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Information and Guidance Note

THE DETERMINATION OF END-LOADS TO BE APPLIED IN THE PERFORMANCE TESTING OF END-LOAD RESISTANT PIPELINE FITTINGS FOR BELOW GROUND USE

CONTENTS

1. GENERAL SCOPE AND OBJECTIVES

This document is intended to provide a basis for the formulation of test criteria to assess the resistance of mechanical fittings to end-loads, for below ground use in water supply, distribution and service pipe applications in the Water Industry. It does not include methods of test but details methods to determine the end-loads imposed on fittings due to those operating conditions which can be predicted. The pipe materials to which the calculations can be applied are MDPE (of nominal size 20 to 1000), PVC-U (of nominal size 90 to 630) and ductile iron (of nominal size 100 to 1600).

Examples of the application of the theory to MDPE (to BS 6572/WIS No. 4-32-03), PVC-U (to WIS No. 4-31-06) and ductile iron (to BS 4772) pipes and fittings have been included to illustrate the use of the equations.

Appendices A, B and C contain examples of suitable forces for pull-out tests on MDPE, PVC-U and ductile iron pipe/fitting assemblies respectively, to act as a guide for the development of test methods.

It is intended that this document be used by those involved in the future preparation of specifications to ensure that a consistent approach is adopted in the testing of mechanical fittings for Water Industry applications.

This document is not intended to be used as a Specification. Information contained within it is given in good faith but neither the Foundation for Water Research, WSA nor WRc plc can accept any responsibility for actions taken as a result.

2. DEFINITIONS

It is recommended that mechanical fittings should be classified into 3 distinct end-load performance levels. For the purpose of this document these are defined as follows:

Type 1 fitting: The end-load resistance of the joint shall be greater than the longitudinal strength of the pipe.

NOTE 1 Type 1 fittings are applicable to polyethylene pipe only. Such fittings would be used on PE pipelines, for example, in areas of mining subsidence and for pull-through applications. Pipelines installed using this type of fitting would not normally require anchoring.

NOTE 2 All fittings for use with polyethylene pipe with outside diameters up to and including 63mm are required to be Type 1.

Type 2 fitting: The end-load resistance of the joint shall be greater than the maximum axial forces (described in Section 3 of this document) assumed to be acting on the joint.

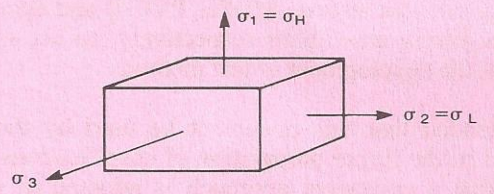
NOTE Pipelines installed using Type 2 fittings would not normally require anchoring.

Type 3 fitting: The end-load resistance of the joint is less than that required by the Type 2 definition.

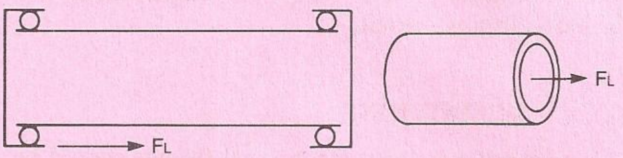
NOTE Pipelines installed using Type 3 fittings will normally require anchoring as for an unrestrained pipeline and the advice of the manufacturer should be sought.

3. THEORETICAL CALCULATIONS (TYPE 2 FITTINGS)

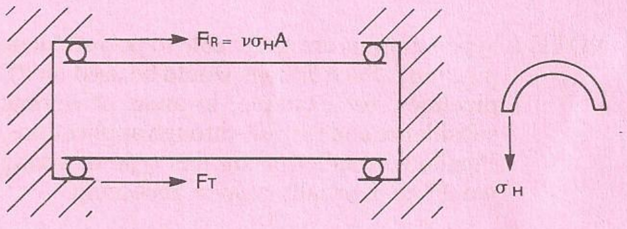
When under pressure, three principal stresses may exist in the pipe wall; the longitudinal stress (σ_L) the circumferential (or hoop) stress (σ_H) and the radial stress (σ_R) (see Figure 1a).



(a) The principal stresses in three dimensions.



(b) The force on an unrestrained joint between a pipe and fitting.



(c) The forces on a restrained fitting.

Figure 1 - The principal forces exerted on a joint due to pressure

It has been assumed that the stresses exerted on the wall of a pressurised pipe covered by this document can be most closely modelled by comparison with a thin-walled cylinder and therefore that the hoop and longitudinal stresses are constant over the wall thickness and that the radial stress is small and can be neglected. However, the use of the mean pipe diameter (D-t) in the formulae instead of the internal diameter (d) practically eliminates any error which may arise from this assumption.

