

STUDIE ON SATURATION DIVING IN POLAND AND PRACTICAL APPLICATION OF THEIR FINDINGS. PART 6 SELECTED PROBLEMS AND SOLUTIONS REPORTED IN SATURATION DIVING BETWEEN 2021 AND 2022. PART 2

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ABSTRACT

This article is a continuation of a series of publications dedicated to studies and practical use of saturation diving technology in Poland. Below, the author discusses the specificity of performing saturation dives against the economic and historical context of the country at that time. In Poland, the Department of Diving Equipment and Technology of Underwater Works (Polish abbr. ZSNiTPP) has been taking care of saturation dives carried out for the needs of the emerging offshore extraction industry for over a decade. At the same time, deep-sea diving technologies are being developed; initially, these served as the primary diving technology, and since 1994, they have complemented the comprehensive safety measures for saturation diving. Since 1995, saturation diving has become commonplace in the Polish exclusive economic zone of the Baltic Sea. This article illustrates the difficulties experienced by those who were putting saturation diving into practice during a period of economic instability when the domestic marine extraction industry's infrastructure operated at a small scale compared to global companies. It highlights selected key figures and participants in the implementation process, which can be divided into periods of cooperation with the Italian underwater services company RANA and the execution of long-term underwater works based on domestic capabilities. The paper also considers the technical and organisational conditions for carrying out saturation dives for the Polish extraction industry. In 1990, Petrobaltic (today LOTOS), a company for the exploration and production of oil and gas played a leading role in the promotion and dissemination of saturation dives in Poland. Practical saturation diving exercises in Poland are linked to the only operational diving system of the Italian-made Af-2, which enabled scientific research into the application of new technical solutions and testing under operational conditions, as well as the development of scientific, engineering and medical personnel for the needs of the Polish offshore industry. This company played a key role in performing saturation dives in our country. The year 1995 marked a turning point in the history of saturation diving in Poland and in the Baltic Sea. This technology enabled the installation of the first two subsea production wellheads B3-7 and B3-10. Saturation dives were made possible by Petrobaltic leasing the Af-2 diving system, which was subsequently purchased by the Naval Academy in 1998. Following modernisation, this system remains in use to this day.

Keywords: saturation diving technology, decompression tables, saturation diving parameters, long-term underwater works, diving system, emergency conditions, technical and organisational support for dives, medical issues involved in saturation diving, mobile diving system, saturation diving centre, breathing mixtures.

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COMMENTS ON THE CONTINUATION OF STUDIES ON SATURATION DIVES

The main recommendations in the specialist literature regarding saturation diving can be summarised briefly in the following way: due to their complexity, saturation dives require appropriate techniques, organisation, and medical support, as well as trained personnel who can reliably operate all equipment and assist in managing the entire underwater operation. These recommendations do not apply to every dive. Besides, one often hears that saturation dives are 'high technology,' very dangerous, and testify to a high standard of diving in a given country. This article, which describes the final stage of the Poland's path to saturation diving is a subjective account of that journey.

How can these main recommendations be described? Nowadays, decision-makers would solve the problem by either hiring a company rendering underwater services or set up a domestic team and train its members in saturation diving assuming there is a technical base available in the country to perform such dives. Analysing which of these approaches to choose is not merely a matter of applied science; one must take into account national conditions across a wide range of fields, such as economics, mining, medicine, organisational theory and many other factors. The intensity and frequency of saturation dives are too low to make it economically viable to maintain a team on a year-round basis. On average, over the first twenty years of the 21st century, the frequency was just over one saturation dive per year, which, from an economic point of view, does not allow for maintaining a team of divers on a 24/7 standby basis, but only on a call-up basis with 4 to 6 weeks' notice prior to the dive. Hiring an overseas specialist underwater services company entails high costs relative to the project schedule within a corporate framework, which is further disrupted by the capricious weather of the Baltic Sea.

Petrobaltic has adopted a hybrid approach to its underwater services policy, namely maintaining a permanent diving team for saturation dives whilst also hiring diving crews on an ad hoc basis; this has enabled the company to carry out work at great depths practically all year round, alternating between free-diving and saturation dives. As to the content and practical delivery, these activities are prepared by a team from the Department of Technology of Underwater Works at the Naval Academy, in consultation with the Maritime Operations Department – the same department that also trains supervisors and divers for deep and saturation diving for the Navy and the national economy.

