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Introduction

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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 10903

Oil and gas industries including low carbon energy — Pipeline transportation systems — Pipeline geohazard monitoring processes, systems and technologies

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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).

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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, 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 intended to provide guidance on the monitoring of geohazards for new and existing buried onshore pipelines. In recognition that pipelines transverse through highly variable environments, this document provides an overview of available technologies and techniques to monitor and manage geohazards rather than prescriptive procedures. This document also recognizes that competent and appropriately qualified geohazard and pipeline stress experts are best suited to assess and develop system-wide or site-specific needs for Geohazard Monitoring Program (GHMP) and are an integral part of the process.

Geohazards may adversely affect the operation or integrity of new and existing pipelines and their Right-of-Way (RoW), or the design and construction of proposed pipelines. Monitoring systems are common techniques for assessing and managing geohazard risk and the impact of geohazards on the integrity of pipelines. In comparison with geohazard engineering mitigation measures, monitoring systems have significant cost-benefit advantages in economic, social, and environmental risk reductions.

This document and development of GHMP will bring potential benefits as follows:

- Technical benefits: It will help operators, regulators, consultants and third parties determine appropriate practices for monitoring geohazards and will provide examples of current and emerging monitoring systems and techniques.
- Risk Reduction: It will assist the operators better assess the impact of the geohazard on the integrity of their pipeline asset, which then allows for an assessment of the resulting consequences.
- Economic benefits: It can assist operators define and develop physical intervention measures to prevent a pipeline integrity incident in cases when a pipeline system faces geohazards by making forecasts of impacts evaluating consequences. It can help interested parties, especially operators of small-and medium-scale pipelines, to properly use their available economic and operational resources among the inventory of their geohazards.
- Social and environmental benefits: Monitoring with early warning notifications can provide the pipeline operators with sufficient time for physical interventions. The early intervention can reduce the likelihood of integrity issues or loss of containment incidents, which can avoid or reduce negative social influences and environmental impacts.

Geohazard monitoring is part of a comprehensive geohazard management and pipeline integrity plan that should be developed as part of the operation of any buried pipeline.

Geohazard monitoring is not typically used to initially identify geohazards. It is a means to confirm the presence of a geohazard and provide characterization of the feature so that an engineering assessment of the impact of the geohazard on the pipeline may be performed, and engineering mitigations can be developed and implemented in a timely manner. While the breadth of geohazards that negatively impact buried pipelines is very large, a select number of hazards (either geotechnical or hydrotechnical) account for most issues. These include landslides of various forms and hydrotechnical events such as lateral and vertical scour. For this reason, much of the discussion and many of the examples in this document relate to these particular hazard types.

Geohazards include any natural feature or event that can negatively impact the integrity of the RoW or pipeline. Although this document can be used for monitoring of most geohazards, the focus is on ground movements impacting pipelines or their RoW, such as landslides or subsidence.

While the breadth of geohazards that negatively impact buried pipelines is very large, a select number of hazards (either geotechnical or hydrotechnical) account for most issues. These include landslides of various forms and hydrotechnical events such as lateral and vertical scour. For this reason, much of the discussion and many of the examples in this document relate to these particular hazard types.

Geotechnical monitoring, such as the use of in-situ instrument, is not a pipeline integrity mitigation. This instrumentation and monitoring is a means to confirm the presence of a geohazard and provide characterization of the feature so that an engineering assessment of the impact of the geohazard on the pipeline may be performed, and engineering mitigations can be developed and implemented in a

timely manner. Geotechnical monitoring is part of a comprehensive geohazard management and pipeline integrity plan that should ideally be developed as part of the operation of any buried pipeline. Other ISO documents provide information on the preparation of geohazard management plans and pipeline integrity requirements. Monitoring should not be performed in isolation of these plans and requirements.

Geohazards include any natural feature or event that can negatively impact the integrity of the RoW or pipeline. There are a wide variety of geohazards which can affect pipelines, but a high proportion are commonly due to landslides (and similar) and hydrological events. Although this document can be used for monitoring of most geohazards, the focus is on ground movements impacting pipelines or their RoW, such as, but not limited to, landslides or subsidence.

Oil and gas industries including low carbon energy — Pipeline transportation systems — Pipeline geohazard monitoring processes, systems and technologies

1 Scope

This document provides guidance for the planning, selection and implementation of methods and strategies for monitoring geohazards that may interact with pipelines.

This document applies to geohazard monitoring of new and existing onshore gathering and transportation pipelines and the RoW.

