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UK Water Industry

THE DETERMINATION OF END-LOADS FOR THE PERFORMANCE TESTING OF FITTINGS FOR POLYETHYLENE PIPE

FOREWORD

The purpose of this Information and Guidance Note is to set out the method of calculation of longitudinal tensile loads between a fitting and a pipe induced by water pressure and temperature changes in the pipe.

It provides a basis for the formulation of test criteria to assess the resistance of mechanical fittings to these 'end loads' or 'pull out' loads for below ground, water supply applications in the water industry.

It does not include methods of longitudinal tensile (pull out) testing but details the equations needed to calculate the loads and examples for those operating conditions which can be predicted.

This guidance has been prepared by British Plastics Federation (BPF) Pipes Group in consultation with the Water Industry for Water UK's Standards Board.

This revision supersedes previous versions.

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 Water UK nor BPF Pipes Group can accept any responsibility for actions taken as a result.

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This document has been prepared on behalf of the Water UK Standards Board. Technical queries should be addressed to the Standards Board c/o The Technical Secretary on e-mail: mikeshepherd@thamesinternet.com. For further copies please visit http://www.water.org.uk/publications/WIS-IGN.

1. SCOPE

The method of calculation of longitudinal tensile loads between a fitting and a pipe induced by water pressure and temperature changes in the pipe is applied to polyethylene pipe.

Examples of the application of the theory to PE80 and PE100 (to BS EN 12201-2) pipes and fittings have been included to illustrate the use of the equations.

Appendices A and B contain examples of suitable forces for longitudinal tensile (pull out) tests on PE80 and PE100 pipe / fitting assemblies respectively, to act as a guide for the development of test methods.

Note 1: The method of calculation applied to ductile iron and PVC-U pipes are given in the previous issue of this IGN which may be used as a basis for determining forces when taken with dimensions and materials characteristics from the current pipe standards.

Note 2: For the purposes of assessing the end-load resistance of a fitting connecting polyethylene and other pipe materials, the performance criteria defined by the polyethylene pipe material should be used.

2. DEFINITIONS

Unrestrained joint: The joint / fitting installed in the pipeline is free to move with the pipe as it contracts or expands due to the effects of temperature or pressure changes.

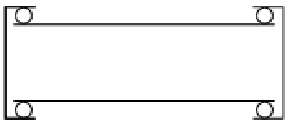

Figure 1 (a) Unrestrained fitting

Note 1: If the forces on the fitting due to pressure in the pipeline exceed the performance of fitting in a longitudinal tensile test, the fitting will blow off the end of the pipe.

Restrained joint: the joint / fitting installed in the pipeline is anchored such that it cannot move with the pipe as it contracts or expands due to the effects of temperature or pressure changes.

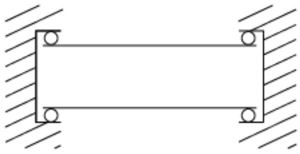

Figure 1 (b) Restrained fitting

Note 2: If the forces on the fitting due to these effects in the pipeline exceed the performance of fitting in a longitudinal tensile test, the pipe will pull out of the joint. Fittings for below ground use will be restrained either by interaction with the surrounding soil or the provision of anchoring points.

The resistance of a fitting to the forces induced in a pipeline during operation can be classified into three distinct end-load performance levels. 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 3: All fittings for use with polyethylene pipe with outside diameters up to and including 63mm are required by the Water Supply (Water Fittings) Regulations 2000 or equivalent to be Type 1.

NOTE 4: Such fittings in larger sizes would be used in specialist applications, for example, in areas of mining subsidence and for pull-through. Pipelines installed using this type of fitting would not normally require anchoring.

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

NOTE 5: 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 6: Pipelines installed using Type 3 fittings would normally require anchoring and the advice of the manufacturer should be sought.

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3. THEORETICAL CALCULATIONS

3.1 Principal stresses in a pressurised pipe

Three principal stresses may exist in the pipe wall when the pipe is under pressure; the longitudinal stress (σ_L), the circumferential (or hoop) stress (σ_H) and the radial stress (σ_R) (see Figures 2a and 2b).

