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Deformation Survey of Newcastle Breakwalls using UAV Technology

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ABSTRACT

Monteath & Powys were approached by the Port of Newcastle to survey and monitor the rock armour surrounding the Nobbys and Stockton Breakwalls forming the entrance to Newcastle Harbour. Previously, the rock armour was monitored by visual inspection only and maintained with no recordable evidence of deformation within the rock walls. This was a costly exercise and posed a substantial risk of failure given the magnitude of the task. In order to monitor each of the thousands of rocks along each breakwall, we needed a method of capturing the data safely, efficiently and accurately. The idea of utilising an Unmanned Aerial Vehicle (UAV) for this purpose came from our experience in aerial surveys combined with our 3D laser scanning capability. Monteath & Powys have operated high-precision 3D laser scanning equipment for a number of years to report on deformation of structures compared to either previous surveys or design models. This paper outlines how we were able to combine the above-water and below-water data to create seamless Digital Terrain Models (DTMs) for comparison and deformation analysis over time. There were significant challenges in incorporating these technologies, but the resulting process allowed Monteath & Powys to provide a superior product to the client in a safe, efficient manner. This project was completed successfully in conjunction with the Port Authority NSW. It was entered into the 2015 Spatial Excellence awards, winning the Spatial Enablement category. This qualified the project for the 2015 Asia Pacific Spatial Excellence awards in Melbourne, which it also won. The success of this technology has led to several other projects including the survey capture of Eden Breakwater and the current Balmain Wharf to Birchgrove Wharf for Roads and Maritime Services.

KEYWORDS: *UAV, 3D modelling, laser scanning, point cloud, deformation monitoring.*

1 INTRODUCTION

The Port of Newcastle is the largest bulk shipping port on the east coast of Australia and the world's leading coal export port. It handles more than 25 different cargoes and 4,600 ship movements per year, all reliant on the protection offered by the breakwalls at Nobbys and Stockton. The breakwalls are constantly battered by the ocean with large swells causing movement in the rock armour, resulting in scouring and possible collapse of the breakwall structure. Previously, the Port of Newcastle would visually inspect the breakwalls after large storm events to check for deformation in the rock armour. Any areas which looked to have

moved would be rectified with additional material. This method was costly and unreliable, risking a critical asset.

Monteath & Powys were approached by the Port of Newcastle to assist in this process by use of our Terrestrial Laser Scanning (TLS) equipment. Once the scope of work was established, it was evident that TLS would prove costly and not provide full coverage of each individual rock from a single direction. Scan locations would only be available from the walkway on top of each breakwall and not from the rocks themselves or the ocean.

A second option raised was the use of Mobile Laser Scanning (MLS) equipment from a vessel. This methodology was considered a viable option, but the cost was prohibitive and data capture is limited by a fixed location on the vessel itself. By capturing the data in this way, sections of the rock wall are hidden from view and not included within the final model.

Having completed several aerial surveys with Unmanned Aerial Vehicles (UAVs), the idea of capturing the breakwalls with photogrammetry was raised. By capturing several passes with the UAV at different camera angles and locations, it was thought that a more complete capture of each rock could be achieved by minimising the shadowing which hampered the laser scanning options. Figure 1 shows the flight level methodology adopted, and Figure 2 illustrates the camera locations and overlap.

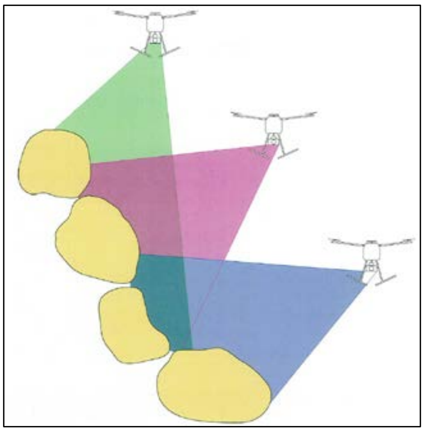

Figure 1: UAV photographic coverage in section view.

