Pressure class....

The Pressure class is related to the long term strength or HDB of the pipe as follows;

$$P_C \leq (HDB/FS)/(2t_S/D_E)$$

where,
HDB = Hydrostatic Design Basis, kN/m²
FS = Minimum factor of safety, 1.8
P_C = Pressure class, kN/m²
t_S = Structural wall thickness, mm
D_E = Minimum effective diameter, mm = $D_i + 2\ t_L + t_S$
D_i = Inner diameter, mm
t_L = Liner thickness, mm

The HDB of fiberglass pipe varies, depending on the materials and composition used in the reinforced wall and in the liner. The HDB may be defined in terms of reinforced wall hoop stress or hoop strain on the inside surface. The design factor ensures that the stress or strain due to sustained working pressure does not exceed the long term hoop strength of the pipe as defined by HDB.

Working pressure....

The pressure class of the pipe should be equal to or greater than the working pressure in the system as follows;

$$P_C \geq P_W$$

where,
P_C = Pressure class, kN/m²
P_W = Working pressure, kN/m²

Surge pressure....

The pressure class of the pipe should be equal to or greater than the maximum pressure in the system, due to working pressure and surge pressure, divided by 1.4 as follows;

$$P_C \geq (P_W + P_S) / 1.4$$

where,
P_S = Surge pressure, kN/m²

The surge allowance is intended to provide for rapid transient pressure increases typically encountered in piping systems. The allowance 0.4 PC is based on the increased strength of the fiberglass pipe for rapid strain rates.

Allowable deflection from Ring bending....

The maximum allowable long-term deflection should not result in a ring bending strain (or stress) that exceeds the long term ring bending strain capability of the pipe reduced by an appropriate design factor.

$$\xi_b = D_f * (\Delta y_a / D_E) * (t_t / D_E) \leq S_b / FS$$

where,

ξ_b = Maximum ring bending strain due to deflection, mm/mm
D_f = Shape factor (table given below)
D_E = Effective pipe diameter, mm
S_b = Long term ring bending strain, mm/mm
Δy_a = Maximum allowable long term vertical pipe deflection, mm
t_t = Total Pipe thickness, mm

The shape factor relates pipe deflection to bending stress or strain and is a function of pipe stiffness, pipe embedment material and compaction, haunching, native soil conditions and level of deflection. Shape factor given below is for moderate to high compaction.

Stiffness	Shape factor	
kN/m²	Gravel	Sand
1.25	7.0	8.0
2.50	5.5	6.5
5.00	4.5	5.5
10.00	3.8	4.5

The long term ring bending strain varies for different products, depending on materials and type of construction used in the pipe wall. The maximum allowable ring bending strain is taken as 0.0018.

Deflection prediction....

Buried pipe should be installed in such a manner that will ensure that external loads will not cause a long term decrease in the vertical diameter of the pipe exceeding the maximum allowable deflection calculated from section-4 or the permitted deflection (5%), minimum.

$$\frac{\Delta Y}{D} = \left(\frac{(D_L . W_S + W_L) K_X}{(8 S + 0.061 E')} \right)$$

where,

$\Delta Y/D$ = Predicted vertical pipe deflection, %
W_S = Vertical soil load on pipe, kN/m²
W_L = Live load on pipe, kN/m²
S = Pipe stiffness, kN/m²
E' = Composite modulus of soil reaction, kN/m²
D_L = Deflection lag factor

K_X = Bedding coefficient

The amount of deflection is a function of the soil load, Live load, Native soil characteristics at pipe elevation, pipe embedment material and density, trench width, haunching and pipe stiffness.

Vertical Soil Load, W_S

$W_S = \gamma_S . H$

where,

γ_S = Specific weight of soil, kN/m^3
H = Burial depth to top of pipe, m

Live Load, W_L

$W_L = P. I_F / L_1 . L_2$

where,

P = Wheel load, kN
I_F = Impact Factor, dimensionless
= 1.1 (for 0.6m < H < 0.9m)
= 1.0 (for H ≥ 0.9m)

L_1 = Load width parallel to direction of travel, m
= 0.253+1.75 H

L_2 = Load width perpendicular to the direction of travel, m
= 0.51+1.75 H(for 0.6m < H < 0.76m)
= (13.31+1.75 H) / 8 (for H ≥ 0.9m)

Deflection Lag Factor, D_L

The deflection lag factor converts the immediate deflection of the pipe to the deflection of the pipe after many years. The primary cause of increasing pipe deflection with time is the increase in overburden load as soil arching is gradually lost. The value is taken as 1.5.

