Full Scale Testing of Rock Bag Filter Units

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Abstract
The use of rock bag type filter units for scour protection on revetments and in berth pockets are becoming more common around Australia. This is primarily driven by their ease of installation and ability to efficiently replace larger rock armour units, especially where there is limited supply. However, to date primarily only scale model testing of rock bag performance against propeller wash has been completed.

Project Material Pty Ltd organised the use of Pacific Tug's Cape Mac tug located at their Brisbane Pacific Marine Base to conduct full-scale trials on the performance of the 2 t, 4 t and 8 t AquaRockBags®. The aim of the trial was to determine the water velocity at which the rock bags fail, or are dislodged from the constructed revetment and base. The trials were conducted on the 7th of October 2022, with the Cape Mac utilising both engines to thrust water towards the rock bags. The water velocities were measured near the revetment using an acoustic doppler velocimeter (ADV).

After each condition, a hydrographic survey was conducted to measure the movement of the rock bags and surrounding riverbed. The bathymetric scans showed minimal movement of the 4 t and 8 t AquaRockBags® in all three configurations, as well as the surrounding 2 t AquaRockBags®.

Keywords: Rock Bag, Filter Units, Scour.

1. Introduction

Project Material Pty Ltd, in conjunction with IGG Internationale Geotextil GmbH and Garware Technical Fibres Ltd, are promoting the AquaRockBag® (rock bag) as an alternative to conventional rock armour to provide scour protection against wash generated by bow and stern propulsion units from ships and tug vessels. The rock bags can be placed on a revetment and bottom of the berth pocket to prevent undermining of quay wall structures or scour around piles. However, only model-scale testing has been completed to date on the stability of rock bags in this application, such as Messiter et al. (2019).

The aim of the trial was to determine the point at which the rock bags fail, or are dislodged, when subject to thrust from a tug vessel, and compare the results to the conclusions made Messiter et al. (2019).

2. Background

Messiter et al. (2019) detailed a study at the University of NSW Water Research Laboratory (WRL) investigating the stability of rock bags as scour protection from wash from cruise vessels. The study involved physical model tests at a 1:20 scale of 4 t and 8 t rock bags on the slope and toe respectively. The cruise ship bow thruster was replicated by a shrouded propeller to channel the thrust. The three full-scale water velocities tested were 4 m/s, 6 m/s, and 8 m/s for various offset distances from the revetment and water levels.

During the testing, there was bag rock movement for Test 10 (8 m/s water velocity, 8 m from the berth line, lowest astronomical tide (LAT) water level) and full failure occurred for Test 6 (8 m/s water velocity, 3.5 m from the berth line, LAT water level) as shown in Figure 1.

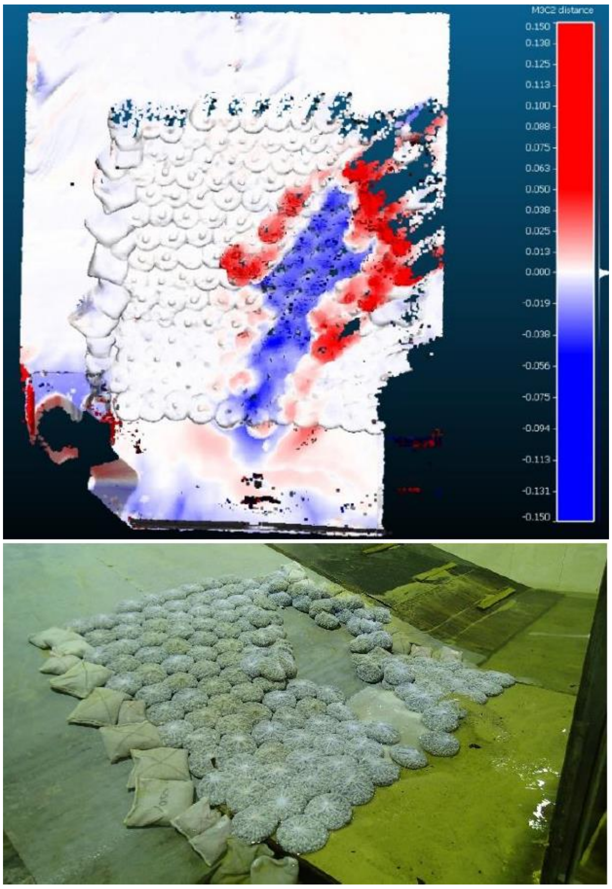

Figure 1: Image of the failed revetment and toe from Test 6 (Messiter, Miller, Simpson, & Lumiatti, 2019)