Geohazards include any natural feature or event that can negatively impact the integrity of the RoW or pipeline. These may include, but are not limited to, earthquakes, landslides, debris flows, rock falls, frost heave and thaw settlement, ground subsidence from karst collapse or underground mining, rock indentation and hydrotechnical hazards, such as lateral or vertical erosion, scour, channel migration or avulsion and others. Although this document can be used for monitoring of most geohazards, the focus is on ground movements impacting pipelines or their RoW, such as landslides or subsidence.

This document does not apply to monitoring of geohazards that are temporary in nature, such as the stability of spoil piles, temporary cut slopes to facilitate pipeline construction, stability of excavation or trench wall and access roads.

One intent of this document is to describe the processes and steps for developing a suitable GHMP. For example, the program should consider the following:

- characteristics of the geohazard and level of threat to the pipeline system;
- recommended monitoring approaches, appropriate monitoring systems and methods;
- monitoring frequency, monitoring program implementation, operation, maintenance and termination;
- components of monitoring systems;
- threshold alarms and levels, criteria and response measures.

2 Normative references

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

ISO 19345-1, *Petroleum and natural gas industry — Pipeline transportation systems — Pipeline integrity management specification — Part 1: Full-life cycle integrity management for onshore pipeline*

ISO 20074¹⁾, *Petroleum and natural gas industries — Pipeline transportation systems — Geological hazard risk management for onshore pipeline*

1) ISO 20074 provides a high-level framework for developing, implementing and improving geohazard management programs for onshore pipelines. The standard is applicable to all geohazards and includes a complete life-cycle approach, meaning that an operator's Pipeline Geohazard Management Program (PGMP) may cover the entire lifespan of the pipeline from conception and design to construction, operation, and decommissioning. The standard envisions that all operators would have an in-house PGMP implemented by an in-house team, unless the operator could demonstrate that a PGMP was not necessary. The ISO 20074 document is usually required to be incorporated in development of a geohazard monitoring program.

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 <https://www.electropedia.org/>

3.1.1

aerial surveillance/reconnaissance

reconnaissance activities of the pipeline RoW and surrounding terrain by means of aircraft (unmanned drones, helicopters or manned airplanes) flying at relatively low heights above the ground to provide visual or video inspection and observation of the ground surface

3.1.2

aerial surveys

a broad category encompassing the collection of data by aerial platforms

Note 1 to entry: It includes aerial surveillance and reconnaissance by manned or unmanned aircraft, airborne surveying platforms such as Light Detection and Ranging (LiDAR), magnetic tomography, Airborne Laser Scanning (ALS) or other techniques.

3.1.3

automatic monitoring

monitoring of in-place instruments by use of an automated data acquisition system such as a data logger

3.1.4

internal caliper tool

a type of In-Line Inspection (ILI) device that measures and record changes in the physical geometry of the pipeline, i.e. ovality, dents, wrinkles), and other physical features

3.1.5

data cleaning

process used to improve data quality by detecting, flagging, or correcting (or filtering and removing) the erroneous or noisy data from instrumentation

[SOURCE: ISO 5127:2017, 3.1.11.21, modified — Data cleaning methods and sources are supplemented]

3.1.6

data management system

a system to receive the instrumentation data through the *data transfer protocol* (3.1.8) in a specific server or cloud and process and present the data

Note 1 to entry: The data can be accessible/viewable with access privileges. Data cleaning and processing, storage, and visualization as well as early notification system can be part of the data management system.

3.1.7

data processing

process used to convert the quality data to engineering units (such as elevation, deformation, strain) by processing the collected data obtained from instrumentation using mathematical equations or algorithms

Note 1 to entry: It may be performed in a specified server or cloud.

3.1.8**data transfer protocol**

common set of rules to transfer the monitoring data from a data acquisition system to a specified server or a cloud repository

3.1.9**early warning information system**

a manual or automated system to perform *data processing* (3.1.7), data management, and data evaluation with the intent of issuing or transmitting a warning message to the operators if pre-defined threshold limits are exceeded

3.1.10**fiber optic sensing****FOS**

The use of small diameter fiber optic cables that are attached to a buried pipeline or installed within the trench backfill and are capable of indirectly detecting various attributes, such as ground movement, loss of containment, backfill loss due to erosion and more

3.1.11**geographic information system****GIS**

a computer program that stores and retrieves information concerning a geographical area or feature

Note 1 to entry: It is a platform for storing and cataloging data about a linear feature such as a pipeline, including geohazard inventory along the pipeline RoW or the characteristics of the pipeline, physiology of the pipeline route, geology, land use and ownership etc.

