# Benefits of saturation diving for dam bottom outlet rehabilitation

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## Introduction

The principle of saturation diving is to keep divers pressurized to the bottom pressure during a period of up to 28 days and to decompress them only once at the end.

Every day, divers are in water, still under pressure, into a diving bell which is winched down to working depth. Then they can perform the required tasks for long working hours (up to 3 hours for each divers). At the end of the shift, they are winched up via the pressurized bell, and reconnected to the living habitat where they rest until the next day.

Modern saturation diving has been developed during the 60's by different countries: USA, France, UK, Switzerland and Sweden amongst others. First needs were military, but it has been quickly adapted to the oil and gas industry even though it is interesting to mentioned that the first commercial saturation dives were performed in 1965 by Westinghouse to replace faulty trash racks at -61m on the Smith Mountain Dam, USA.

Hydrokarst used this technic on several dam maintenance projects: Castello do Bode, Portugal (1998), Bin el Ouidane, Morroco (2001), Hongrin, Switzerland (2011), Grand Maison, France (2012), Rieti, Italia (2013) and more recently Punt dal Gall, Switzerland (2016).

Bottom outlet is one the major asset of dam. It enables to empty or lower water level in case of maintenance required on upstream face or spillways and intakes. It is also used to manage siltation inside reservoir. Periodic flushes are needed to prevent accumulation of sediment in front of the dam and avoid obstruction of equipment. During flood, bottom outlet can be used, combined with spillways, to regulate water level on the reservoir.

Due to their location at the bottom of dams, theses outlets are difficult to maintain when sediment, corrosion or damages altered operation of bottom outlet gates or stoplogs. Water depth or impossibility of lowering reservoir conducts operators to renounce to perform rehabilitation. Recent case studies showed that inefficiency of bottom outlets is a major safety issue on dams in case of flood episode.

This paper describes methods of maintenance of theses bottom outlets by using the saturation diving at a maximum water depth of 200 meters.

# 1. Rehabilitation program of a bottom outlet

## 1.1. Installation of diving equipment

Saturation diving equipment can be set whether on the dam crest or directly on floating pontoons. Operation constraints are considered to choose the most efficient solution.
Usually, a dozen of trailer trucks is mobilized to transfer all equipment on site, excluding pontoons in case of installation directly on dam crest.
Key component in a saturation diving system is the surface hyperbaric complex with its annexes. The pressure level and different environmental parameters such as temperature, humidity, oxygen partial pressure, carbon dioxide contents etc., are continuously monitored and regulated from a control room adjacent to the chambers. The life-support technicians can monitor the movements inside chambers on screens without moving from their control consoles. The bell is controlled entirely from the diving control station. Gas storage (Oxygen, Nitrogen and Helium) is located near saturation diving system

