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Epoxy Helicoid Sleeve for Conductor Casings: An Approach to Enhance Structural Integrity and Corrosion Resistance in Offshore wells

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Abstract

Corrosion poses a significant challenge to the integrity and longevity of offshore structures, more severely will be at the splash zone environment. This is the zone where both marine and atmospheric conditions converge exposing structures to corrosive blend of seawater, waves, tidal actions and different atmospheric conditions.

A combined effect of metocean current due to high water depth, well design architecture and mechanical upward forces plays a significant role in the corrosion rate in conductor casings across the splash zone.

The corrosion rate according to Byron F. (Materials Performance Journal 2020); is highest across the splash zone ranging from 0.8 to 1.0mm/yr. with the least corrosion rate being at the subsoil zone ranging from 0.05 to 0.35mm/yr.

The Epoxy Helicoid solution is designed to address structural integrity and corrosion challenges in conductor pipes, the solution combines the benefits of epoxy coatings and helicoidal reinforcement to create a robust and corrosion-resistant system. The epoxy coating acts as a barrier against corrosive elements, while the helicoidal reinforcement enhances the structural strength of the conductor pipes, reducing vulnerability to external forces such as waves and currents.

The potential for increased service life and reduced maintenance costs presents a compelling case for the widespread adoption of this technology in offshore drilling operations.

In conclusion, the Epoxy Helicoid Solution emerges as a promising strategy to effectively mitigate conductor corrosion at the splash zone, contributing to the ongoing efforts within the offshore industry to enhance infrastructure durability and reduce maintenance costs in corrosive environments.

INTRODUCTION

Offshore platforms, the workhorses of the oil and gas industry, operate in a hostile environment. Among the most critical threats to their integrity is corrosion, a relentless process that eats away at exposed metal structures. This challenge is particularly severe at the splash zone – the area perpetually subjected to the alternating onslaught of air, seawater, and salt spray. This paper delves into the corrosion issues faced by offshore platform operators, focusing on the well conductor, a vital component exposed in the splash zone, and the disastrous consequences of conductor failure.

The splash zone is a unique and unforgiving environment. Here, the steel structures are constantly subjected to a dynamic cycle. During high tide, the platform is submerged, exposing it to oxygenated seawater, a potent electrolyte for corrosion. As the tide recedes, the exposed metal dries, leaving behind a concentrated brine film rich in chlorides, further accelerating corrosion. This continuous wetting and drying cycle, coupled with the abrasive action of waves and wind-driven salt spray, creates an ideal breeding ground for electrochemical reactions that break down the steel.

The well conductor plays a crucial role in offshore drilling. It's a large-diameter steel pipe that guides the wellbore through the platform legs and protects it from the surrounding environment. Conductors are also designed to take the weight of the casings, surface equipment, tree, and internal fluids. During drilling, workover, entire life cycle of the well, the conductor must take the weight of the blow out preventer or the wellhead and associated Christmas tree.

To preserve the integrity of these conductors throughout the asset lifetime, it is critical to recognize the expected load to be carried by the conductor, to understand how corrosion affects the conductor load bearing capability and to anticipate methods of rehabilitation and maintenance (Spuskanyuk et al. 2018). Preserving the integrity of the conductor is essential in making sure an uninterrupted and safe production can take place.

The well conductor is a prime target for corrosion at the splash zone level. Its lower section is constantly submerged, while the upper section experiences the harsh wetting and drying cycle. This dual exposure makes the conductor highly susceptible to various corrosion mechanisms, including pitting corrosion. This highly destructive form of attack creates deep, localized holes in the conductor wall, weakening its structural integrity as shown in Figure 1.