3.1.12**geohazard monitoring program****GHMP**

a program or plan for assessing the spatial and/or temporal evolution of geohazards, triggering events and other physical quantities, which includes objective of monitoring, methods, frequency, threshold levels, response to threshold exceedance, operation and maintenance, and program termination and abandonment

3.1.13**global navigation satellite system****GNSS**

satellite navigation system with global coverage, essentially providing Global Position System (GPS) coverage

Note 1 to entry: It is a unified designation for single satellite navigation orientation systems include Global Positioning System (GPS-USA), BeiDou Navigation Satellite System (BDS-CHN), Global Navigation Satellite System of Russia (GLONASS-RUS) and Galileo Satellite Navigation System (GALLIEO-EUR), etc., and also for their augmentation system, as well as combination of those satellite navigation and position systems and their augmentation systems, such as Wide Area Augmentation System (WAAS-USA), European Geostationary Navigation Overlay Service (EGNOS-EUR), Multi-Functional Satellite Augmentation System (MASS-JPN) etc., and also covers other satellite navigation systems in process and to be established in the future.

[SOURCE: ISO/IEC 18038:2020, 3.10, modified — GPS is emphasized and Note 1 to entry has been added.]

3.1.14**in-line inspection****ILI**

a general term describing the inspection of a pipeline from the interior of the pipeline using specialized physical or electronic tools

Note 1 to entry: Devices or equipment that is inserted into the pipeline and will travel along the pipeline collecting information on the physical state and geometry of the pipeline. Data collected may include information on ovality, bends, curvature, presence of dents or physical deformation, horizontal and vertical position, wall thickness, bending and axial strain.

[SOURCE: ISO19345-1:2019, 3.1.19, modified — Note 1 to entry has been added.]

3.1.15

inertial measurement unit

IMU

a type of in-line pipeline tool that measures and records the physical geometry and position of the pipeline

3.1.16

light detection and ranging

LiDAR

a terrestrial or airborne system to collect data to develop ground elevations or profiles using lasers

3.1.17

magnetic flux leakage

MFL

ILI tool used to detect and size both internal and external metal loss features in a pipeline wall

3.1.18

monitoring network

a network of monitoring instruments established for monitoring the behaviour of a geohazard and its impact on the pipe or other environmental factors such as rainfall or stream discharge/flow

3.1.19

monitoring point

a specific site designated for monitoring geohazard behaviour or other characteristics

Note 1 to entry: The monitoring point may be located on the ground surface, within or on the periphery of geohazards, on the ground surface of the pipeline or RoW, or other locations to monitor groundwater, environmental/meteorological elements or forced pipeline deformation and other change.

3.1.20

pipeline monitoring

process of planned or real-time measurement, information analysing and processing on displacement, strain, cross-sectional geometry of the pipeline with instruments, equipment and technical means

3.1.21

pipeline geohazard risk management program

PGMP

set of processes and procedures for guiding operating companies or operators to carry out coordinated activity for guiding and coping with issues related to pipeline geohazard risk

Note 1 to entry: A comprehensive program as described in ISO 20074 that details the identification, assessment, and mitigation of geohazards that may negatively impact the integrity of buried pipelines or the RoW.

[SOURCE: ISO20074:2019, 3.1.20, modified — Note 1 to entry has been added.]

3.1.22

pipeline geohazard monitoring

activity that tracks the evolution and/or characterizes the behaviour of a geohazard that may impact a pipeline or RoW

Note 1 to entry: These activities refer to the data with regard to geohazards, pipeline and its relevant factors at different times and under various states intermittently or continuously acquired with sensors, instruments and other technical means.

3.1.23

remote sensing

any acquisition of data or information on some property of an object or phenomenon by a sensor that is not in contact with the object

Note 1 to entry: In the common usage, it usually refers to information collection using airborne or satellite platforms, although near-field, non-contact sensing may also be referred to as remote sensing.

[SOURCE: ISO 772:2011, 1.126, modified]

3.1.24

right-of-way

RoW

corridor of land within which the pipeline operator has the right to conduct activities in accordance with the agreement of the pipeline owner and the landowner, and the regulator, if required

[SOURCE: ISO 13623:2017, 3.1.19, modified — regulator has been added.]