The paper summarised that the rock bags were stable when subjected to a 6 m/s bow thrust, which corresponds to standard operations. However, when the rock bags were subjected to the maximum bow thrust of 8 m/s, damage occurred with it being greater when closer to the berthing line and at lower water levels.

3. Purpose

The purpose of this full-scale test, conducted on Friday the 7th of October 2022, was to determine the following water velocity limitations of the AquaRockBags® exposed to wash from a tug, and compare the results to Messiter et al. (2019) for the following conditions:

- Stability for the 4 t and 8 t rock bags on a 1V:2H slope
- Potential for uplift of the 4 t and 8 t rock bags on a flat surface when
  - The tug is located seaward of the bags
  - The tug is located above the bags
- Stability for the 8 t rock bags when stacked as in an unsupported vertical wall

4. Methodology

4.1 Rock Bag Sizes

Three rock bag sizes were used for the testing with two different rock grades as presented in Table 1.

Table 1: AquaRockBag® sizes and rock details used in the testing

Rock Bag Size	Maximum Capacity [t]	Rock Grade [mm]	Rock Density [t/m^2]	Typical Diameter & Height [m]
Small	2 t	75-150	2.7	1.9 x 0.6
Medium	4 t	150-300	2.7	2.2 x 0.8
Large	8 t	150-300	2.7	3.2 x 0.9

4.2 Rock Bag Construction

The small rock bags were made from a warp knitted, double mesh of a polyester and polyolefin blend as shown in Figure 2. The mesh construction resembles that of a trawl net, such that if a strand breaks and causes a hole it does not propagate easily throughout the bag.

Figure 2: Small rock bag mesh and rock size

The large rock bags were made from a larger high-density polyethylene (HDPE) mesh and comprised of four layers, compared to the small and medium rock bags which has a smaller mesh and only two layers.

The rock bags were designed to be used with rounded river type stone which allows the bag to more easily conform in shape to the surrounding area as shown in Figure 3.

Figure 3: Small rock bag shape when stacked and filled to approximately 1.8 t

However, for the medium and large rock bags, larger quarry stone was used which increased the rock size and therefore reduced the roundness causing larger voids inside the bag as the rock could not easily move over each other. This also caused the bag to be slightly more rigid and not conform to the surrounding area as easily as the small bags as shown in Figure 4.

Figure 4: Medium rock bag prior to being placed in the water

4.3 Test Area Overview

The tests were conducted at Pacific Tug's Brisbane Pacific Marine Base, located on the Brisbane River. The site featured a permanently moored barge, Coochie, suitable for loading and installing the rock bags onto the an existing damaged ramp via a mobile crane, as shown in Figure 5.

Figure 5: Original condition of test area

4.4 Test Area Ground Preparation

A bathymetric and topographic survey were conducted to determine the existing topology of the site prior to the installation of any rock bags. From the survey, it was determined that the existing seabed slope to the shoreline and surrounding bathymetry were similar to the required design revetment slope and depth, therefore requiring no civil works beyond placement of small rock bags.

However, there was a requirement to create a flatbed area to test the uplift stability of the bags. Therefore, the small rock bags were placed directly on the seabed with the aid of divers to create the required bathymetry. Small rock bags were also placed around the barge mooring pile and the existing rock revetment to limit erosion from the testing outside of the prepared slope.

Once the small rock bags were placed, a 1,200 GSM geofabric was placed down and held in place by small 1.8 t rock bags along the toe to prevent undermining as shown in Figure 6.