Stresses due to expansion or contraction of the pipe due to a change in temperature between installation and testing may be significant and have been included in the calculations.

Other stresses which may be induced in the pipeline in service but which cannot readily be predicted, e.g. bending, external loading and shear, have not been included in these calculations.

The following calculations involve the quantitative assessment of the forces which tend to separate the fitting from the pipe when a section of pipeline is pressurised.

For the purposes of the calculations, it has been assumed that fittings include a sealing element which forms a frictionless seal on the external surface of the pipe and which is fixed to the bore surface of the fitting in question. Of the sealing arrangements available, this case gives a suitably conservative view of the forces tending to cause separation of a fitting from the pipe.

3.1 Longitudinal forces at the joint due to pressure

3.1.1 *Unrestrained joint*

Where the joint between the fitting and the pipe is unrestrained and using the assumptions given above, it can be shown that the force tending to separate a fitting from a pipe when subjected to internal pressure (p) has a maximum value of F_L (see Figure 1b):

$$F_L = p\pi D^2/4 \qquad (1)$$

where D is the external diameter of the pipe.

3.1.2 *Restrained joint*

When a section of pipe is pressurised, it tends to increase in diameter and reduce in length. The relationship between expansion in the hoop direction and contraction in the longitudinal direction is given by Poisson's ratio υ.

Considering an arrangement of a section of pipe between two fixed (encastré) fittings, the longitudinal force at each joint could achieve a maximum of F_R on pressurisation due to Poisson's ratio effects.

Using the assumption that a pipe can be represented by a thin-walled cylinder under pressure, the hoop stress acting on the longitudinal cross-section area of the pipe is given by:

$$\sigma_H = p\,(D-t)/2t$$

Since the pipe ends are restrained, the Poisson's ratio effect will induce a longitudinal force at each joint tending to separate the pipe from the fitting given as F_R (see Figure 1c):

$$F_R = \upsilon\sigma_H A = \upsilon p\ (D-t)\ .\ A/2t \qquad (2)$$

where υ is Poisson's ratio
A is annular cross-sectional area of pipe
D-t is the mean pipe diameter.

3.2 Longitudinal forces at the joint due to temperature effects

If the pipe ends are restrained, an additional force F_T may be induced due to temperature changes between installation and testing tending to separate the pipe from the fitting:

$$F_T = \sigma_T A = \Delta T.K.E.A \qquad (3)$$

where ΔT = change in temperature (°C)
K = coefficient of expansion ($°C^{-1}$)
E = Young's modulus (MPa).

3.3 Maximum longitudinal force on a joint

Based on the above three cases, the ***maximum*** longitudinal force F_{max} which a fitting may be required to withstand is given by:

(a) *Unrestrained end caps*

$$F_{max} = p\pi D^2/4 \qquad (4)$$

or

(b) *Restrained end caps*

$$F_{max} = F_R + F_T = \upsilon p\ \frac{(D-t)\ A}{2t} + \Delta T\ KEA \qquad (5)$$

For the purposes of type testing, the greatest value of F_{max} will be used to calculate the test forces.

4. EXAMPLES OF THE USE OF THE EQUATIONS FOR DEFINING TEST FORCES FOR PIPE/FITTING ASSEMBLIES

The assessment of the end-load resistance of mechanical fittings can be accomplished by means of a pull-out test. The following procedures demonstrate the application of the theory given in clause 3 to the calculation of pull-out forces for such performance tests.

4.1 Polyethylene pipe/fitting assemblies

4.1.1 *Assumptions*

In order to calculate the maximum end-loads exerted on a fitting due to the stresses in a pressurised SDR 11 125mm polyethylene pipe, the following assumptions are made:

Maximum working pressure (P_W)	= 10 bar
Maximum site test pressure (P_s)	= 1.5 × P_w = 15 bar
Maximum temperature variation (ΔT)	= 40°C
Poisson's ratio (υ)	= 0.42
Young's modulus (E at 20°C)	= 593 MPa
Coefficient of expansion (K)	= 1.45×10^{-4} $°C^{-1}$
External diameter (D	= 125mm
Wall thickness (t)	= 11.4mm
Internal diameter (d)	= 102.2mm
Yield stress (σ_y) (measured at a strain rate of 125% min^{-1} and 23°C.)	= 15 MPa

NOTE 1 The maximum temperature variation has been estimated from the maximum recorded UK summer temperatures and the minimum recorded UK ground temperatures (at pipe cover depth).

