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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 39 /टी - 18 **09 फरवरी 2024**

तकनीकी समिति : भूकंप इंजीनियरिंग अनुभागीय समिति , सीईडी 39

प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **भूकंप इंजीनियरिंग अनुभागीय समिति, सीईडी 39 के सभी सदस्य**
3. **सीईडी 39 की उपसमितियों और अन्य कार्यदल के सभी सदस्य**
4. **रुचि रखने वाले अन्य निकाय।**

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न है:

प्रलेख संख्या	शीर्षक
सीईडी 39 (18804) WC	**संरचनाओं के भूकंपरोधी डिज़ाइन के मानदंड भाग 8 पाइपलाइन (आई सी एस संख्या : 91.120.25)**

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इन पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 10 मार्च 2024

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा **ced39@bis.gov.in** पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, **www.manakonline.in** के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रालेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रालेख को अंतिम रूप दे दिया जाएगा।

यह प्रालेख भारतीय मानक ब्यूरो की वेबसाइट www.bis.gov.in पर भी उपलब्ध हैं।

धन्यवाद।

भवदीय

ह/-
(अरुण कुमार एस.)
वै. 'ई'/निर्देशक एवं प्रमुख
(सिविल अभियांत्रिकी विभाग)

सलंग्न: उपरिलिखित

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 39/T-18 **09 February 2024**

TECHNICAL COMMITTEE: EARTHQUAKE ENGINEERING SECTIONAL COMMITTEE, CED 39

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Earthquake Engineering Sectional Committee, CED 39 and its Subcommittees
3. All Members of Subcommittees, Panels and Working Groups under CED 39
4. All others interested.

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 39 (18804) WC	**DRAFT INDIAN STANDARD** **Criteria for Earthquake Resistant Design of Structures Part 8: Pipelines** (ICS 91.120.25)

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 10 March 2024

Comments if any, may please be made in the enclosed format and emailed at ced39@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you

Yours faithfully,

Sd/-

(Arun Kumar S.)
Scientist 'E'/Director and Head
Civil Engineering Department

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced39@bis.gov.in shall be appreciated**.]

Doc. No.: CED 39 (18804) WC

BIS Letter Ref: CED 39/T-18

Title: CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES PART 8: PIPELINES (ICS 91.120.25)

Last date of comments: 10 March 2024

Name of the Commentator/ Organization: ____

Sl No.	**Clause/ Para/ Table/ Figure No. commented**	**Type of Comment (General/ Technical/ Editorial)**	**Comments/ Modified Wordings**	**Justification of Proposed Change**

NOTE- Kindly insert more rows as necessary for each clause/table, etc

BUREAU OF INDIAN STANDARDS

DRAFT STANDARD FOR COMMENTS ONLY

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Draft Indian Standard

Criteria for Earthquake Resistant Design of Structures
Part 8 Pipelines

ICS No. 91.120.25

Earthquake Engineering Sectional Committee, CED 39 **Last Date for Comments: 10 March 2024**

FOREWORD

(*Formal clauses to be added later*)

Pipelines are considered as lifeline structures and are mainly used for transporting commodities over long distances. Since they traverse over a large geographical area, they may get damaged during earthquakes disrupting the supply of material, leakage of product, the breakout of fire, etc., which can lead to significant financial and environmental impact. A large part of the land area of India is prone to moderate to severe earthquake shaking, and pipelines built in these areas may encounter various seismic hazards en route. Therefore, the seismic design of the pipeline has great importance in the field of lifeline engineering.

The pipelines are usually buried below ground for economic, aesthetic, safety, and environmental reasons. These are normally termed buried pipelines. In certain circumstances, it may also be required to take the pipelines above ground, which are termed as above-ground pipelines. This standard provides guidance to design both buried and above-ground pipelines subjected to various seismic hazards.

This standard has been prepared in accordance with generally recognized engineering principles and practices. While developing this document, many national and international codes, standards, and guidelines have been referred to as listed below.

a) ASCE, Guidelines for the Seismic Design of Oil and Gas Pipeline Systems, American Society of Civil Engineers, USA, 1984;
b) ASCE, Guide to Post Earthquake Investigation of Lifelines, American Society of Civil Engineers, Earthquake Inestigations Committee, USA, 1997;
c) ASCE, Guidelines for the Seismic Upgrade of Water Transmission Facilities, Technical Council on Lifeline Earthquake Engineering, USA, 1999;
d) ALA, Guidelines for Design Of Buried Steel Pipes, AmericanLifelinesAlliance, 2001;
e) ALA, Seismic Guidelines for Water Pipelines, AmericanLifelinesAlliance, 2005;
f) API, Specification for Line Pipe, API Specification 5L, American Petroleum Institute, USA 1990;
g) API, Movement of In-Service Pipelines, American Petroleum Institute, USA, 1996;

h) PRCI, Guidelines for the Seismic Design and Assessment of Natural Gas and Liquid; Hydrocarbon Pipelines, Part-1: Guidelines and Recommended Procedure, Part-2: Commentary, Pipeline Research Council International, USA, 2004
i) PRCI, Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines through Areas Prone to Landslide and Subsidence Hazards, Pipeline Research Council International, USA, 2009;
j) PRCI, Pipeline Seismic Design and Assessment Guidelines, Pipeline Research Council International, USA, 2017;
k) JSCE (2000a), Basic Principles of Seismic Design and Construction for Water Supply Facilities, Earthquake Resistant Codes in Japan, Japan Society of Civil Engineers (JSCE), Japan Water Works Association, 2000;
l) JSCE (2000b), Recommended Practices for Earthquake Resistant Design of Gas Pipelines, Earthquake Resistant Codes in Japan, Japan Society of Civil Engineering (JSCE), Japan Gas Association, 2000;
m) Eurocode 1998-4 (2006) (2004), Eurocode-8: Design Provisions for Earthquake Resistant Of Structure, Part-4: Silos, Tanks and Pipelines, European Committee for Standard, 2004;
n) ASME B31.8, AMERICAN SOCIETY OF MECHANICAL ENGINEERS, USA, 2004
o) IBC , International Building Code, 2003;
p) ISO 13623 , Guidelines for Petroleum and Natural Gas Industries – Pipeline Transportation Systems, International Organization for Standardization, 2000
q) CSA Z 662-89, Guidelines for Oil and Gas Pipeline Systems,1999;
r) BSI PD 8010-1, British Standards Institution, Code of Practice for Pipelines – Steel Pipelines on Land, 2004;
s) FEMA 233, Earthquake Resistant Construction of Gas and Liquid Fuel Pipeline Systems Serving or Regulated by the Federal Government, Federal Emergency Management Agency, USA, 1992;
t) FEMA 450, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Federal Emergency Management Agency ,2003;
u) TCLEE, Guidelines for the Seismic Evaluation and Upgrade of Water Transmission Facilities , Technical Council on Lifeline Earthquake Engineering (TCLEE), Monograph No-15, Eidinger, J. Avila, E., (editors), American Society of Civil Engineers (ASCE), 1999

Unless otherwise stated, provisions of this standard are to be read necessarily in conjunction with the general provisions as laid down in CED39(22343)WC.

This standard contributes to the UN sustainable development goal 9: ‘Industry, Innovation and Infrastructure’, particularly its target to develop quality, reliable, sustainable and resilient infrastructure, and also promote inclusive and sustainable industrialization.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or estimated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2: 2022 `Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

CONTENTS

Draft Indian Standard
Criteria for Earthquake Resistant Design of Structures
PART 8: PIPELINES

SECTION 1 GENERAL PROVISIONS

1 SCOPE

1.1 This standard primarily deals with the seismic design requirements for buried and above-ground pipelines. Provisions for both continuous and segmented pipelines are also covered in this standard.

1.2 This standard can also be used as a basis for evaluating the level of strengthening or increased redundancy needed by the existing facilities to improve their response during seismic events. However, time-dependent material degradation, other existing deficiencies, and the strain acceptance criteria for older pipes need to be developed on a case-to-case basis.

1.3 For this standard, a pipeline is considered as a single line when its behavior during and after a seismic event is not influenced by that of any other pipelines, and the consequence of its failure only relates to the functions demanded from it.

1.4 This standard does not consider the associated facilities in a pipeline system like storage tanks, pumping stations, operation and maintenance stations, or the connections of pipelines to these facilities.

1.5 Offshore pipelines, minor distribution pipelines, industrial piping, pipelines attached to other structures (like tunnels, buildings, etc.) are not under the scope of this standard.

1.6 The provisions in this document deal the analysis and design requirements for typical primary seismic hazards to pipelines. For specific localized secondary seismic hazards (for example fire, landslide, etc.), the seismic response evaluation shall be carried out with reference to specialized literature.

1.7 This section is applicable for steel pipelines, either continuous or segmented for both buried and above ground pipelines.

2 REFERENCES

The Indian Standards listed below contain provisions which, through reference in this standard, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the Standards listed below:

IS No. / Doc No.	*Title*
CED39(22343)WC	Draft Indian Standard Criteria for Earthquake Resistant Design of Structures Part 1: General Provisions
IS 15663 (Part 1): 2006	Design and Installation of Natural Gas Pipelines Part 1: Laying of Pipelines

3 TERMINOLOGY

For the purpose of this standard, the terminologies given below shall apply to all pipelines, in general. If a definition already exists for a term in other standards, for the purpose of this standard, the definition given herein shall be applicable.

3.1 Beam on Non-linear Winkler Foundation (BNWF) Model – It is used to analyse the pipe where the pipe is modelled by means of beam elements, whilst discrete nonlinear springs and dashpots of appropriate stiffness and damping are used to represent relative soil-pipe displacement, applied in the three orthogonal directions.

3.2 Continuous Pipeline – The pipeline is considered continuous when the axial and rotational stiffness at its joints are higher than the stiffness of the pipe section away from those joints. For example, a steel pipe with welded (butt weld, single or double lap fillet weld) joints, bolted flange joints, HDPE pipe with fused joints, etc. are treated as a continuous pipeline.

3.3 Design Level Earthquake (DLE) – The design earthquake considered in this standard for different classes of pipelines, and for various performance objectives.

3.4 Fault Movement – The abrupt differential movement of soil or rock on either side of the fault. Faults can be classified according to the direction of motion as normal-slip, strike-slip, or reverse-slip faults. Often the normal or reverse fault occurs in combination with the strike-slip fault, referred to as an oblique fault. The magnitude of fault displacement depends on various factors like, type of fault, size of the earthquake, focal depth, geology, etc.