3.1.25

shape accel array

SAA

a device that is permanently placed in a casing installed to a specific depth to provide intermittent or continuous monitoring of lateral ground movement with depth

3.1.26

slope inclinometer

SI

a device lowered into a casing with internal grooves and measures the tilt in the casing that can be converted to lateral ground displacement with depth

3.1.27

strain capacity

the amount of strain that a pipeline segment can tolerate before a limit state is reached (either code-based, serviceability or ultimate)

3.1.28

strain demand

the amount of strain that is imposed on a pipeline segment by pipeline operation or external forces, e.g. a landslide that is moving will impose external load on the pipeline segment resulting in additional imposed strain

3.1.29

strain monitoring

process in which fit-for-purpose instruments, equipment and technical means are applied for periodic or real-time measurement, analysis and process of stress or strain information of a pipeline(s)

3.1.30

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 an advanced degree in their area of expertise and at least 10 to 15 years of practical experience working with in their area of specialization. Examples include experts in geohazards, geomorphology, instrumentation, and hydrology.

[SOURCE: ISO 20074:2019, 3.1.27, modified — The years of practical experience have been extended in Note 1 to entry.]

3.2 Abbreviated terms

ALS	Airborne Laser Scanning
CORS	Continuously Operating Reference Station
FBG	Fiber Bragg Grating
FOS	Fiber Optic Sensing
GHMP	Geohazard Monitoring Program
GIS	Geographic Information System

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDD	Horizontal directional drill
ILI	In-Line Inspection
IMU	Inertial Measurement Unit
InSAR	Interferometric Synthetic Aperture Radar
LiDAR	Light Detection and Ranging
MEMS	Micro Electromechanical System
MFL	Magnetic Flux Leakage
PGMP	Pipeline Geohazard Risk Management Program
RoW	Right-of-Way
RTK	Real Time Kinematic
SAA	Shape Accel Array
SI	Slope Inclinator
SME	Subject Matter Expert
TLS	Terrestrial Laser Scanning
TSS	Total Station Survey
UAV	Unmanned Aerial Vehicle

4 Key objectives and principles

4.1 Objectives of geohazard monitoring

The primary objectives of geohazard monitoring are to:

- ensure safe operation of existing pipeline which goes through territories with the corresponding geohazards;
- characterize the geohazard and its relationship and potential threat to a pipeline and RoW;
- make forecast of geohazard development, and to provide probabilistic assessment of the geological risks on the basis of such a forecast;
- allow pipeline operators to manage resources relative to geohazard mitigations and interventions according to the threat posed by the geohazard to a pipeline and RoW;
- provide evidence for mitigation measures or technical solutions to prevent the threat of geohazards;
- provide early warning information to allow for pre-emptive intervention prior to exceedance of a pipeline's strain capacity or an allowable strain demand as represented by a threshold ground movement limit;
- confirm that previously completed mitigation or remediation measures are functioning as intended;
- quantify ground movement caused by natural extreme events, such as an earthquake or storm event.;

- provide necessary monitoring information to enable decision-making by long, mid, and short-term forecasts to minimize negative consequences due to natural extreme events.

Monitoring geohazards may often be conducted by monitoring the hazard feature, the pipeline (+/- RoW) or both, and/or monitoring triggering events such as stream flow, rainfall, underground mining activity, ground temperatures, groundwater levels etc. Pipeline monitoring (such as strain monitoring) provides specific information about whether a geohazard is affecting the pipeline and RoW and to what extent. An integrated approach to monitoring both the hazard and the pipeline provides context for the monitoring results and provides for stronger, more reliable decision-making. Where the hazard is understood to either be directly affecting the pipeline and RoW, or the risk is considered moderate to high, good practice is to apply multiple monitoring techniques and strategies and include redundancy in the geohazard monitoring system.

4.2 Monitoring program development

A development of a complete GHMP generally require consideration of the approach to: identification of geohazard and risk to the pipeline and RoW (4.3), analysis and objectives (4.4, 4.5 and 6.2), monitoring methods (6.3), program implementation (6.5), threshold and responses to monitoring data (6.6, 6.7), operation and maintenance (6.8), program termination (6.9), data acquisition and geohazard monitoring data management (Clause 7).

4.3 Geohazard significance and interaction threat assessment

Table 1 provides a grading system describing the significance of the geohazard based upon the risk level, as determined according to ISO 20074. The significance of this grading system is to assist in assign a level of effort, resources, or technology to the monitoring program. Higher risk hazards should typically justify a greater level of monitoring and sophistication. The risk to the integrity of the pipeline should be assessed by an engineering critical assessment to determine the strain capacity of the pipeline and compare to the potential strain demand imposed by the geohazard.

