Asset Lifecycle – Guidance Note

Seismic displacement for pipeline design

CIVIL AND STRUCTURAL

Problem statement

Watercare's (WSL) standard *DP-07: Design principles for transmission water and wastewater pipeline systems* (2020) sets out the general design guidelines for projects which involve transmission pipelines (pipelines greater than 250mm for water and 300mm for wastewater). The standard recommends consultation with WSL to establish the criticality of assets and confirm specific project performance requirements. *Part D, Section 10.b – Seismic evaluation* states:

"Acceptable methods for evaluation are provided by guidelines produced by the American Lifelines Association and the Water New Zealand Guidelines for Assessing Utilities in Seismic Areas. The design solutions shall be applied to the pipe importance levels as defined in Part A, section 5.2."

American Lifelines Association and the Water New Zealand Guidelines for Assessing Utilities in Seismic Areas refer to American Lifelines Alliance Seismic Guidelines for Water Pipelines (ALA, 2005) and Underground Utilities – Seismic Assessment and Design Guidelines (Opus, 2017), respectively.

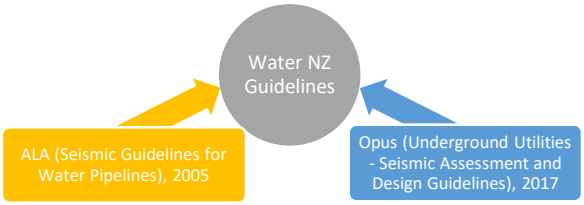

***Figure 1**: Documents referenced in New Zealand for assessing utilities in seismic areas.*

The table in *Part A, Section 5.2.1 of DP-07* defines the requirements for Pipe Function Class, and the notes to the table further define a relationship between Pipe Function Class and Importance Level. Thereafter, *DP-07* interchangeably uses the terminology "importance level" (IL) and "pipe function class". In practice however, "importance level" is generally associated with categorising structures such as buildings or foundations based on their criticality and consequence of failure, whilst "pipe function class" refers to pipeline segments based on their role in system performance and post-earthquake operation / recovery.

The Table in *Part A, Section 5.2.1 of DP-07* also introduces Design Safety Factors (DSF) for various pipe function classes. The table of Design Safety Factors, including the notes, from *DP-07* is reproduced below as per Table 1 of this document. While there is no definition of DSF in the standard, some factors have been interpreted **incorrectly** as equivalent to the minimum Factors of Safety (FOS) against slope instability recommended in the Auckland Council Code of Practice for Land Development, and thus have been followed as criteria for pipelines on sloping ground. However, **Design Safety Factors are originally associated with design seismic displacements and are not intended as Factors of Safety for slope stability assessment.** These minimum required Factors of Safety are explained in *Guidance Note – Factors of Safety for Slope Stability Analysis (ESF-500-GDN-301)*.

This Guidance Note **clarifies the application of Design Safety Factors (or Factors for Design Seismic Displacement, as explained in what follows) and how seismic displacements should be estimated in the New Zealand context.**

Watercare

***Table 1**: Design Safety Factors for Different Pipe Function Classes (reproduction of the table in Part A, Section 5.2.1 of DP-07)*

Pipe function class		Description	Design Safety Factors				Seismic return period factor (NZS1170) R_u
			Peak ground acceleration	Liquefaction /subsidence	Landslide/ lateral movement	Surface loading	
1	Low	Pipework in the local network area that service areas of no or limited economic impact. Post event repairs can be extended for a significant time.	1	1	1	1.2	0.75
2	Moderate	Common pipework in the Transmission networks, or Local Network mains larger than 150mm diameter, that if lost would result in unsatisfactory service disruption for 12 to 24 hours causing moderate economic impact.	1.5	1.2	1.2	1.2	1.3
3	Critical	Pipelines servicing larger numbers of customers (>10,000 people) that if lost causes significant economic impact or substantial hazard to human life, the natural environment and properties.	1.8	1.35	1.6	1.5	1.8
4	Essential lifeline	Pipelines that are essential to maintain service post natural disaster or man-made mishap and are intended to remain in service.	2.3	1.5	2.6	2	1.8

Design Safety Factors that are discussed in this guidance note

Note: Pipelines with multi-use functionality should typically be classed as Type 4. Pipelines that branch off a higher function class of pipe shall be classed at the same as the higher function pipe unless the branch can be demonstrated to be isolated from damage or disruption from the lower function class pipe.

Pipelines servicing critical functional infrastructure of importance level 4 shall be class 4, e.g. hospitals.

Factors for design seismic displacement

The "Design Safety Factors" in Table 1 originate from *the American Lifelines Alliance Seismic Guidelines for Water Pipelines* (ALA, 2005), with some modifications. The Annual Probability of Exceedance (APE) for earthquake loads is provided in NZS 1170.0:2002 (Standards New Zealand, 2011), based on the asset's design working life and importance level. The *Underground Utilities – Seismic Assessment and Design Guidelines* (Opus, 2017) summarises return period factors (R_u) for various important level assets in its Table 4-3, which is the direct reference for R_u in Table 1 above.

