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UPLIFTING THE STUDY OF THE INLINE INSPECTION TECHNIQUE ON THE BUCKLING PIPELINES IN PIPELINE INTEGRITY MANAGEMENT STRATEGY

This work reports the development of inline inspection (ILI) methodology to enhance the pigging activity for the dented pipeline, facilitate the pigging process to prevent Pipeline Inspection Gauge (PIG) from getting stuck and improve the safety passage for buckled pipelines. The recent report unveils the condition of the UNPIGGABLE pipelines, which reduce the inner diameter of pipelines to 257.51 mm, equivalent to 27.58 % of the initial diameter and restricts the pigging activity. In this report, the pull-through test coupled with the collapsibility test was conducted. The success of the test above allows the ILI equipment based on the magnetic flux leakage (MFL) technique to record the internal and external wall loss inwardly and geometric defect on diameter of the pipelines. The prepared artificial dented pipeline was made before it underwent several tests. Based on the pull-through test, the maximum force of 27000 N is more significant than the pipeline operating pressure to enable the MFL tool to pass through the pipelines despite exhibiting the geometry anomaly. Compressing the opposite magnetic yoke of the collapsibility test is critical, showing that the ILI MFL tool reaches its maximum compression of 242 mm. The value is lower than the minimum internal diameter of 257 mm. The ILI results show that the highest metal loss was achieved at 73 % at 15504 m at the bottom of the inspected pipelines. At the same time, the dented area reduces to more than 6 % of the pipelines' nominal outer diameter and imposes the pipe's integrity status to red. The distinctive result of the research can be used to model the future unprecedented pigging process when buckles appear in pipelines

Keywords: pipeline integrity management, inline inspection, internal and external corrosion, pull-through test, collapsibility test, asset integrity, pipeline dent

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1. Introduction

Pipelines are the heart of hydrocarbon delivery, enabling energy distribution to meet national demands. In this instance, the timing of delivery directly relates to the integrity of materials and their corresponding risk [1]. These marine pipelines are partially buried 40 meters below sea level in seabed soil to hinder horizontal and vertical disruption and displacement. However, the major challenge in managing the integrity of the submerged pipelines is the threat of the third party [2–4]. Such external threats can produce compression forces that lead to local stress and undergo plastic deformation. The pipeline buckle becomes the primary issue due to a few cases, including anchor drop and drag from vessel activity. As such, mitigating the threat results in a lower probability of another catastrophic event.

As the subsea pipelines lie in more profound depths of a marine system, the external forces remarkably increase and lead to buckling, fracture, and collapse of pipelines [5]. In addition to the installation flaw of the pipelines, the submerged pipelines also suffer from local dent due to falling objects from the third party, such as anchor drops. When the excessive magnitude of the inward buckle is achieved, the cross-section of the inner diameter of pipelines is reduced. This ovality deformation impacts fluid flow, leading to fatigue issues at specified stress concentration regions [6].

The buckling-related problem has recently gained much interest from the oil and gas industry and has caused consequential accidents. Several scholars have evaluated and investigated the buckling issue and recommended some results of corrective action. In the paper [7], the authors outline the safety issue of the subsea pipelines has a direct correlation with the identification of buckling of pipelines, corrosion and leakage. With such deformation, the authors emphasize that the industry related personnel should reconsider how to tackle such anomalies to minimize the financial consequences. In the paper by [8] described the buckling phenomenon of pipelines and continued with the discovery of the influence of the diameter-to-thickness ratio to better understand the local buckling properties of pipelines [9]. However, it is paramount to consider the effect depth of the dent towards the bending moments for the pressurized pipelines that deliver fluids [10]. The study concludes that immediate corrective action should occur under the compression region instead of the tension region when a dent is evident. Several international standards, such as DNV-OS-F101 [11] and API RP 1111 [12], provide a guideline to determine the capacity of buckling strain. The two standards elaborate on the safety level of the structural assessment for submarine pipelines and the design limit design, construction, and maintenance operation of hydrocarbon pipelines offshore.

In the paper [13] proves that the impact energy directly influences the depth formed, including the effect of strains and residual stresses. The paper of [14] investigates that buckling is identified as local plastic deformation that impacts the pipelines' failure to deliver liquid and gas. They suggest the fitness-for-service (FFS) strategy to gain a profound perspective on the dent severity to prevent crack growth. Moreover, the research of [15] shows the pressure test on the external side effectively evaluates the defect size and initial ovality of the buckling issue.