Table 1 — Geohazard significance grade based on overall risk level of geohazard feature relative to threat to pipeline or RoW integrity or mitigation potential

Significance grade	Description
Level I	— Geohazards with high-risk to very high-risk levels where mitigation measures are difficult to implement and/or the geohazard represents a significant threat to pipeline or RoW integrity; — Geohazards that require rapid or emergency prevention and mitigation.
Level II	— Any other geohazards with high-risk to very high-risk levels; — Geohazards that pose a moderate risk to the integrity of the pipeline or RoW or are of a rate that may be amenable to ongoing regular monitoring (that is, geohazards that will not experience sudden, brittle or similar development).
Level III	— Geohazards with moderate-risk level or below; — Geohazard that are of low threat to the integrity of the pipeline, or RoW, or are very slow in developing.

NOTE This table is adapted from ISO 20074.

For monitoring that is aimed at assessing the integrity of the pipeline, pipeline strain capacity as well as the strain demand from geohazard external force should be assessed to estimate the thresholds of pipeline strain or stress that will initiate an intervention, response or mitigation by the operator. This strain demand should be correlated to the monitoring outputs and the action thresholds discussed in 6.6.

4.4 Monitoring program considerations

In the selection, design, and implementation of a monitoring program the following principles of a monitoring system should be considered.

- The monitoring objective(s) should be defined prior to establishing a monitoring scheme or program. That is, it should be determined in advance whether the monitoring is to be used to provide input to rehabilitation or intervention design or maintenance planning (earthworks, strain relief, pipeline replacement, re-routing etc.) or to provide advance warning of a slowly or rapidly developing pipeline or RoW integrity issue.
- The threat level of a geohazard or areas to be monitored (see [Table 1](#)) should be incorporated into the selection of the monitoring approach. This will allow for consistent selection of monitoring types and appropriate prioritization of monitoring at geohazards where the risk-reduction benefit is greatest.
- The target of the monitoring should be defined from the start (i.e. whether monitoring is focused on a single site or many sites within a given area). If the intention is to monitor many geohazards or large areas where geohazards may occur, regional monitoring techniques are needed. If the intention is to monitor certain, discrete locations that have been previously identified, then specific geohazard and/or pipe monitoring techniques are needed. In many cases, a single site should be monitored through multiple approaches.
- Wherever possible multiple monitoring techniques should be applied and/or installed, especially for high to very high-risk categories. For example, in the case of an identified landslide, SIs are often installed. However, repeated Light Detection and Ranging (LiDAR) surveys, Global Navigation Satellite System (GNSS) survey units, strain gauges attached to the pipeline at critical bending locations and analysis of Inertial Measurement Unit (IMU) and internal caliper tool data should be considered as part of the overall monitoring program. Multiple data sources provide redundancy of information and allow the assessment of different aspects of the geohazard-pipeline interaction.
- The expected duration for monitoring should be incorporated into the selection and design of instrumentation. It is important for the selected instrument(s) to meet the target lifetime of the monitoring program. Depending on the required monitoring duration, the need for instrument recalibration or replacement, should be included in the monitoring system design.
- The frequency of data interpretation and reporting should inform which instruments are selected. Reporting format and frequency may depend on the type of monitoring system, and the methods of transmitting/reporting the collected data.
- Geohazard monitoring of a pipeline or pipeline RoW during construction shall continue with the monitoring during operation; therefore, transfer of the monitoring system and any accumulated data shall be properly conducted. The Pipeline Geohazard Risk Management Program (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.
- For construction of a new monitoring facility or maintenance of a monitoring facility, development or aggravation of geohazard instability or a situation that may endanger the integrity of a pipeline or facilities shall be avoided.
- For geohazard-prone areas, remote sensing and ground monitoring of geohazards during the early design phases for a new pipeline should be performed to allow for potential avoidance or development of design mitigations.
- During pipeline operations, remote and on-ground monitoring of the pipeline and RoW, implementation of geohazard mapping (such as LiDAR or LiDAR change detection), and application of In-Line Inspection (ILI) tools and its immediate analysis of data will likely be the primary means of identifying ground-movement related geohazards that develop or progress during the life of the pipeline.
- During pipeline operation, geohazard monitoring plans or processes should be developed, prior to the start of operations which should be consistent with the design for the pipeline works, geological engineering survey reports, geological and environmental conditions on site and at the periphery, and

other factors, such as environmental/climatic conditions. Monitoring plans may be initiated during initial pipeline operation and used to evaluate the identified geohazards.

