
**Petroleum and natural gas industry —
Pipeline transportation systems —
Geological hazard risk management
for onshore pipeline**

*Industrie du pétrole et du gaz naturel — Systèmes de transport
par conduites — Gestion des risques géologiques pour les conduites
terrestres*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is used by pipeline operators and designers for the implementation and improvement of geohazard risk management of onshore pipelines.

It is used for the orderly and effective identification, assessment and mitigation of geohazards threatening the integrity or safety of the pipeline, and to reduce the potential for risks and accident loss. This document is intended to address geohazards along the pipeline and right-of-way (RoW).

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Petroleum and natural gas industry — Pipeline transportation systems — Geological hazard risk management for onshore pipeline

1 Scope

This document specifies requirements and gives recommendations on the management of geohazard risks during the pipeline design, construction and operational periods.

This document is applicable to all operators and pipelines (existing and proposed/under construction).

This document applies to onshore gathering and transmission pipelines used in the petroleum and natural gas industries.

NOTE This document is not applicable to piping and pipelines within well-defined plants and facilities, such as pump or compressor stations, processing facilities or refineries. It is assumed that the facility site as a whole will be subject to a separate geohazard assessment to evaluate applicable natural and man-made hazards. Nevertheless, this document can provide useful guidance for assessing the geohazard threat to facilities, including the pipelines within the facility.

This document is applicable to all reasonable and credible natural hazards induced by natural forces and hazards induced by human activity that manifest similarly to natural hazards collectively referred to as “geological hazards” or “geohazards”, or through industry as attributed to “natural forces”. Geohazards covered by this document include, but are not limited to (not given in order of significance):

- mass wasting processes, including landslides, lateral spreads, rockfalls, debris flows, avalanches, and similar processes whether naturally occurring or anthropogenic;
- land subsidence and/or sinkhole formation, whether naturally occurring such as from dissolution of salt or carbonate rock formations (karst formation) or human caused, such as from underground mining or withdrawal of subsurface fluids such as groundwater and oil and gas;
- seismic hazards, such as ground shaking, fault rupture, liquefaction, flow failures and lateral spreading or associated secondary effects, such as seismically triggered landslides;
- volcanic hazards, such as lahars, pyroclastic flows, lava flows, dam break, and volcanically induced seismicity (excluding ashfall), where such hazards can be reasonably predicted;
- hydrologic processes, such as flooding, vertical scour of river bottoms, channel migration and bank erosion, channel avulsion, rapid lake drainage;
- permafrost/periglacial processes and geothermal effects, such as thermal degradation, frost heave or thaw settlement, thermal erosion, thermokarst;
- surface (overland), trench backfill, or earthwork fill erosion;
- expansion or collapsing processes caused by expansive and collapsible soils, such as glaciomarine clays, collapsible loess, etc.

This document is not applicable to atmospheric/environmental effects, such as the following:

- high winds induced from hurricanes and tornadoes and similar storms, except where such events are reasonably predictable and will induce geohazards such as landslides, erosion, etc.;
- lightning;
- forest or brush fires;

- ashfall from volcanic eruptions.

Furthermore, this document is not applicable to cascading events, where one remote event leads to a chain of events that eventually induces a geohazard near the pipeline. It is only applicable to geohazards that directly affect the pipeline or RoW.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions 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/>

3.1.1

construction phase

period where the pipeline is physically constructed encompassing all activities from RoW clearing, to commissioning and RoW clean-up/reinstatement

3.1.2

detailed design phase

period consisting of detailed design, which can include but is not limited to detailed hydraulic studies, mechanical design of the pipeline, stress analysis, design of RoW, full characterization of all identified geohazards, construction and logistics planning, and supply management

3.1.3

dynamic management

process that covers the pipeline's full life cycle, which can be implemented when a new hazard is identified or an existing hazard changed

3.1.4

geohazard inventory

list of all identified geohazards which can be maintained, enhanced or decreased throughout the life of the pipeline project

Note 1 to entry: Ideally, the inventory would be computer based and linked to a Geographic Information System (GIS).

3.1.5

geohazard susceptibility

geological or environmental conditions that might allow a geohazard event to occur

Note 1 to entry: A geohazard event can be natural or man-made occurrence that induces an integrity or safety threat to the pipeline or RoW.

3.1.6

geologically sensitive area

area potentially prone to geohazards

EXAMPLE Such areas include seismic fault zones or active faults, medium and large rivers, high and steep slopes, debris flows corridors, landslide prone topography, areas prone to karst collapse, mined-out areas.

3.1.7**hydrologic process**

process associated with flowing water, i.e. river and stream processes

3.1.8**individual pipeline geohazard**

specific geohazard that can impact the pipeline

3.1.9**land subsidence**

sinking or gradual downward settling of the earth's surface with relatively little horizontal movement

Note 1 to entry: It can be caused by karst processes, collapsible or dispersive soils, piping erosion, upward migration of underground mining works, or other processes.

3.1.10**long-term management**

management activities for *pipeline geohazards* (3.1.15) through monitoring and periodic re-evaluation of threat levels from geohazards

3.1.11**mass wasting process**

general term for the dislodgement and gravity-driven downslope movement or transport of soil and rock material

3.1.12**operation and maintenance phase**

period in pipeline lifecycle during which hydrocarbon product fills the pipeline and is transported through the pipeline, and the pipeline operator addresses issues related to pipeline and RoW maintenance and integrity

3.1.13**operator**

person or organization which owns or operates a pipeline system or facilities and which is responsible for the operation and integrity of the pipeline system

3.1.14**pipeline failure consequence**

impact or loss caused directly or indirectly by leakage, damage or reduced performance of a pipeline subject to geohazards.

EXAMPLE Social and environmental impact, loss of life and property, negative impact on corporate reputation, and economic loss.

Note 1 to entry: This includes individual pipeline geohazard and regional pipeline geohazard.

3.1.15**pipeline geohazard**

geological process or phenomenon that have the potential to cause damage to a pipeline or RoW

3.1.16**pipeline geohazard risk**

combination of *geohazard susceptibility* (3.1.5), *pipeline vulnerability* (3.1.22) and *pipeline failure consequence* (3.1.14)

3.1.17**pipeline geohazard risk assessment**

process of determining whether *pipeline geohazard risks* (3.1.16) are acceptable or require mitigation or an intervention

3.1.18

pipeline geohazard risk identification

process of discovery, characterization and description of credible and probable geohazards that can impact the pipeline or RoW

3.1.19

pipeline geohazard risk management

coordinated activity for guiding and coping with issues related to *pipeline geohazard risk* (3.1.16)

3.1.20

pipeline geohazard risk management program

set of processes and procedures for guiding operating companies or *operators* (3.1.13) to carry out *pipeline geohazard risk management* (3.1.19)

3.1.21

pipeline geohazard risk mitigation

process of selecting and implementing a geohazard risk countermeasure or intervention to reduce the probability of a negative event or reduce the consequences of a negative event that can impact the pipeline or RoW

3.1.22

pipeline vulnerability

conditional likelihood of a pipeline being subject to damage due to a geohazard, given a geohazard occurs and impacts the pipeline, which is an estimate of how resistant it is to damage caused by geohazards

3.1.23

preliminary engineering and route selection phase

initial period in the pipeline lifecycle during which basic design work is completed, including but not limited to route study and selection, preliminary design of the pipeline, early planning for logistics, supply management and regulatory planning and submissions

3.1.24

regional pipeline geohazard

group or cluster of existing and potential geohazards located within a defined geographic area

3.1.25

right-of-way

corridor of land within which the pipeline operator has the right to conduct activities in accordance with the agreement of the land owner

[SOURCE: ISO 13623:2017, 3.1.19]

3.1.26

seismic hazard

hazard occurring as a result of an earthquake

3.1.27

subject matter expert

SME

practitioner experienced with evaluating and managing geohazards

Note 1 to entry: The qualifications for a subject matter expert vary by location but they generally include a degree in geology, geomorphology, hydrogeology, geotechnical engineering, geological engineering, civil engineering, or related degree and at least five years of practical experience working with geohazards.

3.2 Abbreviated terms

GIS	Geographic Information System
ILI	In-Line Inspection
LiDAR	Light Detection and Ranging
PGMP	Pipeline Geohazard Risk Management Program
RoW	Right-of-way

4 Pipeline geohazard risk management program

4.1 Key principles

A PGMP is a set of practices and procedures used to systematically identify, evaluate, and manage geohazards for the purposes of reducing the risk of damage to a pipeline system to an acceptable level. A PGMP is operated for the entire lifespan of the pipeline from conception and design, to construction, operation, and until the pipeline system is decommissioned. Thus, the PGMP should be designed and implemented in such a way that critical information will be maintained and accessible for the lifetime of the pipeline.

Because a variety of different groups participate in the design, construction and operation of a pipeline, overall ownership of the PGMP rests with the operator. The operator shall designate an individual or organization (the "PGMP team") to administer the PGMP during and between the different phases. The PGMP team may be the operator's personnel or a qualified third party entrusted by the operator. In case of replacement of one organization by another, a proper handover of geohazard risk management duties shall be ensured. When the geohazard risk management is assigned to a third party, the operator shall be continuously and intimately engaged with the third party to ensure that the interests and needs of the operator and all stakeholders are being adequately addressed and protected.

It is recommended that geohazard risk management throughout the life of a pipeline be carried out by the same organization, which can be either an operator, or a third party entrusted by them.

Dynamic management of pipeline geohazards is required and newly identified geohazards may be included in said management. Geohazards included in dynamic management are referred to as risk management objects.

Where a PGMP is needed, operators shall establish and maintain a PGMP for the life of the asset. Operator shall update the PGMP during the life of the asset as and when conditions warrant.

All work associated with the geohazard risk identification, assessment and mitigation of the pipeline shall be carried out by qualified personnel. SMEs shall be consulted as necessary throughout all stages and phases of the pipeline lifecycle.

PGMP activities shall be documented. Geohazards might change over time, and changes in the PGMP shall be documented over time, to ensure that the most current data and assessments are identified. Out-of-date assessments may be archived.

4.2 Requirements for a PGMP

The PGMP informs an operator of how to design, construct and operate the pipeline in a safe, environmentally responsible and reliable manner.

The PGMP covers the phases of preliminary engineering and route selection, detailed design, construction, as well as operation and maintenance. It is recommended to conduct geohazard risk management as a discrete element of the pipeline design phase, beginning in the earliest phases of design.

Geohazard risks to a pipeline, and thus the need and scope of a PGMP, varies from pipeline to pipeline, due to a number of natural and human-induced factors. Geohazard risk might be higher for pipelines operated in areas of

- a) steep terrain,
- b) active tectonics,
- c) high precipitation,
- d) soluble bedrock,
- e) high seismicity,
- f) geologically young terrain,
- g) significant natural resource exploitation/extraction,
- h) landslide prone geology,
- i) volcanism,
- j) active shallow mining,
- k) significant river crossings, and
- l) geothermal variability such as permafrost.

For example, a short pipeline in a flat, tectonically stable region with minimal rainfall might have a relatively low geohazard risk. In this case, the operator might demonstrate that a PGMP is not needed. Conversely a long pipeline with a 50-year service life, in a remote, steep, tectonically active tropical region would likely have a relatively high geohazard risk. In this case, the operator would very likely establish a PGMP.

Because of the broad variation in geohazard risk between pipelines, an operator is required to assess geohazard risk of existing and future pipelines and determine whether a PGMP is necessary.

If an operator concludes that a PGMP is not necessary for a particular pipeline or section of pipeline, the conclusion shall be documented. The documentation shall be a report titled:

Demonstration that Geohazard Management Program is not Required for [name of pipeline].

It shall include, without limitation, a discussion of the items listed in 4.2 a) to l) with an explanation why the geohazard risks are of such a low level that a PGMP is not needed. The report shall be prepared in consultation with suitable SMEs with appropriate experience in the region and type of geology in which the pipeline is, or will be installed.

If an operator concludes that a PGMP is necessary, the operator shall establish a PGMP team to design and implement the appropriate PGMP, beginning at the earliest phases of project development.

4.3 Elements of a PGMP

4.3.1 General

To prevent and reduce risks caused by geohazards, the PGMP shall be carried out throughout the life of a pipeline under the guidance of the PGMP team. The PGMP covers four interlinked processes:

- **identification** of potential geohazards;
- **evaluation** of the severity of the geohazards;
- **mitigation** of the threat from the geohazards;

- **long-term management** of geohazards through monitoring and periodic re-evaluation of threat levels from geohazards.

The four processes are needed to varying degrees throughout the life of the pipeline.

