Cadent
Your Gas Network

Engineering Policies & Procedures

Specification for the protection of pipelines from ground movement and external loading. External loading on steel pipelines and buried piping at installations

GD/SP/GM/1

Issue Date: July 2019

This document is a reference document within the company Safety Case, all changes to this document shall be notified to the Head of SHES before any changes are initiated.

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Disclaimer

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Mandatory & Non-Mandatory requirements:

In this document:

Shall: Indicates a mandatory requirement.

Should: Indicates best practice and is the preferred option. If an alternative method is used then a suitable and sufficient risk assessment must be completed to show that the alternative method delivers the same, or better, level of protection

The Company: Any reference in this document to 'The Company' shall be taken to mean Cadent Gas Ltd.

Document history

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Comments and queries regarding the technical content of this document should be directed to:

Cadent

Ashbrook Court

Prologis Park

Central Boulevard

Coventry

CV7 8PE

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Document summary

Purpose

This work procedure was approved by the Head of Engineering, in July 2019 for use throughout Cadent.

Users should ensure that they are in possession of the latest edition and related bulletins by referring to the document library of Safety and Engineering documents available on the company Infonet.

Compliance with this safety and engineering document does not confer immunity from prosecution for breach of statutory or other legal obligations.

Responsibilities

This document applies to all those working directly for The Company e.g. employees, or under the direction of The Company, e.g. contractor mate working in a direct labour team.

Background

This specification is intended to provide requirements to ensure the safe and adequate performance of steel pipelines and buried piping at installations (pipe, bends & tees) under conditions of external loading. The sources of environmental actions are typically (but not limited to) soil overburden, ground settlement including subsidence due to longwall coal mining and traffic. These are considered alongside internal pressure, temperature and construction loads to ensure integrity and serviceability under the most adverse combination of actions.

The specification should be applied to:

- the structural design of new pipelines and pipework
- the integrity assessment of existing pipelines under any proposed increase in operating loads or changes in external loading

The specification may be applied to situations involving temporary or occasional traffic actions on new and existing pipelines.

For situations that fail to meet the standard acceptance requirements of this specification or cannot be accepted through more rigorous assessment, there may be a need for a pipeline protection slab and reference should be made to IGEM/TD/1 and GD/SP/CE12.

1. Scope

This specification is intended for application to steel pipelines and buried steel piping at installations designed and operated at pressures above 7 bar.

The specification applies to new and existing steel pipelines and to buried steel piping at Above Ground Installations. It is applicable to buried piping constructed by trenchless or open-cut methods. The specification may be used for river and estuary crossings providing the installation depth is sufficient to eliminate consideration of spanning (due to scour), vessel anchor loads or hydrodynamic loading.

Pipelines containing girth welds with a quality outside the acceptance limits of GD/SP/P2 are excluded and specialist advice should be sought. For existing pipelines (rather than new build), the edition of GD/SP/P2 relevant to the original design applies.

For pipe, bends and tees at installations, the requirements of this specification are additional to those of IGE/TD/12. In cases of any conflict over requirements, the most onerous should apply.

The document provides advice on methods for the calculation of geotechnical actions on buried pipes and on elastic analysis of the pipe structural response. Acceptance limits for integrity are presented for a permissible stress approach based on the principle of yield-limited design.

Where required The Construction (Design and Management) Regulations 2015 shall be followed.

2. Definitions

Adequate performance: meets all operating requirements in normal service.

Environmental actions: actions associated with the external conditions on the pipeline, including actions arising from:

- Subsidence or settlement due to mining and mineral extraction, dewatering, or the action of additional surface loads, typically embankments
- Subsidence due to the pipe being laid on top of disturbed or built up land, taking into account the differences in support between existing pipe and modified pipe at tie in interface
- Slope instability
- Frost heave
- Buoyancy
- Live loading from vehicles
- Earthquakes[1]

[1] Seismic wave loading generated by earthquakes is not covered in this specification. Permanent ground movements of liquefaction settlement and slope instability are rare in the UK however can be evaluated using this specification.

- Overburden loading
- Lateral ground displacement due to adjacent civil or mining works.

Road: a public highway or private access route for use by vehicles. The term may also be used to describe a temporary site route for construction vehicles

Sidefill: soil material placed in contact with the pipe between the pipe ring top and bottom positions

Springing (or springline): the mid-height position on the pipe cross-section

Traffic: agricultural plant, construction plant or any vehicle using a temporary or permanent road

3. Specification overview

3.1 New build (design)

The structural design of new pipelines shall be in accordance with the Institution of Gas Engineers and Managers Publications referenced in Appendix A2.

For new pipelines and installations the design should consider all environmental loading actions on the pipe structure. This may lead to measures to control the loading actions on the pipe or the pipe may be chosen to have sufficient resistance to accommodate the loads and design actions. In areas subject to additional loading due to ground movement or traffic loading, the interaction of the Structural Eurocodes and IGEM series of standards shall also be considered as indicated in Section 4.

