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Industry Guidelines

DEPTH OF ENGAGEMENT FOR PVC PIPES

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DEPTH OF ENGAGEMENT FOR PVC PIPES

The objective of this guideline is to describe in detail two methods that have been used *to determine minimum depth of engagement for PVC pipes with elastomeric seal joints* used for either pressure or non-pressure applications. Both methods have been successfully applied in Australia and New Zealand in the past.

Two methods are described for calculating the socket length of PVC pipes with elastomeric seal joints in order to minimise the risk of failure due to partial or complete separation of the joint. The methods apply to PVC-U, PVC-M and PVC-O with elastomeric seal joints.

Note: The principles may also be applied to pipes of other materials provided the relevant pipe characteristics are known.

Experience to date suggests both methods give comparable results, provided appropriate values are selected for the variables. Either method may be used alone or both applied and the results compared.

The elastomeric seal joints addressed here are not restrained, but are free to move with expansion and contraction of the pipes due to changes in temperature and pressure. In addition, the joints have to be able to accommodate the chamfer cut on the spigot end, any variation in end squareness of the spigot and the angular deflection that might occur at the joint during installation or operation. The methods described do not address any ground strain that might occur, for example, in mine-subsidence areas. The methods can however be readily adapted to take into account potential ground strain.

Both methods describe how to calculate the required depth of engagement of a pipe socket so that the spigot can be inserted to a sufficient depth to accommodate all anticipated expansions and contractions. The required insertion depth, and hence the position of the witness mark, will depend upon not only the minimum depth of engagement, but also the socket design.

Method 1 is the traditional method used in Australia and involves the simple summation of all of the contributing factors, at their realistic extreme. Thus, even if all of the factors affecting the insertion depth occur at their extreme values simultaneously, the joint will continue to perform satisfactorily.

Method 2, developed by Dr Richard Jarrett of the CSIRO, considers the same contributing factors, but applies a statistical technique on the assumption that there is a diminished risk of all the extremes occurring simultaneously. This method assumes there is a normal distribution of each of the variables affecting depth of engagement.

The method requires knowledge of the service conditions applicable to the industry sector under consideration. Where the service conditions differ for two different market sectors, there will be a bimodal distribution of some of the variables, rather than a normal distribution. When a bimodal distribution occurs, Method 2 does not apply unless modified by examining each market sector separately, or by assuming the worst-case sector applies to all. For example, PVC pressure pipes might be operated at much less than class head by the major water agencies and at class head, or higher, by irrigators. In this situation, there will be a bimodal distribution of operating pressures over the range of applications. Assuming the pressure distribution is normal could lead to a higher than the predicted failure rate in the irrigation sector. Treating separately the market sectors with different service conditions, avoids this error.

Depth of engagement

The depth of engagement is the total distance from the elastomeric seal to the end of the pipe when the spigot is fully inserted into the socket, as shown in Figure 1.

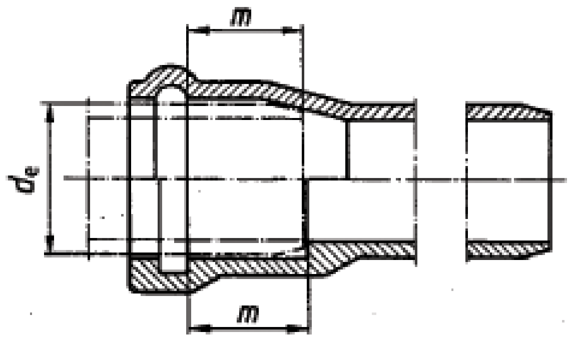

Figure 1 Depth of engagement.

Notation

d_e	=	external diameter of the pipe (mm)
m	=	depth of engagement (mm)
m_p	=	Poisson contraction that occurs when the pipe is pressurised (mm)
m_t	=	thermal contraction resulting from a reduction in temperature (mm)
m_a	=	retraction of one side of the spigot due to angular deflection at the joint (mm)
m_c	=	chamfer length (mm)
m_e	=	tolerance on end squareness (mm)

m_{cf} = construction factor (mm)

L = effective pipe length (mm)

μ = Poisson's ratio

S = hoop (or circumferential) stress generated by the internal pressure within the pipe (MPa)

E_c = long term tensile modulus of the pipe material in the hoop direction (MPa)

λ = linear coefficient of thermal expansion ($^\circ C^{-1}$)

ΔT = temperature range including installation and operation ($^\circ$C)

θ = maximum angular deflection of the spigot with respect to the socket ($^\circ$)