To illustrate the application of the four processes, this document considers four phases of pipeline life:

- preliminary engineering and route selection;
- detailed design;
- construction;
- operation and maintenance.

Each phase is discussed below, with an illustration of the four processes within each phase.

A typical PGMP follows the flowchart in [Figure 1](#). The PGMP process shall occur in parallel with consideration of other constraints, such as economics and societal.

4.3.2 Preliminary engineering and route selection phase

In this phase, the effects of geohazards shall be fully considered to meet the requirements of route selection. Because the most effective mitigation of geohazards is avoidance, this phase represents an important opportunity for the operator to reduce the overall geohazard risk of the project.

[Annex A](#) provides guidelines for route selection in consideration of geohazards.

During this phase, the PGMP shall follow the principles of identification, evaluation, mitigation and long-term management:

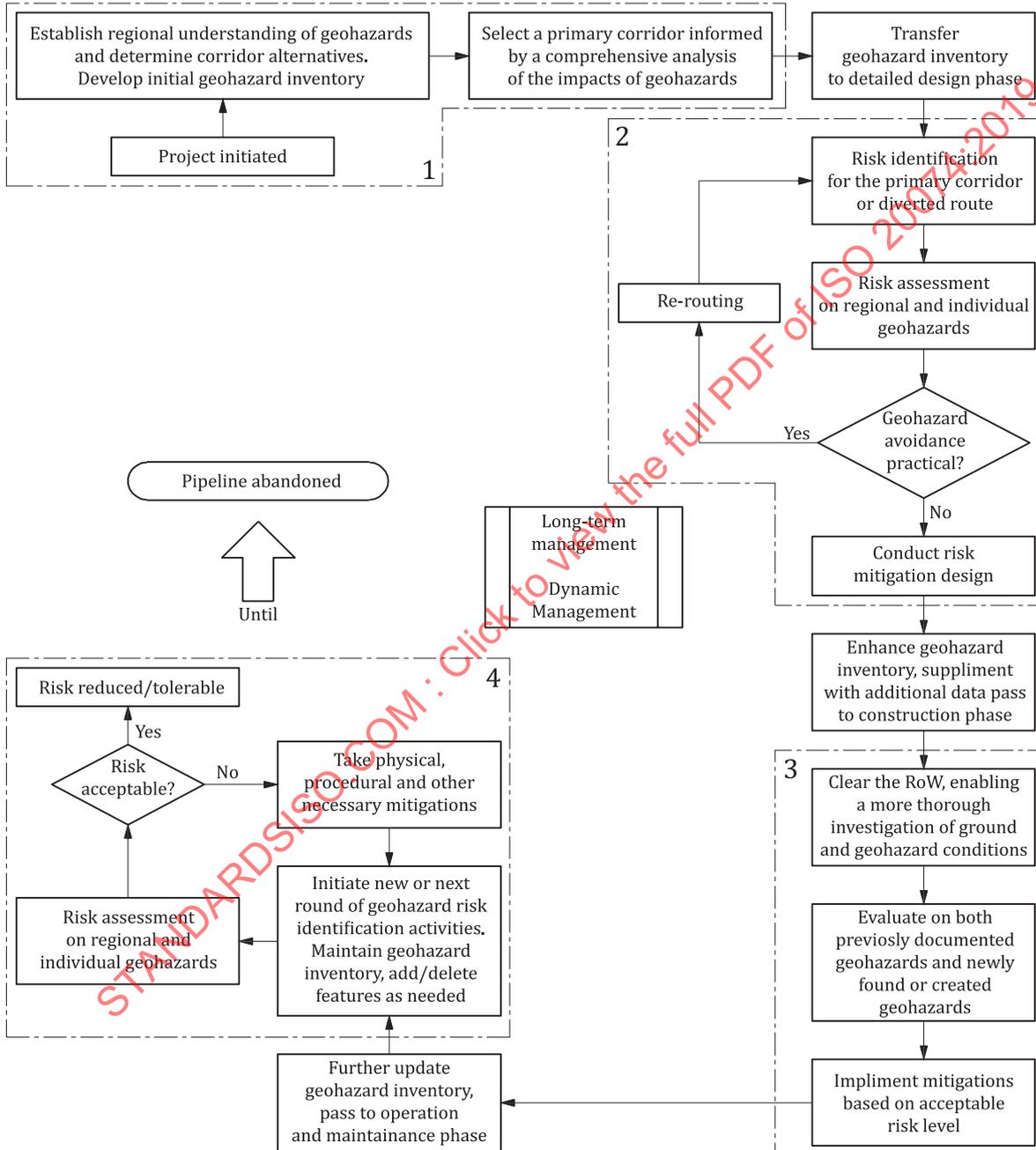
- **Identification:** Establish regional understanding of geohazards and determine whether regional geohazard threat level requires further development of a PGMP. For the initial corridor alternatives, severe geohazards and geologically sensitive areas, such as seismic fault zones or active faults, medium and large rivers, high and steep slopes, debris flows corridors, landslide prone topography, areas prone to karst collapse, mined-out areas should be identified. Acquire regional and local remote sensing data sets, supplement with ground investigation if warranted. Light Detection and Ranging (LiDAR) data combined with expert interpretation have proven to be an extremely valuable tool in identifying geohazards during this phase.
- **Evaluation:** Classify geohazards along the proposed corridors according to severity of their threat to the proposed pipeline. Some geohazards might be found to be sufficiently severe that they create critical conditions and could cause a candidate corridor to be removed from consideration. Other geohazards pose less severe risk. The locations, footprints and severity of the geohazards shall be assembled in a GIS database, and shall form the geohazard inventory ([5.2](#)) that will exist for the life of the project.
- **Mitigation:** The primary mitigation of geohazards at this phase is avoidance. An important responsibility of the PGMP team at this phase is the unambiguous assessment and presentation of geohazards and risks to the broader project team. Quantification of geohazard impacts on design, construction and operations is helpful to fully define the risks. The selection of the final corridor shall consider the impacts of geohazards, balanced against other design, construction and operational considerations. At this stage, the operator may also consider other mitigations, e.g. strain-based design of the pipe.
- **Long-term management:** Because no asset yet exists, long-term management of geohazards at this stage consists of developing the geohazard inventory and associated GIS database, and passing it to the detailed design phase.

The recommended implementation procedures in this phase are:

- Establish regional understanding of geohazards and determine corridor alternatives.

- b) Select a primary corridor.
- c) For the primary corridor, perform regional geohazard susceptibility assessment (6.3). If warranted, individual geohazard risk assessments (6.4) might be necessary for specific locations.
- d) Following selection of the primary corridor, the detailed design phases may begin.

NOTE Considerable pipeline design work, such as pipeline hydraulic studies, construction method studies, logistics and supply assessments and other activities are also being performed in this phase.



Key

- 1 preliminary engineering and route selection phase
- 2 detailed design phase
- 3 construction phase
- 4 operation and maintenance phase

Figure 1 — A PGMP flowchart

4.3.3 Detailed design phase

Detailed design may be conducted by an entity other than the operator. Compared to the previous phase, this phase typically involves a larger project team, more resources, increased ability and complexity of field works, and increased definition of project objectives. All of these activities can benefit the PGMP.

The PGMP shall again follow the four primary principles:

- **Identification:** Identification will begin with the geohazard inventory developed during the previous phase, and enhance the inventory with additional investigation, both remote sensing and ground-based. Consideration should be given to both the proposed primary pipeline corridor, as well as potential re-routes, ancillary and temporary facilities such as quarries, camps and access roads that might be required for pipeline construction.
- **Evaluation:** Existing items in the geohazard inventory shall be re-classified as new data become available, and all additional geohazard items shall be classified. Field and remote data gathering programs shall be designed in part to enable this evaluation. Remote and on-ground monitoring of geohazards may also commence during this phase. Inclinometers may be installed at ground movement locations, and monitoring plans developed. Rainfall and riverflow gauges may also be installed as access to the site improves. Evaluation of geohazard risks specifically to construction, including off-RoW impacts, shall be evaluated by the PGMP team in collaboration with the project's execution specialists.
- **Mitigation:** The primary mitigation of geohazard risk remains avoidance. In this phase, re-routing shall be used to avoid geohazards, balanced with other project objectives such as constructability, cost, environmental and stakeholder considerations. During this phase, other on-RoW mitigations, such as reduced footprint (narrow RoW), ground reinforcement and soil drains, may also be developed. Consideration shall also be given to incorporating mitigations such as strain-based design and geotechnical and integrity monitoring into the design. Adequate seismic design shall be considered for pipelines crossing seismic fault zones or active faults. References [6], [9], [10], [18], [19], [20] and [21] provide guidance for the seismic design of pipeline.
- **Long-term management:** Long-term management of geohazards at this stage consists of further developing the geohazard inventory and associated GIS database, and passing it to the construction phase. Locations and data from monitoring locations, as well plans for RoW and pipe mitigations, shall also be passed to the construction phase.

Note that

- pipeline geohazard risk management requirements shall be regarded as one of the bases for optimizing pipeline design scheme and making decisions, along with other pipeline design factors determined in the preliminary engineering and route selection phase,
- each identified geohazard shall be assessed to determine its impact on pipeline and environmental integrity, and
- mitigation shall be proposed for geohazards that have an unacceptable or unmitigated impact.

The recommended implementation procedures in this phase are:

- a) Start risk identification for the primary corridor selected in the preliminary engineering and route selection phase or alternative corridors proposed by design department or as a result of public/stakeholder consultations.
- b) Perform risk assessment on regional and individual geohazards.
- c) Repeat steps a), and b) above until all identified geohazards have an acceptable level of risk, achieved through re-routing or application of appropriate mitigations.
- d) Prepare PGMP interface with constructor. If detailed design and construction are performed by the same entity, this will be an internal interface.

- e) This phase should be repeated if during or after the evaluation of the potential for geohazard occurrence significantly changes, such as from human activity (e.g. mining or road construction), strong storms (e.g. a tropical cyclone), or large earthquake.

4.3.4 Construction phase

NOTE Subclause 4.3.4 is written as though the pipeline designer and constructor were different entities. If they were the same entity, some of the guidance on interfaces could still apply, although these interfaces are internal to the entity rather than external between entities. In either case, it is ultimately the responsibility of operator through the PGMP team to ensure that the PGMP is properly transitioned from detailed design to construction phases.

Pipeline construction in geohazard-susceptible areas carries increased risk to personnel. The pipeline constructor should be made aware of geohazard risk level during the tender phase. In particular, the tender package prepared should describe the duties expected of the constructor under the PGMP.

Construction of a pipeline in a geohazard environment is a unique phase in the life of the asset, and therefore a unique phase of the PGMP. Some important considerations include the following:

- The relatively large number of personnel on the RoW during the construction phase will result in increased risk of personal injury due to geohazards.
- The RoW will be fully cleared of most vegetation, enabling a better examination of ground and geohazard conditions, and allowing for on-ground examination of some features that were previously only identified by remote sensing. Care should be taken as ground clearing might promote erosion and slope instability.
- The availability of personnel, machinery and logistical support such as transportation and camps, is relatively high. In addition, the presence of personnel and machinery at the construction site presents the ideal time to identify new undetected geohazards and implement geohazards mitigations.
- RoW preparation will require extensive earthmoving particularly in steep terrain, with the potential for creating additional geohazards such as steep cuts, and unconsolidated spoil and fill areas.
- The cutting of the pipeline trench offers a unique opportunity to evaluate subsurface geotechnical conditions along the RoW, might be beneficial to make note of the soil and ground water condition during this construction stage and keep those as records.

The four PGMP processes of identification, evaluation, mitigation and long-term management which apply to the construction phase are described below:

- **Identification:** Identification during the construction phase begins with the existing inventory of geohazards developed during the previous phases. This inventory shall be transmitted to the constructor, typically through GIS shape files and/or Computer Aided Design (CAD) drawings. The constructor's drafting personnel shall be familiarized with the protocol for maintaining existing features and adding new ones. Construction drawings such as alignment sheets should be updated with the existing geohazard encountered and identified during the construction phase to produce as-built drawings.

The scope of the PGMP during construction shall include any off-RoW footprint used by the constructor, including access roads and quarries.

The PGMP team shall establish a formal interface with the constructor to maintain oversight of the PGMP. Arrangements shall be made early in the process for the appropriate level of geohazard expertise to be present during construction. Such expertise can consist of PGMP team and contractor's qualified personnel.