The main earthquake hazards affecting pipelines are **transient and permanent ground movements**. Transient ground movement refers to the **shaking caused by seismic wave propagation**. Permanent ground movement involves ground failures such as **surface fault rupture**, **slope movements** and **landslides**, **liquefaction-induced lateral spreading** and **flow failure**, and **differential settlement**. These seismic hazards are considered and discussed in both the ALA and Opus guidelines.

The ALA guideline includes recommended factors to calculate design seismic lateral displacement subject to fault offset, liquefaction induced movement (horizontal and vertical) and landslide induced lateral movement, as summarised in Table 2 below. For example, to estimate the design seismic displacement for a Function Class 4 pipeline due to a landslide, a factor of 2.6 should be applied to the Permanent Ground Displacement (PGD) resulting from an Annual Probability of Exceedance (APE) 1/475 earthquake event, following the ALA guideline.

***Table 2**: Factors for Design Seismic Displacement Recommended by Seismic Guidelines for Water Pipelines (ALA, 2005)*

Pipe function class	Annual probability of exceedance (APE) for the ultimate limit state (50-year design life)[1]	Factors for design seismic displacement[3]		
		Fault Offset	Liquefaction	Slope Movement /Landslide
1	N/A[2]	N/A[1]	N/A[1]	N/A[1]
2	1/475	1.0	1.0	1.0
3	1/975	1.5	1.35	1.6
4	1/2475	2.3	1.5	2.6

Notes:

1. **ALA (2005)** considers **50-year design basis** to be consistent with American standard engineering practice.
2. **Pipelines in Function Class 1 do not need to consider seismic condition as per ALA (2005).**
3. Design seismic displacement = Factors in the table * PGD for an APE 1/475 seismic event

Clarifications

Factors in Table 2 form the basis for Design Safety Factors in Table 1. However, Importance Level (Function Class) 1 pipelines also need to consider a design seismic event in New Zealand, in line with NZS1170.0:2002 (Standards New Zealand, 2011). Differences in design life and seismic codes between the U.S. and New Zealand have resulted in different design seismic events (APE values). Table 1 from *DP-07* includes additional factors to cover all 4 design seismic events for Function Classes 1 to 4, unlike the ALA guideline, which covers only 3 events for Function Classes 2 to 4.

However, as some terminologies in Table 1 can be misleading, to benefit the subsequent discussion the following improvements are suggested.

- **Design Safety Factors** should be described as **Factors for Design Seismic Displacement**.
- **Peak Ground Acceleration** should be referred to as **Fault Offset**.
- **Liquefaction / Subsidence** should be referred to as **Liquefaction**.
- **Landslide/Lateral Movement** should be referred to as **Slope Movement/Landslide**.
- **Surface Loading** is a static load case and should not be included in the table.
- **Seismic Return Period Factor R_u** is a factor which can be determined in Table 3.5 of *NZS1170.5:2004* (Standards New Zealand, 2016) once the design seismic event (return period) is established. Standards and codes normally define the **APE for the design seismic event based on importance level**.

Table 3 below illustrates the differences in design seismic events (APE values) and factors between *DP-07* and the ALA guideline, incorporating improvements listed above. As shown in Table 3, the base

seismic event used to calculate the PGD before applying any factors is the APE 1/250 event as per *DP-07*. This base seismic event is different from the APE 1/475 event adopted by the ALA guideline.

Therefore, simply **migrating factors from the ALA guideline (Table 2) to DP-07 (Table 1) has not been technically appropriate and could underestimate design seismic displacements.**

***Table 3**: Comparison of design seismic events and factors between DP-07 and ALA guideline*

Pipe function class	Annual probability of exceedance (APE) for the ultimate limit state[1]		Factors for design seismic displacement					
			Fault Offset		Liquefaction		Slope Movement /Landslide	
	DP-07 (100-year design life)[2]	ALA (50-year design life)[2]	DP-07[3]	ALA[4]	DP-07[3]	ALA[4]	DP-07[3]	ALA[4]
1	**1/250**	N/A	**1.0**	N/A	**1.0**	N/A	**1.0**	N/A
2	**1/1000**	1/475	**1.5**	1.0	**1.2**	1.0	**1.2**	1.0
3	**1/2500**	1/975	**1.8**	1.5	**1.35**	1.35	**1.6**	1.6
4	**1/2500**	1/2475	**2.3**	2.3	**1.5**	1.5	**2.6**	2.6

Notes:

1. The APE for earthquake loads in DP-07 follows NZS 1170.0:2002 (Standards New Zealand, 2011).
2. DP-07 and the ALA guideline require different design life for assets.
3. Design seismic displacement **(DP-07)** = Factors in the table * PGD for an APE 1/250 seismic event.
4. Design seismic displacement **(ALA)** = Factors in the table * PGD for an APE 1/475 seismic event.

