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A USEFUL TECHNOLOGY TO SOLVE OR MITIGATE ARTIFICIAL RESERVOIR SEDIMENTATION

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1. RATIONALE

Reduction of sediment flow generated by dam construction leads to erosion on downstream riverbed and on coastal areas; the lack of coarse sediment (sand, gravel) generated channel riverbed deepening and relevant effects on bridge foundation structures, and on other infrastructure affected by water bodies, meanwhile the lack of fine sediment (silt, clay, nutrients) can have serious effects on balance of downstream ecosystems, reducing water turbidity and affecting water temperature.

Loss of reservoir capacity caused by sedimentation can greatly impact reservoir management because it generates a reduction of water availability for several uses (energy generation, irrigation, drinking water). Most recent studies estimated global gross storage capacity at 6,000 km^3 and annual reservoir sedimentation rates at 31 km^3. According to this growing trend, global reservoir storage capacity will be reduced by 50% on 2100.

Both accumulation of sediments in dams and the lack of these in downstream areas have negative effects on the performance and conditions of the infrastructures, on the coastline stability, already endangered by sea level rise (greenhouse effect), therefore actual handling of these sediments is of paramount importance for long term management of artificial reservoirs.

Several possible solutions can be taken into consideration:

- sediment by-passing into the downstream area;
- drawdown routing involves discharging high flows through the dam during periods of high inflows to allow sediment to be transported through the reservoir minimizing sedimentation;
- drawdown flushing, opposite to sluicing, focuses on scouring and re-suspending deposited sediment and transporting it downstream. It involves the complete emptying of the reservoir through low-level gates;
- turbidity current venting can be done when inflowing water with high sediment concentrations forms a higher density current that flows along the bottom of the reservoir without mixing with the lower density clear waters;
- dredging with specialized equipment to remove the sediments from the dam.

In the last years, sedimentation in artificial reservoirs became more and more important, especially in reservoirs where their catchment basin is affected by important surface erosion rates due to poor vegetation coverage (degradation of the vegetation by human action), or to the presence of heavy rains in very short periods (flash floods).

Climate change has increased the frequency of flash floods, therefore sedimentation in artificial reservoirs is one of the most important challenges of Public/Private Authorities responsible for artificial reservoir management. Sedimentation is really important because there are situations, all around the world, where original reservoir capacity has been dramatically reduced by 30/50%, generating important losses in terms of electricity production, reduction of water for irrigation and human use.

This paper deals with the positive experience happened in an artificial reservoir located in the eastern part of the Italian Alps (Ambiesta reservoir) managed by A2A, that is one of the most important energy supplier in Italy. Few years ago, A2A launched a tender to select a Contractor able to propose a cost-effective technology to remove about 23,000 m^3 of sediments settled near the water intake structure located on the right flank of the valley close to the dam, affecting dam bottom outlet, and water intake for hydroelectric purposes.

The tender has been awarded to THETIS COSTRUZIONI & DRAGFLOW which designed, supplied, installed, tested and managed a dredging system which allowed to complete the activity required by A2A fulfilling contractual time and very stringent environmental constraints established by River Tagliamento Authority. In the following pages the reader will find in detail reference data used to dredging system design, characteristics of the dredging system itself, on site activity and monitoring plan during dredging, and finally the conclusions.

2. REFERENCE DATA & CLIENT REQUIREMENTS

2.1. Environmental data

Ambiesta stream is located in the hydrographic basin of Tagliamento river, 3.5 km far from their confluence, in the eastern part of the Italian Alps (Friuli Venezia Giulia region). Ambiesta dam is a symmetric double curved arch dam, with the following characteristics (Fig. 1):

- Dam height: 58.63 m
- Free board: 2.50 m

Fig. 1
Ambiesta reservoir
Ambiesta reservoir

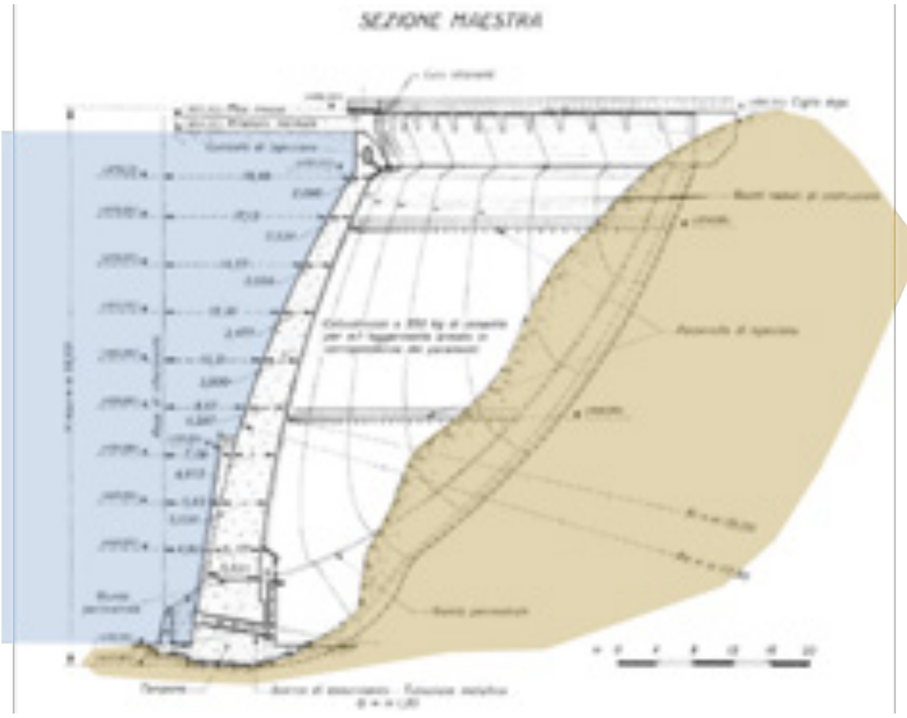

Fig. 2
Ambiesta dam: typical section
Ambiesta barrage: section typique

- Normal operating water level: 484 m a.m.s.l.
- Maximum water level: 485.50 m a.m.s.l.
- Dam volume: 28,734 m^3 of concrete
- Crest length: 144.64 m
- Dam thickness (at the top): 1.80 m
- Dam thickness (at the toe): 5.52 m