In the case of new pipelines it is common for linepipe and fittings to be ordered on the basis of pressure design, minimum handling & transport or location requirements. This inevitably reduces the options for controlling stress levels when deeper installations are required or when shallower installations will experience traffic loading or significant temperature increases. The measures subsequently available to control integrity are associated with reducing the loading on the pipe ring or improving the support performance of the bedding and sidefill materials.

The assessment involves a number of calculations for loading and response of the pipeline structure. Each of the load cases involves acceptance checks.

In some design situations a rigorous structural analysis can be avoided if the design factor, operating temperature conditions and maximum cover depth are within the limits presented in Table 1.

For a trenchless installation the maximum acceptable cover depth presented in Table 1 can be increased by multiplying the Table 1 value by an uplift factor according to Table 2.

In situations involving specialist construction techniques there should also be formal checks on the acceptability of proposed temporary and/or permanent loads on the pipeline structure.

Nominal size (mm)	Nominal Wall Thickness (mm)	Material Grade	Temperature Limits for forged bends – bend spacing ≥ 25.D			Temperature Limits for forged bends – bend spacing < 25.D			Maximum Cover depth (m)
			Min Design (°C)	Range (°C)	Max Design (°C)	Min Design (°C)	Range (°C)	Max Design (°C)	
100	4.8		-1	14	14	4	7	8	8.4
	6.0	B	-2	13	14	3	7	8	12.5
	11.9		-5	15	16	-2	12	13	15.0
150	5.6		-7	18	17	0	9	10	7.1
	7.1	X42	-7	16	17	0	9	10	10.0
	11.9		-9	15	16	-4	10	11	15.0
200	6.4		-8	19	18	0	10	11	6.0
	8.2	X42	-8	18	18	0	10	11	8.3
	12.7		-9	15	16	-3	10	11	15.0
250	6.4		-12	25	21	-3	13	12	5.4
	8.7	X46	-10	21	20	-2	12	13	7.5
	12.7		-9	17	18	-3	11	12	13.2
300	7.1	X46	-13	26	22	-3	15	13	5.2
	9.5		-11	22	21	-3	12	13	6.8
	12.7	X52	-12	21	22	-5	14	14	11.8
400	8.7		-17	30	24	-9	19	17	6.3
	10.3	X52	-15	27	23	-7	16	16	7.2
	14.3		-13	23	22	-6	15	16	10.9
450	9.5	X52	-18	31	25	-8	19	16	6.2
	11.9		-15	24	23	-6	16	15	7.7
	15.9	X60	-16	27	24	-8	18	17	13.1
600	9.5	X52	-25	39	31	-13	24	20	4.4
	14.3		-19	28	25	-9	16	17	6.1
	19.1	X60	-20	26	25	-11	17	17	10.2
750	11.9	X52	-25	39	31	-23	32	23	4.5
	15.9		-25	36	29	-22	30	22	7.1
	19.1	X60	-22	31	26	-18	27	20	8.3
	22.2		-20	28	25	-17	23	20	9.6

Table 1 – Temperature limits and maximum acceptable cover depth to avoid pipeline structural analysis as part of the design

900	12.7	X60	-25	51	38	-21	33	26	5.5
	15.9	X65	-25	46	35	-19	30	23	7.2
	19.1	X60	-25	35	29	-14	22	20	7.3
	25.4	X65	-24	31	27	-14	20	19	10.3
1050	14.3	X60	-25	53	40	-25	35	29	5.3
	17.5	X65	-25	48	36	-23	32	26	6.9
	19.1		-25	45	34	-21	29	24	7.3
	28.7		-24	32	28	-15	20	20	10.3
1200	15.9	X65	-25	59	50	-25	39	29	6.4
	19.1		-25	51	38	-22	33	26	7.0
	22.4		-25	46	34	-19	29	23	7.4
	25.4		-25	39	31	-17	26	21	8.3
1200	14.3	X80	-25	75	50	-25	55	40	6.6
	15.9		-25	75	50	-25	51	36	8.6
	20.6		-25	62	41	-25	40	28	12.3
	22.9		-25	57	39	-25	38	27	12.2

Requirements:

(i) Pipe to GD/SP/DAT/6 & GD/SP/PIP/1

(ii) Design factor not exceeding 0.72

(iii) Maximum operating temperature not exceeding 50 °C

(iv) Minimum operating temperature not below -25 °C.

(v) No settlement or other forms of ground movement.

(vi) Forged bends shall have a radius of 3D or greater and the wall thickness or material grade shall be selected to achieve the design factor.

(vii) Traffic actions (including impact assumptions) shall not exceed the equivalent of 2 x 60kN point loads at 0.9 metre spacing [typically access roads used by very light traffic or agricultural plant operating in fields].

(viii) Pipeline installation by open cut methods.

