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Computational tool for information management and integrity assessment of subsea rigid pipelines

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Abstract. Subsea rigid pipelines, widely used to transport fluids in oil and gas production activities, require an Integrity Management System to ensure that there are no economic, environmental, material nor human losses throughout their design life. In this work, an overview of methodologies for data management and generation of results for integrity assessment will be presented. Then, such methodologies are implemented into an integrated specialist software that is currently under development. The aim is to obtain a robust and efficient computational tool whose application in real scenarios will provide the following benefits: a) Productivity gains during the processes of evaluating the integrity of submarine rigid pipelines, including the centralization of relevant information from the history of inspections and pipeline operating conditions; b) Generation of standardized technical reports containing results of integrity assessments under operational conditions; c) User-friendly interface to access information on the operational history of the pipelines during its design life; d) Assistance in the integrity management of subsea rigid pipeline systems, according to the normative and regulatory requirements; e) Ease in analysis sensitivity of relevant parameters, since it integrates, within the same computational system, resources for data acquisition, information processing and integrated assessments of different engineering analyses.

Keywords: Rigid Pipeline, Integrity Management, Subsea.

1 Introduction

Subsea rigid pipelines, widely used to transport fluids in oil and gas production activities, require an Integrity Management System (IMS) to ensure that there are no economic, environmental, material nor human losses throughout their design life[1]. Recent evolution in field development in deep waters comes with higher challenges for integrity management as well as technical issues to be solved and primarily predicted in the IMS processes. The use of computational tools for the continuous assessment of the integrity of the system, based on project data and information collected from surveys associated with appropriate methodologies, supports the decision makers in the integrity management process. The large volume of information generated at the early stages of concept through abandonment phase requires an effective data management to grant availability of key records as soon as needed by the multidisciplinary team.

In this work, an overview of methodologies for data handling and generation of results for integrity assessment will be presented, as well as their availability through an integrated specialist software currently under development, named IntegriDutos tool. Assessments can be performed at different levels of complexity, according to DNV-RP-F116, generating results consistent with the respective methodology and analysis requirements. The integration of different analysis capabilities into a single tool adds great value[2], allowing level 1 and 2 assessments while enabling pre- and post-processing of information for more sophisticated analysis (level 3 assessments), applying numerical models such as Finite Elements. Additionally, such integration allows great flexibility of use dealing with different situations such as maintenance of operational integrity, fitness for service and life extension.

The remainder of this work is structured as follows. Initially, Section 2 presents an overview of the integrity management process based on the DNV RP F116 code and adapted to the approach used in the development of the IntegriDutos tool. Then Section 3 presents some considerations regarding the management of the information and data related to the subsea pipelines, collected from various sources; and its association with the requirements for integrity assessment, which is the key point for the development of the tool. Section 4 proceeds by describing the main concepts associated to the implementation of the IntegriDutos tool, where the main goal is to facilitate its use by specialist professionals: the structure of the input data, the analyses that are performed, and the presentation of results. Section 5 . presents a brief illustration of the available engineering resources that facilitate a quick integrity assessment and possible recommendations for mitigation, repair, monitoring or planning of future inspections. Finally, Section 6 presents the final remarks and conclusions, highlighting the main benefits provided by the computational tool.

2 Integrity management process

The development of a subsea production system follows the life cycle concept for the project, starting with the conceptual design and extending to decommissioning/abandonment. Integrity management is one of the processes that must be carried out. It should spread for all stages of the life cycle, being usually divided into two major phases: The first is the establishment of integrity, from conceptual design, construction, to pre-commissioning; and the second is the maintenance of integrity, during operation, from commissioning to abandonment [1]. These phases include activities that can be grouped as follows: 1) Risk management and integrity planning; 2) Inspection, monitoring and testing; 3) Integrity assessment and 4) Mitigation, intervention and repairs/maintenance.

Considering the specific case of a submarine pipeline system, which is the object of this work, the flowchart of Fig. 1 illustrates these groups of activities. Each one, as will be described shortly, feeds the following with relevant information, in the form of an upward spiral. The flowchart includes two decision points: the first depends on the identification of anomalies that would require a technical integrity assessment, and the second depends on the result of this assessment to indicate the need of mitigation procedures.