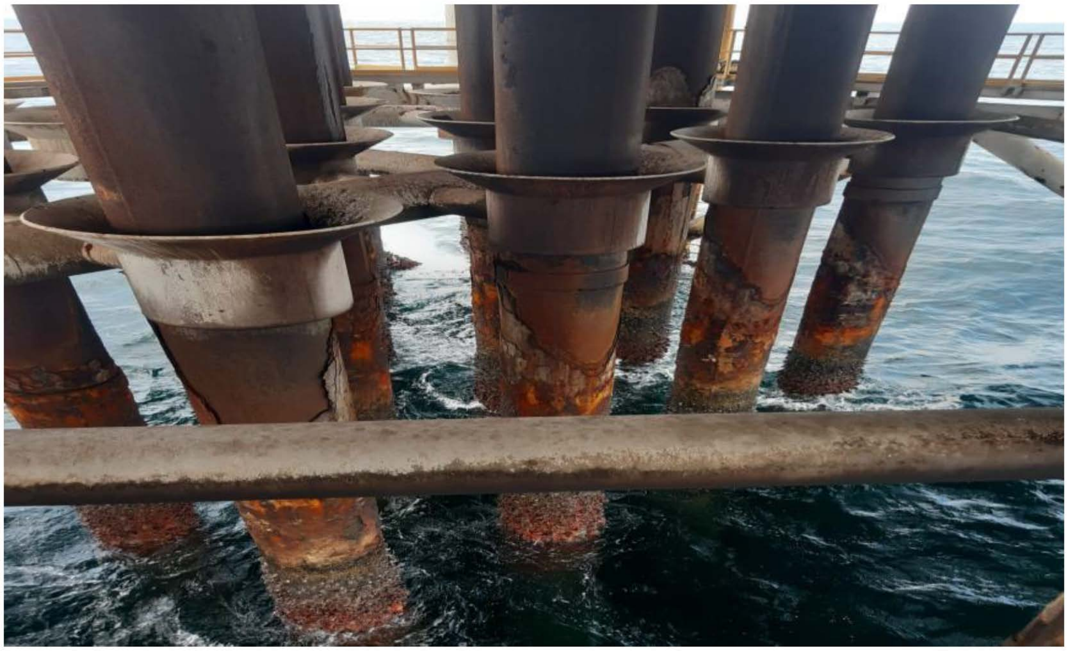

Figure 1—Major Corrosion Issue at Conductor Splash Zone

Corrosion at the splash zone, if left unchecked, can have catastrophic consequences for the platform and its crew. In the case of the well conductor, the most critical concern is perforation and parting as shown in Figure 2. As corrosion eats away at the conductor wall, its thickness is reduced, compromising its ability to protect internal casings and reduce its load bearing capability. This weakening can lead to internal casings being breached, allowing uncontrolled flow of hydrocarbons to the surface, posing a significant safety and environmental hazard. It will also lead to crushed conductors, damaging the internal casings, the surface equipment, the wellheads, and the Christmas tree setups. A parted conductor, completely severed by corrosion, can result in a catastrophic event with potential for loss of life, environmental damage, and immense economic losses.

Figure 2—Perforated and Parted Conductor Casing

Standard maintenance work at the splash zone level on offshore platforms is crucial due to the harsh environmental conditions that can lead to corrosion and structural damage. In Nigeria and West Africa, as in other parts of the world, a combination of conventional and innovative repair systems is used, often with the assistance of diving operations.

TYPICAL CONDUCTOR REPAIR SYSTEMS

The unforgiving splash zone of an offshore platform presents a unique challenge for operators: repairing corroded well conductors. Traditional repair methods, while effective, rely heavily on divers, introducing significant cost and safety concerns. This section explores four common repair systems for splash zone conductors – welded sleeves, epoxy metal clamps, composite wrappings, and composite clamps – highlighting their diver-dependency and associated risks.

Welded Sleeves are prefabricated steel sleeves that is welded onto the damaged section of the conductor, effectively creating a reinforcing jacket. It offers high strength and long-term durability. It requires highly skilled divers for complex underwater welding procedures. Welding in a wet environment introduces challenges like limited visibility, current distortion, and potential for hydrogen embrittlement in the steel. This type of repair also requires the use a support vessel with dynamic positioning (DP) systems as part of the marine spread. This adds to the expensive cost for such repairs.

An epoxy metal clamp is a custom-made steel clamp that is bolted around the damaged area. The annulus between the clamp and conductor is filled with a specially formulated grout, creating a strong and encasing repair. It provides good structural reinforcement and corrosion protection. Grout offers some flexibility to accommodate minor conductor imperfections. However, similar to welded sleeves, installation relies heavily on divers for clamp placement, grouting operations, and underwater cleaning and preparation. Again, this system also requires the use a support vessel with dynamic positioning (DP) systems as part of the marine spread.

Aside from metal reinforcing system, non-metallic options are readily available in the market for this purpose. High-strength composite materials like fiberglass or carbon fiber are saturated with resin and wrapped around the damaged section. The wrapping is then cured, creating a lightweight and corrosion-resistant reinforcement. It offers good corrosion protection and structural strengthening, and it can be applied to complex geometries. Composite materials are lighter than steel, reducing overall weight on the conductor. While diver-less application methods are emerging, traditional techniques still rely on divers with support vessels for surface preparation, wrapping application, and quality control checks.

The final repair system used in the prefabricated composite clamps, made from materials like carbon fiber or glass-reinforced plastic, are bolted or strapped onto the damaged area. The design allows for some adjustability to fit conductor imperfections. The system is lightweight, corrosion-resistant, and offers faster installation compared to other methods. The drawback to this is that the strength and durability might be lower than steel repairs. The system still requires divers and vessels for splash zone applications.

Depending on the criticality, location of defect, and site conditions, each repair method will be evaluated independently to determine the best option. One of the biggest factors in determining the method of repair are the risks involved and the cost of repair. Diving operations are essential for applying the repair systems, as they allow for direct access to the affected areas. Divers are trained to work in the challenging conditions of the splash zone, where the combination of saltwater, oxygen, and fluctuating pressures can accelerate corrosion. Working in the harsh and unpredictable environment of the splash zone exposes divers to a multitude of risks:

- **Decompression Sickness (DCS):** Rapid ascent can cause dissolved gases in the bloodstream to form bubbles, leading to pain, paralysis, or even death.
- **Hypothermia:** Divers lose body heat rapidly in cold water, potentially leading to disorientation and loss of consciousness.
- **Limited Visibility:** Underwater visibility can be severely hampered by currents, waves, and marine growth, increasing the risk of accidents.
- **Equipment Failure:** Malfunctioning diving equipment can have catastrophic consequences.

These risks necessitate specialized training, extensive safety protocols, and expensive decompression chambers on-site. As a result, diver-based repairs contribute significantly to the overall cost of splash zone conductor repair projects.

PROBLEM STATEMENT

Site application of Helicoid Epoxy Sleeve system.

The Helicoid Epoxy Sleeve system has been used to repair multiple conductors having major corrosion issues such as theconductor in Figure 2a. Some of the conductors were badly corroded while one was parted.