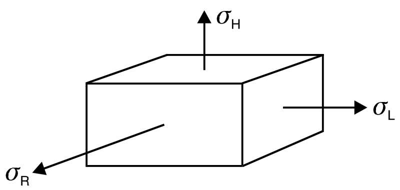

Figure 2 (a) The principal stresses in three dimensions

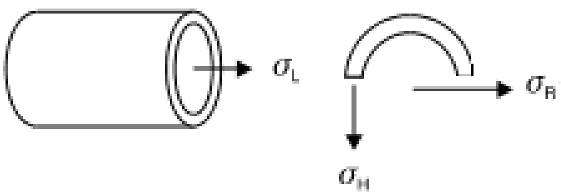

Figure 2 (b) The principal stresses shown on pipe profile

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. 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 calculations in 3.2 – 3.4 involve the quantitative assessment of the forces which tend to separate the fitting from the pipe when a section of pipeline is pressurised.

It has been assumed for the purposes of the calculations 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.

3.2 Longitudinal forces at the joint due to internal pressure

3.2.1 Unrestrained joint

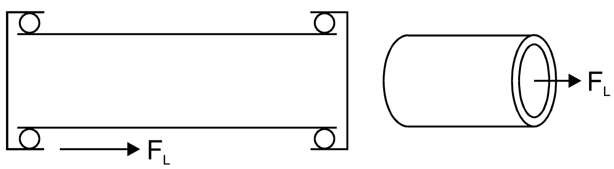

Figure 3 The force on an unrestrained joint between a pipe and a fitting

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 3):

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

where
D = external diameter of the pipe
p = internal pressure

NOTE: Values for performance testing of fittings in this condition are not given in the appendices, but can be calculated from Equation (1).

3.2.2 Restrained joint

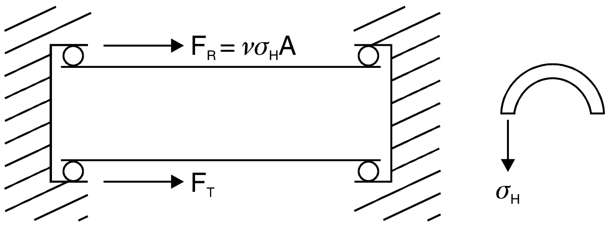

Figure 4 The force on a restrained joint between a pipe and a fitting

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 ν.

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:

$$\sigma_H = \frac{p.(D-t)}{2t} \qquad \text{Equation (2)}$$

where
p = internal pressure
D = external diameter of the pipe
t = pipe wall thickness

Considering an arrangement of a section of pipe between two restrained fittings (see Figure 4), the longitudinal force at each joint could achieve a maximum of F_R on pressurisation due to Poisson's ratio effects.

$$F_R = \vartheta.\sigma_H.A = \frac{\vartheta.p.(D-t).A}{2t} \qquad \text{Equation (3)}$$

where
ν = Poisson's ratio
A = pipe wall cross-sectional area $= \frac{\pi.(D^2 - d^2)}{4}$
D = external diameter of the pipe
d = internal diameter of pipe
σ_H = hoop stress from equation 2

3.3 Longitudinal forces at the joint due to temperature effects

The temperature of the pipe wall during installation is determined by the ambient (surrounding) temperature. The temperature of the pipe wall during operation (including filling of the pipe) is determined by the temperature of the water. Where the pipe is free to move, any change in temperature in the pipe wall would lead to contraction or expansion along the pipe length. Where fixed in place (restrained), any change in temperature would induce a force F_T between the fitting and the pipe.

The additional force F_T induced due to a temperature drop would separate the pipe from the fitting:

$$F_T = \sigma_T.A = \Delta T.K.E.A \qquad \text{Equation (4)}$$

where
ΔT = change in temperature (°C)
K = coefficient of expansion (°C^{-1})
E = Young's modulus (MPa)
A = pipe wall cross-sectional area $= \frac{\pi.(D^2 - d^2)}{4}$
D = external diameter of the pipe
d = internal diameter of pipe

3.4 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) *For unrestrained fittings*

$$F_{max} = F_L = \frac{p.\pi.D^2}{4} \qquad \text{from equation (1)}$$

or

(b) *For restrained fittings*

$$F_{max} = F_R + F_T \qquad \text{from equations (3), (4)}$$

$$F_{max} = \frac{\vartheta.p.(D-t).A}{2t} + \Delta T.K.E.A \qquad \text{equation (5)}$$

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

NOTE: For a temperature drop, force F_T would have a negative value. Similarly, when the pipe is pressurised, force F_R would have a negative value. As shown in Figure 4, the forces pull the pipe away from the fitting. The force which needs to be applied to the pipe / joint assembly in a test to assess resistance is therefore presented as a positive tensile force.