Despite all success, a method to evaluate the irregularity in the pipeline is critical, and it is worth pointing out the strategy to conduct an inline inspection when the dent is evident. Recently, one of the main oil lines from a leading oil and gas company in Indonesia experienced a local geometry anomaly due to a significant stress concentration. The pipelines have been operating since the 1980s with remarkable oil production. Due to their critical role in delivering hydrocarbon, the pipelines are subject to local assessment. It is reported that the abnormality prevents pigging activity during service life, including cleaning and inspecting tools run in the pipelines. The pipelines deliver the corrosive fluid and have been in service for nearly 40 years. They typically have exceeded their design life of 25 years and are susceptible to material degradation due to ageing and wall thinning.

Although some work has been done, as shown above, to obtain the integrity data to predict the remaining life and corrosion rate of the uninspected pipeline, the broad requirement in terms of PIGGING simulation in dented high oil producers' pipelines is presently not wholly explored.

Therefore, studies that are devoted to gain the deeper understanding on the inline inspection (ILI) technique where the buckle section appears are scientific relevance. It is prime to note that the uniqueness of this study corresponds to the selection of the appropriate technique and assess them in conjunction with their feasibility to allow the PIG tool cleaning the pipelines. This undiscovered technique is rare to be involve in developed strategy in these modern conditions that leads to a practical when the deformation pipe was found. Hence, it is critical to remember that the integrity of dented pipeline remains adequate to guarantee the maintenance plan support the target demand of hydrocarbon energy distribution.

2. Literature review and problem statement

Pipelines are commonly composed of low-carbon steel and are the leading equipment for delivering hydrocarbon from the well to the surface facility for further separation between the upstream industry's oil, gas, and water. Nevertheless, the obligation to regularly inspect and monitor is critical due to external and internal corrosion and how it is mitigated [16].

According to the paper [17], the mechanical properties of the carbon steel materials that make an extensive number of oil and gas pipelines, despite their assessment for fitness for service, should be periodically checked. The paper models the degradation of pipe steel when the design life has nearly elapsed while it requires stability in its mechanical and metallurgical properties. However, the resolved question concerns maximizing the inspection when the defect externally occurs which have not fully explored in this work. The reason is to develop several attempts to ensure the inline inspection successfully removes the necessary deposit and simultaneously obtain valid data related to the thickness of the material.

An option to overcome the relevant difficulties can be to simulate a few tests, which several researchers have elaborated. Initially, the analysis study of [18] proposes that a comprehensive study using laboratory assessment, field tests, and simulations can address the leak in the water pipelines. The research discovers a positive correlation between the collapse deformation and initial collapse pressure. As development in collapsibility tests expanded, the scope of the study progressed to integrate the compression of stress ratio and collapsibility tests on the structural load. The result shows the negative correlation between the strain of the deviator and bond failure, describing how the void ratio directly impacts the water content [19] to address the missing gap of the first two earlier publication.

On the other hand, the combination of pull-through tests and affordable pipeline inspection using wireless fidelity enhances the experience of performing the inspection using intelligent pigging, as reported in [20]. The team reveals that the comprehensive assessment of the pull-through test is critical to hindering the stuck of intelligent pigging. In this instance, there are at least a few steps to consider before the test was conducted and to explored the importance of pull-through test as stated in the earlier publication. The foremost part is to consider the diameter of pipelines, length, and operating condition including the corrosion assessment. The expected test covers to provide the data and record the most possible size and integrity of the pipeline. The success of the test assures the pipeline to be in service.

In addition, the work of [21] considers the frictional force on the sealing disc as a unique feature to consider before running the gauge. In the basic operation the sealing disc intends to provides the accurate information in conjunction to the integrity of the buckle pipelines and to assert the reliability of the operation. The two works unveils the requirement to close the gap event between planning for the inspection and the execution of the ILI practicability. However, it is also critical to consider the mitigation plan of the possible flaw when conducting the pigging activity.

The work primarily emphasizes using a pipeline inspection gauge (PIG) to unveil the defect and provide quick data access. However, difficulties arise when the minimum passage of the PIG is more significant than the dent size of the inspected pipelines. In the paper [22] propose to model the dented pipelines using the load cycles function. The model identifies the series of systems and uses several settings for inspection and repair to negate a minor possible cause of the failure. In the paper [22] propose to model the dented pipelines using the load cycles function. The model identifies the series of systems and uses several settings for inspection and repair to negate a minor possible cause of the failure. While identification of the minor cause of failure is important, the inspection on the welded area of the buckle pipeline is equally essential to consider which may carried issue before the pigging activity is performed.

In the paper [23] investigates how the welding segment becomes the weakest point of the pipelines, which the inspection is critical to mitigate before a tiny crack appears. The earlier two reports limit the discussion on using pull-through tests to ensure that the PIG tools can exfoliate the debris in the inner side of the pipe, including collecting relevant inspection data. Their publication seems to offer the solution to complete the whole critical factors to proceed the pigging activity under specific anomalies.

