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METODOLOGIA PARA REDUÇÃO DE CUSTO DA OPERAÇÃO DE DERROCAGEM SUBAQUÁTICAS PARA APROFUNDAMENTO DE CANAIS DE NAVEGAÇÃO UTILIZANDO ROV

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RESUMO

A eficiência da derrocagem subaquática utilizada no aprofundamento de canais de navegação está relacionada à adequação da fragmentação do desmonte de rocha às operações subsequentes, e ao monitoramento e controle dos níveis de escavação e bota-fora determinados em projeto. Estas questões levam a tomadas de decisões que envolvem equipamentos de alto custo horário e procedimentos demorados de movimentação de embarcações. Após caracterizar e analisar todos os procedimentos de derrocagem subaquática, uma nova metodologia foi desenvolvida para melhorar esse processo, aplicando um veículo de observação remota (ROV) de baixo custo. As tarefas do ROV concentram-se em monitorar e controlar algumas etapas estratégicas que otimizam o tempo de operação e que identificam pontos de falha, além de ajudar a monitora e controlar possíveis impactos ambientais na operação. A metodologia proposta foi aplicada em São Paulo-SP, Brasil, em um trabalho de aprofundamento do canal de navegação do rio Tietê, próximo a UHE de Avanhandava. Os resultados dos testes mostram uma economia de 37% em tempo e uma de 32% em custo.

PALAVRAS-CHAVE: ROV, derrocagem subaquática, aprofundamento de canais, hidrovia, dragagem de rocha

REMOTELY OPERATED VEHICLE-BASED METHODOLOGY FOR THE REDUCTION OF COSTS AND OPERATIONAL DELAYS ASSOCIATED WITH ROCK DREDGING FOR CHANNEL DEEPENING

ABSTRACT

Rock dredging for river channel deepening presents improve this process by applying a low-cost observation problems concerning the identification of whether the remotely operated vehicle. The tasks of the vehicle focus blasted rock is properly fragmented for the following on monitoring and controlling some key procedures, operations and whether the excavation and disposal improving the operating time and identifying operation reach the determined project level. These issues lead to fail points, in addition to helping to control the decision making that involves expensive equipment and environmental impact. The proposed methodology was vessel movement procedures that can result in an tested in São Paulo, Brazil, where the deepening of a river increase in costs and time. After characterizing and channel has been used to expand the waterway. The analyzing all underwater blasting and rock excavation results of the tests show a 37% saving in time and a 32% procedures, a new methodology was developed to saving in cost.

KEYWORDS: ROV, underwater blasting, channel deepening, waterway, rock dredging.

1 INTRODUCTION

Waterways, which are the paths ships take to enter and leave a port, represent one of the most important parts of a port. With the continuous increase in the volume of ship traffic, waterways are becoming the bottlenecks of port development (Wang, 2017). Once a waterway is no longer adequate to handle more and larger ships, its capacity is expanded by widening and deepening its dimensions to allow more ships to transit (Tang, 2014). Bracarense et al. (2016) indicate that the waterway specificity highlights the necessity of involving different areas of knowledge on project assessments and expanding out the support analysis to the decision makers.

There are many methods to expand a waterway and deepen its channel. In the case studied in this work, the channel bed consists of hard rock. The excavation of hard rock can be accomplished by using explosives or by mechanical means. Sedimentary rocks are most easily ripped, whereas igneous rocks are very difficult to break using mechanical equipment. The fragmentation of hard rock formation by drilling and blasting methods before dredging is often used as a cost-effective alternative.

Underwater blasting and rock excavation is a complex process because the main steps are carried out without full visualization of the process. Issues like the identification of interferences, collaring borehole, tying-in check, fragmentation analysis and level checks are either not carried out or are not performed in real time.

These issues can be solved or improved with the use of a remotely operated vehicle (ROV). A ROV is an unmanned piece of underwater equipment that is connected to an operator by an umbilical cable. This tether allows the command transmission and controls signals and images between the ROV and the pilot, allowing the vehicle to be remotely navigated and providing real time information. The use of ROVs becomes necessary in activities that involve high risks for the equipment and human safety (De Tomi, 2014).

According to Christ (2014), ROVs in this classification are generally limited to seawater depths of less than 300 m due to the weight of the power delivery components and one atmosphere pressure housings, which imposes limitations upon the vehicle size. The vehicles within this class are typically hand launched and are manually free flown from the surface.

Teague (2017) proposed the use of a low-cost ROV in deep-sea mineral and ore prospecting and monitoring, presenting the efficiency of this equipment to provide real time data prior to decision making. Likewise, the objective of this study is to establish a methodology that, after understanding all stages of the rock dredging process and by using a low-cost observation ROV, will identify some of the process bottlenecks and improve the overall process by saving time and lowering the costs. This methodology was tested in a river channel deepening in São Pauo, Brazil, leading to efficient results.

2 MATERIAL AND METHODS

The observation class ROV used in this research was developed to be applied in offshore oil and gas industry inspection and in academic research (Figure 1).

