GENERAL CONSIDERATIONS

The design principles for flexible pipe are based on the following characteristics of flexible pipe:

1. In buried flexible pipe, the bending stress of trench load is reduced by the lateral soil reaction developed as the pipe deflects under trench load, and the sides of the pipe push outward against the side fill.
2. Flexible pipe, initially deflected by trench loads, is rerounded by internal pressure, which thereby reduces the stress of trench load. Therefore, when a flexible pipe is subjected to external trench load and internal pressure in combination, the stresses of trench load and internal pressure are not additive, and the pipe may be designed for whichever stress requires the greater design thickness. This is contrary to rigid pipe design in which the simultaneous case of internal pressure and external load must be examined.
3. Flexible pipe usually is required to carry smaller earth loads than a more rigid pipe, because the flexible pipe, in deflecting under the earth load, transfers a part of this load to the side fill and alters the frictional forces in the backfill in such a way as to reduce the earth load to a value less than that imposed on a more rigid pipe.

DUCTILE IRON PIPE DESIGN

DESIGN FOR INTERNAL PRESSURE Design equation $t = \dfrac{p \cdot (D-t) \cdot SF}{20\ R_m}$

Where: t = minimum pipe wall thickness in millimeters
p = internal pressure in bars
D = external diameter of pipe in millimeters
R_m = minimum ultimate tensile strength of the material in megapascals (420 MPa)
SF = design safety factor (3.0 for allowable operating pressure)

DESIGN FOR BENDING Design equation $\Delta_{Bending} = 100\ \dfrac{R_f \cdot (D-t)}{SF \cdot E \cdot D_f}$

Where: $\Delta_{Bending}$ = maximum allowable pipe diametrical deflection due to bending in percent of external diameter
R_f = yield bending strength of ductile iron pipe in megapascals (R_f = 500 MPa)
SF = design safety factor (1.5 versus yield)
E = modulus of elasticity of ductile iron in megapascals (170,000 MPa)
D_f = deformation factor for ductile iron pipe (3.5)

DESIGN FOR DEFLECTION Design equation $t = (D-t)\ \sqrt[3]{\dfrac{0.15 \cdot K_x \cdot q}{\Delta \cdot E} - \dfrac{0.0009E'}{E}}$

Where: Δ = pipe diametrical deflection in percent of external diameter (Design Deflection = 4% or $\Delta_{Bending}$, whichever is less)
K_x = deflection coefficient
q = vertical pressure due to all external loads in megapascals
E = modulus of elasticity of ductile iron in megapascals (170,000 MPa)
E' = modulus of soil reaction in megapascals

Tables for allowable operating pressure and design depths of cover for typical trench soil types are shown on the following pages.

DUCTILE IRON PIPE
ISO CLASSES

SIZE (mm)	NOMINAL THICKNESS (mm)		
	K7	K8	K9
100	-	-	6.1
150	-	-	6.3
200	-	-	6.4
250	-	-	6.8
300	-	-	7.2
350	-	-	7.7
400	-	-	8.1
450	-	7.6	8.6
500	-	8	9
600	7.7	8.8	9.9
700	8.4	9.6	10.8
800	9.1	10.4	11.7
900	9.8	11.2	12.6
1000	10.5	12	13.5
1200	11.9	13.6	15.3
1400	13.3	15.2	17.1
1500	14	16	18
1600	14.7	16.8	18.9

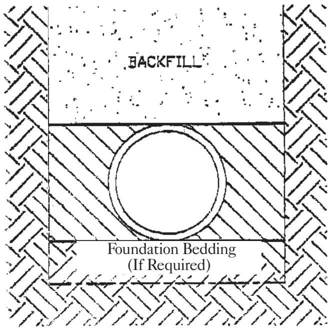
DUCTILE IRON PIPE
MAXIMUM ALLOWABLE OPERATING PRESSURE (BARS)

SIZE (mm)	ALLOWABLE OPERATING PRESSURE		
	K7	K8	K9
100	-	-	33
150	-	-	33
200	-	-	33
250	-	-	33
300	-	-	33
350	-	-	33
400	-	-	33
450	-	35	40
500	-	33	38
600	26	31	36
700	24	29	34
800	23	28	32
900	23	27	31
1000	22	26	30
1200	21	25	29
1400	20	24	28
1500	20	24	27
1600	20	24	27

Operating pressures for 100mm - 400mm sizes are based upon a factory test of 1.5 times the operating pressure. Consult **ACIPCO** if higher pressures are required.