NOTE 2 The Young's modulus is defined as that appropriate to the mean of the temperatures used in these calculations (i.e. 20°C).

NOTE 3 The strength properties of polyethylene are strain-rate dependent. Where strain-rate dependent properties have been used in the calculations, the test forces must be applied at the equivalent strain-rate. Testing at other strain rates is permissible provided the test forces have been recalculated using yield stress values appropriate to the chosen strain rate. Figure 2 can be used to define yield stress values for other extension rates between 1 and 1000mm.min^{-1}.

4.1.2 *Calculations*

4.1.2.1 Type 1 fittings

To comply with the definition given in clause 2, Type 1 fittings for polyethylene pipes shall be capable of withstanding a force equivalent to that required to cause yield of a polyethylene pipe (i.e. fully end-load resistant).

For a pull-out test to assess the end-load resistance of Type 1 fittings, the applied pull-out force, F_y, is therefore required to be equivalent to that which causes yield in a polyethylene pipe, i.e.:

$$F_y = \sigma_y A$$

where σ_y = yield stress

A = pipe wall cross-sectional area

The test forces for nominal pipe sizes from 20 to 1000 have been calculated using the appropriate polyethylene pipe dimensions and assuming a yield stress of 15 MPa (see 4.1.1). These are presented in Table A.1 of Appendix A.

