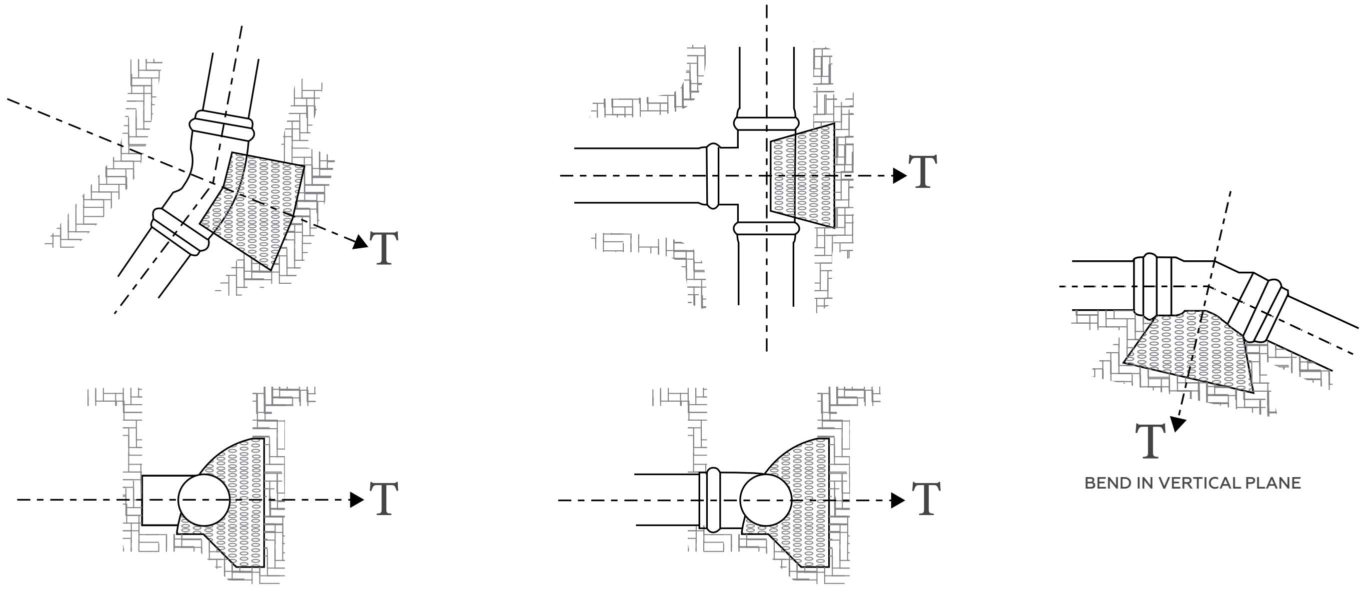
$$T = 2(PA + \rho QV \times 10^{-6}) \sin \alpha/2 \qquad \textit{Eqn. 1.3}$$

HYDRAULIC DESIGN

This equation contains a momentum term ‘$\rho QV \times 10^{-6}$’ to cover the unbalanced forces at bends caused by the velocity of water flow within the pipeline. In general, this term is so small that its effect is insignificant, and thrust forces caused by velocity can be neglected. The thrust acts along the axis of symmetry of the bend.

The magnitudes of these thrust forces for various fittings are given in Table 1.1.

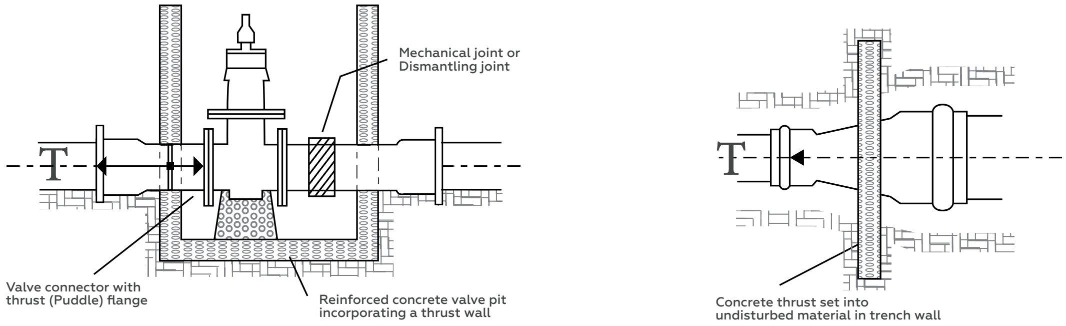
FIGURE 1.1 TYPICAL THRUST BLOCK CONFIGURATIONS



BEND IN VERTICAL PLANE

BEND IN HORIZONTAL PLANE

TEE ANCHORAGE



VALVE ANCHORAGE

REDUCER ANCHORAGE

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TABLE 1.1 HYDROSTATIC THRUST ON FITTINGS UNRESTRAINED BY PIPE

For each 10 metres of water using external pipe diameter as calculation basis.