Supervisors and machinery operators, drivers and labourers spend the most time on the RoW and are at the "front lines" of geohazard identification. If appropriate to the terrain, geohazard training shall also be given to contractor's supervisors and equipment operators. Such personnel should be

trained on personal safety risk posed by geohazards and be trained to identify new geohazards and appropriate health and safety controls to apply.

All personnel whose jobs expose them to geohazards should be trained on basic geohazard risk management.

Updates to existing geohazards as well as newly identified geohazards shall be recorded in the PGMP database and the as-built construction drawings.

- **Evaluation:** During the construction phase, evaluation shall be performed on both previously documented geohazards and newly found geohazards created or discovered during the construction activities. Evaluation may be performed by members of the PGMP team, and constructor's personnel as appropriate. Some important considerations include:
 - Landslides mapped during detailed design phase shall be further evaluated during RoW clearing to update the assigned threat level. Inclinometers may be installed at ground movement locations, and monitoring plans developed.
 - Changes to surface drainage and vegetative cover made during construction might decrease the stability of pre-existing features. Note should be made to the impact of those changes and action should be taken to correct and monitor those areas.
 - Spoil piles, sidecasts and earth fills and cuts created during construction shall be evaluated both for threat to construction personnel and materiel and threat to off-RoW assets, such as houses, settlements and environmental receptors such as streams and rivers.
 - Quarries developed to support pipeline construction shall be evaluated from a geohazard perspective. This includes smaller-scale failures such as rock falls as well as larger global instabilities. The latter in particular have potential to flow outside the quarry and affect neighbouring community. Each quarry shall have a quarry management plan as required by good engineering/construction practice.
 - Due to resource availability, the construction phase might be the best opportunity for the PGMP team to evaluate geohazards through intrusive investigations such as geotechnical boreholes.
- **Mitigation:** The construction phase is likely the ideal time to mitigate against known geohazards because of the availability of personnel and machinery at the RoW.

Mitigation of known geohazards shall be implemented as part of the base design. Mitigation may include stabilization and/or drainage works. Examples include engineered fault crossings at known active faults, reinforcements of known unstable slopes, implementation of heavy walled pipe, site stabilization and/or drainage works and additional installation of survey monuments and monitoring instruments (such as inclinometers).

Mitigations can also be required for geohazards identified during construction. All constructed geohazard mitigations shall be documented in the as-built drawings.

- **Long-term management:** During the construction phase, "long-term management" refers to monitoring and management while the constructor is present on the RoW, prior to handover of the completed asset.

Stability of cuts, access roads, quarry faces, spoil piles and other potentially unstable areas might warrant periodic monitoring and mitigation during the construction phase. Construction assets such as quarries not needed during operation and maintenance phase shall be properly closed and secured. If appropriate, monitoring plans for these areas shall be developed.

The project's geohazard inventory is further enhanced during the construction phase with newly-identified geohazards, re-evaluation of existing geohazards, mitigations, and monitoring outcomes. This enhanced geohazard inventory is passed to the operation and maintenance phase. Construction as-built and data on pipe weld locations and quality are also relevant data to the PGMP.

The transition for construction to operation and maintenance is a significant milestone in a project and will entail significant change in personnel and organizations. The PGMP team shall be closely involved during the transition to ensure that geohazard data and monitoring plans are accurately conveyed to the operations organization, and consistency in the PGMP is achieved.

The recommended implementation procedures in this phase are:

- a) Clear the RoW.
- b) Evaluate both previously documented geohazards and newly found or created geohazards.
- c) Refine or optimize the mitigations that might be needed based on the site conditions encountered during the construction phase and the acceptable risk level.

4.3.5 Operation and maintenance phase

Geohazard risk management in this phase shall again follow the four primary principles:

- **Identification:** Identification will continue with the geohazard inventory developed during the previous phases. During the operation and maintenance phase, periodic remote and on-ground monitoring of the pipeline and RoW will likely be the primary means of identifying any new geohazards that develop during the life of the pipeline. Especially during the beginning of operations, the PGMP team shall identify any new geohazards, such as cuts and spoil storage areas, created as a result of the construction activities. Immediately after construction, vegetative cover of the RoW might not be fully established. This is advantageous from the standpoint of geohazard identification, but also disadvantageous from the standpoint of RoW erosion and stability.
- **Evaluation:** Monitoring plans initiated during project start-up shall be used to evaluate the identified geohazards. Inclinator readings, on-ground inspection, in-Line inspection, repetitive aerial surveying, and satellite monitoring are all relevant techniques that may be used. In cases where ground movement is detected, pipe stress analyses may be undertaken to better characterize the actual effect of the geohazard on the pipe and determine the timing and extent of any mitigation required. The PGMP team shall also consider any impacts that geohazards might have on the off-RoW.
- **Mitigation:** Once the pipeline is installed, avoidance is generally not a mitigation option. During the operation and maintenance phase, mitigations and interventions may include RoW drainage, slope stabilization, slope reinforcement, soil removal, watercourse management and other measures depending on the specific geohazard. Ongoing RoW maintenance might obviate the need for more costly mitigation measures.
- **Long-term management:** Long-term management of geohazards at this stage consists of further developing the geohazard inventory and associated GIS database, and all the activities listed above. Towards the end of the asset life, appropriate abandonment plans shall be developed to ensure the long-term stability of the RoW after operation ends.

Note that

- the PGMP that was developed in the previous phase shall be adopted, if present. If no PGMP is available, an operational specific PGMP shall be developed,
- dynamic management shall be adopted for risk identification, assessment and mitigation of geohazards induced or aggravated during operations,
- geohazards identified in detailed design phase and construction phase as well as related mitigations shall be confirmed prior to the commissioning of the pipeline,
- the pipeline geohazard risk management cycle should be determined in accordance with the development of various geohazards and in combination with business demand, established plan, and the social responsibilities of the pipeline operating company, and

- if events occur that might change the geohazard risk, such as from human activity (e.g. mining or road construction, induced seismicity), strong storms (e.g. a tropical cyclone), or a large earthquake, a new round of geohazard risk management should be conducted as soon as prudent.

The recommended implementation procedures in this phase are the following:

- Start risk identification.
- Perform risk assessment on regional and individual geohazards.
- Assess whether the risk of regional pipeline geohazard or individual pipeline geohazard is acceptable.
- Develop and implement risk mitigation in accordance with risk level.
- Repeat steps a), b), c) and d) above until pipeline risk reduced to acceptable level.

The PGMP shall be terminated when the pipeline is abandoned (out of service).

5 Risk identification

5.1 General

Pipeline geohazard risk identification is a primary stage of pipeline geohazard risk management and the foundation for carrying out risk assessment. It should meet the requirements of risk assessment in various pipeline phases. The technical recommendations for work in different phases are detailed in [Table 1](#).

Risk identification may be carried out through desktop data analysis ([5.3](#)), LiDAR and remote sensing imagery analysis ([5.4](#)) and field investigation ([5.5](#)).

For geologically sensitive areas or complicated geohazards, if desktop data analysis results, remote sensing imagery analysis, and data collected by non-intrusive field investigations do not provide enough information to meet the requirements of the risk assessment, appropriate intrusive geotechnical investigations ([5.6](#)) might need to be performed. In making this assessment, limitations of the data record should be considered.

The greatest reduction of construction related and long-term maintenance costs resulting from geohazards can be secured during the preliminary engineering and route selection phase. Project designers should undertake the following sequence of activities to implement this phase:

- As early as possible, consult with appropriate personnel familiar with the local geohazards to create a list of the types of credible geohazards that can be present along the proposed route. This will determine the types of geohazards to be considered during this phase. For instance, a pipeline built in the Arctic should consider permafrost as part of the suite of hazards, whereas there would be no need for such a consideration for a pipeline constructed in the tropics.
- Determine the width of the corridor for which the identification process should be conducted. This width can be variable, depending on the terrain and geohazards present. The corridor width should at a minimum be as wide as the routing corridor and should ideally be conducted to a distance equivalent to the distance from which hazards initiating outside of the proposed route(s) could affect the route, such as long run-out landslides. In this phase the corridor width for identification process might be in the order of 5 km to 10 km, depending on the nature of the geohazard: erosion and mining subsidence will have a very narrow evaluation corridor, whereas seismic and pyroclastic threats might have a much wider evaluation corridor. Debris flows (from steep mountainous streams) and landslides triggered in bedrock require a corridor width up to potential source, which is height of land, i.e. crest elevation.
- The efficiency of geohazard risk identification can be improved greatly by using high resolution remote sensing imagery, such as LiDAR, aerial photos and satellite images.

In the detailed design phase and construction phase:

- the corridor width for identification process may be in the order of 1 km to 2 km, depending on the identified geohazards,
- site-specific hazard investigations should be conducted for any high-risk hazards identified in the preliminary engineering and route selection phase or for any induced geohazards reported by construction departments,
- attention should be focused on high susceptibility zones identified in the route selection phase, and
- as appropriate for the specific project, consideration should be given to record formation lithology exposed during pipeline trench excavation.

In the operation and maintenance phase, the following apply:

- a) the corridor width for identification process might be in the order of 0,5 km to 1 km, depending on the specific geohazard threats;
- b) the following data shall be collected in addition to those specified in 5.3:
 - as-built data in the design and construction period;
 - data collected during the geohazard risk management in the design and construction period (if any);
 - data collected during the previous geohazard risk management (if any).
- c) geohazards along the entire pipeline system should be appropriately analyzed in terms of likelihood of occurrence and return period and, estimated and summarized in accordance with the previous risk management or risk assessment in the design and construction period.

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Table 1 — Technical recommendations for risk identification

Technical recommendations	Design and construction period		Operation period
	Preliminary engineering and route selection phase	Detailed design phase Construction phase	
Goal of risk identification	<ul style="list-style-type: none"> — Listing of geohazard types that might be present along route — Route alternatives to avoid geohazards (if possible) 	<p>Meet the risk assessment requirements in these phases</p> <ul style="list-style-type: none"> — Geohazards threatening the integrity of pipeline system — Geohazards induced by pipeline construction activities or potential areas where geohazards might be induced by pipeline construction activities — Geologically sensitive areas 	<p>Meet the risk assessment requirements in this phase</p> <ul style="list-style-type: none"> — Geohazards identified in the detailed design and construction period — Geohazards newly identified in the operation period — Geologically sensitive areas
Identification objects	<ul style="list-style-type: none"> — Severe geohazards — Geologically sensitive areas 	<ul style="list-style-type: none"> — Geohazards threatening the integrity of pipeline system — Geohazards induced by pipeline construction activities or potential areas where geohazards might be induced by pipeline construction activities — Geologically sensitive areas 	<ul style="list-style-type: none"> — Geohazards identified in the detailed design and construction period — Geohazards newly identified in the operation period — Geologically sensitive areas
Identification accuracy	<p>A scale of 1:10 000 to 1:50 000 is suggested during hazard identification for topographic map and remote sensing imagery. The scale should be as detailed as possible based on hazard types and source data.</p> <ul style="list-style-type: none"> — Data (maps, text) analysis — LiDAR — Remote sensing imagery (satellite images, air photos) analysis 	<p>The scale of imagery and mapping should be appropriate to the hazard being examined. The scale should be sufficient that the hazard can be fully identified and its geometry or boundaries can be accurately mapped.</p> <ul style="list-style-type: none"> — LiDAR — Remote sensing imagery (satellite images, air photos) analysis — Field investigation based on desktop data analysis — Geotechnical investigation, if necessary 	<p>The scale of imagery and mapping should be appropriate to the hazard being examined. The scale should be sufficient that the hazard can be fully identified and that its geometry or boundaries can be accurately mapped.</p> <ul style="list-style-type: none"> — Field investigation based on desktop data analysis — Remote sensing monitoring and identification — Geotechnical investigation if needed to support pipeline RoW stability and maintenance
Identification method	<ul style="list-style-type: none"> — Geotechnical desk data collection and studies — Geotechnical investigation, if necessary — Interviewing local residents and stakeholders 	<ul style="list-style-type: none"> — Geotechnical investigation, if necessary 	<ul style="list-style-type: none"> — ILI geometry tool assessment of pipeline performance — RoW monitoring and continuous surveillance through walks and identification after environmental events

Table 1 (continued)

Technical recommendations	Design and construction period		Operation period
	Preliminary engineering and route selection phase	Detailed design phase Construction phase	
Data collection	<ul style="list-style-type: none"> — LiDAR imagery — Maps, such as topographic map, hydrogeological map, geological structure map, and seismic ground motion parameter curves — Documents, such as geological data, policies and regulations, social and economic data and other related data — Other necessary documents and maps 	<ul style="list-style-type: none"> — LiDAR imagery — Maps — Remote sensing imagery — Results in previous phase — Materials related to geologically sensitive areas that cannot be avoided — Other necessary documents and maps 	<ul style="list-style-type: none"> — LiDAR imagery — Maps — Remote sensing imagery — As-built data in the detailed design and construction period — Other necessary documents and maps
Results	<ul style="list-style-type: none"> — Recommendations for pipeline route alternatives — Preliminarily sorted areas prone to geohazards and suspected geohazards — Recommendations for design and construction 	<ul style="list-style-type: none"> — Identification object records (refer to Annex B) 	<ul style="list-style-type: none"> — Identification object records (refer to Annex B)

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5.2 Geohazard inventory

A geohazard inventory shall be developed that lists all identified geohazards. This inventory shall be maintained throughout the life of the pipeline project.