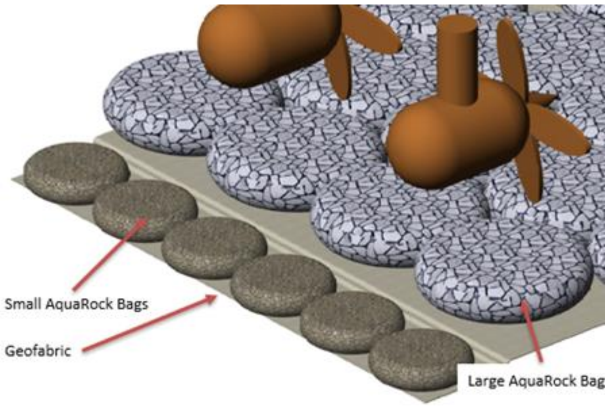

Figure 6: Render of the small and large rock bags placed over the geofabric, with the small bags securing the toe

During the testing, the small rock bags were kept in place and the medium and large rock bags were relocated as required by crane and divers for the test schedule.

4.5 Water Velocity Measurement

The water velocity from the tug wash was measured via a Nortek Vectrino 10 MHz instrument which is a high-resolution acoustic doppler velocimeter (ADV). The device configuration is detailed in Table 2.

Table 2: Acoustic doppler velocimeter parameters (Bluecoast Consulting Engineers, 2022)

Parameter	Value
Mounting	Bottom Mounted (Upward Looking)
Approximate Depth (MLS)	2 m
Sampling Volume Height	3.-15 mm
Current Measurement Interval	Continuous
Current Speed Horizontal Precision	±0.5%
Sampling Rate	25 Hz

Live water velocity readings were observed to estimate the water velocity from the tug to determine if variations in the tug engine RPM were required.

4.6 Tug Particulars

The tug used in the test was the Cape Mac; a twin azimuth stern drive (ASD) towage vessel with the main particulars listed in Table 3. For the testing, the Cape Mac was moored to the barge Coochie with both ASD units operated to a specified RPM.

Table 3: Cape Mac tug particulars

Particular	Value	Unit
Length Overall (LOA)	28.00	m
Length Between Perpendiculars (LBP)	22.94	m
Beam	9.80	m
Aft Draught (During Testing)	3.85	m
Maximum Thrust per ASD	20	t
Maximum Volumetric Flow Rate	8,000	L/s
Maximum Bollard Pull (BP)	42	t

Table 4 outlines the estimated Cape Mac tug engine output for a given throttle/engine RPM input.

Table 4: Cape Mac tug engine throttle details

Tug Engine RPM	Estimated Tug Engine Throttle	Estimated Equivalent BP [t]
400	Idle	11
600	50%	21
650	63%	26
675	69%	29
700	75%	32
800	+100%	42
900	Maximum Engine Capacity	

For each run, the tug engaged the propellers while the ASDs were orientated in the neutral position, and then rotated toward the rock bags and increased the RPM to the required value.

Table 5: Completed testing schedule and water level during test (Bluecoast Consulting Engineers, 2022) (Queensland Government, 2022)

Case	**Configuration**	**Engine RPM**	**Run Time [min]**	**Estimated Peak Water Velocity [m/s]** (Bluecoast Consulting Engineers, 2022)	**End Time**	**Water Level [m]**
A.1	4t Revetment - tug over 8t	400 RPM	5	2.8	0902	1.68
A.1 - Repeat		400 RPM	5	2.8	0923	1.56
A.2		600 RPM	10	2.8	0934	1.49
Tug moved 8 m from revetment						
B.1	Bottom unit lift - 8t	400 RPM	10	4.4	1007	1.25
B.2		600 RPM	10	4.4	1039	1.07
B.2 - Repeat		600 RPM	10	4.8*	1109	0.88
B.3		650 RPM	10	5.1*	1123	0.82
B.4		675 RPM	10	5.2*	1206	0.59
B.5		700 RPM	5	5.3*	1230	0.51
B.5 - Repeat		700 RPM	5	5.1*	1237	0.47
4 t bags moved to bed and 8 t bags stacked into a wall behind the 4 t bags						
C.1	8t wall and 4t uplift	600 RPM	5	4.6**	1735	1.81
C.2		650 RPM	5	5.1**	1755	1.96
C.3		700 RPM	5	5.2**	1810	2.02

* Note: ADP Instrument was damaged for these measurements
** Note: Water velocity assumed equal to the recorded velocities in Case B

4.7 Testing Configurations

There were three different configurations tested on Friday the 7th of October 2022 which are listed in Table 6. These three cases were developed to try and replicate the model-scale testing outlined in Messiter et al. (2019).