3.5 Landslide – The movements of the large ground mass in a sloping ground that may be triggered by an earthquake or some other causes.

3.6 Lateral Spreading – A phenomenon that occurs in gently sloping ground when the soil deposit liquefies due to seismic shaking. The soil loses its shear strength during liquefaction, which in turn results in lateral movement of liquefied soil and any overlaying soil layer.

3.7 Liquefaction – A phenomenon that occurs in loose to medium-dense saturated sandy soil during seismic shaking. During liquefaction, the soil loses a substantial amount of its shear strength and acts like a viscous fluid.

3.8 Peak Ground Acceleration (PGA) – The maximum acceleration recorded at the ground surface during seismic shaking. It refers to the horizontal acceleration unless specified otherwise.

3.9 Peak Ground Velocity (PGV) – The maximum velocity recorded at the ground surface expected during seismic shaking. It refers to the horizontal velocity unless specified otherwise.

3.10 Permanent Ground Deformation (P_mGD) – The non-recoverable ground deformation due to faulting, liquefaction-induced lateral spreading and settlement.

3.11 Segmented Pipeline – The pipeline is considered as segmented, when its stiffness (axial and/or rotational) at joints is considerably lower than that for the pipe section away from the joint. For example, cast iron pipes with lead-caulked joints, ductile iron pipe with push-on rubber gasket joints, concrete or asbestos pipes with rubber gasket joints with exterior cement grout, etc., are treated as segmented pipelines.

4 SYMBOLS

The symbols and notations given below apply to the provisions of this standard. Some specific symbols that are not listed here are described at the place of their use.

Symbol	*Description*
A	Cross-sectional area of pipe
a_{gd}	Design peak ground acceleration
C_P	Hazard Scale factor
c	Coefficient of soil cohesion
C	Velocity of Earthquake Wave Propagation
$C_{apparent}$	Apparent wave propagation velocity of earthquake waves
D	Nominal outside diameter of the pipe
D_{min}	Minimum inside diameter of pipe
E	Initial modulus of elasticity of pipe material
F_b	Buoyant force acting on pipeline
H'	Total height of soil fill above the pipeline
h_w	Height of water table above pipeline
L	Length of permanent ground deformation zone
L_b	Length of pipe in buoyancy zone
L_O	Length of pipe segment for segmented pipeline
L_e	Effective length of pipeline over which friction force t_u acts
M_W	Moment magnitude of earthquake
N_C	Number of chained restrained joints in segmented pipeline
P	Operating pressure in pipe
P_u	Maximum lateral soil resistance per unit length of pipe
P_v	Vertical earth pressure
R_w	Buoyancy factor
Q_u	Maximum soil resistance per unit length of the pipeline in vertical uplift
Q_d	Maximum soil resistance per unit length of pipeline in vertical bearing

t	Pipe wall thickness
t_u	Maximum frictional force per unit length of pipe at soil pipe interface
v_gd	Design peak ground velocity
W	Width of permanent ground deformation zone
Z	Elastic section modulus of the pipe cross-section
$\bar{\gamma}$	Effective unit weight of soil
γ	Total unit weight of soil
γ_d	Dry unit weight of soil
γ_w	Unit weight of water
Δ_eff	Effective design joint displacement
Δ_all	Allowable joint displacement for segmented pipes
Δ_seismic	Maximum joint displacement due to earthquake action
α_ε	Ground strain coefficient
$\delta_\mathrm{l-pgd}$	Maximum longitudinal permanent ground deformation
$\delta_\mathrm{ld-pgd}$	Design longitudinal permanent ground deformation
$\delta_\mathrm{t-pgd}$	Maximum transverse permanent ground deformation
$\delta_\mathrm{td-pgd}$	Design transverse permanent ground deformation
$\delta_\mathrm{v-pgd}$	Maximum ground settlement
$\delta_\mathrm{vd-pgd}$	Design ground settlement
δ_f	Maximum magnitude of fault displacement along its slip surface
δ_fd	Design fault displacement along its slip surface
$\delta_\mathrm{fd-ax}$	Component of design fault displacement in along the length of pipeline
$\delta_\mathrm{fd-tr}$	Component of design fault displacement perpendicular to the pipeline
ε_eff	Effective strain in the pipeline
ε_all	Allowable strain in pipe
θ_all	Allowable joint rotation
θ_eff	Effective design joint rotation
$\varepsilon_\mathrm{seismic}$	Maximum strain in pipe due to earthquake action
ε_y	Yield strain of the pipe material
ε_u	Failure strain of the pipe in tension
ε_a	Axial strain in pipe
ε_b	Bending strain in pipe
$\varepsilon_\mathrm{cr-c}$	Critical strain in pipe in compression
$\varepsilon_\mathrm{cr-co}$	Critical strain in pipe in compression for operational condition
$\varepsilon_\mathrm{c-wave}$	Allowable strain for wave effect in pipe
$\varepsilon_\mathrm{c-pgd}$	Allowable strain for permanent ground deformation effect in pipe
θ_seismic	Maximum joint rotation due to earthquake hazard
λ	Apparent wavelength of earthquake waves at ground surface
σ_bf	Bending stress in pipe due to buoyancy
β	Angle of pipeline crossing a fault line

5 GENERAL DESIGN CONSIDERATIONS

5.1 Design Basis

5.1.1 The pipeline being designed shall achieve an acceptable degree of safety and operability for their design life, to sustain all the loads and deformations during construction and operation as specified in CED39(22343)WC**.**

5.1.2 The performance objectives of the pipeline shall be checked for every possible seismic hazards individually along with its design operating loads.

5.2 Design Method (Limit Strain Based)

5.2.1 To take the advantage of ductility or deformability available in the pipeline material or joints, the pipeline design under seismic load combinations is considered strain based.

5.2.2 The response of a continuous pipeline shall be estimated in terms of longitudinal strain (tensile and compressive) and compared with the allowable strain values corresponding to the pipe material, for all the load combinations.

5.2.3 In case of segmented pipeline, where the design check is carried out at the joints, the joint deformation and rotation under various load combinations shall be estimated and checked against allowable joint rotation and deformation.

5.3 Performance Objectives

For the seismic loading scenario, the pipelines shall be designed for two performance objectives as:

5.3.1 *Normal Operability (NO),* in which uninterrupted operation may continue with safe shutdown; and

5.3.2 *Functional Integrity (FI),* in which the pressure integrity of the pipeline is maintained, but with minor damage (no leak) for oil and gas pipelines. For water pipelines, functional integrity refers to the pipelines that may suffer minor damage and leaks, but its function can be quickly restored with minor repair.

5.4 Engineering Input for Seismic Analysis and Design

The following basic engineering information related to the pipeline for its seismic analysis and design shall be collected.

5.4.1 *Pipeline Data*

a) Pipe geometry (such as diameter and thickness);
b) Type of pipe joint;
c) Allowable stress/strain value of the pipe material;
d) Pipeline function and its post-earthquake performance requirement;
e) External pipe coating specification;
f) Operational loads on pipeline (such as pressure, temperature, etc.);
g) Pipeline alignment detail (such as plan, profile, location of fittings, bends, etc.);

and

h) Support details for above ground pipeline.

5.4.2 *Site Information*

a) Basic soil properties along pipeline route (unit weight, cohesion, internal friction angle, in-situ density, etc.);
b) Burial depth of the buried pipeline;
c) Properties of backfill soil in the trench for buried pipeline;
d) Depth of water table en route (maximum and minimum) and
e) Population along pipeline route

5.4.3 *Seismic Hazard*

a) Expected amount of earthquake ground motion at the site in terms of PGA and PGV;
b) Expected amount and pattern of permanent ground deformation (P_mGD) and its spatial extent;
c) Extent of pipeline/its support exposed to permanent ground deformation;
d) Active fault locations; the expected magnitude of fault displacement and orientation of pipeline with respect to the direction of fault movement.
e) Liquefaction potential of the site (Detailed site information for locations having liquefaction probability may be evaluated for estimation of P_mGD)

5.5 Classification of Pipeline

The pipeline's location, the size of the population that it is exposed to the impact of pipeline rupture, and environmental damage due to the pipeline rupture shall be considered in establishing the level of acceptable risk while designing the pipeline system. Based on the level of acceptable risk, the pipeline shall be designated with the appropriate functional class. The pipelines have been classified into four groups as per their functional requirement (Table 1). For pipeline Class-IV, seismic design need not be considered.

5.6 Classification of Soil

The soil class at the site in the top 30 m can be classified into six groups as A, B, C, D, E or F, as per CED39(22343)WC.

5.7 Load Combinations

5.7.1 The following load combinations shall be used for the design of pipelines.

a) *Normal operability*:
    i) $OL \pm EL_{(NO)}$
b) *Functional integrity*:
    i) $1.2\ OL \pm EL_{(FI)}$, and
    ii) $0.9\ OL \pm EL_{(FI)}$,

where,

$EL_{(NO)}$ = Earthquake load/response corresponding to various design-level seismic hazards for normal operability conditions,

$EL_{(FI)}$ = Earthquake load/response corresponding to various design level seismic hazards for functional integrity conditions,

OL = operational load/response, which includes self-weight/dead load, earth load, operating internal pressure and temperature, residual stress/strain, etc., which can be considered as the permanent load on a pipeline. For internal pressure, two conditions shall be considered in the load combination, such as (a) pipe with normal internal operating pressure and (b) pipe with zero internal pressure.

5.7.2 The vertical seismic effect (inertial) can be ignored for buried or on-ground pipelines. However, it shall be considered for above-ground pipelines.

5.7.3 When lateral load-resisting elements of supports of the above-ground pipeline are not oriented in a mutually orthogonal direction, the combination of earthquake effects shall be considered as per CED39(22343)WC.