The discussion on addressing the inspection in the girth weld of submarine pipelines has recently grown. The PIG sealing disk was introduced by [24] using Kelvin spring damping with extra care in their application. The tool's operator strictly observed how various velocities of motions and the change of position can be examined using the shift in vibration. The approach used [25] is comparable to the above development, with an extensive focus on enhancing the deformation of the PIG cup in the reverse way to obtain the finite element model. They claim that the proportional deformation at the axial direction, stress, and interference correlate.

In accordance to the above argument, it is prime to justify that this research intends to model the actual condition of the dented pipeline which can provide a clearance in conjunction to safety PIGGING activity and evaluate the optimum pull force and compression. In this case, the pull-through and collapsibility assessment is ideal to accept the condition of buckle pipeline test before administer the inline inspection and retains the integrity of pipelines.

3. The aim and objectives of the study

This study aims to design tests when the dented pipelines occur externally and provides a comprehensive test to smoothen the process of ILI using Magnetic Flux Leakage tools.

The following objectives are accomplished to achieve this aim:

– to obtain and evaluate the maximum force of pull-through test and compression to attain the stress value in hindering the cracking during the PIGGING activity;

– to simulate the artificial dented pipelines that are identical to the actual pipelines based on the previous geometry pig inspection of the subsea pipelines;

– to provide an inline inspection summary and recommendation for the leak main oil pipelines which rarely inspected after commissioning.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

It is essential to report that the object of this study is a subsea oil pipeline with a material grade of API 5L-X52 having an outer diameter of 14 inches. The pipeline was built in 1983 and has never been inspected using a magnetic flux leakage tool since the line was established. Despite the inline inspection campaign that has been initiated since 2008. The design and current service are main oil lines installed at 40 m below sea level. The wall thickness is 0.5 inches with a corrosion coating of 5/32″ D&W. The pipelines were coated concrete entities with design and operating pressure of 500 psig and 228 psig, respectively, and the result of monitoring is depicted in Table 1.

Table 1

The result of corrosion monitoring

Type of corrodent	Result
H_2S	50 ppm (0.009 psi)
CO_2	1 % (2 psi)
Sulfate-reducing bacteria (SRB)	10 cfu/ml

Table 1 shows the recent result of the internal corrosion parameters to unveil the types of corrodent in the inspected pipelines. It is prime to note that the bacterial count remains low compared to the standard of NACE TM-0194 (2014) [26]. The pipelines are PIGGABLE with water chemical inhibitors injected to reduce the population of high sulfate-reducing bacteria. Despite being under the category of PIGGABLE pipelines, the line remains under red status, which requires immediate repair and replacement to hinder unprecedented failure.

The main hypothesis of the study is that the inline inspection will be able to clean the pipelines when the tool squeezed up with lower than the value of internal diameter of 257 mm. However, the selected test such as pull-through test and collapsibility test are a good combination to unveil the applicability and feasibility of the assessment. It is assumed that the result value of the given test corresponds to the actual measured geometry anomaly pipeline and maximum force of the magnetic flux leakage (MFL) tool to possibly run without breaking. With this simplification adopted in this work, the future work related to the cleaning the pipelines using PIGGING becomes a feasible to conduct.

4. 2. Progressive pigging

The early evidence to conduct the ILI inspection is to ensure the inspection is safe both at the operation and financial. Fig. 1 shows the experiment's schematic diagram to show the PIG launcher's position, dent location, and PIG receiver. Movement of a PIG before, during, and after passing through the dent location is closely monitored to ensure no damage to the sealing disc, sensing unit, and tool odometer.

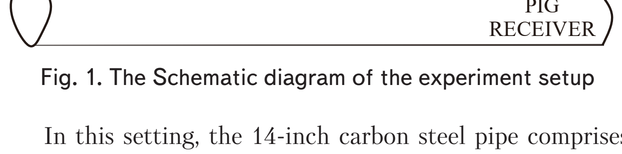


Fig. 1. The Schematic diagram of the experiment setup

In this setting, the 14-inch carbon steel pipe comprises a smooth and rough inner wall of approximately 21.29 km, which was used to assess the eligibility of the pipelines for ILI. The speed of the PIG was forced to flow along the pipe at constant velocity.

Progressive cleaning pigging is required before the inspection tool runs. Certain cleanliness levels of the internal pipe surface will give good data results during the ILI MFL run. Progressive cleaning pigging utilizes a bi-directional PIG, equipped with a brush and magnet. Upon bi-directional PIG arrival at the PIG receiver barrel, the ILI engineer assessed the debris accumulated at the PIG receiver barrel for clearance of the next pig run. In the event of excessive debris, another bi-directional PIG was scheduled to obtain smaller than 10 kilograms of debris, including sand, ferrous material, sludge, wax, and scale.