NAP-Mineração´s ROVs Set up	
Energy	100-240 @ 3KVA
Comunication	Ethernet / VDSL
Operation deep	300m
Image System	HD - TVI
	Resolution 720p
	Frame rate 30FPS
	Vision: 90°
Light System	1.000 limens / LES
	10W / LED
Propulsion (hor.)	2,0Knots - 04 Thursters
Propulsion (Ver.)	0,6 Knots - 01 Thursters
Profundimetro	Transdutor - 0,2 mbar
Size	632 x 602 x 333 mm
Weight	6 kg

Figure 1: Observation class ROV employed in this research.

According to Teague (2017), historically, submarine exploration has been restricted to companies or organizations with considerable funds and resources. However, the last decade has seen the advent of low-cost ROVs, and with the development of ever more powerful microcomputers, the cost and capabilities of robotic systems for underwater surveying using remotely control systems continues to decrease and improve, respectively.

The most common underwater applications for observation class ROVs include object identification, submerged navigation hazards, vessel hull and offshore oil and gas industry inspections. A ROV is not intended to be a replacement for diver investigations, but could serve as a substitute if divers are not available or diver safety is in question (NOAA, 2017), which is relevant in underwater blasting, due to the risks involving the use of explosives.

Therefore, a methodology using low-cost observation ROVs has been developed to improve rock dredging to channel deepening, as shown in the methodology flowchart given in Figure 2.

Process mapping - To develop rock dredging process mapping, bibliographical research and location inspection were carried out to improve our understanding of the process. In this step, it was also observed whether there were proper work conditions for the ROV.

Identification of bottlenecks and key procedures - With the process understanding complete and process mapping ready, the bottlenecks and key procedures were identified. With the correct ROV application, the process could be improved, with a lower aggregate value and the mission made viable.

Mission planning - This is an important document that directs how the ROV´s team would proceed during the mission, according to the needs identified in the previous step. Equipment checklist, maintenance procedure and mission data, such as location, date, objective and team, were also carried out.

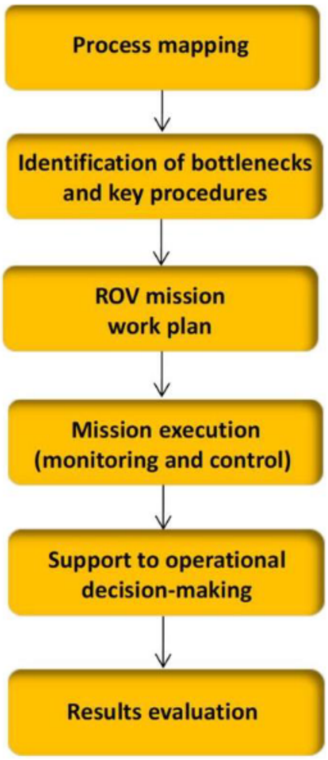


Figure 2: Methodology flowchart

Mission execution (monitoring and control) - In this step, the plan has to be achieved. The whole mission must be recorded to provide information for the next stages.

Support for operational decision-making - Someone with rock dredging process decisionmaking power should be part of the mission team, so decisions regarding the rock dredging could be made while the mission was running and the ROV provided real-time data.

Evaluation of results - This document compiles the mission results, presents the process improvements and indicates operation fail points that remain and the mission lessons learned. Each mission is different even though it is executed through the same process. Many times, the compilation of several mission reports will indicate the best issue solution. A deep diagnosis encourages the examination of a larger system beyond the immediate boundaries of the mission. An adequate failure study and a remediation plan is put into action by a team that focuses on the process improvement and implementation procedures, so that the methodology provides a continuous improvement cycle.

3 EXPERIMENTAL APPLICATION

The proposed methodology was tested in expressive underwater blasting and rock dredging in Brazil. A deepening work at the Tietê-Paraná waterway, in the Tietê River, close to the Avanhandava hydroelectric plant, presented adequate conditions for the application of the proposed methodology.

The Tietê-Paraná (Figure 3) waterway crosses the states of São Paulo, Paraná, Mato Grosso do Sul, Goiás and Minas Gerais. It is integrated with regional and federal highways and railroads, in a multimodal system to dispose of agricultural production in the region, which generates almost half of the Brazilian GDP. Approximately 6.5 million tons of cargo are transported annually through the waterway, mainly soy and corn, as well as sand, gravel, sugar cane, fertilizer, charcoal and other agricultural products (Moreira, 2016). The Tietê waterway portion is 715 km long, with a 3 m minimum depth (Figure 4). The deepening works are being carried out to improve navigability during the dry season.

