UDC 621.791:629.56322

Ivica GARAŠIĆ[1]
Slobodan KRALJ[1]
Zoran KOŽUH[1]
Miroslav PACAK[2]

Analysis of Underwater Repair Technology on the Jack-Up Platform Spud Can

Professinal paper

Underwater welding has been used widely in construction and maintenance of off-shore facilities. With state-of-the-art equipment and filler materials it is possible to achieve high quality of welded joints, particularly if underwater dry welding is applied. On the other hand, wet underwater welding has several advantages from the aspects of flexibility and cost efficiency, but some serious problems could emerge due to weld quality and safety of divers. In this paper analysis of applicable technologies of underwater repair of a jack-up platform spud can is made, including description of possible problems that may occur. Also, a comment on specific details of proposed techniques has been given and a comparative analysis of considered techniques focused on the economic and technological aspects of repair has been made.

Keywords: *jack-up platform, underwater welding*

Analiza tehnologija podvodnog popravka odobalne samopodizne platforme

Stručni rad

Podvodno zavarivanje svakodnevno se primjenjuje pri izgradnji i održavanju pomorskih objekata, te je s današnjim stanjem opreme i tehnologije moguće postići visoku kakvoću zavarenoga spoja, posebno ako je riječ o podvodnom suhom zavarivanju. S druge strane, mokro podvodno zavarivanje ima niz prednosti u smislu ekonomičnosti i fleksibilnosti, ali mogu se javiti problemi zbog kakvoće zavara i sigurnosnih rizika. U ovom radu provedena je analiza mogućih tehnologija podvodnoga popravka papuče noge platforme pri čemu je obrađena problematika popravka, dan je osvrt na specifičnosti predloženih tehnologija, te je u konačnici dana i komparativna analiza navedenih tehnologija popravka s ekonomskog i tehničkog stajališta.

Ključne riječi: *odobalna samopodizna platforma, podvodno zavarivanje*

Authors' Addresses (Adrese autora):
[1] *Faculty of Mechanical Engineering and Naval Architecture*, Department of Welded Structures, *University of Zagreb,* I. Lučića 5, HR-10000 Zagreb, e-mail: zoran.kozuh@fsb.hr;
[2] *Crosco, Integrated Drilling & Well Services Co., Ltd,* Ulica grada Vukovara 18, HR-10000 Zagreb

Received (Primljeno): 2009-11-20
Accepted (Prihvaćeno): 2010-01-10
Open for discussion (Otvoreno za raspravu): 2011-06-30

1 Introduction

This paper presents a study of underwater technology for the repair of damage caused by the impact of the platform spud can into a rocky bottom. On the basis of the requirements made by customer the following scope of services has been agreed upon:

1. analysis of the current state and damage,
2. definition and description of alternative technologies,
3. elaboration of underwater repair technologies based on the project documentation for each of the proposed alternatives,
4. specifications of welding procedures for each of the proposed alternatives,
5. economic analysis and cost estimate,
6. defining of adequate non-destructive testing methods,
7. risk and feasibility assessment of single technologies,
8. comparative analysis of proposed versions,
9. proposal of adequate technology on the basis of the study, with cost estimate and complete welding technology.

The study has been made on the basis of the provided technical documentation, reports on tests carried out on the damaged structure, photos of the damage and video recordings. The technological procedures have been defined according to the principles of the profession and valid standards, in compliance with the safety requirements.

The necessary analyses have been carried out applying professional knowledge, experience, relevant underwater activities in the area of underwater welding and testing, and by relying on literature references as well.

The *Department of Welded Structures* at the *Faculty of Mechanical Engineering and Naval Architecture* in Zagreb has been certified by the *Croatian Register of Shipping* to carry out the works of underwater welding and non-destructive testing.

2 Damage analysis

By analyzing the report on damage inspection at the off-shore platform spud can it has been found that there is a substantial damage on the support of leg No. 3, which may be divided into the damage of the shell and damage of the bottom plate, of the following dimensions:

- shell damage 12.5 mm thick and 2580 mm long and of maximum height of 740 mm,

- bottom plate damage 22 mm thick, at two places which cover approximately the same length as the shell damage determined by the shell and bottom plate joint, i.e. approximately 2500 mm. The length of the damage towards the centre of the leg support is maximally 1320 mm.

Figures 1 to 4 show the damaged section of the exterior and interior. Apart from the damage of the bottom and side plate, one can also see the deformation of stiffeners and transversal girders and fillet elements from the inside, which indicates the need for reconstruction of the internal structure as well, thus substantially complicating and expanding the scope of underwater operations.