Figure 2a – Major Corrosion Issue at Conductor Splash Zone

CONDUCTOR REPAIR USING DIVER-LESS HELICOID EPOXY SLEEVE COMPOSITE REPAIR SYSTEM

The industry is actively seeking ways to minimize diver intervention. Advancements in remotely operated vehicles (ROVs), subsea tooling, and automation are paving the way for diver-less repair systems. These innovations hold the promise of reducing cost by eliminating diver dependency, thus minimizing human exposure to the dangers of the splash zone. Automation can potentially streamline repair processes and expedite project timelines. While diver-based repairs remain a crucial part of the current offshore maintenance strategy, the future points towards a more automated approach to tackling splash zone conductor challenges. This shift promises to deliver safer, faster, and more cost-effective solutions for ensuring the integrity of offshore assets.

The Helicoid Epoxy Sleeve offers a diver-less, support vessel independent, fully composite solution for addressing both structural and corrosion challenges in the splash zone. It combines the benefits of epoxy coatings and spiral reinforcement of carbon fiber within an inert HDPE casing to create a robust and corrosion-resistant system. It can also be equipped with secondary material for additional structural reinforcement or for leak containment to restore the integrity of the conductor. The epoxy coating acts as a barrier against aggressive elements, while the carbon fiber sleeve inside the hard HDPE shell supplements the structural integrity of corroded conductors, reducing their vulnerability to internal and external forces such as casing pressure, waves, and currents. The carbon fiber strips are carried by a high-density polyethylene (HDPE) strip which also acts as the mold to the system. Figure 3 shows the standard configuration of a Helicoid Epoxy Sleeve repair system, and Figure 4 shows the Helicoid Epoxy Sleeve components.

