INFORMATION AND GUIDANCE NOTE (IGN) WSA TN 3

Ring bending stiffness, allowable deflection and embedment design of ductile iron and steel pipe

1 INTRODUCTION

In 2005 TN 3 was developed to cover the significant changes in the manufacture of ductile iron (DI) pipes that resulted from the 2004 publication of AS/NZS 2280. Since then AS/NZS 2280 has been revised twice and the manufacture of DI pipe has ceased in Australia. Also over the past 12 years significant work has been undertaken on allowable deflections for steel pipe.

As a result of all those changes the technical information associated with ring stiffness, allowable ring deflection, and embedment design has evolved and has now been incorporated into a AS/NZS 2566.1:1998/Amdt 1:2017. This revision of TN 3 includes those changes, as well as providing supporting information and extending the document to include steel pipes.

This guidance note covers the issues of diametral / ring stiffness, and allowable diametral / ring deflection for ductile iron and steel pipe manufactured to AS/NZS 2280:2014 and AS 1579-2001 respectively.

2 DIAMETRAL / RING BENDING STIFFNESS

2.1 GENERAL

Ring bending stiffness is calculated using the formula, as shown in AS/NZS 2566.1 Section 2.2.

$$S = \frac{(E \times t^3)}{(12 \times D^3)}$$

Where

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

E = is the modulus of elasticity of the pipe wall material

t = wall thickness

Each DI pipe has a significant range of wall thickness (t) values within each pipe. This is a direct result of the casting process. To achieve the specified minimum wall thicknesses in DI pipe, much of the pipe is at thicknesses significantly above the minimum. In TN 3 Issue 1, 2005, it was recommended to use

$$t_{pipe\ stiffness} = \frac{(specified\ minimum\ t\ + specified\ nominal\ t)}{2}$$

in place of the specified minimum wall thickness for ductile iron pipes when calculating ring bending stiffness. The basis of that data came from the local manufacturer and this thickness is also what is used in EN/ISO DI pipe standards. Even though DI pipes are now all imported there seems to be no reason to change that approach.

The approach for DI pipe is in contrast to that used for other materials, such as steel pipe. With steel pipe, the actual wall thickness of the pipe is very close to the specified minimum wall thickness, and therefore for steel pipe the use of the specified minimum wall thickness should be used for calculating ring bending stiffness.

The value of the DI modulus of elasticity (material stiffness) used in Australia has been 165 MPa. EN/ISO DI pipe standards use 170 GPa. As all DI pipe is now imported from manufacturers that also make pipe to the EN/ISO standards, it is recommended that 170 GPa now be used for the material modulus for DI pipe. This change to 170 GPa has also been made in the AS/NZS 2566.1:1998/Amdt 1:2017.

Typically DI and steel water pipe are supplied with a cement mortar lining (CML), and this increases the overall stiffness of the pipe. Hence it should be included in the overall ring bending stiffness calculation. A simplified conservative approach is used by increasing the metal wall thickness (as used in calculations) by one tenth of the specified minimum CML thickness.

Hence the ring bending stiffness equations for DI and steel pipe become:

For DI pipe:

Ring bending stiffness (S) = $\frac{\left(170 \times \left(t_{pipe\ stiffness}\ + 0.1 \times t_c\right)^3\right)}{12 \times D^3}$

where

$$t_{pipe\ stiffness} = \frac{(specified\ minimum\ t\ + specified\ nominal\ t)}{2}$$

t_c = specified minimum CML thickness and

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - $t_{pipe\ stiffness}$

For steel pipe:

Ring bending stiffness (S) = $\frac{(207 \times (t + 0.1 \times t_c)^3)}{12 \times D^3}$

where:

t = specified minimum wall thickness

t_c = specified minimum CML thickness and

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

These equations have been used to calculate the ring bending stiffness values shown in Tables 1 and 2 for a range of typically used pipes.

TABLE 1

RING BENDING STIFFNESS VALUES FOR DI CML PIPE BASED ON $t_{pipe\ stiffness}$

Pipe size DN	Pipe ring bending stiffness, kN/m/m		
	PN 20	PN 35	Flange
100	N/A	816	3,239
150	N/A	267	1,027
200	N/A	117	668
225	59	83	475
250	45	68	510
300	25	58	286
375	15	53	209
450	13	49	165
500	12	47	122
600	11	44	92
750	10	42	81

TABLE 2

RING BENDING STIFFNESS VALUES FOR STEEL CML PIPE BASED ON $t_{minimum}$

Pipe size *De* x *t* mm	Pipe ring bending stiffness, kN/m/m
219 x 5	309
324 x 5	109
406 x 5	55
508 x 5	28
610 x 5	16
762 x 6	13
914 x 7	13
1219 x 8	8
1422 x 10	9
1626 x 12	10
1829 x 12.5	8

3 ALLOWABLE DIAMETRAL / RING DEFLECTION

3.1 GENERAL

The allowable ring deflection of DI and steel pipes is based on:

(a) Limiting deflection to prevent yielding of the pipe material.