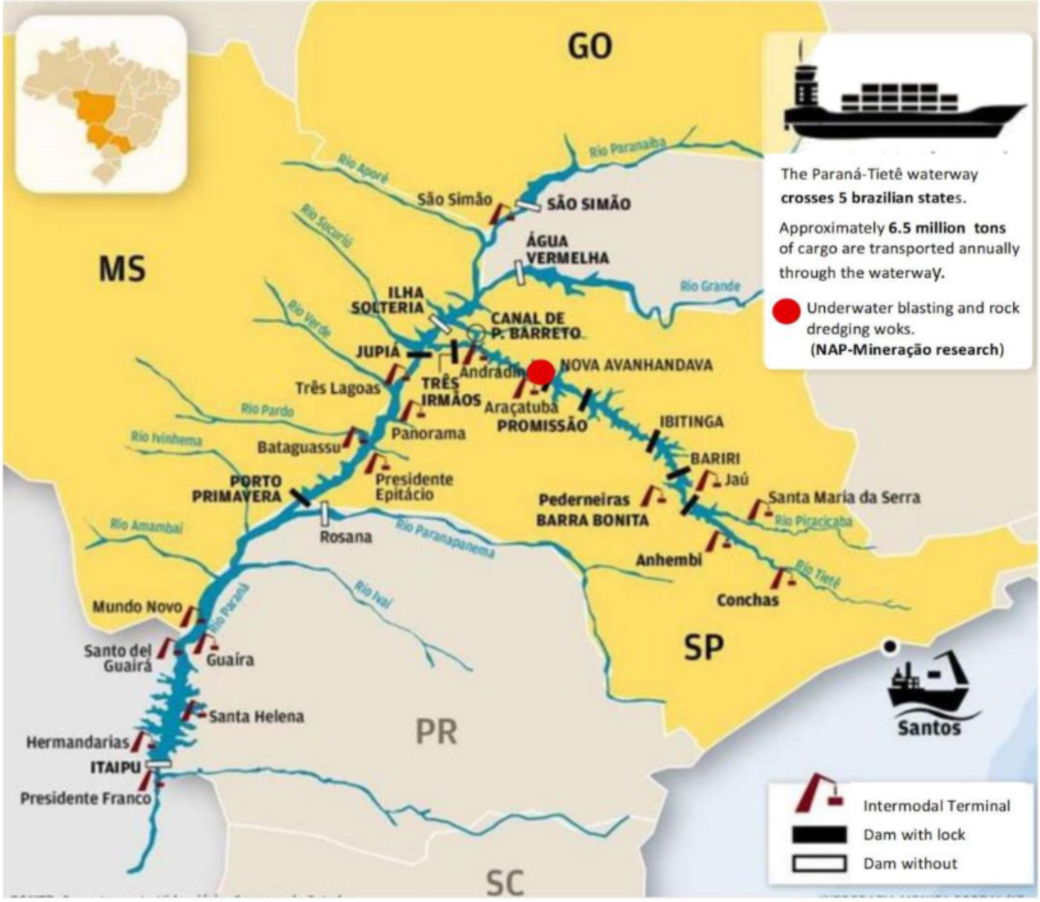


Figure 3: Tietê-Paraná Brazilian waterway (Balbino, 2018).

Fig. 4. Tietê-Paraná waterway - characteristic vessel.

The Tietê River presents appropriate conditions for the application of the low-cost observer ROV technology, since the water is clean with good visibility, the deep work does not overcome 8 m and there are weak waves and flow.

4 RESULTS

4.1 Process Mapping

Underwater blasting or submarine blasting, according to Jimeno (1998), are applied for several kinds of work, such as the excavation of trenches for the installation of oil and gas pipelines and communication cables, water conducts for hydroelectric plants, excavation for foundations in civil constructions, consolidated deposit exploitation and deepening of harbors and waterways. Drilling for underwater blasting is often carried out in deep waters where it is not possible to see the bottom, requiring drilling operating from a barge and accurate survey techniques for drill alignments (Stier, 2011).

As discussed by Tripathy (2015), underwater drilling and blasting applied for rock dredging are associated with many unwanted effects with the potential to cause damage to the environment and civil structures. Though all these ill effects cannot be completely eliminated, by using controlled blasting, they can be minimized to acceptable levels. In Chai (2011), it is affirmed that owing to the lower visibility of water and flow velocity, tides, depths, terrain and others, the drilling and blasting of underwater are rather difficult. Simultaneously, the topography and geology of the channel bed are also important, such as the strength and integrity of rock and the gradient of the rock surface.

For the New Mangalore Port channel deepening project in India, Kamath (2001) explained that upon completion of the underwater blasting and the rock dredging, an underwater “sweeping” was carried out to confirm that the channel bed in the dredged area was clear to the designed depths. The “sweeping” in the channel was carried out by a 12 m-long rigid horizontal sweep bar suspended from the “A” frame of the carrier barge of size 40 x 16 x 2.5 m towed by the survey vessel.

The main potential underwater blasting environmental impacts are ground vibration and the pressure of underwater shock waves that can cause damage to surrounding constructions and injuries or even death to marine fauna. There are some methods to mitigate these impacts, such as the control determined by the right size of charges in relation to the drilling patterns and adequate firing sequence. Another method to mitigate the pressure of underwater shock waves is to use an air bubble curtain around the blasting zone. A bubble curtain consists of one or preferably two perforated tubes laid on the riverbed (Bray et al., 1996). The air bubble is produced using steel or rubber pipes, through which air is pumped and bubbles move up to the surface. The shock waves in the water are partly absorbed in the bubbles. The air bubble curtain reduces the peak pressure of the shock but not the impulse of the wave (IADC, 2016).