Table 6: Case configuration for testing

Case	**Configuration**	**Water Velocity Range [m/s]**
A	- 4 t rock bags on revetment - 8 t rock bags on bottom - Tug located over scour protection bags	3-8
B	- 4 t rock bags on revetment - 8 t rock bags on bottom - Tug located 8 m away from revetment	4-6
C	- 8 t rock bags on revetment - 4 t rock bags on bottom - Tug located 8 m away from revetment	6-8

5. Results and Analysis

5.1 Test Schedule

Table 5 outlines the conducted tests for the different tug RPM and rock bag placement, with Figure 7 showing the measured water level at the nearby tidal gauge. After each case, a bathymetric survey was conducted to determine if any of the bags had dislodged and/or moved. During this time, the water was able to settle. The large gap in testing time between Cases B and C was due to the relocation of the bags taking longer than expected as a result of poor visibility for the diver.

5.2 Water Levels

Figure 7 shows the measured water level for the 7th of October 2022 located at the Port of Brisbane Operations Base at Brisbane Bar (Whyte Island) (Queensland Government, 2022).

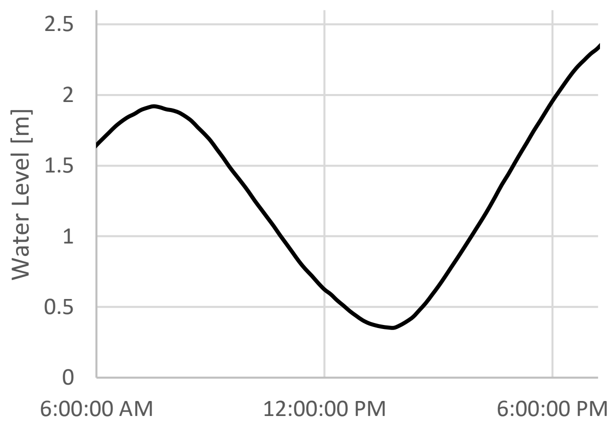

Figure 7: Actual water levels at the Brisbane Bar (Whyte Island) (Queensland Government, 2022) with the test completion times shown in dashed lines

5.3 Rock Bag Installation

The rock bags were installed via a mobile crane and positioned via divers into the correct positions as shown in Figure 8. A bathymetric survey was conducted at several stages during the installation to ensure that the rock bags were installed in the correct location.

Figure 8: Photo of a large rock bag being craned into position with a diver on standby

5.4 Case A

The Case A runs had the tug propeller located above the large rock bags and impacting the medium bags on the revetment while also subjecting the large rock bags to uplift due to lower pressure.

During the tests, it was observed that the water from the tug thrust was severely turbulent with variable flow directions as it hit the rock bags and upwelled as shown in Figure 9. Also, as the water level decreased, the surface water became more turbulent. This is due to the short distance between the propeller and the revetment not allowing the thrust sufficient distance to disperse. It was also observed that large volumes of water were flowing parallel to the shoreline away from the testing site which became more visible for the lower water levels.

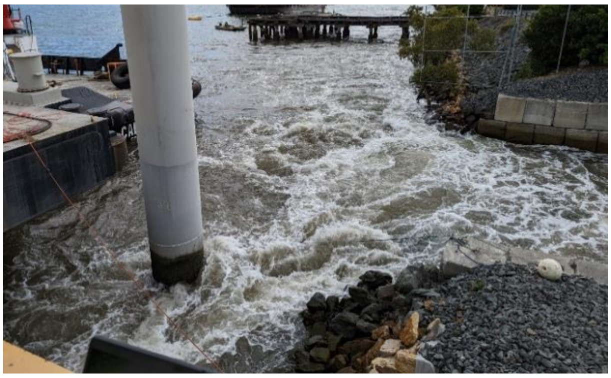

Figure 9: Run A.1 – Repeat where significant turbulence and upwelling can be seen