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

The assessment of the resistance of a fitting to the longitudinal forces which cause joint disengagement during pipeline operation can be accomplished by means of a longitudinal tensile (pull out) test. The following procedures demonstrate the application of the theory presented in clause 3 to the calculation of forces for such performance tests.

4.1 PE80 pipe and fitting assemblies

4.1.1 Assumptions for example calculation

To calculate the maximum end-loads exerted on a fitting due to the stresses in a pressurised SDR 11 125mm PE80 pipe (to BS EN 12201-2), the following assumptions are made:

Maximum working pressure	P_w	12.5 bar
Maximum site test pressure	P_s	1.5 x P_w = 18.75 bar
Maximum temperature of pipe wall (see note 1)		40 °C
Water temperature (see note 1)		11 °C
Maximum temperature variation (rounded)	ΔT	30 °C
Poisson's ratio	ν	0.42
Young's modulus (at 20°C)	E	593 MPa
Coefficient of expansion	K	1.45 x 10^{-4} $°C^{-1}$
External diameter	D	125 mm
Wall thickness	t	11.4 mm
Internal diameter	d	102.2 mm
Yield stress (measured at a strain rate of 125% min^{-1}, 23°C)	σ_y	15 MPa

NOTE: The maximum temperature variation has been estimated from the maximum recorded UK summer temperatures to which an uncovered pipe may be exposed and the average water temperature in a buried pipe, see IGN 4-37-02: 1999.

4.1.2 Calculations

4.1.2.1 Type 1 fittings

In line with the definition given in clause 2, Type 1 fittings for PE80 pipes shall be capable of withstanding a force equivalent to that required to cause yield of a PE80 pipe (i.e. fully end-load resistant).

For a tensile test to assess the end-load resistance of a Type 1 fitting, the applied force, F_y, is therefore:

$$F_y = \sigma_y . A \qquad \text{equation (6)}$$

where
σ_y = yield stress
A = pipe wall cross-sectional area

The test forces for nominal pipe sizes from 20 to 180 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.

4.1.2.2 Type 2 fittings

In line with the definition given in clause 2, Type 2 fittings shall be capable of withstanding the maximum longitudinal forces assumed to be acting on the joint under normal operating conditions.

For a tensile test to assess the end-load resistance of a Type 2 fitting the applied force shall be equivalent to that induced in a pipeline installed under conditions of maximum temperature change and operated at its site test pressure.

Using the assumptions in 4.1.1 and the method in Clause 3, an example calculation is shown below for a pressurised SDR 11 125mm PE80 pipe.

From equation (1), $F_L = \frac{p.\pi.D^2}{4}$

$$F_L = \frac{(1.875).\pi.(125^2)}{4} = 23.01\ kN$$

$$F_L = 23.01\ kN$$

From equation (3),

$$F_R = \frac{\vartheta.p.(D-t).A}{2t} \text{ and } A = \frac{\pi.(D^2 - d^2)}{4}$$

$$F_R = \frac{(0.42).(1.875).(125-11.4).\pi.(125^2 - 102.2^2)}{8.(11.4)}$$

$$F_R = 15.96\ k\text{N}$$

From Equation (4), $F_T = \Delta T.K.E.A$

$$F_T = \frac{30.(1.45x10^{-4}).593.\pi.(125^2 - 102.2^2)}{4}$$

$$F_T = 10.49\ kN$$

So, the maximum longitudinal force (see 3.4) for unrestrained fittings is $F_{max} = F_L = 23.01$ kN

So, the maximum longitudinal force (see 3.4) for restrained fittings is $F_{max} = F_R + F_T = 26.45$ kN

F_{max} represents the maximum longitudinal force on a fitting joined to a predicted 12.5 bar rated, 125mm PE80 pipe restrained at both ends and pressurised to a test pressure of 18.75 bar. Since $F_R + F_T > F_L$, then F_{max} is assumed to be 26.45 kN.

The test forces for nominal pipe sizes from 63 to 180 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.2 of Appendix A.

NOTE: A Type 2 fitting is required to maintain resistance to end-loads at least equivalent to F_{max}. A margin of safety is included in the calculations through the use of site test pressures and the maximum value of ΔT. The pipeline designer should review the need for additional safety factors.

4.1.2.3 Type 3 fittings

In line with the definition given in clause 2, there is no requirement for resistance of a Type 3 fitting to longitudinal tensile forces.