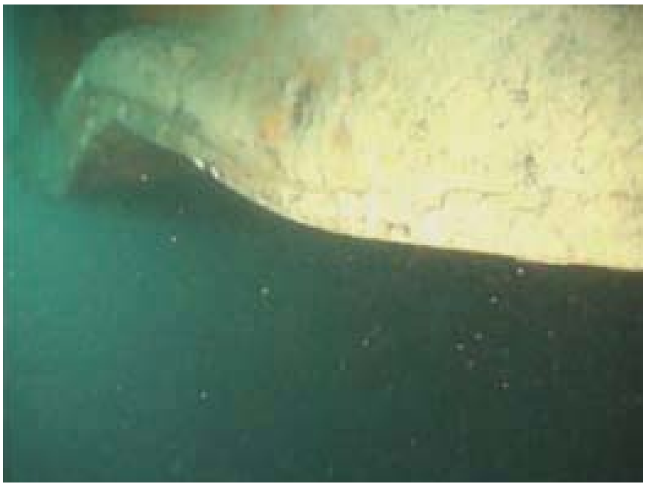

Figure 1 **Deformation on bottom plate and side shell joint**
Slika 1 **Deformacija na spoju donje i bočne ploče**

The mentioned defects have been repaired by epoxy resins and cement mixes whereas the propagation of the crack has been stopped by making holes at the ends of the crack, and as indicated no further propagation of cracks or defects has been noticed.

The analysis of the current state leads to the conclusion that the exterior plates, the bottom and the side one, as well as the

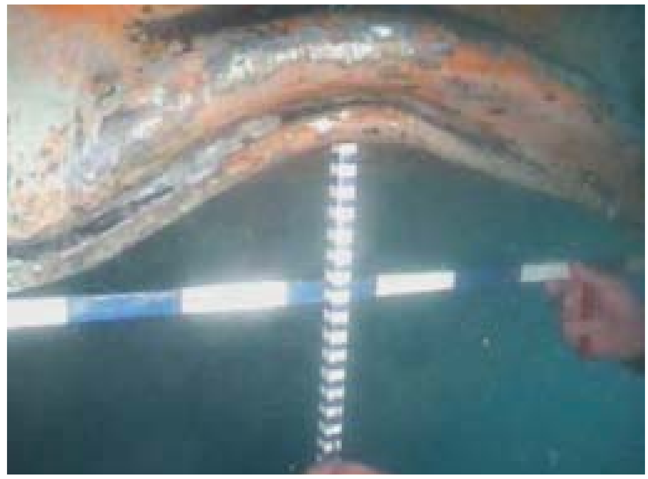

Figure 2 **Damage measurement**
Slika 2 **Izmjera oštećenja**

connecting structure on the interior of the spud can be damaged and the conducted repair is only partially satisfactory from the aspect of water-tightness.

Because of the mentioned problems, the replacement of the complete damaged section is recommended in order to re-establish the former shape and dimensions of the spud can and ensure the possibility to withstand maximum design loads. This would also eliminate any unforeseen behaviour of the material in the damaged structure sections of the spud can at the platform. The distribution and form of the defect enable repair by cutting out the damaged section of the shell and bottom plate as well as the internal structure girders and stiffeners, and by subsequent welding of the new segment. The new segment will be produced in the workshop and welded by applying adequate technology in place of the cut-out damaged section. Figure 5 shows the form of the new section.

Dimensions and the form of the new section have been determined based on the dimensions and pattern of damage and construction restrictions regarding the arrangement of bulkheads,

Figure 3 **Fracture on side shell**
Slika 3 **Pukotina na bočnoj ploči**

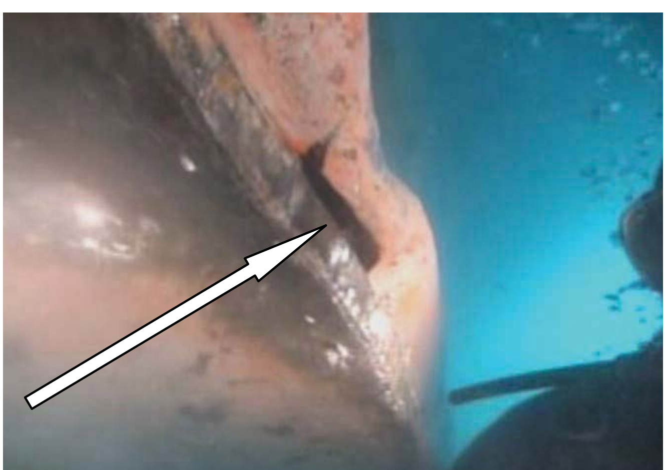

Figure 4 **Deformation of transversal and longitudinal girders**
Slika 4 **Deformacija poprečnih i uzdužnih nosača**

