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THE SUPPORT OF UNDERWATER WORKS WITH THE USE OF REMOTELY OPERATED VEHICLES ON THE EXAMPLE OF WORKS CONDUCTED ON THE WRECK OF THE FISHING BOAT WŁA-127

Marek Dawidziuk[1)], Adam Olejnik[2)]

[1)] 3rd Flotilla, Support Vessel Squadron, Coastal Rescue Group,
[2)] Naval Academy, Underwater Works Technology Department, Gdynia, Poland

ABSTRACT

The article demonstrates use of underwater remotely operated vehicles during an underwater visual inspection of a sunken vessel. The presented tasks were carried out in the course of underwater works performed from a Polish navy rescue vessel on the fishing boat WŁA-127. The discussed examples include a visual inspection of the sunken vessel and the support offered to Polish Navy rescue divers as they carried out underwater works.
Keywords: marine engineering, underwater works, underwater vehicle, underwater visual inspection.

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INTRODUCTION

On 29 April 2009, on the eastern shore of the island of Bornholm, a Polish fishing boat WŁA-127 sank. Its wreck was found by a Danish vessel HDMS HAVKATTEN at the depth of approximately 68 m [6d]. The task of final identification of the wreck, and documentation of its condition for the purpose of determining the causes and circumstances of its sinking, was entrusted to the Polish Navy [6a].

Due to constraints on the permissible duration of the underwater works (resulting from the permits contained in the diplomatic notes (the wreck site is located in the territorial waters of the Kingdom of Denmark) and the changing atmospheric conditions), it was decided that most of underwater works related to the identification and assessment of the wreck's technical condition should be carried out with the use of remotely operated vehicles – ROVs. The works were conducted mainly with the use of FALCON ROVs.

THE FALCON ROV SYSTEM

The Falcon ROVs were put into service by the Polish Navy in December 2008. They replaced the Achille M4 and Benthos MKII ROVs. The Falcon ROV system encompasses the following elements:

- abyssal vessel – vehicle,
- cable-line with manual spooling winch,
- surface power and control unit,
- manual control panel.

The Falcon vehicle (Fig. 1) is a remotely operated vehicle designed mainly to perform underwater inspection tasks. It is controlled from the surface. Control signals along with power supply are sent to the vehicle with the use of an umbilical. The structure of the drive system ensures six degrees of freedom, whereas the software supporting the control system in the autopilot function enables maintenance of the specified course and depth. Moreover, an operator has the possibility to control the video system, lighting, single-axis manipulator, sonar and other devices installed in the vehicle.

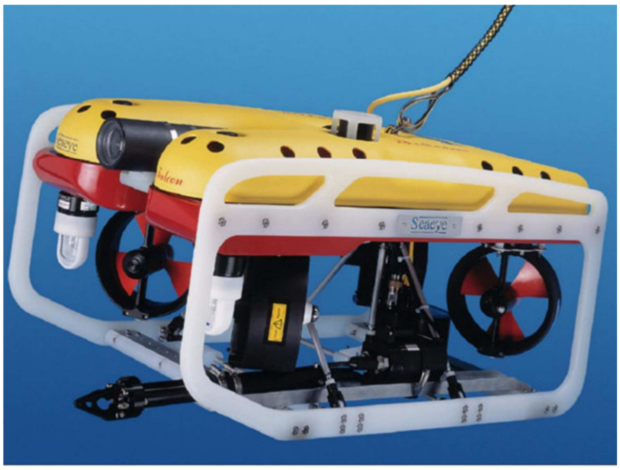


Fig. 1. Falcon ROV system [4].

The supporting frame of the vehicle forms a rigid skeleton of polypropylene and buoyant syntactic foam, reinforced with glass fibre. Most of the equipment is attached directly to the main buoyancy element. The rest is placed in the tooling and skeleton elements. The characteristic feature of the equipment is its autonomy. Each device constitutes a self-contained object that is connected by an electrical cable to a connection unit and operates as an individual "node". The malfunction of one item does not affect the work of another, especially during leaks or its flooding.