At the same time, a visual inspection was conducted to verify the condition of the aluminum gauge and unveil possible bent, deflection, or hit marks when the PIG was run. This instance indicates the potential flaw in the inner side of pipelines. In this report, four bi-directional PIGS were used to unveil the condition of the aluminum plate when running inside the pipelines.

4. 3. Inline inspection tool preparation

In this study, the preparation of the ILI was conducted by considering several factors, such as pipeline operating conditions, pipeline geometry, pigging facilities, and pipeline cleanliness, as illustrated in Fig. 2.

Based on Fig. 2, the pull-through test setup was conducted to mimic the actual dent of the pipelines. The artificial diameter represents the actual geometry anomaly in the pipeline during the previous geometry/caliper pig run of the 257 mm cross-section internal diameter.

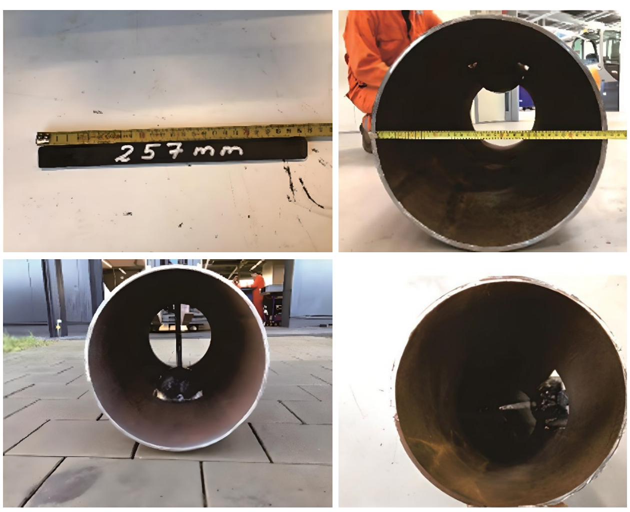


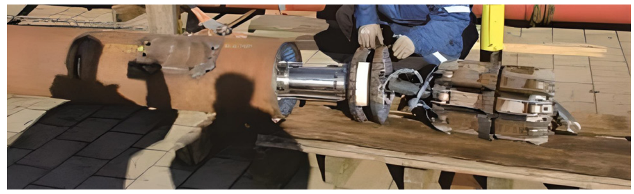
Fig. 2. The simulation of the 14-inch dented pipeline before conducting the pull-through test

4. 4. Pull-through test

Fig. 3 shows the demonstration of the pull-through test to assess the launched inline inspection tool of Magnetic Flux Leakage (MFL) through the pipeline with the artificial anomaly.

In this work, the number of tests was four times to ensure that the ILI instrument was successfully passed through the dented artificial pipelines, as depicted in Fig. 3.

In the initial test, the temporary isolation plug was made to demonstrate the possible fluid to flow before selecting the PIGGING tool with diameter requirement to hinder the stuck of the ILI. The ILI installation includes installing the pigging tool and sensors to monitor and inspect the thinning of the pipelines and analyze the inspection result.



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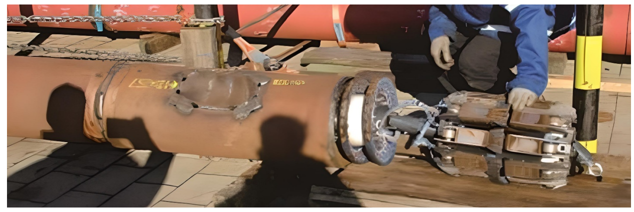

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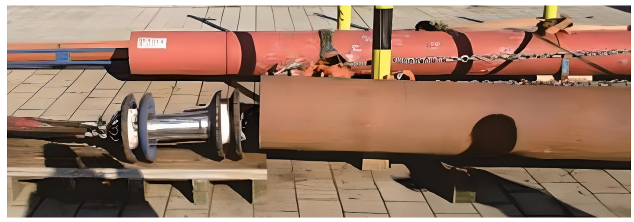

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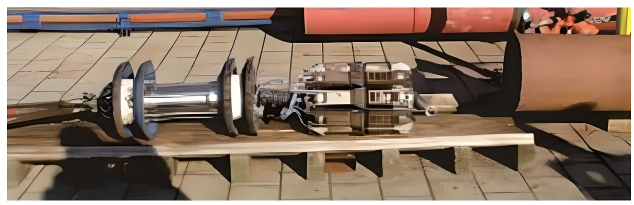

d

Fig. 3. The demonstration of pull-through test: *a* – starting of insertion MFL tools; *b* – 1st MFL module fully inserted into spool; *c* – 1st MFL module completed run through the spool; *d* – all MFL module completed pull-through testing

4. 5. Collapsibility test

A higher confidence in the ILI inspection is required to ensure that the ILI tool incorporates the geometry anomaly. In this instance, the collapsibility test is shown by compressing the opposite magnetic yoke of the inline inspection tool to its maximum squeeze and measuring with a caliper ruler, as shown in Fig. 4.