Φ = skewness of spigot end ($^\circ$)

Additional Notation Specific to Method 2

f	=	anchoring effect due to friction at the pipe – soil interface. f = 1 where there is no friction between the pipe and soil, for example in an above ground installation. f = 0 where soil – pipe friction prevents pipe movement.
f_{mean}	=	mean anchoring effect due to soil friction
f_{sdev}	=	standard deviation of anchoring effect due to soil friction
m_{Tmean}	=	mean total depth of engagement (mm)
m_{Tsdev}	=	standard deviation of the total depth of engagement (mm)
m_{pmean}	=	mean Poisson contraction (mm)
m_{psdev}	=	standard deviation of Poisson contraction (mm)
m_{tmean}	=	mean thermal contraction (mm)
m_{tsdev}	=	standard deviation of thermal contraction (mm)
m_{amean}	=	mean retraction due to angular deflection (mm)
m_{asdev}	=	standard deviation of retraction due to angular deflection (mm)
m_{cmean}	=	mean chamfer length (mm)
m_{csdev}	=	standard deviation of chamfer length (mm)
m_{emean}	=	tolerance on end squareness (mm)
m_{esdev}	=	standard deviation of tolerance on end squareness (mm)
m_{cfmean}	=	mean construction factor (mm)
m_{cfsdev}	=	standard deviation of construction factor (mm)
L_{mean}	=	unanchored pipe length used to calculate the Poisson and thermal contractions (mm)
L_{sdev}	=	standard deviation of unanchored pipe length (mm)
L_{cmean}	=	mean chamfer length (mm)
L_{csdev}	=	standard deviation of chamfer length (mm)
S_{mean}	=	mean hoop stress due to the internal pressure within the pipe (MPa)
S_{sdev}	=	standard deviation of hoop stress due to the internal pressure within the pipe (MPa)
Φ_{mean}	=	mean skewness of spigot end (°)
Φ_{sdev}	=	standard deviation of skewness of spigot end (°)
θ_{mean}	=	mean angular deflection of the spigot with respect to the socket (°)
θ_{sdev}	=	standard deviation of angular deflection of the spigot with respect to the socket (°)
ΔT_{mean}	=	mean temperature range (°C)
ΔT_{sdev}	=	standard deviation of temperature range (°C)

Typical Values for Poisson's Ratio and Long-Term Tensile Modulus

The values given in the following table are typical for PVC-U, PVC-M and PVC-O pipes and may be used when calculating the minimum depth of insertion.

Material	Poisson's ratio	Tensile modulus (MPa)
PVC-U	0.37	1,400
PVC-M	0.37	1,300
PVC-O	0.45	2,000

METHOD 1 (Accumulative, Worst-case)

This method is based on the assumption that each of the contributing factors that require the spigot to be inserted beyond the elastomeric seal may occur simultaneously at their extreme, but realistic, values. The extreme value for each of the factors is calculated and the sum total represents the required depth of engagement.

Note: The accumulative worst-case method ensures the depth of engagement will be sufficient for all intended applications of the product.

The factors that may contribute to a partial withdrawal of the spigot include the following.

a) Poisson contraction. This is the shortening of the pipe as its diameter expands under the influence of internal pressure.

Poisson contraction $m_p = \frac{L \times \mu \times S}{E_c}$ (1)

b) Thermal contraction is the shortening of the pipe due to a reduction in its temperature. This will occur if a pipe is stored in the sun immediately prior to installation and subsequently operated at a lower temperature.

Thermal contraction $m_t = L \times \lambda \times \Delta T$ (2)

$\lambda = 7 \times 10^{-5}$ °C^{-1} for PVC

c) Angular deflection is the retraction of one side of the spigot due to angular deflection of the spigot within the socket.

Angular deflection $m_a = \frac{d_e \times \pi \times \theta}{180}$ (3)

Most parallel sockets are capable of a spigot – socket deflection of up to 1°. The extent to which an individual joint can deflect will depend on the dimensions of the particular spigot and socket.

d) End skewness (or end squareness). The product Standards might nominate the maximum allowable tolerance for squareness of pipe ends. Otherwise, the end skewness is based on the angle of the cut end. Consideration might also need to be given to the skewness of pipe ends cut in the field.

m_e = maximum tolerance specified in the product Standard, other value nominated by the manufacturer or calculated as follows

$$m_e = d_e \times \tan\Phi \qquad (4)$$

e) Chamfer length. How the length of chamfer is allowed for can depend upon the design of the socket. For example, in the case of a square ended socket the spigot end can butt up against the back of the socket. This is the case with many cast metal fittings. If the back of the socket is ramped (upper half of Figure 1) the chamfer allows the spigot to be inserted further into the socket. This is the case with most plastics pipes sockets

Chamfer length = maximum nominated in the product Standard or by the manufacturer.

f) Construction factor (or safety allowance) provides for variations in the quality of construction. Its value is nominated by the manufacturer.