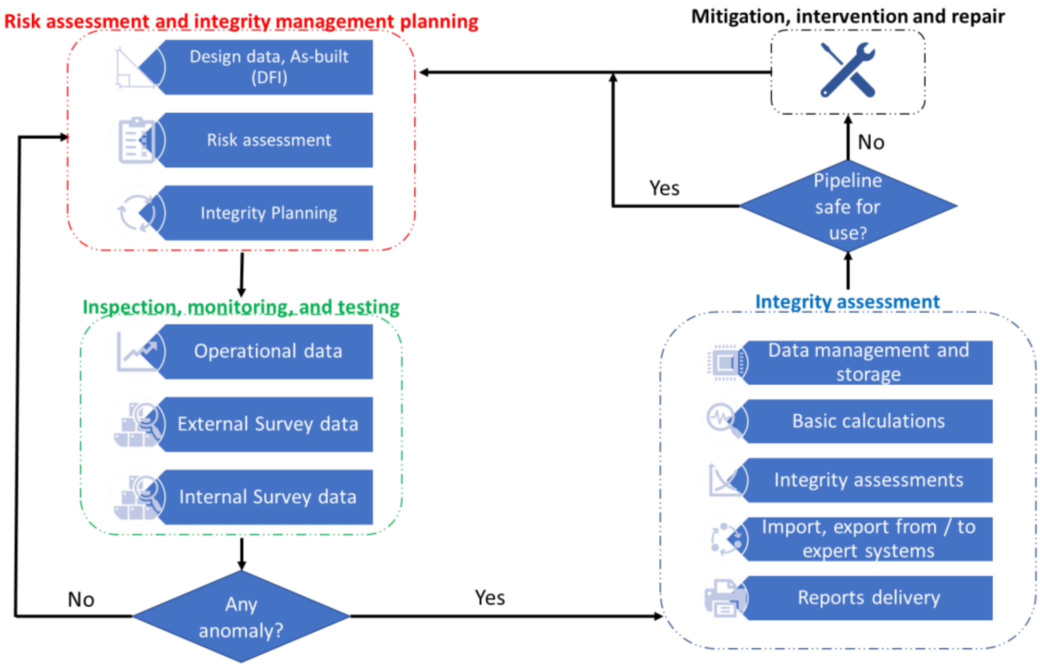

Figure 1. Integrity management process adapted from Rachman, Zhang, and Ratnayake [3]

2.1 Risk management and integrity planning

Risk management and integrity planning activities should be established at initial stages of life cycle including, concept, design and construction to operation of the submarine pipeline systems; therefore, they permeate the two phases of the process e.g establish integrity and maintain integrity. At first, high-level strategies are defined that will be normative for the management of integrity throughout the life cycle of the project. This group of activities includes the identification of threats, process security risk assessments and the planning of inspections, monitoring and interventions (if applicable). During its life, the pipeline is subjected to solicitations that, under certain conditions, can be seen as threats to the system's integrity. These threats can be internal or external and are usually divided into six groups: design, fabrication, and installation errors (DFI); corrosion, erosion; third-party threat; structural; natural hazards; incorrect operation.

Risk analysis quantifies the probability of failure occurrences and the consequences by the possible threats; the risk management and system integrity planning should establish priorities and guidelines for inspections, mitigation procedures, repairs and maintenance. In the integrity maintenance process, this cycle is continuous and dynamic.

2.2 Inspection, monitoring and testing (IMT)

IMT routines are pre-established during the initial design phase, with a view based on risk assessment as mentioned above, to assess the operational conditions of the system considering the threats identified during the planning stage. Inspection activities are performed to check the status of a particular component (loss of wall thickness, insulation defect, pipe displacements, anode status, etc.); monitoring activities gather data for relevant parameters such as temperature, pressure, flow, etc. Then, testing activities are performed at specific times for a specific purpose (pressure testing, safety system testing, etc.). All these activities allow the identification of anomalies and potential system failures. With the information obtained, the capacity of the pipeline to continue operating may be evaluated, or even for a new operating condition. If necessary, the prioritization of mitigations can be established based on the risk of these failures in terms of probability and consequences.

2.3 Integrity assessment

Integrity evaluations can be either routinely performed (according to the original planning), or due to an anomaly pointed out by the IMT routines. They can be divided into two groups: corrosion assessment (internal and external) and mechanical assessment (low and high cycle fatigue, excessive displacement, local buckling, third party damage, etc.).