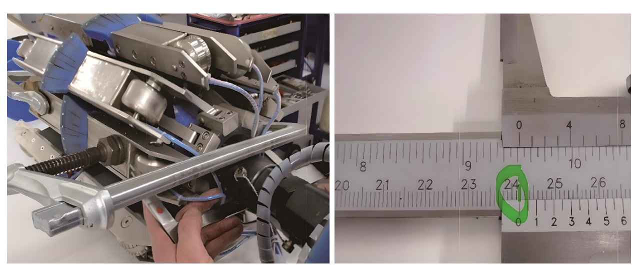

Fig. 4. Collapsibility test instrumentation

The collapsibility test squeezed up to a maximum of 242 mm (Fig. 4). This value is much better than the minimum ID clearance in the artificial geometry anomaly pipe spool for the pull-through test of 257 mm. It indicates that the inline inspection tool can pass through the geometry anomaly in the pipeline safely and with a high confidence level.

5. Results of the inline inspection tool design on the dented pipelines

5. 1. Evaluation the maximum force of pull-through test and compression

The pull-through test is essentially critical to gain understanding related to how the ILI MFL can detect any anomalies such as cracks, corrosion, metal loss, and stress damage. Based on Fig. 5, the profile force records during pull pull-through test is shown in the following graph of force recorded by the time. Monitoring of force profile during pull-through test is important as this force required for the ILI MFL tool squeeze when passing the dent area. If there is no sufficient force and ILI MFL tool difficult to squeeze then probability of ILI tool stuck at dent area will be higher. Further of this risk there will be oil production losses.

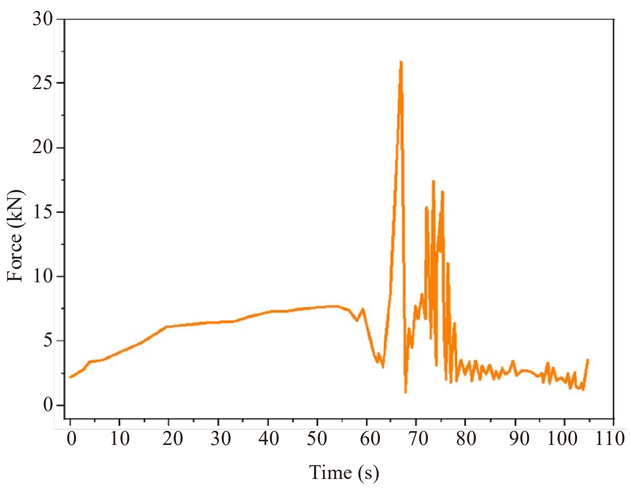

Fig. 5. The profile recorded based on the pull-through test

Based on Fig. 5, the force profile records the various force values in the time range to show the maximum force that can be incorporated when the artificial dent was created. The maximum force was approximately 27000 N, equivalent to 2.7 barg. Meanwhile, the rest of the peak remains significant to show the pressure within the range of force before it drops significantly to less than 5 N after allowing the tool for 94 s. Notably, the collapsibility test results show that the MFL can clean the pipelines as the equivalent stress is below the strength limit and may not cause cracking once the tools can enter the pipelines. The innovation of this work is to develop the simulated spool using the pull-through test with a minimum clearance of inside pipeline diameter of 257 mm, and the intention is to evaluate the smoothness of the PIG travelling within the dented pipeline.

5. 2. Simulation the artificial dented pipelines

As outlined progressive pigging is another critical path to ensure the safety of the inspection tool using the MFL tool. Simulation on several bi-directional PIGs equipped with aluminum plates demonstrates the tool's ability to achieve the pipelines' cleanliness standards. Table 2 shows the result of various runs of the gauging PIGs, and at the same time, the measurement of the outer diameter of the aluminum plate is also depicted.

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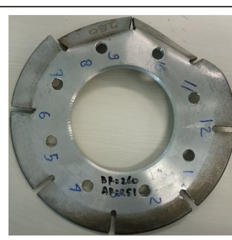
Based on Table 2, a minor outer diameter (OD) aluminum plate post run is 247 mm. The result agrees well with the pull-through test that allows a maximum of 257 mm for the tool to pass without potentially damaging the dented pipelines. In consonance, the tool is permittable and feasible to proceed with the inline inspection based on the post-run OD of the plate after the third simulation.

Standard Bi-directional PIGS are required to be run to remove as much as possible debris accumulated inside the pipeline. If pipeline cleanliness is not sufficient then debris such as wax or scale will cover ILI sensor during the run. This will effect to data degrade of ILI tool on detection capability and sizing accuracy. Bi-directional PIGS will be run several times until certain debris recovered at pig receiver barrel allowed for ILI tool run. Fig. 6 shows debris which sticked on disc of Bi-directional PIGS.

