Inspection of HACC in Jack-up Rigs

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Abstract:

This study is based on physical experiments, standards/codes, and practical service experiences with non-destructive testing hydrogen assisted cracking on offshore jack-up structures as response to increasing interest in prevention of hydrogen related cracking in high strength steel weldments

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1 Summary

The document focuses on the inspection of hydrogen-assisted cold cracking (HACC) in jack-up rigs, particularly in high-strength steel weldments. The study is based on tests, standards, available literature, and practical service experiences.

Main Conclusions:

1. **Challenges in Detection**: Detecting HACC is challenging due to the size, position, orientation, and nature of the cracks. The current standards and methods often fail to detect these cracks effectively.
2. **Ultrasonic Testing**: Various UT methods were tested, including Conventional Manual UT, Phased Array UT, Total Focusing Method and Phase Coherence Imaging. Each method has its advantages and limitations in detecting HACC.
3. **Need for Standardization**: There is a need for revised approaches and standardization in the inspection methods for transverse indications. The industry could benefit from updated standards that better address the detection of HACC.
4. **Inspector Skill**: The skill of the inspector is crucial in identifying faint signals from HACC. The inspection process should be slow and focused, contrasting with the current ultrasonic standards for weld inspection.
5. **Future Work**: Accurate detection and characterization of HACC and the development of new UT methods, specialized procedures, and updated standards are necessary to improve detection and characterization of these defects.

2 Abbreviations and definitions

ABS	American Bureau of Shipping
ACFM	Alternating Current Field Measurement (ET technique)
DNV	Det Norske Veritas
ET	Eddy Current Testing
HACC	Hydrogen Assisted Cold Cracking
HISC	Hydrogen Induced Stress Cracking
Havtil	Havindustritilsynet
ISO	Internation Organization for Standardization
MT	Magnetic Particle Testing
NDT	Non-Destructive Testing
OS	Offshore Standard
PAUT	Phased Array Ultrasonic Testing
PCI	Phase Coherence Imaging (PAUT technique)
PT	Penetrant Testing
QA	Quality Assurance
QC	Quality Control
RT	Radiographic Testing
SMYS	Specified Minimum Yield Strength
TFM	Total Focusing Method (PAUT technique)
UT	Ultrasonic Testing

3 Introduction

3.1 Background

Inspection of welds in newbuilding yards has been prone to show transverse indications in the weld deposit materials, which may result in extensive repairs during operation of the vessels or delays at the newbuilding facility. Transverse indications may propagate as cracks in service under the influence of hydrogen from the cathodic protection system on jack-up rigs or similar marine structures [1].

An issue for debate is how the welds are inspected during the newbuilding phase. Classification society requirements do currently not reveal this error type, and once found on location with other methods, such as specialized UT procedures or grinding and MT, it results in discussions between the fabricator, vessel owner and classification society on what quality is acceptable, how the welds should be investigated and to which acceptance criteria. The industry could benefit from a revised approach and perhaps standardisation for the transverse indication investigation and implementation of the requirements from the classification societies and authorities.

Methods for detection currently exist, however they are not standardised and difficult to implement in a production as they require grinding of the weld surfaces, stringent procedures and personnel that are specifically educated. Even with the mentioned precautions the transverse indications are difficult to detect, so a method that depends less on the personnel is desired, as well as an investigation method where grinding of the weld profiles can be avoided.

3.2 Scope of work

The purpose of this work is to advise regarding non-destructive testing in connection with fabrication of jack-ups and jack-ups in service. The work involves advice regarding the inspection areas of interest under fabrication and in service, as well as advice regarding the suitable methods for non-destructive testing of hydrogen assisted cold cracking.

The examination of relevant methods for detection of defects from fabrication, is based on a test piece with hydrogen assisted cold cracks.
The test piece has been examined with 4 different ultrasonic methods, where each has shown capabilities for detection of small transversal cracks.

3.3 Objectives

The objectives and organization of the study are as follows:

- Provide advice under which circumstances and which areas are important to inspect during fabrication
- Investigate different ultrasonic methods with the aim to find the most suitable for detection of Hydrogen Assisted Cold Cracking, HACC
- Provide advice regarding inspection methods and critical areas for detection of HISC

4 Inspection of HISC in fabrication

4.1 Introduction

Several non-destructive testing methods exist to inspect materials like carbon steel and high-strength steel. These include Eddy Current Testing (ET), Magnetic Particle Testing (MT), Penetrant Testing (PT), Ultrasonic Testing (UT) and Radiographic Testing (RT). Surface methods are ineffective for detecting fabrication-related HACC, as these are internal and not surface breaking. Thus, only RT and UT can detect these subsurface cracks.

RT excels in detecting voluminous defects but struggles with thick materials and certain geometrical challenges. Therefore, UT is preferable for HACC detection.

Various UT methods were tested in this investigation.

To streamline the tests, they were performed on a plate where the weld was ground flush, so the ultrasonic probes can be placed directly on the weld surface. This ensures optimal detection conditions since the ultrasound interacts perpendicularly with defects.

Four UT methods were selected based on experience and literature: Conventional Manual UT (MUT), Phased Array UT (PAUT), Total Focusing Method (TFM), and Phase Coherence Imaging (PCI).

4.2 Which areas to inspect for HACC during fabrication

During a newbuild construction, areas / materials with a specified minimum yield strength above 450 N/mm^2 should be considered investigated for transverse indications. Welding procedures and variables should be considered and mutually and carefully agreed with the fabricator. Typical areas for inspection of jack-up rigs and windfarm installation vessels would be the leg, spudcan and leg well areas, but some designs also have transverse bulkheads in the hull and cantilever constructions with high tensile strength materials for consideration.

There are several other variables to consider for specifying areas to investigate for transverse indications apart from the yield strength, such as filler material alloying elements, pre- and post-heating, material thickness, weld bead size, hydrogen content in the filler materials etc. This is described in further detail in [2]. Cracking related to HACC from fabrication has been observed in thicknesses of approximately 30 mm and above, where we have identified transverse indications. The materials used in these constructions are generally of significant thickness, and the thicker plates, looking at this as one of the variables, will be more sensitive to problems related to welding, as the cooling rate will increase. The most common problem is in our experience that the welding procedures in the new-building yards are not followed, and if pre- / post-heating is left out, it will normally result in issues with HACC.