Ambiesta dam (Fig. 2) has been equipped with following ancillary structures:

- Surface outlet on the left side, equipped with gates, with flood discharge of 72 m^3/s;
- Surface spillway on the dam body with flood discharge of 120 m^3/s;
- Bottom outlet with discharge capacity of 48 m^3/s;
- Water intake structure on the right flank of the reservoir, which feeds two different tunnels with a diameter respectively of 4.40 m and 5.15 m, that feed Somplago hydroelectric plant.

The dam has been built in the period 1955 – 57 on behalf of SADE (Società Adriatica di elettricità) and transferred to ENEL (Ente Nazionale per l'Energia Elettrica) on March 1963.

In the following picture we can appreciate the dam shape during construction.

Fig. 3
Ambiesta dam (during construction)
Ambiesta barrage (pendant la construction)

2.1.1. Area to be dredged

A2A, the Public Company, responsible for management of Ambiesta reservoir, during the last years has monitored the sedimentation in the reservoir and more in detail sedimentation rate close to the dam structure, through a comparison of several topographic campaigns, to understand the evolution sedimentation phenomenon, and its impact to ancillary structures of the dam (dam bottom outlet and water intake), in terms of efficiency and safety.

On basis of this monitoring, A2A noticed that the quantity of sediments, coming from the rain activity on the surfaces of the catchment basin, reached an alert level especially nearby bottom outlet intake, and water intake structure as well. Through the comparison of topographic surveys developed along several years, A2A identified the area where the sediments have to be removed, and the total amount of them.

Total area to be dredged (Fig. 4) has a surface of 4,500 m^2 and is located at a water depth variable between 20 and 36 m, according to the water oscillation in the reservoir. Globally 28,000 m^3 have to be removed to assure a correct efficiency of the ancillary structures, and the right safety factor. The thickness of the sediment layer to be removed was variable between 6 and 10 m.

In the following picture we can appreciate the area to be dredged (green area), which affects dam bottom outlet, located on the left side of the dam (axis indicated with red dotted line), water intake on the right side, through which the water is driven to turbine of Somplago power plant (axis indicated with red dotted line), and the ancient cofferdam, concrete made, built at the beginning of the construction activity, to divert stream water to the dam bottom outlet, to kept dry the area where dam foundations have been built.