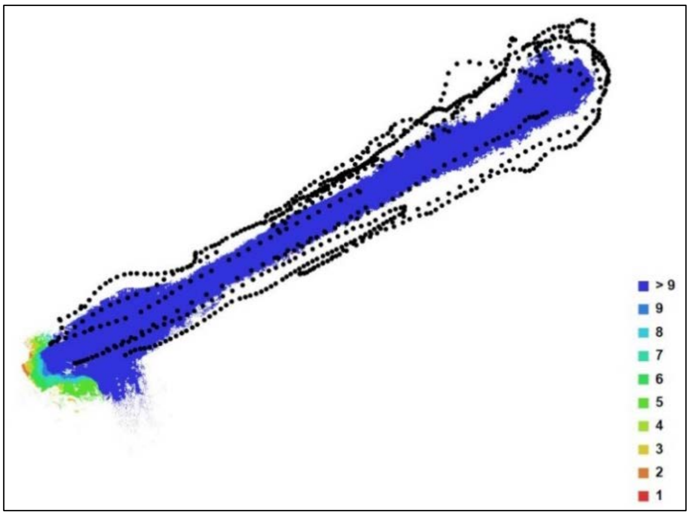

Figure 2: Camera positions and image overlap.

2 RESEARCH AND DEVELOPMENT

All photogrammetric survey work prior to this project had been completed with the camera angle perpendicular to the ground with survey control to orthorectify the unified image and create a Digital Terrain Model (DTM) accurate to approximately ±0.05 m. Along with Airsight Australia, we investigated the software limitations and were able to create a DTM from the combined aerial imagery despite the varying camera angles.

As with any survey process, we needed to prove beyond doubt that our method of survey was accurate and could be reliably replicated in future data captures. An extensive testing regime followed, which included multiple flights and 3D laser scanning of an easily accessible, sample section of breakwall. Using 3D Reshaper software (Hexagon, 2015), a DTM was created from each point cloud model. Each DTM was overlaid and checked for deformation within 3D Reshaper. The initial stages of testing identified some data problems, particularly in areas on the extremity of the survey. Errors up to 200 mm were found (Figure 3).