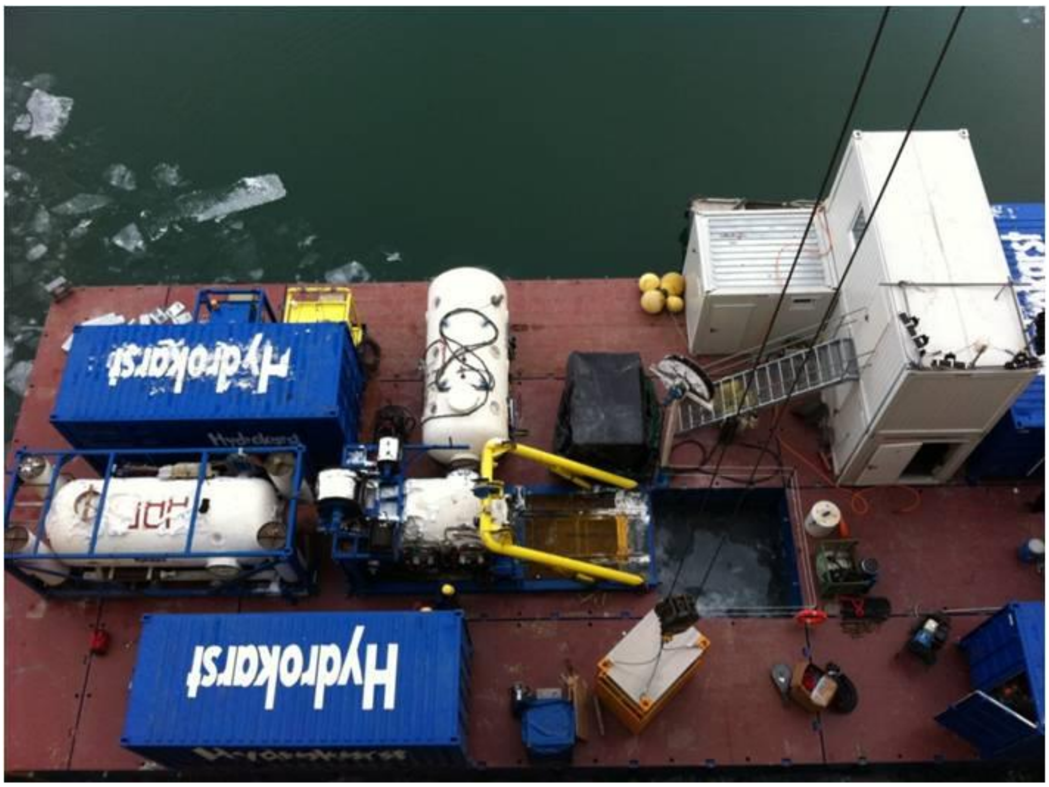


*Fig. 1. View of a saturation diving system on floating pontoons*

After connection of all equipment, divers enter into the saturation system for 3 to 4 weeks and compression can start to reach the working pressure.

### 1.2. Dredging and cleaning

Usually, the first step of a rehabilitation program is the dredging of the area surrounding the bottom outlet. Sediment accumulation is generally the cause of malfunction, by obstructing the outlet or causing damages on steel structures. Special attention will be paid to remove enough sediment to control stability of the slopes of sediment.
Different solution of dredging can be applied:
Grabbing is appropriate in case of:

- Important depth
- Compact sediments
- Presence of debris (concrete from construction, wood, steel structures)
- Water consumption issues

Pumping is appropriate in case of:

- Important quantity of sediments
- Volatility of sediments
- Transportation of sediment through intake and turbines is allowed

After mechanical dredging, divers proceed to final hand cleaning with an airlift pump and/or water jetting.
This is also the occasion to have the first assessment of the structure.

*Fig. 2. Grabbing operation at -110 meters*

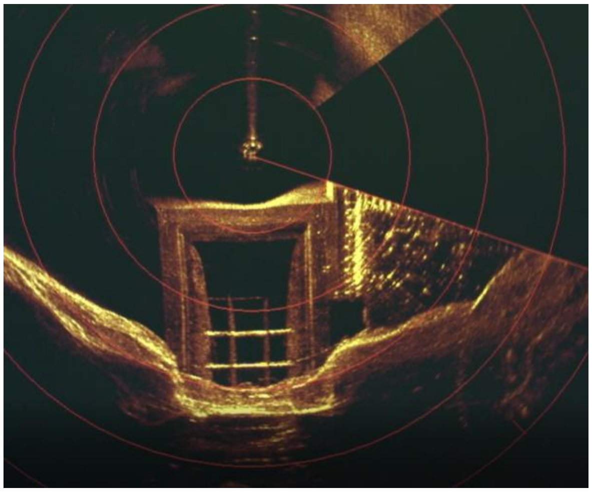

*Fig. 3. ROV survey during pumping operation in front of a bottom outlet*

### 1.3. Installation of plugs, bulkheads

In most common case, a bottom outlet is made of (from upstream top downstream):

- Trash rakes
- Stoplogs or sliding gate that ensure insulation of gallery for maintenance of downstream equipment
- A radial gate or a valve to discharge reservoir

When one of those equipment is faulty, it is necessary to insulate the bottom outlet. A specific plug or bulkhead is designed considering dam specificity especially civil structure geometry and resistance. Saturation diving enables to insulate galleries from upstream regardless of depth so maintenance of all the bottom outlet (but also intakes) can be done in dry condition.