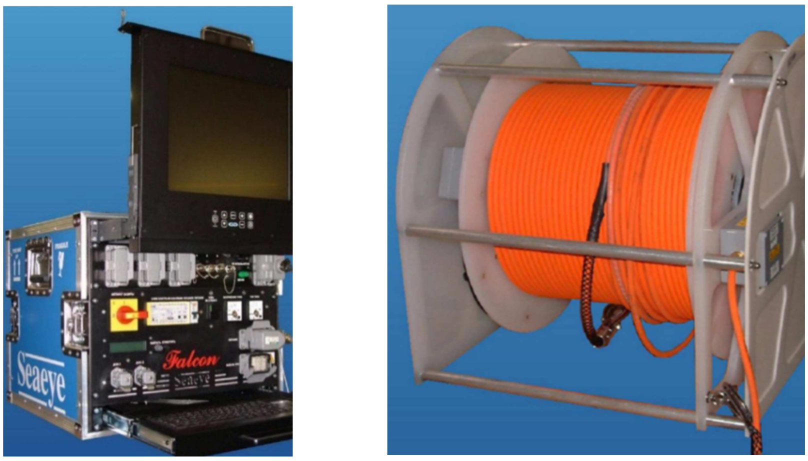
The propulsion system of the vehicle consists of five electric motors. Four are responsible for horizontal movement, one for vertical movement. Control of the propulsors in the horizontal plane is computer-managed according to the direction of motion specified by the operator. The magnetic clutch used in the propeller construction transfers the torque from the axle to the screw using a magnetic field, which eliminated the problem of traditional shaft sealing.

The Falcon ROV equipment used in the discussed works consists of the following components [4]:

- colour high resolution camera with automatic shutter and fixed focal length. It is characterized by Lux sensitivity 0.35 and a viewing angle of 91°;
- a tilting unit that controls the tilt of the camera in the vertical plane;
- two 75W halogen lamps with variable brightness adjustment;
- single-axis manipulator with cable cutters for remote maintenance of objects;
- navigation unit including an electronic compass, displacement sensor, gyroscope and depth sensor;
- imagenex type 881A surround sonar working with 310, 675 or 1000 kHz frequencies.

The control terminal box and the power supply unit constitute control elements for all nodes. The supply unit converts the 500 V DC supplied to the vehicle to a voltage of 48 V DC required to power all devices.

The vehicle has the option of retrofitting or changing the configuration with additional specialized equipment required to perform a specific task; for example via the addition of lighting, a second camera, a multi-function manipulator, wire rope cutter, magnetometer and a number of other items of equipment – especially measuring devices.



A B

Fig. 2. Components of the Falcon ROV system [4].
A - surface control unit, B - umbilical of the vehicle with manual spooling winch.

The vehicle's umbilical (Figure 2B), possessing a total length of 300m, is responsible for transmitting power, telemetry and video signals from the camera to the surface control unit. It consists of a multi-core electric cable, with a core filled with a water-absorbent gel, and an outer protective jacket. It is located on the drum of a hand winch.

The surface power unit (Fig. 2A), is a control interface between the operator and the vehicle. It is responsible for powering up the vehicle with a 500V DC voltage, transmitting of telemetry signals and receiving video signals. It contains a computer that directly controls each node and its operation. The received video signal is displayed on an integrated monitor. It is also responsible for vehicle safety in the event of an electrical breakdown in the umbilical or nodes, as well as their flooding. In the event of a leak, an insulation emergency status monitor automatically cuts off the vehicle's power supply to protect it and minimize damage. A control panel is connected to the control unit by means of which the operator controls the utility functions of the vehicle.

IDENTIFICATION WORKS ON THE WRECK

The position of the wreckage of the fishing vessel WŁA-127 was determined by the HDMS HAVKATTEN [6d]. The examination, conducted with the use of a side scan sonar SSS Homar-P, confirmed the presence of the object at the identified position. A more precise sonar image of the object was achieved with the MS1000 Variable Depth Sonar (VDS). An analysis of the obtained sonar image had substantiated object identification as a fishing boat.

