UKOPA

United Kingdom Onshore Pipeline Operators' Association

Good Practice Guide

Seismic Assessment of UK Onshore Pipelines and Associated Installations

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The guidance in this document represents what is considered by UKOPA to represent current UK pipeline industry good practice within the defined scope of the document. All requirements should be considered guidance and should not be considered obligatory against the judgement of the Pipeline Owner/Operator. Where new and better techniques are developed and proved, they should be adopted without waiting for modifications to the guidance in this document

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CONTENTS

1 EXECUTIVE SUMMARY

This United Kingdom Onshore Pipeline Operators' Association (UKOPA) good practice guide (GPG) was developed by the UKOPA Pipeline Integrity Working Group (PIWG) to provide guidance on simplified and full seismic assessment for UK onshore pipelines and associated installations in 2020. It has been reviewed and where required updated in 2025.

This document is intended to provide further guidance following screening assessments carried out to UKOPA/GPG/019 [1] – "Seismic screening assessment of UK onshore pipelines and associated installations". UKOPA/GPG/019 provides guidance on determining the requirement for "simplified" or "full" seismic assessment.

The guidance within this document is applicable to all buried and above ground pipelines and associated pipeline components operated by UKOPA member companies. The document is based on work carried out by National Grid – now National Gas Transmission (NGT) - to comply with the requirements of Eurocode 8 [2, 3, 4, 5, 6, 7], the UK national annexes [8, 9, 10, 11, 12] and BSI PD 6698 [13], and was provided to UKOPA for inclusion in UKOPA guidance.

This document provides guidance on "simplified" and "full" seismic assessment requirements for pipelines and associated components for use by UKOPA members, summarised below:

- **Simplified seismic assessment:** Guidelines on the use of a pseudo-static analysis using a permanent body force to represent seismic action. The system shall be designed to resist this load in addition to seismic load reversal and other relevant loadings.

- **Full seismic assessment:** Guidelines on the use of a recognised method of seismic analysis to assess pipeline to either ultimate limit state (ULS) or damage limit state (DLS) performance objectives depending on safety and / or supply criticality of the pipeline. Allowable pipeline strain levels for varying limit states and loading conditions are provided.

- **Seismic assessment of pipeline related components:** Guidelines on the use of simple or full seismic assessment to qualify pipeline valves, actuators, vessels, etc.

The approach developed by NGT and summarised in this document provides conservative guidelines for assessing seismic loading on above ground and buried pipelines and components. It is recommended this approach is used to assess seismic effects on pipelines and components operated by UKOPA members. Depending on the level of seismic assessment and corresponding loading complexity required it may be necessary to seek specialist advice in order to ensure the system and seismic response are analysed accurately.

The Pipeline Research Council International (PRCI) guidelines [14], Eurocode 8, the UK national annexes, and BSI PD 6698 should also be consulted as a minimum to ensure full compliance with required assessments.

2 INTRODUCTION

2.1 Background

The requirement for a GPG to provide a methodology for simplified and full seismic assessment of pipelines and associated installations was identified by the UKOPA PIWG. This document is intended to provide follow on guidance to the user for pipeline assets which fail the seismic screening procedure outlined in UKOPA/GPG/019 [1] and require either simplified or full further seismic assessment. This will also ensure compliance with recognised pipeline standards.

The topics included in UKOPA/GPG/019 are:

- Detailed application of the screening criteria to determine if further seismic assessment (simplified or full) is required.
- Seismic hazards to UK pipelines and associated installations.
- Review of National Grid seismic policy.
- UK seismicity levels.
- ISO 20074 [15].

2.2 Scope

This GPG provides guidance on simplified and full screening methodologies to assess the risks posed by seismic activity to UK onshore pipelines and their associated installations. Application of these methodologies is intended to be carried out if screening criteria are not met and further detailed assessment is required on completion of the procedure outlined in UKOPA/GPG/019.

The extent of the pipeline system to which this GPG applies is defined as the assets from the pipeline inlet valve to the outlet valve, including any associated installations (i.e. launch and receive pig traps, block valves, pressure regulation and / or metering installations, multi junctions) and spur connections.