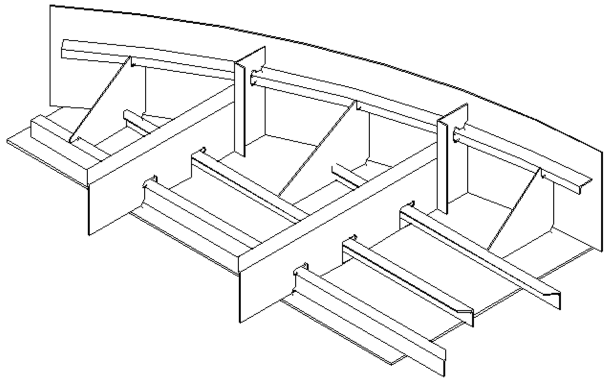

Figure 5 **Shape of the new section**
Slika 5 **Oblik zamjenske sekcije**

girders and stiffeners, as well as certain exterior elements. The basic material of the new section shall comply with the specification ABS grade A, i.e. same material has to be used in order to satisfy all the requirements regarding the structural stresses and material weldability.

In order to realize the necessary preconditions for the realization of repair of the spud can at the platform, the following conditions and preparation activities have to be insured:

- the platform must be towed in a port – berth in which the platform can be stabilized and the necessary equipment and instruments required for the repair installed,
- the platform positioning should be such as to allow maximum lifting of leg No. 3, enabling access and repair activities, and maximally reducing the working depth in order to cut the costs and increase the operating safety,
- sea depth (with lifted spud can) up to 15 m, in order to reduce the costs of installing the equipment and duration of works, especially regarding functionality and safety of diving, but also in order to allow «cofferdam» underwater welding,
- insure the possibility of access and works on the inside of the spud can, which includes the pumping out of water, cleaning and insuring working conditions,
- insure the possibility of access and works from the outside of the spud can, including the assembly of a working platform and installation of the necessary equipment,
- insure necessary infrastructure including electric power network 380 V, adequate equipment for welding and cutting, mobile cranes for the disassembly of the damaged section and positioning of the new section, pneumatic and/or hydraulic installation for powering the underwater tools, security measures for the access and work done by the divers.

3 Possible approaches to repair

Regarding the shape and structure of the spud can, the repair below the water surface is possible, and this requires the application of specific technologies and technological solutions. This means application of underwater activities which include underwater cleaning, dismantling, and assembling, underwater welding and cutting, and underwater non-destructive testing as the activity required by the quality assurance system.

Based on the experience from practice, the feasible operating depths ranging from 10 to 15 m and technical requirements, two versions of the underwater repair of the damaged spud can section are recommended:

- wet repair, where certain technological operations are performed in wet ambient by divers and adequate tools and instruments,
- dry repair, with all operations, except installation of the isolating cofferdam, are performed in dry isolated environment at atmospheric pressure with the application of conventional welding and cutting technologies. The cofferdam is designed with the opening exit towards the sea surface.

During works in wet surrounding, so-called wet underwater welding, no complex and expensive infrastructure is necessary. However, the time necessary for underwater welding and cutting is significantly prolonged, with higher probability of defects. The safety risks are also much higher. On the other hand, the dry version has substantially higher initial costs due to the fitting and installation of the cofferdam. It also requires the application of a special system fixing the cofferdam to the spud can structure, as well as checking the platform stability prior to the very installation of the cofferdam. Besides, the sealing system often requires experience and special knowledge and in case that designed sealing solution does not perform satisfactorily it potentially presents a source of additional problems. It is necessary to equip the cofferdam with a system for draining water, which may possibly enter the dry space, ventilation, lighting, and to insure all safety mechanisms for welders' evacuation. The class of weld determines the level of applicability and mechanical properties, which are determined by mechanical testing, weld appearance and non-destructive testing. Defining of the weld class determines unambiguously the requirements that a welded joint has to comply with.

According to the standard AWS D3.6M:1999 there are four (4) groups of underwater welds:

Class A weld corresponds to identical weld performed in normal conditions, and intended for applications that can withstand structural loads. Class A welds are usually required in underwater dry welding, up to depths of 150 m, but also in wet underwater welding for shallow depths of up to 15 m for stainless austenite steels.

Class B weld is intended for less critical applications where lower toughness, moderate porosity as well as other irregularities can be tolerated. The acceptability of class B for certain applications has to be determined based on the "Fitness for purpose" principles. Class B is usually applied in wet underwater welding of structural steels of up to 50 m depth and austenite stainless steels up to the depth of 25 m.

Class C is applied in cases when the loading capacity of the structural section is not of primary importance. Also, Class C weld should not damage the structure to which it is bonded. Lower requirements compared to classes A, B and O are specified.

Class O refers to other requirements which are not specified by the standard AWS D3.6M:1999, and which can include operating conditions, ambient conditions, etc.