*Fig. 4. View from downstream face of a bulkhead, during dewatering of outlet*

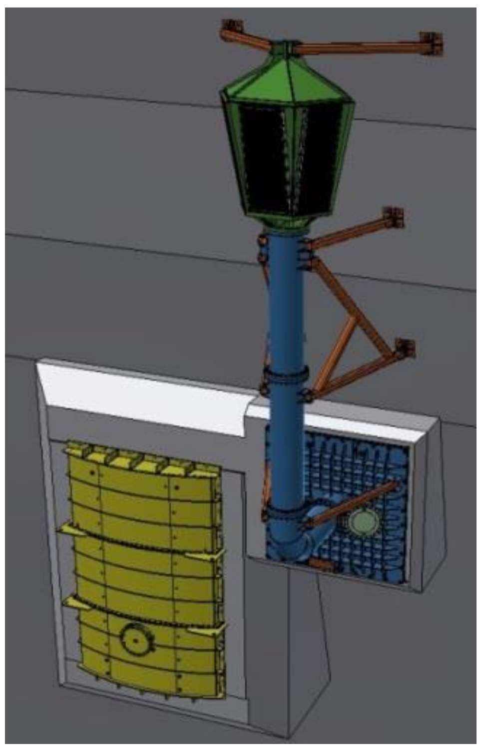

*Fig. 5. 3D modulization of bulkhead and temporary intake*

Because of high water pressure upstream, inflatable plugs are not suitable for such works.
In case of low depth of water, a cofferdam can be also used. It is installed by divers and works inside are carried out in dry condition once the cofferdam is dewatered.

### 1.4. Refurbishment of embedded parts, concrete structures or gates/stoplogs

For some reasons, insulating the bottom outlet is not always the best solution as divers can perform any kind of works underwater. Refurbishment directly the structure underwater can be efficient in term of budget.
Indeed, costs of design and manufacturing of the plug or bulkhead and installation should be compared to underwater maintenance.
After removal of trash rakes, divers can work on embedded parts when stop logs are removed and refurbished in workshop or directly on site.
Depending on the state of deterioration identified during underwater surveys, methods are adapted to restore functionality of sill beams and guiding parts, from small repairs to complete replacement:

- Cutting, oxycutting
- Diamond cable sawing (for both concrete and steel structures)
- Brushing
- Welding
- Resin injection for small cracks repairs
- Grouting for bigger repairs
- Concrete demolition with high pressure water jetting
- Formwork, steel reinforcement installation and concrete pouring