Table 1 Classification of Pipelines
(*Clause* 5.5)

Class	Type of Pipeline	Functional requirements
(1)	(2)	(3)
I	Oil and gas	a) Pipelines that are required to remain functional during and following the design earthquake. b) Pipelines that may cause an extensive loss of life or have a major impact on the environment in case of failure or damage. c) Pipeline crossing through location class-3, 4*.
	Water	Essential water pipelines required to serve for post-earthquake response and intended to remain functional and operational during and following a design earthquake such as: a) Pipelines that provide water to essential facilities post-earthquake such as hospitals, emergency healthcare, and shelters, aviation control towers, structures critical for national defense, facilities containing extremely hazardous toxic or explosive materials, etc., or, b) Pipelines that are required to maintain water pressure for dedicated, reliable fire suppression systems.
II	Oil and gas	a) Pipelines that are vital energy-serving facilities, but their service can be interrupted for a short period until minor repairs are made. b) Pipeline crossing through location class-2*.
	Water	Critical pipelines serving a large community and having a significant economic impact on the community or a substantial hazard to human life and property in the event of a failure such as: a) Pipelines that provide water to a minimum of 1000 service connections including residential, industrial, and business, or other customers for which there is no redundant supply, or, b) Pipelines of which its failure would lead to secondary disasters due to the release of high-pressure water in flood-prone areas, which may ultimately impede potential emergency recovery or evacuation of facilities
III	Oil and gas	Pipeline crossing through location class - 1*.

	Water	The water pipelines used for common use (water distribution systems in the community, etc.), and those not identified as Class I, II, or IV.
IV	Water	Pipelines that have low effect on human life and society in the event of failure and those that do not require post-earthquake system performance, response, or recovery, such as: a) Pipelines that primarily serve for agricultural usage, certain temporary facilities, or minor storage facilities, or, b) Pipelines that provide potable water supply for a maximum of 50 service connections and are not needed for any level of fire suppression following a significant earthquake, etc.
* Location classes for oil and gas pipelines are defined as per Annex C of IS 15663 (Part 1).		

5.8 Design Checks

5.8.1 *Buried Continuous Pipelines*

The effective design strain in pipeline, $\varepsilon_{\mathrm{eff}}$ (both axial tensile and axial compressive), for all possible combinations of loads, under normal operability and functional integrity, shall satisfy the following.

$$\varepsilon_{\mathrm{eff}} \leq \varepsilon_{\mathrm{all}}$$

where, $\varepsilon_{\mathrm{all}}$ = Allowable strain limit for the pipe material corresponding to normal operability condition or functional integrity condition, as the case may be.

5.8.2 *Buried Segmented Pipeline*

5.8.1.1 *Joint displacement*

The effective design joint displacement (Δ_{eff}) for segmented pipeline, for normal operability condition and functional integrity condition, should be less than the corresponding allowable joint displacement (Δ_{all}), that is,

$$\Delta_{\mathrm{eff}} \leq \Delta_{\mathrm{all}}$$

5.8.1.2 *Joint rotation*

The effective design joint rotation (θ_{eff}) for segmented pipeline, for normal operability condition and functional integrity condition, should be less than the corresponding allowable joint rotation (θ_{all}), that is,

$$\theta_{\mathrm{eff}} \leq \theta_{\mathrm{all}}$$

5.8.3 *Above-Ground Pipelines*

The maximum tensile and compressive strain in the pipe induced due to the inertial force being resisted at the supports/ anchors or due to P_mGD at its support shall conform to the design check as per **5.8.1** for a continuous pipeline. For the segmented pipeline, the design joint displacement and rotation shall satisfy the design check as per **5.8.2**.

6 SEISMIC HAZARDS

6.1 Seismic Hazards for Pipeline Design

6.1.1 *For Buried Pipelines*

The seismic hazards important for buried pipeline design are:

a) Permanent ground deformation (P_mGD) related to soil failures:
  i) Ground displacement due to faulting
  ii) Longitudinal P_mGD
  iii) Transverse P_mGD
  iv) Settlement due to liquefaction
b) Buoyancy due to liquefaction
c) Seismic ground motion (*wave propagation induced pipe strain*)

6.1.2 *For Above Ground Pipelines*

The seismic hazards important for above ground pipeline design are:

a) Seismic ground motion

  i) Inertia effect of the pipeline due to seismic ground motion applied to their supports
  ii) Differential ground movement of pipeline supports due to seismic shaking

b) Permanent ground deformation (P_mGD) related to soil failures at pipe supports *(for the supports which are directly on the ground)*:

  i) Ground displacement due to faulting
  ii) Longitudinal P_mGD
  iii) Transverse P_mGD
  iv) Settlement due to liquefaction

6.2 Design Level Seismic Hazard

6.2.1 The design level earthquake (DLE) for different classes of the pipelines shall be as per Table 2.

Table 2 Design Level Earthquake (DLE) for Various Pipeline Classes
(*Clause* 6.2.1)

Sl No.	**Pipeline Class**	**Performance Objectives**	
		Normal Operability	*Functional Integrity*
(1)	(2)	(3)	(4)
i)	I	10% probability of occurrence in 50 Years (Return Period = 475 years)	2% probability of occurrence in 50 Years (Return Period = 2475 years)
ii)	II	20% probability of occurrence in 50 Years (Return Period = 225 years)	5% probability of occurrence in 50 Years (Return Period = 975 years)
iii)	III	50% probability of occurrence in	10% probability of occurrence in

		50 Years (Return Period = 73 years)	50 Years (Return Period = 475 years)
iv)	IV	Seismic design not required	Seismic design not required

6.2.2 When hazard levels corresponding to 475 year earthquake is only available, hazard levels for other return periods shall be obtained by multiplying Hazard Scale Factor in Table 3.

Table 3 Hazard Scale factor (C_p)
(*Clause* 6.2.2)

Sl No.	**Ratio of Seismic Hazard:** ***For EQ of particular Return Period/ For DBE Level earthquake (that is, 475 year Return period)***	**Seismic Hazard Type**	
		Fault displacement	P_mGD (Transverse, Longitudinal, and Settlement)
(1)	(2)	(3)	(4)
i)	2475/475	2.3	1.5
ii)	975/475	1.5	1.35
iii)	475/475	1.0	1.0
iv)	225/475	0.7	0.7
v)	73/475	0.55	0.55

6.3 Quantification of Design Level Seismic Hazards

Based on available data and experience, reasonable assumptions shall be made to define an acceptable model for the seismic hazard quantification. Special care shall be taken while evaluating permanent ground deformation (P_mGD) due to the design level earthquake. It is suggested to evaluate both upper bound and lower bound estimates of P_mGD where applicable and consider them in design.

6.3.1 *Permanent ground deformation (P_mGD) related to soil failure*

When a pipeline is located within or above a liquefiable soil layer, the effect of liquefaction-induced hazards (longitudinal P_mGD, transverse P_mGD, Settlement, and Buoyancy) shall be considered for pipeline design. However, it is not required to design the pipeline for liquefaction-induced hazards when the pipeline is located below the liquefiable soil layer. The liquefaction susceptibility of a site shall be evaluated as per CED39(22343)WC.

6.3.1.1 *Ground displacement due to faulting*

a) Minimum value of ground displacement due to faulting for 475 years return period earthquake can be considered as 0.3 m in Zone II, 0.5 in Zone III, 1.1 m in Zone IV, 1.6 in Zone V and 2.4 m in VI. The design level fault displacement (δ_{fd}) can then be calculated as $\delta_{\mathrm{f}}C_{\mathrm{p}}$.
b) The design level ground displacement due to faulting (δ_{fd}) shall be as per geological study or based on available relationships between earthquake magnitude and fault types corresponds to DLE event.

6.3.1.2 *Longitudinal and Transverse P_mGD*

a) From the geotechnical investigations, the range of spatial extent, that is, length (*L*), width (*W*) and the maximum ground displacement along the pipeline ($\delta_{\mathrm{ld-pgd}}$), shall be established for DLE event.
b) When the length, width and design level permanent ground displacement are not available, corresponding values may be taken from Table 4.

Table 4 Extent of P_mGD Zone
[*Clause* 6.3.1.2(b)]

Sl No.	**Pipeline Class**	**Length (m)**	**Width (m)**	**Design Level Permanent Ground Displacement ($\boldsymbol{\delta_{\mathrm{ld-pgd}}}$) (m)**	
				Normal Operability	*Functional Integrity*
(1)	(2)	(3)	(4)	(5)	(6)
i)	I	220	150	4.6	6.9
ii)	II	160	220	2.1	4.0
iii)	III	95	275	1.1	1.9

6.3.1.3 *Liquefaction induced settlement*

a) In general, the amount of permanent ground deformation is much larger in transverse direction than in vertical settlement. However, if there is a possibility of vertical settlement of soil due to liquefaction en route, the extent of soil settlement along the pipeline axis (L), and maximum ground settlement ($\delta_{\mathrm{vd-pgd}}$) for DLE event shall be established through geotechnical investigation.
b) When ground settlement ($\delta_{\mathrm{v-pgd}}$) corresponding to 475 years return period is only available, design ground settlement $\delta_{\mathrm{vd-pgd}}$ can be calculated as $\delta_{\mathrm{v-pgd}}C_{\mathrm{p}}$.

6.3.2 *Buoyancy force due to liquefaction*

When liquefaction of soil occurs around the pipeline, buoyant forces are exerted on pipeline and must be resisted by a suitable anchoring device. Buoyancy effects are probably of greatest concern in areas such as flood plains and estuaries where massive liquefaction could take place in a major earthquake and the pipeline is empty. Where buoyancy is a possibility, the zone of liquefaction leading to buoyancy along the pipeline axis (L) shall be established for the DLE event.

6.3.3 *Seismic Ground Motion*

a) The seismic ground motion in terms of peak ground acceleration (PGA), a_{gd} and peak ground velocity (PGV), v_{gd} shall correspond to DLE event (as per Table 2), and for the particular soil class as per 5.6.
b) When the site-specific data or code specified values are not available for peak ground velocity (PGV) at the site, Table 5 can be used to define PGV v_{gd}(corresponding to PGA (a_{gd}).

Table 5 Relationship between Peak Ground Velocity and Peak Ground Acceleration
[*Clause* 6.3.3(b)]

SI No.	**Soil Class**	**Moment Magnitude (M_w)**	**Ratio of PGV (cm/s) to PGA (g)**		
			Source-to-Site Distance (km)		
			0-20	20-50	50-100
(1)	(2)	(3)	(4)	(5)	(6)
i)	Rock (Soil Class A)	6.5	66	76	86
ii)		7.5	97	109	97
iii)		8.5	127	140	152
iv)	Stiff Soil (Soil Class B)	6.5	94	102	109
v)		7.5	140	127	155
vi)		8.5	180	188	193
vii)	Soft Soil (Soil Class C, D)	6.5	140	132	142
viii)		7.5	208	165	201
ix)		8.5	269	244	251

NOTE
The relation between peak ground velocity (PGV) and peak ground acceleration (PGA) is less certain in soft soils. Site-specific geotechnical investigation and dynamic site response analysis are recommended to develop appropriate values for soil classes E and F.