As stated by Folchi (2015) in deepening projects in French Guiana, and is frequent in underwater blasting projects, a team of specialists in the protection of aquatic fauna, before each shot is fired, would scan the surrounding to assess clearance within the safety zone in water from protected species, such as dolphins and turtles. When the safety area was found clear, the person in charge would allow the blasting.

Jimeno (1998) still affirms that in the first instance the main underwater blasting impacts are:

- Limited information regarding the rock mass and a lack of topographical precision;
- Difficulty in maintaining the holes open for a length of time;
- Complicated planning and control of the operations;
- Risk of flash-over between holes;

Secondary blasting and toe excavation are costly.

All these characteristics can turn a low-cost observation ROV into an efficient tool to be the “eye” for underwater blasting executors, helping to identify issues to be solved and proposing a solution to improve the blasting and excavation rock process.

In the visit to the Tietê River deepening channel works, it was possible to identify the rock dredging production cycle and its units operations (Figure. 5), as shown below.

1 - Location and barge fixation
2 - Drilling and explosive loading
3 - Blasting Preparation and final tying-in
4 - Safety procedures and Blasting
5 - Blasting material dredging
6 -Rock dredging transporting and disposal
7 - Auxiliary operations

Figure: 5. Rock dredging production cycle.

4.1.1 Location and barge fixation

According to the excavation plan, the drilling floating pontoon is located in real time by an accurate RTK - GPS system indicated by a monitor in a command deck. This operation requires precision to pin the gravity anchor and the spud in their correct positions. The success of the following operations depends on the correct positioning.

4.1.2 Drilling and explosive loading

The boreholes are drilled with an adjusted wagon drill that slides on a trail to locate each borehole according to the blast design. The driller cannot see the drilling and rarely encounters perfect conditions for a better position to ensure a good start for the borehole, doing it by his/her experience feeling the equipment. A casing pipe is a prerequisite to keep boreholes open and clean for loading. Rigidity of the casing and casing supports are critical for these operations, especially in strong current or tidal waters (Stier, 2011). The explosive loading is completed immediately after the drilling ends by a casing pipe that protects the borehole collar and directs the explosive loading.

4.1.3 Blasting preparation and final tying-in

In the most critical phase of the underwater blasting process, before the tie-in process begins, all personnel and equipment not required for the tie-in must be removed from the area of pattern or face to be tied in. All the connectors are tied-in to the main line out of the water, fixed in small floaters that are removed before the blasting time. A count of in-hole detonators is made and used to confirm that the tie-in connected match the number of detonators. The initiation system check is visual, and requires confirmation that all connections are made according to the manufacturer´s specifications and blast design.

4.1.4 Safety procedures and blasting

Before the shot that will start the blasting system, sound warnings are played, and it is confirms that there are no people, vessels or equipment in the isolated area. It may be necessary to block the waterway. A warning shot with minimum explosive charge is made to back the aquatic fauna away. The firing of the blast must be soon after tie-in and the safety procedures are completed. After the blast is finished, the blaster checks if the whole blasting system was activated successfully, with not all the safety and blasting process resumed in the first step.

4.1.5 Blasting material dredging

After the blaster releases the blasting area, the excavation team starts the dredging labor. The barge with a backhoe excavator is located by a RTK-GPS with a real-time system above the blasting rock that digs and loads the material to a transporting barge. The blasting material is excavated and loaded to the transport barge, until the determined project level is reached.

4.1.6 Rock dredging transportation and disposal

The blasting material loaded to the barge is transported and disposed by a split bottom system in a site predefined by the project. Special attention must be given to the material disposal so it does not exceed the level determined by the project.

4.1.7 Auxiliary operations

Some auxiliary operations that support the rock dredging are personnel transportation, fuel and oil tank vessel, divers, safety and environmental teams.

4.2 Identification of bottlenecks and key procedures

After understanding and analyzing the rock dredging production cycle, some potential bottlenecks and procedures that could be more efficient with the observation ROV application were identified. The activities that could be improved are shown below.

4.2.1 Site inspection, interference identification and collaring borehole

Before fixation of the floating pontoons, the ROV will inspect the site to observe if the channel bed will have adequate conditions to start the drilling, making it possible to remove some interference identified, providing a properly collared borehole (Figure. 6).