In this instance, there is a rapid deformation of the PIG before and after run in the pipelines. The geometry anomaly of the pipelines allows the PIG disk to follow their shapes when it follows the stream of fluid in the inner side of the pipelines (Fig. 6). It is critical to note that the plate diameter is 247 mm, and the value was received after the bi-directional PIG and the PIG receiver was obtained. The original outside diameter is 254 mm before the run, as depicted in Table 2. Hence, it is possible to note that the minimum pipeline diameter with dent area has a cross-section detected by the plate is 247 mm. The value ensures the ILI-MFL tool can pass through the cross-section area detected by the plate (247 mm) and run smoothly when the collapsibility test is conducted, which has a diameter of 242 mm. Eventually, plate diameter and previous geometry will work for both cases.

Table 2

The simulation of progressive pigging results using an aluminum plate

Bidi+GP run	1^{st}	2^{nd}	3^{rd}	4^{th}
Original OD Al Plate	254 mm	260 mm	254 mm	280 mm
Post Run OD Al Plate	253 mm	251 mm	247 mm	266 mm
Visual				

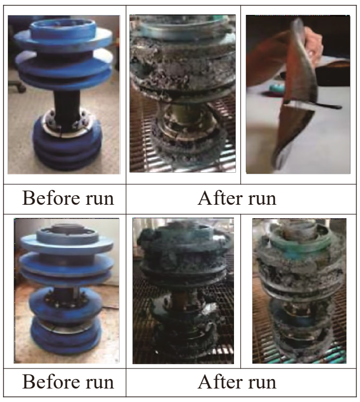


Fig. 6. The results of progressive pigging

5. 3. Inline inspection result

Fig. 7 shows the result of the metal loss distributed when utilizing ILI MFL along the length of the pipelines.

Fig. 7, *a* shows the internal metal loss at the pipe's bottom half over the entire pipeline length. The most profound features accumulate between 13000 m and 16000 m. However, along the pipeline have already experienced by internal metal loss with difference level of loss. Notwithstanding, several girth welds show indications of internal metal loss, reported with the comment 'close to welding'. The most significant location is at log distance 15504 m with a depth of 73 %. Orientation of internal metal loss as shown in Fig. 7, *b* located from 2 o'clock to 10 o'clock position which explain the existence threat of BOLC – bottom of line corrosion (Fig. 7, *b*).

Fig. 8, *a* shows the significant geometric anomaly detected by ILI MFL during the inspection run at 14582 m at 10 o'clock. On the other hand, 10 % internal wall loss is observed at the 02:38 position. This detection reveals that dent is not associated with metal loss. However, the worst internal wall loss above 70 % is near the dent location, as depicted in Table 3. As stated in 5. 2, the diameter of the PIG tool is smaller than the dented area. Therefore, it is essential to note that the success of ILI is secured.

Moreover, the spool test model simulation shows that the dent depth is 98.6 mm with the internal diameter (ID) pipe at 257 mm. Since the result of the actual plate run is 247mm, the collapsibility test has gained a higher confidence level where the ILI MFL can pass through the dented area safely. This fact agrees well with the result of Fig. 4 during the collapsibility test where the ILI tool can be compressed, and the diameter of ILI MFL is squeezed up by 242 mm.