4.2 PE100 pipe and fitting assemblies

4.2.1 Assumptions for example calculation

To calculate the maximum end-loads exerted on a fitting due to the stresses in a pressurised SDR11 125mm PE100 pipe (to BS EN 12201-2), the following assumptions are made:

Maximum working pressure	P_w	16 bar
Maximum site test pressure	P_s	1.5 x P_w = 24 bar
Maximum temperature of pipe wall (see note 1 to 4.1.1)		40 °C
Water temperature (see note 1 to 4.1.1)		11 °C
Maximum temperature variation (rounded)	ΔT	30 °C
Poisson's ratio	ν	0.38
Young's modulus (at 20°C)	E	712 MPa
Coefficient of expansion	K	1.30×10^{-4} °C^{-1}
External diameter	D	125 mm
Wall thickness	t	11.4 mm
Internal diameter	d	102.2 mm
Yield stress (measured at a strain rate of 125% min^{-1}, 23°C)	σ_y	19 MPa

NOTE: See note to 4.1.1.

4.2.2 Calculations

4.2.2.1 Type 1 fittings

In line with the definition given in clause 2, Type 1 fittings for PE100 pipes shall be capable of withstanding a force equivalent to that required to cause yield of a PE100 pipe (i.e. fully end-load resistant).

For a tensile test to assess the end-load resistance of a Type 1 fitting, the applied force, F_y (as given in 4.1.2.1, equation 6) is required to be equivalent to that which causes yield in a PE100 pipe.

The test forces for nominal pipe sizes from 63 to 1200 have been calculated using the appropriate polyethylene pipe dimensions and assuming a yield stress of 19 MPa (see 4.2.1). These are presented in Table B.1 of Appendix B.

4.2.2.2 Type 2 fittings

In line with the definition given in clause 2, Type 2 fittings shall be capable of withstanding the maximum longitudinal forces assumed to be acting on the joint under normal operating conditions.

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For a tensile test to assess the end-load resistance of a Type 2 fitting the applied force shall be equivalent to that induced in a pipeline installed under conditions of maximum temperature change and operated at its site test pressure.

Using the assumptions in 4.2.1 and the method in Clause 3, an example calculation is shown below for a pressurised SDR 11 125mm PE100 pipe.

From equation (1), $F_L = \frac{p.\pi.D^2}{4}$

$$F_L = \frac{(2.4).\pi.(125^2)}{4} = 29.45\ kN$$

From equation (3),

$$F_R = \frac{\vartheta.p.(D-t).A}{2t} \text{ and } A = \frac{\pi.(D^2 - d^2)}{4}$$

$$F_R = \frac{(0.38).(2.4).(125-11.4).\pi.(125^2 - 102.2^2)}{8.(11.4)}$$

$$F_R = 18.49 \text{ kN}$$

From Equation (4), $F_T = \Delta T.K.E.A$

$$F_T = \frac{30.(1.30x10^{-4}).712.\pi.(125^2 - 102.2^2)}{4}$$

$$F_T = 11.30\ kN$$

So, the maximum longitudinal force (see 3.4) for unrestrained fittings is $F_{max} = F_L$ = 29.45 kN

So, the maximum longitudinal force (see 3.4) for restrained fittings is $F_{max} = F_R + F_T$ = 29.79 kN

F_{max} represents the maximum longitudinal force on a fitting joined to a predicted 16 bar rated, 125mm PE100 pipe restrained at both ends and pressurised to a test pressure of 24 bar. Since $F_R + F_T > F_L$ then F_{max} is assumed to be 29.79 kN.

The test forces for nominal pipe sizes from 63 to 1200 have been calculated using the appropriate polyethylene pipe dimensions and assuming a yield stress of 19 MPa (see 4.1.1). These are presented in Table B.2 of Appendix B.

NOTE: See note to 4.1.2.2

4.2.2.3 Type 3 fittings

In line with the definition given in clause 2, there is no requirement for resistance of a Type 3 fitting to longitudinal tensile forces.

5. REFERENCES

BS EN 12201-2: Plastics piping systems for water supply, and for drainage and sewerage under pressure. Polyethylene (PE). Pipes.

APPENDIX A - CALCULATED TEST FORCES FOR TYPE 1 AND TYPE 2 MECHANICAL FITTINGS FOR USE WITH PE80 PIPE MANUFACTURED TO BS EN 12201-2

A.1 Type 1 Fittings

Table A.1 presents the pull-out test forces for PE80 pipe / Type 1 fitting assemblies of nominal sizes over the range 20 to 180. The properties listed in 4.1.1 are assumed to apply with the relevant pipe dimensions.