To allow an accurate evaluation of the system integrity, the data collected in the IMT often needs to be treated or conditioned: for example, the position data obtained via ROV multibeam that need to be evaluated in terms of the inherent error in the data acquisition process. Through the evaluation of the data, points of attention can be identified that will need a more detailed analysis according to the level of threat identified. The calculations and simulations are then carried out, which will allow the assessment of the failure mode against the design standards for the current condition of the pipeline. In this way, the state of the pipeline is established as acceptable or not, from which mitigating actions should be carried out for situations that do not meet the requirements established in risk management and integrity planning.

Depending on the situations that the pipeline engineer is faced with, integrity assessments can be performed in a variety of ways, from the least accurate and fastest to the most sophisticated. Initial (Level 1) assessments allow a preliminary screening by simpler visual methods, indicating or not the need for more detailed analyses. Then, once it has been determined that there is some issue that requires particular attention, follows the Level 2 analyses, where the identified issues are evaluated by simplified methodologies based on analytical formulations. In cases where analytical methodologies do not fulfill integrity criterion that is being checked, numerical simulations such as Finite Element Analyses (FEA) are required, comprising the so-called Level 3 analyses.

2.4 Mitigation, intervention and repairs/maintenance.

During the assessment phase, if damage or potential threats are identified that do not fall within the limits established in the risk management, it will be necessary to carry out mitigation, intervention or repair procedures so that the system works as established in the risk management and in the regulatory integrity requirements contained in the documentation. Mitigation and intervention activities involve mechanisms to reduce the probability of occurrence and/or the magnitude of the damage if it occurs, the first (mitigation) are mainly related to the internal condition of the pipeline (e.g restriction in operation conditions, use of chemicals, etc.) and the latter (intervention) are mainly related to external treatment (e.g protection against third part damage, reduce free span, etc.). Repair activities are necessary to restore the safety level of the pipeline to the established requirements.

3 Data management

The IMS handles a large volume of data of different types. This becomes a challenge in treatment, accessibility, availability and use depending on the type of inspection and the resources used to collect data along the pipeline [4]. Using various resources, information such as wall thicknesses, conductivity, geodetic data can be collected, which, depending on the accuracy required along the entire length of the pipeline, can characterize a "big data" problem. [3]

The nature and typology of the data that compose the integrity management system create another type of challenge. Structured and unstructured data, images, reports, emails, equipment logs, the most diverse analysis results are collected, so that this cluster of information, in addition to the volume, presents a big challenge. Thus, infrastructure for data management must be robust to meet the needs of the IMS [5].

In addition to the volume and type, it is important to remember that data acquisition throughout the pipeline life may not be performed with the same equipment technology and references along operational life. As a result, it is not easy to relate this information in a chronological and positional manner on the same basis that can allow reliable comparative assessments. Thus, it is necessary to create methodologies for the treatment or conditioning of these data. Additionally, these information can carry noise that must be filtered. The treatment of measured data is a big issue, considering that they are the starting point of all evaluations carried out from the results generated in the system. These results form the basis for the decision maker in assessing the integrity of the system.

4 Implementation of the Computational Tool

In order to adequately deal with the aforementioned issues, regarding the accessibility and availability of the involved data, the IntegriDutos computational tool is being developed. In the actual stage, its goal is to organize and storage the relevant input data for external inspections, and to perform several structural analyzes to provide the engineer with the information to auxiliate integrity assessment.

As presented in Section 3 and following recommendations from DNV RP F116 [1], data management is an essential point to guarantee the availability and reliability of the information accessible to the different actors involved in integrity management. In this sense, the tool is designed so that it is not limited to providing engineering calculations. It allows the user to access pipeline system information in an organized and structured way, considering the complexity of the whole integrity management process. In the IntegriDutos tool, the data is structured to facilitate its use and allow the correlation of information in space and time. The recording of data in time is organized by inspection; the starting point within the tool is the information related to the design phase. The recording in space is correlated with time and makes use of geodetic data obtained from each inspection. In this way, information from the design to the abandonment phase is available within a single tool, thus meeting the recommendation of DNV RP F-116.

