



BSI Standards Publication

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

National foreword

This British Standard is the UK implementation of EN ISO 20074:2019. It is identical to [ISO 20074:2019](#).

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A list of organizations represented on this committee can be obtained on request to its secretary.

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management for onshore pipeline (ISO 20074:2019)**

Industries du pétrole et du gaz naturel —
Systèmes de transport par conduites —
Gestion des risques géologiques pour les
conduites terrestres (ISO 20074:2019)

Erdöl- und Erdgasindustrie —
Rohrleitungstransportsysteme — Geologisches
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Gasfernleitungen (ISO 20074:2019)

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European foreword

This document (EN ISO 20074:2019) has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" in collaboration with Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" the secretariat of which is held by NEN.

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The text of [ISO 20074:2019](#) has been approved by CEN as EN ISO 20074:2019 without any modification.

Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	2
3 Terms, definitions and abbreviated terms	2
3.1 Terms and definitions	2
3.2 Abbreviated terms	4
4 Pipeline geohazard risk management program	5
4.1 Key principles	5
4.2 Requirements for a PGMP	5
4.3 Elements of a PGMP	6
4.3.1 General	6
4.3.2 Preliminary engineering and route selection phase	7
4.3.3 Detailed design phase	9
4.3.4 Construction phase	10
4.3.5 Operation and maintenance phase	12
5 Risk identification	13
5.1 General	13
5.2 Geohazard inventory	18
5.3 Desktop data analysis	18
5.4 LiDAR and remote sensing imagery analysis	19
5.5 Field investigation	19
5.5.1 Field investigation techniques	19
5.5.2 Field investigation scope	19
5.5.3 Field investigation recommendations	19
5.6 Geotechnical investigation	20
6 Risk assessment	20
6.1 General	20
6.2 Assessment systems and methods	20
6.2.1 Assessment systems	20
6.2.2 Assessment methods	21
6.3 Assessment for regional pipeline geohazard susceptibility	23
6.4 Assessment for individual pipeline geohazard	23
7 Risk mitigation	24
7.1 General	24
7.2 Mitigations	24
7.2.1 Physical and procedural mitigations	24
7.2.2 Short-term and long-term mitigation measures	25
8 Techniques and methods for geohazard risk management	27
9 Data management	30
Annex A (informative) Guidelines for pipeline route selection	31
Annex B (informative) Field investigation recommendations	33
Annex C (informative) Example of classification of geological environmental conditions by complexity level	35
Annex D (informative) Example qualitative assessment method	37
Annex E (informative) Example semi-quantitative assessment method	47
Annex F (informative) Potential methods to mitigate risk	56

Annex G (informative) Some key influencing factors of selected geohazards	63
Bibliography	68

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).

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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).

Petroleum and natural gas industry — Pipeline transportation systems — Geological hazards 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:

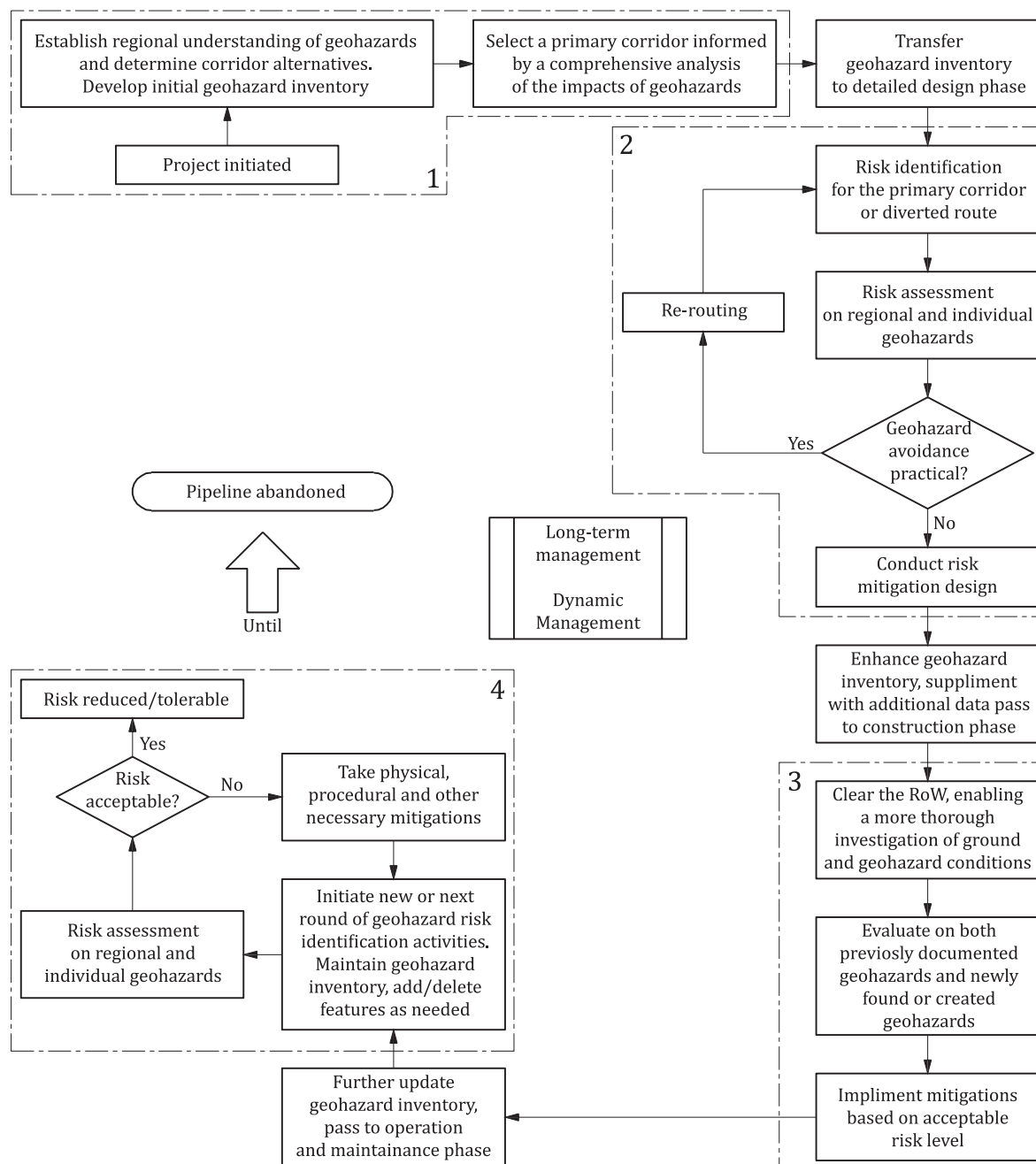
- **Identification:** Establish regional understanding of geohazards and determine whether regional geohazard threat level requires further development of a PGMP. For the initial corridor alternatives, severe geohazards and geologically sensitive areas, such as seismic fault zones or active faults, medium 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:

- a) 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. Inclinoimeters 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.

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	— Listing of geohazard types that might be present along route — Route alternatives to avoid geohazards (if possible)	Meet the risk assessment requirements in these phases	Meet the risk assessment requirements in this phase
Identification objects	— Severe geohazards — Geologically sensitive areas	— 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	— Geohazards identified in the detailed design and construction period — Geohazards newly identified in the operation period — Geologically sensitive areas
Identification accuracy	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.	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.	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.

Table 1 (continued)

Technical recommendations	Design and construction period		Operation period	
	Preliminary engineering and route selection phase	Detailed design phase Construction phase	Operation and maintenance phase	
Identification method	— Data (maps, text) analysis	— LiDAR	—	Field investigation based on desktop data analysis
	— LiDAR	— Remote sensing imagery (satellite images, air photos) analysis	—	Remote sensing monitoring and identification
	— Remote sensing imagery (satellite images, air photos) analysis	— Field investigation based on desktop data analysis	—	Geotechnical investigation if needed to support pipeline RoW stability and maintenance
	— Field investigation as appropriate	— Geotechnical investigation, if necessary	—	ILI geometry tool assessment of pipeline performance
	— Geotechnical desk data collection and studies	—	—	RoW monitoring and continuous surveillance through walks and identification after environmental events
	— Geotechnical investigation, if necessary	—	—	
	— Interviewing local residents and stakeholders	—	—	
	—	—	—	
Data collection	— LiDAR imagery	— LiDAR imagery	—	LiDAR imagery
	— Maps, such as topographic map, hydrogeological map, geological structure map, and seismic ground motion parameter curves	— Maps	—	Maps
	— Documents, such as geological data, policies and regulations, social and economic data and other related data	— Remote sensing imagery	—	Remote sensing imagery
	—	— Results in previous phase	—	As-built data in the detailed design and construction period
	— Other necessary documents and maps	— Materials related to geologically sensitive areas that cannot be avoided	—	Other necessary documents and maps
		— Other necessary documents and maps	—	