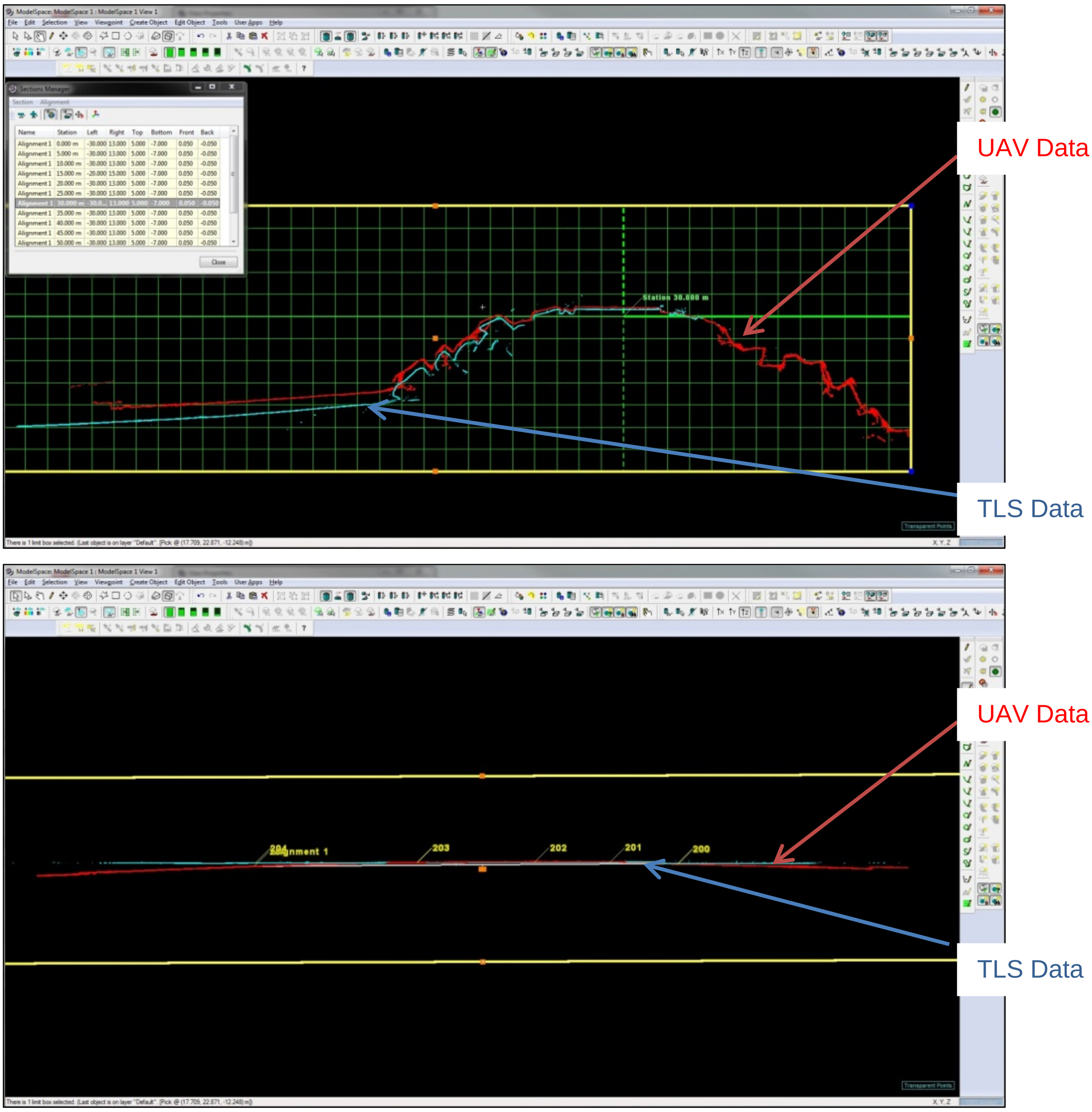

Figure 3: Initial errors between UAV and TLS data.

By reconfiguring the survey control to the extremities of the capture area and widening the linear control network, it was possible to reduce the DTM from the UAV with a higher level of confidence. When overlaid with the laser scanning data, the error between the two sets of data was found to be well within the ±0.05 m considered acceptable for this task. The DTM deformation plot between TLS and UAV data can be seen in Figure 4. With great confidence in our field capture technique, this methodology was presented to our client as a viable option for the ongoing monitoring and reporting of the breakwall structures.