An accurate identification of a wreck using sonar is difficult to implement, the success of the undertaking being determined by factors such as the class of measurement equipment and measurement technique used, environmental conditions encountered, and the ability of the hydrographer/analyst [1] to interpret the sonar images.

It was decided to obtain the final identification of the wreck by comparing images of the vessel’s characteristic elements with materials collected in the shore based phase undertaken whilst preparing for the operation. The video material collected using the Falcon ROV was to be used for identification.

Fig. 3. The object located near the site of the wreck (own studies).

The first stage of work for the ROV operators was to familiarise themselves with the work area, and, in particular conduct an analysis of the collected sonograms for the presence of hazards to the ROV vehicle – such as fishing nets, and a general characterisation of the seabed with the objects present on it (Fig. 3).

Taking into account the orientation of the wreck (laying on its starboard side) and the position of their own ship, the ROV's operational zones were identified with regard to safety and risk of damage or loss of vehicle. Using the characteristics of performing underwater works on rescue ships, in particular, the fact of using a diving system to submerge the VDS sonar, the operations[1] of vehicle submersion and ascending were carried out utilising the ropes of the diving system, using them as guide ropes for the descent.

This allowed elimination of the risk of drift of the vehicle during immersion due to the occurring sea currents, while at the same time informing the operator that the first contact with the bottom is directly under the ship, or more precisely, under the diving platform. The Falcon's rotating vertical camera system allows the observer to see the water under the vehicle as it dives and above as it ascends, giving the operator more complete information on the situation both above and under the vehicle, thus reducing the risk of collision with obstacles during ascending/descending manoeuvers.

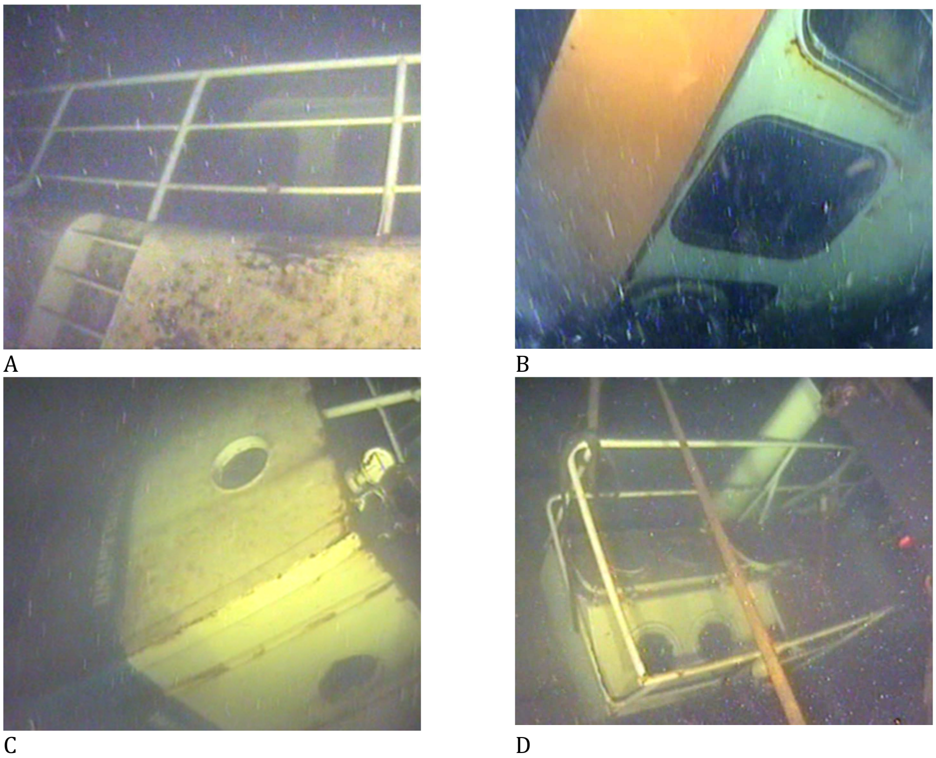


Fig. 4. Structure elements of the sunken boat shown in underwater position using the vision system installed on the Falcon ROV (own studies). A – companionway on the port side amidships, B – superstructure, C – stern, D – stern, engine room skylights.