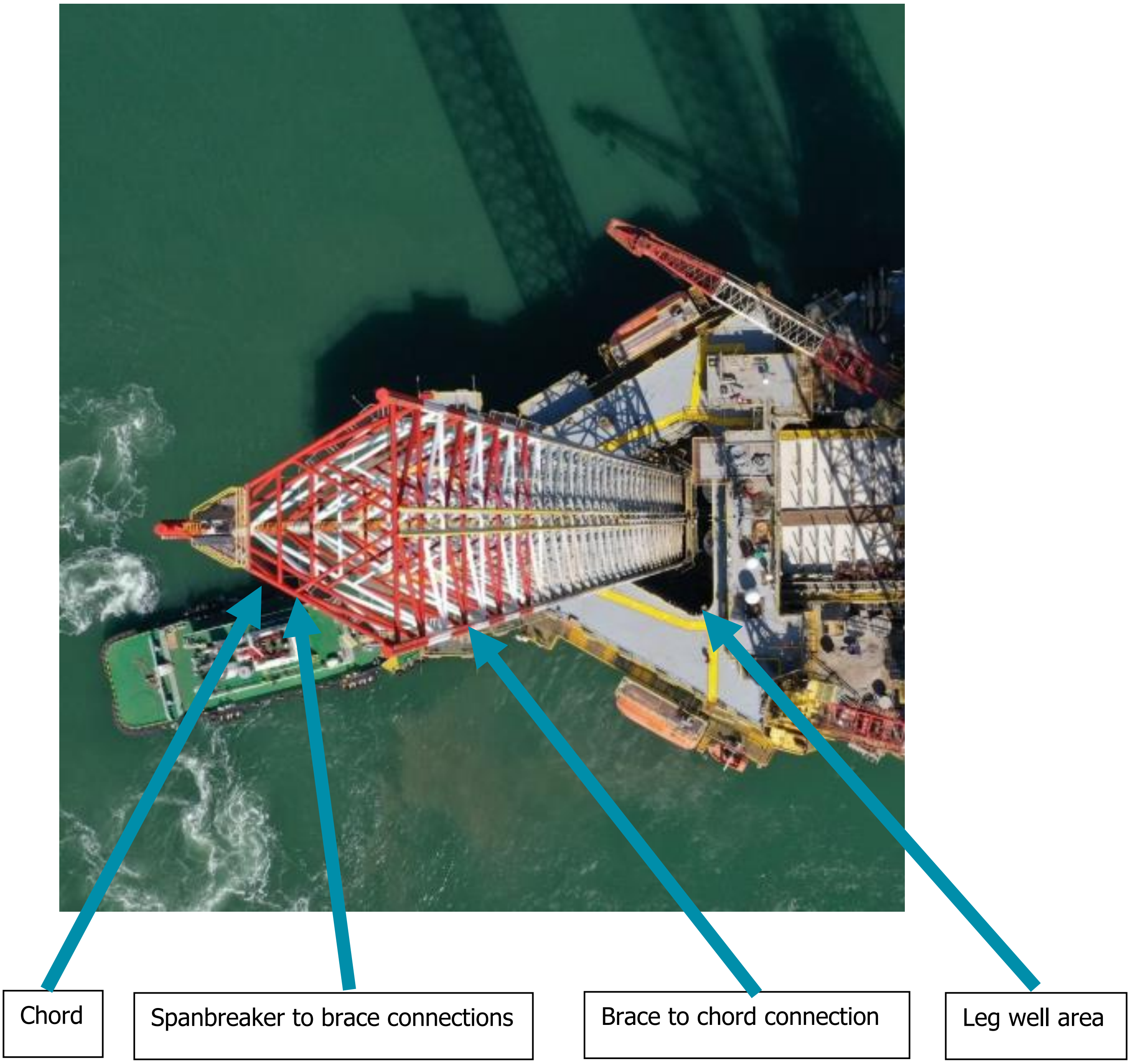

Figure 1 Areas to be considered for transverse indication investigation.

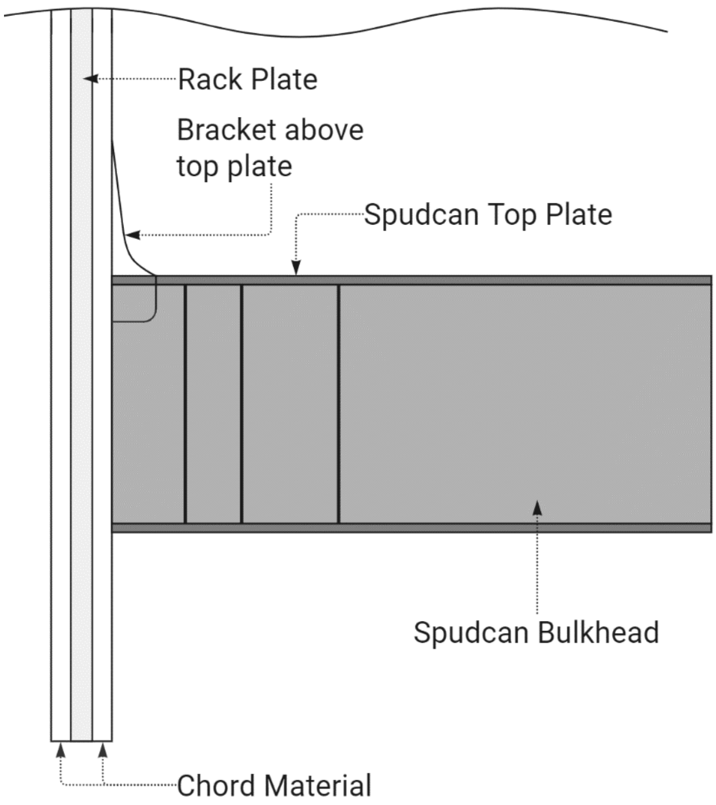

Figure 2 Structural details at the spudcan to leg transition

Areas such as the brace to chord connections, spanbreaker to brace connections, the bracket above the spudcan top plate, the connection between the spudcan bulkhead and chord, the chord itself, the welds between the plates making up the spudcan, are areas that should be considered for transverse indication investigation during newbuild and service / UWILD (Under Water Inspection in Lieu of Dry-docking).