In the opinion of some representatives of the Polish scientific community dealing with issues relating to underwater works, LOTOS Petrobaltic is merely providing "ordinary common services." This approach discourages the company's specialists, who prefer to purchase specific underwater services without delving into the technology used to provide them. A scientific approach is adopted in only one instance: the investigation of accidental incidents.

As a result, scientific and implementation issues requiring new solutions are addressed in parallel with the ongoing work. Generally, these stem from the need to ensure the safety and execution of underwater works, as well as to improve the diving team's performance. Even securing a grant (so vital for the national economy and

defence) for the analysis and assessment of operational requirements and safety measures for underwater works, based on national experience and needs, proved difficult due to the niche nature of the project. The underwater works regulations drafted in Poland in the early 21st century require the setting up of a team, which, given the dispersion and ambitions of the scientific and technical staff and the divergent interests of the various institutions involved in their creation, does not bode well for success. On top of that, formal documents and standards that have been drafted disregard the experience accumulated at the Polish Naval Academy, the only institution in Poland having 40 years of experience and data from underwater works in the Polish offshore in the deep-sea diving zone. Unfortunately, there are many more examples of this absurd approach.

In the light of the development of offshore energy, as well as penetration and exploitation of the seabed, and the country's rescue capacity, underwater works potential of Poland is a strategic issue.

Strengthening the capacity for manned underwater operations should form part of national policy, even though the current trend favours equipment designed to replace divers, as well as so-called underwater support systems, non-diver techniques and ROVs, including those utilising artificial intelligence.

This problem can be resolved by pooling resources and funding from sectors such as mining, energy, and defence. The ultimate solution in our country should be a standard medium-displacement diving vessel equipped with a stationary diving system for saturation dives, which would allow operations to commence almost immediately should the need arise.

SATURATION DIVING PLANNING

When planning underwater works, the first fundamental decision is which diving technology to choose for their execution. In many cases, opting for saturation diving is the only sensible and economically viable decision. Based on the data collected, it is important to select the most suitable plateau depth from the diver's perspective. In the saturation diving technology adopted by LOTOS Petrobaltic, the principle is that the diver returns to the bell immediately after completing the work, without making any stops. This means that the depth at which the diver works, relative to the depth of the bell (saturation plateau), must be a no-decompression depth. The depth is selected by conducting an analysis based on the anticipated depth ranges at which the diving work will be carried out. When selecting the saturation plateau, it is necessary to make a decision based on the experience of the dive supervisor or, as is unfortunately not mentioned, to take into account the financial aspect that is beneficial to the divers and support staff.

Another important factor is the planning of on-shore support, taking into account the supply and logistical capabilities of LOTOS Petrobaltic and the Department of Technology of Underwater Works at the Polish Naval Academy, namely:

- the necessary quantities of breathing mixtures and oxygen, as well as the provision of an adequate number of cylinder bundles and storage space for them,

- equipping the centre and the diving system with technical devices and diving equipment not included in the Af-2 system,
- providing specialist and auxiliary equipment for the specific type of underwater works,
- identifying a safe location for storing supplies and consumables (including oxygen, chemical sorbents, chemicals for filling measuring devices, hyperbaric fire extinguishers, disinfectants, lubricants, etc.),
- securing welfare and hygiene/sanitary facilities, e.g., meals are served in the chamber using disposable crockery and cutlery; meals are transported from the galley at the bow to the chamber located at the stern of the vessel regardless of weather conditions.

Plans also provide for the organisation of communication, supplies, handling emergency situations, including divers evacuation under pressure.

An important aspect of planning is to ensure that the work is supported by an ROV, the use of which is now standard practice. The vehicle is deployed prior to the actual works; it carries out underwater reconnaissance in the work area, and the TV footage from this vehicle is utilised at all stages of the subsequent works, from preparation, through the execution phase, to the post-excavation period. During the planning stage, the vehicle provides information on crucial factors such as hydrological conditions, particularly visibility, the presence of strong sea currents, and obstacles posing a risk to the diver's work. In the Baltic Sea, for example, the vehicle has encountered heads entangled in fishing nets. In such cases, work plans had to include the removal of the nets, which is an additional and technically challenging operation.