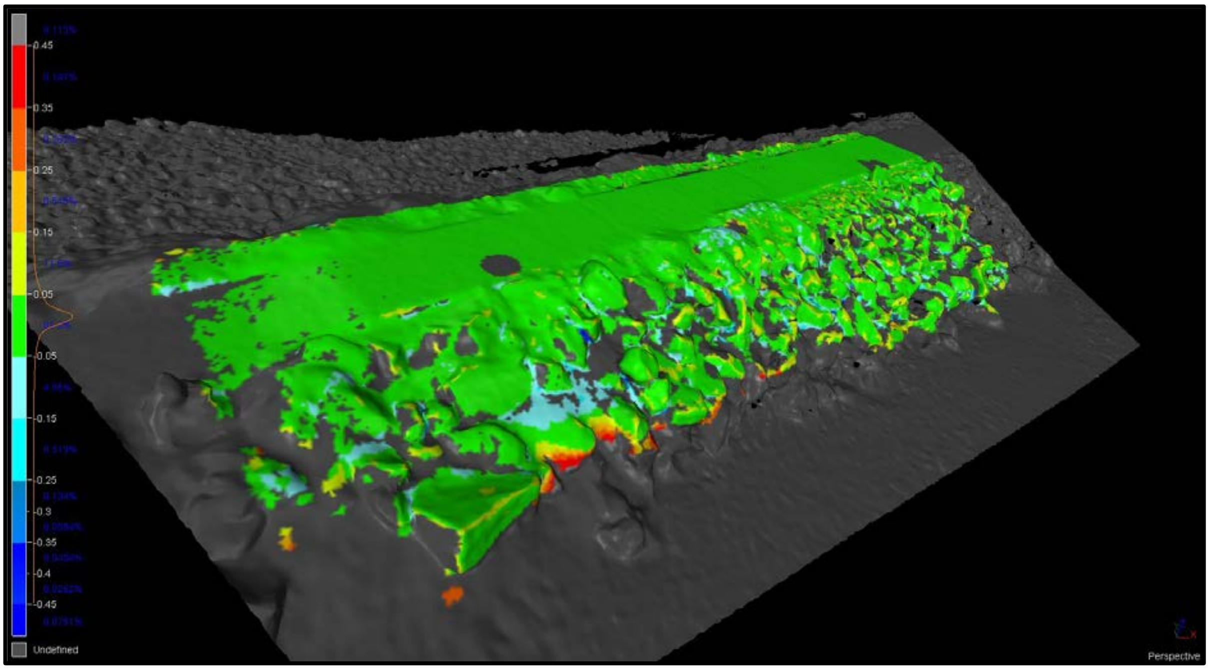

Figure 4: Colour deviation plot showing all areas within ±0.05 m coloured green.

3 FIELD CAPTURE

3.1 Initial Baseline Survey Capture (2014)

As part of the project deliverables, Monteath & Powys were asked to incorporate bathymetric Light Detection and Ranging (LiDAR) data from the Port of Newcastle's survey vessel. The data is captured on high tide to ensure maximum coverage is achieved. Conversely, Monteath & Powys were to capture photogrammetric data on an extreme low tide within 0.3 m of the Lowest Astronomical Tide (LAT). This occurs approximately once a month for a period of around three days. It is also best to capture the data with minimal swell to limit the amount of water splash in the image capture. Extreme wind conditions can also affect the flight of the UAV. In order to achieve accurate flight paths and image capture, the UAV can only fly in wind less than 35 km/hr.

Newcastle being coastal and exposed to the elements, the wind speed is often over 35 km/hr, particularly in the afternoons. With this knowledge it was decided the proposed capture dates should be aligned to the extreme low tides falling in the morning periods between 7.00 am and 10.00 am. This results in a small window of opportunity to capture each breakwall structure. Other events such as ship movements in and out of the harbour as well as defence exercises from the nearby RAAF base at Williamtown also caused delays in the field capture.

Once a suitable date was set, survey control was placed on Map Grid of Australia (MGA) coordinates and Australian Height Datum (AHD) levels (heights) using the Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) technique in locations chosen specifically to encompass as much of the capture area as possible. Survey control was placed using CORSnet-NSW (Janssen et al., 2016; DFSI Spatial Services, 2017) with two readings taken on each station using different initialisations. The accuracy of the control must be within ±50 mm, which was achieved easily using this this methodology. Marks placed were a 200 mm wide cross painted on the ground in locations visible from the air. Secondary control marks were also placed as wide on the wall as possible and on the beach to confirm results.

Flight paths were chosen at specific offsets from the breakwall centreline running parallel to the centreline and each other. This was designed from our preliminary research and development results to maximise the coverage of each individual rock and minimise shadowing. A diagram showing the flight paths can be seen in Figure 5. Flights were completed over a period of two days with minor interruptions caused by ship movements, wind and interested members of the public.

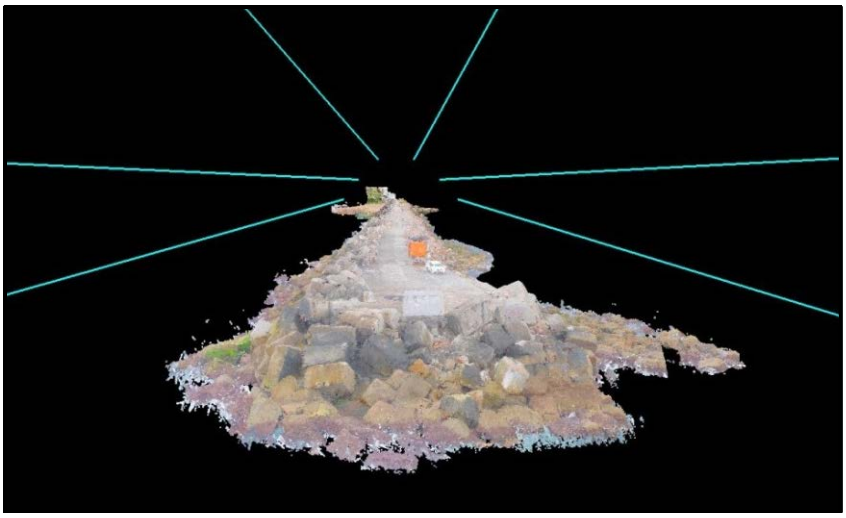

Figure 5: Flight paths used to capture the breakwall.