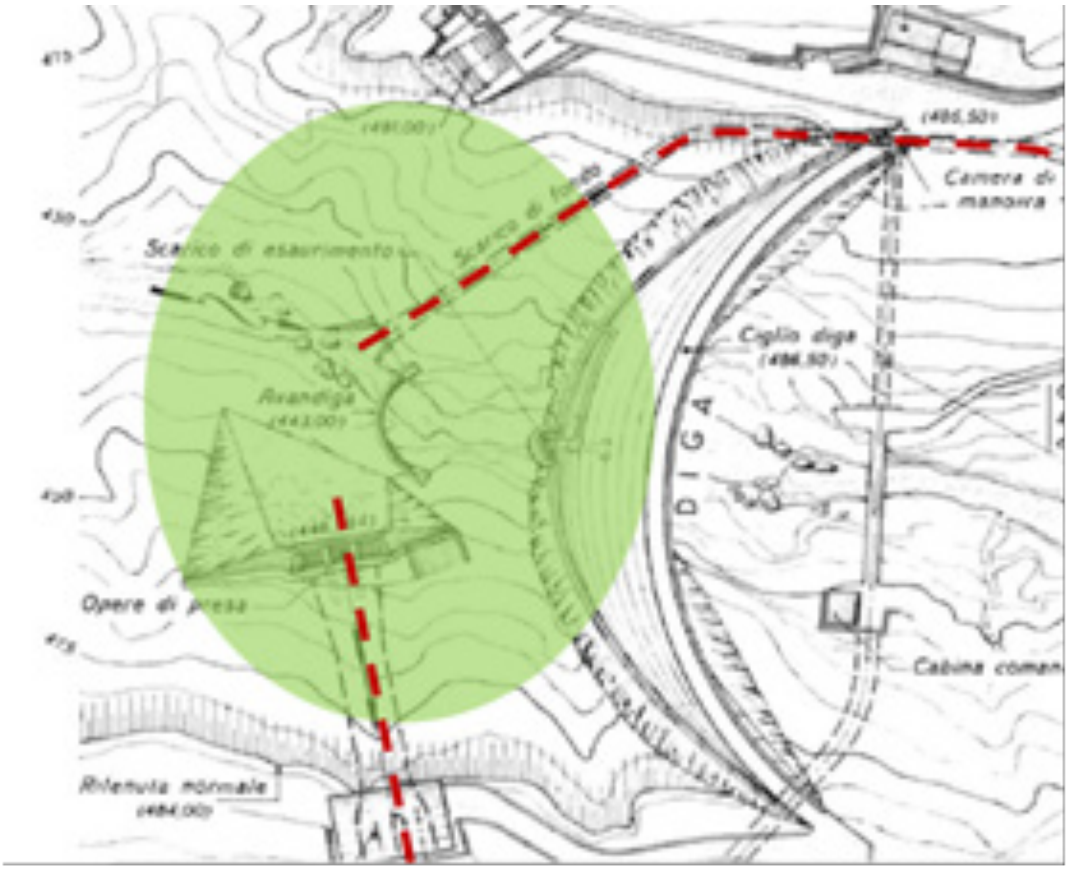

Fig. 4
Area to be dredged
Surface à draguer

As you can imagine, dredging activity has been developed in a quite complicated area from a morphological point of view because of the presence of artificial structures, forcing the submersible pump operator to carefully proceed between existing structures. In Fig. 5 we can appreciate, through an historical photo taken during construction time, the original morphology of the area, with quite big concrete structures (intake screen of the water intake channel) and very steep flanks of the valley.

To correctly design dredging system and determine dredging efficiency of the submersible pump, A2A supplied to the tenderers detailed information on the sediments to be dredged, collected through a field campaign developed all along the reservoir (Fig. 6).

The information used for the project has been related to the sample taken close to the dam. According to the grain size distribution analysis, the sediment to be dredged showed a granular fraction equal to 5%, meanwhile the cohesive fraction reaches 95% (74% silt and 21% clay).