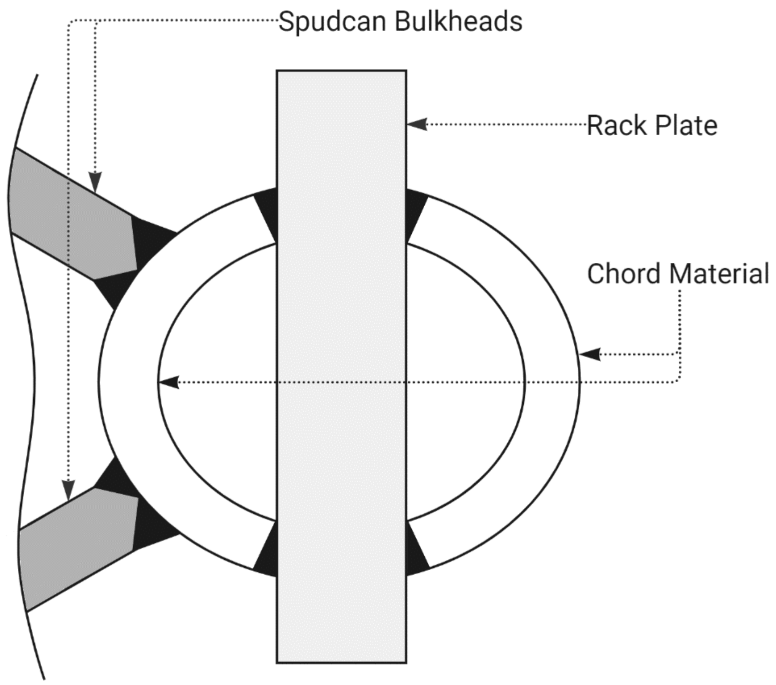

Figure 3 Top view through a jack-up leg showing the position of chord, rack and spudcan bulkheads

4.3 HACC from an ultrasonic perspective

Despite qualified inspectors, ultrasonic method- and acceptance standards applied for detecting both longitudinal and transverse defects including cracks, the HACC is very difficult to detect. The reason for this has primarily two causes:

- The size, position, orientation and nature of HACC
- The test execution and acceptance levels of the available standards

4.3.1 Basics of ultrasonic testing

Ultrasonic testing (UT) is a non-destructive testing method that uses high-frequency sound waves to detect imperfections and characterize materials. The basic principle of UT involves sending acoustic waves into a material and analyzing the wave patterns that are reflected. This is widely used in various industries to inspect welds, detect cracks, measure thickness, and evaluate the integrity of structures.

The process begins with an ultrasonic transducer, which generates sound waves at frequencies typically ranging from 0.5 to 20 MHz, where steel is often inspected in the range 2-10 MHz depending on the material. These waves are introduced into the material through a coupling medium, usually a gel or water, to ensure efficient transmission. As the sound waves travel through the material, they encounter boundaries or discontinuities, such as cracks or voids, and are reflected to the transducer.

The amount of ultrasonic energy is highly related to the size and orientation of the reflector. As a rule of thumb, the larger the reflector the more energy is returning. However, the orientation of the reflector also plays a crucial role. For optimal response the sound should interact perpendicularly to for example a plane reflector. If the reflector is tilted or skewed only a few degrees, the response is significantly reduced.

The reflected waves are then converted into electrical signals and displayed on a screen, creating an image known as an A-scan. The interpretation of these signals requires skilled technicians who can differentiate between various types of reflections and determine the size, shape, and location of defects.

The principle of UT is therefore based on a probe that is transmitting and receiving ultrasound. To evaluate how much ultrasonic energy is received, the received signal is compared to a well-known reflector, often a ø3 mm side drilled hole (SDH). The signal response from a ø3 mm SDH, is referred to as reference level and set to 0 dB on a decibel scale. The decibel scale is seen Table 1.

Table 1 - description of the decibel (dB) scale. The dB response, together with lengths, is used to evaluate the acceptance of indications.

Amplitude Level (dB)	Description
0 dB	Reference Level (Signal response from a 3 mm SDH)
+6 dB	Signal is twice the reference level
+12 dB	Signal is four times the reference level
-6 dB	Signal is half the reference level
-12 dB	Signal is one-quarter the reference level
-18 dB	Signal is 1/8 the reference level, or 12.5 %

The signal response from indications is evaluated relative to the reference level or response from a SDH. The acceptance criteria, i.e. to determine if an indication is accepted or rejected, are defined in terms of the amplitude of the indications relative to the reference level, as well as the length and location of the indications. So, if an indication has a response lower than the acceptance level, the indication is approved.

Several factors influence the accuracy of ultrasonic testing, including the frequency of the sound waves, the material properties and the angle of incidence. Especially the angle of incidence, or interaction angle between sound waves and defects are important related to detection of transverse cracks.

4.3.2 HACC and ultrasound

Ultrasonic testing faces several challenges when it comes to detecting small transverse cracks within the volume of weld material. One of the primary issues is the orientation of the cracks relative to the direction of the ultrasonic waves. When inspecting perpendicular to the weld, i.e. inspecting for longitudinal defects, the transverse cracks are perpendicular to the direction of the wave propagation, which makes them less likely to reflect the sound waves back to the transducer. This can result in weak or missed signals, making the cracks more difficult to detect.

Therefore, the inspection must pe performed perpendicular to the orientation of the defects, which means that the probe should be pointing in the direction parallel to the weld, to increase the probability for detection. This means that the welds should be ground smooth to ensure good contact between probe and object to ensure optimal coupling of the ultrasound into the material.

Small cracks may produce very subtle reflections that could be overlooked, especially if they are located deep within the weld and have a skew or tilt that is unfavourable for ultrasound.

Based on FORCE Technology's experience, we have encountered cracks varying from 3 to 15 millimetres in length and 1 to 5 millimetres in depth. The complexity and shape of HACC contribute to the difficulty in detection. Frequently, the cracks change direction, altering the reflection plane along their length, thereby reducing the reflection area. As illustrated in Figure 1, the cracks can be oriented at any angle from transversal to 45° relative to the axis perpendicular to the weld seam.

