Observations From The Design, Construction And Drone Monitoring Of A Geotextile Sand Container (GSC) Seawall

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Abstract
The coastline of the Central Coast Council (Council) region located north of Sydney is a highly valued asset as it supports significant economic activity. In mid-2015 following a major storm event, Council identified that coastal erosion was causing an immediate hazard to The Esplanade despite substantial beach scraping. The Esplanade was deemed to be at imminent threat of collapse into the ocean which necessitated the closure of this beachfront road. The Water Research Laboratory (WRL) of UNSW Sydney proposed the design of an interim geotextile sand container (GSC) seawall to mitigate further erosion which is outlined in this paper along with details of its construction. Ongoing monitoring, using UAS (unmanned aerial system or drone) surveying provided a cost-effective monitoring solution and allowed for coastal engineering analysis of sediment transport in the vicinity of the seawall. Based on visual observations and analysis of the data, the seawall combined with beach scraping has thus far been successful at managing the risk of the road being undermined. However, the underlying natural tendency for erosion at this site may continue which could require additional coastal engineering works.

Keywords: Coastal structures, Geotextile Sand Containers (GSC), monitoring, UAS surveying, drone

1. Introduction
The coastline of the Central Coast Council (Council) region located north of Sydney is a highly valued asset to the community supporting significant economic activity. However, the infrastructure associated with this asset is particularly difficult to manage due to extensive growth in the region, a history of severe coastal erosion and the threat of sea level rise projections. To manage erosion along the Ettalong Point foreshore, Council is considering the following coastal management options under the draft coastal zone management plan [20]:

- Undertake various beach works as needed including beach scraping and dune reconstruction following storm events;
- Undertake erosion protection works fronting The Esplanade at Ettalong Point in the short term; and
- Investigation into the feasibility of long term beach nourishment to create a buffer against storm erosion.

In mid-2015 following a major storm event, Council identified coastal erosion was causing an immediate threat to The Esplanade despite substantial beach scraping (Figure 1 and Figure 4). The Esplanade was deemed to be at imminent threat of collapse into the ocean and this necessitated the closure of this beachfront road. The Water Research Laboratory (WRL) of UNSW Sydney proposed the design of an interim geotextile sand container (GSC) seawall to mitigate further erosion. This paper presents the design of this seawall followed by details of its construction. Ongoing monitoring, using UAS (unmanned aerial system or drone) derived photogrammetry provided a cost-effective solution for rapid and accurate sampling of the coastal zone. Analysis of the data is also provided by erosion intensity maps, beach volume calculation and movement of the 1.5 m contour. Finally, commentary is provided on the effectiveness of the stabilising works at Ettalong Point.

2. Site Location
Ocean Beach and Ettalong Point is at the mouth of the Brisbane Water estuary which is located approximately 50 km north of Sydney on the NSW Central Coast (Figure 1). This site is in a semi-open coast location which is most exposed to wave energy from the south-south-east. The area has a recorded history of erosion and subsequent coastal management works dating back to the 1940s [17]. The site is dynamic and is more complex than typical embayed beaches due to:

- Extensive sand shoals offshore;
- Tidal and flood flows to/from Brisbane Water;
- Longshore currents, rips and migrating shoals and gutters from Ocean Beach; and
- Several groynes are between Ettalong Point and Ettalong.

The development of substantial shoals immediately offshore of the site significantly dissipates incident wave energy (Figure 1) but also reduces navigability of the channel into the estuary. While dredging of the entrance channel and offshore shoals appears to be an obvious source for nourishment material in line with

Council's long term erosion mitigation strategy, this entrance shoal is one of the best and most iconic surf breaks in NSW. As a result of these complexities, interim stabilisation of the Ettalong foreshore to allow the road to be reopened was required until a source of suitable nourishment material is identified.

3. GSC Seawall Design

Design wave and water level conditions used for design of the GSC seawall are summarised in Table 1.