Figure 10 is a Delta Z bathymetric plot which shows the change height between two surveys. This plot type was used during the trial to estimate quickly if any of the rock bags had moved compared to the previous case. Figure 10 shows the change in bathymetry between pre-Case A and post-Case A, which shows that there is minimal movement of any of the rock bags, including the small rock bags placed at the toe and around the revetment. However, minor scour of the riverbed to the east (right of page) of the geofabric and small rock bags was observed.

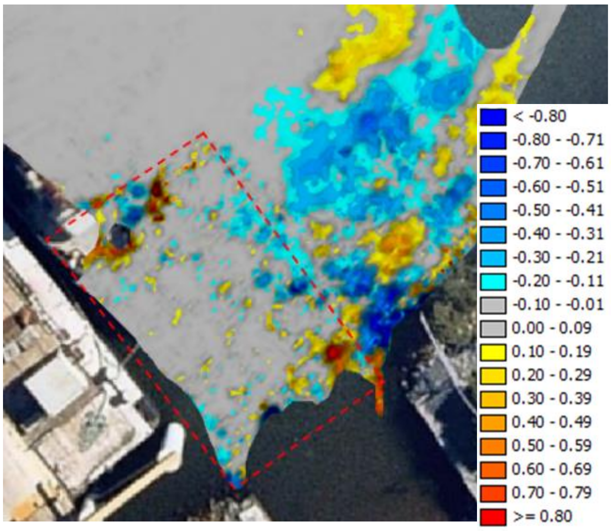

Figure 10: Delta Z colourmap showing where there are changes in surface levels after the Case A runs compared to the pre-trial bathymetry with the approximate location of the geofabric outlined (Total Hydrographic, 2022)

5.5 Case B

The Case B runs required moving the tug 8 m along the barge away from the revetment to test the uplift of the large rock bags and the medium rock bags on the revetment.

During the test, it was observed that the water was not as turbulent compared to Case A and that more surface flow could be seen impacting the revetment. There was also more noticeable surface flow parallel to the shoreline in both directions at an estimated 3-5 m/s, which caused erosion along the banks where no rock bag protection was installed. The boiling and upwelling of the water also pulsated which was both observed and measured and was assumed to be as a result of the tug engine hunting around the set engine RPM.

Similar to Case A, a bathymetric survey was conducted after each run where it was determined that there was minimal movement of any of the bags post Case B.5 – Repeat compared to pre-trial, as shown in Figure 11. However, the scour hole to the east of the rock bags and geofabric became deeper and widespread compared to the end of the Case A testing, with accretion on the northeast corner of the geofabric and rock bags.

During Case B.2 – Repeat, an unknown underwater debris struck the ADP instrument and bent the probe. This resulted in inaccurate readings for the remainder of the cases with the instrument failing to respond when redeployed prior to commencing Case C. Additional post processing methods were conducted on the recordings to estimate the velocities, which are presented in Table 5.

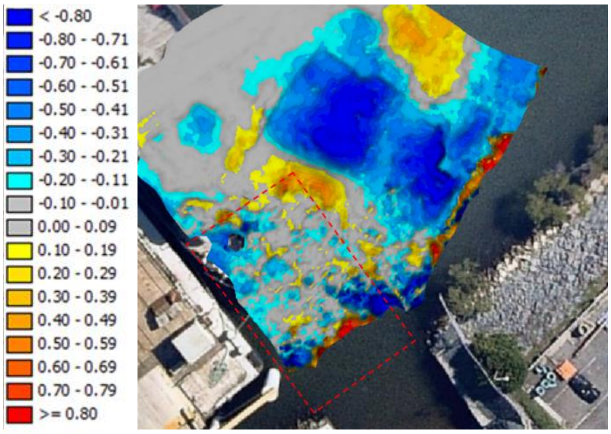

Figure 11: Delta Z colourmap showing where there are changes in surface levels after the Case B runs compared to the pre-trial bathymetry with the approximate location of the geofabric outlined (Total Hydrographic, 2022)

5.6 Case C

Case C required moving the medium rock bags to the base with the large rock bags being placed in a freestanding wall configuration behind the medium bags, as shown in Figure 12. This movement required more time than expected with testing commencing at approximately 1730 on the 7th of October. Additionally, as the ADP instrument was not operational for Case C, the run time was reduced from 10 min to 5 min with no repeats due to time constraints and no data recording.