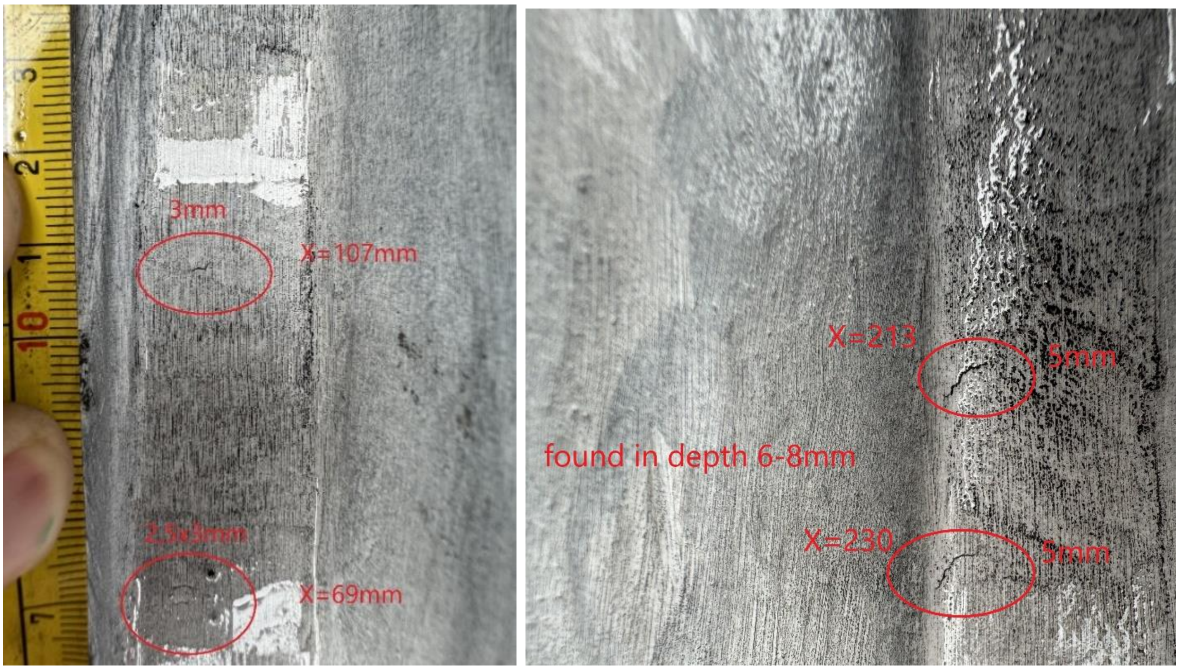

Figure 4 - Images of HACC inspected by magnetic particle testing. The weld material is ground to the depth where indications were detected by UT. The images provide good insight into the shape and size of the cracks.

Due to the placement in the weld volume and the size and nature of the cracks, a low ultrasonic signal response is received from the cracks. This fact means that the skill of the inspector is crucial in identifying these faint signals. Even if the probe is rotated only a few degrees, it can result in the ultrasound not interacting with the crack, and consequently it could be overseen. The inspection of a weld for HACC should be a slow and focused process, which contrasts with the ultrasonic standards used for weld inspection. Furthermore, the inspectors performing the inspection should be educated and trained in the task of finding such defects.

Upon detecting signals, another important consideration arises: How can we ensure accurate characterization of these indications so that a crack is correctly identified as a crack? The inherent nature of cracks presents challenges for inspectors. Since cracks can change direction both along their length and in the depth plane, they are often detectable from multiple probe angles and positions. This technique is frequently employed to differentiate between planar and non-planar indications. An accurate characterization process of HACC could be a future project.

4.3.3 Testing for HACC with available standards for ultrasonic testing

Examinations for transverse defects in welds of high-strength steel are commonly conducted. Welds are often correctly accepted even though HACC is present in the weld. The problem is that the acceptance levels of the approved and commonly used standard, do not reject the faint reflections from the HACC.

Often the response from HACC is in the range between -24 dB and -20 dB compared to a ø3 mm SDH, where the standards used only consider indications above -14 dB. Consequently, all indications originating from HACC are approved or not even considered.

Another issue is that the standards do not require the examination for transversal defects to be scanned on the weld itself, as least not for all thicknesses. By scanning on the weld with beam direction parallel to the weld, the cracks are perpendicular to beam direction which increases the probability for a high response of the defects. Instead, the standards specify that the examination for transverse cracks, to be performed from the parent material with probe direction as perpendicular to transverse cracks as possible. When the ultrasound and defects do not interact perpendicularly, the already small response from the cracks is highly reduced.

FORCE Technology have performed inspection with an in house developed procedure designed for examination of HACC using manual UT. In former approved welds, based on standards, we found numerous indications characterized as HACC. Before verifying the results by grinding and performing magnetic particle testing, we conducted the examination again, but with the standards used initially. We also approved the weld according to these standards.

Hence, the applied standard does not reject the presence of HACC in high-strength steel welds.

To detect and characterize HACC, new UT methods, specialized procedures and updated standards must be considered.

4.4 Description of ultrasonic methods used in study

The non-destructive testing of the test object was conducted using four different ultrasonic methods. In the following a brief description of each method is given.

4.4.1 Manual Ultrasonic Testing (MUT)

This technique is widely used in various industries to inspect welds, detect cracks, and measure thickness.

An ultrasonic single crystal transducer is capable of both transmitting and receiving ultrasonic waves. The frequencies used in steel structures typically ranging from 1-10 MHz.

The transducers only generate one angle, so often it is necessary to do the inspection with 2-3 probes, according to standard, with angles ranging from 45° to 70°.

The probes are available in various sizes to suit different applications. A significant advantage of conventional transducers is that small footprint probes are well-suited for transverse examinations when placed directly on the weld, as their small size minimizes coupling issues. However, these probes come with the limitation of having only one angle and therefore cover a limited volume. Therefore, an accurate scan pattern is essential to ensure comprehensive coverage of the inspection volume.