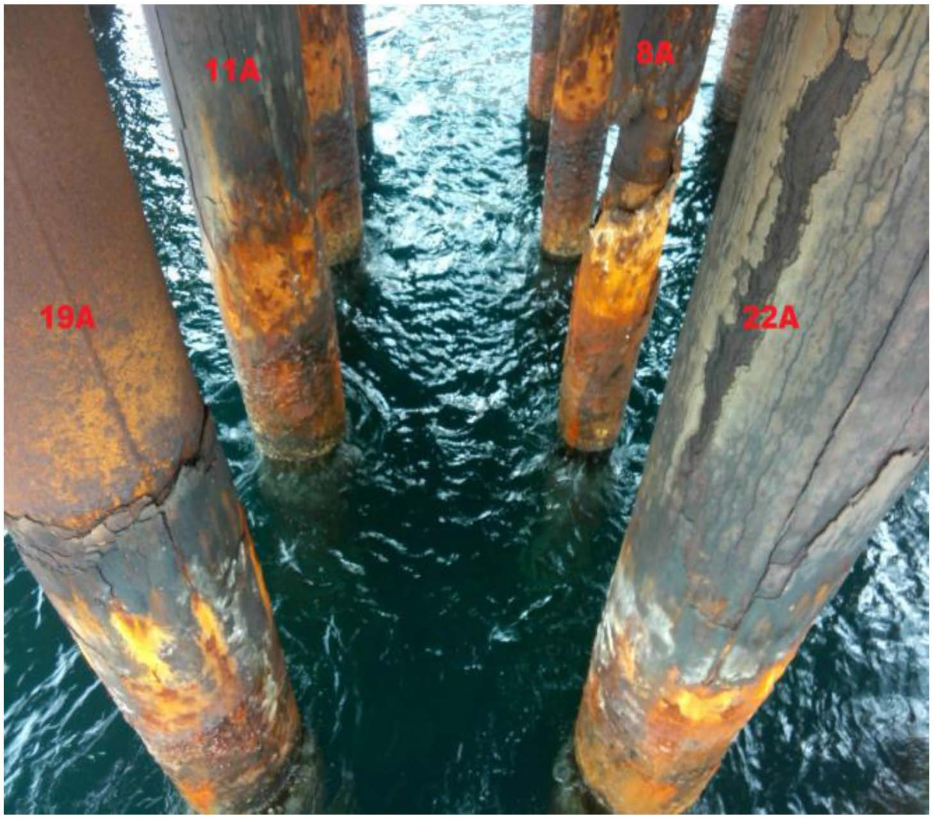

Figure 3a—Major Corrosion Issue at Conductor Splash Zone

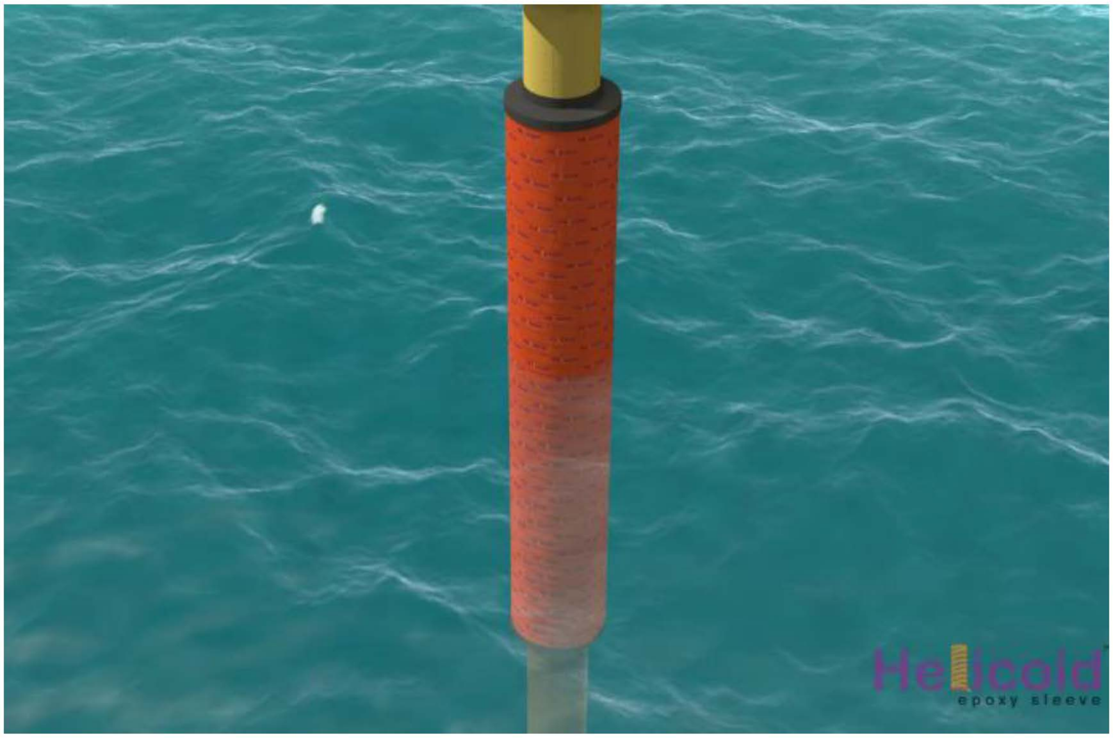

Figure 4—Typical Helicoid Epoxy Sleeve Installation

The Helicoid Epoxy Sleeve is a hybrid repair method, combining the methodologies of *epoxy metal clamp* and composite wrapping approach. The carbon-fibre reinforced HDPE sleeve comes in a strip form, which is then coiled to form a mold around the pipe and then grouted like an epoxy metal sleeve. The Helicoid Epoxy Sleeve installation requires specialized equipment to allow diver-less installation. The equipment was designed so that the installer will only work at a safe working level well above the water level. The standard installation length of Helicoid Epoxy Sleeve is EL. (+) 3.0 meters and EL. (-) 3.0 meters the mean sea level (MSL), as shown in Figure 5.

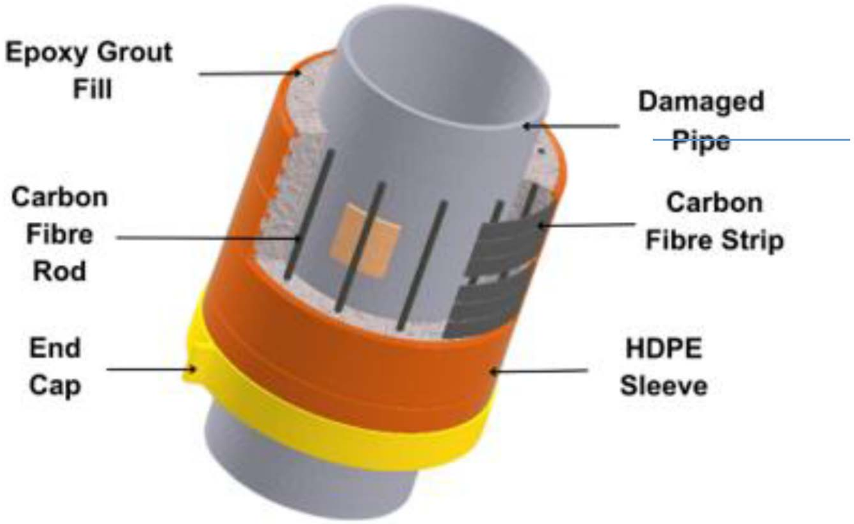

Figure 5—Helicoid Epoxy Sleeve Components

The installation of the Helicoid Epoxy Sleeve consists of three major steps. The first step is to perform surface preparation to remove existing debris, coating, marine growth, corrosion, and any oil residue on the pipe surface. The cleaning process is made in accordance with SSPC-SP12-WJ3-Thorough Cleaning, standards producing completely cleaned metal surface by using an ultra-high pressure waterjet system. In most cases, the water used is filtered sea water, reducing the need to mobilize fresh water from shore as the amount of water used is very high. The waterjet pressure ranges from 1000 to 2500 bar and a rotating cleaning nozzle are used for the operation. A specialized and patented equipment called the Helicoid Surface Preparation System (HeliSurp) is deployed to perform underwater cleaning. By installing the main bracket system above water level, the system will allow cleaning of pipe up to EL. (-) 3.0 meters underwater. For the above water section, the water blasting activity shall be done using manually i.e. handled by blaster manpower, as shown in Figure 6.