On the first descent of the ROV, the seabed and the wreckage were inspected to establish the vehicle's safety, taking into account the direction and strength of the sea' current, the visibility in the area of operation, the structural elements of the wreck (masts, shrouds, superstructures) and the presence of fishing nets in which the vehicle or the control cable could be caught (Fig. 4). The element which most facilitated the vehicle's operation was the in water visibility, this being up to 4 m.

During material collection, particular attention was paid to the vehicle's trajectory over the structure of the wreck. In this type of work, it is important that the material collected by the on-board television system is arranged in a logical whole, with consecutive construction elements of the identified unit being shown one after another. This methodical approach meant that during the comparative analysis of the video material collected by the vehicle, and the material related to the construction of the unit, it was possible to unequivocally confirm the identity of particular components and their location in the hull.

By identifying the wreck and analysing the previously collected photographic materials, the conformation of the construction elements on the vessel that was searched was confirmed. Due to the short period of time that the wreck had been on the bottom, and a lack of vegetation on the hull, the identification of structural components did not pose any problems, allowing to assume high probability coefficients for the conformity of the wreck's condition with that visible on the photographic materials collected prior to its sinking.

The definitive element confirming the identification of the wreck sought was the well-visible name of the wreck "WŁA-127" on the bow section of the widoczna nazwa wraku „WŁA-127" w części dziobowej na lewej burcie i desce trałowej, jak również nazwa portu pochodzenia „WŁADYSŁAWO" na jego rufie (Rys. 5). port side and trawl board as well as the name of the port of origin "WŁADYSŁAWO" on its stern (Fig. 5).

Fig. 5. Identification inscriptions on the hull of the sunken boat (own research).

WRECKAGE INSPECTION

Positive identification of the wreck initiated the next phase of works, namely inspection of the sunken vessel, which was carried out in two stages. The first stage involved visual inspection of the outer plating and wreckage components that were carried out by ROVs. The second stage of inspection inside the vessel was performed both by divers and ROV vehicles. The purpose of the inspection was to provide photographic and video materials to the administrative services to explain the cause of sinking and to search the interior of the vessel to find bodies of the crew.

An inspection of the outer hull was initiated with a visual inspection on the port side of the wreck (Fig. 6). The first surveyed areas were the midships and the bow section. The inspection consisted in an assessment of the shell condition for any dents, damage, leaks, or the condition of the fishing boat equipment.

The inspection of the superstructure was already associated with an increased risk due to the protruding elements of the mast, antennas and ropes that could catch the vehicle's control cable. The execution of the inspection of the stern involved the greatest risk of snagging on the elements of the fishing boat, in particular the hanging rigging, ropes and floating nets. Performance of inspection under the overhangs of the superstructure, fishing gear or under masts required particular attention and skill from the ROV operators in order to retrieve the vehicle from the area upon completion of the inspection – the vehicle being manoeuvred backwards to the direction of movement.

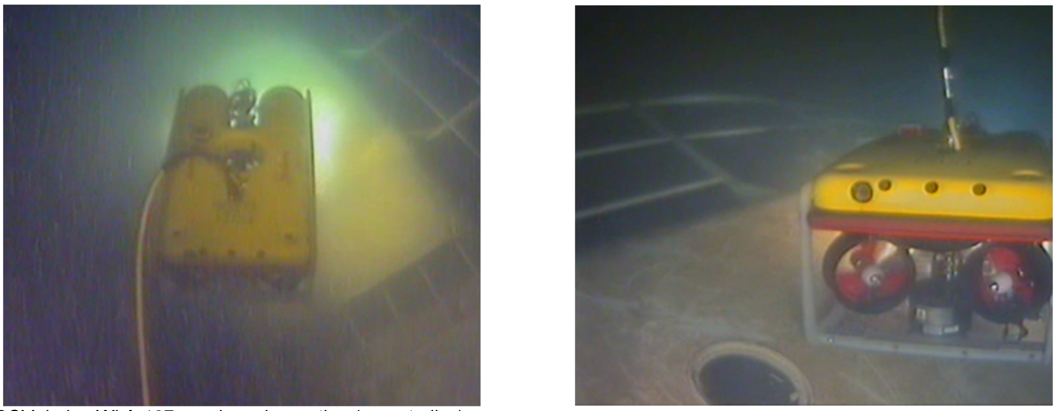


Fig. 6. The Falcon ROV during WŁA-127 wreckage inspection (own studies).