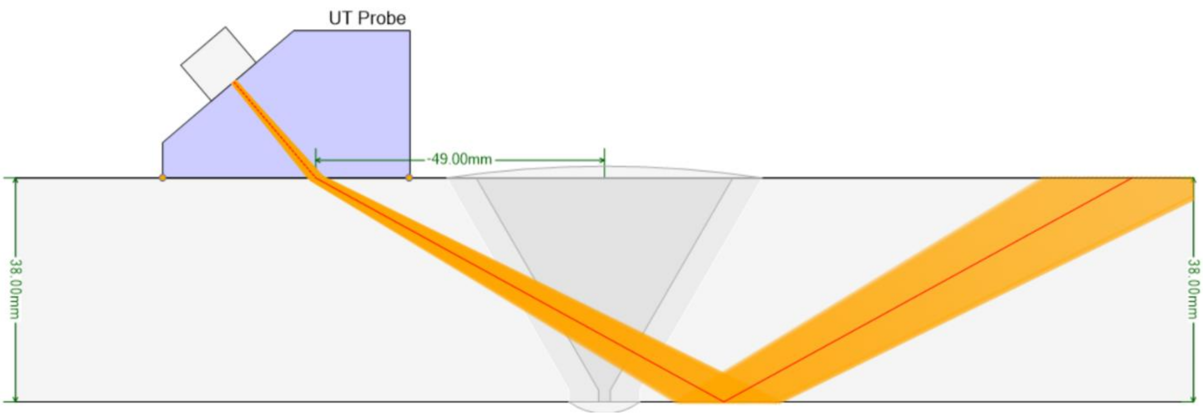

Figure 5 – Beam profile of a shear wave transducer. The yellow represents the area to which the sound pressure is decreased by 50%.

The interpretation of ultrasonic signals is critical for distinguishing between different types of reflections and determining the size, shape, and location of defects. Nevertheless, the success of MUT, particularly in detecting HACC, is highly dependent on the inspector's experience and expertise.

4.4.2 Phased Array Ultrasonic Testing (PAUT)

Phased array ultrasonic testing is an advanced form of UT that uses multiple transducer elements, each independently controlled to emit sound waves at specific times. This allows for dynamic focusing and steering of the ultrasonic beam, enabling the technician to inspect a larger area with greater precision. PAUT can produce high-resolution images and is particularly effective in detecting complex defects in welds and other materials. The ability to adjust beam angles and focal points in real-time enhances the accuracy and comprehensiveness of the inspection.

Especially the generation of multiple angles at the same time is beneficial for detection of HACC, since the probe is covering a larger volume. On the downside, the phased array probe has larger footprints which can result in coupling issues when inspecting on the weld.

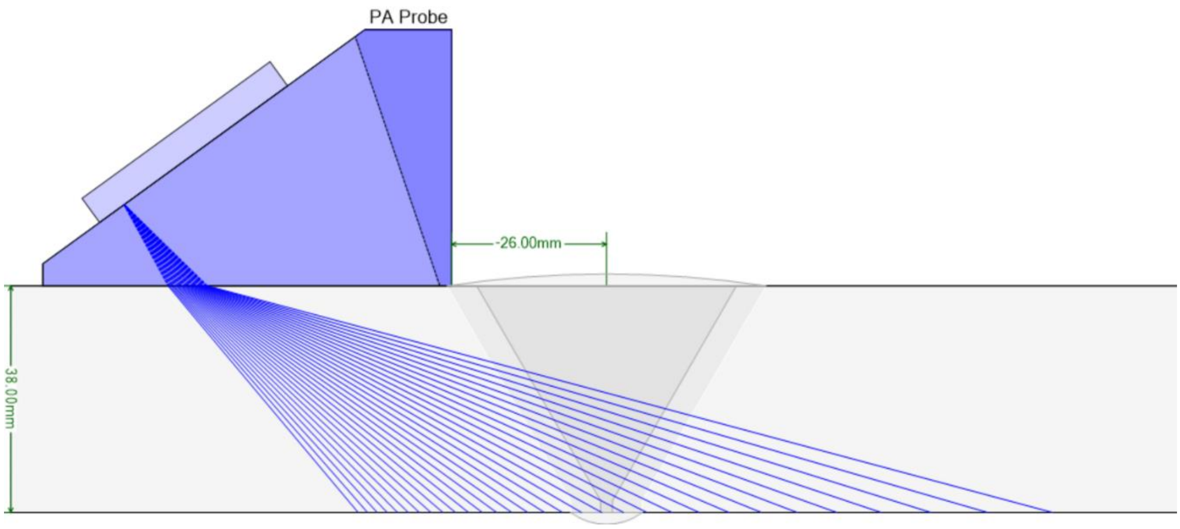

Figure 6 – phased array probe with angles from 40° to 70°. It is seen that the beams cover a large area.

4.4.3 Total Focusing Method (TFM)

The total focusing method is an imaging technique that further refines the capabilities of PAUT. TFM uses the full matrix capture (FMC) data acquisition approach, where every element in the phased array transmits and receives signals independently. The data is then processed to create a highly detailed image of the inspected area. TFM provides superior resolution and defect characterization, making it a powerful tool for identifying and evaluating flaws that might be missed by conventional UT or even standard PAUT.

4.4.4 Phase Coherence Imaging (PCI)

Phase coherence imaging is another advanced ultrasonic method that enhances defect detection by analyzing the coherence of the ultrasonic waves. PCI focuses on the phase relationships between signals received by different transducer elements in the phased array probe, allowing for improved identification of small or weak reflectors. This technique is the only method that does not rely on amplitude, which can be beneficial since the response from HACC is weak. This technique is particularly useful in materials with high background noise, where conventional methods might struggle to identify flaws. PCI can increase the reliability of ultrasonic inspections by providing clearer and more accurate images of the material's internal structure.

4.5 Examination of test object with HACC

To investigate the different ultrasonic methods' capabilities of detecting HACC, we borrowed a test object which was cut out from a structure where HACC has been an issue. The test piece had to be delivered back in same condition as received, and verification of HACC was not possible with other techniques.

The test object is 38 mm thick and has a length of approximately 400 mm. The weld is ground flush, with small geometrical variations along the weld due to grinding. The material is high strength steel 690 N/mm^2.

The test object is "blind", in the sense that the amount, sizes orientations etc. of the HACC in the test object is unknown. Consequently, it is not possible to have an exact evaluation of each method, since we cannot verify the findings with destructive testing. Digital RT was performed on the object with poor result.

The testing has therefore been a comparison between each method, with the aim to find the most suitable and objective method for detecting HACC.

Figure 7 – The test object containing HACC.