In real situations class B welds can be obtained also in more severe conditions, unlike class A, in which top criteria in joint preparation, workpiece positioning, selection of welding filler material, welding technology, etc. have to be met. This significantly influences the increase in costs and longer times.

If optimal technological solution and adequate design which avoids critical stresses are selected, class B provides the optimal solution which results in acceptable underwater weld quality with acceptable time consumption and financial investment. This applies especially to wet underwater welding where there are a number of complicating factors such as poor visibility, sea currents, cold, high safety risk, etc. From the aspect of technological and economic features, Class B weld has advantage over Class A, whereas Class A has much better mechanical properties.

3.1 Approach No. 1: wet underwater welding

Wet underwater welding is a technique which is used today very often to perform underwater welding. Its characteristic is that the place where welding is done is not isolated from water, but rather performed in water ambient so that the welder, workpiece and the electric arc are exposed to the wet environment, Figure 6.

Figure 6 **Underwater wet welding of platform jacket**
Slika 6 **Podvodno mokro zavarivanje na «jacketu» platforme**

The increased freedom of welder's movement makes this method very flexible and cost-efficient, compared to dry underwater welding techniques. In wet welding MMA (manual metal arc) welding procedure with a covered electrode is used. Such electrodes are specially prepared for the specific operating conditions. Although wet underwater welding is used generally at the depths of up to 50 m, tests have been done at depths greater than 100 m, but due to a high hydrostatic pressure it is difficult to maintain the electric arc, and the joint quality becomes questionable. At greater depths there are also physical restrictions which represent inevitable problems for divers.

It is necessary to take into consideration the welder's safety, especially at greater depths, where additional measures of caution have to be insured. Therefore, direct current sources are used for welding with somewhat reduced open circuit voltage.

The welding device is on the surface and has to be fitted with a safety switch for immediate interruption of the power supply. The drawbacks of the technique refer primarily to the consequences of direct exposure of the welding location and the electric arc to water. The contact between water and the welded joint causes fast cooling, creating thus unfavourable structures that are brittle, have reduced toughness and are prone to fractures. Over the recent ten years, the status of the wet underwater welding technique in the world has been significantly improved. The wet underwater welding technique has been generally accepted and multiply used in maintaining of vessels and off-shore plants.

3.1.1 Assessment of acceptability of base material ABS grade A for wet underwater welding

The wet weldability of the base material is determined by the carbon equivalent (CE), according to the standard AWS D3.6M:1999: "Specification for Underwater Welding" according to the following expression:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad [1]$$

Since the obtained value *CE* of 0.3475 is lower than 0.4 which is the upper limit value used to determine the eligibility of material for wet underwater welding, and if one takes into consideration that in this case maximum values of mass share of C and Mn were taken, then it may be concluded that the base material steel ABS grade A is eligible for wet underwater welding. However, the base material has to be tested as well prior to welding in order to determine whether it corresponds to the specification.

Structural steels with less than 0.1% C are suitable for wet underwater welding, and steels with carbon equivalent smaller than 0.4%. Steels with *CE* greater than 0.4% have high sensitivity to hydrogen induced cold cracking (HICC) and can be wet underwater welded only if special welding filler material and welding techniques are used. The sensitivity to the occurrence of hydrogen-induced cracks can be reduced by applying electrode oscillation or by applying additional runs. If heat treatment by means of additional runs is applied, then it is necessary to keep an interval between the application of two layers shorter than 1 minute. In combination with multi-run welding, this is the most cost-efficient technology which significantly improves the properties of the welded joint.

When welding involves steels with the carbon equivalent *CE* greater than 0.4%, the heat affected zone of the base material is sensitive to hydrogen-induced cold cracking and to undesired high hardness. In underwater dry welding, it is possible to implement pre-heating and maintenance of inter-layer temperature in order to reduce the humidity level. Sometimes special regimes of heat treatment may be required in order to improve toughness and reduce hardness in the heat affected zone.

3.1.2 Technology of replacing the damaged section by wet underwater cutting and welding

When replacing the damaged section of the spud can in the wet environment, it is necessary to take into consideration all the limitations and drawbacks stipulated by the application of wet underwater welding technology, and these are as follows:

- low productivity,
- increased safety risks,
- increased possibility of defects,
- difficult operating conditions,

- relatively poorer mechanical properties of the welded joint (for B Class shear strength 60% of the nominal tensile strength of the base material for fillet joints, increased hardness and lower toughness),
- limited duration and operation of divers at a certain depth.

Taking into consideration the mentioned limiting factors, there has been proposed the technological solution that would apply wet underwater welding in dismantling and fitting, and then that will insure for the welding of the joint the fixing of the new section to the base structure of the spud can, and would besides serve as the seal joint which will allow draining of water from the spud can.