Due to the water level at the time when the pre-test survey was conducted, only limited datapoints could be captured on the top and front of the large rock bag wall causing artificial changes bathymetry, as shown in the red circle in Figure 12.

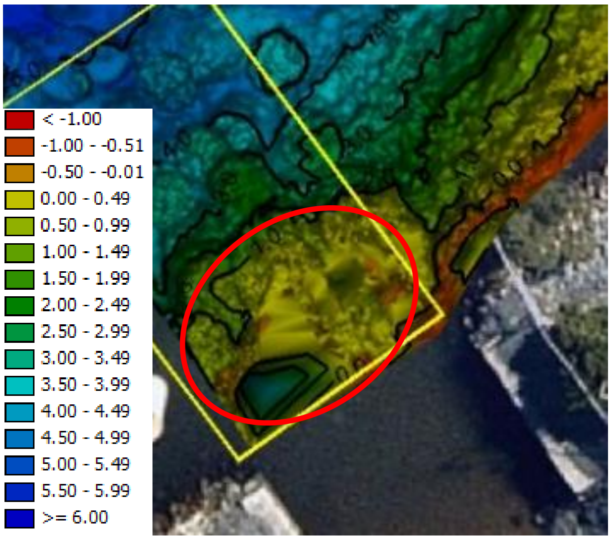

Figure 12: Medium and Large rock bag placement along the base and stacked into a wall respectively (Total Hydrographic, 2022)

During the tests, significant upwelling was observed approximately where the large rock bag wall was located. Strong water flows were also observed flowing along the wall and parallel to the shoreline, similar to Case B. The water level was also higher for these runs compared to Case A and B reducing the surface level turbulence.

Figure 13 shows the change in bathymetry from the pre-Case C runs to the post-Case C runs, where significant positive and negative changes can be seen in the location of the rock bags. However, when overlaid with the bathymetric survey, as shown in Figure 14, the below can be observed:

- the accretion was located at the base of the large rock bag wall with minimal change in the contours along the front of the wall (red), and
- the loss was located on top of the large rock bag wall, and in between the medium rock bags located near the barge (blue).

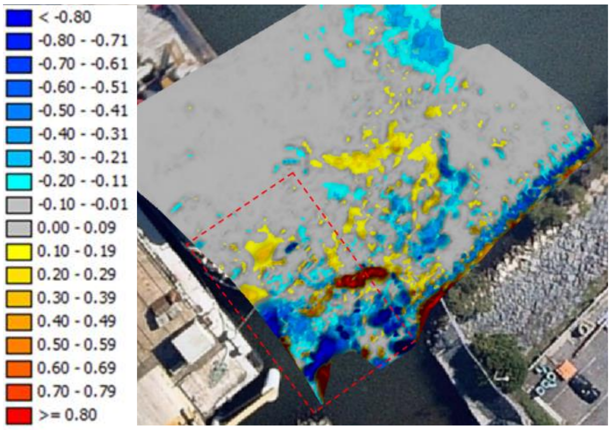

Figure 13: Delta Z colourmap showing where there are changes in surface levels after the Case C runs compared to the pre-Case C bathymetry with the approximate location of the geofabric outlined (Total Hydrographic, 2022)