Depth of engagement $m = m_p + m_t + m_a + m_e + m_c + m_{cf}$ (5)

EXAMPLE 1

Consider a Series 2 DN300, PN16, MRS500, PVC-O, 6m long pipe with an outside diameter of 345 mm.

Assume a Poisson ratio of 0.45 for PVC-O.

Assume the manufacturer has nominated a maximum angular deflection at the joint of 1°, a maximum chamfer length of 25mm, a maximum end skewness of 2mm and a construction factor of 10mm.

Let $\lambda = 7 \times 10^{-5}$ °C^{-1} and E_c = 2000MPa.

Let the maximum temperature variation be 50°C.

Apply equation (1) $m_p = \frac{L \times \mu \times S}{E_c} = \frac{6000 \times 0.45 \times 32}{2000} = 43.2$ mm

Apply equation (2) $m_t = L \times \lambda \times \Delta T = 6000 \times 7 \times 10^{-5} \times 50 = 21$ mm

Apply equation (3) $m_a = \frac{d_e \times \pi \times \theta}{180} = \frac{345 \times \pi \times 1}{180} = 6.0$ mm

From the product Standard, manufacturer's specification or equation (4), as appropriate.

$m_e = 2$ mm

$m_c = 25$ mm

$m_{cf} = 10$ mm

Apply equation (5) $m = m_p + m_t + m_a + m_e + m_c + m_{cf}$

Therefore, $m = 43.2 + 21 + 6.0 + 2 + 25 + 10 \approx 107$.

Minimum depth of engagement = 107 mm. That is, the spigot end of the pipe must extend at least 107 mm beyond the seal when the joint is assembled in order to avoid any risk of subsequent leakage due to the spigot withdrawing past the seal.

METHOD 2 (Statistical)

The same six independent contributing factors to the depth of engagement, Poisson contraction, thermal contraction, angular deflection, chamfer length, end skewness and construction factor as used in Method 1 are applied in Method 2. It is assumed that each of the contributing factors exhibits a normal distribution of possible values from the minimum to the maximum. Mean and standard deviations are assigned to each factor. The mean and standard deviation for the total depth of engagement is then calculated. A value is assigned to the proportion of the population that exhibit acceptable performance and the minimum depth of engagement calculated.

The mean of the total depth of engagement is the sum of the means of the individual contributing factors. If the variation in each of the individual terms is independent of the others the standard deviation of the total depth of engagement is the root of the sum of the squares of the standard deviations of the individual contributing factors. However, in the method described, provision is made for variables, e.g. *L*, that occur in two different factors that subsequently need to be added together.

The depth of engagement required for the possibility of one joint in a million failing because the barrel of the pipe has retracted past the seal, is calculated using equation (6).

$$m = m_{Tmean} + 4.7537 m_{Tsdev} \qquad (6)$$

It is known from both theoretical calculations and practical experiments that, in normal conditions, buried pipes expand and contract approximately about their centre. That is, the sockets do not remain anchored with all the longitudinal movement occurring at the spigot. This means that whilst the pipe length is used to calculate the minimum depth of engagement of pipe-to-pipe sockets, only half the length need be used when calculating the depth of engagement of fittings. That is, for 6m pipes the length of 6m is applied when calculating the minimum depth of engagement for pipe sockets but only 3m is applied when calculating the depth of engagement for fittings.

Equations for the mean values of the five factors.

$$m_{pmean} = \frac{L_{mean} \times f_{mean} \times S_{mean} \times \mu}{E_c} \qquad (7)$$

$$m_{tmean} = L_{mean} \times f_{mean} \times \lambda \times \Delta T_{mean} \qquad (8)$$

$$m_{amean} = \frac{d_e \times \theta \times \pi}{180} \qquad (9)$$

$$m_{c\,mean} = \left(\frac{L_{cmean}}{d_e}\right)_{mean} \times d_e \qquad (10)$$

Note Equation (10) assumes a fixed ratio of chamfer length to pipe diameter. Alternative values can be used if appropriate.