One of the tasks carried out during the inspections was to determine the angle of heel of the wreck by the ROV operator. Analysis of the pictures of the stem and mast allowed only an estimation of this angle. Additionally, using the vertical propulsion drive, the vehicle was "glued" to the ship's side to read the vehicle's tilt angle from the on-board navigational unit which then corresponded to the tilt angle of the wreck. Measurement of this parameter was also made indirectly using the methodology based on two depth measurements conducted with the use of the vehicle's on-board devices (Fig. 7).

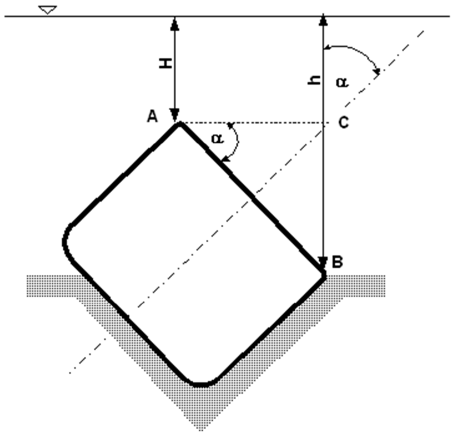


Fig. 7. Graphical representation of the wreck position for calculating its heel angle based on two depth measurements (schematic diagram without a scale).

A depth gauge mounted on the vehicle was used to measure depths at point A and point B, then using the known AB value and simple trigonometric relations (1), (2) the hull angle of the wreck was calculated.

$$sin\alpha = \frac{BC}{AB} \quad 1)$$

$$BC = h - H \rightarrow sin\alpha = \frac{h-H}{AB} \quad 2)$$

As a result of the inspection of the hull plating, a petroleum substance leakage was detected from one of the wreckage compartments (Fig. 8).

A more thorough investigation has indicated its cause. The leakage source was a porthole. Then, based on the archived video, the leakage scale was estimated and the method of its sealing was developed.

Fig. 8. Leakage of petroleum substances (own studies).

The results of the works carried out by vehicles allowed to confirm the name of the sunken craft (wreck identification) and to estimate its technical condition after sinking (wreck inspection). The effects of these actions were used in the preparation and planning of the next stage of underwater works in the vicinity of the wreck and its structure – the diving works.

SUPPORTING OF DIVING WORKS

PREPARATION FOR DIVING

The use of vehicles in the preparation for diving included: depth measurements in the work area, setting of the diving system and use of video material to present the wreck situation and its diving area during the briefing of the diving crew prior to descent.

Carrying out depth measurements in the region of underwater works is a basic activity before the commencement of diving works. Undersea depth measurements were taken around the wreck, key points on the wreck and possible snagging elements. This information is used when planning a dive and determining the depth of safe water, and it also allows for the proper definition of the required decompression profile.

An important element before diving initiation was to use the vehicle to position the elements of the diving system, such as anchors and a dive platform in relation to the wreck. Upon platform submersion to the depth of the diving works, the vehicle operator determined the position of the platform with regard to the wreck. The defined distances of these elements in relation to each other, in the vertical and horizontal plane, were the key pieces of information for the work manager and navigator officer to position the ship and the diving platform in relation to the vessel being researched. Setting up the diving platform against the wreck was carried out in 3 directions (Fig. 9).

Fig. 9. Location of the diving system anchor in relation to the stern part of the wreck (own studies).

The depth was set using the winch of the system, whereas the position in the horizontal plane was determined by moving the ship in a horizontal plane in relation to the bottom. Operating a vehicle while setting up the diving platform against a wreck, involves continuous observation of these objects. The operator had to observe and control the position of the system components with respect to the wreck, anticipate any possible catches or collisions, and react accordingly in order to be able to transmit a signal to the ship's navigation officer to avoid contact of the diving system with the wreck.