3.2 Secondary Field Data Capture (2015)

After a period of 6 months and several large storm events, Monteath & Powys were engaged to perform a secondary survey of the breakwall being the first comparison to the baseline dataset. Field capture was carried out in the same manner as the initial data capture using the same survey control network. As with any monitoring survey, keeping the methodology as similar as possible reduces the variables and potential for error in the datasets. The Port of Newcastle also had a secondary field capture of the bathymetry, allowing a full comparison of the above and below water rock armour to take place.

4 OFFICE COMPUTATIONS

4.1 Creation of DTMs

With two full sets of data, it was now possible to complete the comparison and report on deformation over time. This presented many challenges creating complex meshes of

thousands of rock structures including overhangs. Most software packages create DTMs by triangulation in 'plan view' and will not allow for triangulation under another triangulated surface. A diagram of a triangulated mesh from a standard surveying software package can be seen in Figure 6.

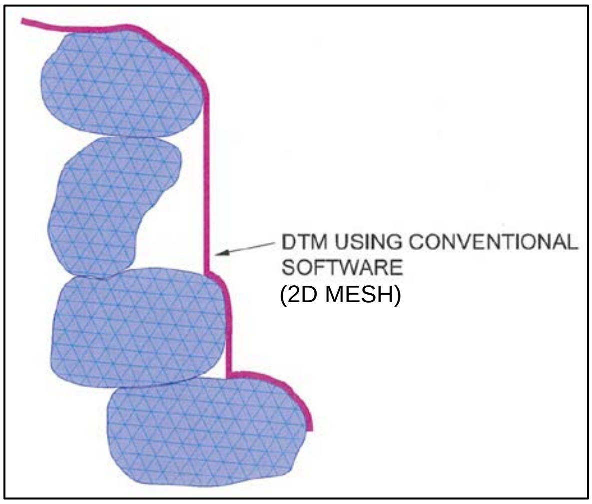

Figure 6: Typical rock structure section view using a conventional 2D mesh.

By using 3D Reshaper software (Hexagon, 2015) and our knowledge of complex meshes, it was possible to accurately model the entire visible surface of each individual rock including the underside in some instances. The complex mesh can exist above and below itself where the standard mesh cannot (Figure 7). Only a specialised few processing programs can perform complex meshing. The 3D Reshaper software was not cheap ($13,000) but well priced for functionality when compared to more expensive packages on the market.

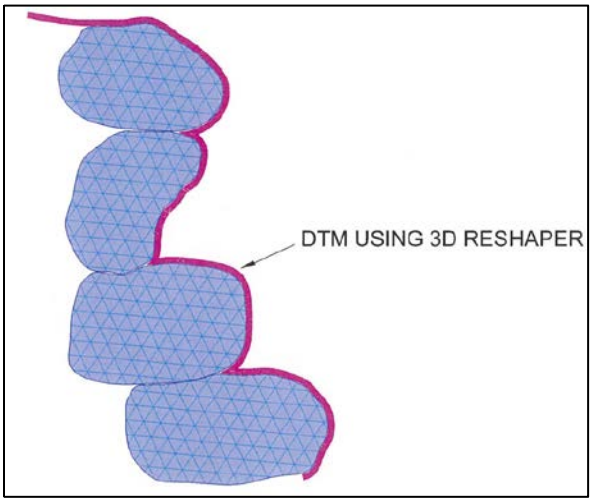

Figure 7: Typical rock structure section view using complex meshing via 3D Reshaper.

4.2 Data Comparison

A significant challenge in this project was the comparison of two large datasets. With over 65 million points per dataset, this may seem like a lot of data but in the laser scanning world this is a relatively small point cloud. The challenge was creating an accurate surface that could be compared to another accurate surface in a way that could be easily reported on and minimised false indication of movement between the two datasets.

Colour deviation mapping between two surfaces was deemed to be the most suitable reporting method for the task. By calculating a colour-coded map between the two surfaces, areas on both breakwalls that showed significant movement could be easily identified by means of a 'hot spot' or areas of a different colour (Figure 8).