$$m_{emean} = d_e \times Tan\left(\frac{\pi \times \Phi_{mean}}{180}\right) \qquad (11)$$

Equations for the standard deviation of the five factors.

$$m_{psdev} = m_{pmean}\sqrt{\left(\frac{L_{sdev}}{L_{mean}}\right)^2 + \left(\frac{f_{sdev}}{f_{mean}}\right)^2 + \left(\frac{s_{sdev}}{s_{mean}}\right)^2} \qquad (12)$$

$$m_{tsdev} = m_{tmean}\sqrt{\left(\frac{L_{sdev}}{L_{mean}}\right)^2 + \left(\frac{f_{sdev}}{f_{mean}}\right)^2 + \left(\frac{\Delta T_{sdev}}{\Delta T_{mean}}\right)^2} \qquad (13)$$

$$m_{asdev} = d_e \times \left|\cos\left(\frac{\theta_{mean} \times \pi}{180}\right) \times \frac{\theta_{sdev} \times \pi}{180}\right| \qquad (14)$$

$$m_{csdev} = \left(\frac{L_{csdev}}{d_e}\right)_{sdev} \times d_e \qquad (15)$$

$$m_{esdev} = \frac{d_e}{\cos\left(\Phi_{mean} \times \frac{\pi}{180}\right)^2} \times \left(\Phi_{sdev} \times \frac{\pi}{180}\right) \qquad (16)$$

The total mean and standard deviation can now be calculated.

$$mT_{mean} = m_{pmean} + m_{tmean} + m_{amean} + m_{cmean} + m_{emean} + m_{cfmean} \quad (17)$$

$$mT_{sdev} = \sqrt{m_{psdev}^{\;2} + m_{tsdev}^{\;2} + m_{asdev}^{\;2} + m_{csdev}^{\;2} + m_{esdev}^{\;2} + m_{cfsdev}^{\;2} + 2F_{m_p,m_t}} \quad (18)$$

Where the commonality factor

$$F(mp,mt) = m_{pmean} \times m_{tmean} \times \left[\left(\frac{L_{sdev}}{L_{mean}} \right)^2 + \left(\frac{f_{sdev}}{f_{mean}} \right)^2 \right] \quad (19)$$

To allow for the possibility of 1 joint in 100,000 failing, the depth of engagement should be not less than $mT_{mean} + 4.265mT_{sdev}$.

For 1 joint in 1,000,000 the depth of engagement should be not less than

$$mT_{mean} + 4.7537mT_{sdev}.$$

EXAMPLE 2

Using the same product as in Example 1 above, consider a Series 2 DN300, PN16, MRS500, PVC-O, 6m long pipe with an outside diameter (*de)* of 345 mm.

Let the mean unanchored pipe length be 6000mm and the standard deviation be 60mm.

Assume a Poisson ratio of 0.45 for PVC-O, a modulus of 2000MPa and $\lambda = 7 \times 10^{-5}$ °C^{-1}.

Also assume the manufacturer has nominated:-

- a mean temperature range of 20°C but the actual temperature could vary from -10°C to +50°C. These values encompass situations from a pipe installed at say 5°C and operated at 15°C to one installed at say 60°C and operated at 10°C.
- a maximum angular deflection at the joint of 1° with the actual angle ranging from 0 to 1°,
- a mean chamfer length of 0.075 x *de* mm (ranging from 17.2 to 34.6mm),
- a mean end skewness created by an 'off-square' spigot cut at a mean angle of 0.25°, but in any case, not less than 1mm and with a range of 0 to 0.5°,

- a construction factor of 10mm with a range of 5 to 15mm,

and the PN16 pipe will be installed in systems operating at pressures ranging from 8 to 16MPa.

Variable	Mean values	Variable	Standard deviation
L_{mean}	6000	L_{sdev}	60
S_{mean}	24	S_{sdev}	2
ΔT_{mean}	20	ΔT_{sdev}	7.5
C_{mean}	$0.075d_e$	C_{stdev}	$0.0063d_e$
Φ_{mean}	0.25	Φ_{sdev}	0.0625
θ_{mean}	0.5	θ_{sdev}	0.125
f_{mean}	0.85	f_{sdev}	0.0375

Using equations (12) to (16) calculate the following:

Factor	Mean	Standard Deviation
m_p	27.54	2.61
m_t	7.14	2.74
m_a	3.01	0.75
m_c	25.88	2.17
m_e	1.51	0.38
m_{cf}	10.00	1.25
Commonality factor (m_p, m_t)	0.402	

Inserting these values into equations (17) and (18) mT_{mean} and mT_{sdev} are determined. Therefore

$$mT_{mean} = 75.1$$

and $$mT_{sdev} = 4.7$$

Allowing for the possibility that one joint in 100,000 might fail, the depth of engagement should be not less than $mT_{mean} + 4.265\ mT_{sdev} = 95.1$mm.