Bedding Coefficient, K_X

The bedding coefficient reflects the degree of support provided by the soil at the bottom of the pipe and over which the bottom reaction is distributed.

K_X = 0.083 (for uniform shape bottom support)
= 0.1 (for direct bury condition)

Composite Modulus of Soil Reaction, E'

The vertical loads on a flexible pipe cause a decrease in the vertical diameter and an increase in the horizontal diameter. The horizontal movement develops a passive soil resistance that helps support the pipe. The passive soil resistance varies depending on the soil type and the degree of compaction of the pipe zone backfill material, native soil characteristics, cover depth and trench width. To determine E' for a buried pipe , separate E' values for the native soil (E'_n) and the pipe backfill surround (E'_b) must be determined and then combined using the equation,

$E' = S_c . E'_b$
where,

S_c = Soil support combining factor
E'_b = Modulus of soil reaction of the pipe embedment, kN/m^2
E'_n = Modulus of soil reaction of the native soil at pipe elevation, kN/m^2

The values of S_c and E'_b can be found from the table 5-4 and 5-5 given in AWWA M-45 manual. For finding S_c, the value of E'_n should be determined from the table 5-6.

Pipe Stiffness, S

$S = E_{HF}.I / D_E^3$

where,

D_E = Effective diameter, m
E_{HF} = Hoop modulus in flexure, kN/m^2
I = Moment of Inertia for unit length, m^3
= $t_t^3 / 12$
t_t = Total thickness of the pipe wall, m

Combined Loading....

Strain due to internal pressure

$\xi_{pr} = (P_W.D_E) / (2t_s. E_{HT})$

where,

P_W = Working pressure, kN/m^2
E_{HT} = Hoop modulus in tension, kN/m^2
D_E = Effective diameter, mm
t_s = Structural wall thickness, mm

Bending strain due to permitted deflection

$\xi_b = D_f (\delta d/D_E) (t_t / D_E)$

where,

D_f = Shape factor
$\delta d/D_E$ = Permitted deflection, %
D_E = Effective diameter, mm
t_T = Total wall thickness, mm

The maximum stress or strain resulting from the combined effects of internal pressure and deflection should meet the following equations,

$$\frac{\xi_{pr}}{HDB} \leq \frac{1 - (\xi_b . r_c / S_b)}{FS_{pr}} \quad \text{and}$$

$$\frac{\xi_b . r_c}{S_b} \leq \frac{1 - (\xi_{pr} / HDB)}{FS_b}$$

where,

FS_{pr} = Pressure design factor, 1.8
FS_b = Bending design factor, 1.5
HDB = Hydrostatic Design Basis, mm/mm
S_b = Long term ring bending strain, mm/mm
r_c = Rerounding coefficient. = 1 – P_W / 3, ($P_W \leq 3$ N/mm²)

Buckling....

The buried pipe is subjected to radial external loads composed of vertical loads and possibly the hydrostatic pressure of ground water and internal vacuum, if the latter two are present. The summation of appropriate external loads should be equal to or less than the allowable buckling pressure which is determined by the following equation.

$$q_a = (1 / FS).(32\, R_w \,.\, B' \,.E'.\, (E_{HF}.\, I / D_E^3))^{1/2}$$

where,
q_a = Allowable buckling pressure, kN/m²
E' = Composite Modulus of soil reaction, kN/m²
E_{HF} = Hoop modulus in flexure, kN/m²
FS = Design factor, 2.5
R_w = Water Buoyancy factor
= 1 – 0.33 (h_w / h), $0 < h_w < h$
h_w = Height of water surface above the top of pipe, m
h = Height of ground surface above the top of pipe, m
B' = Empirical coefficient of elastic support, dimensionless
= $1 / (1 + 4.e^{-(0.213 H)})$
H = Burial depth to the top of pipe, m

Satisfaction of the buckling requirement is assured for normal pipe installations by the following equation,

$\gamma_w h_w + R_w(W_c) + P_v \leq q_a$, with vacuum

$\gamma_w h_w + R_w(W_c) + W_L \leq q_a$, If live load is considered

where,
γ_w = Specific weight of water, kN/m³
W_c = Vertical soil load, kN/m²
P_v = Internal vacuum pressure, kN/m²

Buoyancy....

If the water table is above the pipe, a check against buoyancy with the pipe empty of water has to be done. The load for unit length due to weight of soil has to be higher than the buoyancy force, F_{up}.

$$F_{up} < FS\,(W_p + W_s)$$

where,

F_{up} = Buoyancy force, N/m = $\pi/4\,(D_o^2 .\, \gamma_w)$
W_s = Soil load, N/m = $D_o.\gamma_S.R_w.\,H$
W_P = Pipe weight, N/m
D_o = Pipe external diameter, m
γ_S = Specific weight of dry soil, N/m³
FS = Safety factor, 1.5

Axial Loading....