Compressor stations, pump stations, refineries and storage facilities are not included to align with the guidance in UKOPA/GPG/019. The pipeline system is shown in Figure 1.

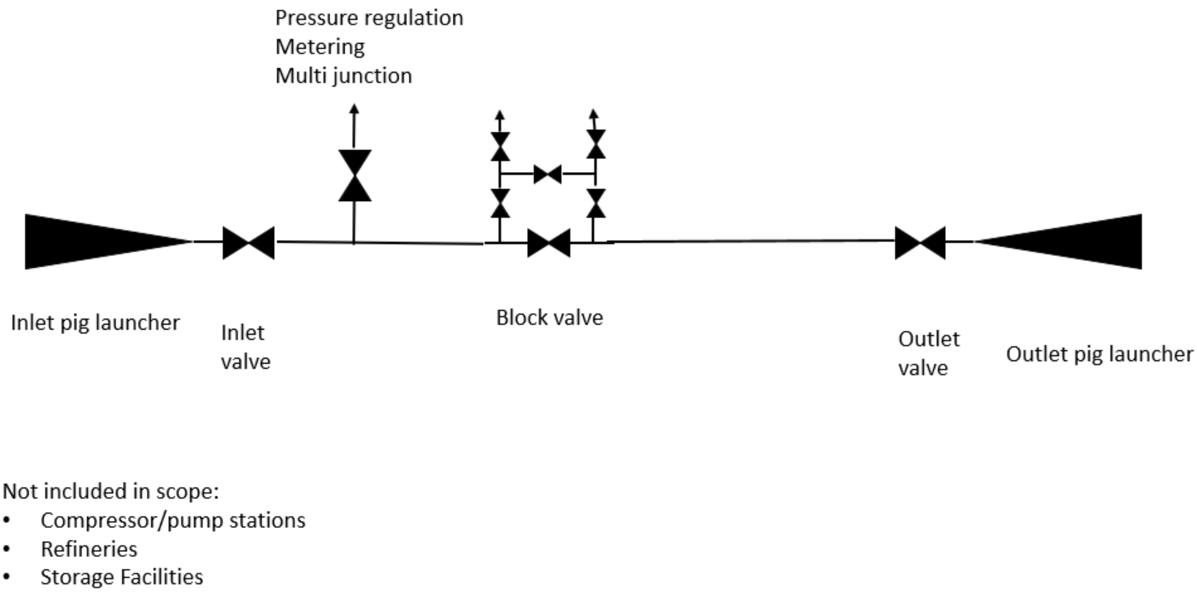

Figure 1: Extent of pipeline system covered by this GPG

2.3 Application

The guidance in this document is applicable to all buried and above ground pipelines operated by the UKOPA member companies.

Within this document:

Shall: indicates a mandatory requirement.

Should: indicates good practice and is the preferred option.

3 SEISMIC HAZARD SCREENING ASSESSMENT OVERVIEW

The seismic assessment screening methodology for application to operating pipelines and installations described in UKOPA/GPG/019 [1] is based on that developed by NGT for seismic design of new pipelines and installations, excluding a ground motion partial factor γf = 1.5 (removed from the procedure following a review of ground motion values in the USA and Europe).

The seismic assessment screening methodology applied to pipelines and above-ground installations in a particular location involves the following four steps:

1. Assignment of Importance Class according to the safety, economic, social and environmental consequences of failure.

2. Assignment of Importance Factor based on the Importance Class.

3. Calculation of seismic action parameters:

    a. Ground acceleration, $\boldsymbol{a_g}$ (using the seismic hazard map given in PD 6698 [13]).

    b. Soil factor, S (using Table 3.3 in BS EN 1998-1 [8]).

4. Application of threshold ground acceleration criteria.

Further assessment requirements based on ground acceleration $(a_g.S)$ and pipeline Importance Class are shown in Table 1.