It is recommended that a standard template be developed for populating the geohazard inventory. Ideally, the inventory would be computer based and linked to a GIS platform.

The information in the inventory should include the following^[23], as appropriate:

- geohazard name and unique identifier;
- geohazard location;
- geohazard process/type (e.g. landslide, land subsidence, sinkhole, erosion, scour, seismic, etc.);
- geohazards process rate;
- potential effects or impacts of geohazard on pipeline system;
- triggering mechanism of geohazard;
- controlling parameters (e.g. physiographic and topographic setting, climatic and environmental conditions, geological and geotechnical factors, geometry, etc.);
- contributing parameters or factors (e.g. secondary events that may influence the initiation or severity of a geohazard);
- relations and possible links to other geohazards;
- constraints on geohazard (e.g. spatial or physical factors that may limit initiation, extent or severity of a geohazard);
- identification criteria.

Actual data structure of the inventory, and included data fields, will be dependent on the asset, geohazard environment, and other project requirements.

5.3 Desktop data analysis

Sufficient data should be collected and analyzed to identify preliminary geological environmental conditions along the RoW, including regional geological background, geomorphology, formation lithology, geological structure, hydrometeorological conditions, and seismic conditions. Data may also be collected to estimate potential geohazard types along the RoW. Geohazard risk identification should be facilitated through the appropriate collection, organization, and review of data prepared by the project team and outside parties. Examples of outside parties that may have prepared data relevant to geohazard risk identification includes government agencies or academic institutions. Collected data should include, but are not limited to the following:

- data related to the pipeline and stations (e.g. pump station, compressor station, valve station), such as pipeline material and diameter, wall thickness, welding processes, and station functions;
- geological, hydrological and other related data, such as active faults, lateral and vertical scour values and similar information;
- LiDAR and remote sensing imagery or images collected by others (not collected specifically for the project, see 5.4);
- previous mapping conducted by others (typically government agencies or academic institutions), such as fault mapping, prior landslide mapping, hydrography datasets, known areas of subsidence and underground mining, probabilistic seismic hazard maps, soil mapping, and similar references;
- mineral resource distribution and mining right;

- socioeconomic environment;
- documents such as geohazard-related laws, regulations and plans formulated by governmental agencies;
- human activities (e.g. mining or road construction).

The absence of suitable geotechnical input and data might lead to an unbalanced expectation on the part of the pipeline designers, particularly the stress analysts, relative to soil resistance and stiffness values. In consideration of variety and complexity of soil-pipe interaction issues, the use of assumed, default or text-book values for stress analysis might be inappropriate. Reference [17] provides methods and suggestions for dealing with soil-pipe interaction issues. Knowledge gained from an appropriate level of geotechnical investigations (5.6) would identify some issues, provide suitable parameters for design and help identify suitable mitigation strategies for implementation in design, construction or operations.

5.4 LiDAR and remote sensing imagery analysis

The efficiency of geohazard risk identification can be improved greatly by collecting project specific LiDAR and remote sensing imagery, such as aerial photos and satellite images, especially in the preliminary engineering and route selection phase. These methods can be also employed selectively in the detailed design, construction, as well as operation and maintenance phase to provide greater refinement and identification of the aerial extent of the hazard.

5.5 Field investigation

5.5.1 Field investigation techniques

The following field investigation techniques individually or in combination with others might be useful/needed in carrying out PGMP:

- aerial reconnaissance of the route, and/or corridors to identify and assess geohazards;
- site-specific hazard investigations, which is detailed on-the-spot investigation by investigators for single specific or suspected geohazard, a small segment, or a land area/location requiring more investigation;
- geophysical surveys (e.g. ground penetrating radar, electromagnetic terrain conductivity, electrical resistivity imaging, seismic refraction/acoustic);
- intrusive investigations including trenching, test pits, boreholes and associated soil laboratory testing;
- instrumentation to monitor pipeline integrity and the characteristics of a geohazard, such as slope inclinometers for landslides, radar reflectors for landslides or land subsidence processes, deformation sensing, fibre optic sensing, elastic guided waves for pipe integrity. For more monitoring methods, see 7.2.1;
- other effective means, such as collecting and reviewing LiDAR.

5.5.2 Field investigation scope

Field investigation scope can encompass the entire pipeline system, partial segments, individual geohazards, geologically sensitive areas or other areas of concern.

5.5.3 Field investigation recommendations

For field investigation recommendations for risk identification, refer to [Annex B](#).

5.6 Geotechnical investigation

The purpose of geotechnical investigations is to document the detailed engineering and geological conditions of geohazards, thus providing the data necessary for risk assessment. Geotechnical investigations are necessary to supplement desktop data analysis, remote sensing imagery analysis and field investigations.

6 Risk assessment

6.1 General

The objective of pipeline geohazard risk assessment is to assess the likelihood and consequence of pipeline failure due to geohazards, and to determine whether action is required to reduce the risk. This can include mitigation and remediation activities to reduce the occurrence or magnitude of hazardous events that might lead to pipeline failure, or to reduce the consequences following such events. A range of risk assessment methods are available, but the key elements are common across all approaches:

- a) Hazard identification, including the event magnitude and frequency ([Clause 5](#)).
- b) Likelihood of pipeline failure as a result of the hazard occurrence.
- c) Consequence analysis of failure of the pipeline.
- d) Risk estimation based on the combination of b) and c).
- e) Risk evaluation to establish the significance of the estimated risk.

As part of the risk assessment, consideration is taken of available mitigation and risk reduction options, including the cost of possible actions. The management of risk, including decisions on appropriate mitigation actions, is covered in [Clause 7](#).

Determination of the likelihood of pipeline failure as a result of a geohazard event is challenging. In some cases, the failure mechanism can be simulated in structural models but requires representative input parameters to be defined such as soil restraints and pipeline strain behaviour. Frequently, qualitative judgements of pipeline failure are based on an expected magnitude of ground displacement.

Consequence analysis considers a range of possible failure modes, such as pipeline loss of containment, the likely behaviour of the product following failure and the effect it would have on the environment. The assessment to estimate a hazard zone can be performed in detail if pipeline operational data is available, using outflow and dispersion modelling and thermal radiation calculations. Fields of consequence such as safety, environmental, economic and reputation are assessed.

The evaluation of risk involves assessing whether the combination of the probability of pipeline failure and subsequent consequences are at an acceptable risk level. An acceptable risk level might be determined by regulation or by the operator, using industry standards or best practices, such as a risk matrix.

Risk assessment shall be carried out on the basis of risk identification, and it is a basis for risk mitigation. Depending on circumstances, it should be implemented at two levels: first considering regional pipeline geohazard susceptibility assessment ([6.3](#)) and second considering individual pipeline geohazard risk assessment ([6.4](#)).

6.2 Assessment systems and methods

6.2.1 Assessment systems

A PGMP should adopt a suitable assessment system(s) for assessing or calculating risk from geohazards. Assessment systems can be broadly broken into qualitative, semi-quantitative, and quantitative methods.

The determination of the types and methods of assessment systems are critically important components of an effective geohazard management because the assessment system informs the type of data collection and methods implemented during the identification and evaluation processes and ultimately, the response to known and potential geohazards. Prior to beginning of the identification and evaluation processes, an assessment system should be determined.

Operators or third parties performing a PGMP should consider the following when choosing and implementing an assessment system:

- The type of geohazards likely to be present along the pipeline route(s). As appropriate, separate assessment systems may be implemented for each hazard type (i.e. separate systems for landslides, hydrotechnical hazards, subsidence, etc.).
- The local geologic conditions present along the pipeline route should be considered. An assessment system appropriate for one area might be inappropriate for another. Operators with pipelines that span multiple geologic environments might need to have multiple assessment systems to account for these local variations, even for a single geohazard type.
- The types of data that can realistically be collected during the identification and evaluation processes. Assessment systems should not be based on data collection where collection of these data is difficult or unlikely in the course of pipeline design or operation.
- The state of the practice for each hazard type in terms of deciding whether to use qualitative, semi-quantitative, or quantitative assessment systems. For some hazard types, the state of the science has not progressed to the point where quantitative assessments or even semi-quantitative assessments can be performed. It is important to clearly understand the limitations of the current state of practice before implementing an assessment system. Attempting to implement a semi-quantitative or quantitative system with incomplete data or incomplete understanding of hazard mechanisms can produce spurious results less reliable than a well-documented and rigorous qualitative assessment.
- The types of mitigation and monitoring options available. If there are few options, then a relatively simple assessment system is sufficient. Conversely, if many response options can be implemented, then the assessment system shall be complex enough to accommodate these multiple options.
- The pipeline characteristics, such as diameter, grade, material, product, wall thickness, coating type and welding method(s), depth of cover, age, and operating history.
- The consequence resulting from pipeline impacts on the environment and pipeline operation.

6.2.2 Assessment methods

Methods to assess risk are classified as qualitative, semi-quantitative and quantitative (see [Table 2](#)). The appropriate assessment method should be selected for different pipeline phases and work requirements.

It is recognized that there are sometimes differences in the definition of terms used between the approaches, particularly for scoring schemes in qualitative methods and estimates of event probability in semi-quantitative schemes.

It is desirable to have uniformity in terminology and definitions used in the assessment of geohazard risk. This minimizes problems in the comparison of studies between different practitioners particularly within the same environment or at the same location.

Table 2 — Description of geohazard risk assessment methods

Method	Scope	Advantages	Disadvantages
Qualitative	Hazard probability and consequences expressed in qualitative terms. Risk normally assigned to classes in matrix format.	Based on observation, experience and inference. Enables a basic comparison of different levels of risk.	The method is subjective. Expert judgment is required to execute assessments and reduce inconsistency between comparisons.
Semi-quantitative	Numerical estimates of the relative significance of the key parameters that control the geohazard mechanism and assigning weighting factors. Threat and consequence classes are similar to a qualitative matrix but with numerical ranges.	Less subjective than qualitative methods. Systematic classification of key factors for simple and rapid evaluation of the geohazard. Provides screening and prioritisation of risk. Can be adapted to suit GIS data collection and processing methods.	Typically applies to specific regions and not easily transferable across diverse geographic or geological environments. Expert judgement is required to ensure consistency between assessments.
Quantitative	Engineering and statistical models are used to quantify the likelihood and consequence of an event.	Perceived as objective and facilitating rigorous comparison of relative risk. Robust approach to reduce uncertainty and increase confidence in assessment results for decision making.	Very demanding in terms of data definition and analysis. The significance or weakness of the assumptions in the mechanism or data might be unclear or concealed within the analysis. Some hazard types cannot be effectively quantified using existing technology/science given the timelines and constraints of pipeline projects.

An example of a qualitative method is provided in [Annex D](#) and an example of a semi-quantitative method is provided in [Annex E](#).

There is no single recommended method to assess geohazard risk. Selection of the appropriate method will depend on the level of quantification necessary to define acceptable risk and the level of detailed information available. The following factors should be considered when selecting the most appropriate method:

- a) Definition of the purpose of the risk assessment, in terms of the significance of the decisions that need to be made based on the outcome.
- b) The scope of the assessment should be based on
 - the nature of the hazard or hazards, (e.g. the method for landslides will differ from the method for river crossings),
 - the geographical area, (e.g. the size of the study area and the variation in geology or topography may require different approaches), and
 - the time period (e.g. a single hazard event or the exposure during the service life).
- c) The resources and time available for the assessment which have an influence on the scope.
- d) The available historical data or planned investigations to support the assessment.
- e) The stage of the project (e.g. conceptual, route selection, detailed design, construction, operation).
- f) The elements exposed to adverse effects of pipeline failure (e.g. people, property environment).
- g) The nature of the uncertainties involved.
- h) The assumptions in the assessment.