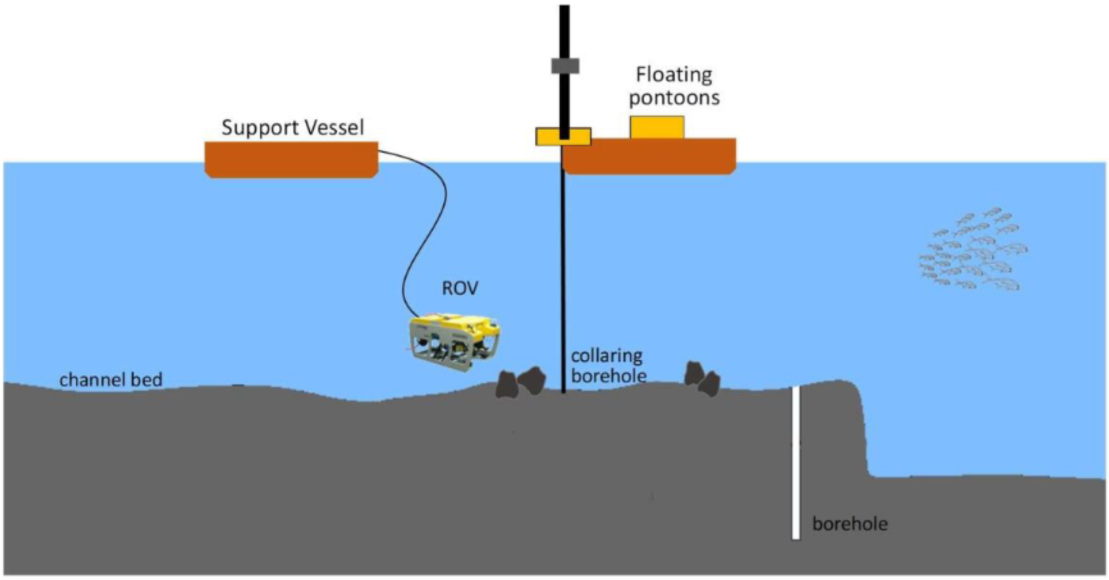


Figure 6: Site inspection, interference identification and collaring borehole.

4.2.2 Monitoring of explosive loading and tying-in

Observation ROVs can detect explosive loading mistakes in real time, allowing contingency measures to be taken before the blasting. A final underwater tying-in is also important to be inspected to avoid possible blasting issues (Fig. 7).

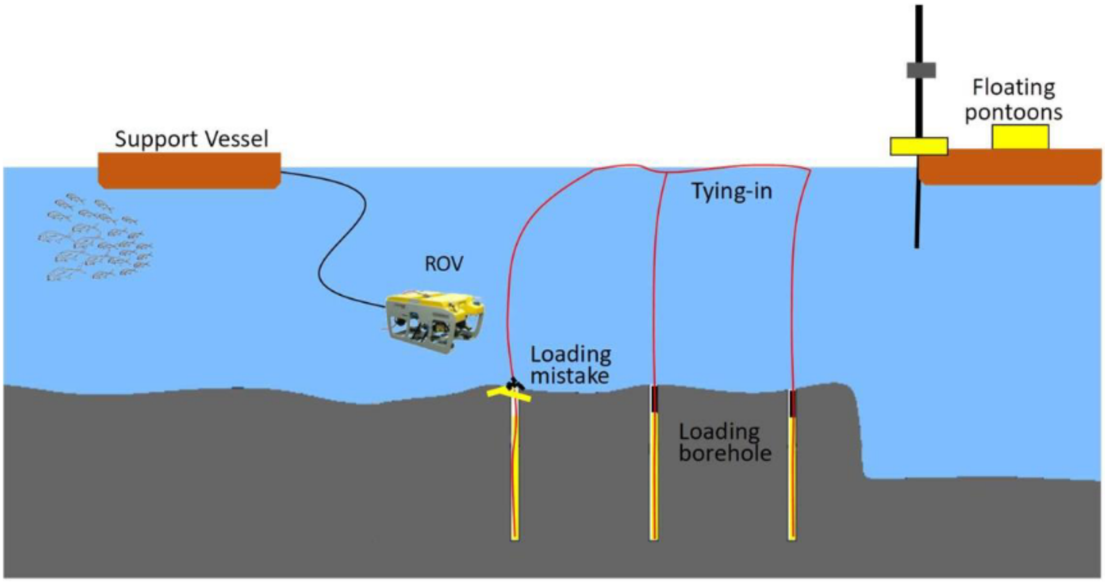


Figure: 7. Monitoring of explosive loading and tying-in.

4.2.3 Blasting pile monitoring and fragmentation analysis

After the blasting, an observation ROV can make the first blasting inspections, detecting blasting issues, observing if the blasting pile has adequate fragmentation to be loaded, and more importantly, allowing or not the backhoe to start the loading procedure (Figure 8).