7 MATHEMATICAL MODELLING

7.1 General

7.1.1 The mathematical model for the buried and above-ground pipelines shall be as per **7.2** and **7.3**, respectively.

7.1.2 The pipeline response obtained from the seismic analysis shall be combined with the pipeline response during operation, as per the load combination defined in **5.7**. The response in the pipeline due to operational loads shall be estimated as per IS 15663 (Part 1).

7.1.3 The response of the pipeline for various permanent ground deformation can be obtained by using suitable numerical or analytical model as mentioned in this standard. When discontinuity in the pipeline (such as, pipe bends, tees, anchor blocks, pipe reducer, etc.) exists in the P_mGD zone, two-dimensional (2D) or three-dimensional (3D) Finite Element Model considering soil-structure interaction shall be employed with reference to specialized literature.

7.1.4 Geometric (*P-delta* effect) and material nonlinearity for pipeline and soil shall be included in the analysis.

7.2 Mathematical Model for Buried Pipeline

7.2.1 Several numerical models are used in practice to represent the soil-pipe interaction, of which, BNWF (Beam on Winkler’s Foundation) model is extensively used due to its simplicity, mathematical convenience, and ability to incorporate nonlinear behavior of soil and pipe. The modelling details for continuous and segmented buried pipelines for BNWF model is presented in **7.2.7** and **7.2.8**.

7.2.2 The pipe can either be modeled as 3D solid element/2D shell element or 1D beam element.

7.2.3 While analyzing the pipeline for seismic effect, a pseudo-static analysis is preferred. The ground deformation due to wave propagation or P_mGD should be assigned at the fixed ends of the soil springs.

7.2.4 Inertial effect of the seismic event on the buried pipeline may be ignored.

7.2.5 A time-history analysis can also be employed for wave propagation effect on the buried pipeline, where time is a parameter, whose function is to displace the wave along or across the pipeline, which is connected to the soil through radial and longitudinal springs.

7.2.6 *Soil-Pipe Interaction*

In a BNWF model, the actual three-dimensional (3D) soil-pipe interactions (Fig. 1) can be ideally modeled as a pipe resting on nonlinear disjointed soil springs as shown in Fig. 2 and Fig. 3. The soil surrounding the pipe is modeled as three types of nonlinear springs, as follows, whose nonlinear load-deformation behaviour are defined in **7.2.9**.

a) *Axial soil spring* – To represent soil resistance over the pipe surface along its length.
b) *Lateral soil spring* – To represent the lateral resistance of soil to the pipe movement.
c) *Vertical soil spring* – To represent the vertical resistance of soil at the bottom of the pipe for bearing and at the top of the pipe for uplift.

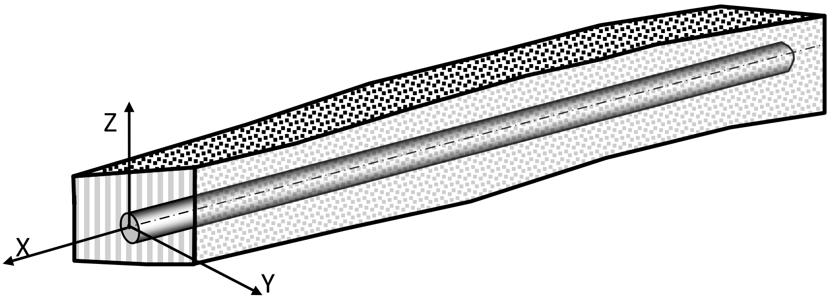


FIG. 1 THREE DIMENSIONAL SOIL-PIPE INTERACTION FOR BURIED PIPELINE

7.2.7 *Modeling of Continuous Pipeline*

In continuous pipelines, the lateral and rotational stiffness of the joint is equal to or more than that of the pipe material. Hence, the continuous pipeline can be treated as a single continuous beam/pipe without intermediate joints as shown in Fig. 2.

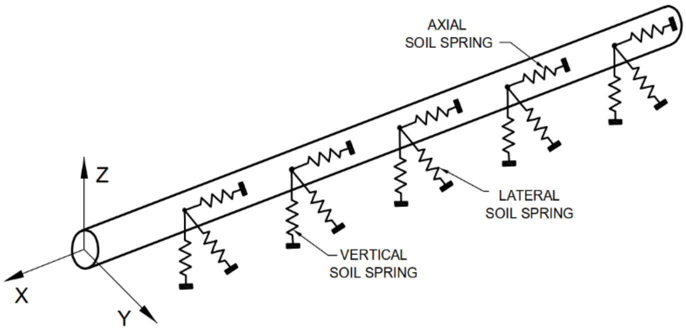


FIG. 2 BEAM ON NONLINEAR WINKLER FOUNDATION MODEL REPRESENTING PIPE-SOIL INTERACTION FOR CONTINUOUS PIPELINE

7.2.8 *Modeling of Segmented Pipeline*

The segmented pipelines are modeled as small segments of stiff pipes with flexible joints. The joints are modeled as equivalent axial and rotational springs connected between adjacent pipes as shown in Fig. 3.

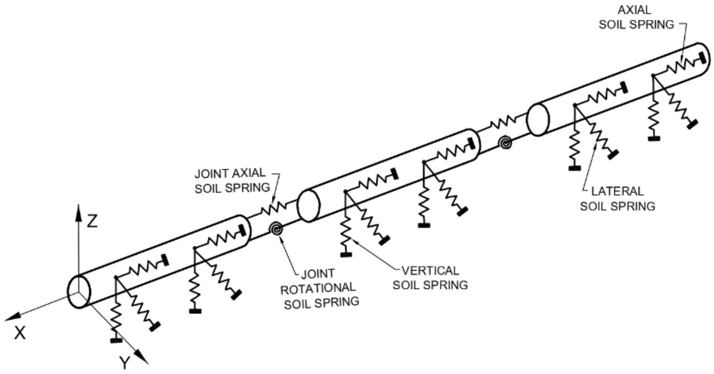


FIG. 3 BEAM ON NONLINEAR WINKLER FOUNDATION MODEL REPRESENTING PIPE-SOIL INTERACTION FOR SEGMENTED PIPELINE

7.2.9 *Spring Properties to Model Soil-Pipe Interaction*

7.2.9.1 *Axial soil spring*

a) The properties of axial soil spring shall be estimated considering the soil properties of the backfill material used in the pipeline trench. Fig. 4 shows actual (solid line) and idealized bi-linear (dotted line) representation of the axial soil spring.

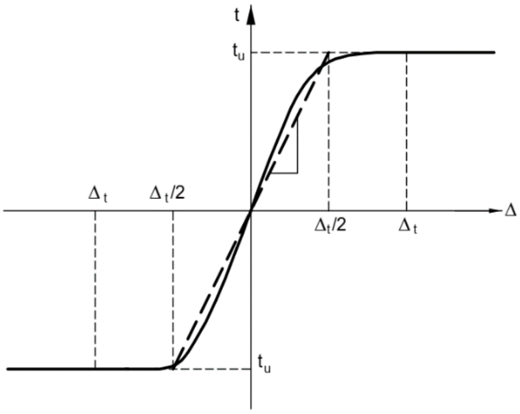


FIG. 4 SOIL-PIPE INTERACTION SPRING IN AXIAL DIRECTION

b) The maximum axial soil resistance (t_u) per unit length of the pipe can be calculated as:

$$t_u = \pi D c \alpha + \pi D H \bar{\gamma} \frac{1+K_0}{2} \tan\delta'$$

where

D = Outside diameter of pipe;
c = Coefficient of cohesion of backfill soil;
H = Depth of soil above the center of the pipeline;
$\bar{\gamma}$ = Effective unit weight of soil;
α = Adhesion factor = $0.608 - 0.123c - 0.274/(c^2+1) + 0.695/(c^3+1)$ (c in kPa/100);
δ' = Interface angle of friction between pipe and soil = $f \times \phi$;
ϕ = Internal friction angle of backfill soil;
f = Friction factor for various types of pipes based on external coating (1.0 for concrete, 0.9 for coal tar, 0.8 for rough steel, 0.7 for smooth steel, 0.6 for fusion bonded epoxy or polyethylene);
K_o = Coefficient of earth pressure at rest

c) The maximum mobilizing displacement (Δ_t) of soil in the axial direction of pipe can be taken as 3mm for dense sand, 5mm for loose sand, 8mm for stiff clay and 10mm for soft clay.

d) The equivalent stiffness of the axial soil spring can be taken as the ratio of maximum axial resistance (t_u) divided by $\Delta_t/2$.

7.2.9.2 *Lateral soil spring*

a) The properties of lateral soil spring are estimated considering the native soil at the site. Fig. 5 shows the idealized representation of the lateral soil spring.

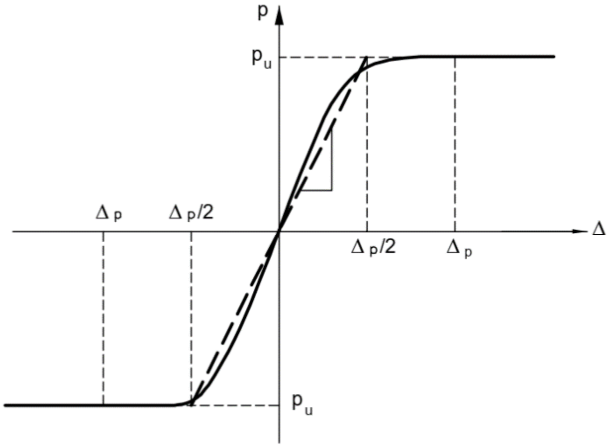


FIG. 5 SOIL-PIPE INTERACTION SPRING IN LATERAL DIRECTION

b) The maximum lateral resistance of soil per unit length of pipe can be calculated as:

$$P_{\mathrm{u}} = N_{ch} cD + N_{qh} \bar{\gamma} HD$$

where

N_{ch} = Horizontal bearing capacity factor for clay (Table 6),

$N_{ch} = a' + b'x + \frac{c'}{(x+1)^2} + \frac{d'}{(x+1)^3} \leq 9$,

N_{ch} = 0 for sandy soils having c = 0

N_{qh} = Horizontal bearing capacity factor for sandy soil (Table 6),

$N_{qh} = a' + b'x + c'x^2 + d'x^3 + e'x^4$,

in which

x = *H/D*, N_{qh} = 0 for clayey soils having ϕ = 0

c) The mobilising displacement Δ_p at P_u is taken as:

$$\Delta_p = \begin{cases} (0.07 \sim 0.1)(H + D/2) \text{ for loose sand} \\ (0.03 \sim 0.05)(H + D/2) \text{ for medium sand} \\ (0.02 \sim 0.03)(H + D/2) \text{ for dense sand} \end{cases} \quad \text{for sand}$$

$$\Delta_p = (0.03 \sim 0.05)(H + D/2) \quad \text{for clay}$$

d) The equivalent stiffness of the lateral soil spring can be taken as the ratio of maximum lateral resistance (*P*u) divided by *Δ*p*/2*.