- During pipeline operations on-ground inspection, strain gauge measurements, ILLI, IMU, ground movement monitoring methods (such as inclinometer, survey monuments), repetitive aerial surveying, and satellite monitoring are all relevant techniques that may have applicability depending on the nature of the hazard. [Annex A](#) provides more detail on individual monitoring methods.
- In cases where significant ground movement is detected or anticipated, that may negatively interact with the pipeline, particularly for moderate to high-risk circumstances, pipe stress analyses and strain capacity evaluations should be undertaken to characterize the actual effect of the geohazard on the pipeline.

4.5 Requirement for monitoring program

Before the establishment of a monitoring program, a needs-assessment should be carried out, and then the corresponding monitoring program initiated, if required. This is followed by the monitoring scheme being designed according to the established requirements. The project then enters the implementation, operation, and maintenance stages. If a predetermined goal or objective (for example, geohazard stabilization or geohazard avoidance) is defined and achieved, the program may be terminated. Review and updating of the program requirements and monitoring schemes should be conducted on a regular basis and as a minimum when site conditions change, new information becomes available, or other circumstances warrant a review and update.

Geohazard monitoring is required when a geohazard has been identified that may adversely affect an existing pipeline or the design construction or operation of the proposed pipeline.

New monitoring programs shall be established under the framework guidance of ISO 20074.

NOTE 1 ISO 20074 is applicable to all geohazards and includes a complete life-cycle approach, meaning that an operator's PGMP will cover the entire lifespan of the pipeline from conception and design to construction, operation, and decommissioning. A PGMP covers four interlinked processes that are performed through the pipeline life cycle: a) identification of geohazards; b) evaluation of geohazards; c) long-term management of geohazards through monitoring and periodic re-evaluation, and d) mitigation of geohazard threats.

NOTE 2 Each process is then linked to the four main phases of the pipeline life cycle: preliminary engineering and route selection; detailed design; construction; and operation and maintenance. ISO 20074 provides workflows and recommendations for executing each process within each project phase, but generally avoids prescriptive requirements, other than that operators create and implement a PGMP. The standard also provides recommendations and discussion for the following elements: a) creating and populating a geohazard inventory; b) methods for desktop and field investigation (including a discussion on LiDAR and remote sensing analysis); c) geohazard risk assessment method and assessment systems, including the relative strengths and weaknesses of qualitative, semi-quantitative, and quantitative systems; d) data management, including recommended elements for geohazard databases; e) sample classification systems.

The program should be established based on significance grade, and other requirements (see [4.3](#)). [Figure 1](#) presents the recommended initiation procedures.