(b) Limiting deflection to ensure that the CML is not damaged.

(c) Ensuring the joint is able to withstand the recommended deflection limit.

(d) Ensuring transport deflections are not excessive.

These aspects are reviewed below in determining the allowable ring deflection of DI and steel pipes.

3.2 DEFLECTION LIMITS BASED ON PIPE YIELDING

ISO 10803 – 2011 (Design method for ductile iron pipes) provides the following formula for the allowable deflection for DI pipe:

Maximum Deflection = $\frac{100 \times R_f \times (D_e - t)}{(SF \times E \times t \times DF)}$

where:

D_e = diameter of the most extreme external surface along the pipe barrel.

t = nominal wall thickness (as specified in AS/NZS 2280).

R_f= yield bending strength of the pipe wall material.

SF = the safety of factor.

DF = the deformation factor which depends mainly on the pipe diametral stiffness

E = is the modulus of elasticity of the pipe wall material

Using all the values used in EN/ISO standards (R_f = 500 MPa, SF = 1.5, E = 170 GPa, DF = 3.5, and t = nominal wall thickness) the equation reduces to:

Maximum Deflection of DI pipe = $0.56 \times \frac{D}{t}$,

where:

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = nominal wall thickness (as specified in AS/NZS 2280)

Note: The effective yield strength used is R_f/SF = 500/1.5, which at 333 MPa is unconservative. However this is compensated by using the nominal pipe wall thickness instead of $t_{\text{pipe stiffness}}$ in the calculation. If one uses a more typical minimum yield strength value of 280MPa, combined with $t_{\text{pipe stiffness}}$, the limiting values calculated are very similar to those determined by the equation shown above, i.e. 0.56 x D/t Using 0.56 x D/t (using the nominal pipe wall thickness) aligns with EN/ISO practice and gives appropriate limiting deflection values. The equation for DI pipe, using 0.56 x D/t, has been adopted in AS/NZS 2566.1:1998/Amdt 1:2017 and in this technical note.

A theoretical assessment for steel pipe gives:

Maximum Deflection of steel pipe = $0.00014 \times YS \times \frac{D}{t}$

where:

YS = Nominal or specified minimum yield strength

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

This equation for steel pipe has been adopted in AS/NZS 2566.1:1998/Amdt 1:2017 and in this technical note.

For steel with the common 300 MPa yield strength the equation reduces to:

Maximum Deflection $(of\ 300\ MPa\ YS\ steel\ pipe) = 0.042\ \times\ \frac{D}{t}$

where:

YS = Nominal or specified minimum yield strength

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

It should be noted that the yield limiting equations that are used for both DI and steel pipe have an inherent factor of safety included in them for two reasons. The limit is based on minimum yield values and arguably could be based on much higher tensile values, and any possible yielding would occur in only part of the wall thickness at only two locations within the pipe.

In order to check that the equations for both DI and steel give safe deflection outcomes, deflection tests on unlined DN 375 and DN 750 DI pipes and unlined 419 x 5 and 813 x 6 steel pipes were undertaken by the local pipe manufacturers. At the deflection limits (as calculated by the above equations) the amount of permanent deformation measured in the pipes was insignificant. These tests demonstrated the suitability of the equations, which have now been recommended for some time.

3.3 DEFLECTION LIMITS BASED ON CEMENT MORTAR LINING (CML) CRACKING

The prime criteria in determining the allowable deflections in cement mortar lined pipe is that the mortar is not damaged. As the tensile strength of CML is very low, cracking of the CML can occur under low deflections. Nonetheless, because the lining provides “active” corrosion protection, some CML cracking is acceptable. The product standards allow crack widths up to 0.8 mm for DI and 2mm for steel pipe.

From a theoretical viewpoint, if one assumes the CML has zero tensile strength, then a model can be used to determine the maximum crack widths that are obtained. Theoretical analysis has indicated that using the deflection limiting equations based on pipe yielding, plus an overall limit of 4.0%, CML cracking would be kept below the product standard limits. Note that these deflection limits apply to the pipe body. To test/verify this model, tests on DI and steel pipes were performed as shown in Table 3.

TABLE 3

DEFLECTION TEST RESULTS FOR DI AND STEEL PIPE

Pipe type/size	Number of pipes tested	Maximum deflection tested	Maximum CML crack width
DI DN375	2	3.0%	0.2 mm
DI DN750	2	4.0%	0.2 mm
Steel 419mm D_e x 5mm t	2	4.0% & 5.0%	0.3mm for each pipe
Steel 813mm D_e x 6mm t	2	4.0%	0.6mm & 0.7mm

In all cases cracking was well within the limits allowed in the product standards, indicating a sufficient factor of safety in the equations. The yield limiting equations together with a 4.0% limit have now been used for DI and steel pipe deflection limits for several years with no excessive cracking being reported and they have been included into the AS/NZS 2566.1:1998/Amdt 1:2017. Deflections for DI and steel pipe, based on the limiting equations and an overriding 4% limit, are shown in Table 4 and 5.