3.1 Design Life

Explicit guidance is not readily available for selection of an appropriate design event for a maritime structures equivalent to a GSC seawall. Conventional coastal engineering practice in Australia is to allocate a design ARI ranging from the design life of the project up to that suggested in AS 4997-2005. While AS 4997-2005 specifically excludes the design of "flexible coastal engineering structures such as rock armoured walls etc.", in the absence of any other relevant Australian Standard, it is commonly used for guidance in the contemporary design of coastal structures. By defining the GSC seawall as temporary works and considering it to be "Function Category 1 – Structures presenting a low degree of hazard to life or property", a design life of 5 years and a design ARI of 20 years were adopted.

3.2 Design Scour Level

A range of options are available to determine a design scour level including:

- Engineering "rules of thumb";
- Erosion modelling;
- Published data on profile change i.e. [9], [4]
- Allowances using a Dean equilibrium profile [6].

In NSW, the scour level of -1.0 m AHD is commonly adopted as an engineering rule of thumb for rigid coastal structures located at the back of the active beach area. This is based on stratigraphic evidence of historical scour levels and scour occurring during major storms in front of existing seawalls along the NSW coast [15]; [8]. A design scour level of -1 m AHD was adopted for this design combined with the use of a three container wide toe meaning the structure will withstand slightly more than the design scour. The justifications for this level are [3]:

- The 5 year initial design life;
- It is in line with the rule of thumb for NSW;
- It is much lower than many historical structures in NSW;
- There is no net long term recession at Ocean Beach [20].

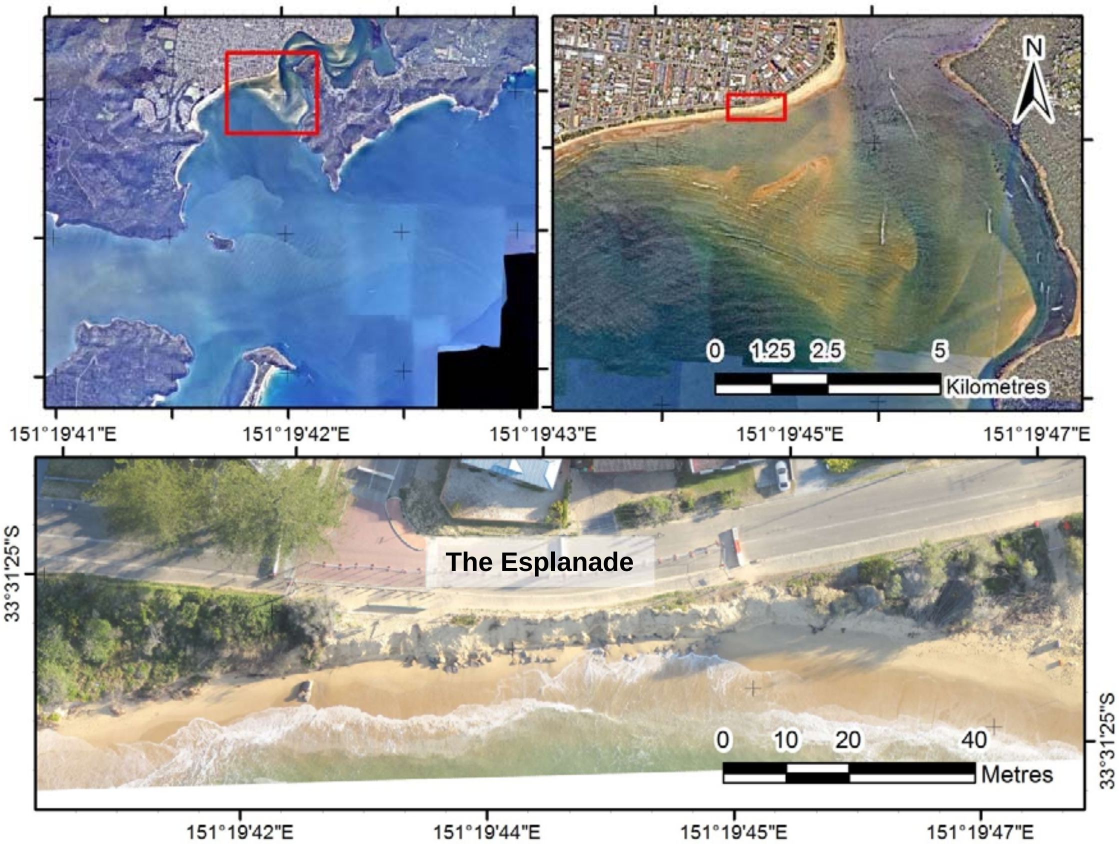

Figure 1 Clockwise from top left: site location showing semi-protected orientation with exposure to swell from the south east, Ettalong Point and the Brisbane Water estuary shoal, UAS-derived orthomoasic taken on 14th August 2015 showing proximity of erosion scarp to The Esplanade before construction of the GSC seawall.

