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Earthquake-resistant and subsidence-resistant design of ductile iron pipelines

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National foreword

This British Standard is the UK implementation of ISO 16134:2020. It supersedes BS ISO 16134:2006, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PSE/10, Iron pipes and fittings.

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Conception de canalisations en fonte ductile résistant aux tremblements de terre et aux phénomènes de subsidence

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

This second edition cancels and replaces the first edition (ISO 16134:2006), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the classification of pipelines components in Table 3 is modified;

— the relationship between seismic intensity and ground surface acceleration in Table B.1 is modified;

— the calculation method of checking the safety of pipeline against ground deformation is added in 5.3.

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Introduction

Buried pipelines are often subjected to damage by earthquakes. It is therefore necessary to take earthquake resistance into consideration, where applicable, in the design of the pipelines. In reclaimed ground and other areas where ground subsidence is expected, the pipeline design must also take the subsidence into consideration.

Even though ductile iron pipelines are generally considered to be earthquake-resistant, since their joints are flexible and expand/contract according to the seismic motion to minimize the stress on the pipe body, nevertheless there have been reports of the joints becoming disconnected by either a large quake motion or major ground deformation such as liquefaction.

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Earthquake-resistant and subsidence-resistant design of ductile iron pipelines

1 Scope

This document specifies the design of earthquake-resistant and subsidence-resistant ductile iron pipelines suitable for use in areas where seismic activity and land subsidence can be expected. It provides a means of determining and checking the resistance of buried pipelines and gives example calculations. It is applicable to ductile iron pipes and fittings with joints as specified in ISO 2531, ISO 7186 and ISO 16631 that have expansion/contraction and deflection capabilities, used in pipelines buried underground.

NOTE Subsidence is not the effects of an earthquake or a sinkhole.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2531, *Ductile iron pipes, fittings, accessories and their joints for water applications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2531 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
burying
placing of pipes underground in a condition where they touch the soil directly

3.2
response displacement method
earthquake-resistant calculation method in which the underground pipeline structure is affected by the ground displacement in its axial direction during an earthquake

3.3
liquefaction
phenomenon in which sandy ground rapidly loses its strength and rigidity due to repeated stress during an earthquake, and where the whole ground behaves just like a liquid

3.4
earthquake-resistant joint
joint having slip out resistance as well as expansion/contraction and deflection capabilities

3.5
flexible joint
joint having expansion and deflection capabilities

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4 Earthquake-resistant design

4.1 Seismic hazards to buried pipelines

In general, there are several main causes of seismic hazards to buried pipelines:

a) ground displacement and ground strain caused by seismic ground shaking;

b) ground deformation such as a ground surface crack, ground subsidence and lateral spread induced by liquefaction;

c) relative displacement at the connecting part with the structure, etc.;

d) ground displacement and rupture along a fault zone.

Since the ductile iron pipe has high tensile strength as well as the capacity for expansion/contraction and deflection from its joint part, giving it the ability to follow the ground movement during the earthquake, the stress generated on the pipe body is relatively small. Few ruptures of pipe body have occurred during earthquakes in the past. It is therefore important to consider whether the pipeline can follow the ground displacement and ground strain without slipping out of joint when considering its earthquake resistance. The internal hydrodynamic surge pressures induced by seismic shaking are normally small enough not to be considered.

4.2 Qualitative design considerations

4.2.1 General

To increase the resistance of ductile iron pipelines to seismic hazards, the following qualitative design measures should be taken into consideration.

a) Provide pipelines with expansion/contraction and deflection capability.

EXAMPLE Use of shorter pipe segments, special joints or sleeves and anti-slip-out mechanisms according to the anticipated intensity or nature of the earthquake.

b) Lay pipelines in a firm foundation.

c) Use smooth back fill materials.

NOTE Polyethylene sleeves and special coating are also effective in special cases.

d) Install more valves.

4.2.2 Where high earthquake resistance is needed

It is desirable to enhance the earthquake resistance of parts connecting the pipelines to structures and when burying the pipes in

a) soft ground such as alluvium,

b) reclaimed ground,

c) filled ground,

d) suddenly changing soil types (geology) or topography,

e) sloping ground,

f) near revetments,

g) liquefiable ground, and/or

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h) near an active fault.

4.3 Design procedure

To make earthquake-resistant design for ductile iron pipelines:

a) select the piping route;

b) investigate the potential for earthquakes and ground movement;

c) assume probable earthquake motion (seismic intensity);

d) undertake earthquake resistance calculation and safety checking;

e) select joints.

Solid/firm foundations should be chosen for the pipeline route.