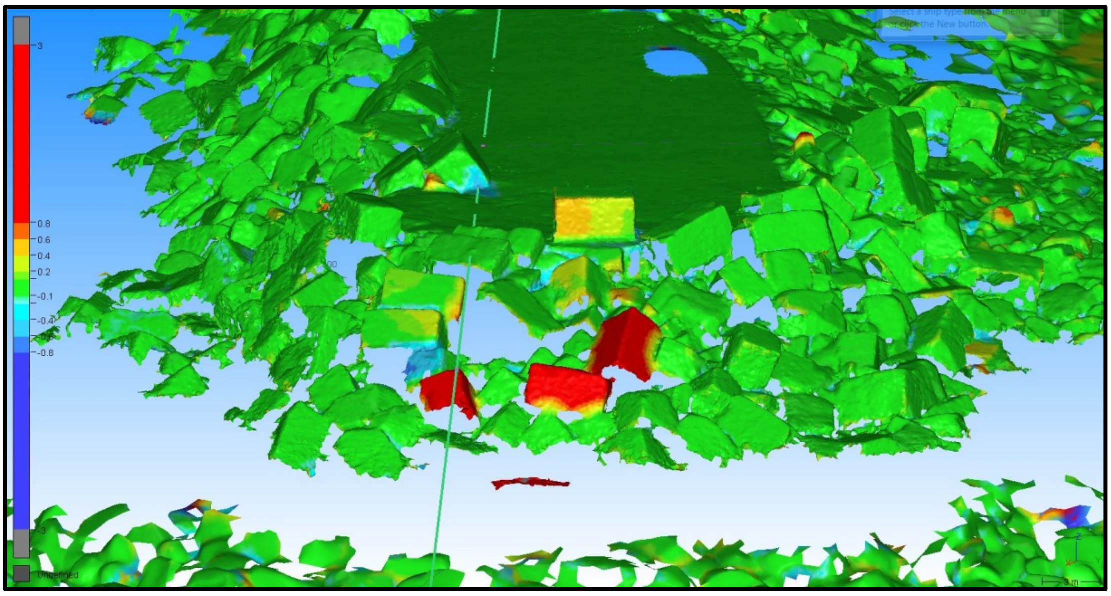

Figure 8: Example of colour deviation mapping on the southern breakwater. Positive values on the scale show addition to base surface, while negative values show removal of base surface.

The base surface in this case was created from the 2014 survey (see section 3.1) and compared to the surface created from the 2015 survey (see section 3.2). The perpendicular or normal distance between surfaces is then used to colour the nominated surface as shown in Figure 9. A positive value indicates a growth or addition to the surface, while a negative value indicates a retreating or removal from the base surface.

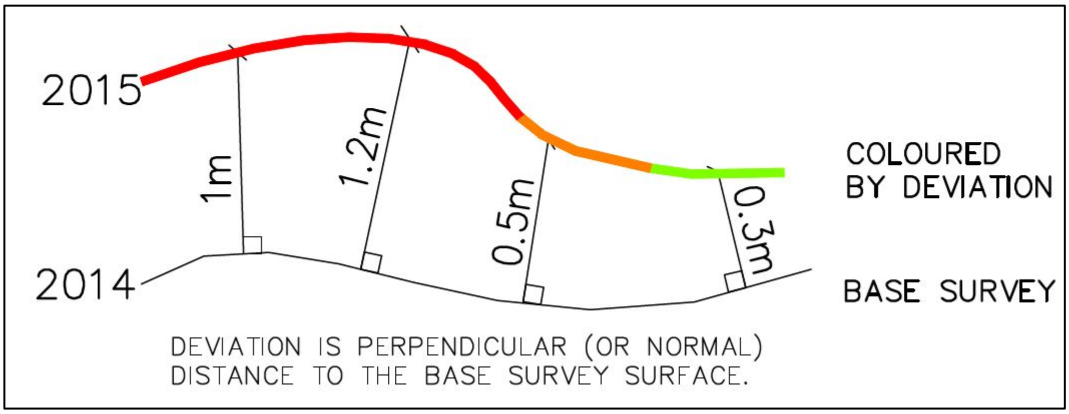

Figure 9: Colour deviation calculation method.