In general terms, starting from the highest level, the pipeline is defined as the primary entity to which all other items organized in time, surveys and space, data from the bathymetric profiles and pipeline, referenced to the design route by geodesics coordinates. In terms of data hierarchy, at the level just below the pipeline are artifacts such as equipment, buckling mitigators, documents, temperature, pressure and density profiles, all of which are related to the pipeline design phase. At this same level of hierarchy is the inspection group. In each inspection, chronological records of operational information, pipe geometry, soil-pipe iteration, burials, free spans, equipment position, support status, etc. are available.

The information topology is essential to allow different assessments to be carried out with different levels of complexity, in an agile, assertive way and with minimal effort. The IntegriDutos tool allows performing level 1 and 2 evaluations, generating results that are input for specialist tools and/or FEA where simulations are carried out for level 3 evaluation. Then the results from all these tools are post-processed within the system allowing the access to the full range of level 1, 2 and 3 assessment [2] results available in the same tool.

In summary, data processing and availability are costly tasks in engineering processes; in this context the IntegriDutos system is designed as an integrity information assessment tool to allow the expansion of integrity evaluation capabilities through specialized modules, maintaining a good integration of the entire workflow. The following section describes the hierarchical structure of the data as implemented in the tool.

4.1 Hierarchical Data Structure

Pipeline: The pipeline is the highest hierarchical point in the data tree structure. Pipeline information is organized into general data, geographic data, geometric data, material data, design operational data, and environmental data. This set is the basis and reference for all resources available in the tool. Another relevant information is design route, a fundamental piece of information associated with the pipeline. Conceived in the design phase, it is the spatial reference axis of the entire pipeline system. It allows the comparison of geographic information over time in the same reference system, including data collected from different inspections.

Soil Sections**:** As the pipeline is laid on the seabed along the design route, it can cross regions with different soil properties. These different sections of soil are recorded in the data hierarchy below the pipeline. The intersections of the different soil sections with the pipe sections generate soil-pipe behaviors that impact assessments such as buckling, hydrodynamic stability, etc.

Features**:** Equipment, buckling initiators, supports and crossings. These are structures used in data processing to better locate events along the route, and of greater importance in the absence of a design route. This way, events can be tracked throughout the pipeline and inspections. The history of the pipeline events as free span intervention can be established based on installation data. Additionally, the location of the features allows adjustment of the relevant events along the route as the identification of problems related to the quality of field data measured for different inspections. Assessing data quality is important and can help in the elaboration of recommendations in the planning of the next inspections, such as attention to certain points or requirement of a certain level of accuracy in data collection. In summary, a correct control of the feature location can increase the reliability of the information generated and engineering results produced by the tool.

Surveys**:** Survey data comprise the set of data collected in each inspection that can be external e/or internal (ILI): In the case of external surveys, typical data comprises KP definitions, basic pipeline data, DTM models including bathymetric profiles, pipeline profiles, etc. In the hierarchy, the inspection group is at the same level as features, soil sections, design documents, and external design data. This is one of the resources that generates the greatest bulk of information to feed the phases of integrity assessment, risk assessment and integrity planning/maintenance, mitigation, and repair. The inspections bring chronological information on the evolution of the integrity of the pipeline, and its response to the threats. The data collected in the external inspections, such as pipeline geometry (curvature, displacements, etc.), interactions with the seabed (embedment, free spans) allow, with specific treatments, a quick generation of results including low-cost level 1 and 2 analyses. Additionally, the data processing methodologies allows generating input for specific engineering tools and FEA software for a level 3 analysis. In conjunction with survey data, operational informations like pressure and temperature profiles are recorded that allows associating the survey data directly with deformations of the pipeline during the inspection. For the free spans, the variation in length and gaps can be mapped comparing different inspections. The status (active or inactive) of the pipe in relation to supports and crossings can be inferred by analyzing gap results. These integrations are of great value for integrity assessments aiming at a reduction in analysis time for different analysis levels.

External results: Resources to import external results (generated by other systems) have been implemented in the IntegriDutos tool. Results from Finite Element simulations can be imported and combined with the internal level 2 analyses. This provides several benefits, such as an easy comparison and calibration of numerical models that are usually computationally expensive. This feature is very useful for the flexibility of the tool, considering that the sources of information are not unified, and the data are made available in different formats.

4.2 Analyses

As mentioned in the previous subsection, the main products of the external inspections used in the IntegriDutos tool are the pipeline and bathymetric profiles. These data comprise the main input required for the structural analyses for integrity assessment.