4.5.1 Methodology

Manual UT was performed with various probes, varying in size, frequency and angle of incidence. The tests were performed with available acceptance standards, as well as the FORCE Technology prepared procedure.

Phased array UT was performed with angle span from 40° to 70°, using both a 5 MHz and 10 MHz probe. Small phased array probes were chosen, to minimize the footprint ensuring as good contact as possible. All indications 6 dB above noise level from the material have been evaluated.

Both for manual UT and Phased array UT, the probe was handheld, making it possible to twist the probe in zig-zag patterns.

TFM and PCI have been conducted with a 64 element 10 MHz probe. Both testing methods use the same setup, where TFM is amplitude based, and PCI evaluate the phase of the signals. In both cases a 0° and angle beam wedge, optimized for angles in the range 40 to 70° (fig. 6) have been used.

For the case of TFM and PCI, data was collected semi-automatically, where scanning was performed along the length of the weld in multiple line scans, separated 2 mm. The probe direction was parallel to the weld.

4.5.2 Test Results

4.5.2.1 Manual UT

Manual UT was conducted by two independent inspectors, both possessing substantial experience and knowledge in ultrasound inspection techniques. The first inspector, who lacked specific experience in detecting HACC, inspected the test piece following ISO 17640 [1] with the most stringent acceptance criteria per ISO 11666 [2], and reported no indications. Following this initial examination, the inspection was repeated utilizing the FORCE Technology procedure developed for HACC detection, resulting in six unacceptable indications according to this procedure. The acceptance criteria was defined as - no linear indications acceptable.

Similarly, the inspector experienced in detecting HACC identified 8 indications using the FORCE procedure, yet none of these were classified as reportable under ISO 11666 standard.

According to standards, no reportable indications were detected in either case, meaning that all indications were below -14 dB. In fact, most indications were below -20 dB.

Manual UT results reveal two key findings: available standards are inadequate for detecting HACC due to low defect response, and a high level of inspector education specifically for HACC detection is crucial, even with specialized procedures.

4.5.2.2 Manual Phased Array

Phased array was conducted manually with the possibility to twist the probe like MUT and was inspected with same acceptance level as FORCE procedure.

Even for the smoothly ground test piece, there were places where coupling between probe and surface was poor, however the benefits of using phased array was significant.

The large angle span, here 40° to 70°, resulted in a large volume coverage, making it possible to see more indications at the same probe position, see Figure 8. This makes it less likely to miss indications. Another benefit was the inspection time was decreased significantly.

Phased array technology faces a similar challenge as MUT, in which the signal response from defects often falls below acceptance standards. However, the use of multiple angles in phased array makes it more likely to achieve a larger response from cracks, as the interaction angle between the defect and sound can be optimized, rather than being restricted to the individual angles generated by conventional probes.

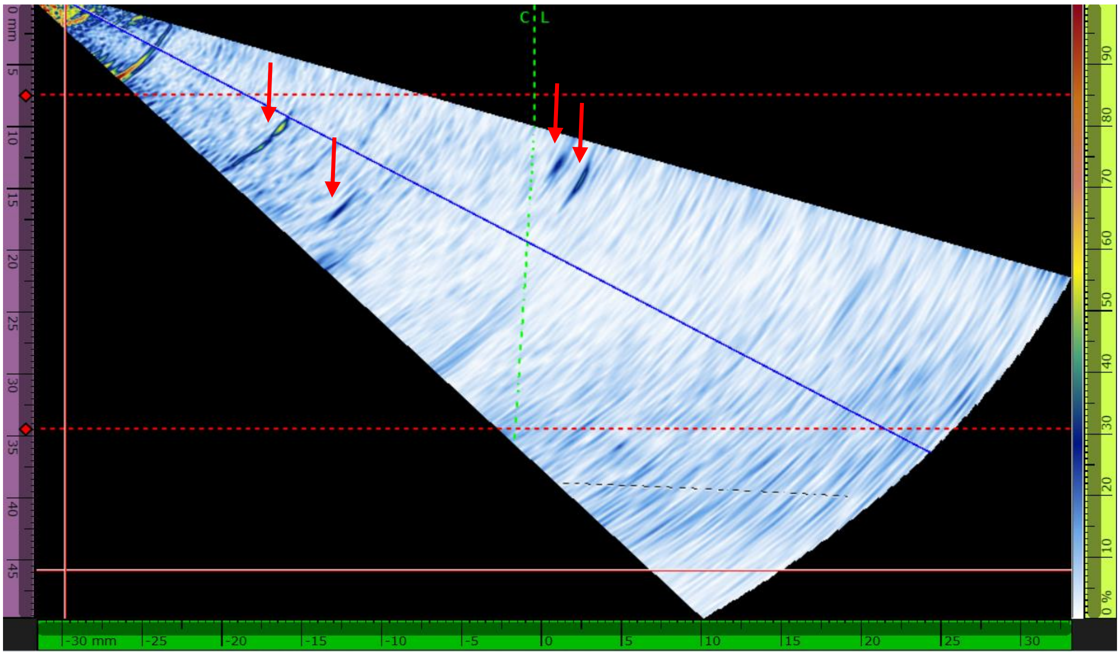

Figure 8 - Sector scan from phased array probe at probe position x=145 mm from end of plate. It is seen from the image (marked with red arrows), that 4 indications are presented.

4.5.2.3 TFM and PCI

TFM and PCI share the same setup and are the data collection is conducted mutually, but the signal processing of the incoming signals is different in the two methods. TFM processes the amplitude of the received signals, where PCI processes the phase of the signals. Both methods are from a theoretical point promising at detecting small signals.

Data was collected semi-automatically in multiple scan lines. Note, that due to limitations in the software which do not support transversal probe positions, the data is displayed incorrectly. However, the data presented in Figure 9 still gives a good overview if the capabilities of the methods.

Figure 9 shows data for both TFM and PCI. The upper part of the image is TFM (blue colours), where the lower part of the image is PCI (grey colours). The x-axis in the image is the length of the weld, and the y-axis is the beam width in the transverse direction. Note, that the indications in the image, visualized as colour differences, are displayed as lying in the longitudinal direction, which is not the case, but is due to software limitations.

Comparing the two methods, the indications using PCI technique stands out much clearer than the TFM method. The amplitude based TFM technique suffers, like MUT and phased array, from low signal response which gives a low signal to noise ratio.