DN	OUTSIDE PIPE DIAMETER (mm)	90° BEND (kN)	TEE OR CLOSED END OR 60° BEND (kN)	45° BEND (kN)	22 ½° BEND (kN)	11 ¼° BEND (kN)
16	16	0.03	0.02	0.02	0.01	0.00
20	20	0.04	0.03	0.02	0.01	0.01
25	25	0.07	0.05	0.04	0.02	0.01
32	32	0.11	0.08	0.06	0.03	0.02
40	40	0.17	0.12	0.09	0.05	0.02
50	50	0.27	0.19	0.15	0.08	0.04
63	63	0.43	0.31	0.23	0.12	0.06
75	75	0.61	0.43	0.33	0.17	0.08
90	90	0.88	0.62	0.48	0.24	0.12
110	110	1.32	0.93	0.71	0.36	0.18
125	125	1.70	1.20	0.92	0.47	0.24
140	140	2.13	1.51	1.15	0.59	0.30
160	160	2.79	1.97	1.51	0.77	0.39
180	180	3.53	2.49	1.91	0.97	0.49
200	200	4.36	3.08	2.36	1.20	0.60
225	225	5.51	3.90	2.98	1.52	0.76
250	250	6.81	4.81	3.68	1.88	0.94
280	280	8.54	6.04	4.62	2.36	1.18
315	315	10.80	7.64	5.85	2.98	1.50
355	355	13.72	9.70	7.43	3.79	1.90
400	400	17.42	12.32	9.43	4.81	2.42
450	450	22.05	15.59	11.93	6.08	3.06
500	500	27.22	19.25	14.73	7.51	3.77
560	560	34.15	24.15	18.48	9.42	4.73
630	630	43.22	30.56	23.39	11.93	5.99
710	710	54.89	38.82	29.70	15.15	7.61
800	800	69.69	49.28	37.71	19.23	9.66

Note: A factor of safety of 1.1 to 1.5 may be applied as friction of concrete block on soil has been ignored.

HYDRAULIC DESIGN

Restraint for these thrust forces may be provided by a concrete thrust block or by the development of friction forces between the pipe and the soil through using lengths of pipeline which are monolithic with the bend (eg harnessed joints) or by a combination of these two methods.

When thrust blocks are used, the bearing area of the block is determined by the bearing capacity of the soil against which the thrust force will act, ie:

$$\text{Bearing Area } (w \times h) = \frac{T \times (F \text{ of } S)}{b_s} \qquad \textit{Eqn. 1.4}$$

The value for horizontal bearing capacity of the native soil should be determined from the geotechnical report on site conditions. That is passive horizontal soil resistance can be calculated from equation:

$$b_s = K_p \gamma H + 2c\sqrt{K_p} \qquad \textit{Eqn. 1.5}$$

Typical values of soil parameters and calculated soil resistances are given in Table 1.2.

TABLE 1.2 SOIL BEARING STRENGTHS

SOIL GROUP (See App. C for full description)	SOIL FRICTION ANGLE ω (degrees)	SOIL COHESION c (kPa)	K_p	UNIT WEIGHT (kN/m^3)	SOIL BEARING STRENGTH (kPa) for cover height *h=			
					0.75m	1.0m	1.25m	1.5m
GW, SW	38	0	4.20	18	57	76	95	114
GP, SP	37	0	4.02	16	48	64	80	97
GM, SM	34	0	3.54	18	48	64	80	96
GC, SC	31	11	3.12	17	79	92	105	119
CL	28	13	2.77	15	74	85	95	106
ML	32	9	3.25	15	69	81	93	106
OH	0	0	1.00	10	0	0	0	0

**h = height of soil cover measured from centreline. The bearing strength of rock can be taken as 240 kPa as a minimum.*

Where bends are in the vertical plane with upward acting thrusts, the weight of the anchor block must be sufficient to provide the restraining force.

Restrained or harnessed joints may also be used to resist thrust forces through the development of friction forces between the pipe and the soil surrounding it. When this method is used, sufficient length of pipe must be made continuous by welding or harnessing (eg flanged or shouldered end couplings) to resist the unbalanced forces. These unbalanced forces are equal to PA at dead ends, tees and 90° bends, although they reduce for bend deflections of less than 90°.

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The frictional resistance F_S is the product of the pipe/soil friction coefficient μ and the sum of lateral forces comprising of weight of overburden soil above the pipe plus weight of water filled pipe ie

$$F_S = \mu \times L \times (W_e + W_w + W_p) \qquad \textit{Eqn. 1.6}$$

In the preceding equation, all parameters except the value of the friction coefficient (μ) between the pipe and the soil can be readily determined. Tests together with experience indicate that the value of μ is not only a function of the type of soil, but is also greatly affected by the degree of compaction and moisture content of the pipe embedment material. Therefore care must be exercised in it's selection. The coefficient of friction on PE pipes can be taken to be in the range of 0.1 to 0.2.