Table 1 – Temperature limits and maximum acceptable cover depth to avoid pipeline structural analysis as part of the design (continued)

External diameter/nominal wall thickness (D/t_{nom})	**Uplift factor**
$D/t_{nom} \leq 20$	2.0
$20 < D/t_{nom} \geq 30$	1.8
$30 < D/t_{nom} \geq 40$	1.6
$40 < D/t_{nom} \geq 50$	1.4
$50 < D/t_{nom} \geq 60$	1.3
$60 < D/t_{nom} \geq 70$	1.2
$70 < D/t_{nom} \geq 80$	1.1
$D/t_{nom} > 80$	1.0

Table 2 – Cover depth uplift factors for trenchless installations

3.2 Existing pipelines and installations

For existing pipelines and installations the extent and quality of factual information on ground and groundwater conditions will influence the decisions on pipe loading and restraint. Uncertainty may need to be reduced by site investigation work to determine the pipeline stress state and geotechnical conditions.

Site investigation should be carried out in accordance with BS 5930.

If the cover depth is to be increased then consideration should be given to the possibility of ground settlement along the pipeline. This ground settlement should be included as an environmental action on the pipeline structure.

The integrity and performance assessment follows the same approach as for a new build situation.

4. Assessment methodology

4.1 Soil overburden pressure

4.1.1 Geotechnical parameters

The geotechnical parameters shall be defined and derived in accordance with Eurocodes or general publication being considered for the design work.

BS EN 1997-2 and the first four sections of BS EN 1997-1 may be used to conduct ground investigations and derive geotechnical parameters which may be used in pipeline/above ground installations pipework design. Ground investigations can also be performed in accordance with BS5930: 2015, which complies with BS EN 1997.

Where BS EN 1997 is used in conjunction with other design methods, care should be taken in deriving geotechnical parameters according to the specific assumptions of the design standard being used.

4.1.2 Calculation of soil overburden pressure

The calculation of soil overburden pressure on the pipe ring should recognise the influence of construction technique and sequence, pipe ring stiffness and backfilling. These factors will dictate whether the soil load is concentrated onto the pipe ring or reduced by arching onto the sidefill material.

The soil overburden pressure shall be calculated using the techniques and methods appropriate for the specific design to be considered as described in the following general publications and standards.

For trenchless construction, the technique embodied in the API Recommended Practice 1102 is appropriate. Alternative methods involving the Marston tunnel load equation or a prism loading can also be adopted.

GD/SP/CE/14 provides further guidance on undertaking horizontal direction drilling (HDD).

For conventional trenched construction, the methods presented in NEN3650 or BS EN 1295-1: 1998 are considered acceptable.

The Young & O'Reilly work applies Marston load theory to determine soil loading on buried rigid pipes. The approach identifies a load concentration or load relaxation depending on the specified construction trench width. A semi-empirical factor, the settlement ratio, is required for the loading calculation. This should be carefully selected according to the pipe bedding stiffness, the pipe ring stiffness and the sidefill compaction state.

The NEN3650 approach applies simplified equations to approximate the results of Marston load theory to loads on shallow buried pipes. A semi-empirical parameter, the compaction factor, is required to account for the influence of ring deflection, pipe support and sidefill condition. Clear guidance is offered on the appropriate selection of the compaction factor according to ground conditions and construction backfilling practice. The NEN3650 approach also identifies a transition from loading on shallow pipes to loading on deep pipes. This is achieved by checking if the soil passive loading using a 'shallow' burial algorithm exceeds the passive loading using a 'deep' burial algorithm.

The ATV A127 approach calculates a load distribution on the pipe ring and sidefill according to the ring and soil stiffness. The soil stiffness is conveniently linked to ground type and degree of compaction.

The ATV A127 methodology allows the compaction requirements of the backfill to be determined in a form suitable for construction control or for checks on existing installations.

The calculation of a soil lateral 'support' pressure should recognise that any load concentration on the pipe ring will involve a load reduction over the pipe sidefill material. The calculation of this load reduction requires an assumption about the zone of load re-distribution over the pipe. This should be in accordance with ATV A127.

The method according to BS EN 1295-1:1998 for semi-rigid pipes involves adjusting the settlement ratio according to the pipe ring stiffness. The settlement ratio, r_{sd}, applicable to semi-rigid pipes is adjusted as follows:

$$r_{sd(adjusted)} = r_{sd} \cdot (1 - n) \qquad \textbf{(1)}$$

Where

r_{sd} is the settlement ratio

$$n = \frac{\frac{E'}{D_L}}{\left(\frac{105.E_p.I}{D^3} + \frac{0.8.E'}{D_L}\right)}$$

E' is the modulus of soil reaction

D_L is the deflection lag factor [taken to be = 1.5]

E_P is the Young's modulus of the pipe material

I is the second moment of area of the pipe wall

D is the external pipe diameter

The designer will need to consider whether the application of the above techniques and methods complements or is alternative to the design basis of BS EN 1997and BS EN 1990, including the geotechnical limit states and material partial factors for geotechnical parameters.

When using BS EN 1997 for deriving geotechnical parameters, the confidence level shall be set according to the BS EN 1997 assumptions. When using any of the above techniques and methods as an alternative to the design basis of BS EN 1997 and BS EN 1990, the calculations should seek to achieve a 95% confidence level.