Before colour deviation mapping can take place, the two DTMs to be compared need to be created from the point clouds. The ability to create accurate surfaces that wrap around all the ins and outs, overhangs, etc. of this complicated structure accurately is the crux of the project. The majority of software packages are unable to compute a meshed surface that can exist above or below itself. This type of mesh is called a 'complex mesh' and was essential in this project.

By varying the angles of the camera position on the UAV, it was possible to maximise the point cloud coverage of the structure above water. Areas of sparse data or no data (i.e. shadows) still existed in the point cloud data. It was important to exclude these areas from being meshed to minimise false hot spots in the colour deviation mapping.

By using the meshing parameters to leave holes in the mesh when insufficient data was present, we were able to report or compare only true surfaces against true surfaces. While a water tight mesh usually looks more impressive, the triangulation across areas with little data could be different each time the survey is performed, creating false hot spots (Figure 10).

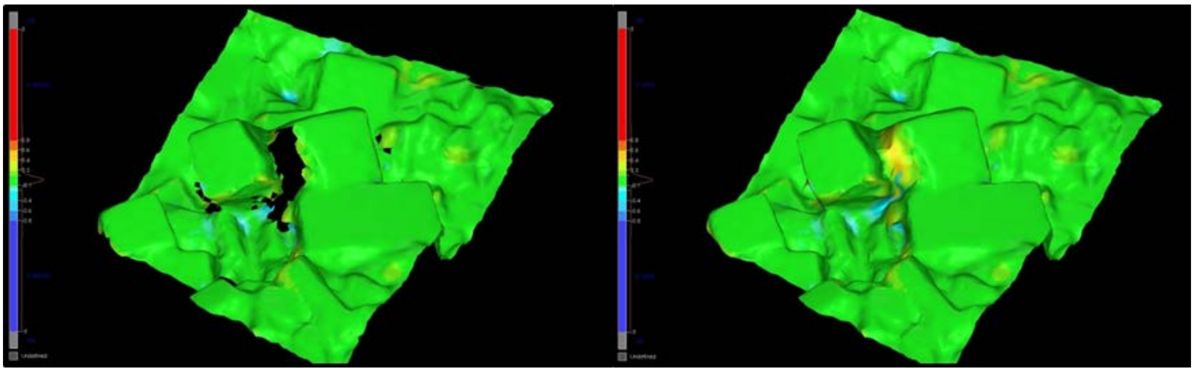

Figure 10: Comparison of the result between a mesh with holes (left) and a water tight mesh (right). In the latter case, a false 'hot spot' is created between two rocks shown.

The ability to eliminate false hot spots saves a significant amount of time in the next step of the process, matching hot spots with captured aerial images to identify possible causes for the hot spot and creation of a simple report. Each area of potential change is examined in both sets of images and reported on. A view is set up in 3D Reshaper so that the hot spot is easily identified in the digital data and referenced to the report. False hot spots would greatly increase an already lengthy process, so for efficiency and accuracy it is crucial to avoid them. Tight trimming of the UAV point cloud at the water line is also completed to minimise false identification. Photogrammetry creates points on surfaces visible in low lying water, which needs to be removed as these are usually incorrect.

5 PRESENTATION OF DATA

The results obtained showed several areas of change between the two surveys, and a simple reporting style needed to be created to concisely present the client with the location and magnitude of each occurrence. Each area of deformation from the UAV data highlighted by the software package was cross referenced to the images in that particular area. This allowed us to clearly show the movement in both a virtual graphic and photographic image. An example page of the full report is provided in Figure 11.