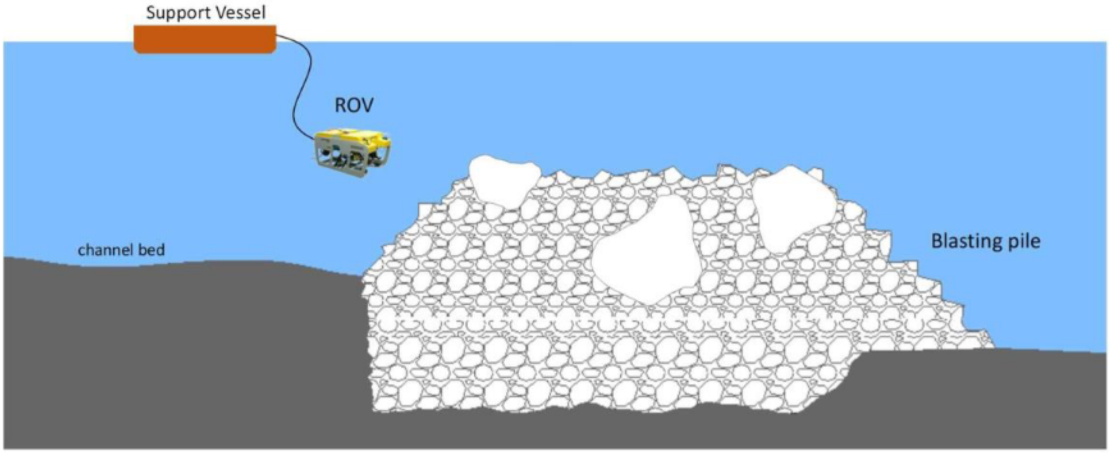


Fig. 8. Blasting pile monitoring and fragmentation analysis.

4.2.4 Rock excavation monitoring (excavation project limits)

Before allowing the excavator to move to another work front, the ROV will inspect if the rock dredging has reached the project excavation limits, avoiding unnecessary and costly displacements (Fig. 9).

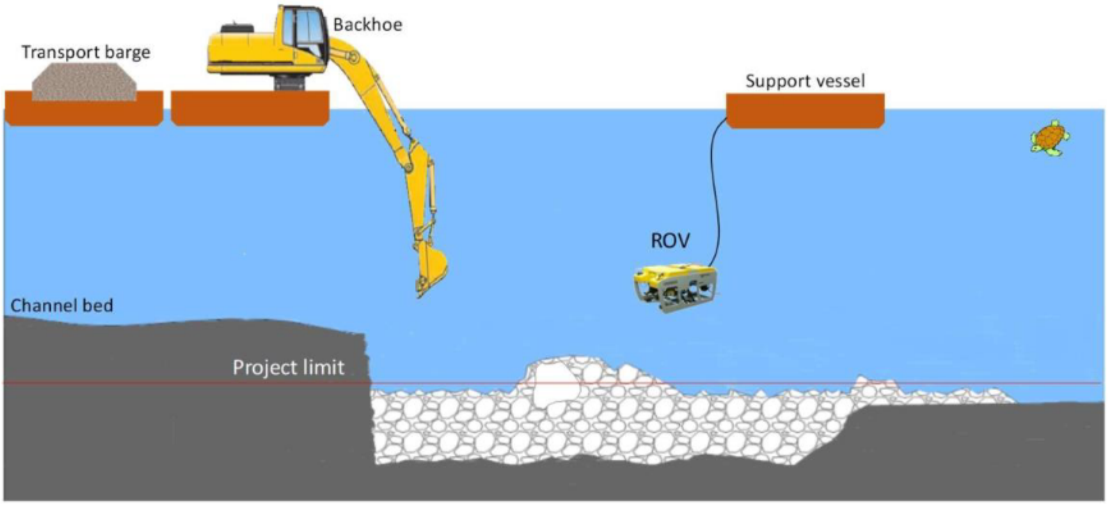


Figure: 10. Monitoring of dredging material disposal limits.

4.2.5 Environmental issues

A ROV can be an efficient environmental tool when applied for monitoring and keeping the aquatic fauna away and for detecting leaks or unwanted throw away, as well as bubble curtain efficiency (Figure 11).

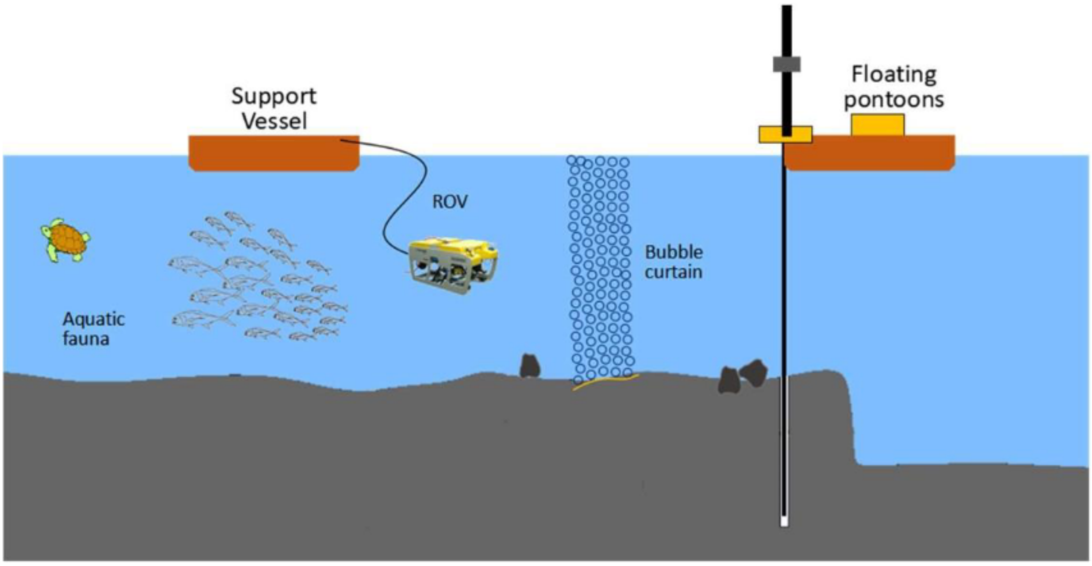


Figure: 11. Environmental issues.