DUCTILE IRON PIPE MINIMUM FACTORY TEST PRESSURE (BARS)			
SIZE (mm)	K7	K8	K9
100	-	-	50
150	-	-	50
200	-	-	50
250	-	-	50
300	-	-	50
350	-	-	50
400	-	-	50
450	-	71	80
500	-	68	76
600	55	62	70
700	51	59	60
800	49	56	60
900	47	53	60
1000	45	52	58
1200	40	40	40
1400	40	40	40
1500	40	40	40
1600	40	40	40

Minimum factory test pressure for 450mm and larger pipe is based upon internal pressure required to produce stress in nominal pipe wall equivalent to 75% of the minimum specified yield strength of the material. In some sizes and pipe classes, test pressures are limited by the maximum allowable factory test pressure currently in ISO 2531.



TYPICAL TRENCH -- Pipe placed on flat bottom trench. If rock or hardpan are encountered, a layer of loose soil should be used as a bedding. Bell holes are recommended.

TRENCH TYPE 1 Embedment -- dumped, less than 70% standard Proctor density.

TRENCH TYPE 2 Embedment -- lightly consolidated, 70% - 80% standard Proctor density.

TRENCH TYPE 3 Embedment -- light compaction, greater than 80% standard Proctor density.

TRENCH TYPE 4 Embedment -- medium compaction, 85% - 95% standard Proctor density.

TRENCH TYPE 5 Embedment -- high compaction, greater than 95% standard Proctor density.

The following ASTM D2487/US Bureau of Reclamation Soil Groups classify different soils for embedment, i.e., soils which are used for placement in the trench surrounding the pipe, compacted or uncompacted, to provide support for the pipeline. These groups classify naturally occurring soils as well as manufactured materials. The groups are also for use in classifying undisturbed trench wall materials.

SOIL CLASSIFICATION

GROUP A -- Angular graded stone (6mm - 40mm), including a number of fill materials that have regional significance such as crushed stone, crushed gravel, and crushed shell.

GROUP B (GW, GP, SW, SP) -- Coarse-grained soils with little or no fines, no particles larger than 40mm, including a number of fill materials that have regional significance which have rounded grains such as pea gravel.

GROUP C (GM, GC, SM, SC, CL, ML, ML-CL, CL-CH, ML-MH) -- Coarse-grained soils with fines and fine-grained soils with medium to no plasticity, with greater than 25% coarse particles, liquid limit (LL) less than 50%.*

GROUP D (CL, ML, ML-CL, CL-CH, ML-MH) -- Fine-grained soils with medium to no plasticity, with less than 25% coarse particles, liquid limit (LL) less than 50%.*

GROUP E (CL, MH, CH, MH) -- Fine-grained soils with medium to high plasticity, liquid limit (LL) greater than 50%.

GROUP F (PT) -- Organic soils.

*Designer must determine percentage of coarse particles to accurately determine soil group.

MAXIMUM RECOMMENDED DEPTHS OF COVER (m) (ACCESS ROADS, SOIL TYPE C, BEDDING IN 100mm LOOSE MATERIAL)			
NOMINAL SIZE (mm)	CLASS	TRENCH TYPE II	TRENCH TYPE III
100	K9	40	40
150	K9	18	19
200	K9	12	13
250	K9	9.9	10
300	K9	8.4	9.4
350	K9	7.4	8.6
400	K9	6.7	8
450	K8	4.9	6.4
450	K9	6.3	7.9
500	K8	4.6	6.3
500	K9	5.9	7.3
600	K7	3	4.9
600	K8	4.4	6.2
600	K9	5.4	7
700	K7	2.7	4.6
700	K8	3.9	5.7
700	K9	5.1	6.7
800	K7	2.5	4.4
800	K8	3.5	5.4
800	K9	4.9	6.6
900	K7	2.4	4.3
900	K8	3.3	5.2
900	K9	4.5	6.3
1000	K7	2.3	4.2
1000	K8	3.1	5
1000	K9	4.2	6
1200	K7	2.1	4.1
1200	K8	2.9	4.7
1200	K9	3.9	5.7
1400	K7	2	4
1400	K8	2.7	4.6
1400	K9	3.6	5.4
1500	K7	2	4
1500	K8	2.7	4.5
1500	K9	3.5	5.3
1600	K7	2	3.9
1600	K8	2.6	4.5
1600	K9	3.4	5.2