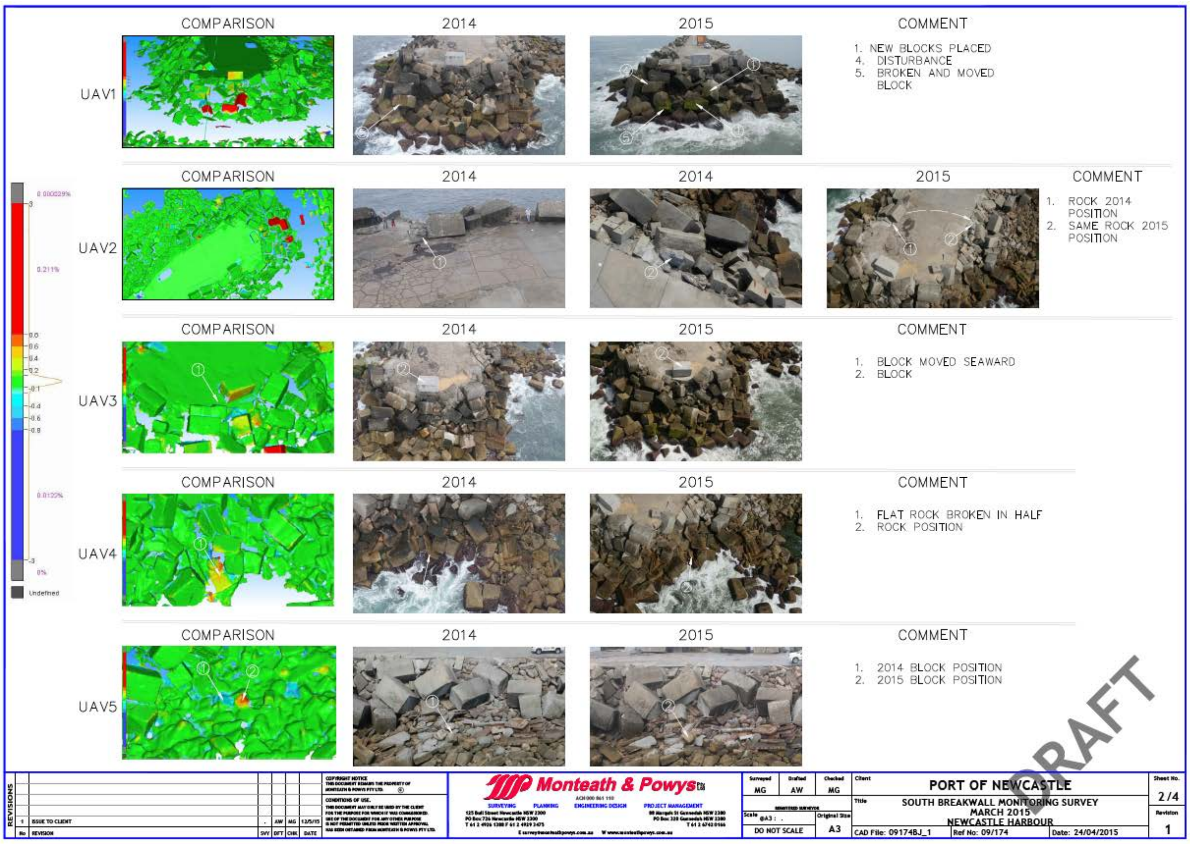

Figure 11: Example page from the report showing areas of detected deformation.

6 CONCLUDING REMARKS

This project has been incredibly successful for Monteath & Powys, allowing us to provide a service to several of our clients that was not previously possible. By combining these technologies, our clients have benefited from several aspects of the deliverables as well as promoting Monteath & Powys and the surveying industry. By utilising UAVs to produce a comprehensive point cloud of the rock wall structure, we were able to create a full 3D mesh which could be directly compared to the previous surveys. This was possible through our intimate knowledge of 3D data and specialised software packages acquired from our laser scanning experience.

As a promotional tool for both Monteath & Powys and the broader surveying industry, a cinematographer was engaged to create a 3-minute video to briefly outline the task and results we were able to achieve (Figure 12). This video was placed on YouTube and has so far received over 1,000 views (Monteath & Powys, 2014).

The response to the video has been outstanding, and we believe material such as this contributes significantly to the growth and maturity of the industry. By adapting to new technology and promoting ourselves and the industry in a professional manner, we can continue to enhance the public’s perception of the surveying and spatial information industry as a whole.

Figure 12: Screenshot of YouTube video showing the breakwall (Monteath & Powys, 2014).

ACKNOWLEDGEMENTS

Special mention must be made to Airsight Australia who we have formed a close relationship with to operate the UAV. By using Airsight Australia as the chief operating pilot, we have access to a range of UAVs for different purposes. We now have internal staff members trained in the operation of the UAV camera and form a combined team with the pilot from Airsight Australia. This relationship has allowed us to provide clients with a full range of UAV options, and not just a single limited-use UAV.

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