4.2 Vehicles or construction plant transient loads

Determination of traffic loading

Variable actions due to traffic loading acting on UK highways and railways shall be obtained from BS EN 1991 “Actions on structures. Part 2: Traffic loads on bridges” and the UK National Annex to BS EN 1991-2.

The traffic models for design should be appropriate for the location of the pipeline and the class of traffic. The following load models should be applied where appropriate:

- For pipelines under or adjacent to public highways: LM1, LM2 and LM3 (with the LM3 vehicles appropriate to the type of highway, as required by the Highway Authority), which gives a maximum axle load of 400kN;
- For pipelines that are remote from public highways but are subject to traffic loading that Cadent has little or no control over: LM3 (based on SV100 vehicles), which gives a maximum axle load of 165kN;
- For pipelines that are remote from public highways and subject to traffic loading that is controlled to vehicles that are permitted to use the highway without special authorisation: 0.685 x LM3 (based on SV100 vehicles), which gives a maximum axle load of 113kN.

Further details on these traffic models are provided in GD/SP/CE/12. The above models include the dynamic effect of impact.

An appropriate method should be adopted to calculate the transient vertical pressure increase at the pipe crown due to distributed surface loadings associated with vehicles, trains & rolling stock, and agricultural or construction plant. The dynamic effect of the impact factor should be included in the loadings.

Guidance on vertical and horizontal surcharge models for UK highway and railway loadings can be obtained from BS EN 1991-2 and PD 6694-1. The models introduced by EN 1991-2 and PD 6694-1 are not specific for pipeline design and reference to other methods indicated in literature may be needed. In particular, for trenchless pipeline installations the predictive technique incorporated within the API Recommended Practice 1102 can be applied. Alternatively, for trenchless or trenched pipelines the methods of Boussinesq (also covered in Young & O’Reilly) may be used.

Allowance for the load spreading influence of surface layers should be incorporated as described in NEN 3650 and Braunstorfinger.

4.3 Ground movement

4.3.1 Settlement

Ground settlement predictions will generally only be warranted for earthworks constructed over cohesive or organic natural soils. In these cases, the settlement should be quantified through conventional one dimensional consolidation theory or estimated from observational data from relevant case histories.

The ground settlement assessment should include the profile of movement at the margins of the earthworks. This zone is important in relation to longitudinal bending effects on the pipeline structure.

Calculation of settlements usually provides an approximate indication and should not be regarded as accurate. In assessing the magnitude of displacements account shall be taken of comparable experience.

The assessment of settlements that arise from vibration disturbance of the soil including the potential for liquefaction is covered in specification GD/SP/GM/4.

4.3.2 Horizontal movement

In certain circumstances it may also be appropriate to quantify and include horizontal ground movements. This is likely to apply to situations involving slope instability, adjacent shafts, boxes, retaining walls or underground excavation.

4.3.3 Subsidence from longwall coal mining

4.3.3.1 General

Subsidence occurs almost instantaneously at surface when coal seams are removed from the underlying rock strata by longwall mining methods. In addition to vertical subsidence, which extends beyond the plan area of the worked panel, horizontal ground extension occurs at the boundary of the subsidence zone and horizontal compression occurs in the centre of the subsidence zone. Areas of maximum tension and compression in subsidence zones can potentially cause pipeline damage by fracture or buckling.

4.3.3.2 Notification

The Coal Mining Subsidence Act 1991 (Section 46), requires the Coal Authority as the licensing body to notify affected landowners and occupiers (including Statutory Undertakers) of proposals to carry out underground mining that is likely to cause subsidence.

The notifications are provided in the form of key notice maps outlining blocks of the country where underground mining is proposed. Unless a pre-existing arrangement exists between the

Coal Authority and an affected party, the notice will be within 12 months of operations commencing. There is no minimum notice period specified.

Cadent Gas will generally require a minimum of two years notice in order to investigate the potential effect of mining subsidence on affected pipelines and as such contact with operators should be made at the earliest possible stage to establish the nature and scheduling for the extraction activities. Where underground mining is indicated or suspected, the Network should consult the Coal Authority with regard to confirming the location of proposed mining in relation to existing or planned pipelines and for the Operators contact details so that more detailed discussions can take place. The contact address for the Coal Authority is Director of Mining Information and Services, Coal Authority, Mining Reports Office, 200 Lichfield Lane, Berry Hill, Mansfield, Nottinghamshire, NG18 4RG.

Preventative works are sometimes required to avoid the pipeline incurring damage. These can be carried out with the Operators agreement under Coal Mining Subsidence Act 1991 (Section 33). The precise wording of the Act is that the Operator is only liable for damage sustained and therefore is not under an obligation to pay the costs for preventative measures. It is generally sufficient to demonstrate that damage is likely to occur or that pipeline strain changes are recorded for the Operator to agree to preventative measures. Historically, the Operator has paid 80% of costs where the pipeline installation pre-dates the intention to mine and 50% of costs for situations where the intention to mine pre-dates the pipeline installation. Costs incurred should be recovered regardless of whether the proposal is subsequently altered and mining is discontinued.