Table 6 Lateral bearing capacity factor of soil
[*Clause* 7.2.9.2(b)]

Factor	ϕ	a'	b'	c'	d'	e'
N_{ch}	0	6.752	0.065	-11.063	7.119	-
N_{qh}	20	2.399	0.439	-0.03	1.059×10^{-3}	-1.754×10^{-5}
N_{qh}	25	3.332	0.839	-0.090	5.606×10^{-3}	-1.319×10^{-4}
N_{qh}	30	4.565	1.234	-0.089	4.275×10^{-3}	-9.159×10^{-5}
N_{qh}	35	6.816	2.019	-0.146	7.651×10^{-3}	-1.683×10^{-4}
N_{qh}	40	10.959	1.783	0.045	-5.425×10^{-3}	-1.153×10^{-4}

N_{qh}	45	17.658	3.309	0.048	-6.443×10^{-3}	-1.299×10^{-4}

7.2.9.3 *Vertical soil spring*

a) The soil spring properties are different for uplift and bearing cases. For bearing soil spring, the properties of native soil at the site may be used. However, for uplift soil spring, the properties of backfill soil are to be considered. Fig. 6 shows the idealized representation of the vertical soil spring.

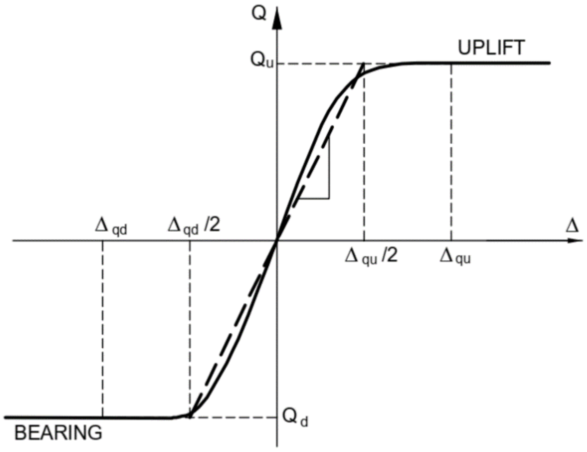


FIG. 6 SOIL-PIPE INTERACTION SPRING IN VERTICAL DIRECTION

b) The maximum soil resistance per unit length of the pipeline in vertical uplift can be calculated as

$$Q_u = N_{cv} cD + N_{qv} \bar{\gamma} HD$$

where,

N_{cv} = Vertical uplift factor for clay (0 for sandy soil with c = 0);

N_{qv} = Vertical uplift factor for sand (0 for clayey soil with ϕ = 0°);

$N_{cv} = 2\left(\frac{H}{D}\right) \leq 10$ for $\left(\frac{H}{D}\right) \leq 10$, and

$N_{qv} = \left(\frac{\phi H}{44D}\right) \leq N_q$

c) The mobilizing displacement of soil for vertical uplift, Δ_{qu}, at Q_u can be taken as

(i) $\Delta_{qu} = min\begin{cases} 0.01H \text{ to } 0.02H \\ 0.1D \end{cases}$ for dense to loose sands

(ii) $\Delta_{qu} = min\begin{cases} 0.1H \text{ to } 0.2H \\ 0.2D \end{cases}$ for stiff to soft clay

d) The maximum soil resistance per unit length of pipeline in the vertical bearing can be calculated as

$$Q_d = N_c cD + N_q \bar{\gamma} HD + N_\gamma \gamma (D^2/2)$$

where

N_c, N_q and N_γ are bearing capacity factors as shown in Fig. 7 or can be calculated as:

$$N_c = \left[cot(\phi + 0.001)\right]\left\{exp\left[\pi tan(\phi + 0.001)\right]tan^2\left(45 + \frac{\phi + 0.001}{2}\right) - 1\right\},$$

$N_q = exp(\pi tan\phi)tan^2\left(45 + \frac{\phi}{2}\right)$,

$N_\gamma = exp(0.18\ \varphi - 2.5)$, and

γ = total unit weight of soil.

e) The mobilizing soil displacement in vertical bearing, Δ_{qd}, at Q_d can be taken as 0.1*D* for granular soils, and 0.2*D* for cohesive soils.

f) The equivalent stiffness of the soil spring can be taken as the ratio of maximum soil resistance (Q_u or Q_d) divided by *Δ_{qu}/2* or *Δ_{qd}/2,* respectively, for uplift and bearing springs.

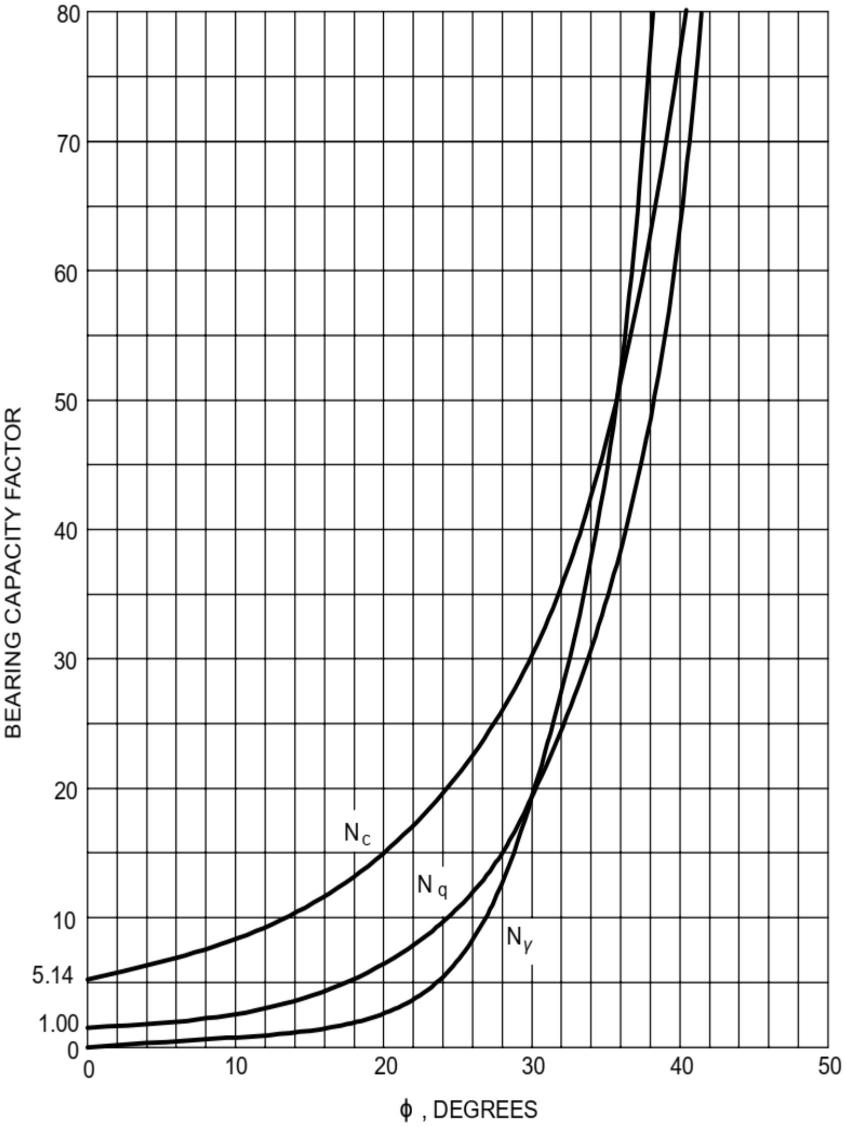


FIG. 7 BEARING CAPACITY FACTORS OF SOILS OF DIFFERENT SOIL FRICTION VALUES

7.3 Mathematical Model for Above-Ground Pipeline

7.3.1 The model of the above-ground pipeline shall be such as to represent the stiffness, damping and mass properties, as well as dynamic degrees of freedom of the system, with explicit consideration of the following aspects, as appropriate:

a) Flexibility of the foundation soil and foundation system;
b) Mass of the fluid inside the pipeline;
c) Dynamic characteristics of the supporting structures;
d) Type of connection between the pipeline and its supporting structure; and
e) Joints along the pipeline and between the supports.

7.3.2 Typically the model of pipeline system shall begin and end at anchor points, which effectively restrain all six degrees of freedom. If there is no anchor for a significantly large segment, the pipeline could be analysed in segments with appropriate end conditions.

7.3.3 The energy dissipative capacity (damping) of an above-ground pipeline system, shall be restricted to its supporting structure. Damping values shall be considered based on the material used in the supporting structure.

7.3.4 Once the earthquake forces transferred to the support (based on the connection between pipeline and supporting structure) by the pipeline is estimated, the support structure shall be designed conforming to relevant design standards such as IS 456, IS 1893 and IS 13920 for RCC, and IS 800 for steel.

7.3.5 Above-ground pipelines may be analysed by means of the modal response spectrum analysis with the associated design response spectrum as given in CED39(22343)WC**.**

7.3.6 When time history analysis is carried out, spectrum compatible accelerograms in accordance with CED 39(22343)WC shall be used.

7.3.7 The “lateral force method” of (linear-elastic) analysis may also be applied, provided that the value of the applied acceleration is justified. The principles and application rules specified in CED39(22343)WC can be applied for the above-ground pipeline with supports.

