Technical Note 14 – Effect of Installation Practice on Seismic Response of Buried Pipeline Systems

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1 Background

Service life for pipeline systems in normal service can range from less than 2 years to more than 100 years (Black and Morris, 2008). The shortest lives typically include materials with low durability that are installed poorly and poor installation can reduce service life by an order of magnitude in its own right.

2 Design Philosophy

The influence of bedding and compaction practices on the life of systems is different for rigid pipelines (concrete and earthenware) and for flexible pipelines (PVC, PE, steel and GRP).

- Rigid pipes rely on strength to resist circumferential loads and the load-bearing ability is increased by well-placed support and bedding (AS/NZS 3725). Sub-standard bedding practice can reduce the effective factor of safety against loads by as much as a factor of 4, although less significant defects would typically reduce the support by 25% to 50%.

- Flexible pipelines deform under load and rely on the support of the surrounding embedment and soil to resist loads (AS/NZS 2032 and AS/NZS 2566). Substandard embedment practice can reduce the effective side support so that the pipe deflects excessively.

2.1 Response of Rigid Pipes

Design loads specified in rigid pipe standards are determined for a worst-case loading condition of a pipe with uneven longitudinal support from the bedding in which the pipe effectively spans the distance between support points. The bedding factor used in rigid pipe design recognises that more even support reduces the effective separation between support points which increases the effective strength of the pipe.

Uneven compaction is typically more destructive than poor compaction because.

- Different levels of support along the length of the pipeline generate beam bending forces and point loads, and may disturb invert levels.

- Different levels of support around the pipe will lead to uneven loading.

- Over-sized stones will generate point loads that can trigger failures.

In contrast, lightly compacted soil around the pipeline will tend to consolidate over time, resulting in settlement of the soil above lightly compacted layer but without necessarily causing uneven loading of the pipe.

Manufacturer's installation guidance indicates that minor cracking of up to 1 mm in concrete pipes can be expected to close up over time by autogenous healing. Autogenous healing is a process in which dissolved minerals precipitate out of solution into the cracks, thereby sealing them.

Earthenware pipes do not undergo autogenous healing. However, work on pipe repair systems has revealed cases where overloaded pipes had remained serviceable for decades despite undergoing a classic four-point break during installation (Morris, 1991 to 1999). In these cases, the contact points between the fragments worked as hinges (Figure 1), allowing the damaged pipe to mobilise support from the surrounding soil so that it was interacting with the soil as a flexible pipe does. While overloading and resultant cracking may not cause outright failure, a pipe in this condition would have minimal resistance to any soil disturbance.

Figure 1. Asbestos cement pipe sample after crush testing. This illustrates how a fractured rigid pipe can hinge about the four breaks to behave as a flexible pipe.

The effect of cracking on rigid pipes can be summarised as follows:

Table 2-1: Effect of installation defects on useful life of rigid concrete and earthenware pipelines

Scale of defect	Rigid (Concrete)	Rigid (Earthenware)
Minor	No impact	Reduction of 10 to 20 years
Moderate	Reduction of 10 to 20 years	Reduction of 10 to 20 years
Severe	Factor of 5 to 10 reduction	Factor of 5 to 10 reduction

2.2 Response of Flexible Pipes

While flexible pipeline design is largely dominated by the acceptability of deflection under load, other factors can constrain the deflection limits. For GRP pipelines, excessive deflection can overstrain the individual glass reinforcing fibres even when the bulk structure is undamaged, so the fibre strain presents an upper limit of acceptable deflection . For steel pipes, a higher maximum deflection is acceptable when the pipe has a flexible a polymer lining than when the pipe has a more rigid cementitious lining.

Deflection under load is controlled by a number of factors, including the pipeline properties, the properties of the native soil and the properties of the pipe surround material. In practice, for any given system, the pipe surround properties are essentially controlled by the degree of compaction (Janson, 2003) and by the placement of the fill prior to compaction (Hardie, 1972).

Janson states:

> *"the soil-pipe interaction process is primarily a process controlled by the soil volume changes around the pipe".*

and

> *"It is therefore essential [for flexible pipelines] to ensure that the backfilling materials and compaction methods for the refill are clearly specified and controlled".*

Inadequate placement of fill materials leaves voids around the pipeline that result in uneven loading around the pipeline and out of roundness. Out of roundness is particularly harmful if it is uneven since this increases risk of buckling and local pipe wall strains.

Acceptance tests for flexible pipelines acknowledge that some deflection is present inall flexible systems. Acceptance limits may be viewed as slightly conservative as smaller modern PVC and PE pipes can withstand complete flattening without immediate fracture. Such extreme deformation would clearly have major operational implications, but serves to illustrate that the pipes themselves are highly tolerant of short-term deflections. .

As with rigid pipes uneven compaction is typically more destructive than poor compaction because.

- Different levels of support along the length of the pipeline generate beam bending forces and point loads, and may disturb invert levels.
- Different levels of support around the pipe will lead to uneven loading.
- Over-sized stones will generate point loads that can trigger failures.

The operational effect of deflection varies according to the function of the pipeline:

- Acceptable long term deflection of 7.5% for a PVC pipe changes the cross section by only 0.6%, although it can affect hydraulic flow characteristics. The impact of any changes to the hydraulic radius and resulting impact on the head loss are negligible in comparison.
- The reduced section could hinder the ability to launch inspection tools, but this would mainly affect smaller gravity pipelines (DN100 and DN150) where the space available for in-pipe maintenance tools and inspection equipment (CCTV cameras and related instruments) is already limited by the small bore. In contrast, pressure pipelines tend to re-round themselves when pressurised and in-pipe inspection and maintenance is rarely used.