Geometry*:* The pipeline profile allows the determination of its actual location in relation to the design route. The transversal measurement of each point of the pipe allows evaluating its lateral displacements between inspections. The starting point in evaluating and monitoring lateral displacements of the pipeline is the as-laid inspection that is the configuration immediately after laying.

Stresses: Using the pipeline profile for each inspection, the curvatures are extracted and then the stresses associated with this deformed configuration can be calculated. Two types of results are generated: Raw and smoothed stresses. A smoothing methodology has been developed and implemented in the IntegriDutos tool, based on the calculation of the curvature distribution error.

Embedment: Using the bathymetric profiles, pipe embedment is calculated with the raw data. Then, smoothed results are generated using special procedures based on statistical distributions.

Free spans: The bathymetric and pipeline profiles are used to determine the free spans distribution. These are mapped for each inspection and can be evaluated over time to determine if mitigation is needed. The vortex-induced vibration (VIV) phenomenon that generates fatigue damage is analyzed by specialized external tools, including FEA software (Abaqus) and specific tools such as the Fatfree software. For this purpose, the IntegriDutos system has a feature to export the input data required by those specialist tools, and then collecting their output to compare with other internal results (e. g. buckling).

Pipe-soil interaction (PSI): Taking the embedment results described above, the IntegriDutos tool employs analytical formulations and statistical treatments to estimate friction coefficients for the different types of soils along the route. Those calculations also employ the information described previously regarding the soil sections and the operational conditions.

Virtual anchors spacing (VAS): Using the information presented above, the tool incorporates a methodology for the analytical identification of lateral buckling locations along the pipeline. Using the lateral displacements, stresses and embedment limits, friction coefficients and pressure and temperature profiles, the buckle locations are identified and the post buckling effective axial force profile is build with the VAS calculated for each buckle along the pipeline.

5 Typical Results

To illustrate the application of the methodologies described above, this section presents some results provided by the IntegriDutos tool for a typical oil pipeline. The tool allows a simple and practical visualization of geometric changes of the pipeline over time (between inspections). Given the design route, geodetic surveys of the pipeline coordinates allow determining its transversal displacement between different inspections. The user can display, together with the pipeline results, the equipment, buckling initiators, crossings, etc. For example, the evaluation of the effectiveness of a buckling initiator can be verified by analyzing geometric data, stresses, temperature and pressure acting during the inspection.

With the calculation of the vertical and horizontal curvatures, the pipe stresses during the inspection can be determined. The smoothing methodology applied to raw field data removes measurement noise; In the Fig. 2 is compared the horizontal stresses before and after the smoothing procedure.