4.3 Mission planning

The first step was to develop a ROV mission plan to inspect a channel bed after a rock dredging. The excavated channel bed has not been approved by the supervisors of dredging that frequently claimed that the channel project limits are not being reached. The ROV mission plan objective was to detect some rock excavation irregularities and provide conditions to make a fast and adequate decision to eliminate the problem.

An area of ~500 m² was inspected for 1 h during the dredging team lunch time, once the dredging rock stage was finished. The ROV´s pilot controlled the ROV in an excavation barge that was fixed above the rock dredged site and was accompanied by a responsible engineer to make the correct decision if necessary. The ROV has 4 h-power autonomy and carries two extra batteries on standby. A high quality camera records and shows in real time the channel bed conditions that can be observed by the pilot and the engineer through a laptop monitor, with a reference ruler helping the rock fragmentation analysis. Weather, water visibility, river current and water surface waving are analyzed and considered.

4.4 Mission execution

It is standard procedure to make an operation checklist before all ROV missions, once everything follows the guideline, the mission can start (Figure 12). For accurate measurement of the rock blasting size, a 1 m ruler was descended to the riverbed using a fishing rod (Figure 13). After a few minutes of inspection, a rock block was detected at the bottom of the channel, above the project limit and with a greater dimension than that of the backhoe load capacity (Figure 14). The rock block position was recorded and the inspection was carried out. The whole area was inspected and there were no other irregularities. The mission ended 3 min before planned and could be considered successful. The dredging operation could continue without being disturbed by the ROV mission.

Figure 12: ROV´s operation checklist.

4.5 Support to operational decision-making

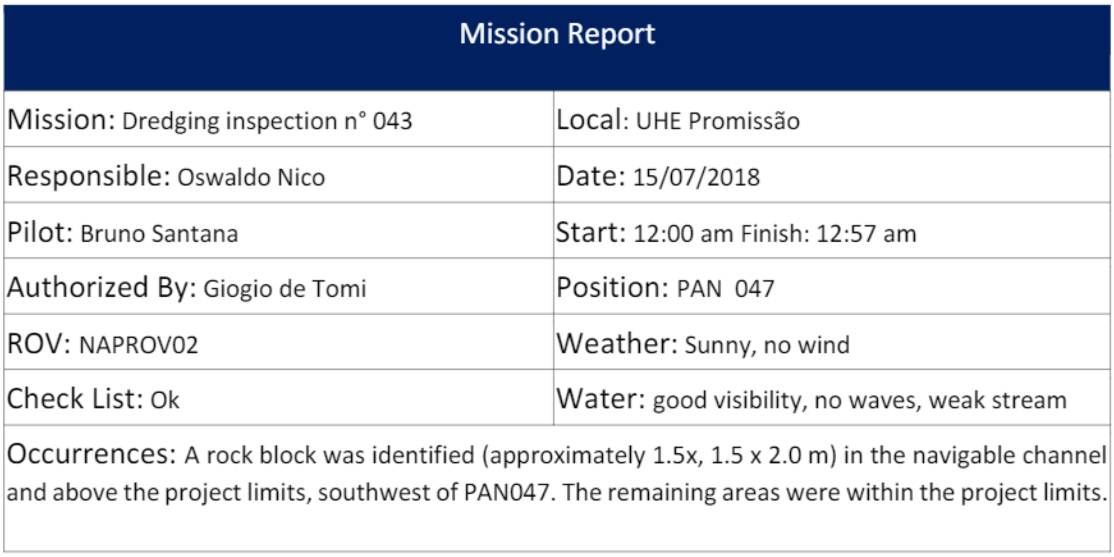
The responsible dredging engineer followed the ROV monitoring and a problem that needed to be solved was identified (removal of the rock block), but he also had all the information to help choose the best solution. The best solution was to push the rock block beyond the channel boundaries using the backhoe. As the vessel with the backhoe was close to the rock block, the excavation barge was relocated fast enough and performed the action successfully.

Figure 13: A ruler in the channel bottom.

Figure 14: A ruler and an irregular rock block.

4.6 Mission report

The following is a mission report summary that lists the main data and occurrences of the mission (Figure: 15).



Mission Report	
Mission: Dredging inspection n° 043	Local: UHE Promissão
Responsible: Oswaldo Nico	Date: 15/07/2018
Pilot: Bruno Santana	Start: 12:00 am Finish: 12:57 am
Authorized By: Giogio de Tomi	Position: PAN 047
ROV: NAPROV02	Weather: Sunny, no wind
Check List: Ok	Water: good visibility, no waves, weak stream
Occurrences: A rock block was identified (approximately 1.5x, 1.5 x 2.0 m) in the navigable channel and above the project limits, southwest of PAN047. The remaining areas were within the project limits.	

Figure: 15. Summary of mission report.