In order to accurately determine the position of the diving platform in relation to the wreck in the 3D space, the operator was forced to continuously change the position of the vehicle and to conduct observation at various angles to the objects to be able to accurately determine the distance between the elements in the 3D space. The difficulty with this operation involved controlling of the position and positioning of the control cable of the vehicle during a dynamically changing situation. The operator had to avoid a situation where the vehicle control cable is placed between the diving system and the wreckage so that it would not be crushed or cut.

An important element was also the correct determination of the value of the sea current to take into account its influence on the control cable in order to avoid it being caught in the diving system, or elements of the ship wreck. In the conditions occurring at the bottom, the visibility allowed the control cable to be positioned just a few meters from the vehicle. Simultaneous control by the operator of all of the aforementioned elements has contributed to qualifying the above operations as difficult tasks with a significant risk to ROV safety.

DIVING WORKS

The basic use of vehicles during diving works was to provide the underwater works manager with a current image of the work area with a direct view of the divers (Fig. 10), their activities or situation around the workstation. Changing the perspective of the image by adopting different positions of the camera and the vehicle in the water allowed the manager to obtain extensive information about the work area, thus reducing the correspondence with the divers concerning the underwater situation and saving the working time of the divers.

In tasks requiring continuous and uninterrupted observation of objects, while simultaneously changing the position in water (changing of the view perspective), the Falcon ROVs operated without any problems. The drive system used in the vehicle enables it to move horizontally along the longitudinal and/or transverse axes of the vehicle as well as rotate about the vertical axis. In the vertical plane, the vehicle moves up / down without tilting about the transverse or longitudinal axis.

Such tilts are automatically compensated by the vehicle's automatics. The operator has the possibility to guide the vehicle in each of the directions described above separately, which in combination with the simultaneous rotation of the camera along the transverse axis, allows the operator to change the position of the vehicle in the 3D space, thus ensuring continuous, uninterrupted observation of a selected object.

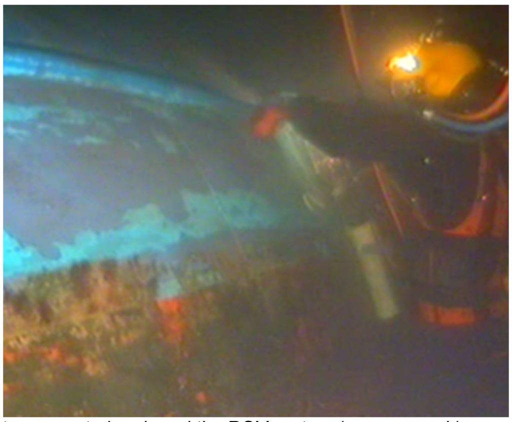



Fig. 10. Technical observation of an underwater diving workstation using the vision system mounted on-board the ROV system (own research).

Underwater works were carried out at depths of more than 65m at different times of the day, which involved divers' working in conditions of limited visibility. Divers equipped with a lighting system installed on their diving helmets illuminated a very limited area – just a few meters. Utilising the divers' own illumination with the beam of light having the same direction as their eyes, significantly deteriorates the visibility as a result of light dispersion and reflections on the detritus suspended in the water.

The elimination of this phenomenon consists in illuminating an object or area from a different angle in the space than the direction of divers' sight. This task was performed using the ROVs. Falcon vehicles are equipped with standard halogen lighting (optionally diode lighting) with adjustable power. In addition, hid lighting has been fitted to increase the intensity of light on vehicles. The task of the vehicle operator was to manoeuvre the vehicle so as to always illuminate the objects from the divers' side and not to dazzle them. Particular attention was paid to the position of the control cable to prevent its entanglement with the diving bundle connecting the divers to the diving bell.