DIVING SYSTEM PREPARATION FOR SATURATION DIVES

Organisation of saturation dives can be divided into three main stages. The first, and also the most challenging one in terms of organisation and technical aspects, is the time-consuming preparatory phase. It starts with the decision to perform the dive and goes on until the divers enter the chamber and the hatches are closed to begin decompression. All tasks involved in preparing for a saturation dive must be completed six to twelve weeks before the scheduled start date of the dive.

INSTALLATION OF THE DIVING SYSTEM

This task involves

- drafting the documentation,
- arranging for material, technical and medical support,
- setting up onshore safety measures,

installing the diving system on the designated vessel.

Once the chamber and the marshalling cabinet base have been positioned, the frames of these components are attached to the foundation using clamps. The foundation and clamps are welded to the vessel's deck, and the quality of the welds is inspected using NDT methods in accordance with the recommendations of the classification society, which has adopted strength calculation conditions for the angle of list 22.5°. The

welding and mechanical work takes between 5 and 9 days, whilst the actual installation process on site takes 4–5 working days. During this period, if the installation is taking place on a vessel, all components of the diving system are transported from the storage facility to the quay. In the case of installation on an offshore structure, the system is transported to the vessel once it has been prepared at the base. All components, containers and gas cylinders are secured to the ship's deck and positioned to ensure safe unloading without the risk of damage or destruction in maritime conditions.

SPECIFICITY OF THE INSTALLATION OF Af-2 DIVING SYSTEM ON THE LOTOS GIANT PLATFORM

The formal commissioning, which requires the prior consent of the classification society for the installation of a diving system on a given offshore structure, is also very time-consuming when the structure on which the diving system is being installed and the diving system itself are under the supervision of different classification societies. Just such a difficult case arose in 2019, when it was decided that the Af-2 diving system would be installed on the LOTOS GIANT platform, purchased in 2018. The LOTOS GIANT platform was subject to the supervision of the classification society DNV, which initially rejected the installation of the system on this platform, explaining that its structure was not designed for this purpose.

Once clarifications were provided to DNV, the society requested documentation of the diving system, its layout plan, and the strength and structural calculations for the platform's pontoon. Finally, following discussions and amendments to the documentation, the DNV inspectors acknowledged that the Af-2 system is a small-scale, lightweight diving system, which did not correspond to the dimensions of the systems routinely used for North Sea shelf operations and therefore familiar to the DNV inspectors. Regarding the platform's design it was agreed that modifications would be made to allow divers to work within the limits of the length of their cable and hose bundles supplied from the bell. The second issue that needed to be resolved was the requirement that the installed diving system must not interfere with the platform's operations, i.e., the fire safety and emergency evacuation routes and zones, and must ensure the platform's functionality even in exceptional circumstances, such as crew evacuation, loading and unloading, and the performance of so-called 'well operations.' Due to the lack of space, an additional difficulty on the GIANT platform was the positioning of the drilling rig, which left no room for the installation of a safety diver station.

PRS (Polish Register of Shipping) approved the documentation for the new service routes for the chamber, bell and support structures, as well as the safety measures for the operation of this system. Also at the request of PRS, new documentation was prepared for the foundations and service routes, taking into account crew movement and enabling the evacuation of divers under pressure, as well as the installation of the diving system's power supply.

For the contractors, the installation of the main component of the hyperbaric chamber required its weight to be reduced, due to the load limits within the reach of the crane on the platform that was to place it on its

foundations. Furthermore, it was necessary to select hoses and cables of the appropriate length to ensure the system operability without hindrance, and to position the containers in such a way as to allow space for the entrances to be opened, given the limited space available.

The approval of the installation and results of functional tests of the system on the LOTOS GIANT platform by the PRS did not take long compared to the time needed to obtain administrative approval for its installation. In this challenging undertaking, the staff of the Marine Operations Department at LOTOS Petrobaltic demonstrated a lot of 'resilience.' Their efforts were a complete success. By installing the diving system on the mobile platform, they freed up the service vessels, which, with the diving system installed, have very limited capacity to support platform operations at sea.