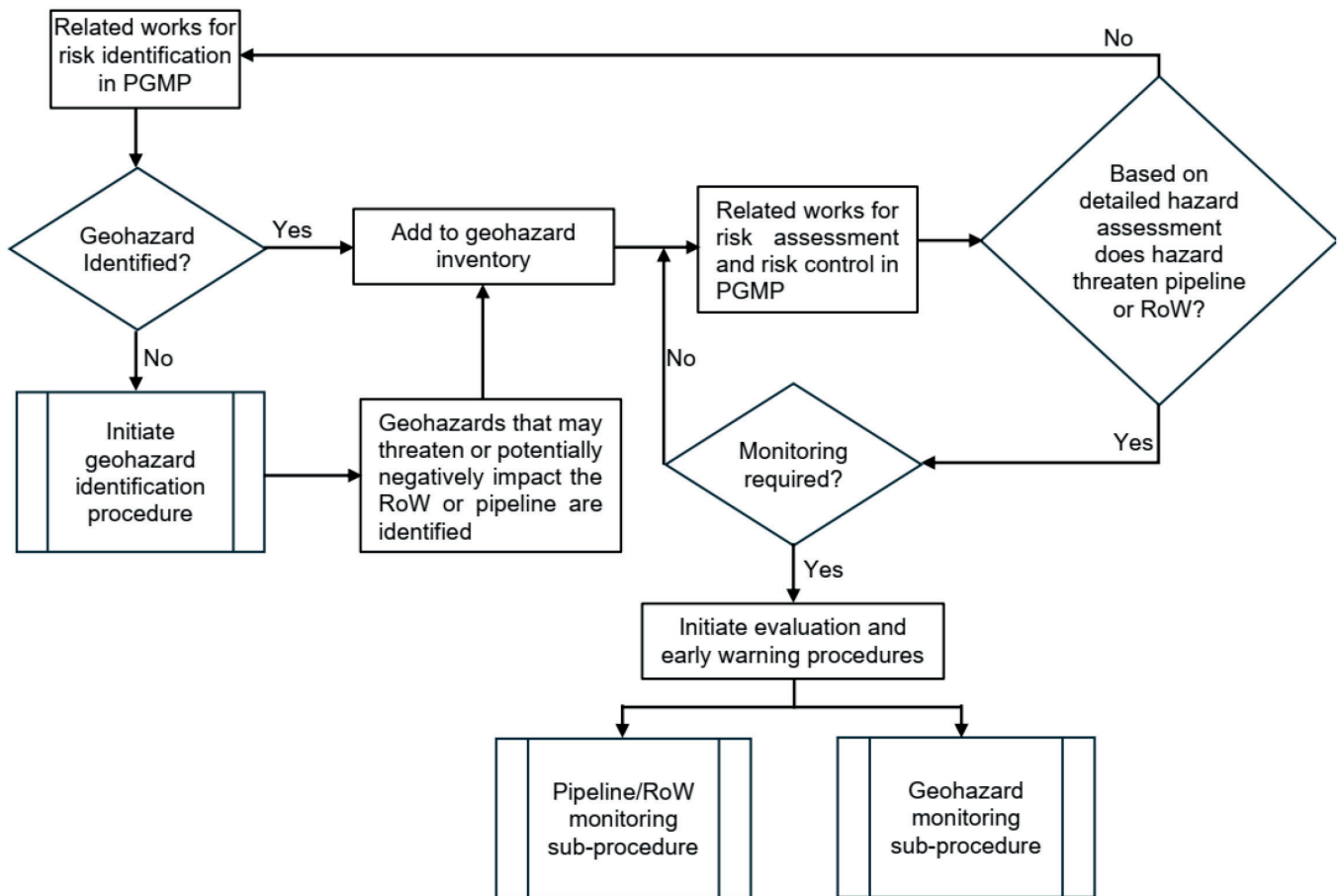


Figure 1 — Recommended program initiation procedure for pipeline geohazard monitoring

The identification of geohazards shall be completed using a staged process with progressive detail and analysis, as per the requirements and recommendations of ISO 20074.

5 Monitoring geohazards on pipeline projects

5.1 Monitoring project category

Monitoring projects can be classified into the following categories:

- pipeline strain monitoring;
- Terrain monitoring;
- geotechnical instrumentation monitoring;
- geohazard trigger monitoring.

5.2 Pipeline strain Monitoring

Pipeline strain monitoring can be divided into three categories: strain gauges, ILI tools, and physical survey of the pipeline position. Strain gauges and ILI tools provide related but separate information about whether a geohazard is affecting the pipeline (geohazard-induced strain). Strain gauges provide measurements at discrete locations and can be recorded via a data acquisition system. ILI tools provide information over entire pipe segments. Like many other methods and technologies discussed herein, strain gauges and ILI tools can be a complementary and integrated technologies. ILI tools may be used for a site-specific geohazard

monitoring or regional monitoring where the geohazard (or multiple geohazards) extend over a large area; whereas strain gauge monitoring is typically used for localised/site-specific geohazard monitoring.

The primary ILI technology used for geohazard monitoring is IMU bending strain analysis, but this does not preclude the use of other ILI technologies (such as internal caliper and Magnetic Flux Leakage (MFL)), as appropriate. Axial strain measurement by ILI tools is an emerging and maturing technology that is likely to reach full applicability and maturity within a decade. Where applied, IMU, internal caliper, and axial strain measurement tools and their analysis represents a continuous assessment of geohazard threats along the pipelines.

Both strain gauges and ILI tools have distinct advantages. Strain gauges can provide near real-time reporting of actual pipe strain at the location of strain gauges, making them ideally suited for tracking trends over time and as an early warning information system. ILI tools can provide information over pipeline segments and are useful for identifying and analysing landslide effects on pipelines over the length of the segment but are limited by inspection intervals that typically extend into years.