After that, welding would be performed in dry atmosphere from the inside, since good accessibility is provided. This may be treated as dry underwater welding since the activity is done below the water surface. The application of conventional MMAW technology in dry atmosphere would result in a good quality of the welded joint of Class A according to AWS D3.6M:1999 and mechanical weld characteristics adequate to the characteristics of the base material, which will insure the integrity of construction and the possibility of design loads of the spud can. This will allow good fitting and welding of the girders and stiffeners for the spud can structure.

In order to realize such a solution, while producing the section in the workshop, a strip 300 mm wide, 12 mm thick of steel type ABS grade A has to be welded along the whole flange of the new section, with one half of this strip being laid on the new section. The other half of this strip is to adhere to the base structure of the spud can during mounting, allowing wet underwater welding of fillet welds, which is according to both experience and literature the optimal preparation in such situations. This reduces significantly the volume and time of underwater welding. Figure 7 shows the pre-fabricated new section with the welded strip along the flange.

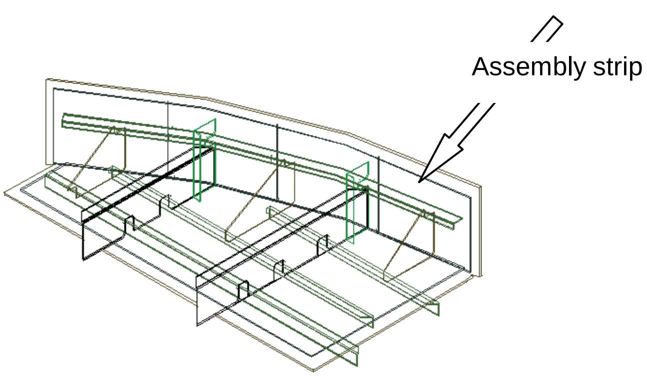

Figure 7 **Prefabricated new section with welded assembly strip**
Slika 7 **Predfabricirana zamjenska sekcija sa zavarenom montažnom trakom**

Complete underwater welding from the outside would be prolonged during the welding procedure three to four times, making it almost impossible to attain the A Class weld. Besides, the possibility of defect occurrence is substantially increased, thus having to take into consideration also the performance of possible corrective actions, which prolongs substantially the time of performance.

Since, according to the specification of the base material of the spud can, steel ABS grade A has even up to 0.21% C, increased hardness would also be very likely, close to the margin of 375 HV10 which is stipulated by B Class in the standard AWS D3.6M: 1999. The works from the inside in dry atmosphere allow also improved fitting and welding of girders and stiffeners to the already existing structure.

Taking into consideration everything mentioned it can be said that the proposed technological solution optimizes the application of wet underwater welding, which will allow shorter time consumption, better weld quality as well as greater safety of operations. The basic concept of welding the new section to the basic spud can structure is presented in Figure 8.

Figure 8 shows that for the wet underwater welding technology only the fillet welds are applied fixing the section to the base structure, which represents also the seal joint which allows subsequent welding from the inside of the spud can under normal dry conditions.

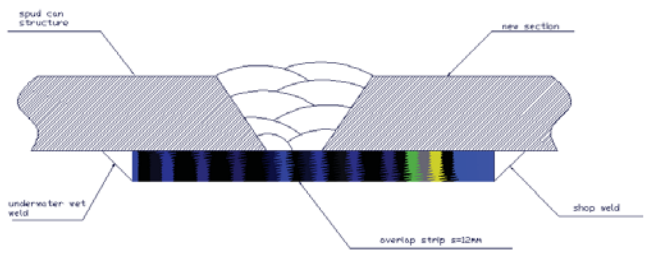

Figure 8 **Basic concept for welding of the new section on spud can structure**
Slika 8 **Osnovni koncept zavarivanja zamjenske sekcije za osnovnu strukturu papuče**

3.2 Approach No. 2: dry underwater welding in cofferdam

Dry underwater welding in cofferdam is characterized by the fact that the welder and the welding site are in dry atmosphere, without the presence of water. To isolate the working site from water, a steel, or more recently aluminium box-like structure is used. Such a structure has an exit towards the sea surface, so that the activities are performed at the atmosphere pressure, eliminating thus the diving problem and the influence of increased pressure on the welding parameters.

The main advantage of such welding is better quality of weld related to wet underwater welding, flexibility in the selection of the procedure and the welding technology and higher security in works. The drawbacks are additional costs of realization and positioning of the cofferdam, as well as problems that may occur in the structure sealing. This concept is often used in practice and there are a number of examples where this technology has been successfully implemented.

The foreseen working depth of maximally 15 m enables installation of a box-like structure which would allow work in dry atmosphere.