RISKS ASSOCIATED WITH TRANSPORTING THE DIVING SYSTEM BY SEA AND UNLOADING IT ON THE PLATFORM

Assembly on the platform requires the components to be transported by sea and unloaded at sea, which carries the risk of damage during crane operations (e.g., hitting against the deck or the ship's structure in rough seas). To reduce assembly time on the platform, selected components of the Af-2 system are transported partially assembled and specially stowed on the deck. Storage tanks for gases and other materials, as well as certain containers, are transported later, so that the transport of the system's core components allows assembly to commence more quickly.

The risks involved in transport to the platform and the duration of the installation work stem from the following factors:

- the start time of the transport depends on weather conditions. The transfer of diving system equipment from the ship to the platform should ideally take place in perfect weather (sea state as low as possible, 1 to 2),
- the risk of damage during crane operations (hitting the ship's deck and simplified rigging, or hasty preparation for transport in the past have damaged the lift, chamber, airlock and other installations),
- transport of diving system components alongside other offshore industry components,
- the lack of a prepared storage area prior to installation on the platform.

Transport of the diving system to the platform took two days under the optimal scenario.

Working in winter conditions with severe frosts significantly extended the installation time, and the lifting operations were difficult for the crew.

Once the basic components have been successfully positioned on the deck, and after the welders have left, the actual assembly takes place, i.e., the connection of the systems using flexible couplings and their securing. Diving on the installed Af-2 system could commence following functional tests and trials, as well as after the divers had completed rescue and evacuation drills. From the moment the diving system equipment is placed on the platform deck, these operations take 10–14 working days (with the team working 12 hours a day).

During the installation period, partial and shipowner's inspections of individual components are

carried out, as required by the annual maintenance exercise, often with the participation of PRS inspectors.

OPERATIONAL INSPECTION OF THE DIVING SYSTEM

Three to four days before the operational inspection, a team of divers arrives on board, comprising the underwater operations manager, selected divers and technicians who did not take part in the installation. The task of this team is to inspect and prepare the entire diving team – and in particular the divers, both those taking part in the work and the safety divers – for the tasks ahead. The entire team, however, should report for duty 2–3 days before the start of the compression phase.

Before commencing the operational inspection, the underwater works manager should compile the documentation required for conducting a saturation dive and assign tasks to the diving team and support staff. Preparing the platform or vessel for diving should include the precise positioning of the base (vessel) above the work site and, in the case of a ship, the disengagement of the propulsion system and the immobilisation of all equipment affecting diving safety.

An operational check of the system is carried out in accordance with the plan drawn up by the underwater operations manager and the relevant personnel. The inspection begins with a pre-dive briefing and concludes at the end of the day with a summary and assessment of the work and tests carried out.

The operational inspection plan should take into account the scope specified in the operating manuals for individual components, devices and diving system equipment. The scope of the inspection and preparation for operation should cover checks similar to those carried out during periodic inspections and include:

- inspection of the condition of equipment carriers and their fittings, preparation for transport, and maintenance of surfaces, structures, markings and hatches,
- inspection of the hyperbaric chamber and diving bell shells, and in particular the condition of the seals in the hatches and airlock covers, periodic replacement of rubber seals (regardless of their condition), assessment of the condition of the portholes, assessment of connections and penetrations through the shells of pressure vessels, and periodic checks of their leak-tightness,
- checking the metrological validity of pressure measuring devices, gas analysers and other parameters relating to the atmospheric conditions of the chamber and bell,
- inspection of winches and lifting equipment, in particular the tightness of the hydraulic system, assessment of the condition of load-bearing ropes, especially the end section of the rope operating the swing frame during the operation of attaching the bell to the chamber,
- inspection of the condition of the bell-to-chamber connection mechanism under pressurised conditions,
- inspection of the data recording system and IT equipment,
- inspection of the cleanliness of the oxygen installation,
- inspection of information boards and signage,

- inspection of the electrical system and certification of the insulation condition of individual circuits,
- checking the operation of life support systems,
- inspection of welfare facilities,
- inspection of emergency equipment for the bell and chamber,
- checking the validity of certification, authentication and technical inspections of diving system equipment,
- checking the quantity, quality and expiry dates of consumables,
- updating or renewing the qualification documents of operating personnel,
- checking the diving team's knowledge of the system's operation and handling, particularly in emergency situations (including conducting an evacuation drill for divers under pressure using a rescue chamber).