When investigating earthquakes and ground conditions, take into account any previous earthquakes in the area where the pipeline is to be laid.

4.4 Earthquake resistance calculations and safety checking

When checking the resistance of pipelines to the effects of earthquakes, the calculation shall be carried out for the condition in which the normal load (dead load and normal live load) is combined with the influence of the earthquake.

The pipe body stress, expansion/contraction value of joint, and deflection angle of joint are calculated by the response displacement method. Earthquake resistance is checked by comparing these values with their respective allowable values. The basic criteria are given in Table 1.

A flowchart of earthquake resistance determination and safety checking is shown in Figure 1. The basic formulae only for earthquake resistance calculation are given in 4.5. A detailed example of calculation is given in Annex A.

Table 1 — Basic earthquake resistance check criteria

Load condition	Criterion	
Load in earthquake motion and normal load	Pipe body stress	≤ Allowable stress (proof stress) of ductile iron pipe
	Expansion/contraction value of joint	≤ Allowable expansion/contraction value of ductile iron pipe joint
	Deflection angle of joint	≤ Allowable deflection angle of ductile iron pipe joint

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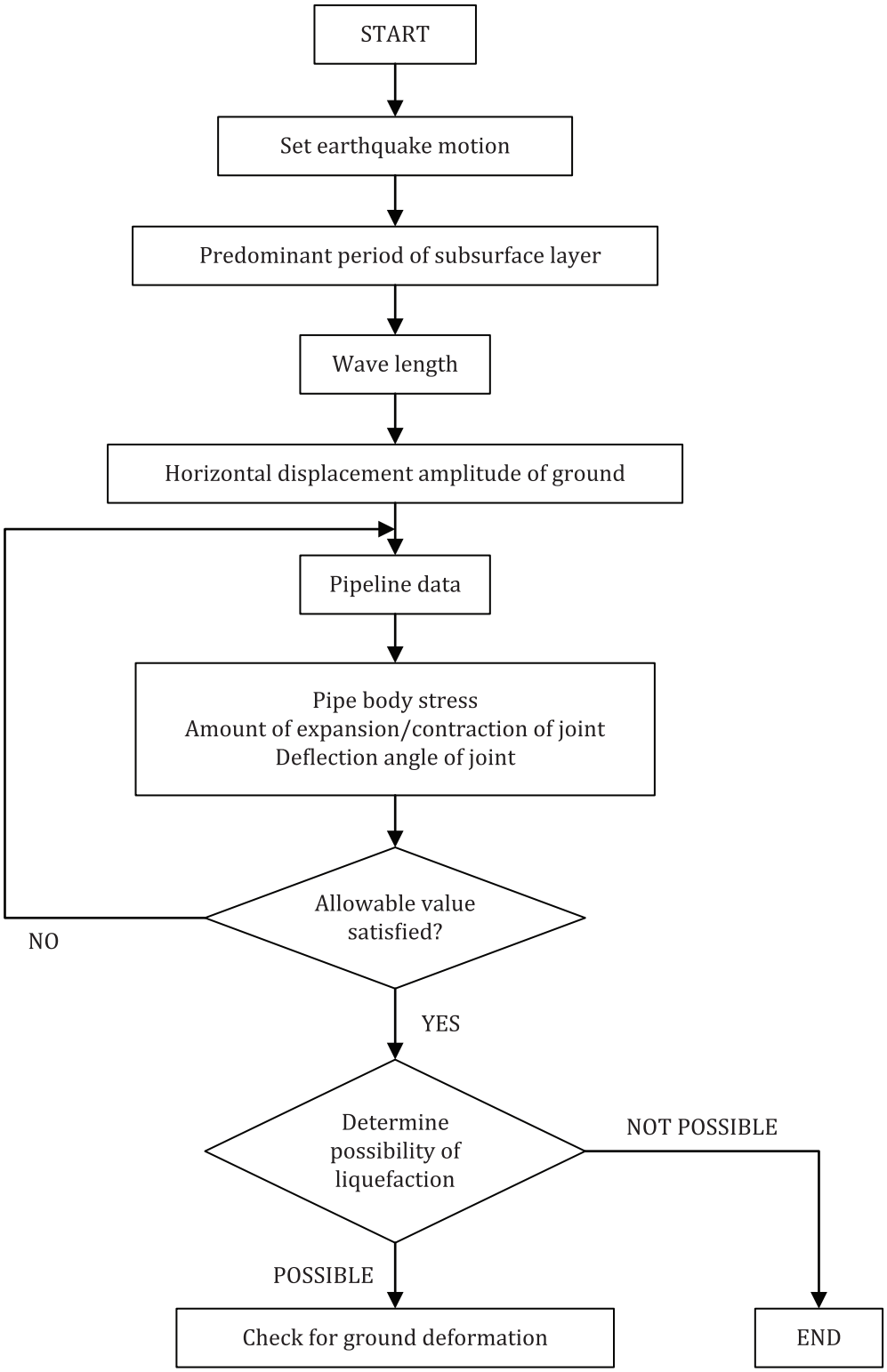