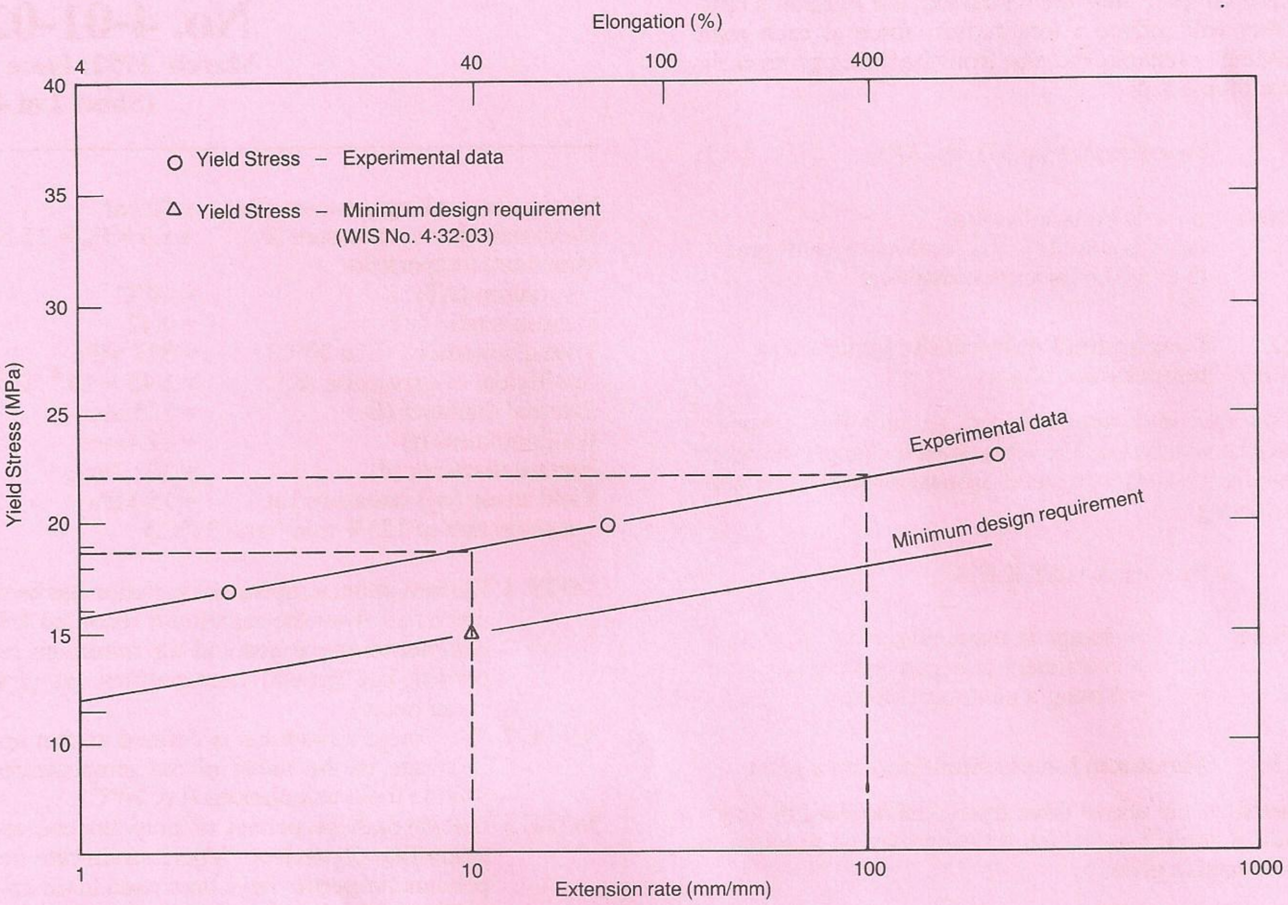


Figure 2 - The relationship between yield stress and extension rate for an MDPE pipe

4.1.2.2 Type 2 fittings

To comply with the definition given in clause 2, Type 2 polyethylene fittings shall be capable of withstanding the maximum axial forces assumed to be acting on the joint under normal operating conditions. Thus, for the assessment of the end-load resistance, a Type 2 fitting shall be considered to be subjected to a force equivalent to that induced in a pipeline installed under conditions of maximum temperature change and operated at its site test pressure. The following details the calculations conducted to determine the appropriate test forces.

(1) $$F_L = \frac{p\pi D^2}{4} \qquad \text{from Equation (1)}$$

$$= \frac{1.5 \times \pi \times 125^2}{4}$$

$$= 18.41\text{kN}$$

(2) $$F_R = \upsilon p\ (D-t)\ A/2t \qquad \text{from Equation (2)}$$

$$= 0.42 \times 1.5 \times \frac{(125 - 11.4) \times \pi}{8 \times 11.4} \times (125^2 - 102.2^2)$$

$$= 12.77\text{kN}$$

and,

(3) $$F_T = \Delta T.K.E.A \qquad \text{from Equation (3)}$$

$$= 40 \times 1.45 \times 10^{-4} \times 593 \times \frac{(125^2 - 102.2^2) \times \pi}{4}$$

$$= 13.99\text{kN}$$

(4) *Unrestrained end-caps*

$$F_{max} = F_L = 18.41\text{kN}$$

Restrained end-caps

$$F_{max} = F_R + F_T = 26.76\text{kN}$$

Since $F_R + F_T > F_L$, then F_{max} is assumed be 26.76kN

F_{max} represents the maximum longitudinal force on a fitting joined to a predicted 10 bar rated, 125mm MDPE pipe restrained at both ends and pressurised to a test pressure of 15 bar.

A Type 2 fitting is required to maintain resistance to end-loads at least equivalent to F_{max}. For a pull-out test to assess the end-load resistance, the applied pull-out test force F should be that which can be induced by F_{max} plus a safety factor (25% has been agreed for current purposes).

NOTE A margin of safety has already been included in the calculations through the use of site test pressures and the maximum value of ΔT. Only a small safety factor has therefore been added to allow resistance to be maintained during integrity testing of the pipeline.

Using appropriate values of F_{max}, test forces (F) can be calculated for each remaining combination of pipe sizes and classes. All test force values are presented in Table A.2 of Appendix A.

4.1.2.3 Type 3 fittings

There are no requirements for pull-out resistance of Type III fittings.

4.1.3 *Assemblies incorporating polyethylene and other service pipe materials*

Where pipe/fitting assemblies incorporate both polyethylene and other service pipe materials, for the purposes of end-load resistance assessment, the assembly is required to meet the performance criteria defined by the polyethylene pipe material.

4.2 PVC-U pipe/fitting assemblies

4.2.1 *Assumptions*

In order to calculate the maximum end-loads exerted on a fitting due to the stresses in a pressurised 12.5 bar rated, 110mm PVC-U pipe, the following assumptions are made:

Maximum working pressure (P_w)	= 12.5 bar
Maximum test pressure (P_s)	= 1.5 × P_W
	= 18.75 bar
Maximum temperature variation (ΔT)	= 40°C
Poisson's ratio (υ)	= 0.38
Young's modulus (E)	= 3.4 GPa
Coefficient of expansion (K)	= 6×10^{-5} °C^{-1}
External diameter (D)	= 110.0 to 110.4mm
Wall thickness (t)	= 5.3mm
Internal diameter (d)	= 99.4 to 99.8mm

4.2.2 *Calculations*

Type 1 fittings are not currently made for use with PVC-U pipes. For Type 2 fittings the calculations detailed in 4.1.2.2 for polyethylene pipe can be similarly conducted for PVC-U using the assumptions given in 4.2.1.