FUNCTIONAL TESTS AND INSPECTIONS OF THE DIVING SYSTEM FOLLOWING ASSEMBLY AND ON-SITE TRAINING

Following an operational inspection, functional tests are carried out, which include:

- a leak and stress test of the system: chamber – bell – rescue chamber – life support systems at a depth of 1.1 to 1.2 times the saturation plateau pressure, lasting 24 hours. The test is carried out using a mixture of air and helium with a minimum helium content of 10%. At the same time, the operation of all measuring components is checked;
- during the leak test, on-site training is conducted, and diving, rescue and emergency equipment, as well as disinfectants for the chamber, diving bell and rescue chamber, are prepared. The technical team familiarises the divers and supervisors with the operation of the system and its characteristics.

Following a successful leak test, the following procedures are carried out:

- a test dive of the bell to the working depth to check the operation of the lifts, supply winches, lighting and measurement systems, etc.,
- a drill for the evacuation of divers under pressure (TUP transfer procedure) from the hyperbaric (habitation) chamber to the HRC rescue chamber. The exercise involves a team of four divers who will take part in the saturation dive, as well as the facility crew designated to conduct this operation. In this exercise, we use air compressed to 10–12 m H₂O; a no-decompression depth,
- a test of the safety diver's controlled descent. Testing the safety diver's position is particularly important on platforms where this position is

situated more than 20 m above the water's surface,

- test or operational deep diving.

Functional trials and tests are carried out under the supervision of a PRS inspector, who usually begins working at the base by taking part in the shipowner's trials or the annual maintenance exercise, if this coincides with the scheduled date of the saturation dive. Approval by PRS marks the start of direct preparations for the dive. Functional tests, including on-the-job training and dive preparation, usually last 2–3 days, during which the full diving team and underwater work support crew are brought together to the site where the dive system works.

Once the operational checks have been completed, the chamber undergoes sanitation procedures, including washing, cleaning, disinfection and UV lamp irradiation for disinfection. The quality of this work is monitored by the technical staff responsible for dive safety and by life support system technicians. When the chamber has been approved for use, divers equip it with bed linen, personal clothing, welfare and living essentials, as well as diving and medical equipment. Before placing items in the chambers, a doctor checks that the equipment meets hygiene requirements. The above also applies to the evacuation chamber and the diving bell. All these hygiene and disinfection procedures should be supervised by the diving safety officer.

The dive supervisor, together with the client's underwater operations coordinator, shall decide to commence the dive following the successful completion of the preparatory phase and after consultation with the ship's captain or platform manager, the medical officer and the system technicians. In life-saving and emergency situations, the preparatory cycle may be reduced to the absolute minimum. In such cases, the scope of preparatory activities is determined by the dive supervisor based on the condition of the diving system and the divers' working conditions.

For financial reasons, the party ordering underwater works is obviously interested in restricting their time to the absolute minimum. As shown by the table below, this stage takes on average over a month and it is even longer on the platform where the assembly takes place away from the diving centre and is affected by hydrometeorological conditions. Data for the assembly time included in the table come from reports covering the latest six years. On the Petrobaltic/LOTOS platform the assembly time was 35 days while on the 'Bazalt' ship - 28 days.

Duration of the preparatory stage for the mobile diving system Af-2.

Assembly year	Start and finish dates	Assembled on	Transport duration for Af-2 [days]	Preparation of foundations and fixing [days]	Assembly of the system Af-2	PRS tests	No. of days
2007	27.03. 25.05.	Petrobaltic platform	4	8	18	4	58
2008*	02.08 02.09	ATHS Bazalt	3	10	15	2	31
2009*	10.07 22.08	Petrobaltic platform	3	9	22	2	37
2010	01.10, 07. 11.	Petrobaltic platform	5	10	17	1	35
2011	09.05 15. 06	ATHS Bazalt	2	12	14	1	30
2012	13.08 15. 09	ATHS Bazalt	2	10	15	1	28
2019 2020**	28.12 2019 28.02.2020	LOTOS GIANT platform	7	10	21	2	40

*System for deep-sea dives – smaller scope of works.