Figure 1 — Flowchart for calculation of earthquake resistance of buried pipelines

4.5 Calculation of earthquake resistance — Response displacement method

4.5.1 General

This method shall be used except when the manufacturer and the customer agree on an alternative recognized method.

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4.5.2 Design earthquake motion

The design acceleration for different seismic intensity scales can be determined according to the relationship between the several kinds of seismic intensity scales and the acceleration of ground surface, as given in Annex B.

4.5.3 Horizontal displacement amplitude of ground

The horizontal displacement amplitude of the ground is calculated using Formula (1) (see Annex A):

$$U_{\mathrm{h}}(x)=\left[\frac{T_G}{2\pi}\right]^2\cdot a\cdot\gamma\cdot\cos\frac{\pi\cdot x}{2H} \tag{1}$$

where

$U_{\mathrm{h}}(x)$ is the horizontal displacement amplitude of the ground x m deep from the ground surface to the centre line of the pipe, in metres (m);

x is the depth from the ground surface, in metres (m);

T_{G} is the predominant period of the subsurface layer, in seconds (s);

a is the acceleration on the ground surface for design, in metres per second squared (m/s^2);

γ is the ground inhomogeneous coefficient (see Table 2)

H is the thickness of the subsurface layer, in metres (m).

Table 2 — Ground inhomogeneous coefficient

Geotechnical condition	Ground inhomogeneous coefficient γ
Homogeneous	1,0
Inhomogeneous	1,4
Extremely inhomogeneous	2,0

4.5.4 Pipe body stress

Pipe body stress is calculated using Formulae (2), (3) and (4).

Axial stress:

$$\sigma_{\mathrm{L}}=\xi_1\cdot\alpha_1\cdot\frac{\pi\cdot U_{\mathrm{h}}(x)}{L}\cdot E \tag{2}$$

Bending stress:

$$\sigma_{\mathrm{B}}=\xi_2\cdot\alpha_2\cdot\frac{2\pi^2\cdot D\cdot U_{\mathrm{h}}(x)}{L^2}\cdot E \tag{3}$$

Combined stress:

$$\sigma_x=\sqrt{3{,}12\cdot\sigma_{\mathrm{L}}{}^2+\sigma_{\mathrm{B}}{}^2} \tag{4}$$

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where

σ_L, σ_B are the axial stress and the bending stress, respectively, in pascals (Pa);

σ_x is the combination of the axial and bending stresses, in pascals (Pa);

ξ_1 is the correction factor of axial stress in the case of expansion flexible joints;

ξ_2 is the correction factor of the bending stress in the case of expansion flexible joints;

α_1, α_2 are the transfer coefficient of ground displacement in the pipe axis and pipe perpendicular directions, respectively;

$U_h(x)$ is the horizontal displacement amplitude of ground x m deep from the ground surface, in metres (m);

L is the wavelength, in metres (m);

D is the outside diameter of the buried pipeline, in metres (m);

E is the elastic modulus of the buried pipeline, in pascals (Pa).

4.5.5 Expansion/contraction of joint in pipe axis direction

The amount of expansion/contraction of the joint in the pipe axis direction is calculated using Formula (5) (see Annex A):

$$u = \pm \varepsilon_G \cdot l \tag{5}$$

where

u is the amount of expansion/contraction of the joint in the pipe axis direction, in metres (m);

ε_G is the ground strain $= \dfrac{\pi \cdot U_h}{L}$;

L is the wavelength, in metres (m);

U_h is the horizontal displacement amplitude of ground x m deep from the ground surface, in metres (m);

l is the pipe length, in metres (m).

4.5.6 Joint deflection angle

The joint deflection angle is calculated using Formula (6) (see Annex A):

$$\theta = \pm \frac{4 \cdot \pi^2 \cdot l \cdot U_h}{L^2} \tag{6}$$

where

θ is the joint deflection angle, in radians (rad);

l is the pipe length, in metres (m);

U_h is the horizontal displacement amplitude of ground x m deep from the ground surface, in metres (m);

L is the wavelength, in metres (m).

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