The Coal Authority currently send the Section 46 plans of proposed mining to the Land and Development Section, Ashbrook Court, Prologis Park, Central Boulevard, Coventry, CV7 8PE who can be consulted for further guidance on any aspect of the notification process.

4.3.3.3 Assessment

Ground movement predictions generally include empirical or semi-empirical factors for the subsidence magnitude and distribution and these factors vary with location across the UK (Subsidence Engineer's Handbook, Whittaker and Reddish). Assessment of the pipeline response to the mining requires a series of ground movement profiles that represent different stages of the longwall face advance in the panel being extracted. Predictions tend to be more difficult and less reliable in areas with complex near surface geology, where geological faults are located and where multi-seam working has previously taken place. Uncertainty over predicted subsidence applies to both the magnitude and profile at a particular location and can be reduced by calibration against existing measurements of ground movement resulting from longwall extraction in the same area.

The ground movements associated with the mining induced subsidence should be established at a target confidence level of 95%. This can be achieved through a contingency factor to increase predicted movements calculated using mean subsidence factors. Alternatively, the calculation of ground movements can use subsidence factors selected at a target confidence level of 95%.

Ground movement predictions should be formally reported showing the basis and value of all parameters used in the calculations, the analysis methods adopted and the results.

4.3.3.4 Monitoring

Measurements of the pipeline stress state should be considered in all circumstances where previous deep mining has been carried out to address uncertainties in the nature and effect of the previous subsidence. These need to be carried out prior to any structural assessments associated with the new extraction activities. Excavations associated with stress measurement work provide an opportunity to make observations and measurements on the ground conditions for decisions on soil friction and restraint assumptions.

Where pipelines are considered to lie within the subsidence influence zone, measurements of 3D ground movements shall be undertaken along the pipeline route at a suitable interval and extend into the unaffected area beyond the influence zone. For the purposes of this specification, the influence zone is defined as the area where subsidence exceeds 1% of the maximum predicted subsidence for the panel. The measured movements should be compared to the predictions for the same stage of extraction to ensure that the trend of measured movements lies within the predicted values.

Consideration should be given to conducting additional assessment based on measured ground movements if the profile suggests higher stresses or localised stress highs. This may influence the monitoring requirements.

Direct measurement of the pipeline response to the ground movements by the fitting of strain gauges should follow guidance in GD/SP/GM8.

4.3.3.5 Remedial action

Techniques employed to reduce pipeline stress arising from ground movement due to coal mining include uncovering pipeline sections, use of low friction backfill, stress relieving cuts, expansion units or sliding joints in areas of restricted access, replacement of sections in higher strength pipe or pipeline re-routeing. Remedial action, particularly uncovering operations, need to be carefully planned on the basis of monitoring and structural modelling simulations. The uncovering operation needs to be controlled by monitoring.

4.3.4 Temperature

The temperature change from tie-in condition to the operating case shall be estimated and included in the pipeline stress state calculation.

For installations with an unknown tie-in temperature, separate assessments shall be undertaken involving both a +10°C temperature change and a -10°C temperature change. The most onerous value should be used.

4.3.5 Internal pressure

The value of internal pressure varies according to the load case and the circumstances of the assessment. For new build pipelines or buried piping, the calculations shall use the design pressure. This may be equal to or greater than the maximum operating pressure (MOP). For existing pipelines, the load calculations involving the pressurised structure require values for the maximum operating pressure (MOP), the maximum incidental pressure (MIP) or the operating pressure depending on the load case being considered.

4.3.6 Construction

The possibility of construction induced stress due to laying practice should be included in the assessment. Elastic bending of linepipe to accommodate vertical ground profile or horizontal alignment changes may be characteristic of some small diameter pipeline installations. This can be included in the assessment if appropriate intelligent pigging has quantified curvature levels and locations. Internal inspection survey reports suggesting an absence of cold field bends may be indicative of potential elastic bends in the pipeline. Uneven trench bottom conditions during pipeline laying may also contribute to localised construction stresses.

Any permanent longitudinal curvature imposed by pipeline installation by trenchless methods should be quantified and included in the assessment.

The assessment of localised construction stress may involve a statistical analysis of available stress state measurement records on similar pipelines in the system network. Alternatively for existing pipelines, a curvature survey may be required using a suitable internal inspection tool. NEN3650 offers a semi-empirical assessment to quantify potential localised construction stress due to uneven trench bottom conditions.

In the case of existing pipelines, consideration should be given to establishing the current pipeline stress state using the centre hole residual stress measurement technique.

5. Load Cases to be considered

5.1 Internal pressure case

This involves a calculation of hoop stress using the design pressure or the MOP. The calculation involves the use of the Barlow formula:

$$\sigma_{hoop} = \frac{p.D}{2.t} \qquad (2)$$

Where:

p is the design pressure or MOP

D is the pipe external diameter

t is the minimum wall thickness (nominal less mill under tolerance)

5.2 Normal operating case

The normal operating case involves all permanent and variable loads on the pipeline structure. These include:

- Internal (MIP) – (maximum incidental pressure)
- Temperature change from tie-in
- Soil overburden pressure
- Ground movement
- Construction movement
- Traffic
- Self-weight including buoyancy and buoyancy control measures.