In the case of a bend, properly compacted backfill will provide lateral restraint as in the case of normal thrust block design of thickness 0.5xD and reduce the tendency for movement due to the unbalanced lateral force. Because of the flexibility of PE it is suggested that only 20% of the length harnessed to the fitting be considered as giving effective lateral resistance. This can be written:

$$R_S = b_S \times 0.5D \times 0.2L \qquad \textit{Eqn. 1.7}$$

This lateral force will develop a frictional restraining force which has been disregarded for the purposes of these calculations. Figure 1.3 shows the diagram of forces, where each of the two resultant axial thrusts is equal to PA (1- cos α). By resolving forces along the pipe on each side of the change of direction, the approximate length of pipeline or extension of the bend required to act as the restraint for the angular deflection in the pipeline is determined:

$$L = \frac{PA\,(1 - \cos \alpha) \times (F\ of\ S)}{\mu\,(W_e + W_w + W_p) + 0.1Db_S \sin \alpha} \qquad \textit{Eqn. 1.8}$$

Note: A factor of safety of at least 3 should be applied as compaction around pipe will significantly affect the degree of soil resistance.

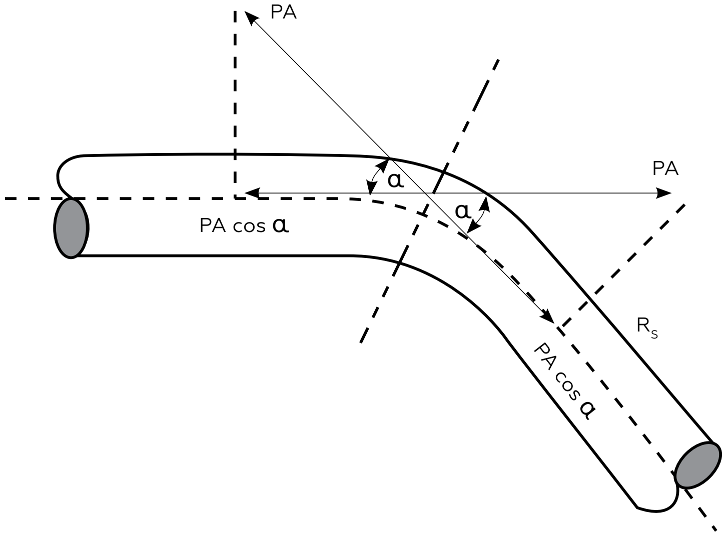

FIGURE 1.3 AXIAL HYDROSTATIC THRUST FORCE AT BEND = PA (1 - COS α)

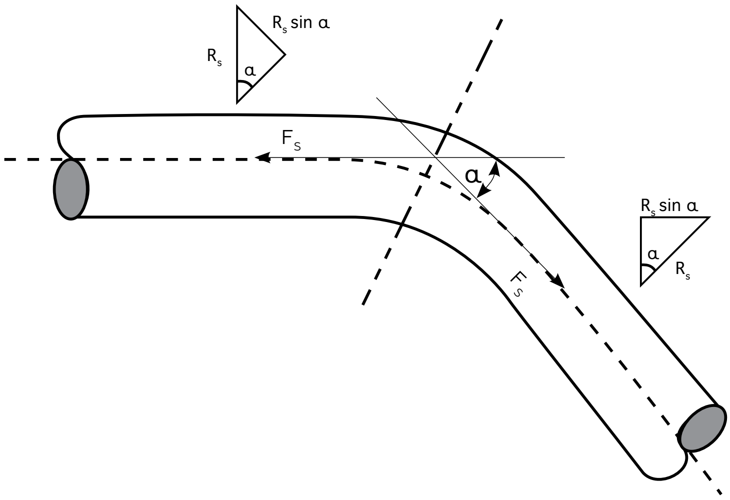

FIGURE 1.4 NET AXIAL SOIL RESISTANCE = F_S + R_S SIN α

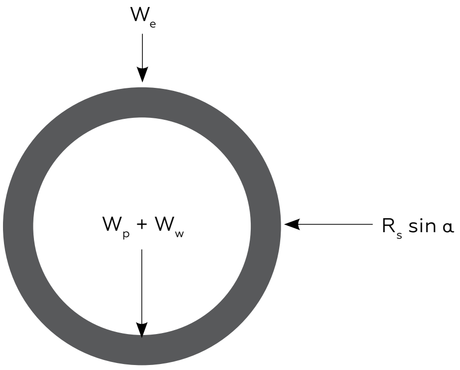

FIGURE 1.5 LATERAL FORCES – CONTRIBUTING TO AXIAL SOIL FRICTION RESISTANCE