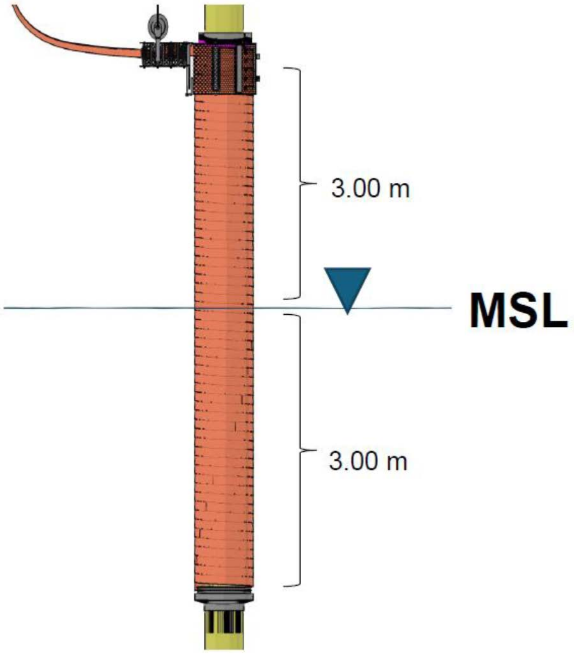

Figure 6—Helicoid Epoxy Sleeve Installation

The second step of the installation is to wind the carbon fiber-reinforced HDPE sleeve. For this activity, another specialized equipment called the Helicoid Winding Cage (HeliCage) system is used. Designed specifically for each pipe size, the winding cage will be clamped and secured on the pipe, as shown in Figure 7. The carbon fiber reinforced HDPE strip will then be inserted into the winding cage to for a sleeve around the conductor, leaving an annulus of 30mm to 40mm between the pipe to the outer sleeve as shown in Figure 8. After winding of around 1 meter, the sleeve is trimmed at the bottom and an end cap is installed. The end cap serves as the sealing mechanism for the sleeve to ensure there will be no epoxy grout leaking through the bottom of the sleeve during the grouting process, as Figure 9. After that, the winding process will continue until the overall length of the repair is achieved, as shown in Figure 10. The sleeve is then trimmed at the top and secured by using bracket to prevent further movement.

Figure 7—Riser Surface Preparation by Hydro Blasting for Underwater and Above water

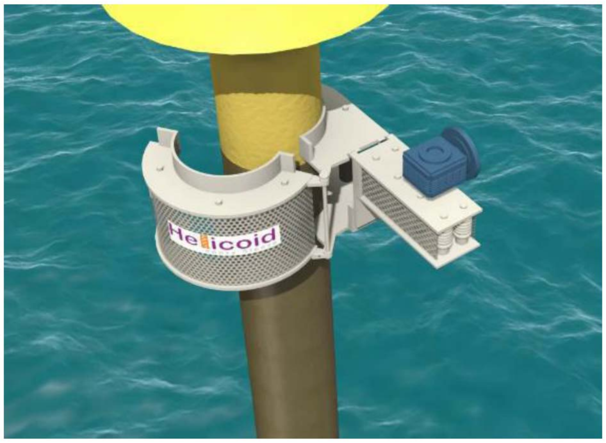

Figure 8—Typical Installation of Winding Equipment

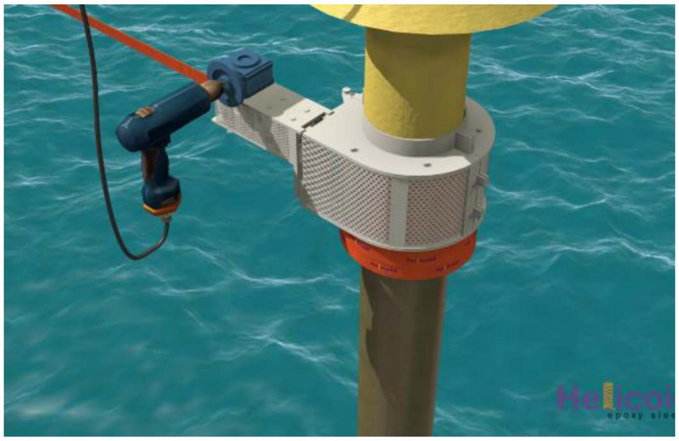

Figure 9—Insertion of Carbon Fiber Reinforced Strip

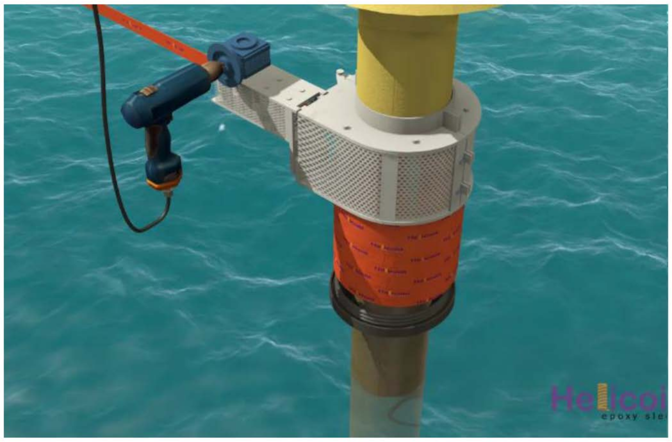

Figure 10—Fixing of Polyamide End Cap

The last step of the installation is to perform the epoxy grouting activity by injecting a proprietary high strength epoxy grout (HeliGrout) into the annulus. The grouting activity is done in accordance with the Tremie method, where the hose is inserted into the annulus until it reaches the lowest point, followed by epoxy injection through the hose. By doing this, the epoxy grout will fill in from the bottom part of the sleeve towards the top. Since epoxy grout is denser than sea water, the epoxy will push up the water towards the top of the sleeve where the water will be displaced, and the epoxy grout will completely fill the sleeve, as in Figure 11. After the epoxy grout cured, the final step is to install the top end cap to prevent water pooling on top of the sleeve.