Assessment of risk due to geohazards typically concentrates on the identification of hazards and likelihood of pipeline failure; this is particularly common during pipeline design. Therefore, qualitative or semi-quantitative methods are often used, due to the available data and time constraints. The consequence analysis using these methods would typically apply approaches to grade the consequence level of pipeline failures as presented in [Table D.3](#) and [Table E.2](#), for qualitative or semi-quantitative methods, respectively.

The maturity, effectiveness and viability of quantitative assessment methods employed should be fully considered when used. ASME B31.8S provides examples of data sets that should be collected for each segment and reviewed before a risk assessment is conducted. Where the data is missing, conservative assumptions may be used to perform the risk assessment. Examples of data may include, but are not limited to the following:

- pipe jointing method (e.g. mechanical coupling, acetylene weld, arc weld);
- topography and soil conditions (e.g. unstable slopes, water crossings, water proximity, soil liquefaction susceptibility);
- active faults (e.g. location and type, magnitude, displacement, return period);
- profile of ground acceleration near fault zones (e.g. greater than 0,20 *g* acceleration);
- soil characteristics (e.g. stratigraphy, seasonal frost depth, groundwater);
- year of installation;
- pipe grade, diameter, and wall thickness [internal stress calculation added to external loading; total stress not to exceed 100 % Specified Minimum Yield Strength (SMYS)].

Guidance and details of assessment methods are provided in References [\[7\]](#), [\[11\]](#), [\[13\]](#), [\[14\]](#), [\[15\]](#), [\[22\]](#), [\[24\]](#) and [\[25\]](#).

6.3 Assessment for regional pipeline geohazard susceptibility

Regional pipeline geohazard susceptibility zones may be used when considering a very long pipeline that traverses many different terrain and physiological provinces. Within these zones, similar geohazards might be present and exhibit common characteristics. The susceptibility can be divided into three levels (high, moderate and low susceptibility zones), based on the complexity of geological environmental conditions and threats of individual geohazards and they can be further subdivided as necessary. The zoning principles are shown in [Table 3](#).

Table 3 — Zoning principles for regional pipeline geohazard susceptibility

Susceptibility level	Description
High susceptibility zone	Geological environmental conditions are complex, and numerous individual geohazards which greatly affect the pipeline will happen throughout its life cycle
Moderate susceptibility zone	Geological environmental conditions are intermediate, and individual geohazards which greatly affect the pipeline might happen throughout its life cycle
Low susceptibility zone	Geological environmental conditions are simple, and individual geohazards which greatly affect the pipeline are unlikely to happen throughout its life cycle
NOTE For the suggested division for complexity of geological environmental conditions, refer to Annex C .	

6.4 Assessment for individual pipeline geohazard

The operator shall develop a geohazard risk classification system consistent with the operator’s risk matrix or other risk management tools. Risk can be separated into four categories, as shown in [Table 4](#). [Table 4](#) is given as an example. The operator shall create risk levels appropriate to their PGMP.

Table 4 — Example rating categories for individual geohazard risks

Risk level	Risk description
Very high	Unacceptable risk, which shall be reduced immediately
High	Unacceptable risk, which shall be reduced within a limited time
Moderate	Conditionally acceptable risk, shall maintain active monitoring and assessment
Low	Acceptable risk, should maintain awareness

7 Risk mitigation

7.1 General

Reasonably practicable pipeline geohazard risk mitigation should be applied until the estimated risk is reduced to an acceptable level.

Methods selected for mitigation of geohazards should be decided in conjunction with the geohazard SMEs, pipeline designers, construction experts, and operational personnel and should be implemented using the following key principles:

- Prior to the implementation of a mitigation measure, the hazard characteristics, including boundaries, movement rate, depth, and mechanism should be clearly understood. The mitigation measure selected shall address the actual characteristics of the hazard. This information should be collected during the evaluation phase.
- The method selected shall be site and hazard specific.
- The method selected shall be appropriate for the location, time of implementation, terrain conditions, and shall consider equipment availability, accessibility, and other considerations that might make methods appropriate in one area inappropriate in others.
- Mitigation measures that require frequent maintenance or follow-up should be avoided in difficult access areas.

To the extent possible, mitigation should be applied during the construction phase. The cost and ease of implementation of mitigation are typically much less during construction than during operation.

Options to implement mitigation during the operation and maintenance phase can be more limited than during the construction phase because of access restrictions and difficulty in transporting heavy or specialized equipment to remote locations. Planning should account for the relative ease or difficulty in transporting equipment to an area requiring mitigation.

7.2 Mitigations

7.2.1 Physical and procedural mitigations

From a mitigation objectives oriented perspective, the pipeline might be protected from geohazards by a combination of physical and procedural mitigations at the location of each identified geohazards. Examples of potential physical and procedural mitigations are shown in [Annex F](#).

- Physical mitigations applied shall be demonstrated to protect the RoW and/or pipeline from the specified geohazards. The purpose of physical mitigations is to prevent failure resulting from an identified geohazard by either physically preventing contact with the pipe, or by providing adequate resistance to penetration in the pipe itself. Typical physical mitigations include strengthening or protection for pipe body, geohazard prevention, trenchless installation, avoidance or route change, etc. Examples of physical mitigation measures are included in [Table F.1](#).
- Procedural mitigations shall be demonstrated to be effective in reducing the frequency of the geohazards. The purpose of procedural mitigations is to minimize the likelihood of geohazards

damaging a pipeline without the knowledge of the operator. An additional purpose of procedural mitigation is to make sure that staff, contractors, and third parties are aware of both the geohazard and the pipeline to reduce the potential for inadvertent damage to the pipeline. Typical procedural mitigations include, among others, patrol inspection (F.2.1), awareness (F.2.2), earthworks management (F.2.3), monitoring (F.2.4).

NOTE More information can be found in AS 2885.1.

It is worth noting that the application of monitoring can effectively reduce the cost of mitigation under certain circumstances. For example, for systems where there are many potential hazards with uncertainty as to which ones will occur during the lifetime of the pipeline, application of a monitoring program (followed by as-needed mitigation) is typically a more cost-effective method to reduce risk than mitigation of all of the potential hazards. Examples of monitoring methods are shown in Table F.3.

Geohazard risk mitigation should be conducted in accordance with Table 5. The mitigation response should be proportional to the risk level and the potential effects experienced by the pipeline. A loss of containment event (pipeline failure) should elicit the greatest response.

7.2.2 Short-term and long-term mitigation measures

Physical mitigation can be further broken into two major categories:

- Short-term mitigation measures designed to reduce the risk to a pipeline or RoW associated with the geohazards, but not entirely eliminate the risk from the geohazards. An example of a short-term mitigation measure is conducting an excavation of the affected pipeline section to relieve strain accumulation in the pipe.
- Long-term mitigation measures designed to effectively (if properly conducted) eliminate the geohazard as a threat, such as geotechnically stabilizing an unstable hillside.

The method selected should be clearly identified as having a short-term mitigation objective or a long-term mitigation objective.

If a short-term mitigation measure is applied, a process shall be prepared to monitor the geohazards and to identify the conditions for when additional mitigation is needed.

If a long-term mitigation measure is applied, a process shall be prepared to confirm that the long-term mitigation measure is working, and if it is not, to take appropriate corrective action.

The application of mitigation should be based on the operator/pipeline specific classification system.

Table 5 is given as an example. The operator shall create risk levels, appropriate to their PGMP.

Table 5 — Principles for geohazard risk mitigation

Risk level of individual geohazards	Principles	Possible mitigation actions
Very high	<ul style="list-style-type: none"> — Geohazard risk is unacceptably high and there might be little time prior to pipeline distress. Appropriate actions need to be implemented as soon as possible. 	<ul style="list-style-type: none"> — As soon as possible conduct physical or procedural mitigation to either address the geohazard(s), the vulnerability of the pipeline(s) to the geohazard, or the consequences of pipeline failure to reduce risk to moderate or lower, as defined in Table 4. — Measures to address the geohazard(s) could include measures such as slope stabilization, bank armouring, or reguarding. — Measures to address pipeline vulnerability could include measures such as increasing wall thickness and adjusting weld procedures to increase pipeline resilience. — Measures to reduce consequences could include reducing pressure or removing product from the pipeline or evacuating vulnerable populations.
High	<ul style="list-style-type: none"> — Geohazard risk is unacceptably high, but there is time to plan and implement a suitable response prior to pipeline distress. 	<ul style="list-style-type: none"> — Plan and implement physical or procedural mitigation to either address the vulnerability of the pipeline(s) to the geohazard, or the consequences of pipeline failure to reduce risk to moderate or lower, as defined in Table 4. <p>Example measures are described above for “Very high”.</p>
Moderate	<ul style="list-style-type: none"> — Geohazard risk is currently low, but there is a reasonable potential for it to worsen with time. A plan should be implemented to manage the hazard if it worsens. 	<ul style="list-style-type: none"> — Plan and implement physical or procedural mitigations to pre-emptively manage the hazard as described above for “High” and “Very high” or develop a risk management plan to monitor and respond appropriately to the hazard if it worsens.
Low	<ul style="list-style-type: none"> — Geohazard risk is low and unlikely to worsen significantly. However, because there is a potential for worsening, a plan should be implemented to continually re-evaluate the hazard. 	<ul style="list-style-type: none"> — Formulate a risk management plan to monitor and re-evaluate the hazard on an appropriate timescale (determined by the hazard type and characteristics). The plan should include steps to implement if the hazard worsens and risk level increases.

8 Techniques and methods for geohazard risk management

Techniques and methods used in pipeline geohazard risk management should be considered with respect to the technical feasibility, availability, economics, safety and other aspects, from which optimal ones shall be selected. [Table 6](#) gives examples of techniques and methods appropriate for various phases of the lifecycle of a pipeline.

Table 6 — Techniques and methods for geohazard risk management

Phase	Techniques and methods	Design and construction period				Operation period Operation and maintenance phase
		Preliminary engineering and route selection phase	Detailed design phase	Construction phase		
Risk identification	Desktop data analysis (5.3)	●	●	●	●	
	LIDAR and remote sensing imagery analysis (5.4)	●	●	●	●	
	Aerial reconnaissance	●	●	●	●	
	Site-specific hazard investigations	◐	●	●	●	
	Geophysical surveys	◐	◐	◐	◐	
	Intrusive investigations	◐	●	●	●	
Risk assessment	Monitoring	◐	◐	◐	◐	
	Geotechnical investigation (5.6)	◐	●	●	●	
	Qualitative assessment (refer to Annex D)	●	●	●	●	
Risk assessment	Semi-quantitative assessment (refer to Annex E)	●	●	◐	●	
	Quantitative assessment	◐	◐	◐	◐	

Table 6 (continued)

Phase	Techniques and methods	Design and construction period				Operation period
		Preliminary engineering and route selection phase	Detailed design phase	Construction phase	Operation and maintenance phase	
Risk mitigation	Pipe body strengthening and protection					
	Geohazard prevention					
	Trenchless installation				/	
Risk mitigation	Avoidance or route change					
	Patrol inspection	/	/	/		
	Awareness	/	/	/		
Risk mitigation	Procedural risk mitigations	/	/			
	Earthworks management	/	/			
	Monitoring					
Key means that the item is appropriate means that the item may be used selectively or if technical and economic conditions permit means that the item is not likely appropriate or is unnecessary / means that the item is not applicable						

9 Data management

A PGMP should maintain a database(s) including suitable GIS(s) to organize and manage geohazard data collected as part of the program. It is recommended that a standard template(s) be developed for populating the databases. It is also recommended that these databases be maintained for the life of the pipeline, with appropriate updates to keep the databases functioning as technology changes.

The database(s) should, at a minimum, contain the following elements for each identified geohazard:

- the geohazard inventory information listed in [5.2](#);
- the classification or risk score resulting from the application of the assessment system;
- the dates of identification and evaluation;
- the types of mitigation and monitoring conducted for the hazard (if applicable);
- the intervals at which hazard-specific monitoring is conducted (if applicable);
- links to or summaries of the details of mitigation conducted for the hazard (if applicable);
- links to or summaries of monitoring conducted for the hazard (if applicable);
- links to photographs, emails, reports, and other pertinent information concerning the hazard.

The database(s) should also contain the following information for each area managed by the PGMP (not hazard specific):

- a) the date of prior assessments (i.e. identification and evaluation processes);
- b) the area covered by these assessments (length along pipeline system and corridor width);
- c) hazards considered under these assessments;
- d) the intervals at which non-hazard specific monitoring is conducted (such as ILI or remote sensing);
- e) if the operator has multiple assessment systems for a given hazard type, the assessment system(s) utilized;
- f) the scheduled date of the next reassessment.