5 DISCUSSION

The rock dredging processes involve heavy and expensive equipment, with the inefficient mobilization of an excavation barge or drilling pontoon ahead of time causing extra work, time loss and extra costs. The ROV mission detected a process failure, where a rock portion did not reach the dredging limits determined by the project. It is important to report that this kind of issue was common and frequent in this rock dredging case, representing a significant rate of unwanted issues. If the ROV had not identified the problem, it would only have been solved after the bathymetric check performed by a contractor inspection vessel.

The methodology proposed here prevents the need for an excavation barge to be mobilized before reaching the dredging limits, thereby saving time, cost, team wear and conflict with the contractor. By observing the excavation cycle time, it is possible to determine the time and/or cost saved with the methodology applied. Table 1 presents the times and costs of a regular underwater rock excavation cycle.

Table 1. Regular underwater rock excavation cycle (times and estimated costs).

Excavation unit operation	Time (h)		Cost (US $)	
Barge location (GPS localization)	2.6	19%	10,400	16%
Barge fixation (gravity anchor)	1.3	9%	5,200	8%
Excavation and loading (blasting material)	7.9	57%	39,500	62%
Barge transport to new excavation front	2.1	15%	8,400	13%
Total	13.9	100%	63,500	100%

Table 2 shows the times and estimated costs of an underwater rock excavation cycle with extra work due to the rock block detected.

Table 2. Regular underwater rock excavation cycle with rework needs (times and estimated costs).

Excavation units operation	Time (h)		Cost (US $)	
Barge location (GPS localization)	2.6	19%	10,400	16%
Barge fixation (gravity anchor)	1.3	9%	5,200	8%
Excavation and loading (blasting material)	7.9	57%	39,500	62%
Barge transport to new excavation front	2.1	15%	8,400	13%
Barge relocation (GPS localization)	2	14%	8,000	13%
Barge fixation (gravity anchor)	1.3	9%	5,200	8%
Excavation rework	0.9	6%	4,500	7%
Barge transport to new excavation front	2	14%	8,000	13%
Total	20.1	145%	89,200	140%

Finally, Table 3 presents the times and estimated costs of a underwater rock excavation cycle with an extra excavation cycle using the methodology proposed.

Table 3. Regular underwater rock excavation cycle with rework needs using the methodology proposed (times and estimated costs).

Excavation units operation	Time (h)		Cost (US $)	
Barge location (GPS localization)	2.6	19%	10,400	16%
Barge fixation (gravity anchor)	1.3	9%	5,200	8%
Excavation and loading (blasting material)	7.9	57%	39,500	62%
Barge transport to new excavation front	0	0%	0	0%
Barge relocation (GPS localization)	0.25	2%	1,000	2%
Barge fixation (gravity anchor)	0	0%	0	0%
Excavation rework	0.9	6%	4,500	7%
Barge transport to new excavation front	2	14%	8,000	13%
Total	14.95	108%	68,600	108%

Analysis of Table 3 shows that the underwater rock excavation cycle increased 8% in time and cost due to rework, compared to 45% in time and 40% in cost with the rework without the ROV monitoring, representing a 37% saving in time and a 32% saving in cost. The methodology avoided the unduly excavation barge mobilization and new barge fixation, in addition to significantly reducing the barge relocation (2 to 0.25 h). Once the barge had already been fixed, the new location could be reached by simply moving the fixation cables.

The ROV use during all the processes can avoid losses, save time and correct inefficient procedures before starting the next step. The ROV mission also allowed the blast team to study why the blasting resulted in a rock block above the determined size.

The findings of the identification of key procedures during the experimental phase appear to confirm the conclusions of Teague (2017) that low-cost ROVs may be significantly useful for monitoring and oversight, providing essential information for regulatory agencies to ensure that the work is following Standard Operating Procedure (SOP) and adhering to potential environmental issues set out by the Environmental Impact Assessment (EIA).

Furthermore, if the ROV is able to provide the correct spatial position, it could help the excavating unit to locate the problem faster and also help the team determine if the dredging is in the correct project limit. This issue can be solved by ROV devices, such as GPS and sonar, which have already been studied to be applied. It can even be used as a measurement tool by the dredging contract inspector.

6 CONCLUSIONS

This study presents a new methodology to improve the rock dredging process for channel deepening of harbors and waterways. This process is also frequently applied for the excavation of trenches for the installation of oil gas pipelines and communication cables, water conducts for hydroelectric plants, excavation for civil constructions foundations and in the exploitation of consolidated deposits.

The proposed methodology was tested on the Tietê River waterway in Brazil, where the river channel is being deepened to expand the local navigation capacity. After mapping out the whole dredging rock process, key procedures were identified. The tests demonstrated that an observation ROV application can improve dredging efficiency. A ROV mission was planned and executed to identify problems, allowing the rock dredging team to make faster and more accurate decisions, resulting in savings of 37% in time and of 32% in cost. The observation ROV proved to be an efficient tool for monitoring and inspecting underwater blasting, allowing greater process control and helping in environmental issues.

7 ACKNOWLEDMENTS

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