Vehicle lighting was also used during the initial phase of the divers' work. In limited visibility, the orientation of the divers, in relation to their position on the wreck, was significantly impeded, especially when the divers transferred to the work site from the diving platform. To limit the time of divers needed for the orientation in the area and quickly reach the workstation, the operator would in advance guide the vehicle to the workstation and direct the vehicle's lighting towards the diving bell. The presented method of diver guidance was particularly used during works in the area of the vessel's masts (Fig. 11).

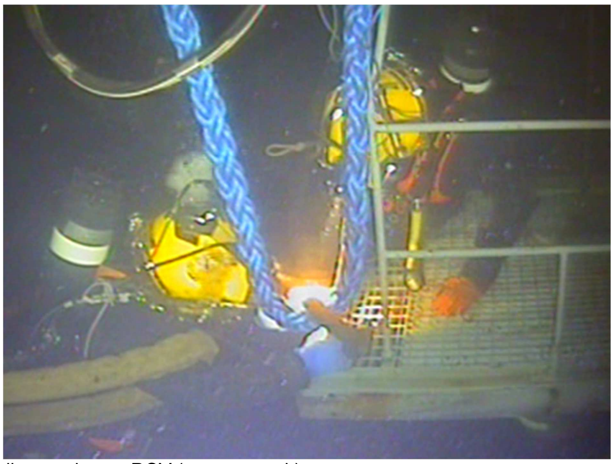


Fig. 11. Supervision of activities performed by divers using an ROV (own research).

An important task implemented by ROVs consisted in assisting divers in works connected with wreck penetration or welding works. These particularly dangerous works required continuous supervision from the operator to control the positioning of diving bundles and welding wires to prevent getting caught or entangled in elements of wreckage.

The divers' control of the diving bundles was limited in water to a few meters. The use of vehicles to visualise the complete situation, along with the divers and their equipment, showed the manager the current situation, which had an impact on the management of underwater operations (Fig. 12).

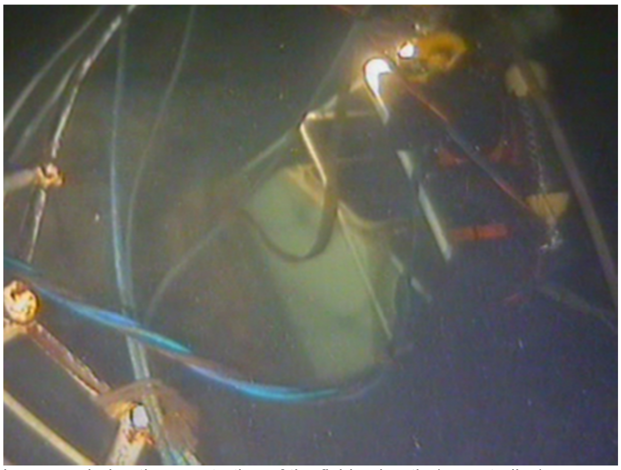


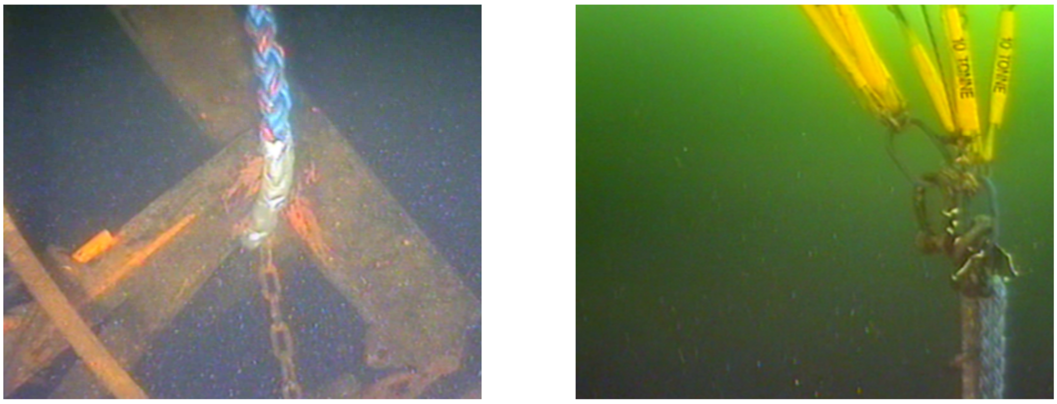
Fig. 12. Supervision at the entrance to the engine room during the penetration of the fishing boat's (own studies).