The effect of deflection on flexible plastics pipes (PE and PVC) can be summarised as follows:

Scale of defect	Short term deflection	Long term deflection	Effect
Minor	<5%,	<7.5%	No impact
Moderate	>5% to 10%	>7.5% to 15%	Pressure: Operational issues; increased head loss, Gravity Possible minor capacity problems; Increased maintenance needs; possible risk of inspection and maintenance problems.
Severe	>10% or uneven shape	>15% or uneven shape	Pressure: Operational issues; increased head loss, Gravity Minor flow and capacity problems likely; increased maintenance needs likely and more difficult; risk of collapse and buckling; re-rounding and repair may be needed.

Poor placement of fill results in voids around the pipe and uneven support which can lead to uneven deflection. Poor compaction and poor placement both create an opportunity for subsequent consolidation of the pipe surround and fill which can result in uneven loading as well as surface settlement in response to changes in the soil column density.

The effect of compaction on pipe deflection for a DN300 PVC pipe with 1 m cover and no traffic loading, and different native soil and pipe surround modulus is summarised below. The effective modulus of the fill is determined mainly by the degree of compaction (TEPPFA) and effectiveness of placement of the fill.

Native soil modulus (MPa)	Pipe surround modulus (MPa)[1]	Calculated deflection %	Factor of safety for deflection	Factor of safety for buckling
5	5	0.5	13.1	8.1
	3	0.8	9.8	6.3
	1	1.7	4.5	3.4
3	5	0.7	12.0	7.2
	3	0.9	8.7	5.8
	1	1.7	4.3	3.3
1	5	1.1	6.7	4.7
	3	1.3	5.7	4.2
	1	2.1	3.6	2.8

1. This figure reflects the degree of compaction of the pipe surround
1=effectively uncompacted (placed, uncompacted), 3=placed and compacted, 5=well compacted

Inferior compaction and placement of the fill material increases deflections and reduced factor of safety against deflection and buckling in all of these conditions under normal service loads.

The addition of a pseudo static load from an earthquake reduces the factor of safety on a flexible pipeline in the same way that additional traffic load or other external load would. Table 4 summarises the effect of a pseudo static load from a vertical load pga of 0.6g acting on a DN300 PVC pipe.

Native soil modulus (MPa)	Pipe surround modulus (MPa)[1]	Calculated deflection %	Factor of safety for deflection	Factor of safety for buckling
5 Static soil load only.	5	0.54	13.1	8.1
	3	0.76	9.8	6.3
	1	1.66	4.5	3.4
5 Static soil load plus pseudo static seismic load of 15kN/m PGA 0.6g	5	0.69	10.8	6.6
	3	0.97	7.7	5.1
	1	2.13	3.5	2.7

1. This figure reflects the degree of compaction of the pipe surround 1=effectively uncompacted (placed, uncompacted), 3=placed and compacted, 5=well compacted

Table 2-2: Summary of asset lives as influenced by installation practice

Construction standard	Rigid (Concrete)	Flexible (PVC, PE, steel etc)
Good	100 to 120 years	80 to 100 years (or more)
Minor defects	100 to 120 years	80 to 100 years (or more)
Moderate defects	80 to 90 years	60 to 70 years (or more)
Severe defects	20 to 40 years	10 to 20 years
Severe defects in combination with other factors	~2 to 20 years	~2 to 10 years

3 Other Installation-Related Factors

There are several examples where specific detailing appears to have influenced the behaviour of pipelines and cables.

The presence of rigid concrete beams or encasement appears to have promoted bending failure of a concrete-encased pipe in a pipe bridge, where compression caused the concrete to fracture in bending (Black, 2013), which in turn fractured the encased pipe. An apparently similar case was reported where a concrete slab laid under electrical cables fractured in compression and then bent, causing the cables laid above it to fail (Eidinger, 2012).

Other examples relate to detailing of pipe transitions between buildings and buried services, and pipe transitions within pipe bridges. In pipe bridges, where the pipe was able to move it survived relatively undamaged, but where there was insufficient clearance, the pipe was damaged from uncontrolled contact with the bridge abutment.

Installation depth has limited effect on response of soil to seismic loadings. In seismic terms shallow is typically 10 to 30 m deep (AS/NZS 1170) but few pipelines are buried below 5 m and very few below 10 m. However, experience in Christchurch clearly showed that accessing a deeper pipeline access for repair is considerably more difficult and expensive than for a shallower one.

4 Conclusion

Installation practice has a substantial impact on the ability of a buried pipeline to withstand normal in-service loads. Since seismic loads can often be treated as pseudo-static loads, installation practice will also influence seismic response of buried pipelines.

The difference between good installation practice and poor installation practice is considerably greater than the additional impact of typical seismic loads acting on a buried pipeline. This means that, where seismic loads are a possibility, there is more benefit for most pipelines in insisting on good installation practice than in modifying detailed design.

Because rigid beam-like structures can impose severe local damage to adjacent or embedded services if they bend, unreinforced slabs in particular should be avoided.

Pipelines and cabled services should be allowed room to move where they pass through bridge abutments or enter buildings to avoid unwanted damage if they make contact while moving.

While deeper-buried utilities pipelines do not appear to be more or less vulnerable than shallower ones, the increased cost and difficulty of repairing deeper pipelines means that they should be avoided where possible.

5 References

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