MAXIMUM RECOMMENDED DEPTHS OF COVER (m) (MAIN ROADS, SOIL TYPE C, BEDDING IN 100mm LOOSE MATERIAL)			
NOMINAL SIZE (mm)	CLASS	TRENCH TYPE II	TRENCH TYPE III
100	K9	40	40
150	K9	18	19
200	K9	12	13
250	K9	9.7	10
300	K9	8.2	9.3
350	K9	7.2	8.4
400	K9	6.5	7.8
450	K8	4.6	6.2
450	K9	6	7.4
500	K8	4	6.1
500	K9	5.6	7.1
600	K7	2.3	4.6
600	K8	4	5.9
600	K9	5.1	6.8
700	K7	*	4.3
700	K8	3.5	5.5
700	K9	4.8	6.5
800	K7	*	4.1
800	K8	3.1	5.1
800	K9	4.6	6.4
900	K7	*	4
900	K8	2.8	4.9
900	K9	4.2	6.1
1000	K7	*	3.9
1000	K8	2.6	4.7
1000	K9	3.9	5.8
1200	K7	*	3.7
1200	K8	2.3	4.5
1200	K9	3.5	5.4
1400	K7	*	3.7
1400	K8	2.1	4.3
1400	K9	3.2	5.2
1500	K7	*	3.7
1500	K8	2.1	4.3
1500	K9	3.1	5.1
1600	K7	*	3.6
1600	K8	2	4.2
1600	K9	3.1	5

*Type III Trench should be used for this condition.

In some situations, it is necessary or desirable to use supports at designated intervals along pipelines. Aboveground, supported pipe is needed to transport water and other fluids within treatment plants and buildings. Also, pipe on piers is utilized to cross natural or man-made objects.

This section reviews the pertinent design considerations for aboveground ductile iron pipe-on-supports installations. Bridge-crossing installations, which are not specifically addressed, require special attention to their unique situations.

ABOVEGROUND INSTALLATIONS For aboveground installations with one support per length of pipe (i.e., a span length of 6m), the minimum K-class of ductile iron pipe manufactured in all sizes is more than adequate to support the weight of the pipe and water it contains when analyzed in accordance with the suggestions of this procedure.

DESIGN OF DUCTILE IRON PIPE ON ABOVEGROUND SUPPORTS

Other design considerations for pipes supported above ground may include the carrying capacity of the supports themselves, the strength of the structure from which a pipe may be suspended, and/or unusual or additional loads not in the scope of this section. Such loading may include seismic, frequency or resonance of vibrations, wind, water current, and other special design considerations.

It is also necessary to ensure a minimum of lateral and vertical stability at the supports for aboveground piping. Deflected pipe joints can result in thrust forces of hydrostatic or hydrodynamic origin, and if not laterally and vertically restrained, unbalanced forces may result in additional joint deflection and possible failure of the pipeline.

Thermal expansion of ductile iron pipelines supported above ground is not usually of concern in correctly designed and installed systems because of the nature of the push-on joint. A 50° Celsius change in temperature results in expansion or contraction of a 6m length of ductile iron pipe of approximately 3.4mm. This is easily accommodated by correctly installed pipe and joints. Occasionally, where support structures are expected to have significantly different behavior than the pipeline, special considerations for expansion, contraction, and supports may be necessary. For reference, the following are coefficients of thermal expansion for various materials:
Ductile iron: 11.2 x 10^{-6}mm/mm degree Celsius
Steel: 11.7 x 10^{-6}mm/mm degree Celsius
Concrete: 12.6 x 10^{-6}mm/mm degree Celsius

SUPPORT LOCATION System security is maximized by positioning the supports immediately behind the pipe bells. When the support is placed near the bell, the bell section contributes beneficial ring stiffness where it is most needed. This ring stiffness, in turn, reduces the effect of support loads and localized stress. Supports should normally not be placed under spigots adjacent to bells, due to possible undesirable effects on joints.

SADDLE ANGLE AND SUPPORT WIDTH Pipe supports should cradle the pipe in a saddle (see Figure 1). This cradling, which should follow the contour of the pipe, minimizes stress concentrations at the supports. It is recommended that the saddle angle (ß) of the support be between 90° and 120°. Little or no benefit is gained by increasing the saddle angle more than 120°. With angles smaller than 90°, the maximum stress tends to increase rapidly with decreasing saddle angle.