When an open ended pipe is subjected to internal pressure, the pipe expands both circumferentially and longitudinally. Since the movements are resisted in a buried pipe by the surrounding soil, a tensile load is produced within the pipe which is independent of the length of the pipe.

The axial strain due to poisson effect

$$\xi_P = (\nu_{ha}.P.D_E) / (2\, t_s\, .E_{HT})$$

where,

ν_{ha} = Poisson's ratio (applied hoop load)
P = Pressure, kN/m²
D_E = Effective diameter, m
t_s = Pipe structural wall thickness, m
E_{HT} = Hoop Modulus in Tension, kN/m²

The axial strain due to temperature gradient

Longitudinal tensile loads are generated by a temperature gradient in the piping system. We have to find out the tensile forces imposed on the pipe because of cooling. When an open ended pipe cools, it tries to shorten longitudinally. The tensile load is imposed by the resistance of the surrounding soil. The temperature change in the surrounding soil or media which the pipe is carrying can produce this tensile load.

$$\xi_T = \Delta T\, .\, \alpha$$

where,

$\Delta T = (T_{max} - T_{min}) / 2$, °C
α= Coefficient of thermal expansion, mm/mm/°C

The axial strain due to bridging

Longitudinal tensile loads are imposed on the pipe due to bridging also. Bridging can occur in all sub aqueous installations and also when the trench bearing strength varies and when a pipe projects from a head wall. The pipe should be designed to be strong enough to support the weight of its contents, its own weight, the weight of the overburden, while spanning of void more than two pipe diameters.

$$\xi_B = W_t\ (2D_E)^2\ D_E\ /\ 16\ E_{AT}.\ A$$

where,
W_t = Weight of pipe + pipe contents + overburden, kN
E_{AT} = Axial modulus in tension, kN/m²
$A = \pi(D_E/2)^3\ .\ t_s$

The total axial strain due to the combined effect of poison ratio, temperature gradient and pipe bridging,

$$\xi_{Total} = \xi_P + \xi_T + \xi_B$$

Thrust Block....

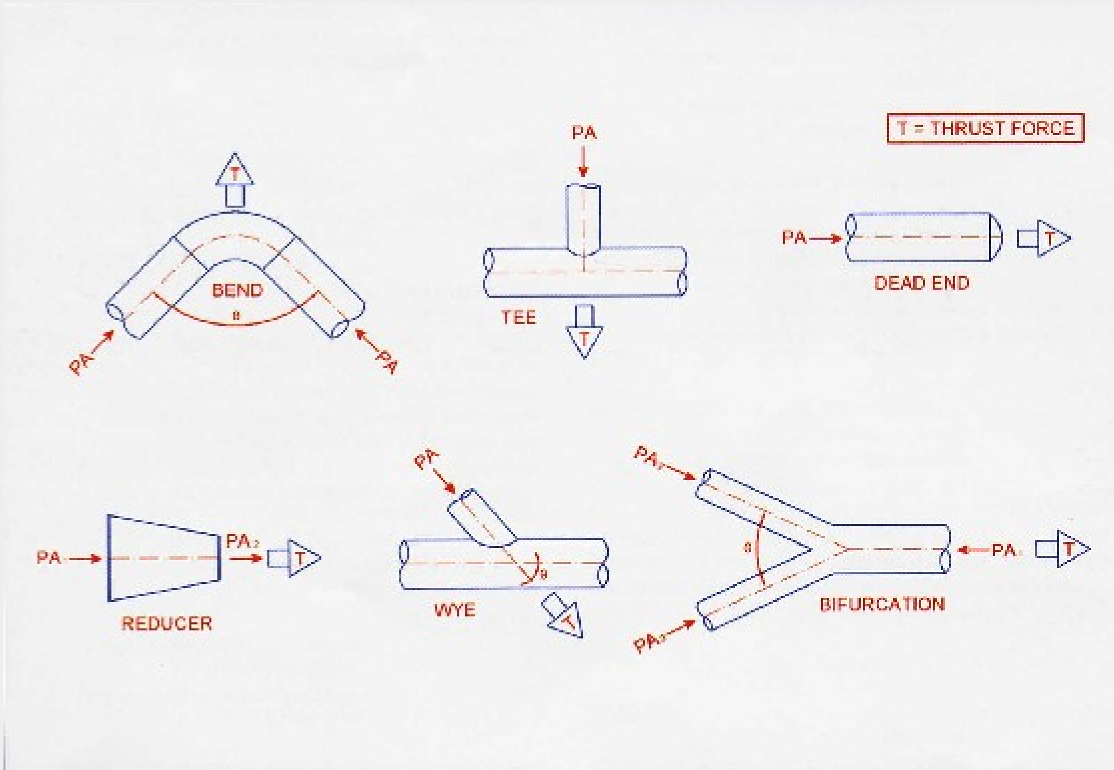
Unbalanced thrust forces occur in pipelines at changes in direction (elbows, wyes, tees, etc), at changes in cross sectional area (reducers) or at pipeline terminations. These forces, if not adequately restrained, may cause pipeline movement resulting in separated joints and/or pipe damage. Thrust forces are hydrostatic thrust force due to internal pressure of the pipeline and hydrodynamic thrust force due to change in momentum of flowing fluid. Since most of the pressure lines operate at relatively low velocities, the hydrodynamic force is very small and is usually ignored.