7.3.8 Response reduction factor shall be considered for the supporting structures as per CED39(22343)WC.

7.3.9 The earthquake action shall be applied separately along two orthogonal directions (transverse and longitudinal, for straight pipelines); the maximum combined response shall be obtained according to **7.5.3** of CED39(22343)WC.

7.3.10 Spatial variability of the motion shall be considered whenever the length of the pipeline between the supports exceeds 600 m or when geological discontinuities or marked topographical changes are present. Specialist literature may be referred to generate spatially varied ground motion.

SECTION 2 STEEL PIPELINES

8 TERMINOLGY

In addition to the definitions covered in **4**, the following terms shall be applicable.

8.1 Apparent Earthquake Wave Propagation Velocity – The propagation velocity of earthquake waves with respect to the ground surface.

8.2 Chained Joint – A series of segmented joints in the pipeline with the additional requirement of having mechanical stops to prevent the pipes from pulling apart.

8.3 L-Waves – Surface earthquake waves that cause movement of ground from side to side in a horizontal plane but at right angles to the direction of propagation.

8.4 P Waves – The fastest body waves that carry energy through the Earth as longitudinal waves by moving particles in the same line as the direction of the wave. These can travel through all layers of the Earth. These waves are often referred to as compressional or longitudinal waves.

8.5 Phase Velocity – The velocity at which a transient vertical disturbance at a given frequency, originating at the ground surface, propagates across the surface of the medium.

8.6 R-Wave – The surface wave that causes the particles of ground to oscillate in an elliptical path in the vertical plane along the direction of the traveling wave.

8.7 S-Wave – The body wave that causes material particles to oscillate at right angles to the direction of energy transmission. S-waves cannot travel through fluids, such as air, water, or molten rock.

9 MATERIAL MODELLING

9.1 The material model of the pipeline must include nonlinear stress-strain behaviour. Ramberg-Osgood's relationship can be used to represent stress-strain response of the pipe material as:

$$\varepsilon = \frac{\sigma}{E}\left[1 + \frac{n}{1+r}\left(\frac{\sigma}{\sigma_y}\right)^r\right]$$

where

ε = Axial strain

σ = stress in the pipe

E = Initial Young's modulus

σ_y = Yield stress of the pipe material

n,r = Ramberg - Osgood parameters (*see* Table 7)

Table 7 Ramberg -Osgood parameters for Steel Pipes
(*Clause* 9.1)

Grade of Pipe	**Grade B**	**X 42**	**X 52**	**X 60**	**X 70**
Yield stress (MPa) of the pipe material	227	310	358	413	517
n	10	15	9	10	5.5
r	100	32	10	12	16.6

9.2 Other stress-strain relationship for design may also be used with the permission of engineer-in-charge.

10 SEISMIC DEMAND ON STEEL BURIED PIPELINES

10.1 Ground Displacement due to Faulting

10.1.1 *Continuous Pipeline*

For continuous pipelines subjected to design ground displacement due to faulting *(δ_{fd})*, the maximum pipe strain shall be estimated through mathematical modelling as per **7**.

10.1.2 *Segmented Pipeline*

(a) For segmented pipelines, the ground displacement due to faulting along the longitudinal axis of the pipeline is assumed to be accommodated equally by pipe joints located on each side of the fault line. Assuming that the pipe segments are rigid and only the pipe joints accommodate the ground deformation, seismic displacement of each joint can be considered as:

$$\Delta_{\text{seismic}} = \delta_{\text{fd}-\text{ax}}$$

Where

$\delta_{\text{fd}-\text{ax}}$ = Component of the design fault displacement along the pipeline

(b) The seismic joint rotation (θ_{seismic}) due to transverse fault displacement can be obtained as:

$\theta_{\text{seismic}} = \arcsin(\delta_{\text{fd}-\text{tr}}/L_0)$, Considering fault line passing through pipe segment
$\theta_{\text{seismic}} = \arcsin(\delta_{\text{fd}-\text{tr}}/2L_0)$, Considering fault line passing through pipe joint

where

$\delta_{\text{fd}-\text{tr}}$ = Component of the design fault displacement perpendicular to the pipeline, and
L_o = pipe segment length

10.2 Longitudinal Permanent Ground Deformation (P$_m$GD)

10.2.1 *Continuous Pipeline*

10.2.1.1 Due to design longitudinal P$_m$GD ($\delta_{\text{ld}-\text{pgd}}$), the design earthquake strain in the pipe ($\varepsilon_{\text{seismic}}$) in the axial direction (tensile/compressive) can be evaluated through mathematical modelling as per **7.2**.

10.2.1.2 The value of $\varepsilon_{\text{seismic}}$ for a straight continuous pipeline can also be estimated through a simplified analytical method as the lowest of the strains obtained from the two cases as per **10.2.1.3** and **10.2.1.4**.

10.2.1.3 *Case 1*

When the amount of ground movement ($\delta_{\mathrm{ld-pgd}}$) is large and the pipe strain is controlled by length (*L*) of the P$_{\mathrm{m}}$GD zone (*see* Fig. 8), the maximum value of both axial tensile and compressive strain in the pipe can be calculated as:

$$\varepsilon_a = \frac{t_u L}{2\pi DtE}\left[1+\frac{n}{1+r}\left(\frac{t_u L}{2\pi Dt\sigma_y}\right)^r\right]$$

where
L = Length of the permanent ground deformation zone;
σ_y = Yield stress of pipe material;
n, r = Ramberg-Osgood parameter;
E = Initial Modulus of elasticity of pipe material;
t_{u} = Peak friction force per unit length of pipe at soil pipe interface as per **7.2.9.1**;
D = Outside diameter of pipe; and
t = Thickness of pipe.

10.2.1.4 *Case 2*

The Length (*L*) of P$_{\mathrm{m}}$GD zone is large and the pipe strain is controlled by amount of ground movement ($\delta_{\mathrm{ld-pgd}}$) (*see* Fig. 9)

$$\varepsilon_a = \frac{t_u L_e}{\pi DtE}\left[1+\frac{n}{1+r}\left(\frac{t_u L_e}{\pi Dt\sigma_y}\right)^r\right]$$

where
L_e = Effective length of pipeline over which friction force t_u acts, and can be evaluated from the following equation

$$\delta_{ld-pgd} = \frac{t_u L_e^2}{\pi DtE}\left[1+\left(\frac{2}{2+r}\right)\left(\frac{n}{1+r}\right)\left(\frac{t_u L_e}{\pi Dt\sigma_y}\right)^r\right]$$

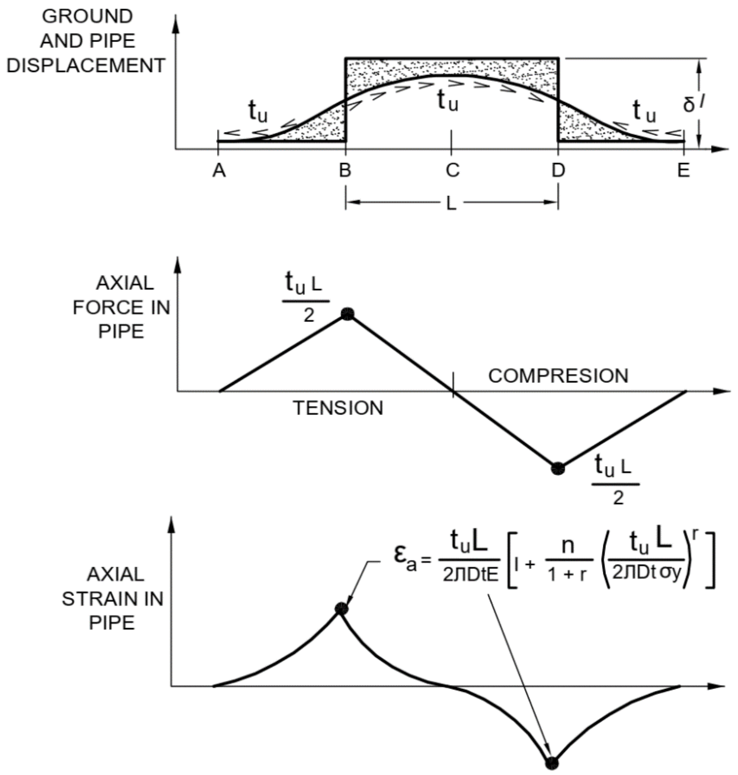


Fig. 8 INELASTIC MODEL FOR LONGITUDINAL P_mGD (Case 1)

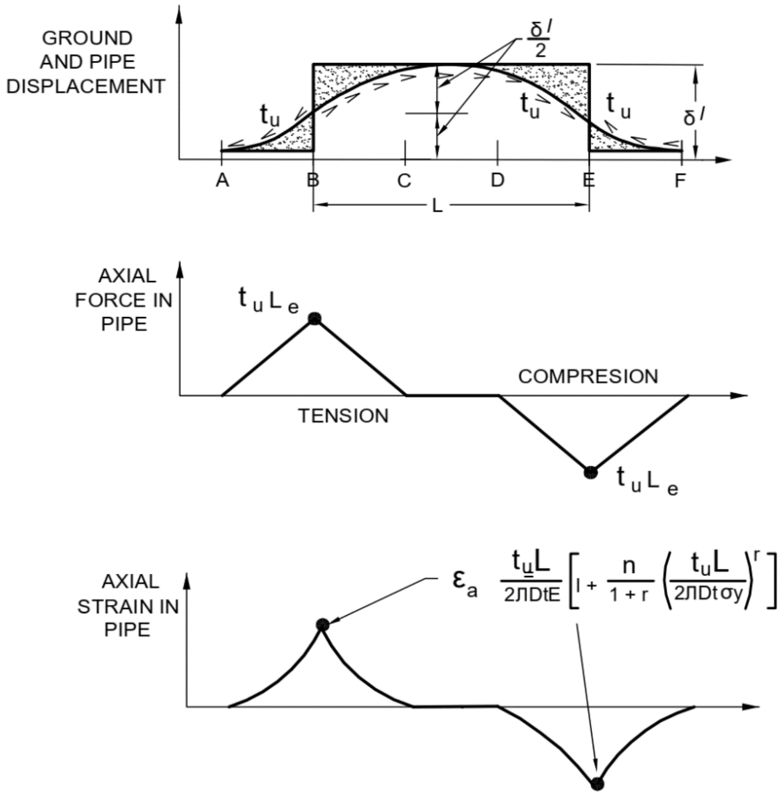


Fig. 9 INELASTIC MODEL FOR LONGITUDINAL P_mGD (Case 2)

10.2.1.5 *Influence of expansion joint*

Depending on their positions, expansion joints may have no effect, beneficial effect or a detrimental effect on the pipeline. Often, the expansion joints are provided to mitigate the effect of longitudinal P_mGD in the continuous pipeline. It is advisable to provide at least two expansion joints, one close to the head of the P_mGD zone and the other close to the toe. The effect of expansion joints, if provided, shall be considered in the analysis for the evaluation of pipe strain.