<table>
<tr><th rowspan="2">Importance Class</th><th colspan="2">$a_g.S \leq 0.1\,g$</th><th colspan="2">$a_g.S > 0.1\,g$</th></tr>
<tr><th>Buried Pipelines</th><th>Above-Ground Installations</th><th>Buried Pipelines</th><th>Above-Ground Installations</th></tr>
<tr><td>I</td><td colspan="4">None</td></tr>
<tr><td>II</td><td colspan="3">None</td><td>Simplified</td></tr>
<tr><td>III</td><td>None</td><td>Simplified</td><td>Full</td><td></td></tr>
</table>

Table 1: Application of screening criteria

Pipeline sections subject to either simplified or full assessments are covered within this GPG. Seismic design of buried pipelines is not required provided the conditions listed below are met. Where uncertainty exists regarding compliance with these conditions being met, seismic assessment should be carried out.

- The pipeline is located in competent ground[1].

- The pipeline is manufactured from steel with adequate fracture toughness, weldability and ductility[2].

[1] *Ground that is not prone to liquefaction, landslide, ground rupture, unacceptable settlement, or any other instability caused by earthquake excitation. Note that the stability of the ground depends on the intensity of ground shaking.*

[2] *For adequate fracture toughness and ductility, the average Charpy energy in the pipe, weld and heat affected zones should be greater than 40J at the design temperature, and the ratio of yield strength to tensile strength should be less than 0.92.*

- Pipeline sections are joined by full penetration butt welds, with verified weld quality, and weld strength matching or exceeding the strength of the parent material.

- The factor of safety against yield is at least equal to 1.25 in all persistent design situations (normal operating conditions, see definition in BS EN 1990 [16]).

4 PERFORMANCE OBJECTIVES

Following seismic screening assessment, simplified or full seismic assessment shall be applied to pipeline assets according to Table 1. The assessment guidance is based on principles outlined in the standards and papers provided in the references.

4.1 Damage Limit State and Ultimate Limit State Performance Objectives

NGT set two limit state objectives based on safety and security of supply in the event of a design basis earthquake (DBE).

Notes on the impact on safety and supply security from the original screening assessment should be reviewed by the pipeline operator to determine which objective requires assessment. When both Ultimate Limit State (ULS) and Damage Limit State (DLS) verifications are required for any particular system, only the DLS verification should be carried out, provided the design seismic action is the same in both cases.

4.1.1 Ultimate Limit State

The ULS is defined as that state prior to structural collapse which, although possibly severe, allows for safe evacuation of people. To satisfy this objective, the structure should maintain sufficient integrity and stability during and after the DBE so as to avoid collapse or other hazardous modes of failure. For pipelines and other structures containing hazardous materials, containment of such materials shall be maintained. Controlled release of the contents should be possible, but not necessarily continued operation.

A pipeline that poses a threat to the safety of people in the event of an uncontrolled leak shall be designed such that the ULS is not exceeded during and after a DBE. Performance objectives for the ULS are as follows:

- The pipeline shall maintain pressure integrity during and after a DBE.
- Controlled release of the pipeline's contents shall be possible after a DBE.

4.1.2 Damage Limit State

The DLS is defined as that state that maintains the function of vital services and allows continued operation, possibly at some reduced capacity. To satisfy this objective, the response of the structure should generally remain within the elastic range. However, some local damage and permanent deformation may be acceptable provided such damage does not undermine the functionality of the system as a whole. Short term outages during and after an earthquake may also be acceptable for some systems.

A pipeline that is required for security of supply shall be designed such that the DLS is not exceeded during and after a DBE. Performance objectives for the DLS are as below:

- The functionality of the pipeline shall be maintained such that operation can be resumed shortly after a DBE, possibly at some reduced capacity.
- Where in-line inspection (ILI) is normal practice, ILI of the pipeline should remain possible after a DBE. To this end, plastic deformations shall be limited.

5 SEISMIC ANALYSIS

In general, pipelines should be designed in accordance with BS EN 1998-4 [5] with reference to BS EN 1998-4 Clause 6.6, for design measures at fault crossings. As secondary references, the PRCI guidelines [14] and the ASCE guidelines [17] should be consulted.

Both simplified and full seismic assessment require the use of a mathematical model to determine response to seismic loadings. Depending on the complexity of the pipeline system under assessment, solutions can range from simple hand calculations to finite element analysis.

The model should accurately represent the main load resisting structure, permanent and variable masses, stiffness and damping characteristics of the pipeline under assessment.