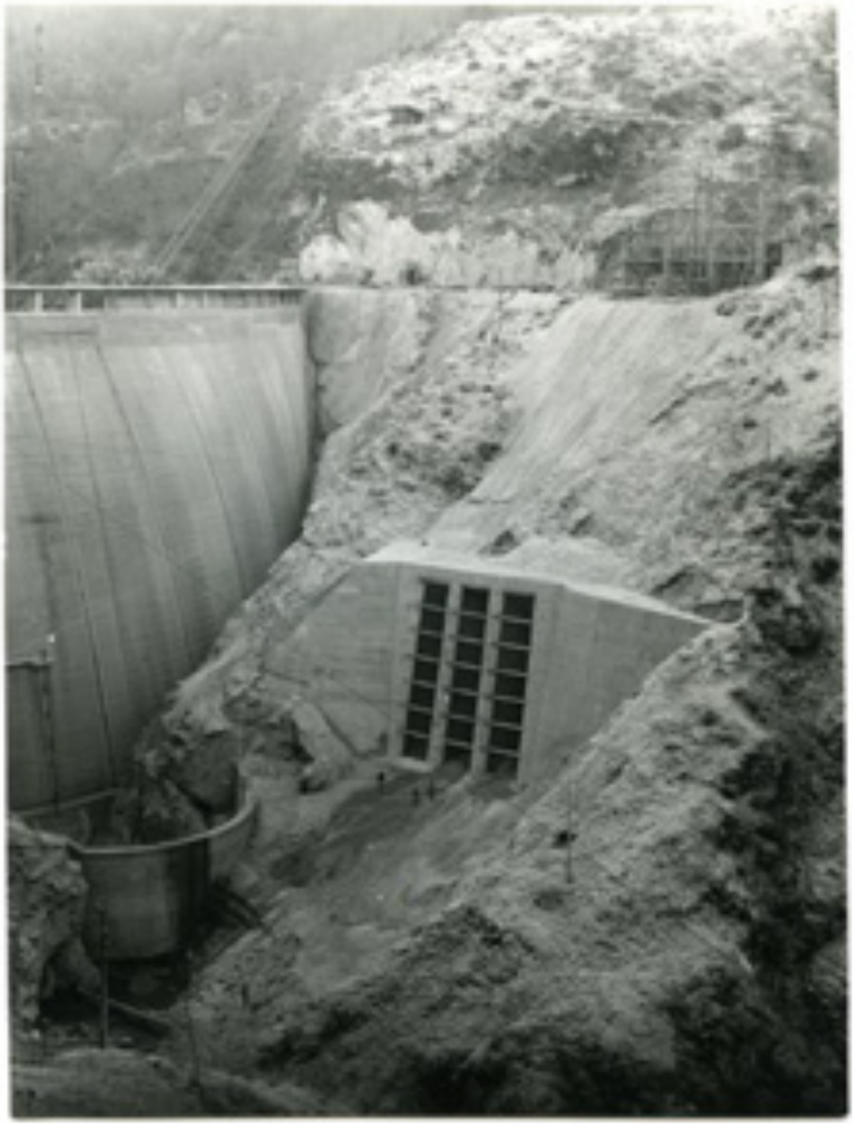

Fig. 5
Dam during construction
Barrage pendant la construction

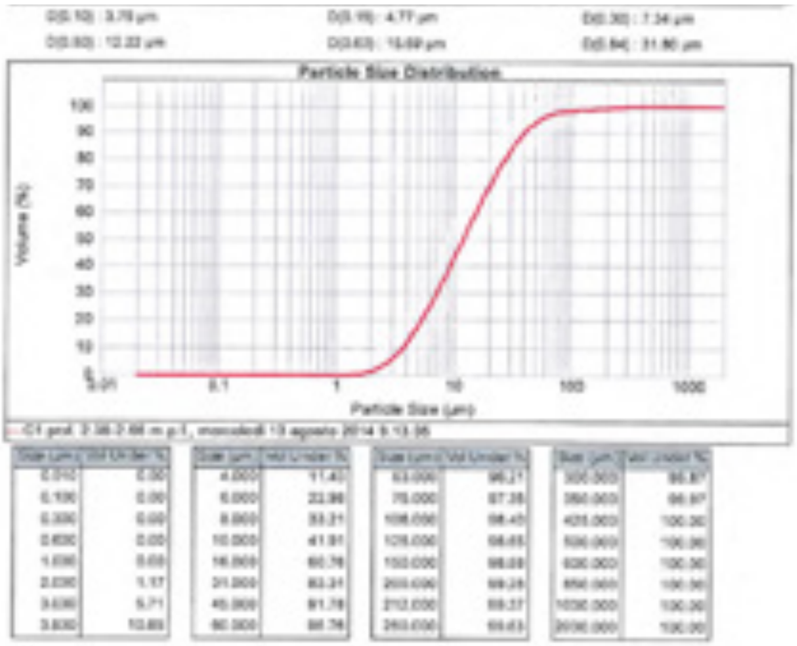

Fig. 6
Sediment particle size distribution
Distribution de la granulométrie du sédiment

2.2. Client requirements

On basis of the management plan of dam operation, and on the environmental constraints, A2A requested to fulfil following design criteria:

- maximum water level variation to be considered inside the reservoir is 9 m, with a water level variation between 475 and 484 m a.m.s.l.; maximum gradient of water level variation can reach 1 m/hour;
- maximum concentration of sediment in the slurry discharged downstream the dam cannot overcome 9 g/l for environmental reasons;
- possible presence of wood debris and large stones on the sediment layer to be dredged has to be considered;
- during dredging activity, the water intake feeding Somplago power plant is in operation discharging 66 m^3/s (three Francis turbines), therefore turbidity generated by the dredging pump has to kept at the minimum;
- during dredging activity, maximum allowed noise level at a distance from dredging pump of 300/400 m cannot overcome 45/50 dB;
- dredging activity of 28,000 m^3, including mob - demob activities has to be developed and completed in 100 natural days.

3. PROPOSED SOLUTION

On basis of Client’s requirements, and taking into consideration dam location and characteristics, and usual dredging solutions already experimented for similar projects, DRAGFLOW, together with the Contractor THETIS COSTRUZIONI decided to propose following technical solution:

- Submersible pump located on a pontoon fully equipped, able to cover all the area to be dredged (4,500 m^2);
- Floating pipeline conveying the slurry from the pontoon to the surface outlet located on the left side of the dam, and from this structure downstream the dam;
- To respect environmental constraints (9 g/l), slurry has been mixed with water discharged by the surface outlet of the dam, managing the gates accordingly;
- To check the respect of maximum concentration of sediment in the slurry, three check points have been organized (on the pumping pipeline on the pontoon, just after the confluence of slurry and Ambiesta stream at the toe of the dam itself, and finally at the final confluence between Ambiesta steam and Tagliamento river, 2 km downstream Ambiesta dam;
- Service boat to allow the staff involved in the activity to reach the pontoon and to leave it at the end of the working shift.

3.1. Dredging system

Taking into account the characteristics of the sediment to be dredged, and the total dredging time allowed by the Client A2A, average slurry discharge has been fixed at 500 m^3/hour, and it has been mixed with 4 m^3/s clear water, taken form the reservoir, and discharged by the surface outlet of the dam located on the left side of the dam, to meet Client's requirements (9 g/l).

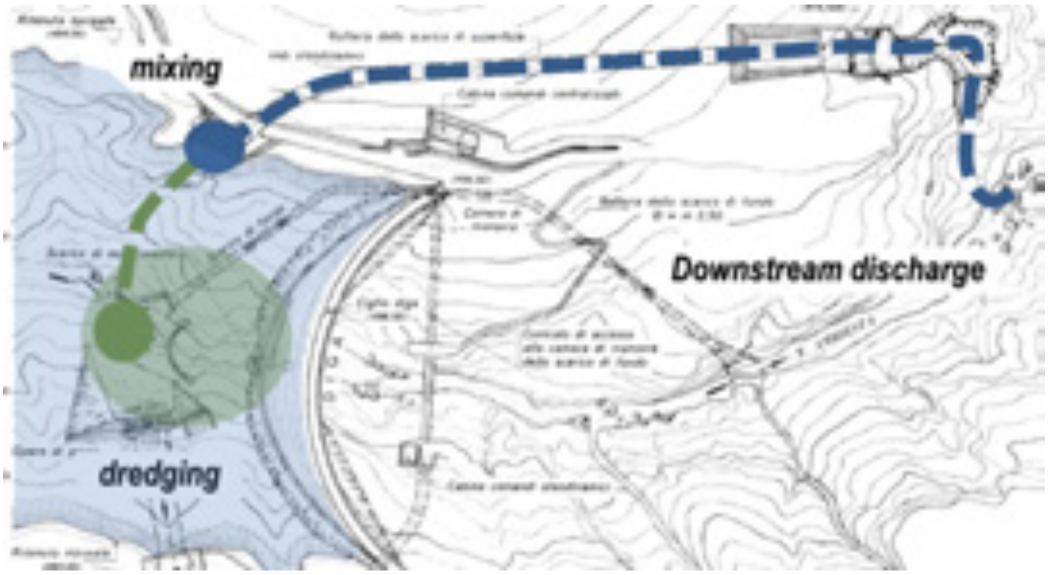

Fig. 7
Slurry mixing to fulfil environmental requirements
Mélange du "slurry" pour se conformer aux critères environnementaux

In Fig. 7 you can appreciate the location of the dredging area, and the mixing point where slurry produced by dredging activity has been mixed with fresh water coming from the reservoir to fulfil Client's environmental requirements. The pump selected for this project has been DRAGFLOW pump HY85/160B; it's a hydraulic pump with following characteristics (Fig. 8).