(1) $$F_L = \frac{1.875}{4} \times (110.2)^2 \times \pi = 17.88\text{kN}$$

(2) $$F_R = 1.875 \times \frac{(110.2 - 5.3) \times 0.38}{8 \times 5.3} \times (110.2^2 - 99.6^2) \times \pi = 12.32\text{kN}$$

(3) $$F_T = 40 \times 6 \times 10^{-5} \times 3400 \times (110.2^2 - 99.6^2) \times \pi = 14.25\text{kN}$$

(4) *Unrestrained end-caps*

$$F_{max} = F_L = 17.88\text{kN}$$

Restrained end-caps

$$F_{max} = F_R + F_T = 26.57\text{kN}$$

Since $F_R + F_T > F_L$, then F_{max} is assumed be 26.57kN

F_{max} represents the predicted maximum longitudinal force on a fitting joined to a 12.5 bar rated, 110mm PVC-U pipe restrained at both ends and pressurised to a test pressure of 18.75 bar. To this maximum force, a safety factor of 25% is added to calculate the pull-out test force, F, for a Type 2 fitting for this size and class of PVC-U pipe.

Using appropriate values of F_{max}, test forces (F) can be calculated for each remaining combination of pipe sizes and classes. All test force values are presented in Table B.1 of Appendix B.

4.3 Ductile iron pipe/fitting assemblies

4.3.1 *Assumptions*

In order to calculate the maximum end-loads exerted on a fitting due to the stresses in a pressurised 100mm, Class K9 ductile iron pipe, the following assumptions are made:

Maximum working pressure (P_w)	= 16 bar
Maximum site test pressure (P_s)	= 1.5 × P_W
	= 24 bar
Maximum temperature variation (ΔT)	= 40°C
Poisson's ratio (υ)	= 0.26 - 0.29
Young's modulus (E)	= 169 GPa
Coefficient of expansion (K)	= 10.5 - 11.8 × 10^{-6} °C^{-1}
External diameter (D)	= 118mm
Wall thickness (t)	= 6.1mm
Internal diameter (d)	= 105.8mm

4.3.2 Calculations

Type 1 fittings requirements are not applicable to ductile iron pipes.

For the assessment of the end-load resistance of Type 2 fittings for DN 100, Class K9 ductile iron pipe, F_{max} can be calculated as follows:

(1) $$F_L = 2.4 \times \frac{(118)^2 \times \pi}{4} = 26.25\text{kN}$$

(2) $$F_R = 2.4 \times \frac{(118 - 6.1) \times 0.27}{8 \times 6.1} \times (118^2 - 105.8^2) \times \pi = 12.75\text{kN}$$

(3) Due to the relative rate of heat transfer in a ductile iron pipe for a given wall thickness (coefficient of heat transfer k is 48, 0.5 and 0.15W/m/K for cast iron, HDPE and PVC respectively), it has been assumed that any contraction due to temperature variation will occur during installation, such that the temperature change after assembly will be negligible. In particular for a temperature change ΔT of less than 22°C after installation, $F_R + F_T < F_L$.

F_{max} is assumed to be 26.25kN.

F_{max} represents the maximum predicted longitudinal force on a fitting joined to a DN 100, Class K9 ductile iron pipe pressurised to a test pressure of 24 bar. To this maximum force, a safety factor of 25% is added to calculate the pull-out test force, F, for a Type 2 fitting for this size and class of ductile iron pipe.

Using appropriate values of F_{max}, test forces (F) can be calculated for each remaining pipe size. All test force values are presented in Table C.1 of Appendix C.

5. REFERENCES

This IGN refers to:

BS 4772 Specification for ductile iron pipes and fittings.

BS 6572 Specification for blue polyethylene pipes up to nominal size 63 for below ground use for potable water.

WIS 4-31-06 Water Industry Specification for blue unplasticised PVC (PVC-U) pressure pipes and fittings for buried cold potable water - Metric series.

WIS 4-32-03 Water Industry Specification for blue polythylene (PE) pressure pipe for cold potable water (nominal size 90 to 1000) for underground or protected use.