3.4 DEFLECTION LIMITS BASED ON JOINT DESIGN

FEA analysis as well as full scale testing has been undertaken by local manufacturers on TYTON DI JOINT® pipe as well as the Sintajoint® steel elastomeric joint. The results demonstrate that both these joints are able to withstand the loads that result from ring deflections up to 4.0%. A 4.0% limit is also appropriate for welded steel joints (based on the CML limit). The limits for any other elastomeric pipe joints (other than TYTON® and Sintajoint®) should be tested/verified to determine appropriate limits before they are considered for use.

It is noted that in designing pipe embedment one determines the allowable loading based on ring bending stiffness based on the pipe body and the allowable deflection in the pipe body. As the joints for both DI (in particular) and steel are stiffer than the pipe body, the limits for deflection and any field measurements, should also be based on the pipe body.

TABLE 4

TYTON JOINT® DI PIPE DEFLECTION LIMITS

Pipe size DN	Maximum allowable deflection, %		
	PN 20	PN 35	Flange
100	NA	1.3	0.9
150	NA	1.9	1.3
200	NA	2.6	1.5
225	3.2	2.9	1.7
250	3.4	3.0	1.6
300	4.0	3.2	2.0
375	4.0	3.4	2.2
450	4.0	3.5	2.4
500	4.0	3.5	2.6
600	4.0	3.6	2.8
750	4.0	3.7	3.0

TABLE 5

SINTAJOINT® STEEL & FULLY WELDED STEEL PIPE DEFLECTION LIMITS

(FOR 300 MPa YIELD STEEL)

Pipe size D_e x t, mm	Maximum allowable deflection, %
219 x 5	1.8
324 x 5	2.7
406 x 5	3.4
508 x 5	4.0
610 x 5	4.0
762 x 6	4.0
914 x 7	4.0
1219 x 8	4.0
1422 x 10	4.0
1626 x 12	4.0
1829 x 12.5	4.0

3.5 DEFLECTIONS DURING TRANSPORT AND STORAGE

A review of deflections that can result from transport and storage has been undertaken. The analysis was based on users following the manufacturers recommended instructions for transport and storage of pipe. The results show that the expected deflections are well below the allowable deflections determined from the model that is based on pipe yielding plus an overall limit of 4.0%.

3.6 SUMMARY

In summary it is concluded that a model that uses the deflection limiting equations based on pipe yielding plus an overall limit of 4.0% for DI and steel water pipe is appropriate for TYTON JOINT® jointed DI pipes, and Sintajoint® steel elastomeric jointed pipes, as well fully welded steel pipelines.

The equations to be used are:

For TYTON JOINT® jointed DI pipe:

Allowable Deflection of DI pipe = $0.56 \times D/t$, with a limit of 4.0%

where:

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = nominal wall thickness (as specified in AS/NZS 2280)

For Sintajoint® steel elastomeric jointed pipes and fully welded steel pipelines:

Maximum Deflection of steel pipe = $0.014 \times YS \times D/t$, with a limit of 4.0%

where:

YS = Nominal or specified minimum yield stress

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

For steel with 300 MPa YS the equation for steel becomes:

Maximum Deflection $(of\ 300\ MPa\ YS\ steel\ pipe)$= $0.042\ x\ D/t$

Where

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

Using these equations allowable deflections for typically used pipes have been calculated and are shown in Tables 4 and 5.

4 RECOMMENDATIONS

This IGN covers analysis and testing of ductile iron and steel pipes to determine the appropriate values for ring bending stiffness and allowable ring deflections.

The recommendations are summarised as follows:

For TYTON JOINT® jointed DI pipe:

Ring bending stiffness (S) = $\frac{\left(170 \times \left(t_{pipe\ stiffness} + 0.1 \times t_c\right)^3\right)}{12 \times D^3}$

where:

$$t_{pipe\ stiffness} = \frac{(specified\ minimum\ t + specified\ nominal\ t)}{2}$$

t_c = specified minimum CML thickness and

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t pipe stiffness

Allowable Deflection of DI pipe = $0.56 \times {}^{D}/_{t}$, with a limit of 4.0%

where:

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = nominal wall thickness

For Sintajoint® steel elastomeric jointed pipes and fully welded steel pipelines:

Ring bending stiffness (S) = $\frac{(207 \times (t + 0.1 \times t_c)^3)}{12 \times D^3}$

where:

t = specified minimum wall thickness

t_c = specified minimum CML thickness and

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

Allowable Deflection of steel pipe = $0.014 \times YS \times {}^{D}/_{t}$, with a limit of 4.0%

where:

YS = Nominal or specified minimum yield stress

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

For steel with 300MPa YS the equation becomes:

Maximum Deflection $(of\ 300MPa\ YS\ steel\ pipe)$= $0.042 \times {}^{D}/_{t}$

where

D = diameter at the neutral axis of the pipe = outside diameter (D_e) - t

t = specified minimum wall thickness

The limits for elastomeric DI and steel pipe joints other than TYTON JOINT® and Sintajoint® would need to be tested/verified.