An inspection of the interior of the wheelhouse and the inside decks of the wreck was not possible due to the wreck being positioned on its starboard side, i.e. laying on the location of the access ways of the superstructure. In order to access the interior, tasks were initiated to bring the wreck to the vertical position. In short, this complicated task consisted in the use of open pontoons to raise the mast of the vessel and the rear gantry, thus bringing the shipwreck to the vertical position.

The video material collected by the vehicle was used to develop the method of placing the wreck in a vertical position. Underwater vehicles secured the entire scope of works, in particular the process of control and the state of task implementation (Fig. 13).

In the critical phase, only the ROV vehicle was present during the lifting of the pontoons due to safety reasons. The operator maintained continuous supervision of the progress of works. He also determined the level of execution of the task, by constantly determining the current degree of tilt of the wreck. The operation of straightening the wreck took several hours, which with the use of the applied diving technology, prevented the continuous control of the tilt of the boat by using divers.

This task was carried out completely by the vehicles, only the operators were changed in the course of the watch system.



A B

Fig. 14. Wreckage verticalisation operation (own studies):
A – stretching of the mooring line to the pontoons through the gantry,
B – fixing of recovery pontoons.

During the penetration of the wreck, the bodies of missing fishermen were found. The extraction of bodies and placing them on the diving platform was vested in the divers. Due to the diving technology and the lengthy process of preparation of the ship to recover the corpses, the task of the operator of the vehicle consisted in a continuous observation of the body attached to the diving platform. The occurring sea currents and waves on the surface of the sea resulted in a continuous movement of the platform in the water, and thus of the body, which could lead to its release. In such a situation, the operator was ready for an immediate intervention by keeping the body on the platform and holding it by properly manoeuvring the vehicle.

Vehicle operators also performed auxiliary intervention tasks. During the works on the wreck a diving flashlight was detached from one of the divers. Due to the saving of the working time of divers, the task of finding and extracting the lost flashlight was entrusted to the vehicle. This task was performed using a single-function manipulator, which is the basic equipment of the Falcon ROV.

CONCLUSION

The use of Falcon ROVs in underwater inspection of the WŁA-127 wreck was their first application in the Polish Navy at large depths. The vehicles worked in total for approximately 200 hours. This work has contributed to enhancing the experience concerned with the use of a new type of ROV.

The main strengths of the Falcon vehicle are evident in its marine prowess and in its ability to maintain a stable position. The wide-angle low-light camera performed very well in the conditions of limited sunlight. Lighting with variable power well illuminated the work area, especially the divers' work stations.

The single-axis manipulator was used to pick up small items. For more complex works requiring a greater motor activity of the manipulator, it was be advisable to use a 5-axis manipulator. During the implementation of this task, in addition to the Falcon ROVs described in detail, other ROV systems of the Polish Navy were used.

A practical comparison of the usability and manoeuvrability of the applied constructions during the discussed underwater works confirmed the validity of the decision to abandon the use of older systems in favour of the Falcon vehicle of the Polish Navy.

Underwater works at the wreck of the WŁA127 fishing boat were performed by a wide range of specialists in underwater works from different organisational units of the Ministry of Defence: 3FO Support Vessel Squadron, Divers and Scuba Diving Training Centre, Hydrographic Defence Division and Underwater Works Technology of the Naval Academy.

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mgr inż. Marek Dawidziuk
3rd Flotilla, Support Vessel Squadron, Coastal Rescue Group,
e-mail: marekdawidziuk@wp.pl

[1] The diving system, i.e. the hoisting device of the diving bell, is a set of equipment used to carry out diving works. The basic elements of the system are: diving bell, movable platform, swing frame with winch (crane device). The diving system enabled controlled descent and ascent of divers on the platform or in the diving bell to the depth of the performed works. The platform and dive bell are immersed with wire ropes, which constitute a good reference for the ROV vehicle operator in the water during vehicle immersion/emergence.