10.2.2 *Segmented Pipeline*

10.2.2.1 *For push-on type joints*

For segmented pipelines in small P_mGD zones, that is, having 2 to 3 pipe segments within P_mGD zone, the design joint displacement ($\mathit{\Delta}_{\mathrm{seismic}}$) is considered as the maximum opening at the joints of the pipe due to longitudinal permanent ground deformation within the P_mGD zone.

$\mathit{\Delta}_{\mathrm{seismic}} = \delta_{\mathrm{ld-pgd}}$ = Design level ground displacement in the longitudinal direction.

10.2.2.2 *For chained joints*

a) In the areas of large ground displacement, a chained joint can be designed. Normally, chained joints are required when one single joint cannot accommodate the expected ground displacement. The pullout capacity of the whole series of joints is going to resist the expected ground movement in the axial direction of the pipeline.

b) The designed chained joints should be provided at both head and toe of the P_mGD zone, of which at least three joints are to be installed outside the P_mGD zone at the P_mGD zone boundary. The design joint displacement of each such pipe segment may be calculated as:

$$\Delta_{seismic} = \left(\frac{\delta_{ld-pgd}}{L/2}\right) \times L_0$$

where

L_0 = Length of pipe segment; and

L = Length of permanent ground deformation zone.

10.2.3 *Influence of Field Bend, Tees, or Sectional Changes*

Special attention shall be given in the modelling while analyzing the pipeline subjected to P_mGD with field bends, tees, or sectional changes, where they are inside or near the P_mGD zone.

10.3 For Transverse Permanent Ground Deformation (P_mGD)

10.3.1 *Continuous Pipeline*

10.3.1.1 The maximum strain in pipe ($\varepsilon_{seismic}$) in both tension and compression due to design transverse P_mGD can be evaluated through mathematical modelling as per **7.2**. While subjected to design transverse P_mGD, the pipeline may experience peak bending strain either at the center or near the boundaries of the transversely moving soil mass. Conservatively, the maximum bending strain in the pipe can also be calculated as:

$$\varepsilon_b = \pm \frac{\pi D \delta_{td-pgd}}{W^2} \quad \text{or} \quad \varepsilon_b = \pm \frac{P_u W^2}{3\pi E t D^2}, \quad \text{whichever is smaller.}$$

where

D = Outside diameter of pipe;

$\delta_{\mathrm{td-pgd}}$ = Design level transverse ground displacement;
W = Width of permanent ground deformation zone;
t = Thickness of pipe;
P_u = Maximum lateral resistance of soil per unit length of pipe as per **7.2.9.2**, and
E = Initial modulus of elasticity of pipe material

10.3.1.2 The maximum bending strain (ε_{b}), as obtained above, shall be considered as the earthquake pipe strain in both tension and compression ($\varepsilon_{\mathrm{seismic}}$) along the longitudinal axis of the pipeline.

10.3.2 *Segmented Pipeline*

10.3.2.1 For segmented pipeline, the design joint displacement ($\Delta_{\mathrm{seismic}}$) for transverse PmGD can be approximately (considering a sinusoidal variation of PmGD) estimated as follows:

$$\Delta_{seismic} = \frac{\pi^2 L_0 \delta^2_{td-pgd}}{W^2}\left[\frac{2D}{\delta_{td-pgd}}\right] \qquad \text{For } 0.268 \leq \frac{D}{\delta_{td-pgd}} \leq 3.73$$

$$\Delta_{seismic} = \frac{\pi^2 L_0 \delta^2_{td-pgd}}{2W^2}\left[1+\left(\frac{D}{\delta_{td-pgd}}\right)^2\right] \qquad \text{For other values of } \frac{D}{\delta_{td-pgd}}$$

10.3.2.2 The earthquake joint rotation ($\theta_{\mathrm{seismic}}$) due to transverse PmGD can be approximately obtained as:

$$\theta_{\mathrm{seismic}} = \arcsin(\Delta_{seismic} / L_0)$$

where
L_0 = Length of pipe segment.

10.4 For Liquefaction Induced Settlement

When subjected to relative ground settlement due to liquefaction en route, the pipeline shall be analysed considering soil-pile interaction. A static analysis can be carried out considering rigid displacement of soil mass around the pipeline in the settlement zone.

10.4.1 *Continuous Pipeline*

The maximum design strain (tension and compression) values can be obtained from the static analysis, by modelling the pipe-soil interaction as described in **7.2**.

10.4.2 *Segmented Pipeline*

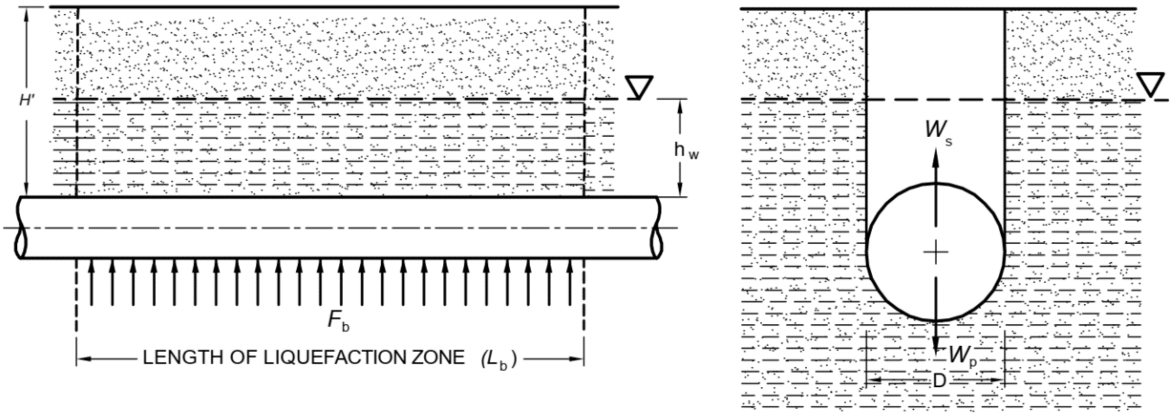
The maximum joint displacement and rotation can be obtained from the static analysis, by modelling the pipe-soil interaction as described in **7.2**.

10.5 For liquefaction induced buoyancy

10.5.1 *Buoyant Force calculation for Pipeline in Liquefiable Soils*

10.5.1.1 The net upward force per unit length of the pipeline (see Fig. 10) due to buoyancy may be calculated as:

$$F_{\mathrm{b}} = W_{\mathrm{s}} - [W_{\mathrm{p}} + W_{\mathrm{c}} + (P_{\mathrm{v}} - \gamma_{\mathrm{w}} h_{\mathrm{w}})D]$$



1 A LONGITUDINAL SECTION

1 B CROSS - SECTION

Fig. 10 PIPELINE SHOWING THE FORCES ACTING ON IT DUE TO BUOYANCY

10.5.1.2 When the pipeline is located below the water table and placed in a trench, the vertical earth pressure on the pipeline can be calculated as:

$$P_v = \gamma_w h_w + R_w \gamma_d H'$$

10.5.1.3 When the pipeline is jacked into undisturbed and unsaturated soil instead of being placed in the trench and covered with backfill, the earth load on pipe can be calculated as:

$$P_v = \gamma_w h_w + R_w \gamma_d H' - 2c\frac{H'}{D}$$

where

W_s = total weight of soil displaced by pipe per unit length,

W_p = weight of pipe per unit length,

W_c = weight of pipe content per unit length,

P_v = vertical earth pressure,

D = outside diameter of pipe,

γ_w = unit weight of water,

γ_d = dry unit weight of backfill,

h_w = height of water table above pipeline,

H' = total height of soil fill above pipeline,

c = coefficient of soil cohesion, and

R_w = buoyancy factor = $1 - 0.33\left(\frac{h_w}{H'}\right)$.

10.5.1.4 The adherence of soil to pipe wall can conservatively be neglected.

10.5.2 *Continuous Pipeline*

10.5.2.1 Bending stress being induced for a relatively short section of a continuous pipeline subjected to buoyancy can be calculated as:

$$\sigma_{bf} = \frac{F_b L_b^{\;2}}{10Z}$$

where

L_b = length of pipe in buoyancy zone,

Z = Elastic section modulus of the pipe cross-section, and
F_b = buoyant force acting on the pipeline.

10.5.2.2 For longer sections of pipeline subjected to buoyancy force, the pipe can exhibit both cable and beam action to resist the upward force. The maximum strain corresponding to bending stress, as mentioned above, can be obtained from the stress-strain curve of the pipe material as per **9**. The maximum strain thus obtained can be considered as the earthquake strain in pipe ($\varepsilon_{\text{seismic}}$).

10.5.3 *Segmented Pipeline*

The response of the segmented pipeline subjected to buoyancy force can be analysed according to the location of the joint by using the equilibrium of forces and moments. In the analysis, the joint of the segmented pipe may be considered as a hinge joint, and the extension and rotation of the joint are obtained. The maximum extension/rotation of the joints can be considered as the earthquake joint displacement/rotation of the pipeline.

10.6 For Earthquake Wave Propagation

While designing for earthquake wave propagation, the pipeline is assumed to fail primarily due to wave passage and is not combined with any other earthquake effect (that is, P_mGD and wave propagation effects are not to be combined). The response of pipeline due to wave propagation is generally described in terms of axial strains in pipes. Flexural strains in pipes due to ground curvature can be neglected since these are relatively small.

10.6.1 *Apparent Wave Propagation Velocity*

10.6.1.1 The apparent wave propagation velocity is an important parameter which is used to calculate the strain in pipe induced by earthquake waves. The apparent propagation velocity of both body and surface waves are of interest, since the pipelines are typically buried at shallow depth (1 – 3 m) below the ground surface. For body waves, only S-waves are considered since they carry more energy and generate larger ground motion than P waves. For surface waves, only R-waves are considered since they induce axial strain in the pipeline, which is significantly higher than that of the bending strain induced by L-waves.