In the considered case, the problems occur because of the dimensions and mass of the new section.

Before designing the cofferdam it is necessary to know and analyze the following:

- technical documentation of the spud can,
- actual dimensions and spud can surface condition,
- the possibility of fixing and sealing the cofferdam structure,
- details of putting to shore and positioning of the platform,
- complete situation at the bottom and the surrounding port infrastructure.

After installing the cofferdam it is necessary to provide a surveillance system or to install adequate sensors to detect water leakage, and a system for water exclusion, i.e. pumps. This indicates that the very design and construction of the cofferdam represent an additional cost and investor's engagement. On the other hand, the application of underwater welding in dry atmosphere substantially increases the productivity of welding, providing a selection of different welding and cutting procedures, and the weld quality is improved.

From the aspect of welding, it is very positive that more productive cutting and welding procedures may be applied compared to wet underwater welding. Apart from MMAW procedure, MAG procedure and flux cored wire welding can be considered. However, MMAW procedure is recommended because of the problems that occur due to the separate wire feeder and contamination of the working ambient by shielding gas. Regarding the composition and the thickness of material, gas cutting and air plasma cutting are suitable, the latter being especially favourable since supply of dangerous gases (flammable gas and oxygen) into the cofferdam is thus avoided.

In the application of this repair technology, it is necessary to plan also the pre-fabrication of the cofferdam structure together with the new section, in order to reduce the time of overall activity. Figure 9 shows the basic concept of repairing the spud can using the isolation dry box-like structure of the cofferdam.

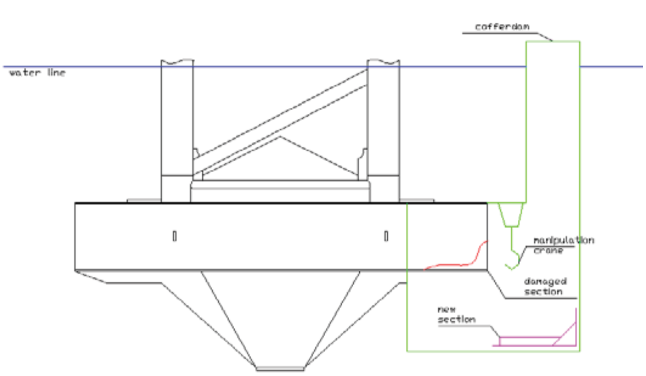

Figure 9 **Basic concept of spud can repair in dry atmosphere using cofferdam**

Slika 9 **Osnovni koncept tehnologije popravka papuče noge na suhom pomoću primjene «cofferdama»**

3.2.1 Assessment of acceptability of base material ABS grade A for dry underwater welding and weld class according to AWS D3.6M:1999

According to Sections 2.1.1 it may be concluded that the base material ABS Grade A is suitable for dry underwater welding. For a depth of 15 m A Class weld is specified. Besides, by welding in dry atmosphere and with insulation of the wall against water significantly influence reduction in the cooling rate, which results in lower hardness of the weld. The foreseen consumables, base covered electrodes with low hydrogen content in the weld metal, insure very good mechanical properties of the welded joint.

4 Comparative analysis of proposed approaches of repair

Based on what has been presented in this paper, it is possible to carry out comparative analysis of the proposed versions according to all considered segments as follows:

- The base material of the spud can ABS grade A is suitable both for wet and for dry welding. The new section has to be made of the same material.
- The expected quality of the welded joint is Class A for dry underwater welding and for the welding from the inside of the spud can, whereas in wet underwater welding Class B of the welded joint is expected. Because of the accessibility from the inside, the problems of wet underwater welding are avoided. Wet underwater welding is implemented only for the welding of the assembly seal weld, which does not withstand structural stresses, but has primarily the function of insuring the conditions or welding from the inside.
- For the implementation of both proposed versions the same equipment for diving and welding is required. However, the cofferdam requires a much more complex surface infrastructure due to the problems of setting and fixing the structure.
- Along with the design of the cofferdam, complete calculation of the platform stability needs to be carried out, which additionally increases the price and complicates the entire problem regarding the design of the cofferdam.
- In wet underwater welding the MMAW welding procedure is applied, with special filler material. In dry underwater welding and in welding of the spud can from the inside the MMAW procedure is used with conventional consumables.
- For underwater cutting in wet ambient, the oxy-arc is used, which is slower than the conventional air plasma cutting procedure, which is applied in the cofferdam method.
- For wet underwater welding several foreseen operations include surface assistance of cranes, in setting the diving platform, taking out of the damaged section and setting the new section. However, these activities require cranes of lifting capacity of up to 5 t. In case of cofferdam, surface cranes participate only in installing and uninstalling of the cofferdam and have to have a lifting capacity of a minimum of 20 t. The preparation and finishing works for the installation and dismantling of the underwater dry cofferdam are of significantly larger scope than the works in setting the operating platform for wet underwater welding and cutting.
- Pulling out of the damaged section and setting the new section in the dry cofferdam is additionally complicated by space restrictions as well as restrictions in the possibility of cargo handling. In the application of the wet underwater welding technology there is a significantly greater number of possibilities and movements during section handling, both in dismantling of the damaged section as well as in assembling of the new section.
- The time necessary for repair applying Approach No. 1 is approximately 15% longer than for Approach No. 2. However, as already emphasised, the welding and cutting times in Approach No. 1 can be significantly reduced with simultaneous welding done by 2 welders. In Approach No. 2 more time