Fig. 8
Submersible pump
Pompe submersible

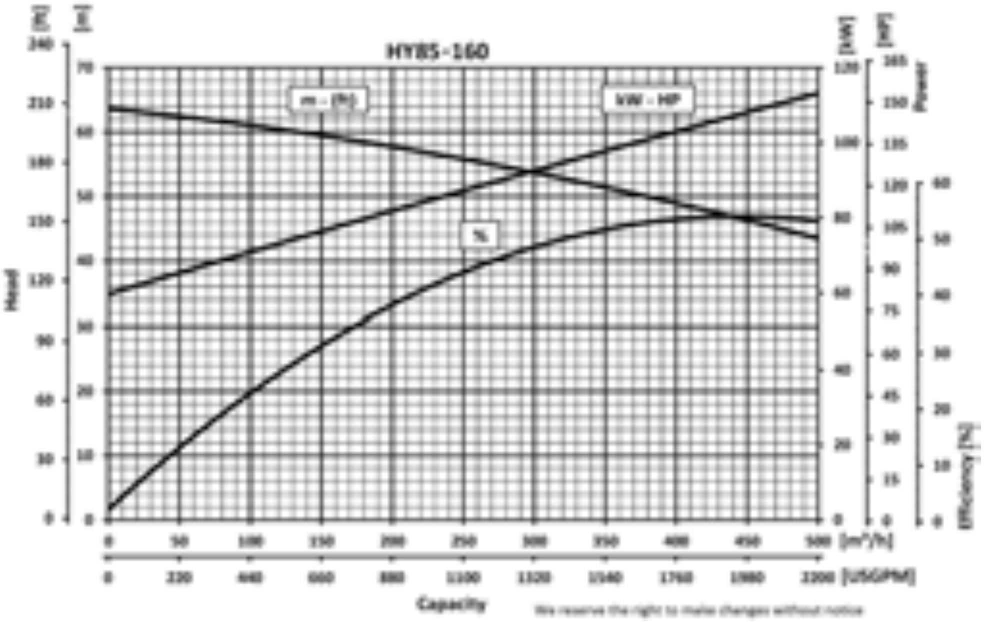

Fig. 9
Submersible pump – working diagram
Pompe submersible – schéma de travail

Since most of the percentage of the sediment to be dredged is cohesive, to assure the correct productivity requested by total project time allowed by A2A, the pump has been coupled to two cutter heads, specifically designed for cohesive materials (Fig. 10).

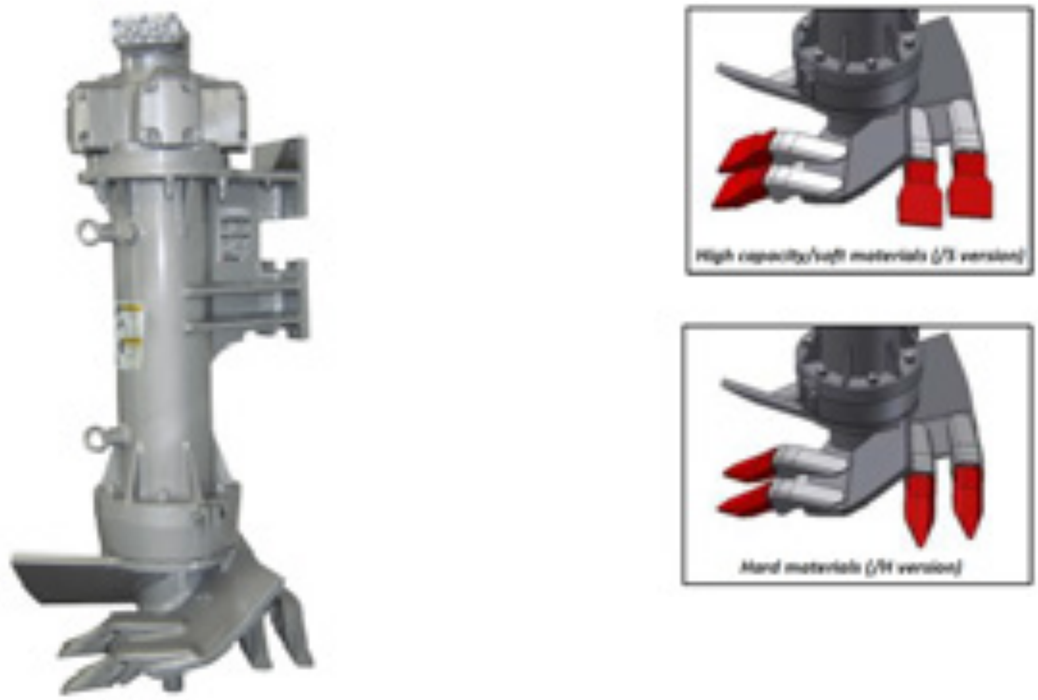

Fig. 10
Cutter heads
Têtes de coupe

In addition to that, according to the request of the Client to minimize the turbidity generated by dredging activity, a special anti-turbidity tool (Fig. 11) has been installed on the submersible pump. This tool allowed to minimize the dispersion of fine sediment around dredging area, avoiding the movement of fine sediment to right side water intake, and the ingestion of fine sediment by turbines installed at Somplago power plant.