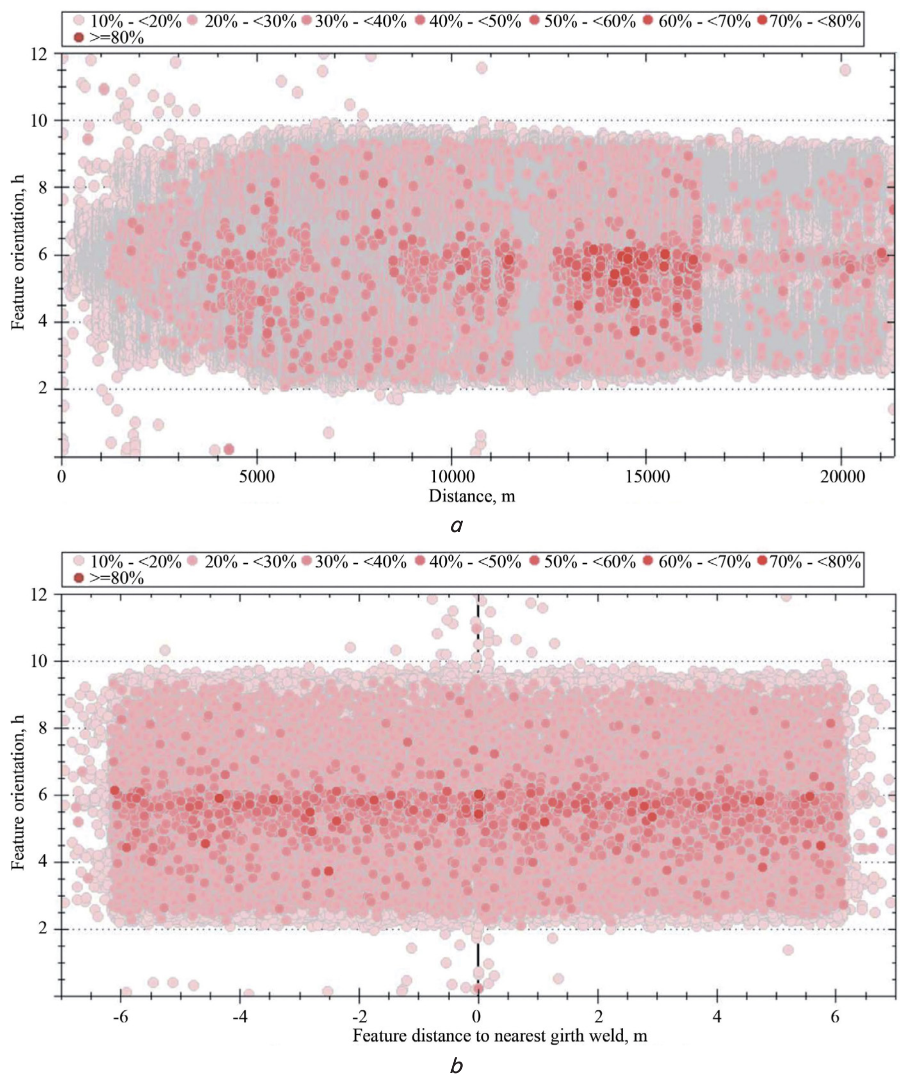
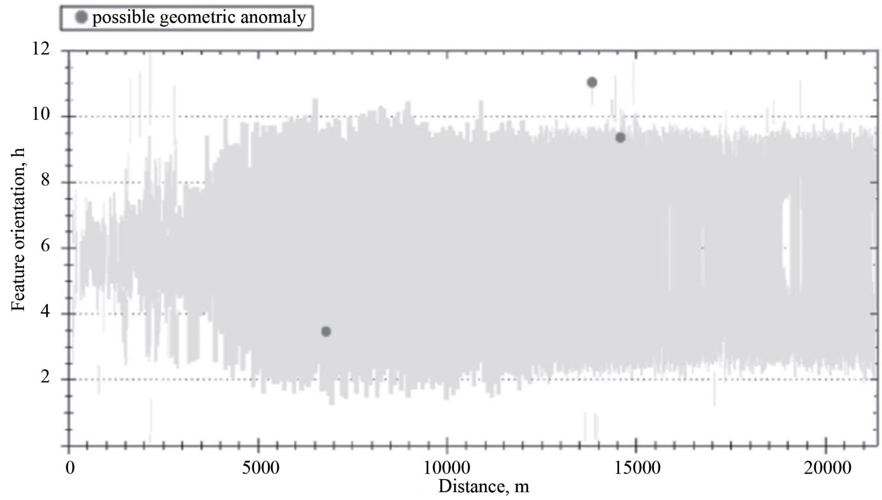


Fig. 7. The inline inspection result: *a* – distribution of internal metal loss over the pipeline length and circumference; *b* – distribution of internal metal loss to closest girth weld and circumference



a

b

c

Fig. 8. The inline inspection result on: *a* — distribution of geometry anomalies over pipeline length and circumference; *b* — the profile PIG tool with multi-diameter aluminum plate size; *c* — the inspection MFL tool condition post retrieval

Table 3

The principal evidence of wall loss based on inline inspection

Location (m)	Amount of internal wall loss (%)	Defect orientation (clock position)	Defect length (inch)
14210.88	70	05:24	0.31
14382.04	72	05:56	0.35
14536.72	70	05:53	2.17
15503.73	73	06:00	0.35

Based on Table 3, the further the location, the higher the amount of internal wall loss, with the orientation near the bottom part of the pipelines. It is predicted that the solid deposition may reduce the fluid flow despite creating a smaller defect length of 0.35 inches. It is a prime fact that the previous wall loss has declined 70 % of the wall thickness of pipelines, which has an identical root cause, although it is the most extensive defect length of 2.17 inches. The inspection outcome is obvious to confirm the result in Fig. 8, *b*, *c*. The solid, comprised of sand, ferrous material, sludge, wax, and scale, is attached to the aluminum gauge plate with a few observable defects (Fig. 8, *b*) with a reported mass of seven kilograms. It indicates that the prepared design in PIGs shows good progress in cleaning the pipelines correctly [27]. On the other hand, the inline inspection MFL tool confirmed that it can safely pass through the known geometry anomaly inside the pipeline, as shown in Fig. 8, *b*, *c*, and a similar result was obtained in [28].