APPENDIX A - CALCULATED TEST FORCES FOR TYPE 1 AND TYPE 2 MECHANICAL FITTINGS FOR USE WITH POLYETHYLENE PIPE

A.1 TYPE 1 FITTINGS

Table A.1 presents the pull-out test forces for polyethylene pipe/Type 1 fitting assemblies of nominal sizes over the range 20 to 1000. The properties listed in 4.1.1 are assumed to apply with the relevant pipe dimensions.

NOTE For polyethylene pipes whose parameters vary from these assumed values, the criteria in Table A.1 will need to be re-calculated using the appropriate figures.

Table A.1 - Pull-out test forces for Type 1 fittings for use with polyethylene pipe

Nominal size	Test force F_y (kN)*	
	SDR 11 (10 bar)	SDR 17.6 (6 bar)
20	1.56	
25	2.74	
32	3.98	
50	9.75	
63	15.39	
90	31.62	20.46
125	61.04	39.47
180	126.46	81.84
250	243.19	157.87
315	386.08	250.63
355	491.28	318.33
400	623.81	404.14
450	788.64	511.49
500	974.71	631.47
560	1221.38	792.11
630	1546.72	1002.52
710		1272.08
800		1618.08
900		2044.58
1000		2525.11

* Strain rate = 125% min^{-1} at 23°C

A.2 TYPE 2 FITTINGS

Table A.2 presents the pull-out test forces for polyethylene pipe/Type 2 fittings assemblies of nominal sizes over the range 20 to 1000. The properties listed in 4.1.1 are assumed to apply with the relevant pipe dimensions and site test pressures.

NOTE For polyethylene pipe whose parameters vary from these assumed values, the criteria in Table A.2 will need to be re-calculated with the appropriate figures.

Table A.2 - Pull-out test forces for Type 2 fittings for use with polyethylene pipe

Nominal size	Test force F (kN)*	
	SDR 11 (10 bar)	SDR 17.6 (6 bar)
20	N/A	
25	N/A	
32	N/A	
50	N/A	
63	N/A	
90	17.33	11.22
125	33.46	21.63
180	69.32	44.85
250	134.56	86.54
315	211.94	137.40
355	269.70	174.48
400	342.76	221.50
450	432.94	280.39
500	535.09	346.14
560	670.50	434.21
630	849.10	549.51
710		697.30
800		885.58
900		1120.72
1000		1384.11

* Strain rate = 125% min^{-1} at 23°C
N/A – Not Applicable

APPENDIX B - CALCULATED TEST FORCES FOR MECHANICAL FITTINGS FOR USE WITH PVC-U PIPE (TYPE 2 FITTINGS ONLY)

Table B.1 presents the pull-out test forces for PVC-U pipe/Type 2 fitting assemblies of nominal sizes over the range 90 to 630. The properties listed in 4.2.1 are assumed to apply with the relevant pipe dimensions and site test pressures.

Table B.1 - Pull-out test forces for Type 2 fittings for use with PVC-U pipe

Nominal size	Test force F (kN)	
	12.5 bar rated pipe	8 bar rated pipe
90	22.07	14.62
110	33.10	21.77
160	70.00	45.85
200	109.24	72.06
250	170.04	112.25
315	270.00	178.19
400	435.92	287.13
450	551.87	362.92
500	681.46	447.58
630	1080.00	710.96

NOTE For PVC-U pipes whose parameters vary from these assumed values, the criteria in Table B.1 will need to be re-calculated using the appropriate figures.

APPENDIX C - CALCULATED TEST FORCES FOR MECHANICAL FITTINGS FOR USE WITH DUCTILE IRON PIPE (TYPE 2 FITTINGS ONLY)

Table C.1 presents the test forces for ductile iron pipe/Type 2 fitting assemblies of nominal sizes over the range 100 to 1600. The properties listed in 4.3.1 are assumed to apply with the relevant pipe dimensions and site test pressures.

NOTE For ductile iron pipes whose parameters vary from these assumed values, the criteria in Table C.1 will need to be re-calculated using the appropriate figures.

Table C.1 - Pull-out test forces for Type 2 fittings for use with ductile iron pipe

Nominal size	Test force F (kN)
100	32.81
150	68.09
200	116.12
250	176.89
300	250.41
350	336.66
400	433.64
450	542.87
500	666.86
600	950.08
700	1283.29
800	1670.46
900	2104.14
1000	2587.82
1100	3126.92
1200	3711.07
1400	5036.23
1600	6555.46