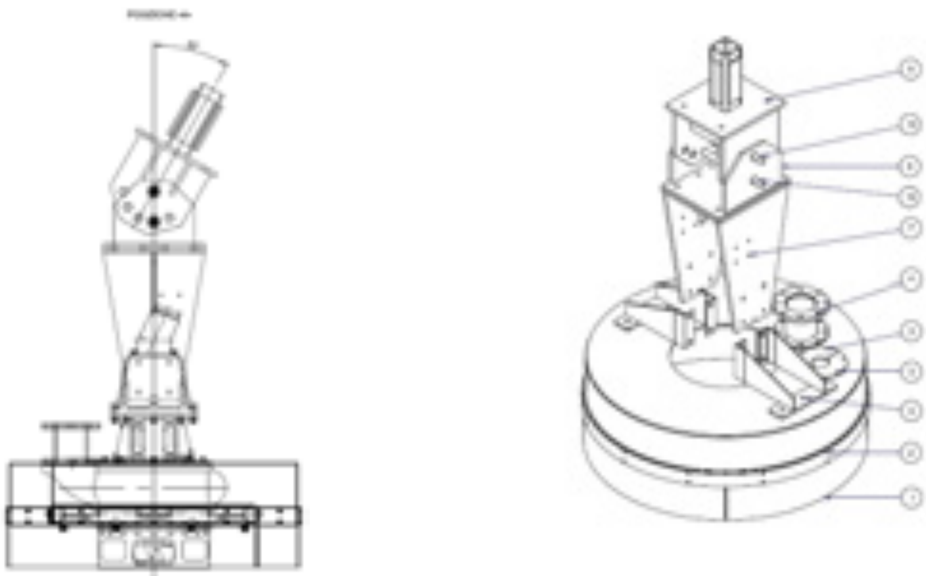

Fig. 11
Turbidity reduction tool
Outil de réduction de la turbidité

Submersible pump is managed through a pontoon specifically equipped (Fig. 12 and Fig. 13). DRAGFLOW's pontoons follow a modular design that has been tested over the years in several projects all around the world. The submersible pumps adopted for this project allowed to use very compact pontoon, achieving at the same time quite large working depths requested by A2A.

Fig. 12
Pontoon
Ponton

Fig. 13
Pontoon and main operation cabin
Ponton et cabine principale de travail

All DRAGFLOW's pontoons are designed for an easy transportation either by container or by trucks. The pontoons are built with internal reinforcement structures and divided in different compartments. The pontoons follow a catamaran design with a steel tripod and hoist as main movement system for the submersible dredging pump. The pontoon is complete with handrails and skids under the floaters with an integrated high capacity fuel tank.

The pontoon is equipped with 4 mooring winches driven by individual electric motors, each one with cable length of up to several meters. The entire dredging equipment is easily controlled and operated from the central cabin were the operator manages all necessary controls to drive each component of the dredging system with indicators of working depths, current absorption and bathymetric survey system.

3.2. Parameters monitored during dredging activities

During dredging activity, several parameters have been monitored, for both reasons: to be sure that Client's requirements are always fulfilled, especially which ones related to the environment, and to check dredging productivity which has a direct impact on the total duration of the project established by the Client's to 100 natural days.

To do that, the Contractor has to know, during dredging activity, where the submersible pump actually is (x,y,z coordinates), which is the actual water depth where the pump is dredging, in relation with water level in the reservoir, and what is the concentration of sediment in the "slurry".

Summarising, following devices have been installed and continuously monitored:

- GPS installed on board (Fig. 14) of the pontoon to know in every moment real time position of the submersible pump (x,y,z coordinates);
- Sediment concentration device installed on board of the pontoon (on the pumping pipeline) able to continuously record sediment concentration of the "slurry".

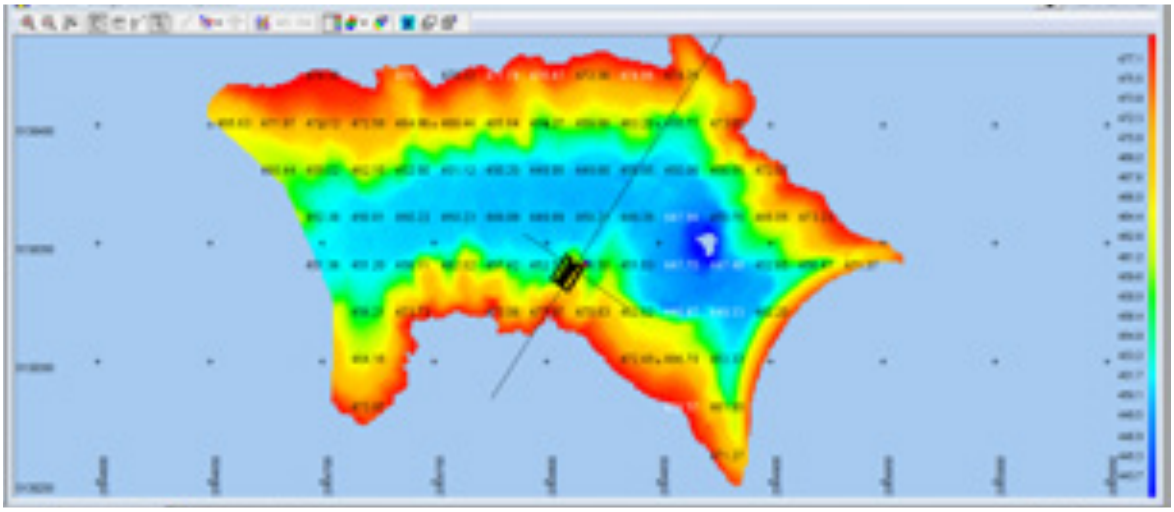

Fig. 14
Dredging pump positioning
Positionnement de la pompe de dragage

GPS coupled with topographic maps of the area to be dredged (Fig. 14) allowed to check every now and then if the dredging thickness required by the Client has been respected.