6. Discussion on the inline inspection tool design on the dented pipelines

Progressive pigging has a long-standing reputation for managing the risk of deposition in marine main oil pipelines, as reported in [29]. It is also possible to note that the recovered debris obtains by the PIG tool is nearly ten kilograms which indicates that the bi-directional pig remains in siloes. Based on the identity of the retained solids in the previous section, the PIG is successfully run through the dented pipelines [30]. A total of 412491 indications of internal metal loss are reported, with the deepest one having a depth of 73 %. The extreme metal loss corresponds to the continuous exposure of the pipelines to the transported fluid.

It is generally accepted that several cleaning run of bidi PIGs are required, although the intention to prepare the bidi pig is to run the profile PIG before the final cleaning and inspection process is conducted. The evaluation on the pull-through and collapsibility test shows the maximum pressure remains under acceptable value (Fig. 5). By considering the pipeline operating pressure of around 200 psig (13.7 barg), it has a high confidence level that the MFL tool can pass through the pipeline which has geometry anomaly safely since it only requires 39 psig (2.7 barg) for the MFL tool to be squeezed enough to pass over the dent.

According to Fig. 7, *a,* the most significant defect orientation is at 06:00, which may indicate the most critical wall loss. It can be related to extensive debris in the designated points despite the internal wall thinning [31]. Several girth welds indicate internal metal loss, which was reported with the comment 'close to welding'. The most significant one is located at 15504 m with considerable reduction due to the location within the heat-affected zone (HAZ), where the structure of the pipe material has changed due to the welding process, and thus, the magnetic properties are affected [32]. The poor HAZ exacerbates the corroding pipelines within the buckle region (Fig. 7, *b*).

Table 3 is consistent with the result of Fig. 8, *b*, *c* to show the success of the simulation when utilizing the UNPIGGABLE lines due to geometry anomaly. Most of the orientation of the defect occurs in the bottom region, which explains why the MFL declines the amount of debris. Accordingly, the significant internal loss is slightly bigger than the external wall loss of 58 %, which shows that the UNPIGGABLE line experiences simultaneous defects when inspected at the same distance. It indicates that the pipelines require immediate repair.

However, the work limits its discussion to a few things. This research has not utilized the variation of other types of inspection, such as ultrasonic (UT). The test detects the flaw by sending the specific wavelength imposed on the metallic material. At the same time, it receives the reflected signal to understand the flaw. On the other hand, comparing the UT result to the ILI test would enhance the accuracy of the measurement to determine the maintenance activities. In addition, the disadvantage of the research is attributed to the remaining practical life calculation. The other disadvantage is the utilization of ILI MFL since it exhibits a more stringent condition of the pipeline before a run, such as a cleanliness level of the pipeline so that the UT sensor is not covered by debris, ensuring all pipeline segments are flooded by liquid as UT required couplant, the liquid to transmit and received the signal, and also to avoid echo loss. On the other hand, the use of ILI MFL is more applicable since the MFL working method is based on magnetic flux, which is recorded by its sensor.

One primary solution to remove them is collecting the ILI data and utilizing the ASME B31.G standard to determine the remaining life to ensure the specific treatment is implemented. As such, the calculated value of each flaw point leads to a significant improvement when performing inline inspection for the dented pipelines [33]. While the calculation is essential, using machine learning to demonstrate and devise the schedule to replace material (during the turnaround session) is critical.

In the future, the presented work can be used as a practical model to solve the PIGGING process in the buckle pipelines. With this in mind, the method can also be applied at any pipeline laying condition (underwater/offshore, onshore, swampy). The technique is also applicable to underpin the whole process of underwater pipeline inline inspection.

7. Conclusion

1. The maximum force of the pull-through test is 27000 N and the value has revealed good agreement with the result of the collapsibility test, which allows 247 mm for the tool to run without breaking. With this in mind, the high performance of the tools is promising and repeatable.

2. This work uses the simulation to prepare the magnetic flux leakage (MFL) tool to fit the prepared buckle pipelines. This indicates that the tool allows for running the inline inspection tests even though the inspected pipeline has deformed by about 28 % compared to the actual conditions before commissioning.

3. The majority region that experiences corrosion defects is nearly 15500 m away from the pig launcher and to obtain a moderate amount of debris. Hence, it is inevitable to redo the inline inspection after five years and conduct the cut and replacement scenario due to the quicker thinning rate beyond their initial design.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript contains the data which cannot be made available for reasons disclosed in the data availability statement.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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