Conclusions

Given the differences and inconsistencies between *DP-07* and the ALA guideline as discussed above, **the ALA approach of obtaining design seismic displacements by applying factors on a base seismic event is not recommended for estimating seismic displacements**. Therefore**, factors in the above tables are not considered appropriate for assessing seismic displacements**.

Recommendations

The recommended approach is to directly estimate seismic displacement from a given seismic hazard (e.g., fault offset, liquefaction and slope movement/landslide) under the design seismic event specified by the current DP-07 document, as summarised in 4 below.

This Guidance Note does not serve as a prescriptive guideline for the assessment of PGD of seismic hazards. The geotechnical specialist should use commonly accepted analysis methods, as outlined in the following New Zealand guidelines, for project-specific assessments:

(a) Fault Offset – Fault rupture hazards can be assessed in accordance with ***Underground Utilities – Seismic Assessment and Design Guidelines*** (Opus, 2017)

(b) **Liquefaction** – Liquefaction hazards and liquefaction-induced PGD can be assessed in accordance with ***Earthquake Geotechnical Engineering Practice Module 3. Identification, Assessment and mitigation of liquefaction hazards*** (MBIE & NZGS, 2021).

(c) **Slope Movement / Landslide** – The Newmark sliding block method can be used for estimating PGD of slope instability in accordance with ***Bridge Manual (SP/M/022) Third Edition, Amendment 4*** (Waka Kotahi, 2022).

In summary, **Table 4** below is recommended for use in assessing seismic permanent ground displacement in pipeline design.

***Table 4**: Applicable Design Reference for Seismic Permanent Ground Displacement*

Pipe function class	Annual probability of exceedance (APE) for the ultimate limit state (100-year design life) DP-07 / NZS 1170.0:2002	Applicable Design Reference for Seismic Permanent Ground Displacement		
		Fault Offset	Liquefaction	Slope movement /landslide
1	1/250	***(a)***	***(b)***	***(c)***
2	1/1000			
3	1/2500			
4	1/2500			

Notes:

(a) Underground Utilities – Seismic Assessment and Design Guidelines (Opus, 2017)

(b) Earthquake Geotechnical Engineering Practice Module 3. Identification, Assessment and mitigation of liquefaction hazards (MBIE & NZGS, 2021)

(c) Bridge Manual (SP/M/022) Third Edition, Amendment 4 (Waka Kotahi, 2022)

A calculation example is provided below to illustrate how the design seismic displacement for a Function Class 4 pipeline, subject to slope movement, can be estimated using the ALA guideline, current DP-07 and the approach recommended in this guidance note. The PGD values used are assumed only for this example.

Following the ALA guideline (**Table 2**):

*Design seismic displacement (slope movement) for an **APE 1/2500** event = **2.6** * PGD for an **APE 1/475** seismic event = 2.6 * 30mm = 78mm*

Following the current Part A, Section 5.2.1 of DP-07 (**Table 3**):

*Design seismic displacement (slope movement) for an **APE 1/2500** event = **2.6** * PGD for an **APE 1/250** seismic event = 2.6 * 20mm = 52mm*

Following this guidance note recommended approach:

*Design seismic displacement (slope movement) for an **APE 1/2500** event = PGD for an **APE 1/2500** seismic event = 90mm*

References

1. ALA. (2005). *Seismic Guideline for Water Pipelines.* Oakland, California, United States of America: American Lifeline Alliance.

2. MBIE & NZGS. (2021). *Earthquake Geotechnical Engineering Practice Module 3. Identification, Assessment and mitigation of liquefaction hazards* (1st ed.). Wellington, New Zealand: Ministry of Business, Innovation and Employment (MBIE) and New Zealand Geotechnical Society.

3. Opus. (2017). *Underground Utilities - Seismic Assessment and Design Guidelines* (1st ed.). Wellington, New Zealand: Opus International Consultants Ltd.

4. Standards New Zealand. (2011). *Structural Design Actions - Part 0: General Principles (AS/NZS 1170.0:2002 Incorporating Amendment Nos 1, 2, 3, 4 and 5).* Wellington, New Zealand: Standards New Zealand.

5. Standards New Zealand. (2016). *Structural Design Actions - Part 5: Earthquake Actions - New Zealand (NZS 1170.5:2004 Incorporating Amendment No.1).* Wellington, New Zealand: Standards New Zealand.

6. Waka Kotahi. (2022). *Bridge Manual (SP/M/022) Third Edition, Amendment 4.* Wellington, New Zealand: Waka Kotahi NZ Transport Agency.

7. Watercare. (2020). *Design Principles for Transmission Water and Wastewater Pipeline Systems (DP-07).* Auckland: Watercare.