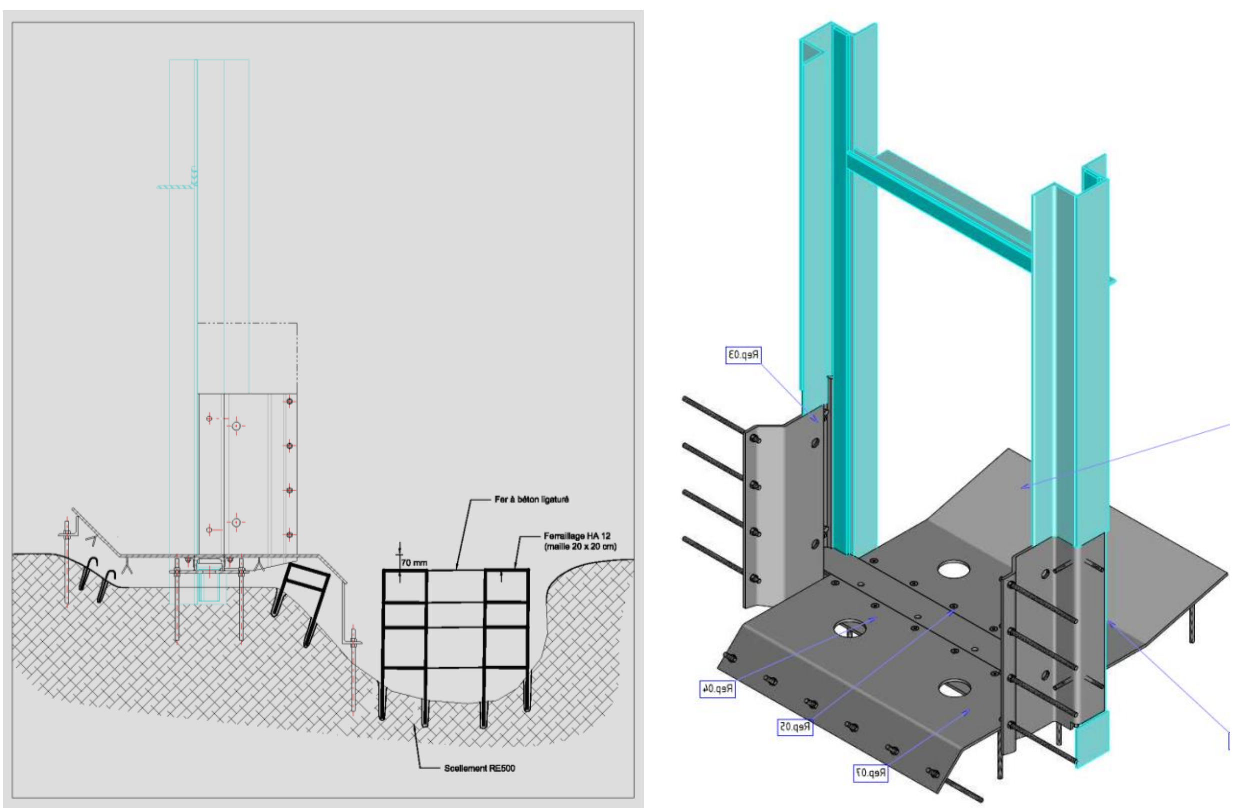


*Fig. 6. Drawings and modelization of new embedded parts and concreting*

## 2. Benefits of saturation diving

Depth is usually the first criteria considered when it comes to choose a diving method. But saturation diving offers also the possibility to work longer under water by reducing time of decompression. Type of works to be executed and duration should therefore also be considered to choose the best solution.
For example, during a classic bounce diving at -40m, maximum effective time of work is around 1 hour for 2 hours of decompression. Saturation diving allows divers to work for 3 consecutive hours which represent a gain of productivity of 200%.
With such improvement in time spent under water, saturation diving enables to save significant loss of revenues in term of power generation.

In a lot of countries, water storage is a key component on multipurpose dams, for both irrigation and drinking water. By avoiding lowering reservoirs or even emptying them, saturation diving gives the opportunity to perform maintenance and rehabilitation without wasting a precious resource and reducing impact on aquatic ecosystem.

Divers health is continuously monitored with this technic, and decompression is taking place only once, which therefore reduces significantly risk of diving incidents.

Saturation diving provides a wide range of possibility in term of working methods, accesses in narrow areas (inlets, galleries) and improvement of work duration. When it comes to optimize power generation and water storage during operation maintenance, saturation diving is the most efficient and safest solution.

### The Authors

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He has been qualified as a professional diver – HSE 1 in 1986 and has specialized in Non-Destructive Testing of off shore structures CSWIP/3.
He has joined Hydrokarst in 1990 and after several years in different positions, he has taken the management of the company as CEO since 2003.

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