5.3 Occasional operating case

The occasional operating case involves both static loads and temporary or occasional vehicle loads. These include:

- Internal pressure (maximum during period of temporary loading)
- Temperature change from tie-in
- Soil overburden pressure
- Ground movement
- Construction movement
- Temporary traffic (e.g. construction plant)

- Occasional traffic (e.g. agricultural plant)

5.4 Depressurised case

The depressurised case involves the external loads listed in section 5.2 at zero internal pressure. Any appropriate adjustment to the operating temperature to reflect the removal of internal pressure should be included.

5.5 Cyclic load cases

The cyclic load case will usually involve an assessment of the maximum principal stress range in the pipeline due to the application of traffic loading only.

For pipelines subjected to both traffic loading and internal pressure cycles a fatigue assessment will be required based on the calculation of cumulative damage. Further guidance is provided in IGEM/TD/1.

In some cases a shakedown assessment will be required in order to verify that any local yielding identified in the operating case will not lead to alternating yield.

5.6 Summary of load cases

An overview of the load case requirements of this specification are presented in figure 1.

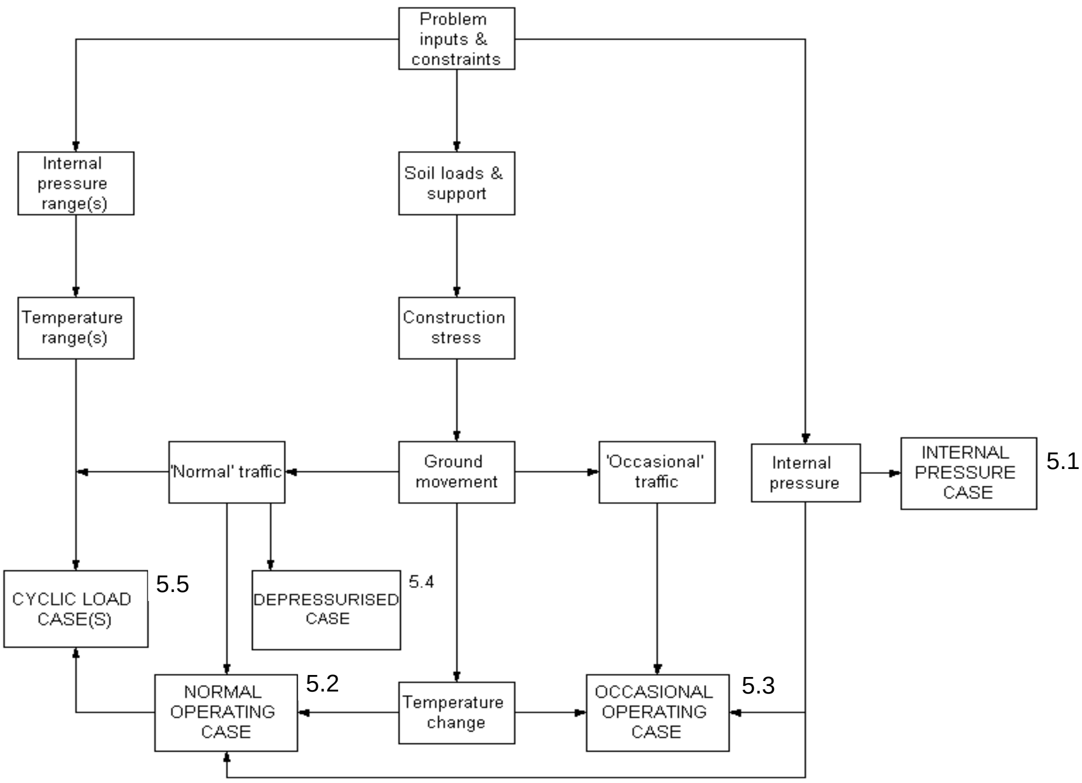

Figure 1 – Overview of load case assessments

6. Methodology requirements for structural response

6.1 General

With the exception of the hoop stress check presented in section 5.1, all other calculations of internal forces and stresses within the pipe structure should adopt the nominal wall thickness.

6.2 Ring response

The minimum requirement is the application of ring statics using distributed loading and support to determine internal forces and moments. Stresses are then calculated according to the section properties.

The actions on the ring should include the vertical soil overburden pressure, the horizontal sidefill loading, passive soil support due to ring deflection, vertical variable actions (if applicable), bedding support reactions, and any additional transverse loading due to ground and construction movement.

A calculation of the critical wall buckling stress should be performed according to the method described in BS EN 1295:1.

6.3 Longitudinal response

The longitudinal response will generally require numerical analysis using a piping stress analysis program. This will enable the calculation of longitudinal bending stresses due to ground movement and differential construction movements. Contributions due the Poisson effect from internal pressure, axial thrust forces from pressure load at bends and tees and thermal stresses should also be quantified in the same analysis.

For problems involving straight pipe and where ground movement need not be considered, the determination of longitudinal stress can be based on standard equations assuming longitudinal fixity.