Annex A (informative)

Guidelines for pipeline route selection

During pipeline route selection, the provisions of ISO 13623 should be followed, and the impact of geohazards should also be fully considered. The following lists some recommendations for pipeline route selection:

- a) Landslide masses, unstable slopes, rock fall areas and flow region of debris flow should be avoided when pipelines cross mountainous terrain areas and sharply undulating areas.
- b) When soil-fill placement and excavation are required for laying pipeline on a sloping area, the new slope should meet the requirements for slope stability; otherwise, risk mitigation design should be conducted. Pipelines should be installed in undisturbed ground, not in fill soils.
- c) Pipelines crossing through a seismic fault zone or active fault should be avoided whenever possible; otherwise, risk mitigation design should be conducted.
- d) Pipelines should be laid in valley regions except adjacent to terrain susceptible to flooding or water inundation.
- e) River crossings can have a significant effect on both the cost of a pipeline and the total length of the pipeline. See Reference [16] for basic rules of route selection at river crossings, and it's worth noting the following:
 - 1) Many jurisdictions require that pipelines that cross water crossing be installed by trenchless methods except where geological conditions preclude trenchless methods.
 - 2) It is essential to find the most suitable riverbed. Bedrock requires expensive blasting while very silty river beds can require large excavations.
 - 3) Trenched pipelines should normally cross rivers at right angles to minimize the width of the crossing and to avoid cross slopes on the approaches.
 - 4) Active bank erosion can lead to exposure and damage of the pipeline as well as impacting the environment.
 - 5) Fast-flowing sections of the river should be avoided as they can make construction difficult.
 - 6) The crossing should be located in a straight section of the river to reduce active bank erosion.
 - 7) As for river-crossing segments, in addition to the natural erosion of the river, possible riverbed changes caused by human activities and other factors during pipeline operation also need to be considered. Assessment of historical river channel patterns and future channel migration should be considered.
- f) In permafrost terrain, the pipeline route should avoid, to the extent possible, areas containing ice wedges, ice mound areas as well as sloping areas containing ice-rich soil.
- g) Land subsidence or uplift areas, ground deformation edges, as well as a certain range outside the edge should be avoided as much as possible when pipelines need to be buried underground when crossing land subsidence areas and collapsible soil areas.
- h) Stakeholders for water conservancy, agriculture, fishery, mining and other human activities within the proposed pipeline routing corridor should be consulted to provide suggestions for pipeline route selection.

For more recommendations on pipeline route selection, refer to References [1], [4], [8] and [24].

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Annex B (informative)

Field investigation recommendations

B.1 Geohazard information to ascertain and record

B.1.1 The following information about geohazard-affected areas, including, but not limited to, the following should be collected and recorded:

- pipeline route and construction method;
- pipe trench backfill soil properties;
- spatial relationships of pipeline and geohazards;
- geological characteristics and geotechnical properties of the hazard;
- sensitivity of hazard to rainfall, rainfall conditions and surface infiltration conditions;
- sensitivity of hazard to earthquake ground shaking;
- current evidence of deformation and forecasted development trends of hazard;
- the possibility of inducing secondary geohazards;
- other necessary information.

B.1.2 The following information should also be ascertained and recorded during early stages of the project, such as during preliminary engineering and route selection phase:

- existing oil and gas pipelines in or near the proposed RoW;
- buried municipal utilities, communication cables and service cables in the proposed RoW;
- buried historical relics and underground tunnels or workings, or shafts/wells near the RoW;
- research on the impact of the hazard to the pipeline; assessing the possible form and degree of impact to the pipeline and RoW;
- significance or potential impact of climate change.

B.1.3 The following information should also be ascertained and recorded during field investigations of geohazards in the pipeline operation period:

- occurrence of a geohazard event and its effect on the pipeline and/or RoW; assess form and degree of pipeline impact and ancillary facilities;
- value and success of adopted monitoring measures and hazard prevention/mitigation measures (including their type, status, effects and the capability to continue functioning);
- current and future human activities near the pipeline, as well as their possible impacts on hazards or the pipeline.

NOTE Reference [24] provides a comprehensive list of geohazards where the phenomenon and associated effects are described. Users can refer to Reference [24] for more information to ascertain and record.

B.2 Imagery, photos and drawings

B.2.1 Film or record any geohazards of field investigations. Prepare plan or profile of hazard when necessary.

B.2.2 The filming or recording date should be recorded, and the photo imagery should reflect the scope, form, any obvious deformation (if any), or associated human activity (if any). Written descriptions of the feature should be made to supplement the imagery.

B.2.3 The photo imagery of deformations of the hazard should embody specific reference information, such as geo-reference data.

B.2.4 LiDAR, aerial photographs, satellite (photographic, infrared, radar, etc.) imagery should also be obtained for the pipeline route corridor. Such imagery should be provided with full "meta-data" characteristics.

B.2.5 Plan or profile scale should be appropriate for the phase of the investigation.

B.2.6 Geohazard plan or profile drawings should, as a minimum, include the following:

- scale;
- pipeline route and direction;
- scope of geohazards;
- development trend of geohazards;
- deformation characteristics of geohazards;
- types of rock-soil masses and subsurface materials, as appropriate;
- any manmade or natural structure that may have impacts on the geohazard.

B.2.7 For active faults, relevant parameters may include those that can represent its damage capability and trends, such as historical activities, seismic peak ground acceleration and fault movement rate and size, should be recorded in accordance with collected data, historical statistics or existing monitoring results.

Annex C (informative)

Example of classification of geological environmental conditions by complexity level

Table C.1 gives an example of a complexity classification method for geological environmental conditions for a regional context as a qualitative geohazard assessment. The list of conditions provided in Table C.1 is not exhaustive but is intended to illustrate the process of selecting and defining the ratings for different conditions that may be present along a pipeline corridor. For example, a single aquifer, if artesian, could constitute a higher complexity than multiple aquifers that are not artesian. The classifications are appropriate for use in a qualitative geohazard assessment. The conditions and criteria in Table C.1 might be adapted for each pipeline project but specific criteria should be developed with consideration of location, susceptibility, and other appropriate factors.

The complexity level should be assigned based on the existence of a single condition, rather than the presence of all conditions.

Table C.1 — Example of regional complexity classification of geological environmental conditions

Conditions	Complexity level		
	High	Medium	Simple
Regional geological background	<ul style="list-style-type: none"> — Complex regional geological structure; — With active faults nearby; — Seismic peak ground acceleration exceeds 0,20 g for a return period of 475 years 	<ul style="list-style-type: none"> — Complex regional geological structure; — With active faults nearby; — Seismic peak ground acceleration 0,10 g to 0,20 g for a return period of 475 years 	<ul style="list-style-type: none"> — Simple regional geological structure; — No active fault nearby; — Seismic peak ground acceleration less than 0,10 g for a return period of 475 years
Geomorphology	<ul style="list-style-type: none"> — Complex geomorphology; — Relative height difference exceeds 200 m; — Surface slope is dominantly more than 25°; — Multiple geomorphology types 	<ul style="list-style-type: none"> — Simple geomorphology; — Relative height difference 50 m to 200 m; — Surface slope is mainly 8° to 25°; — Single geomorphology type 	<ul style="list-style-type: none"> — Simple geomorphology; — Relative height difference less than 50 m; — Surface slope less than 8°; — Single geomorphology type
Formation lithology	<ul style="list-style-type: none"> — Complex and diverse formation lithology; — Complex rock-soil structure, widespread presence of problematic soil or terrain conditions (e.g. permafrost, dispersive soils); — Poor engineering geological properties 	<ul style="list-style-type: none"> — Large relative changes in lithology and lithofacies; — Complex rock-soil structure, limited presence of problematic soil or terrain conditions; — Poor engineering geological properties 	<ul style="list-style-type: none"> — Small changes in lithology and lithofacies; — Simple rock-soil structure, absence or infrequent presence of problematic soil or terrain conditions; — Good engineering geological properties

Table C.1 (continued)

Conditions	Complexity level		
	High	Medium	Simple
Geological structure	<ul style="list-style-type: none"> — Complex geological structure; — Folds and faults developed; — Broken rock mass 	<ul style="list-style-type: none"> — Relatively complex geological structure; — With folds and faults; — Relatively broken rock mass 	<ul style="list-style-type: none"> — Relatively simple geological structure; — No fold or fracture
Hydrogeology	<ul style="list-style-type: none"> — Multiple aquifers; — Annual water level change in excess of 20 m; — Poor hydrogeological conditions 	<ul style="list-style-type: none"> — 2 to 3 aquifers; — Annual water level change 5 m to 20 m; — Relatively poor hydrogeological conditions 	<ul style="list-style-type: none"> — A single aquifer; — Annual water level change less than 5 m; — Good hydrogeological conditions
Impacts of human activities on geological environment	<ul style="list-style-type: none"> — Intense human activities, that have severe impacts on and cause severe destruction to geological environment 	<ul style="list-style-type: none"> — Relatively intense human activities, that have relatively severe impacts on and cause relatively severe destruction to geological environment 	<ul style="list-style-type: none"> — General human activities, that have small impacts on and cause small destruction to geological environment

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Annex D (informative)

Example qualitative assessment method

D.1 General

The examples provided are not intended to be reflective of the criteria that should be applied to all situations. Specific criteria should be developed with consideration of location, susceptibility, and other appropriate factors. Some of the factors that influence selected geohazards are provided in [Annex G](#).

D.2 Geohazard susceptibility grade

[Table D.1](#) gives a grading method for geohazard susceptibility for selected hazards. The listing of geohazards is not exhaustive but is intended to illustrate the process for assessing and assigning a level of susceptibility. For example, low angle slopes in certain geologies might pose a greater threat to a pipeline than other geological materials at a higher slope angle. Users can develop similar grading systems for all applicable geohazards associated with their pipeline project.

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Table D.1 — Geohazard susceptibility grade for selected hazards

Hazard type	Level	Grading basis
Landslide	High	<ul style="list-style-type: none"> — Toe of landslide is exposed and the slope is steep. It is often eroded by surface runoff and has a retrogressive trend. There is seasonal spring water and the rock-soil mass is very wet and waterlogged; — Average gradient of the slope exceeds 40°, many new developing fissures occur on the slope. There are new signs of deformation of the above ground appurtenances and vegetation; — There are fissure/tension cracks and/or other obvious signs of displacement of the landslide. The head shows continuous fissures. There are grabens, sag ponds and other terrain features indicative of mass slope movement.
	Medium	<ul style="list-style-type: none"> — Toe of landslide is in the air exposed. There is discontinuous seasonal surface runoff and the rock-soil mass is wet or may be saturated seasonally. The average gradient of slope is 30° to 45°; — Average gradient of slope is 25° to 40°, small fissure occurs partially on the slope. No new signs of deformation of above ground appurtenances and vegetation; — There are less obvious signs of displacement of the landslide. Tension cracks are present on a discontinuous basis.
	Low	<ul style="list-style-type: none"> — Slope at the toe of landslide is gentle and the elevation difference is low or well-drained. There is no surface runoff or any sign of continuous deformation. The rock-soil mass is dry; — Average gradient of slope is less than 25°, there are no developing fissures on the slope. There is no new sign of deformation of above ground appurtenances and vegetation; — There are no fissures/tension cracks or obvious signs of displacement of the landslide mass. Original fissure has already been filled.

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Table D.1 (continued)

Hazard type	Level	Grading basis
Rockfall	High	<ul style="list-style-type: none"> — There are many similar rockfalls nearby and most of them have already happened; — Many tensile fractures are growing in the upper rockfall mass. The main fracture surface is wide in its upper part and narrow in its lower part and the bottom inclines outward. Gravelly soil recently fell from fractures and crushing or breakage has occurred in the bottom rock mass; — There are obvious fissures in upper rockfall mass.
	Medium	<ul style="list-style-type: none"> — There are less similar rockfalls nearby and a few have already occurred; — A few horizontal fractures grow in upper rockfall mass. The main fracture surface is wide in upper part and narrow in lower part. Recently, gravelly soil fell from the fractures. Upper fractures are filled with soil and weeds grow there.
	Low	<ul style="list-style-type: none"> — There are similar rockfalls nearby, but none has occurred; — Rockfall fracture surface is upright. There is no gravelly soil falling from fractures. Upper fractures are filled with soil and shrubs are flourishing there; — There is no new fracture in upper rockfall mass.
Debris flow	High	<ul style="list-style-type: none"> — Longitudinal slope is large in the middle-upper reaches of the main gully and main branches. Loose materials are abundant and water flow is obstructed; — Region is susceptible to sudden and heavy rainfall.
	Medium	<ul style="list-style-type: none"> — Longitudinal slope is relatively large in the middle-upper reaches of main gully and main branches. Loose materials are abundant and water flow is basically unobstructed, with potential periods of moderate rainfall.
	Low	<ul style="list-style-type: none"> — Longitudinal slope is small in the middle-upper reaches of main gully and main branches. Loose materials are scarce and water flow is unobstructed, with little rainfall.