If the possibility of one joint in 1,000,000 might fail, then the depth of engagement should be not less than 97.4mm.

Comment: *In this example, the statistical method suggests the depth of engagement can be 10mm less than the traditional method. The difference between the two is less if it is assumed in Method 2 that the mean operating pressure is closer to class head.*

An Excel spreadsheet, *POP103Calculations.xls,* demonstrating the calculations is available with this document.

Acknowledgement

The statistical method was developed by Dr Richard Jarrett, CSIRO Mathematical and Information Sciences and his contribution is gratefully acknowledged.

Witness Marks

The above calculations demonstrate how to determine the accumulated affect of all the variables that contribute to the minimum depth of engagement.

According to the product standards, pipes with a socket for elastomeric seal jointing are also required to carry a witness mark on the spigot end to indicate the "optimum" insertion length. This can equally be considered to be the minimum insertion depth and is calculated by adding the depth of engagement to the distance between the socket mouth and the plane from which the depth of engagement, *m*, is measured.

Minimum insertion depths will differ between manufacturers because:

- a manufacturer might choose to have a longer depth of engagement than the calculated minimum and
- not all socket mouth designs and seals are the same.

Moreover, the position of the witness mark will be determined taking into account a number of manufacturing tolerances including:

- the positioning of the witness mark itself and
- the socket length, including the 'lead-in' at the front of the socket and the groove in which the elastomeric seal sits.

Therefore, the position of the witness mark is also likely to differ between manufacturers.

AS/NZS 2032 notes that “a witness mark is normally positioned at the optimum insertion depth”. This standard also advises to push the spigot home to the witness mark.

In practice there are four possible outcomes to spigot insertion:

1. **The spigot is not inserted to the witness mark**.

   This situation should be avoided. If the witness mark is located so as to achieve the minimum depth of engagement, insufficient insertion might lead to premature failure of the joint.

   However, it should be remembered that after construction, PVC pipes might contract in length due to a reduction in temperature and/or Poisson contraction when the pipeline is pressurised. Exposure of the witness mark at this stage does not necessarily indicate faulty construction.

2. **The spigot is inserted to the witness mark.**

   This is an acceptable situation.

3. **The spigot is inserted past the witness mark.**

   This is a common occurrence, not just in Australia, but also overseas. Given the inertia of the pipe during insertion, the spigot often goes past the witness mark. This does not present any performance problems, even if the spigot strikes the back of the socket.

4. **The spigot is forced past the back of the socket into the barrel of the adjoining pipe.**

   Over insertion to this extent must be avoided because of the stress it imposes on the pipe. Pushing the spigot into the barrel of the adjacent pipe requires forces many times greater than the normal insertion force and will only be achieved by excessive use of mechanical equipment such as excavators.

   Over insertion of one pipe into the next can be detected at the time of construction. This may be done by measuring the distance from one socket face to the next. Ideally, this will be equal to the effective length. If the measurement is less than the effective length the manufacturer can advise, based on the detailed socket design, whether the spigot has been forced into the pipe barrel. Alternatively, the overall length of a companion pipe from the same production run can be measured and used to assess whether the spigot in question has penetrated into the barrel of the adjacent pipe.

   Note that because of the interaction of the spigot chamfer and the ramped section at the back of the socket, the spigot can penetrate beyond the shoulder of the socket before interference occurs.

Finally, the joint can be inspected to see if there is any obvious distortion in

a. the spigot, when viewed from inside the pipe, or

b. the outside diameter of pipe immediately behind the socket.

In summary, when inspecting an assembled joint, a number of points need to be considered:

1. If the witness mark is short of the socket mouth, and this has been caused by a change in temperature and/or pressurisation of the pipeline, there is no problem as both of these factors have been taken into account when calculating the depth of engagement.

2. If the spigot has been inserted past the witness mark, and has simply been over inserted into the socket and not gone past the back of the socket, the joint will perform satisfactorily. It is common for contractors to insert spigots until they reach the back of the socket. This means that more than the minimum depth of insertion has been achieved, but does not compromise performance of the joint.

3. If the spigot has been forced into the barrel of the adjacent pipe, then this is an issue and the joint should be replaced.