6.4 Combined response

For situations involving separate calculations for ring and longitudinal response, the circumferential and longitudinal stresses will be summated at the inner and outer wall locations at the bottom, springing and top positions on the ring. This should be considered for two possible scenarios of construction stress; hogging at the point of interest or sagging.

In the general case the combined response will be handled through a piping stress analysis product capable of dealing with the combined ring and longitudinal response under all load case conditions.

7. Performance/acceptance criteria

The stress acceptance requirements of this section incorporate the requirements of IGEM/TD/1.

7.1 Stress

7.1.1 Internal pressure

The hoop stress according to the Barlow formula (section 5.1) shall meet the following criteria:

$$\sigma_{hoop} \leq f.s \qquad (3)$$

Where:

f is the design factor

s is the specified minimum yield strength of the pipe material

7.1.2 Operating, depressurised & occasional load cases

The maximum equivalent stress for total stress components (membrane & bending) should meet the criterion:

$$\sigma_e \leq 0.9s \quad (4)$$

Where

σ_e is the Von Mises equivalent stress $\{= \sqrt{\sigma_c^2 + \sigma_l^2 - \sigma_c.\sigma_l + 3.\tau^2}\}$

σ_c is the circumferential stress

σ_l is the total longitudinal stress

τ is the torsional shear stress

s is the specified minimum yield strength of the pipe material

The maximum equivalent stress for membrane components should meet the criterion:

$$\sigma_e \leq 0.8s \quad (5)$$

Where:

σ_e is the Von Mises equivalent stress $\{= \sqrt{\sigma_h^2 + \sigma_a^2 - \sigma_h.\sigma_a}\}$

σ_h is the hoop stress due to internal pressure

σ_a is the longitudinal axial stress due to axial (excluding bending) (through-wall component of σ_l)

s is the specified minimum yield strength of the pipe material

For girth welds with a Charpy (full size or equivalent) V-notch impact energy at the minimum design temperature of less than 40 J average or 30 J single value, the following additional requirement on the longitudinal tensile stress across girth welds will apply:

$$\sigma_l \leq 0.9s \quad (6)$$

Overstress conditions in the operating and occasional load cases should be reviewed for possible acceptance under a shakedown assessment.

7.1.3 Cyclic load cases

The following criteria shall be met for variable loading from traffic:

$$\Delta\sigma \leq 35 \text{ N/mm}^2 \qquad (7)$$

Where $\Delta\sigma$ is the maximum circumferential stress range due to external transient loading. For highway traffic the stress range may be calculated based on the FLM3 Load Model in BS EN 1991-2. For rail traffic the stress range may be calculated based on the LM71 Load Model and factored by the appropriated dynamic factor as given in BS EN 1991-2.

The cyclic loading from external transient sources can be considered acceptable if the calculated vertical pressure increase over the pipe diameter is less than calculated using Equation 8.

$$\frac{64}{\left(\frac{D}{t_{nom}}\right)^2} \qquad (8)$$

Where:

D is the outer diameter (mm)

t_{nom} is the nominal wall thickness (mm)

If a full fatigue assessment is required then the acceptance condition is that the calculated fatigue usage factor is less than 1. Further guidance is provided in IGEM/TD/1.

For local yielding in bends, a shakedown assessment should demonstrate an adequate factor of safety against alternating yield and yielding should be controlled by restricting the total (elastic & plastic) tensile strain in the bend to the permissible limit for the material and welds.

7.2 Over-deflection (ovality)

The diametral deflection of the pipe cross-section should be limited to 5% of the nominal diameter.

7.3 Stability

A factor of safety of at least 3.0 against buckling of the pipe wall should be demonstrated.

7.4 Strain

For strain based assessments (see Clause 9), consideration should be given to acceptance criteria as follows:

- An equivalent plastic strain limit of 0.5% as defined in PD 8010-1: 2015.
- A longitudinal total strain limit based on the results of curved wide plate testing of representative girth weld samples containing appropriate planar defects.

8. Backfill requirements for compliance

The integrity assessment may indicate that a minimum performance is required from the backfill material that supports the pipe ring. For existing installations, the reliability of an assessment can be improved by the identification of the type of pipe sidefill material and the determination of the compaction state by site measurements.

For new installations, any requirement for the control of backfilling in the pipe zone should be achieved through a specification of material suitability and a method or performance statement for placement of the material. The objective should be to achieve a minimum compaction level in order to ensure an acceptable performance. This is likely to involve requirements that are additional to GD/SP/P/10**.**

Care should be exercised in the application of API Recommended Practice 1102 to trenched installations. The guidance presumes a high standard of reinstatement (and hence support performance) as part of the construction practice. The required standard is likely to be similar to the standard required for UK highways, which is outlined in the Specification for the Reinstatement of Openings in Highways. The critical importance of providing a backfill of equivalent performance to that of the natural ground should be noted.

9. Dealing with out of compliance problems

For problems that cannot be resolved by the assessment methods and acceptance criteria of this specification, consideration should be given to more advanced forms of assessment. Alternatives include stress categorisation approaches, for example NEN3650 and BS5500 or strain based methods, for example NEN3650.