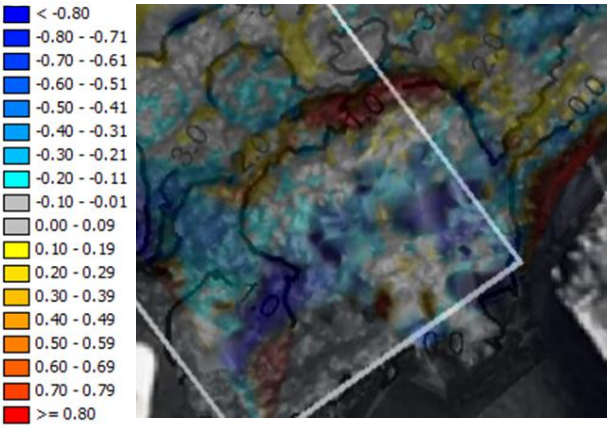

Figure 14: Cropped post Case C.3 bathymetric survey (greyscale) overlaid on the Delta Z colourmap showing the areas of greatest change (Total Hydrographic, 2022)

6. Discussion and Conclusions

From the analysed ADP instrument data, the measured maximum water velocity of 5.3 m/s was lower than required 8 m/s for the test. However, as the ADP instrument was damaged during Case B.2 – Repeat, which was prior to the maximum tested RPM, this could have lowered the recorded velocities. Additionally, as the water flow from the

ASD was severely turbulent, this may have further provided lower readings from the sensor, as evident between the difference in measured velocities in Case A and Case B. Although the maximum required velocity was not measured, a significant volume of water was thrust at the rock bag structure for an extended duration, as observed in the figures, and resulted in minimal movement of any rock bags.

The bathymetric surveys showed that there was minimal movement of the medium and large rock bags on the revetment and base respectively for Cases A and B. Additionally, the small rock bags that were installed at the toe, around the revetment, and at the base of barge mooring pile had minimal movement even though erosion along the riverbank either side of the revetment was observed. There was also a significant scour hole developed to at the northeast corner of the geofabric and small rock bags, however no small rock bags slipped into the hole. This highlights the stability of interconnected rock bags compared to single rock bags, as during construction three small rock bags slid into an existing scour hole.

However, for Case C, the Delta Z plot showed that there was significant movement on and in front of the large rock bag wall. From Figure 14, it could be seen that:

- majority of the loss areas are due to interpolation errors on the top of the large rock bag wall as the survey vessel could not travel over or around the large rock bag wall due to low water levels,
- loss occurred where the rock bags were not located, therefore could be attributed to the geofabric and/or sediments shifting, and
- loss and accretion occurred where the bags may have settled after being relocated and subjected to the tug thrust.

Additionally, based off the bathymetric survey there was no indication that any of the rock bags had significantly moved, or the large rock bag wall had collapsed.

In comparing the outcomes from this trial to Messiter et al. (2019), similar conclusions can be drawn as there was no movement of the bags for water velocities less than 6 m/s in both studies. However, the scale model had the large rock bags placed on the revetment whereas this study had the medium rock bags installed and still achieved minimal movement.

In summary, the rock bags in the three test configurations had no movement from the direct and indirect tug wash in velocities up to an estimated 5.3 m/s, which was the maximum the tug could safely deliver, similar to Messiter et al. (2019). Therefore, this test showed that the AquaRockBag® units are suitable to be installed as scour protection in a berth pocket, around piles and on revetments, as well as revetment armour units in water velocities up to 5.3 m/s with minimal movement. Due to the large tidal range at the time of the test, it was not practical to test each rock bag configuration (Case A, B, and C) for a range of water levels and tug positions.

7. Recommendations and Further Works

Listed below are the recommendations and potential further works that should be conducted to provide additional results to better determine the failure water velocity for the rock bags:

- Use smaller rock in the medium and large rock bags to match the designer's specifications to allow the bag to settle more efficiently and replicate what would be typically installed
- Conduct the test in a less tidally impacted area to quantify the impact of different water levels and reduce the interference of tidal currents
- Test for more ASD offset distances to the rock bags
- Place additional water velocity sensors to the sides of the revetment to measure the flow parallel to the shoreline
- Utilise a larger vessel to provide greater water velocities and test to failure

8. Acknowledgements

The author thanks Project Material Pty Ltd, in conjunction with IGG Internationale Geotextil GmbH and Garware Technical Fibres Ltd for permission to publish the results of the study.

9. References

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