According to Client's requirement, sediment percentage in the slurry has been continuously checked in three different positions: on board of the pontoon, at the toe of the dam, and at the confluence between Ambiesta stream and Tagliamento river. To correctly understand the location of the dredging activity, the submersible pump productivity, and the new water depths after dredging, the bathymetric survey, done using a multi-beam device (Fig. 15) just before dredging starting, has been compared to a second survey, developed just after dredging activity (Fig. 16).

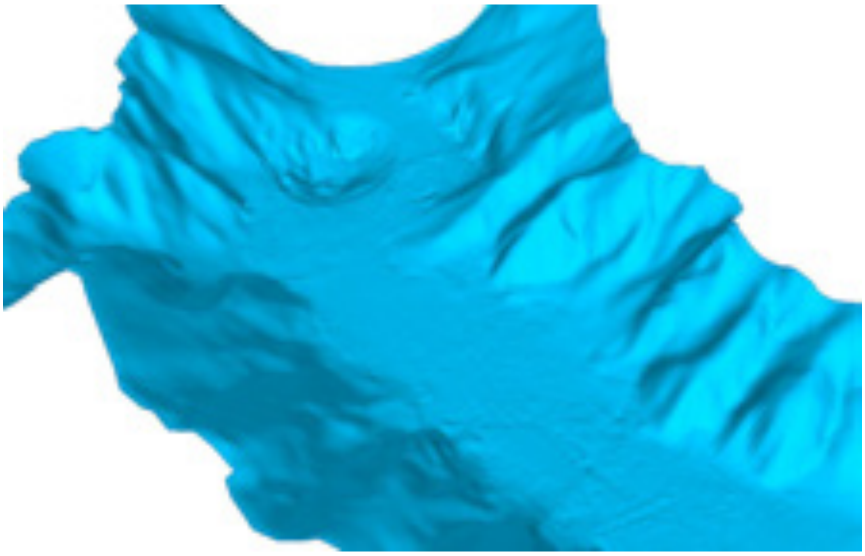

Fig. 15
Multi-beam topographic survey
Relèvement topographique avec le multi-beam

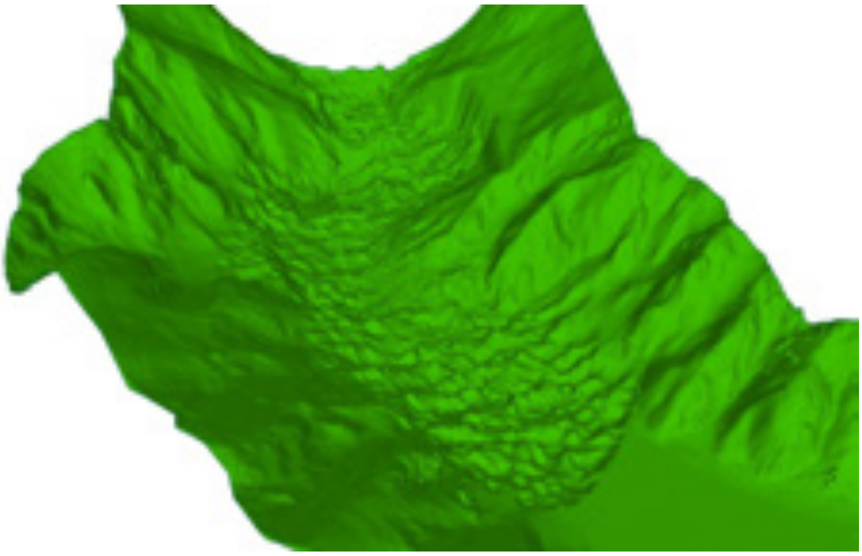

Fig. 16
Multi-beam topographic survey after dredging
Relèvement topographique avec le multi-beam depuis le dragage

From the comparison between two multi – beam surveys, developed just before and just after dredging activity, Client's Project Manager has been able to check total quantity of the materials actually dredged from the reservoir and the relevant time needed to dredge.

In Fig. 17 we can have a clear picture of the monitoring of the concentration of the sediments in the slurry pumped from the reservoir downstream the dam, till to the confluence between Ambiesta stream and Tagliamento river.

Fig. 17
Slurry concentration monitoring system
Système de monitoring de la concentration du slurry

According to Client's requirements, concentration of the sediments in the slurry has been continuously monitored, giving to the Client and to the Contractor itself, every day, maximum/minimum and average concentration values, through which a simple calculation gave a confirmation of the sediments removed from the bottom of the reservoir calculated using different topographic surveys.

3.3. Productivity rates

Taking into consideration dredging technology, time needed for regular maintenance of the equipment, out of service of some part of the equipment, not constant characteristics of the sediment to be dredged, variable water depth, variable thickness of sediments to be dredged, the dredging productivity, evaluated on daily basis has been the following:

- minimum productivity: 200 m^3/day
- average productivity: 400 m^3/day
- maximum productivity: 800 m^3/day

Dredging activity has been developed along three shifts, therefore 24 hours per day, using the noise reduction tool to avoid any impact on the nearby village.