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Table D.1 (continued)

Hazard type	Level	Grading basis
Land subsidence	High	<ul style="list-style-type: none"> — Soils are known to be susceptible to collapse or are dispersive; — The surface shows significant settlement or collapse; — Surface shows a clear continuous fissure; — For karst collapse, limestone or dolomitic bedrock is present, with seasonally fluctuating groundwater levels that change greatly and the overlying unconsolidated formation thickness is less than 30 m; — Groundwater pumping volumes exceeds natural replenishment level; — Above ground structures show obvious deformation or destruction.
	Medium	<ul style="list-style-type: none"> — Surface shows slight settlement or collapse; — Surface shows a slight fissure; — Surface shows sporadic collapse pits; — For karst collapse, limestone or dolomitic bedrock is present, with small seasonal variations in underground groundwater levels that does not change much and the overlying unconsolidated formation thickness is 30 m to 80 m; — Groundwater pumping is basically balanced with natural replenishment level; — Above ground structures show slight deformation or destruction.
	Low	<ul style="list-style-type: none"> — Surface shows no deformation or ground fracture; — For karst collapse, limestone or dolomitic bedrock is not present, or if present then groundwater levels change slightly and the overlying unconsolidated formation thickness is larger than 80 m; — There is no groundwater withdraw or the amount of groundwater extraction is small.

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Table D.1 (continued)

Hazard type	Level	Grading basis
Bank erosion/channel avulsion	High	<ul style="list-style-type: none"> — Active riverbed undercutting, stream bank collapse or channel avulsion. Riverbed undercutting depth exceeds 1,0 m and stream banks show continuous signs of collapse; — Stream banks show obvious slump blocks; — A large number of block stones (poor roundness) were stacked in stream channel and many block stones have a diameter of more than 50 cm. — Region is susceptible to heavy rainfalls and watercourse has a history of flooding, overtopping and/or channel migration.
	Medium	<ul style="list-style-type: none"> — Recent, riverbed undercutting, stream bank collapse or channel avulsion has occurred. Riverbed undercutting depth is less than 1,0 m and the collapse along the stream banks is discontinuous and the scale is small; — Stream channel shows signs of slump block development; — There are slump blocks stacked in stream channel, but the number is small.
	Low	<ul style="list-style-type: none"> — Recent, there was no riverbed undercutting, stream bank collapse or channel avulsion; — Stream channel shows no signs of erosion.

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Table D.1 (continued)

Hazard type	Level	Grading basis
Surface and backfill erosion	High	<ul style="list-style-type: none"> — Soils comprise silts (loam) and fine-grained sands. Slope surface comprises exposed soil; lack of vegetation; — Slope gradient is steep (greater than 25°); — Water and soil loss of the slope surface was serious recently. Slope surface shows large erosion gullies, and vegetation is rare; — There was an obvious geomorphology change within 1 year; — Above ground facilities recently showed obvious signs of deformation or destruction.
	Medium	<ul style="list-style-type: none"> — Soils comprise fine-grained soils (silts and clays). Slope surface has partial vegetation cover; — Slope gradient is moderate (10° to 25°); — Recent, there was water and soil loss of the slope. Slope shows small erosion gullies and vegetation is abundant; — There is no obvious geomorphology change within 1 year.
	Low	<ul style="list-style-type: none"> — Soils comprise hard and compact clays, coarse sands or gravels, bedrock. Slope surface has full and dense vegetation cover; — Slope gradient is low (less than 10°); — Recent, there was no water and soil loss of slope; — There is no significant geomorphology change within 1 year; — Recently, the above ground appurtenances showed no obvious signs of deformation.

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Table D.1 (continued)

Hazard type	Level	Grading basis
Permafrost	High	<ul style="list-style-type: none"> — Pipeline is operating above freezing on a mean annual basis within continuous or discontinuous permafrost with ice-rich or thaw sensitive soils; — Pipeline is operating below freezing on a mean annual basis within discontinuous permafrost with frost susceptible soils and high groundwater table; — Pipeline traverses forested terrain with steep slopes in ice-rich permafrost.
	Medium	<ul style="list-style-type: none"> — Pipeline is operating above freezing on a mean annual basis within continuous or discontinuous permafrost with moderately ice-rich or thaw sensitive soils; — Pipeline is operating below freezing on a mean annual basis within discontinuous permafrost with moderately frost susceptible soils and high groundwater table, or frost susceptible soils and deeper groundwater table; — Pipeline traverses forested terrain with moderately steep slopes in ice-rich permafrost or steep slopes in moderately ice-rich permafrost.
	Low	<ul style="list-style-type: none"> — Pipeline is operating above freezing on a mean annual basis within continuous or discontinuous permafrost with ice-poor or non-thaw sensitive soils; — Pipeline is operating below freezing on a mean annual basis within discontinuous permafrost with non-frost susceptible soils and high groundwater table, or frost susceptible soils and deep groundwater table; — Pipeline traverses forested terrain with steep slopes in ice-poor permafrost or gentle slopes in moderately ice-rich permafrost.
Collapsible soil	High	<ul style="list-style-type: none"> — Surface recently showed significant sedimentation or collapse; — Surface subsidence features recently developed, forming a bead-shaped collapse pit or subsurface erosion cave; — Above ground facilities recently showed obvious deformation or destruction.
	Medium	<ul style="list-style-type: none"> — Surface recently showed general sedimentation or collapse; — Recent, there were collapse pits or holes but the scale is small; — Above ground appurtenances recently showed slight deformation or destruction.
	Low	<ul style="list-style-type: none"> — Surface recently showed slight sedimentation or collapse; — Surface recently showed no or sporadic collapse pits or holes; — Above ground facilities showed no deformation or destruction.

Table D.1 (continued)

Hazard type	Level	Grading basis
Seismic hazards	High	<ul style="list-style-type: none"> — Seismic peak ground acceleration exceeds 0,20 <i>g</i> for a return period of 475 years; — Data indicates that the seismic fault zone is highly active; — Soil liquefaction level is high.
	Medium	<ul style="list-style-type: none"> — Seismic peak ground acceleration is 0,10 <i>g</i> to 0,20 <i>g</i> for a return period of 475 years; — Soil liquefaction level is low.
	Low	<ul style="list-style-type: none"> — Seismic peak ground acceleration is less than 0,10 <i>g</i> for a return period of 475 years; — Data indicates that the seismic fault has not ruptured in more than 10 000 years; — No soil liquefaction.

D.3 Pipeline vulnerability grade

Table D.2 gives a grading method for pipeline vulnerability for selected hazards. The listing of hazards is not exhaustive but is intended to illustrate the process for assessing and assigning a vulnerability grade. Users can develop similar grading systems for all applicable geohazards associated with their pipeline project.

Table D.2 — Pipeline vulnerability grade

Level	Grading basis
High	<p>There is a significant threat to the pipeline or RoW, including pipeline rupture or breakage. Loss of containment or serious distortion might occur, causing product transportation interruption. This level of vulnerability might be confirmed under the following conditions:</p> <ul style="list-style-type: none"> — In the landslide; — In the directly impacted area of rockfall; — In the debris flow region, leading to pipeline exposure and physical impact by debris; — Due to land subsidence or other ground movement mechanisms such as thaw settlement or frost heave; — There might be pipeline suspension, buoyancy, water flow or stone impact in water courses; — Across the affected areas of the permafrost and collapsible soil or other similar soil; — Intersecting with the seismic fault zone and active fault or within 500 m in case of a parallel laying.

Table D.2 (continued)

Level	Grading basis
Medium	<p>There is relatively high threat to the pipeline, in the form of pipeline exposure, suspension, floating, deformation or damage. Minor loss of containment (pinhole leak) may occur. Repair and incident handling can be conducted without transportation interruption. The level can be confirmed under the following conditions:</p> <ul style="list-style-type: none"> — Pipeline located in affected areas of landslide and rockfall, or debris flow accumulation region; — Pipeline is exposed or the pipeline cover is severely reduced; — Pipeline is located in terrain susceptible to land subsidence or movement due to collapsible soils, thaw settlement or frost heave; — Pipeline route does not intersect seismic fault zone and active fault or beyond 500 m in case of parallel laying.
Low	<p>There is no obvious impact to pipeline or RoW. The possibility of hazard impact on pipeline safety is low.</p>

D.4 Pipeline failure consequence grade

Table D.3 provides a grading method for pipeline failure consequence.

Table D.3 — Pipeline failure consequence grade

Level	Grading basis
High	Significant impact or serious loss, examples include loss of containment, loss of service
Medium	Relatively great influence or ordinary loss, examples include severe damage to pipeline but no loss of containment, or reduced level of service
Low	No or few influence and loss, examples include slight damage to pipeline but no interruption or reduction in service, repairs made as part of scheduled maintenance

NOTE Other important influence or losses might include the following:

- life;
- towns and traffic nearby;
- environmental damage and issues, including fisheries, habitat or spawning areas, impacts on drinking water quality, soil quality and damage to vegetation and animals;
- economic or financial impact for clean-up and penalties;
- loss of profits, company reputation/corporate goodwill;
- loss of social licence;
- environmental fines and litigation, including legal costs;
- loss of future pipeline approvals by regulatory agencies;
- potential for increased regulatory standards and expectations;
- collateral damage to the public and other stakeholders/third parties.

D.5 Risk level grading

The risk level of the geohazard is assessed in accordance with the various combinations of geohazard susceptibility grade, pipeline vulnerability grade, and pipeline failure consequence grade. Geohazard risks fall into four levels. The grading criteria are shown in Table D.4.

Table D.4 — Risk level grading based on qualitative assessment

Risk level	Combination of each assessments
Very high	(high, high, high), (high, high, medium), (high, high, low), (high, medium, high), (medium, high, high)
High	(high, medium, medium), (high, medium, low), (medium, high, medium), (medium, high, low), (high, low, high), (high, low, medium), (medium, medium, high), (medium, medium, medium), (low, high, high), (low, high, medium)
Moderate	(high, low, low), (medium, medium, low), (low, high, low), (medium, low, high), (medium, low, medium), (low, medium, high), (low, medium, medium), (low, low, high)
Low	(low, medium, low), (medium, low, low), (low, low, medium), (low, low, low)
NOTE Contents in brackets from left to right indicate the geohazard susceptibility level, the pipeline vulnerability level and the pipeline failure consequence level successively.	

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Annex E (informative)

Example semi-quantitative assessment method

E.1 General

The examples provided are not intended to be reflective of the criteria that should be applied to all situations. Specific criteria should be developed with consideration of location, susceptibility, and other appropriate factors. Some of the factors that influence selected geohazards are provided in [Annex G](#).

E.2 Assessment procedure

Semi-quantitative assessment procedures for pipeline geohazard risk based on index scoring method are as follows:

- a) calculate the risk probability index [see [Formula \(E.2\)](#)];
- b) divide the risk probability into five levels (Very high, High, Medium, Low, Very low) in accordance with risk probability index;
- c) divide pipeline failure consequence into five grades (see [Table E.2](#)): A, B, C, D, E;
- d) determine individual pipeline geohazard risk in accordance with risk probability level and pipeline failure consequence grade. Risk matrix is recommended, as shown in [Table E.1](#). Clause [E.4](#) gives an assessment example of landslides for user reference.