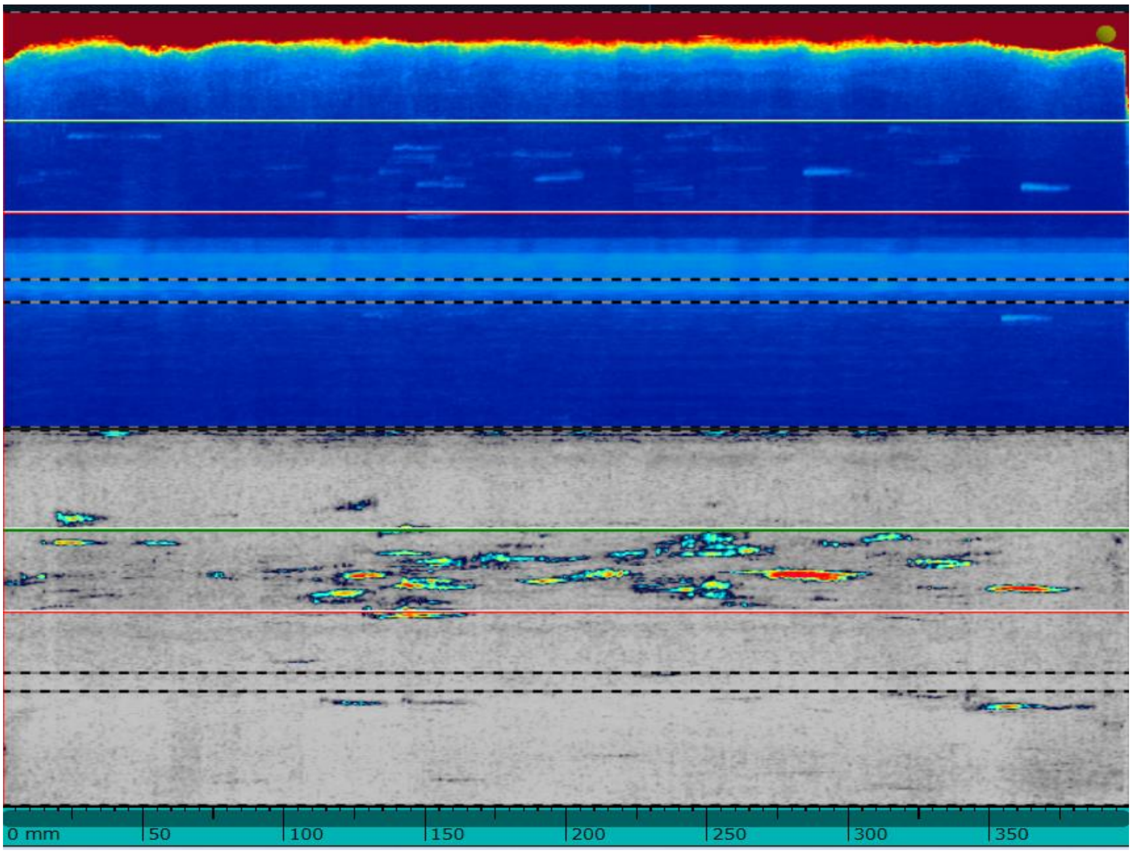

Figure 9 – Data from TFM (above) and PCI (below). Note that the data is not displayed correctly. The colour differences illustrate signals from indications in the weld.

The many indications detected by PCI, give rise to the question if all indications are due to HACC, or it could be porosity or just the small impurities from the welding process. To investigate this, a reference scan at another transversal position in the weld was made, where no indications were observed with neither MUT nor PAUT, which was also the case for PCI. However, a clear characterization process for these types of indications must be developed.

Comparing PAUT and PCI at the same position in the weld, see Figure 8 and Figure 10, it is seen that PCI detects more indications than PAUT.

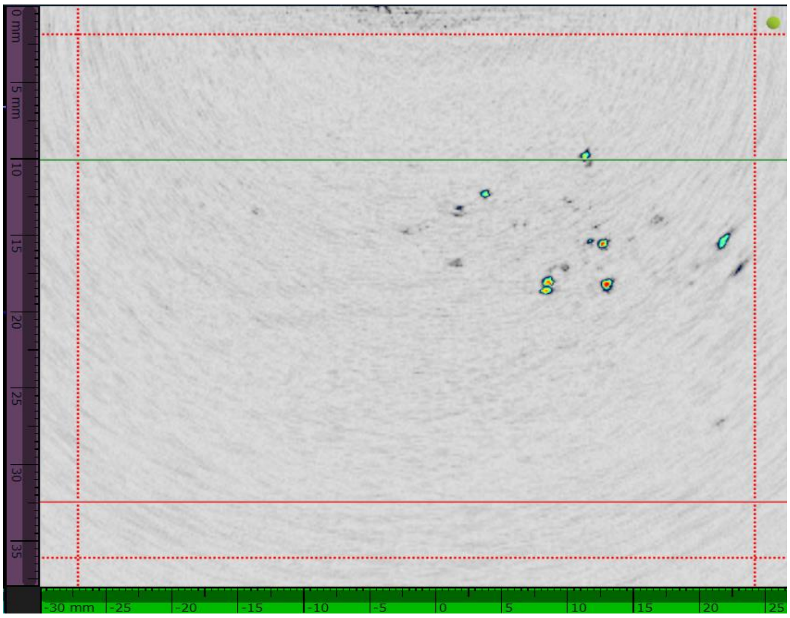

Figure 10 – PCI image at the same location as for the phased array probe, shown in Figure 8.

4.6 Conclusion from test results

The test from manual UT results reveals two key findings: available standards are inadequate for detecting HACC due to low defect response, and a high level of inspector education specifically for HACC detection is crucial, even with specialized procedures.

Phased array testing showed a higher detection capability than MUT and was easier and less time consuming to perform. The signal response from the cracks could be optimized, however the amplitude was still not high enough to be rejected by standards.

The test results from TFM/PCI indicate a significant difference in the performance of TFM and PCI techniques. TFM, which relies on amplitude-based signal processing, showed limitations similar to traditional MUT and phased array methods, primarily due to low signal response and a poor signal-to-noise ratio. On the other hand, PCI, which processes the phase of the signals, provided clearer indications and demonstrated a higher sensitivity to detecting potential defects originating from HACC in the weld.