10.6.1.2 To evaluate the axial strain in pipe, as a general rule, the velocity of shear wave (S-wave) is used for the sites within the epicentral distance of 5 times the focal depth. On the other hand, the velocity of the Rayleigh wave (R-wave) is considered for the sites having epicentral distance more than five times focal depth (*see* Fig. 11).

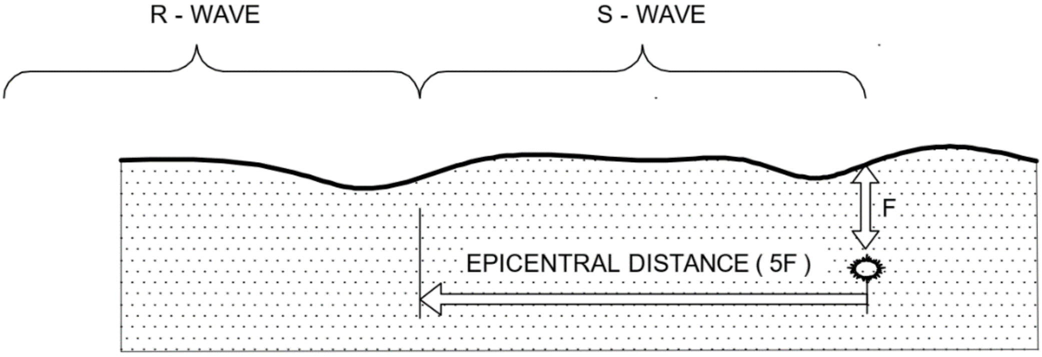


Fig. 11 CONSIDERATION FOR S-WAVE AND R-WAVE IN PIPELINE DESIGN

10.6.2 *Continuous Pipeline*

10.6.2.1 The maximum longitudinal axial strain induced in the pipeline due to wave propagation can be approximated as:

$$\varepsilon_a = \frac{v_{gd}}{C_{apparent}} = \frac{v_{gd}}{\alpha_\epsilon C}$$

where

V_{gd} = Design level peak ground velocity

α_ϵ = Ground strain coefficient (it can be conservatively assumed 2.0 for S-waves, and 1.0 for R-waves)

C = Velocity of earthquake wave propagation, conservatively it can be considered as 2.0 km/s for S-waves and 0.5 km/s for R-waves

10.6.2.2 The axial strain ε_a calculated above can be considered as the earthquake strain ($\epsilon_{\text{seismic}}$) of the pipe. But, this strain need not exceed the maximum strain that can be induced in pipeline by soil friction ϵ_{af} given by:

$$\varepsilon_{af} = \frac{t_u \lambda}{4AE};$$

where

t_u = Peak frictional force per unit length at soil-pipe interface as per **7.2.9.1**

λ = Apparent wavelength of earthquake waves at the ground surface. It can be taken as 1.0 km in the absence of detailed information)

A = Cross-sectional area of the pipe

E = Initial modulus of elasticity of pipe material

10.6.3 *Segmented Pipeline*

10.6.3.1 The design level joint displacement in the pipeline can be calculated as:

$$\Delta_{seismic} = \varepsilon_{seismic} L_0$$

where

$\epsilon_{\text{seismic}}$ = Axial strain as calculated as per **10.6.2.2** for the continuous pipeline, and

L_0 = Length of pipe segment

10.6.3.2 For a long straight run segmented pipe, the ground strain is accommodated by a combination of pipe strain and relative axial displacement (expansion/contraction) at pipe joints. Since the overall axial stiffness for pipe segments are typically much larger than that for the joints, the ground strain results primarily in relative displacement at the joints. The earthquake joint rotation in the pipeline due to wave propagation can be calculated as:

$$\theta_{seismic} = 1.5\frac{a_{gd}}{C^2}L_0$$

where a_{gd} is the design peak ground acceleration in a direction normal to the direction of propagation of ground wave generated by design earthquake.

11 SEISMIC DEMAND ON STEEL ABOVE GROUND PIPELINES

Above-ground pipelines are often used as one of the mitigation techniques to reduce excessive strain in buried pipelines. The above-ground pipelines are placed on varieties of supports, including on-ground with intermediate anchor blocks, on the ground with sliding supports, elevated frame supports, existing road or rail bridges, specifically designed pipeline bridges, etc. For above-ground pipelines, if there is no flexible joint provided between two anchor blocks, they are considered continuous pipelines, else segmented pipelines.

11.1 Inertia Effect

11.1.1 The earthquake forces due to the inertia of the pipeline and its supports can be evaluated by carrying out analysis as outlined in **7.3**. The pipeline along with its supporting structure shall be modeled to represent its dynamic characteristics. For the segmented pipeline, the analysis shall consider joint flexibility.

11.1.2 The inertia force of the pipeline shall be transmitted to its support through appropriate load path and support type.

11.1.3 The supporting structure shall be designed depending on its type based on applicable codes of practice. For example, a frame type support is designed like a building frame as per IS 1893 (Part 1), and a pier type support is designed as per IS 1893 (Part 3).

11.2 Differential Support Movement due to Earthquake Shaking

11.2.1 When the pipeline is directly supported on the ground, the differential movement due to earthquake shaking may be neglected.

11.2.2 For the above-ground pipelines identical earthquake excitation at all points applied at the base of the support can be considered and the differential support movement can be neglected, with the following exceptions:

a) *Widely spaced support:* When the pipeline anchors are spaced widely (600m or more), the pipeline shall be analysed for earthquake excitations with spatial variability (in terms of amplitude and phase).

b) *Pipeline rested on non-uniform support:* When the pipeline supports are non-uniform, or they are located on different structures, the earthquake response of the non-uniform supporting structure may apply differential movement on the pipeline.

11.3 Permanent Ground Deformation due to soil failure

11.3.1 When subjected to the $\mathrm{P_mGD}$ due to soil failure, the above-ground pipeline shall be analysed for differential movement of its supports due to design $\mathrm{P_mGD}$. The $\mathrm{P_mGD}$ could be due to faulting, longitudinal or transverse $\mathrm{P_mGD}$ due to liquefaction, settlement due to liquefaction, etc.

11.3.2 The maximum tensile and compressive strain in the pipe due to differential support movement shall satisfy the design check as per **5.8.1** for the continuous pipeline. For segmented pipeline, the design joint displacement/rotation shall satisfy the design check as per **5.8.2**.

11.3.3 Under large P_mGD, pipeline may be designed to be placed over closely spaced slider supports so as to allow its longitudinal and transverse movement. The slider supports may be provided with end stoppers so as to prevent unseating of the pipe from the support. The support spacing shall calculated to prevent excessive sag, bending and shear stresses in the piping, with special consideration given where components, such as flanges and valves, impose concentrated loads. The width of the slider support shall be calculated based on the expected transverse movement of the pipeline.

12 ALLOWABLE STRAIN, DISPLACEMENT AND ROTATION

12.1 Allowable Strain Limit for Continuous Pipelines

The allowable strain (ε_{all}) given in Tables 8 and 9 can be used for API grade welded steel pipes. For other types of steel pipes, the allowable strain limit provided by the manufacturer may be used.

12.1.1 *Displacement-Controlled Loading*

Table 8 provides the allowable strain limits for continuous steel pipelines under displacement-controlled loading (P_mGD).

12.1.2 *Force-Controlled Loading*

Table 9 provides the allowable strain limits for continuous steel pipelines under force-controlled loading (earthquake wave propagation, buoyancy).

12.2 Allowable Joint Displacement/Rotation for Segmented Pipeline

12.2.1 The allowable joint displacement/rotation varies widely according to its type and material; hence it shall be as per manufacturer data.

12.2.2 For normal operability conditions, no leak/excessive joint displacement/rotation may be allowed with good safety margin. However, for functional integrity conditions, minor leaks or joint displacements/rotations may be allowed keeping the system to continue functioning.

Table 8 Allowable strain ($\varepsilon_{\mathrm{all}}$) for continuous steel pipeline for displacement-controlled loading

(*Clauses 12.1 and* 12.1.1)

Type of Pipeline	**Allowable Strain**			
	Pressure Integrity Limits		***Normal Operability Limits***	
	Tension	Compression	Tension	Compression
Oil and Gas	4%	$\varepsilon_{\mathrm{cr-c}}$	2%	$\varepsilon_{\mathrm{cr-co}}$
Water	$0.25\varepsilon_{\mathrm{u}}$ or 5%	$\varepsilon_{\mathrm{c-pgd}}$	-	-

Table 9 Allowable strain (ε_{all}) for continuous steel pipeline for force-controlled loading

(*Clauses 12.1 and* 12.1.2)

Type of Pipeline	**Allowable Strain**			
	Pressure Integrity Limits		***Normal Operability Limits***	
	Tension	Compression	Tension	Compression
Oil and Gas	1%	$\varepsilon_{\mathrm{cr-c}}$	0.5%	For Earthquake Wave: $0.75\varepsilon_{\mathrm{cr-co}}$ For Buoyancy: 0.5%
Water	$0.25\varepsilon_{\mathrm{u}}$ or 5%	$\varepsilon_{\mathrm{c-wave}}$	-	-

where,

$$\varepsilon_{\mathrm{c-pgd}} = 0.88\frac{t}{R}$$

$$\varepsilon_{\mathrm{c-wave}} = 0.75\left[0.5\frac{t}{D'} - 0.0025 + 3000\left(\frac{PD}{2Et}\right)^2\right]$$

$$\varepsilon_{\mathrm{cr-c}} = 0.175\frac{t}{R}$$

$$\varepsilon_{\mathrm{cr-co}} = 0.5\frac{t}{D'} - 0.0025 + 3000\left(\frac{PD}{2Et}\right)^2$$

$$D' = \frac{D}{1 - \frac{3(D - D_{min})}{D}}$$

D = Nominal outside diameter of pipeline,

D_{min} = Minimum inside diameter of pipe (that is, outside diameter excluding out of roundness thickness),

t = Thickness of pipe wall, and

ε_{u} = failure strain of pipe in tension

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Annex A

(Committee composition will be added after finalization)

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