6 SIMPLIFIED SEISMIC DESIGN

This section outlines the requirements for simplified seismic design of above ground pipeline sections. Note that buried pipelines either pass the screening criteria or require full seismic design, i.e. there is no requirement for simplified assessment (refer to Table 1).

6.1.1 General Analysis Requirements

A pseudo-static analysis using a permanent body force to represent seismic action on a pipeline is considered sufficient for a simplified assessment.

Pseudo-static horizontal acceleration is calculated as per the below equation. The acceleration should be assumed to act in a uniform manner over the height of the structure. The acceleration shall be considered to act simultaneously in two perpendicular horizontal directions, and for each direction in a positive or negative sense, whichever produces the more onerous action.

$$\boldsymbol{a_{ps}} = \boldsymbol{\gamma_{ps}} \times \mathbf{0.1}\ \boldsymbol{g}$$

Where:

$\boldsymbol{a_{ps}}$ = pseudo-static horizontal acceleration

g = acceleration due to gravity

The factor γ_{ps} shall be determined as follows:

a) γ_{ps} = 2.50 for all DLS verifications and ULS verifications of structures or components whose failure modes are predominantly brittle.

b) γ_{ps} = 1.25 for all ULS verifications of structures or components whose failure modes are predominantly ductile.

In case of doubt, the default value shall be as specified in (a).

The effects of vertical excitation can be ignored unless is there is clear evidence the structure is sensitive to excitation in that direction. Where vertical sensitivity is identified a vertical seismic acceleration shall be taken as ±0.11 g.

This value is derived from BS EN 1998-1 Clause 3.2.2.3 [2], which takes the vertical peak ground acceleration as 0.45 times the horizontal value (0.1 g) and applies a pseudo-static amplification factor of 2.5 to account for potential resonance and modelling uncertainties.

6.1.2 Performance Objectives

The structural components of the system shall be designed to resist the effects caused by the seismic action defined in Section 6.1.1, considering seismic load reversal and other loads as defined in BS EN 1990 Clause 6.4.3.4 [16]. Alternatively, any system may be designed in accordance with the full seismic design procedure outlined below.

7 FULL SEISMIC DESIGN

7.1 General Analysis Requirements

Full seismic design of pipeline sections should be undertaken in accordance with commonly accepted methods of seismic analysis such as the following methods:

- Equivalent static method.
- Equivalent single degree of freedom method.
- Response spectrum method.
- Time history analysis.

Other adequately validated methods may also be used.

Rigid systems (systems whose natural frequencies are all greater than the rigid frequency (refer to Section 7.1.1)), may be analysed statically. The pseudo-static seismic acceleration applied to rigid systems supported directly on the ground need not exceed the product $\boldsymbol{a_g.S}$ determined for the site in the initial screening assessment.

7.1.1 Modal Analysis

Rigid frequency with respect to ground seismic movement is specified as 40 Hz for ground type A, or 33 Hz for ground types B-E, with ground types determined in accordance with BS EN 1998-5 Clause 4.2.2 [6].

Where applicable, modal analysis undertaken should ensure the system's dynamic response is adequately modelled. This can be ensured by one of the following two approaches:

- The sum of the modal masses shall be equal to at least 90% of the total mass of the system (discounting any mass rigidly attached to the supports).
- The mode combination shall include all significant modes up to the rigid frequency as well as the residual rigid response due to missing mass, which shall be treated as an additional mode with a frequency equal to the rigid frequency.

7.2 Specific Analysis Requirements

7.2.1 Above Ground Pipelines

Above-ground pipelines should be analysed in accordance with BS EN 1998-4, Clause 5.4.2 [5]. Further guidance can be obtained from ASCE guidelines [17]. These guidelines also provide information on when a simpler pseudo-static analysis of an above ground pipeline may be appropriate.

7.2.2 Buried Pipelines

Buried pipelines should be analysed in accordance with Section 4 of the PRCI guidelines [14], considering as a primary concern for most cases the response of the pipeline to permanent ground displacement. Finite element analysis can be used, however there are cases where induced strain can be derived from more simple formulas outlined in the ASCE guidelines.

Soil-pipe interaction must also be considered for buried pipeline sections, with appropriate soil properties for the site in question. Soil resistance guidelines are provided in Section 4.3 of the PRCI guidelines.