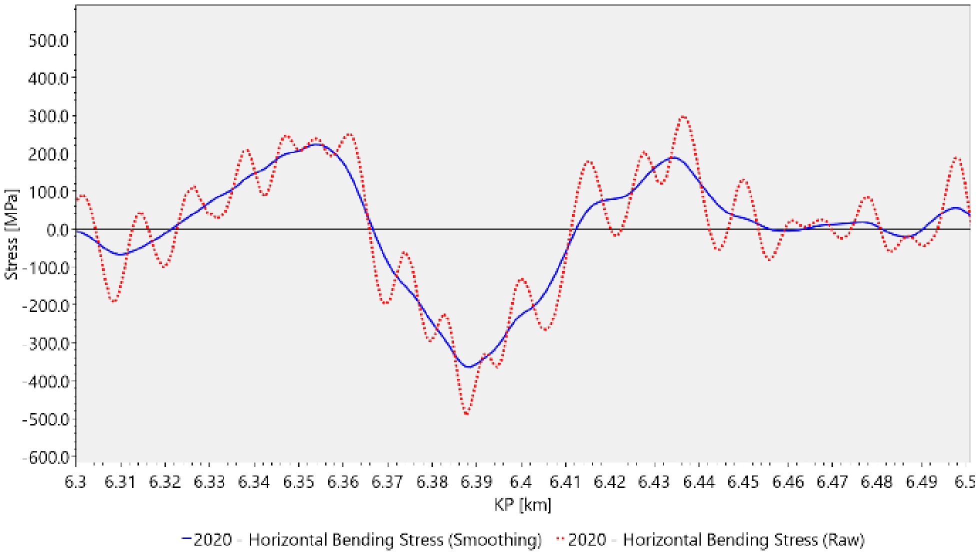

Figure 2. Horizontal stresses: raw and smoothed

As mentioned before, the combination of the data management and processing resources available in the tool allows the identification of points of interest that need a more detailed integrity assessment, becoming a source of information for quick and agile decision making. For instance, in the Fig. 3 is presented a combination of several results such as stress, lateral displacement (or distance cross course – DCC), left and right embedments. One can see that at this point a possible buckling location. Quick unit checks and effective axial force checks (comprising level 1 and 2 assessments) also can be performed, thus evaluating the need for a level 3 analysis. If required, the input data needed for such level-3 analyses to assess for global buckling or free spans and fatigue can be generated. In the case of results provided by other specialist tools are made available, the data can be imported and visualized inside the IntegriDutos tool. Thus, it can be seen that the flexibility of the tool allows for several combinations of results enabling the user to investigate the pipeline integrity increasing the level of complexity if required. Its several modules are integrated to enable these multidisciplinary interactions that the integrity assessment requires, with the advantage of all being carried out within the same tool.

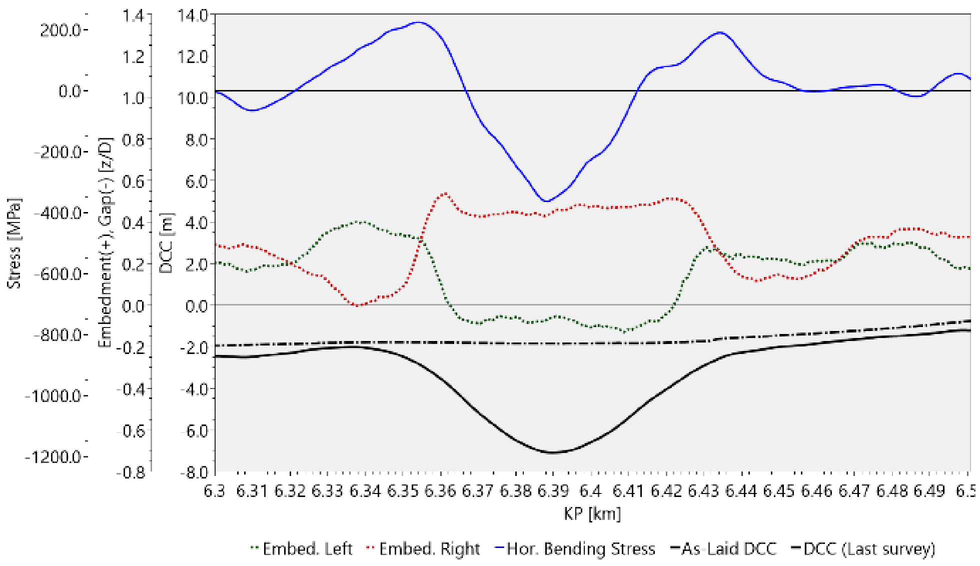

Figure 3. Combined Results

6 Final Remarks

The integrity assessment of submarine pipelines is a complex process, which involves the participation of several professionals, in addition to the application of multidisciplinary knowledge from the collection and processing of data from various sources. It is essential for maintaining the safety of subsea production and flow systems at adequate levels, considering the operational history and the safety levels to obey regulatory requirements.

The development of an integrated software for the integrity assessment of submarine pipelines arose from the need for a tool that could help analysts with the centralization of information, data processing, and the availability of different calculation methods and standardized graphics. These resources allow to combine in the same tool the treatment of information and knowledge of the team, in addition to reducing analysis times.

Once given this challenge, the IntegriDutos system has been developed in incremental stages, and is currently in an intermediate stage of development. The goal is to obtain a robust and efficient tool whose application in real scenarios will provide the following benefits: a) Productivity gains during the processes of evaluating the integrity of submarine rigid pipelines, including the centralization of relevant information from the history of inspections and pipeline operating conditions; b) Generation of standardized technical reports containing results of integrity assessments under operational conditions; c) User-friendly interface to access information on the operational history of the pipelines during its design life; d) Assistance in the integrity assessment of subsea rigid pipeline systems, according to the normative and regulatory requirements; e) Ease in analysis sensitivity of relevant parameters, since it integrates, within the same computational system, resources for data acquisition, information processing and integrated assessments of different engineering analyses.

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