HYDROSTATIC THRUST

The hydrostatic thrust in dead ends, tees, laterals and reducers is a function of internal pressure and cross sectional area at the pipe joint. The resultant thrust at a bend is also a function of deflection angle.

$T = 2\ P.\ A.\ \sin(\theta/2)$	Elbow
$T = P.\ A$	Tee
$T = P.\ A$	Dead End
$T = P.\ (A_1 - A_2)$	Reducer
$T = P.\ A$	Wye
$T = 2\ P.\ A_2.\ \cos(\theta/2) - P.\ A_1$	Bifurcation

where,
T = Thrust force, kN
P = Internal pressure, kN/m²
A = Cross section area at the pipe joint, m²
θ= Deflection angle, degrees



THRUST FORCE DEFINITIONS

THRUST RESISTANCE

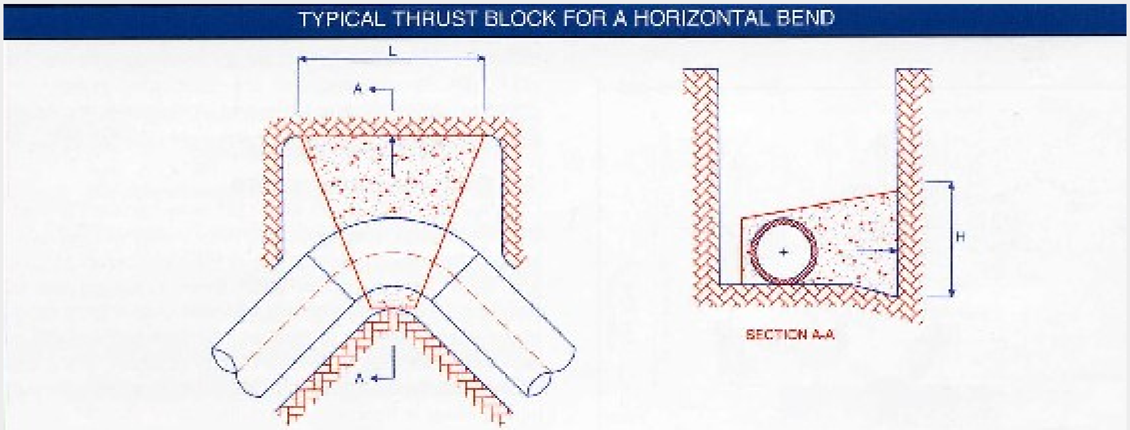
For buried pipelines, unbalanced horizontal thrust forces have two inherent sources of resistance;

1. The frictional drag from dead weight of the pipe, earth cover and the contained fluid and
2. Passive resistance of soil against the pipe or fitting in the direction of the thrust.

If this resistance is not sufficient to resist the thrust, then it must be supplied by increasing the supporting area on the bearing side of the fitting with a thrust block.

THRUST BLOCK

Concrete thrust blocks increase the ability of fittings to resist movement by increasing the bearing area and the dead weight of the fitting. Ignoring the dead weight of the thrust block, the block size can be calculated based on the bearing capacity of the soil.



A = L x H = (T x FS) / σ

where
A = Thrust block area, m^2
L = Length of thrust block, m
H = Height of thrust block, m
T = Thrust force, kN
σ = Bearing strength for soil, kN/m^2
FS = Factor of safety

HORIZONTAL SOIL BEARING STRENGTH

Type of Soil	Bearing strength (kN/m^2)
Soft clay	50
Silt	75
Sandy silt	150
Sand	200
Sandy clay	300
Hard clay	430

For vertical thrusts acting downward, the safe bearing pressure of the various soil may be taken as twice those for horizontal thrusts as given in the table above.