**Assembly on the GIANT platform included holidays and over a month break between the assembly and approval and the start of saturation diving.

DAILY ROUTINE OF DIVERS DURING SATURATION DIVES

Organising a saturation dive requires the implementation of certain procedures, which are repeated daily at fixed times throughout the day. These include:

- serving meals to the divers,
- carrying out hygiene procedures, such as chamber disinfection, diver ear hygiene, a bath before going to bed and cleaning,
- changing divers' underwear and clothing, and periodically changing bed linen,
- medical examination and consultation,
- a stock-take of consumables and the consumption of breathing and reference gases, carried out at a specified time,
- recording and logging (every half-hour in the log book) of the chamber's atmospheric parameters,
- metrological checks of gas analysis equipment,
- handover of the watch (held by 12 hours),
- periodic weather forecasts (at least twice daily, in the morning and evening) for the sea area from a specialist forecasting agency for the Baltic Sea.

The divers' daily routine is 'interrupted' by preparations for their work shift, which include:

- briefing the divers on their tasks, preparing and handing out the necessary tools,
- passing the divers' undersuits through the airlock, washed helmet components, gloves and other equipment, as well as a container of sorbent for the bell's absorber,
- providing sandwiches and bottles of water (still),
- heating the bell to a comfortable temperature one hour before the transfer to the bell. The bell is maintained at saturation plateau pressure, thereby keeping it ready for diving.
- the procedure carried out by the deck crew to prepare the bell and the lowering and lifting apparatus for submersion, and lowers the bell's ballast to stabilise its position in the water,

- replenishing (if necessary) the bell's breathing gas supplies, as well as the 'bail-out' cylinder (the reserve cylinder for the diver working inside the bell),
- a preliminary check of the bell's external systems and preparations for the operation,
- replenishing the bell's equipment (e.g., first-aid kit contents, batteries for instruments, divers' torches, etc.),
- putting on water-insulated suits in the transfer compartment by the divers,
- preparation of tools and emergency equipment,
- preparation and mounting of the tools for the job on the outside of the bell or on the ballast.

Once the bell and divers have been prepared, the transfer into the bell takes place. This operation is performed as quickly as possible, whilst simultaneously isolating the living compartment from the transfer compartment by closing the hatch. After entering the bell and collecting their equipment, the divers close and bolt the bell hatch from the transfer compartment, whilst the crew do the same with the chamber hatch. The result of the transfer is the pressurised separation of the bell and the chamber by depressurising the shaft connecting them. After checking the tightness of the bell and chamber hatches and after the jaws of the movable connector have been moved apart, the bell is separated from the shaft flange, which begins the operation of tilting the bell over the side. Following these operations, the bell is ready for immersion.

Until the bell reaches the surface, its descent speed is moderate. The bell is lowered into the water at full lift speed until it reaches a depth of approximately 5 metres below the saturation plateau. It then slows down and the divers unlock the bell hatch to equalise the pressure with the surrounding environment.

The bell comes to a halt at the saturation plateau depth, and the divers begin their ascent preparation procedures. They carry out an operational check of the bell, including checking the valve settings and the positioning of the equipment. Next, a working dive is carried out by the safety diver, who is the bell operator. After the dive, he

returns to the bell and prepares the working diver for the task. Our technology does not provide for bell manoeuvres at depths below or above the saturation plateau, due to the need to introduce additional procedures for divers and the crew. A change in the bell's saturation plateau depth is only envisaged in an emergency situation.

The working diver is deployed once authorisation has been granted following a successful test dive. Whilst the working diver is underwater, the operator diver supplies him with air as required, monitors the operation of the diving bell and stands ready for a possible emergency ascent to assist the working diver. Once the

working diver has returned to the bell, the operator prepares himself and takes over the role of the working diver.

Having completed the task, the divers prepare the bell for ascent by checking the systems and fittings after disconnecting the breathing apparatus, and ensuring the hatch remains watertight once closed. A watertight hatch is essential for the bell's safe return to the surface. A leak in the bell hatch is one of the most difficult emergency situations. If it cannot be sealed, the bell remains at the

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