The PRCI guidance, along with associated industry guidance, addresses the assessment of below ground pipelines in terms of load-controlled and displacement-controlled scenarios. In general, the primary earthquake hazards to below ground pipelines result in loading which is limited by displacement of the surrounding soil (displacement controlled). It is also possible that conditions arise in which loading of the pipeline is not related to permanent ground displacement (load controlled). Strain limits for both scenarios are provided in Section 7.3.

7.3 Performance Objectives

Pipeline sections should be assessed to DLS and / or ULS as outlined in Section 4.1. The behaviour factor referenced below is a factor represented by the symbol q used for design purposes to reduce the forces obtained from a linear analysis in order to account for the ductility and inherent over-strength of a structure or pipeline.

7.3.1 Below Ground Pipelines

For ULS verifications of buried pipelines, the following acceptance criteria apply:

a) In displacement-controlled situations, the longitudinal strain shall not exceed the limits given by:

$$\varepsilon_c = 1.76\frac{t}{D} \leq 3\%$$

$$\varepsilon_t = 3\%$$

b) In load-controlled situations, the longitudinal strain shall not exceed the limits given by:

$$\varepsilon_c = 0.4\frac{t}{D} \leq 1\%$$

$$\varepsilon_t = \frac{\sigma_y}{E}$$

For DLS verifications of buried pipelines, the following criteria apply:

a) In displacement-controlled situations, the longitudinal strain shall not exceed the limits given by:

$$\varepsilon_c = 0.4\frac{t}{D} \leq 1.5\%$$

$$\varepsilon_t = 1.5\%$$

b) In load-controlled situations, the longitudinal strain shall not exceed the limits given by:

$$\varepsilon_c = 0.4\frac{t}{D} \leq 1.5\%$$

$$\varepsilon_t = \frac{\sigma_y}{E}$$

Where:

ε_c = compressive strain

ε_t = tensile strain

t = pipeline wall thickness

D = pipeline external diameter

σ_y = pipeline material specified minimum yield strength (SMYS)

E = pipeline material Young's modulus

Note: The guidance detailed above has used aspects of the PRCI guidance; however, simplifications have been made to reduce strain limits to conservative levels. In general, for ULS calculations the PRCI guidance recommends maximum compressive and tensile and strain levels of up to 4%, and for DLS calculations up to 2%. The strain levels are considered appropriate; however, comparison should be made to PRCI, BS and Eurocode references in Section 10 for individual cases.

7.3.2 Above Ground Pipelines

For ULS verifications of above-ground pipelines, the following acceptance criteria apply:

a) The equivalent Von Mises stress anywhere in the pipe shall not exceed the SMYS when a behaviour factor q = 3 (valid for D/t < 100) has been used to account for the capacity of the pipeline to dissipate energy through inelastic deformation.

b) All supports and joints connecting the pipe to other components shall be designed to remain essentially elastic with q = 1.0. However, the design forces need not exceed the available capacity of the pipe section provided an allowance for over-strength has been made.

For DLS verifications of above-ground pipelines, the following acceptance criteria apply:

a) The equivalent von Mises stress anywhere in the pipe shall not exceed the SMYS. The behaviour factor q shall be taken as equal to 1.0 (as per BS EN 1998-4, Clause 2.4(1)P).

b) All supports and joints connecting the pipe to other components shall be designed to remain essentially elastic with q = 1.0.

8 GUIDANCE FOR PIPELINE SPECIFIC SYSTEMS

This section provides guidelines on the seismic assessment of pipeline systems associated with the pipeline system as shown in Figure 1. Assessment of components may be required if they fall within the pipeline section (buried or above ground) which requires seismic assessment (either simplified or full). A simple or full seismic assessment may be required depending on safety criticality of the component. Reference should be made to IEEE 693 [18] and BS EN IEC 60068-3-3 [19].

The following systems have been included:

- Actuators.
- Valves.
- Cabinets.
- Cable trays.
- Pipework.
- Earth retaining structures.

The following systems have not been included:

- Heating, ventilation, and air conditioning (HVAC) systems.
- Overhead traveling cranes.
- Pumps.
- Rotating machinery.
- Tanks.
- Pressure vessels.