Table E.1 — Risk matrix

Risk probability index and level	≥0,4 (≥0,2)	Very high	Very high	Very high	Very high	Very high	Very high
	0,2 to <0,4 (0,1 to <0,2)	High	High	High	High	High	Very high
	0,1 to <0,2 (0,05 to <0,1)	Medium	Moderate	Moderate	Moderate	High	High
	0,05 to <0,1 (0,01 to <0,5)	Low	Low	Low	Moderate	Moderate	Moderate
	<0,05 (<0,01)	Very low	Low	Low	Low	Low	Low
Risk matrix			A	B	C	D	E
			Pipeline failure consequence grade				
<p>The risk probability index has specific values. Different numerical intervals correspond to relevant risk probability level. This table shows the numerical intervals corresponding to recommended risk probability levels. However, in consideration of the regional differences, users need to judge whether the numerical intervals are appropriate for the specific project, or adjust the intervals to fit the specific project by taking into account the pipeline operation, local geohazard characteristics, relevant working experience of the operator and its acceptable level of geohazard risk into consideration. With an accumulation of application experience, the corresponding relation between the numerical intervals and levels will become more and more reasonable and accurate.</p> <p>NOTE 1 This table is based on SY/T 6828-2017, Table B.2.</p> <p>NOTE 2 In the risk probability index, values outside the brackets are suitable for landslides, rockfalls, debris flows, land subsidence, permafrost and seismic hazards. Values within the brackets are suitable for bank erosion/channel avulsion, surface and backfill erosion, collapsible soil or other similar soil. Other hazards can be individually assessed as to the appropriate risk probability index group.</p>							

E.3 Calculation method of risk probability index

E.3.1 The risk probability index may be calculated with [Formula \(E.1\)](#) [5]:

$$P(R) = H \times (1 - H') \times S \times V \times (1 - V') \tag{E.1}$$

where

- $P(R)$ is the risk probability index;
- H is the probability index of a hazard under natural conditions, value range of 0 to 1;
- H' is the probability index that hazard can be completely prevented by hazard mitigation measures adopted, with a value range of 0 to 1;
- S is the probability index that the hazard impacts the pipeline, with a value range of 0 to 1;
- V is the probability index of damage after an unprotected pipeline is affected by the hazard, with a value range of 0 to 1;
- V' is the probability index that pipeline damage can be completely prevented by a pipeline protection measure, with a value range of 0 to 1.

E.3.2 The assessment indicator system is as follows:

- a) Build five assessment indicator groups which correspond to H , H' , S , V and V' . Each assessment indicator group includes several assessment indicators;

- b) Set each assessment indicator weight w_i and value u_i ;
 c) Calculate $P(R)$ using [Formula \(E.2\)](#).

$$P(R) = \frac{\sum_{i=1}^{n_1} u_{1i} \times w_{1i}}{10} \times \left(1 - \frac{\sum_{i=1}^{n_2} u_{2i} \times w_{2i}}{10} \right) \times \frac{\sum_{i=1}^{n_3} u_{3i} \times w_{3i}}{10} \times \frac{\sum_{i=1}^{n_4} u_{4i} \times w_{4i}}{10} \times \left(1 - \frac{\sum_{i=1}^{n_5} u_{5i} \times w_{5i}}{10} \right) \quad (\text{E.2})$$

where

- n is the indicator number in each assessment indicator group, n_1 corresponds to H , n_2 corresponds to H' , n_3 corresponds to S , n_4 corresponds to V , n_5 corresponds to V' ;
 w_i is the weight of the i indicator in each assessment indicator group, w_{1i} corresponds to H , w_{2i} corresponds to H' , w_{3i} corresponds to S , w_{4i} corresponds to V , w_{5i} corresponds to V' ;
 u_i is the value of the i indicator in each assessment indicator group, u_{1i} corresponds to H , u_{2i} corresponds to H' , u_{3i} corresponds to S , u_{4i} corresponds to V , u_{5i} corresponds to V' .

NOTE 1 Weight w_i is the description for indicator importance. It is larger when the effect of the assessment indicator on the assessment result is more significant. The weight sum of all indicators in each assessment indicator group is 1,0.

NOTE 2 Value u_i is the description for the assessment indicator status, with a value range of 0 to 10. u_{1i} is higher when the possibility of a hazard is higher. u_{2i} is higher when the hazard mitigation effect is better. u_{3i} is higher when the possibility that a hazard affects the pipeline is higher. u_{4i} is higher when the possibility of damage to the pipeline is higher. u_{5i} is higher when the protection effect for the pipeline is higher.

NOTE 3 This document does not specify the indicator weight w_i , indicator status and the corresponding value u_i due to regional differences. The indicator weight w_i is determined in light of the pipeline operation, local geohazard characteristics and the relevant working experience of the operator. The indicator name, w_i , indicator status and u_i can be confirmed by experienced professionals. [Annex G](#) lists some key influencing factors of selected individual geohazards. Users can add, delete or directly use them as assessment indicators.

NOTE 4 [Formula \(E.1\)](#) and [\(E.2\)](#) are used for pipelines where mitigations are already in place by appropriate modification of V and V' .

E.4 Identify the pipeline failure consequence grade

Assessment of failure consequences is to take the safety, cost, environment, service interruption and reputation into consideration, see [Table E.2](#).

Table E.2 — Pipeline failure consequence grade, selected examples

Consequence categories	Increasing consequence				
	A	B	C	D	E
Safety	No or superficial injuries	Major injury, long term absence	1 to 2 Fatalities	3 to 9 Fatalities	>10 Fatalities
Cost (e.g. \$M)	<0,01	0,01 to 0,1	0,1 to 1	1 to 10	>10
Environment	Insignificant	Slight/Minor effect	Local effect	Major effect	Massive effect
Service Interruption	Insignificant	Major impact to service	Major impact to upstream/downstream company	Major national impact	Major international impact
Reputation	Insignificant	Local impact	Major regional impact	Major national impact	Major international impact

E.5 Example

E.5.1 Example description

Subclause E.4.1 considers the process of conducting a semi-quantitative risk assessment for a pipeline within terrain susceptible to landslide movements.

A steel gas pipeline is 1 016 mm in diameter, has a wall thickness of 17,5 mm, an internal pressure of 8,2 MPa, and a medium density of 53,1 kg/m³. The buried pipeline traverses a slope in a remote area with limited vehicle access. The affected length of the pipeline is 23 m and the burial depth to the top of the pipeline is 1,5 m. After a heavy rainfall, the pipeline patrol personnel found that there were several transverse cracks in the middle-upper part of the slope and there were fresh signs of soil collapse and slumping. After a field investigation, the technical personnel ascertained that the slope was unstable and was susceptible to a massive landslide movement, during which the pipeline would suffer a loss of containment with a major national impact on service interruption.

E.5.2 Risk probability index and level

Through field investigation, the landslide assessment indicator records are shown in [Table E.3](#). Note that for other landslides and other geohazard, the assessment index table should be adapted for site-specific use.

Table E.3 — Landslide assessment index records

SN	Key influencing factors/assessment indicators	Weight w_i	Indicator status	Value u_i	Check
H-1	Seismic effect	0,05	Seismic peak ground acceleration $\geq 0,20 g$	10	
			Seismic peak ground acceleration $0,10 g$ to $<0,20 g$	8	√
			Seismic peak ground acceleration $0,05 g$ to $<0,10 g$	5	
			Seismic peak ground acceleration $<0,05 g$	1	
H-2	Active faults	0,01	Large active fault in the neighbourhood	10	
			Small active fault in the neighbourhood	6	
			No active fault	0	√

Table E.3 (continued)

SN	Key influencing factors/assessment indicators	Weight w_i	Indicator status	Value u_i	Check
H-3	Sensitivity to rainfall	0,05	High; surrounding similar landslides are likely to be unstable during rainfall	10	√
			Moderate; only heavy rainfall is likely to induce slope instability	6	
			Low; rainfall has little effects on landslide	2	
H-4	Rainfall	0,10	Rainstorm frequency is over 3 times/year, and the duration of each rainstorm is long	10	
			Rainstorm frequency is 1 to 3 times/year, and the duration of each rainstorm is ordinary	6	√
			Occasional rainstorms with short duration	2	
H-5	Slope	0,08	>40°	10	√
			15° to 40°	6	
			<15°	2	
H-6	Vegetation cover	0,10	Cultivated land	10	
			Slope with vegetation coverage of less than 40 %	8	√
			Slope with vegetation coverage of 40 % to 90 %	6	
			Slope with vegetation coverage of more than 90 %	4	
H-7	Types of rock — soil mass	0,10	Construction land	2	
			Loose soil; easy to dig with the help of simple tools	10	
			Medium-dense soil; able to dig with the help of simple tools	6	√
			Dense soil; difficult to dig with the help of simple tools	2	
H-8	Rainfall infiltration condition	0,01	Fast infiltration	10	√
			General infiltration	6	
			Difficult infiltration	2	

Table E.3 (continued)

SN	Key influencing factors/assessment indicators	Weight w_i	Indicator status	Value u_i	Check
H-9	Deformation signs	0,35	Obvious signs of deformation at the toe or head; or monitoring shows landslide is deforming as a whole	10	
			Obvious signs of deformation locally; or monitoring shows landslide is deforming locally	6	√
			No recent sign of deformation, or monitoring shows no deformation	2	
			Massive slide has happened and the form of slope has changed greatly	1	
H-10	Human activities	0,15	Current and future excavation at toe of slope, head loading and other human activities	10	
			Current and future agricultural activities, or blasting, frequent transport nearby	5	
			No current and future human activities, or only people walking or occasional vehicles	0	√
H'-1	Engineering measures for landslide	0,7	Hazard is eliminated, and it is no longer possible for landside to be active again	10	
			Significant effect; engineering measures such as load shedding, press foot and retaining significantly improve slope stability	8	
			Low impact; simple measures such as drainage and cracks compacting improve slope stability	1	
			None or invalid; no engineering measures, or measures have lost efficacy or are invalid	0	√

Table E.3 (continued)

SN	Key influencing factors/assessment indicators	Weight w_i	Indicator status	Value u_i	Check
H-2	Monitoring measures for landslide	0,3	It is no longer possible for landside to be active again, and no specific inspection or monitoring is required	10	
			Specialized monitoring	8	
			Simple monitoring	4	
			Patrol inspection measures for the hazard	1	√
			No patrol inspection or monitoring measure for the hazard	0	
S-1	Pipeline laying method	0,2	Underground burial	10	√
			Overhead; but landslide may affect the stability of overhead structure	8	
			Overhead or horizontally directional drilled under slope; little possibility of landslide affecting the stability of pipeline	0	
S-2	Relative position of pipeline and landslide	0,7	Horizontal or oblique laying in the landslide area	10	√
			Vertical position in the landslide area, direction same as deformation	9	
			Nearby laying outside the landslide area, and landslide will rapidly develop outward, thus affecting the pipeline	7	
			Pipeline is laid near sliding surface or above or below the shear zone of toe and it is impossible to determine whether the pipeline is affected	5	
			Pipeline is not laid in the landslide area, large landslide displacement may affect the pipeline	3	
			Pipeline is laid below the shear zone of landslide; or landslide affects the parallel road of pipeline but it will not be cut off	2	
No effect on pipeline and pipeline facilities	0				

Table E.3 (continued)

SN	Key influencing factors/assessment indicators	Weight w_i	Indicator status	Value u_i	Check
S-3	Position relation between pipeline and potential sliding surface of landslide	0,1	Pipeline laid above the sliding surface	10	√
			Pipelines laid below the sliding surface or outside landslide body	0	
V-1	Affected length of pipeline	0,30	>15 m	10	√
			3 to 15 m	7	
			<3 m	3	
V-2	Landslide scale	0,45	Large-scale	10	
			Middle-scale	7	√
			Small-scale	3	
V-3	Types of landslide movement	0,15	Fast speed	10	
			Low speed	6	
			Creep	3	√
V-4	Compositions of sliding mass material	0,10	Rock	10	
			Gravel and sandy soil and other soils with high coarse grain content	6	√
			Silt and cohesive soil and other soils with high fine grain content	3	
V'-1	External protection measures for pipe body	0,5	Measures such as re-routing, overhead and hazard mitigation works are adopted, so it will no longer be affected by landslide	10	
			Emergency measures such as stress release or reduction of contact between pipeline and hazard are carried out	4	
			No external protection measures for pipeline or measures adopted have lost efficacy or are invalid	0	√
V'-2	Strengthening measures for pipe body	0,5	Effective strengthening measures for pipe body are adopted	10	
			Adopted strengthening measures for pipe body have a common effect	4	
			No strengthening measures for pipe body	0	√

Substitute the weight and status value of each assessment indicator in [Table E.3](#) into [Formula \(E.1\)](#) and [\(E.2\)](#), to obtain the risk probability index of the landslide shown in [Formula \(E.3\)](#):

$$P(R) = H \cdot (1 - H') \cdot S \cdot V \cdot (1 - V') = 0,59 \times (1 - 0,03) \times 1,00 \times 0,72 \times (1 - 0) = 0,41 \quad (\text{E.3})$$

In accordance with [Table E.1](#), the risk probability level of the landslide is Very high.

E.5.3 Pipeline failure consequence grade

In accordance with [Table E.2](#), the pipeline failure consequence grade of this landslide is D.

E.5.4 Risk level

In accordance with [Table E.1](#), risk level of this landslide is Very high when the risk probability level is Very high and the pipeline failure consequence grade is D.

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