A.2 Type 2 Fittings

Table A.2 presents the test forces for PE80 pipe / Type 2 fittings assemblies of nominal sizes over the range 63 to 180. The properties listed in 4.1.1 are assumed to apply with the relevant pipe dimensions and site test pressures.

NOTE: For PE80 pipe whose parameters vary from these assumed values, the criteria in Table A.1 and Table A.2 would need to be re-calculated with the appropriate values.

APPENDIX B - CALCULATED TEST FORCES FOR TYPE 1 AND TYPE 2 MECHANICAL FITTINGS FOR USE WITH PE100 PIPES MANUFACTURED TO BS EN 12201-2

B.1 Type 1 Fittings

Table B.1 presents the pull-out test forces for PE100 pipe / Type 1 fitting assemblies of nominal sizes over the range 63 to 1200. The properties listed in 4.2.1 are assumed to apply with the relevant pipe dimensions.

B.2 Type 2 Fittings

Table B.2 presents the pull-out test forces for PE100 pipe / Type 2 fittings assemblies of nominal sizes over the range 63 to 1200. The properties listed in 4.2.1 are assumed to apply with the relevant pipe dimensions and site test pressures.

NOTE: For PE100 pipe whose parameters vary from these assumed values, the criteria in Table B.1 and Table B.2 will need to be re-calculated with the appropriate figures.

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Table A.1 - Pull-out test forces for Type 1 fittings for use with PE80 pipe

Nominal Size	Test force Fy (kN)			
	SDR 11	SDR 17	SDR 21	SDR 26
20	1.6			
25	2.4			
32	4.0			
40	6.2			
50	10.0			
63	15	10	8	7
75	22	15	12	10
90	32	21	17	14
110	47	32	26	21
125	61	41	33	27
140	76	51	42	34
160	100	67	55	45
180	126	85	69	56

Table A.2 - Pull-out test forces for Type 2 fittings for use with PE80 pipe

Nominal Size	Test force F (kN)			
	SDR 11	SDR 17	SDR 21	SDR 26
63	7	5	4	3
75	10	7	5	4
90	14	9	7	6
110	20	14	11	9
125	26	18	14	12
140	33	23	18	15
160	43	30	23	19
180	55	37	29	25

Table B.1 - Pull-out test forces for Type 1 fittings for use with PE100 pipe

Nominal Size	Test force F (kN)					
	SDR 11	SDR 17	SDR 21	SDR 26	SDR 33	SDR 41
63	20	13	11	9		
75	28	19	15	12		
90	40	27	22	18		
110	60	40	33	27		
125	77	52	42	34		
140	97	65	53	43		
160	126	85	69	57		
180	160	107	88	72		
200	197	132	108	88		
225	250	167	137	112		
250	308	207	169	138		
280	387	259	212	173		
315	489	328	269	219	174	141
355	622	416	341	278	221	179
400	789	529	433	353	281	227
450	999	669	548	447	355	288
500	1233	826	677	552	438	355
560	1547	1036	849	692	550	445
630	1958	1312	1074	876	696	564
710	2487	1666	1365	1113	884	716
800	3157	2115	1733	1413	1123	909
900	3996	2677	2193	1788	1421	1150
1000	4933	3305	2707	2207	1754	1420
1200		4759	3898	3179	2526	2045

Table B.2 - Pull-out test forces for Type 2 fittings for us with PE100 pipe

Nominal Size	Test force F (kN)					
	SDR 11	SDR 17	SDR 21	SDR 26	SDR 33	SDR 41
63	8	5	4	3		
75	11	7	6	5		
90	15	10	8	7		
110	23	16	13	10		
125	30	20	16	13		
140	37	25	21	16		
160	49	33	27	21		
180	62	41	34	27		
200	76	51	42	33		
225	96	65	53	41		
250	119	80	65	51		
280	149	100	82	64		
315	189	127	104	81	68	54
355	240	161	132	103	86	69
400	305	205	167	131	109	88
450	386	259	212	166	138	111
500	476	320	262	204	170	138
560	597	401	328	256	213	172
630	756	508	415	325	270	218
710	960	645	527	412	343	277
800	1,219	818	669	523	435	352
900	1,542	1,036	847	662	551	445
1000	1,904	1,279	1,046	817	679	549
1200		1,841	1,506	1,178	978	791