8.1 Specific Systems Subject to Simple Seismic Assessment

The components below and equipment that poses a secondary hazard to Importance Class III systems but is itself not required to function after an earthquake can be assessed according to these recommendations.

The equipment and its support structure shall be anchored to a suitably robust foundation designed to resist the imposed seismic ground acceleration. Acceleration is to be calculated using the below equation:

$$a_{ps} = \gamma_{ps.} a_g . S$$

Where:

a_{ps} = ground acceleration.

γ_{ps} = compound factor determined in Section 6.4.1.

$a_{g.}S$ = ground acceleration factor outlined in UKOPA/GPG/019 Section 4.5 [1].

8.1.1 Actuators

In general, actuators are not expected to be vulnerable to seismic loading due to inherently robust construction.

Note that safety critical actuators without a fail-safe mode should be fully seismically qualified with reference to Section 8.2.

8.1.2 Cabinets and Cable Trays

Cabinets and cable trays associated with a pipeline system (e.g. valve hydraulic cabinets and associated cable trays) should be provided with adequate restraint.

8.1.3 Valves

Valves are not expected to be vulnerable to seismic loading due to robust construction. However, valve weight if considered significant, should be included as part of the pipeline seismic assessment.

If valves are considered safety critical then they should be subject to a full seismic assessment.

8.2 Specific Systems Subject to Full Seismic Assessment

Safety critical pipeline components requiring full seismic assessment are to be assessed to a 'performance level'. This requires physical testing in accordance with IEEE 693 or BS EN IEC 60068-3-3. The equipment and its support shall not fail, crack, slip, buckle, topple or show any permanent distress during and after testing.

Acceptance criteria for the particular functions of each piece of equipment shall be specified with due regard for the operational and safety functional requirements. The functions shall be checked before and after the shake-table testing. For qualification to the performance level, the functions shall also be checked during the testing.

8.2.1 Pipework

Pipework generally performs well in earthquakes. However, certain details can strongly affect the seismic resistance of pipework and lead to failure. Potential failure modes to consider during seismic assessment are:

- Pipe failure caused by large displacement of inadequately anchored equipment.
- Failure of small stiff pipes attached to large flexible pipes.
- Failure of pipework between buildings as a result of large relative displacement.
- Failure of brittle connections.
- Failure of corroded or brittle cast iron sections.

Both stress due to inertial actions (to be considered primary stress) and stress due to imposed displacement (to be considered secondary stress) should be considered.

Pipework should be designed in accordance with an appropriate standard.

8.2.2 Earth Retaining Structures

Earth-retaining structures should be designed in accordance with BS EN 1998-5, Section 7 [6].

9 CONCLUSIONS AND RECOMMENDATIONS

The seismic approach summarised in this document provides conservative guidelines for assessing seismic loading on above ground and buried pipelines and components. It is recommended this approach is used to assess seismic effects on pipelines and components operated by UKOPA members.

Depending on the level of seismic assessment and corresponding loading complexity required, it may be necessary to seek specialist advice to ensure the system, loading and seismic response are analysed accurately.

The PRCI guidelines [14], Eurocode 8 [2, 3, 4, 5, 6, 7], the UK national annexes [8, 9, 10, 11, 12] and BSI PD 6698 [13] should also be consulted as a minimum to ensure full compliance with required assessments.

10 REFERENCES

[1] United Kingdom Onshore Pipeline Operators' Association, “Seismic screening assessment of UK onshore pipelines and associated installations,” UKOPA/GPG/019 Edition 2, 2026.

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APPENDIX A ACRONYMS

ASCE	American Society of Civil Engineers
BSI	British Standards Institution
DBE	Design Basis Earthquake
DLS	Damage Limit State
GPG	Good Practice Guide
HVAC	Heating, Ventilation, and Air Conditioning
ILI	In-line Inspection
ISO	International Organization for Standardization
NGT	National Grid Transmission
PIWG	Pipeline Integrity Working Group
PRCI	Pipeline Research Council International
SMYS	Specified Minimum Yield Strength
ULS	Ultimate Limit State
UKOPA	United Kingdom Onshore Pipeline Operator’s Association