10. Reporting requirements

Integrity assessments to this specification should be formally reported and checked. An appraisal to Cadent Gas management procedure GD/PM/G/17 is required. The reporting shall document the information and data used, the basis and value of all parameters used in calculations, the analysis methods adopted and the results.

Appendix A: References

A.1 Standards and specifications

Reference	Document title
BS EN 1990	"Basis of structural design" and UK National Annex to BS EN 1990
BS EN 1991	"Actions on structures" Part 2: 'Traffic loads on bridges' and UK National Annex to BS EN 1991-2
BS EN 1997	"Geotechnical Design" Part 1: 'General Rules' Part 2: 'Ground investigation and testing' + A1:2013 UK National Annex to Eurocode 7.
BS 5930: 2015	Code of practice for ground investigations. Compliance with BS EN 1997-1 and BS EN 1997-2
PD 6688	Part 2: 'Background to the National Annex to BS EN 1991-2. Traffic loads on bridges'
PD 6694	Part 1: 'Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004'
ATV-Standard A 127	Standard for the Static Calculation of Drainage Sewers and Pipelines. Abwassertechnische Vereinigung e.V. 2nd edition. December 1988.
NEN 3650	Requirements for Pipeline Systems, issued by Nederlands Normalisatie-instituut: Part 1: General Requirements Part 2: Additional specifications for steel pipelines
TS-C4Gas-PIP0v7.5	Specification for Steel Pipes for Pipelines – common requirements. June 2011.
TS-C4Gas-PIP4 V12	Specification for Steel Pipes for Pipelines – National Grid specific requirements. 2011.
PD 8010-1:2015	Pipeline systems. Steel pipelines on land – code of practice (+A1:2016)

A.2 Institution of Gas Engineers and Managers Publications

Reference	Document title
IGEM/TD/1	Steel Pipelines for High Pressure Gas Transmission. Recommendations on Transmission and Distribution Practice. Edition 5.

Reference	Document title
IGEM/TD/12	Pipework Stress Analysis for Gas Industry Plant. Communication 1252. Recommendations on Transmission and Distribution Practice. The Institution of Gas Engineers. Edition 2.

A.3 Cadent engineering documents

Reference	Document title
GD/SP/CE12	Specification for The Design, Construction and Testing of Civil and Structural Works. Part Twelve: Pipeline Protection Slabs. January 2002
GD/SP/P2	Specification for Welding of Land Pipelines and Installations Designed to Operate at Pressures Greater Than 7 bar (incorporating BS4515). February 2003.
GD/PM/G/17	Management Procedure for the Management of New Works, Modifications and Repairs.
GD/PM/G/35	Management Procedure for the Management of Modifications and Repairs.
GD/PM/IGE/TD/1	Management procedure for the Application of IGEM/TD/1 – Steel Pipelines and Associated Installations for High Pressure Gas Transmission, Cadent Gas.
GD/SP/P/10	Technical Specification for General Pipelining Designed to Operate at Pressures Greater Than 7 bar (Complementary to BS8010). May 1995
GS/SP/DAT/6	Data Sheet. Carbon and Carbon Manganese Steel Pipe for Operating Pressures Greater Than 7 bar. February 1994

A.4 General publications

Reference	Document title
BS EN 1993-4-3	Bibliography contained in Annex B
API Recommended Practice 1102	Steel Pipelines Crossing Railroads and Highways, Seventh Edition, December 2007+Errata November 2008+Errata May 2010
Gauthier-Villars, Paris 1885.	Boussinesq V. J. Application des potentiels à l'étude de l'équilibre, et du mouvement des solides élastiques avec des notes etendues sur divers points de physique mathématique et d'analyse.

Reference	Document title
Rohre – Rohrleitungsbau – Rohrleitungstranport. Heft 4. August 1971	Braunstorfinger M. Einfluss von Verkehrslasten gemass DIN 1072 auf eingeerdete Rohre mit geringer Scheitelhberdeckung.
BS EN1295: 1998	Structural design of buried pipelines under various conditions of loading. Part 1. General Requirements. British Standards Institution.
CIRIA Report 78. July 1978	Compston D.G., Cray P., Schofield A.N. and Shann C.D. Design and construction of buried thin-walled pipes.
Highway Research Record 30. 1963. Highway Research Board (Washington DC).	Meyerhof G.G. and Baikie L.D. Strength of steel culvert sheets bearing against compacted sand backfill.
McGraw-Hill. Third Edition, 2008.	Moser A.P. Buried Pipe Design.
HMSO. April 2010.	Specification for the Reinstatement of Openings in Highways. A Code of Practice.
National Coal Board. London 1975.	Subsidence Engineer’s Handbook.
Whittaker B.N. and Reddish D.J. Elsevier. 1989.	Subsidence – Occurrence, Prediction and Control.
Young O.C. and O’Reilly M.P. HMSO. 1987.	A guide to design loadings for buried rigid pipes.

Cadent
Ashbrook Court
Prologis Park
Central Boulevard
Coventry
CV7 8PE