While PCI shows promise as a phase technique, its practical application is hampered by the lack of established standards and the need for further work on characterization. Conversely, TFM does not appear promising, at least with the setup used for the tests, due to its low signal response.

4.7 Future work

Future efforts should focus on the development of standards, characterization procedures, and acceptance criteria to enhance the reliability and applicability of ultrasound, including conventional UT, PAUT and PCI in detecting HACC.

Development of a method to inspect the weld from the parent material to avoid grinding of the weld, is also very important.

5 Inspection of HISC in service

5.1 Introduction

Under wrong circumstances, described in the report "Hydrogen assisted cracking of jack-up installations" [3], fabrication-related HACC can grow and eventually during service develop into which are larger and surface breaking cracks (HISC). The inspection methodology on the larger cracks differs from the technique for detection of HACC, but in return, the inspection for HISC must be performed while the jack-up rigs are in service. This means that subsea equipment maneuvered by an ROV must be used for the inspection, which limits the accuracy of the positioning and maneuvering of the equipment.

5.2 Areas of interest for inspection of HACC in service

Cracks have been identified in various connections, including brace to chord connections and chord to chord connections. However, they are more frequently detected in the spudcan region, both on the brackets above the spudcan and below the spudcan top plate in the chord to bulkhead welds. These cracks gradually propagate over time during operation, leading to significant crack lengths.
During operation, wetted areas / wetted materials with a yield strength above 450 N/mm^2 should be considered investigated for transverse indications. Typical areas for drilling rig and windfarm installation vessels would be the part of the leg, spudcan and wetted leg well areas.
It has been noticed that investigations with ACFM (eddy current) of the weld materials have not revealed the cracks occurring in operation, and it should be considered to include the chord plates and bulkhead in the investigation scope to ensure that the cracks have not propagated. This, combined with UT detection should be considered as a baseline for UWILD investigations.

5.3 Inspection methods for detection of HISC

Subsea inspections differ fundamentally from those conducted above water. The NDT tool must be deployed using an ROV, which often restricts the accuracy of positioning. Despite the availability of cameras for remote monitoring, detecting minor geometric variations on surfaces can be challenging which also complicates the positioning. Moreover, marine growth frequently complicates these inspections.

All equipment used for NDT mentioned earlier can be used underwater with the appropriate precautions. Some useful automated methods for detection of HISC are already in use subsea, including PAUT, conventional UT and Alternating Current Field Measurement (ACFM).

The detection of long surface breaking cracks, or even larger subsurface cracks, can be inspected with current available equipment, and using available method- and acceptance standards.

For surface breaking defects both ACFM and UT/PAUT can be used. If the geometry of the object to be tested does not allow for inspection in skip (i.e. use the back wall to reflect in order to inspect the outer surface), a wave type called creep waves is used. Creep waves are a type of ultrasonic wave that propagates along the surface of a material, just beneath the surface. They are particularly useful for detecting surface-breaking cracks, as they are highly sensitive to these defects while being relatively insensitive to surface conditions like coatings or rust.

ACFM is frequently employed for the inspection of surface-breaking defects. While ACFM is highly sensitive to detecting cracks, it can also detect geometrical variations such as those found in welds. Consequently, as with any testing method, it necessitates highly skilled inspectors to conduct evaluations accurately. Without proper training, there is a risk that even significant cracks may be incorrectly attributed to geometric features.

For sub-surface cracks UT is the only applicable method. With the proper equipment the principles and testing methods described in section 4 can be used.

Visual testing performed by educated operators is also available. Often cracks on coated surfaces can be observed by cracks in the coating, however the presence of the crack must be confirmed by other methods. For an uncoated surface, where the cracks are not open, it is impossible to see visually.

6 Conclusions

The inspection and analysis of hydrogen-assisted cold cracking (HACC) in jack-up rigs have highlighted the critical importance of using advanced non-destructive testing methods. The study has shown that traditional inspection techniques conducted in accordance with available standards, are not sufficient to detect the subtle and complex nature of HACC, which can lead to significant structural integrity issues if left unaddressed. The findings emphasize the need for a revised approach to inspection standards, incorporating more reliable and sensitive methods such as advanced ultrasonic testing methods to ensure the early detection and mitigation of these defects. By adopting these improved practices, the industry can enhance the safety and longevity of jack-up rigs and similar offshore structures, ultimately contributing to more reliable and efficient offshore operations.

The ultrasonic tests conducted on the test piece revealed the necessity for highly skilled operators to detect fabrication-related HACC with the use of manual UT. To make the examinations more objective and less operator dependent the use of PAUT is beneficial. PAUT showed a higher detection capability with reduced inspection time but requires a smooth weld due to the larger footprint of the probe.
PCI shows promise for detection of HACC, however its practical application is hampered by the lack of established standards and the need for further work on characterization of defects. PCI can initially be used as a screening technique, to quickly have an overview of the weld condition.
Conversely, TFM does not appear promising, at least with the setup used for the tests, due to its low signal response and signal to noise ratio.

For detection of HISC cracks propagating during service, the effectiveness of NDT methods, particularly ACFM and UT, in detecting surface-breaking and subsurface cracks in subsea environments is reliant on the proper deployment and skill of the operators. The unique challenges posed by marine growth, remote monitoring limitations, and geometrical variations of the test object are difficult to monitor, necessitating a well-planned inspection conducted by skilled operators. It is imperative to expand the scope of investigations to include critical areas such as chord plates and bulkheads to ensure comprehensive crack detection and prevent progression into base materials. Combining multiple methods and adhering to stringent standards will significantly enhance the accuracy and reliability of subsea inspections, thereby ensuring structural integrity and safety.

7 References

[1] "ISO 17640 - Non-destructive testing of welds - Ultrasonic testing - Techniques, testing levels , and assessment," 2018.

[2] "ISO 11666 - Non-destructive testing of welds - Ultrasonic testing levels," 2018.

[3] 323-20070-002, "Hydrogen assisted cracking of jack-up installations," FORCE Technology Norge, Rev. 3, 2024.

[4] K. P. Fischer and T. Sydberger, "In-situ Testing of Cathodic Protection on the Northern Norwegian Continental Shelf," in *NACE CORROSION*, 1984, paper no. 344.

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