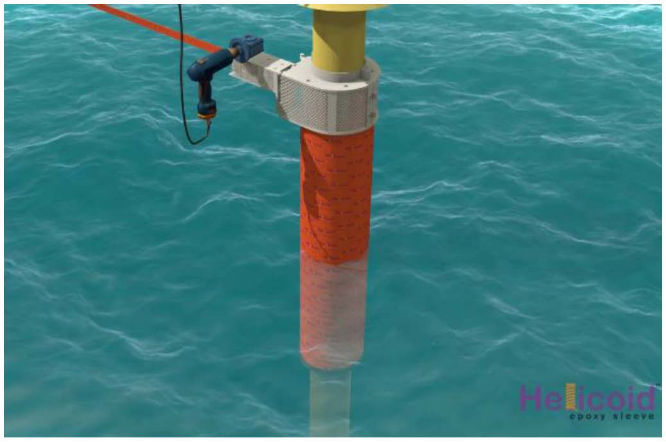

Figure 11—Winding of Helicoid for Conductor

Overall, the whole installation will take around five to seven days to complete per conductor. The system will provide corrosion protection and structural strengthening to the conductor at the splash zone level, covering the above water and the underwater sections without diving operations. Aside from splash zone applications, Helicoid Epoxy Sleeve can also be applied to repair corroded and damaged surface casings below the wellhead and the Christmas tree to provide axial strengthening and leak containment during well intervention activities.

QUALIFICATION AND ENGINEERING STUDY

A corresponding FE model was developed for evaluation of the Helicoid Epoxy Sleeve conductor casing rehabilitation system. The Finite Element Analysis (FEA) numerical analysis conducted on an industrial based Composite Repair System (CRS) served to provide a repair methodology on the defect/corroded pipe, hence re-enhance the pipe fitness and strength for operational activities, (Chan, P., Tshai, K., Johnson, M. et al. 2015). Systematic Simulation using thorough FEA analysis was carried out for the conductor casing pipe on several load cases for load comparison and proposed suitable Helicoid Epoxy Sleeve system repair configuration.

The FEA analysis was done by using the actual setup of the conductor casing. The output of this analysis was the Von Mises Stress of the conductor casing that will determine whether the pipe is failing or not. A few configuration cases were simulated in the analysis. First, simulation was done on a pipe without repair and subjected to internal pressure and axial load. Next, simulation on the defective pipe with the Helicoid Epoxy Sleeve was done with the same internal pressure and axial load. The following are the detailed configurations of the load cases:

1. Un-Corroded Conductor Casing - Conductor Casing with nominal thickness.
2. Corroded Conductor Casing with Defect
3. Conductor casing with defect and repaired with Helicoid Epoxy Sleeve

In this work the functional loads imposed on the conductor casing pipe setup are mainly due to axial loading (the weight of the Christmas Tree, blow out preventor or the hydraulic workover unit) and exerted internal pressure. The allowable Von Mises Stress of 0.9 x SMYS is the maximum stress at which a pipe may be operated in accordance with the provisions of the design code. In addition, the maximum compressive force on the casing pipe is also checked against Euler buckling limit of the pipe repair length to make sure the pipe/column will not deflect / tilt on this critical load.

In theHelicoid Epoxy Sleeve system, the load shall be effectively transferred from the steel conductor casing to the CFRP material when the pipe is subjected to the axial and internal loadings. The epoxy grout is acting as the load transfer medium between the corroded steel pipe and the CFRP strip. In addition, the grout is further strengthened by introducing carbon fiber rod length throughout the filled grout repair length. Figure 12 shows the example FE analysis on conductor casing with Helicoid Epoxy Sleeve repair (Max Von Mises Stress) – Axial Load & Internal Pressure

Figure 12—Injection of Epoxy Grout via Tremie Method

OPERATIONAL STEPS FOR HELICOID EPOXY SLEEVE INSTALLATION

- A site survey was conducted to assess the site and conductor condition, to verify conductor report and dimensions, and to identify laydown area for equipment. Next, a working procedure wasdeveloped, and risk assessment was conducted based on input received during the site survey.

The proposed repair wasdesigned in accordance with ASME PCC-2 standards for Non-Metallic repair system.

- Prior to the mobilization of the installation team, scaffoldings were erected at the splash zone level around the conductor to be repaired. There were two or three stages of the scaffoldings, one is around one meter from the MSL and the other is around three meters from the MSL. These are the working area where the manpower and equipment will be located at, as shown in Figure 13.
- Upon mobilization, the standard equipment including the ultra-high-pressure waterjet, air compressor and consumable containers will be placed at the top deck, while the specialized Helicoid Epoxy Sleeve equipment will be placed at the working area. Hoses will be rigged down to the working area and connected to the specialized equipment.
- The installation process started by marking the top of repair section on the conductor, in this case at EL +10ft.
- The HeliSurp system was utilized for the surface preparation process, from EL. (+) 10 ft until EL. (-) 10 ft m to completely remove marine growth and existing coatings until the conductor reaches bare metal. Upon completion, visual inspection was conducted by using an underwater camera for the below water section.
- Next, the HeliCage is installed on the conductor pipe, just above the top of the repair section. Carbon-fiber reinforced HDPE sleeve is then inserted into the winding cage to form a sleeve around the conductor. After the installation of the bottom end cap, winding process continued until the desired repair length is achieved, as shown in Figure 15.
- The annulus between the sleeve to the conductor pipe is then filled by using HeliGrout, a proprietary epoxy grout. A grout mixer and pump are used to mix and the pump the epoxy grout. The grout is injected by using a hose that is placed at the bottom-most part of the sleeve to ensure that water is completely removed from the system, as shown in Figure 14. An underwater camera was deployed throughout the installation to monitor the bottom of the sleeve, ensuring that there was no epoxy leakage during the activity.
- The installation was completed by the installation of the top end cap upon the curing of the epoxy grout. It served to prevent any water pooling on the top of repair which will lead to corrosion, as shown in Figure 17.