is required for installing and uninstalling of the cofferdam, which represents also the critical path of the entire operation.

- In case of the use of cofferdam for dry underwater welding, it is necessary to solve the issue of sealing and water tightness. However, some very successful methods exist but it is very important to analyze the sealing method before underwater activities so that any eventual problems could be avoided. It is also necessary to provide and install the pumps that will drain water that might leak into the cofferdam through the seal. In the design of the cofferdam a system for fast evacuation in case of water breakthrough has to be foreseen and realized. Wet underwater welding carries also a high risk, but it should be taken into consideration that these works are performed by diver-welders with exceptional psycho-physical characteristics and the latest professional diving and working equipment.
- In case of wet underwater welding where there is a much greater scope of diving activities, there is a higher risk of classical diving problems. However, this can be solved by applying mixtures for breathing and optimization of the diving plans.
- Underwater non-destructive testing is of smaller scope in case of cofferdam, since there is no need to check the wet underwater weld. Also, in this case, conventional instruments can be used, as well as procedures for non-destructive testing. For testing in water significantly better skills and competence of the tester are required.
- Anticorrosion protection requires a special coating and application technology in Approach No. 1, since the external part of the spud can is always in contact with water. In Approach No. 2, complete anticorrosion protection is done by conventional coatings and technologies.

Table 1 shows basic elements taken into consideration for making economic analysis, i.e. comparison of the proposed technologies from the economic aspects. For non-destructive testing and anti-corrosion protection, costs for installation and usage of special equipment and tools are taken into consideration. Although the scope and the presented order may vary depending on contractor's experience and technology defined, working activities must be analyzed and described in detail before performing repair on the real object. Also, some activities may require additional work and this must be evaluated when cost is in question.

Table 1 **Sequence of activities for underwater welding technologies**
Tablica 1 **Redoslijed aktivnosti tehnologija podvodnog zavarivanja**

Work order	Activity for underwater wet welding repair	Activity for underwater dry welding repair
1	Mobilization and installation of necessary equipment for work and safety elements	Design and construction of cofferdam
2	Provision of access for wet underwater welding and cutting on platform construction	Mobilization and installation of working equipment and safety elements
3	Cleaning of spud can by underwater water jet and/or sandblasting	Setting of cofferdam using cranes
4	Underwater welding of hinges for lifting and handling of the damaged section	Fixing of cofferdam
5	Cutting of girders and stiffeners from the inside	Draining water out of the cofferdam and spud can
6	Cutting of bottom plate and side shell from the outside	Control of sealing and check of cofferdam before welders' entry
7	Taking out of the damaged segment	Installation of equipment and ventilation system and welders' entry
8	Grinding of edges and preparation of joint with hydraulic tools, control of preparation and opening dimension	Cutting out of the damaged section (incl. taking out or disposal of section)
9	Fitting and pre-assembling of the new section	Grinding and preparation of edges for welding
10	Tacking by wet welding	Fitting and pre-assembly of the new section
11	Welding of the seal weld by underwater wet welding	Welding of tack joints
12	Visual and MT control of the seal weld	Welding from the inside and outside
13	Pumping out water of the spud can	Inspection of welded joints
14	Insuring conditions for work from the inside in dry atmosphere – ventilation, gas detectors, detectors of explosive vapours and gases	Anticorrosion protection
15	Cleaning of edges and preparation of joint, final grinding	Evacuation of cofferdam and taking out of the equipment
16	Welding of the V-butt joint with metal backing (assembly strip) using MMAW	Dismantling of cofferdam
17	Visual and UT, MT control of the welded joint	Dismantling of set auxiliary elements necessary for installation of cofferdam
18	Final control and control of watertightness	Final inspection
19	Anti-corrosion protection	Completion of works and demobilization of equipment
20	Completion of works and demobilization of equipment	Cost of expert surveillance
21	Cost of expert surveillance	

After completed cost calculation on the basis of presented work activities and taking into perspective infrastructural and facility limitations, the authors' estimation indicates that underwater wet welding has up to 15% lower expenses.