In the following picture we can appreciate the dredged profile (blue line) compared to the original bed of the reservoir (green line).

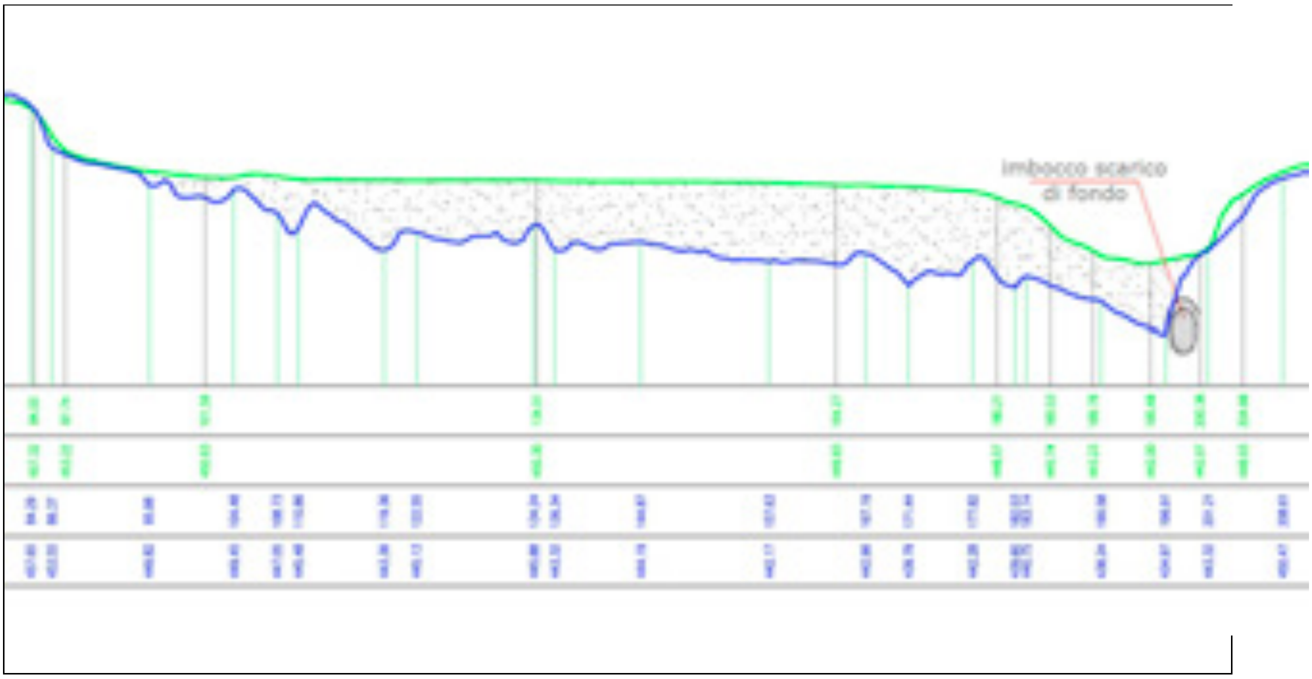

Fig. 18
Dredged profile versus original bed profile
Surface de dragage par rapport au fond original du reservoir

4. CONCLUSIONS

Dredging activity has been concluded fulfilling the total time allowed by the Client, taking into consideration supply and installation of the equipment, preparation of the jobsite area, assembling and testing of the dredging system, maintenance of equipment, and finally the disassembly of the equipment, and the restoration of the jobsite area to the original situation.

Selection of the dredging system demonstrated its validity to fulfil Client’s requirements, and maintenance activity was really reduced, demonstrating that DRAGFLOW pumps are really a good and cost-effective solution for slurry dredging. For security reasons a stock pump has been located at the job site just in case, because the respect of the total time (100 days) was mandatory, but this pump has been never used.

In addition, the high efficiency reached by the dredging system, and the capacity to work 24 hours per day along three shifts, allowed the Contractor to get the bonus made available by the Client.

The system used for the topographic surveys (multi – beam) made at the beginning, in an intermediate time, and at the end of the job, has proven high reliability and a good level of precision. The Client really appreciated the job done by THETIS COSTRUZIONI and DRAGFLOW, their availability to discuss together the best solutions to be proposed to overcome usual small problems that sometimes happen during dredging activity, and their proactive attitude.

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SUMMARY

This paper deals with the technology proposed and used to remove sediments settled nearby Ambiesta dam, located in the eastern part of Alps, Friuli Venezia Giulia region, Italy. In the Document many aspects have been detailed starting from design data needed to correctly design a dredging system, Client's requirements, characteristics of dredging system detailing all the components, and finally achieved results. Dredging activity has been developed fulfilling total time established by the Client, and the Contractor got the bonus offered by the Client if the job had been completed on time.

Ce rapport concerne la technologie proposée et utilisée pour enlever les sédiments installés à proximité du barrage d'Ambiesta, situé dans la partie orientale des Alpes, région Friuli Venezia Giulia, Italie. Dans le document de nombreux aspects ont été détaillés à partir des données de conception nécessaires pour concevoir correctement un système de dragage, les exigences du Client, les caractéristiques du système de dragage détaillant tous les composants, et enfin les résultats obtenus. L'activité de dragage a été développée en respectant le temps total établi par le Client, et le Constructeur a obtenu le bonus offert par le client si le travail avait été achevé à temps.