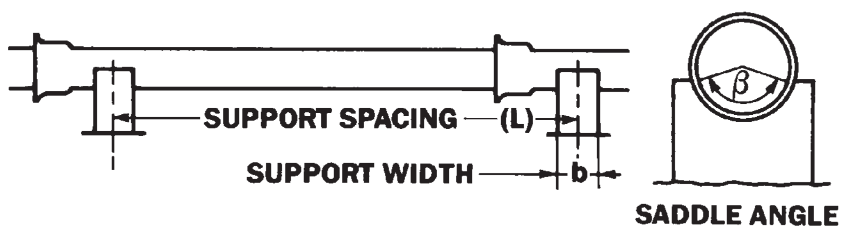
There are some differences among published theories and data regarding the importance of axial support width for saddles. The most accepted formulas are found to be completely independent of saddle width. Some test data, however, show a decrease in measured stresses with an increase in saddle width. There is little effect on the maximum stress when saddle support width is increased more than $\sqrt{2Dt_c}$. Therefore, for saddle supports, the minimum width (b) is determined by the following equation:

$$b = \sqrt{2Dt_c}$$

Where: b = minimum (axial) saddle width (mm)
D = actual outside diameter of pipe (mm)
t_c = nominal pipe wall thickness (mm)

SUPPORT DESIGN Additionally, supports, piles, and/or foundations should be adequately designed from a structural and soil-engineering standpoint to safely handle any loads transferred from the pipe.

FIGURE 1 -- SADDLE ANGLE AND WIDTH



BEAM SPAN FOR DUCTILE IRON PIPE ON SUPPORTS Ductile iron pipe is normally manufactured in 6m nominal lengths, depending on the pipe manufacturer. The most common joint used with ductile iron pipe is the push-on type joint. This rubber-gasketed joint allows a certain amount of deflection and longitudinal displacement while maintaining its hydrostatic seal. This makes these pipe joints ideally suited for normal underground and aboveground installation. The flexibility of the joints reduces the chance of excessive beam stresses occurring. For pipe supported at intervals, however, flexible joints usually require that at least one support be placed under each length of pipe for stability.

Various schemes have been successfully used to obtain longer spans where particular installation conditions presented the need, but these are special design situations and are not specifically addressed in this section. The design presented herein is based upon one support per length of pipe.

BEAM DEFLECTION AT CENTER OF SPAN Computations for beam deflection are also based on the simply supported beam concept. This is likewise conservative due to the reality of offset joints. The maximum allowable deflection at mid-span to prevent damage to the cement-mortar lining is limited to:

$$y_r = \frac{L}{.120}$$

Where: y_r = maximum allowable deflection at center of span (mm)
L = length of span (m)

Less deflection may be desired. The deflection of the beam may be significant for aesthetic reasons in aboveground installations or possibly for hydraulic reasons in gravity-flow pipelines. Limitations on the deflection, if any, should be determined by the designer as appropriate to a specific installation.

The beam deflection at center span for a uniformly loaded, simply supported beam can be calculated using the following formula:

$$y = \frac{wL^4(2.6 \times 10^6)}{E(D^4\text{-}d^4)}$$

Where: y = deflection at center span (mm)
w = unit load per linear foot (kg/m)
L = length of span (m)
E = modulus of elasticity of ductile iron (170 GPa)
D = pipe outside diameter (mm)
d = D - $2t_n$ (mm)
t_n = pipe nominal thickness (mm) - casting tolerance (mm)
(for aboveground installations)

DESIGN TABLE FOR PIPE ON SUPPORTS FOR ABOVEGROUND PIPING

NOMINAL PIPE DIAMETER (mm)	K CLASS	SADDLE ANGLE "ß" (°)	CLEAR SPAN "L" (m)	BEAM DEFL. AT CENTER OF SPAN "y" (mm)	MINIMUM SUPPORT WIDTH (mm)
100	9	90	6	9.680	38
150	9	90	6	5.320	46
200	9	90	6	3.514	53
250	9	90	6	2.494	61
300	9	90	6	1.850	69
350	9	90	6	1.463	76
400	9	90	6	1.175	83
450	8	90	6	1.080	85
500	8	90	6	0.902	92
600	7	90	6	0.756	99
700	7	90	6	0.582	111
800	7	90	6	0.459	124
900	7	90	6	0.371	136
1000	7	90	6	0.307	148
1200	7	90	6	0.221	173
1400	7	90	6	0.168	197
1500	7	90	6	0.148	209
1600	7	90	6	0.131	221

NOTES:
1) Calculations for maximum support reaction stress, midspan deflection, and flexural stress based on design principles from DIPRA Design of Ductile Iron Pipe On Supports. This analysis assumes a simply supported beam.
2) Weight calculations are based on **ACIPCO** Fastite® pipe full of water with standard ISO 4179 cement linings.