Both also have limitations. Strain gauges provide the strain in the pipeline only at the distinct (discrete) locations and provide the changes in pipe strain (bending and axially, depending on the orientation of the strain gauge) from the time of installation. Their installation requires exposure of the pipeline in a excavation. ILI tool runs are relatively expensive, infrequently run (time between measurements is usually years) and cannot be used for all pipeline segments (i.e. non-piggable lines). Further, IMU and internal caliper tools provide an indirect measure of pipeline strain; for example, the bending strain is calculated as function of the change in pipeline bending curvature and thus require a benchmark to refer to.

The physical survey of the pipeline position in comparison to the original location of the pipeline can provide information about the state of stress on the pipeline. The original (or baseline) location of the pipeline can be measured from previously collected survey points established at the time of construction, records of prior line location or IMU runs, so long as the IMU data is sufficiently accurate. In general, it is the change in shape of the pipeline over a defined cord-length (i.e. bending strains) that are more important to the assessment of pipeline integrity than the absolute position of the pipeline. Note that pipe strain from the pipeline surveyed position can be estimated using the pipeline bending curvature.

For specific selection, use, and considerations of ILI tools shall be in accordance with the provisions of ISO 19345-1 regarding inspection and monitoring.

5.3 Terrain monitoring

Terrain monitoring is typically applied to large or small areas of terrain and can be used for site-specific geohazard monitoring, or regional monitoring where the geohazard extends over a large area. Regional terrain monitoring provides information related to ground movement such as direction of ground movement in newly developed geohazards or in known geohazards. Regional terrain monitoring methods may not provide specific information, e.g. about the depth of the slip surface, rate of ground movement, or changes in subsurface conditions. Site specific monitoring could include traditional topographical surveys (see [5.4](#)), or regional techniques.

The rational for regional terrain monitoring include the following:

- multiple geohazards may be present, or where the underlying geology is susceptible to geohazards and has the potential for future geohazard occurrence;
- large geohazard that extends outside of the RoW limits.

Terrain monitoring typically comprises the following techniques (i) ground patrol/reconnaissance, (ii) aerial surveillance and (iii) remote sensing.

5.4 Geotechnical instrumentation monitoring

Geotechnical instrumentation monitoring refers to monitoring of a specific identified geohazard by installing instrumentation. It is distinguished from regional terrain (e.g. LiDAR) or strain (ILI tools) monitoring discussed in [5.3](#) (no installed instruments) and pipeline strain monitoring discussed in [5.2](#)

(instruments used to monitor the pipeline integrity directly). Geohazard monitoring instrumentation does not directly monitor effects of a geohazard on a pipeline but can be used to infer or model those effects. This instrumentation is installed on the ground surface or shallow buried, such as GNSS unit or ground survey monuments, or deeply buried instruments, such as SI or Shape Accel Array (SAA).

5.5 Geohazard trigger monitoring

Geohazard triggers include events, systems or conditions that could lead to initiation of a geohazard event. Event triggers should be differentiated between direct and indirect triggers.

Direct triggers are those likely to be the mechanism causing the instability of the ground and examples include:

- toe erosion of slopes;
- channel migration and scour during hydrological events;
- elevated soil porewater pressure;
- thawing or degrading of permafrost;
- seismic or ground vibration events which give rise to a change in soil structure.

Indirect triggers are those events, characteristics or attributes that are contributing factors. Examples of indirect triggers include:

- rising water levels and increased watercourse energy due to increased precipitation;
- changes in burial depth due to creep or erosion;
- changes in land cover such as deforestation by logging or wildfires.

It is important in the development of GHMP to assess whether to monitor direct or indirect triggers.

Monitoring of these events or conditions provide supplemental information that can be used to better understand the conditions under which some geohazards occur (or accelerate), or to confirm the efficacy of measures designed to reduce the impact of the triggering events (e.g. use of piezometers to monitor drawdown of groundwater). Geohazard trigger monitoring should not be used as the primary method of geohazard monitoring but may provide advanced warning of a potentially unsafe condition.

6 Geohazard Monitoring Program (GHMP)

6.1 Overview

Prior to initiating geohazard monitoring, a GHMP should be developed to address the monitoring needs to system wide GHMP or site-specific monitoring plan. In most cases, pipeline operators should develop a system-wide geohazard monitoring plan to cover the extent of their pipeline system crossing a geohazard region as well as site specific geohazard monitoring plan to address the needs to monitoring a specific geohazard site(s). Nevertheless, the geohazard monitoring program or plan should address the following components:

- objective of monitoring;
- methods used for monitoring;
- monitoring frequency;
- program implementation;
- threshold levels;
- response to threshold exceedance;