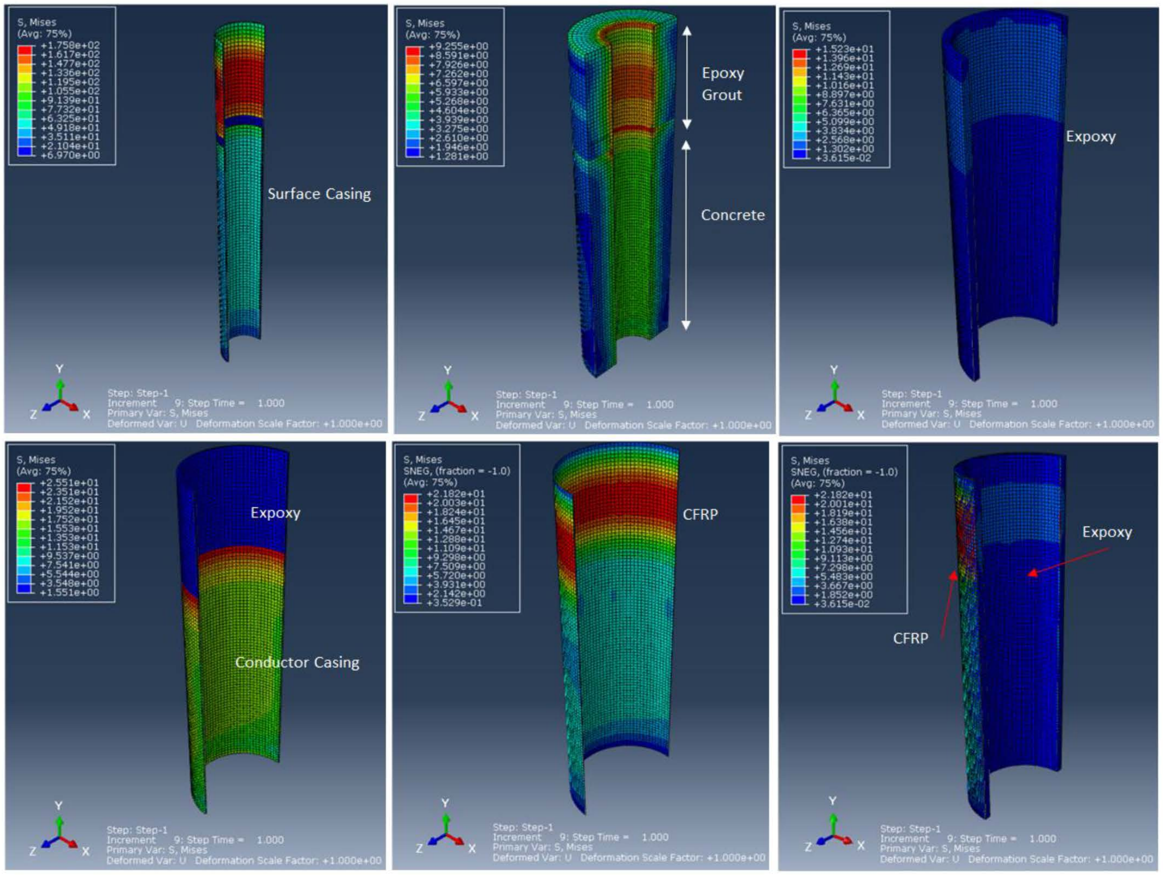

Figure 13—FE analysis on Conductor Casing with Helicoid Epoxy Sleeve Repair (Max Von Mises Stress) – Axial Load & Internal Pressure