5 Conclusion

Based on the performed study and analysis there are two solutions which apply underwater cutting and welding that are technologically and economically viable for the repair of the damaged spud can on the jack-up platform. Approach No. 1 plans the application of wet underwater welding, whereas Approach No. 2 plans the application of dry underwater welding in the cofferdam. Due to doubts regarding underwater wet weld quality it is very important to emphasize that in Approach No. 1 only welding of the sealing joint on the assembly strip engages wet welding, while connection of the inserted element to the spud can structure is to be performed from the inside in dry atmosphere after exclusion of water. The possibility of access to the damaged place from the inside of the spud can increases the flexibility in performing the works, and is to be used in both versions. The feasibility assessment has shown that both versions can be performed in compliance with the stipulated technology and safety protocols.

As to economical evaluation, the final costs for both proposed technologies greatly depend on contractor's experience and knowledge as well as on existing limitations considering the time and facility issues. It is highly recommended to evaluate the possible contractor through references in order to avoid additional costs. Taking into consideration the technological and economic aspects of the proposed repair technologies, it may be concluded that for the repair of the spud can on the jack-up platform in this particular case both analyzed technologies are suitable. However, the authors' estimations indicate that in the case under consideration underwater wet welding can possibly save up to 15 % of the costs compared to underwater dry welding in cofferdam. In order to confirm weld quality and prior to starting welding on the spud-can it is necessary to certify the proposed welding technology and the welding procedures by authorised institutions.

References

[1] AWS D3.6M: 1999 Specification for Underwater Welding

[2] API RP2X: Recommended Practice for Ultrasonic and Magnetic Examination of Off-shore Structural Fabrication and Guidelines for Qualification of Technicians

[3] ABS Publication Rules for Building and Classing Steel Vessel Rules 2006

[4] ABS Publication Rules for Building and Classing Mobile Offshore Drilling Units (2006) – 2006

[5] ABS Publication Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities – 2002

[6] ABS Publication Guide for Nondestructive Inspection of Hull Welds – 2002

[7] ABS Publication Approved Welding Consumables

[8] ABS Publication Rules for Building and Classing Offshore Installations – 1997

[9] ABS Publication Guide for Shipbuilding and Repair Quality Standard for Hull Structures During Construction – 1998

[10] ABS Publication Rule Requirements for Materials and Welding/Supplementary Requirements for Naval Vessels – 2000

[11] ABS Publication Guidance Notes on SafeHull Finite Element Analysis for Hull Structures – 2004

[12] COOPER, M.A.: "Some aspects of underwater engineering", IIW Doc. XII-1874-05.

[13] RICHARDS, B.:, "Wet underwater welding - a real alternative", IIW Doc. XII-1870-05.

[14] KRALJ, S., KOŽUH, Z., GARAŠIĆ, I.: "State-of-the art and trends of development in underwater wet welding and NDT inspection", Proceedings of the 2005 International Congress, Tel-Aviv, Israel, p. 69-84.

[15] MAKSIMOV, S.Y., ILYAHOVAYA, X.: "Structure and properties of the austenite weld metal in wet underwater welding of low-alloyed higher strength steel", Proceedings of the 2005 IIW International Congress, Mumbai, 16-19 February 2005.

[16] PFEIFER, W., EISENMANN, B., BACH, F. W., VERSEMANN, R., BIENIA, H., KRINK, V., LAURISCH, F.: "Plasma cutting in the multi-purpose research reactor (MZFR) - Underwater use at steel thicknesses of up to 130 mm", IIW Doc. I-E-381-04, I-1151-04.

[17] RICHARDSON, I.M.: "A review of underwater welding processes - Part 1: the influence of pressure on the welding arc", IIW doc. SC-UW-202-03.

[18] LUCAS, W., FRAZER, I.: "Underwater cutting technology for decommissioning offshore structures", IIW Doc. XII-1753-03.

[19] OGDEN, D.: "Operational risk management in underwater welding operations", Proceedings of the IIW Asian Pacific International Congress, Singapore, 29 Oct. - 1 Nov. 2002, publ. by The Welding Technology Institute of Australia (WTIA), ISBN 0-909539-99-5, vol. ST 1/2, paper No. 32.

[20] LANGLEY, C.: "Advanced underwater welding technology and training techniques research and development program - Conclusions and implementation", Proceedings of the 2000 IIW International Congress, Melbourne, 29 October - 2 November 2000.

[21] COOPER, M.A.: "Underwater engineering. Experience/ costings", IIW Doc. SC-UW-190-00.

[22] Equipment specification: Hydraulic hand tool Mk11, LD 50 Hydraulic Power Pack, UMC International, Southampton.