Figure 14—Scaffolding Erection

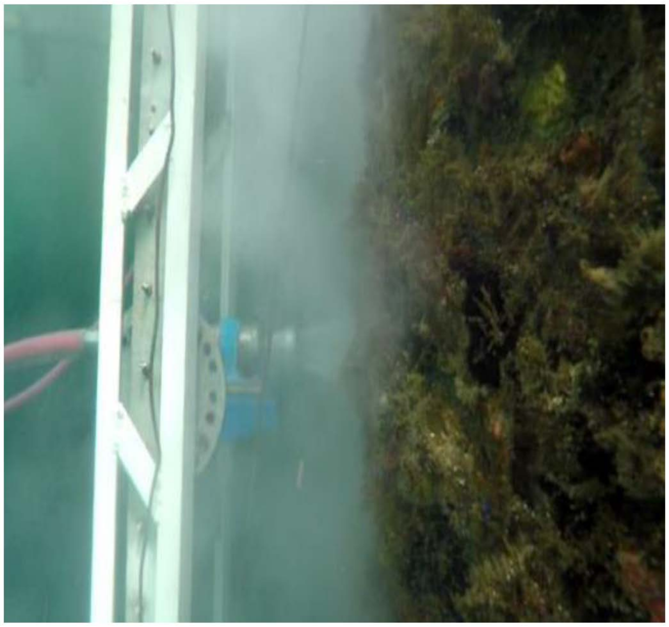

Figure 15—Surface Preparation Underwater

Figure 16—Winding of HDPE Sleeve

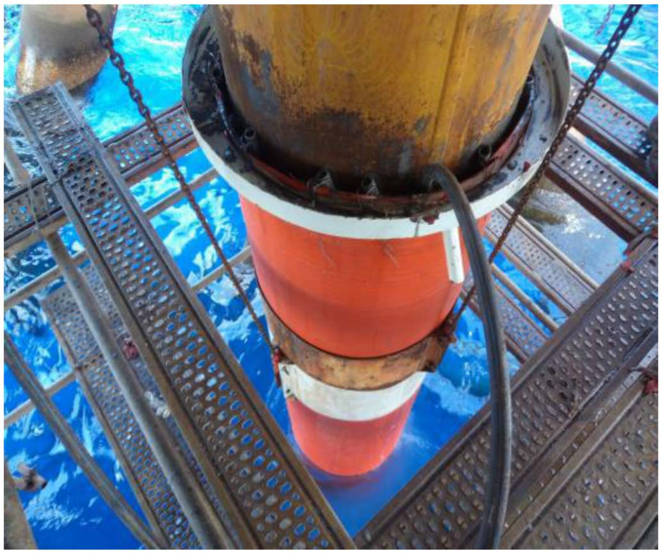

Figure 17—Injection of Epoxy Grouting

Figure 18—Completed Helicoid Epoxy Sleeve System

OPERATIONAL LESSON LEARNT OF HELICOID EPOXY SLEEVE INSTALLATION.

Overall, Helicoid Epoxy Sleeve has shown its capability to repair damaged conductors at the splash zone level without the need for diving support. This approach will allow for significant savings on the repair costs compared to conventional repair methods, and with the permanent nature of the repair it will also reduce future maintenance costs and reduce the operational hazard of the components. Another advantage of the system is the short lead time for fabrication and mobilization. Most of the equipment and consumables are off the shelf and only require minimal lead time for packaging and freight. The installation does not require support vessel, unless there is no lifting crane and/or accommodation available at site. The installation also does not involve any hot works at the defect location; therefore, it is safe for a zone zero hazard classification area on the platform.

However, the activity is still bound by weather conditions. This is because the installation team is working one meter from water level and will be impacted should the waves exceed the scaffolding level. Nevertheless, scaffolding level can be adjusted accordingly should there be any safety issue arises.

Application during monsoon season or during bad weather conditions will require extensive risk assessment, but it is still feasible with proper planning and a contingency plan.

Table 1 below summarize the comparison of Helicoid Epoxy Sleeve approach against other methods.

Table 1—Summary Comparison of Helicoid Epoxy Sleeve with other methods

Method of Repair	Fabrication Lead Time	Average duration for installation on 1 conductor, excluding mobilization	Diving Support Required for Underwater Section
Welded Sleeve	2-4 Weeks	3-5 Days	Yes
Epoxy Metal Clamp	8-12 Weeks	3-5 Days	Yes
Composite Wrapping	1 Week	4-5 Days	Yes
Composite Clamp	1-3 Weeks	3-5 Days	Yes
Helicoid Epoxy Sleeve	1 Week	4-5 Days	No

FUTURE WORK

Further research is being conducted to investigate the long-term performance of the Helicoid Epoxy Sleeve under real-world conditions in this region. Additionally, studies exploring the feasibility of applying the Helicoid Epoxy Sleeve to existing conductor casings and its effectiveness in different environmental conditions with extremities of heat and cold would also be beneficial. It is also recommended that the Helicoid Epoxy Sleeve approach be tested on risers and caissons at the splash zone area on aging platforms that are facing the same problem with conductors. These pipelines located at the splash zone area, especially risers, are also a critical asset as they are pressurized and carry hydrocarbon products.

CONCLUSIONS

The integrity issue for conductors at splash zone level is a common issue in aging platforms. The conductors have been exposed to the harsh environment of water splash, alternating tide level and marine growth that leads to coating damage and corrosion. These conductors are still subjected to the load of the surface equipment including the Christmas tree and the wellhead. Without proper intervention, the integrity issue shall persist and leads to structural integrity, operational safety, and environmental issues to operators. There are many conventional and unconventional approaches in reinstating the integrity of the conductor at the splash zone level. These methods are proven to work if installed correctly, however the main limitations to them are the requirements to have diving support to install if the repair were to be done at the water level or underwater level, which may lead to budget constraints and safety issue. The Helicoid Epoxy Sleeve presents a promising alternative to traditional repair methods for addressing conductor corrosion in the splash zone of offshore structures. By offering a diver-less, efficient, and cost-effective solution with good corrosion resistance and structural reinforcement, the Helicoid Epoxy Sleeve contributes to enhancing the durability and sustainability of offshore infrastructure. The method and equipment used allow for safe operation throughout the installation, without interruption to the ongoing processes on the platform. The system has been tested in the field in other regions for more than 10 years and has a proven track record for the repair of well casings, conductors, risers, and caissons. The first successful deployment of the technology in Nigeria paves the way for more economics and safer splash zone maintenance work for offshore platform operators in this region.

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