3.3 Nearshore Wave Heights

Depth limited nearshore significant wave heights were estimated with an inner nearshore sand slope of 1V:20H [10]. It was found that breaker indices and wave height at the structure did not change substantially due to a depth limitation for wave periods of 10 and 15 s. Estimated depth limited wave heights for a range of bed elevations are shown in Table 1 based on inputs from Table 2.

3.4 Container Stability

Due to the depth limited nature of waves at the structure and the substantial protection provided by the ebb tide shoal, waves at the structure are much smaller than offshore. Physical model testing indicates that the 2.5 m^3 geotextile containers (double layer a slope of 1V:1.5H) are stable (less than 2% of units displaced) up to the following significant wave heights at the structure [2]:

- 1.8 m for 10 s Tp waves;
- 1.5 m for 15 s Tp waves.

These wave heights would be the threshold of "initial damage" (2% of units displaced), but not failure. By combining Table 1 with the above, the containers would be stable (<2% damage) under depth limited waves if the following bed levels can be retained:

- -1.0 m AHD: stable up to ~10 year ARI;
- -0.5 m AHD: stable <100 year ARI; and
- 0.0 m AHD: stable >100 year ARI.

Table 1: Nearshore Hs at Structure

Bed level (m AHD)	Nearshore Hs at Structure (m)		
	1 ARI	10 ARI	100 ARI
-1.0	1.7	1.8	1.9
-0.5	1.4	1.6	1.7
0.0	1.1	1.2	1.3

3.5 Adopted Design

Based on geotechnical constraints, it was deemed that the structure (down to the -1 m AHD footing) should not be located within a 30° slope from the edge of the footpath/cycleway [11]. This resulted in a structure with the cross section shown in Figure 2. The main elements of the design are:

- Founded at -1 m AHD;
- Crest at +4 m AHD;
- Slope 1V:1.5H;
- Two layers of 2.5 m^3 containers; and
- Vandal deterrent fabric on the outer layer.

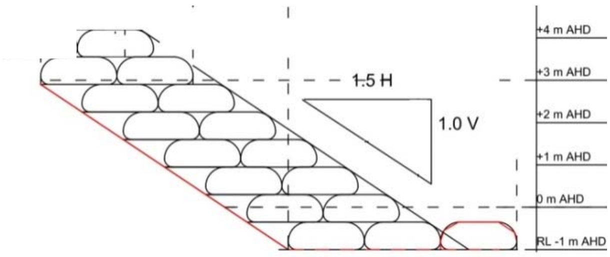

Figure 2: GSC Seawall Design Cross Section

4. GSC Seawall Construction

The 100 m length of seawall was constructed by Council crews throughout October 2015 (Figure 4). The seawall was initially built to a height of 1 m AHD (3 courses high) to reduce potential wave overtopping during the construction period. Based on geotechnical advice, the excavated sand used to backfill behind the seawall was compacted to limit post construction settlement [11]. The total cost of construction was estimated to be $570,000 or $5,700 per lineal metre.

5. Monitoring Program

An emphasis was placed on ongoing monitoring of the GSC seawall due to its interim nature and the potential for adverse impacts to the adjacent beach. Monitoring of the structure by WRL is ongoing at regular intervals using UAS surveying and on-ground RTK-GPS. Surveys undertaken to date are summarised in Table 3. A monitoring checklist was also developed based on the Condition Index System [16] to allow Council staff to conduct more frequent inspections of the seawall and track its condition throughout time.

5.1 Wave Conditions During Monitoring

Wave data was sourced from the Sydney wave buoy which is owned by the Office of Heritage and operated by the Manly Hydraulics Laboratory.

Table 2: Design Conditions for GSC Seawall

Variable	Symbol	Unit	1 ARI	10 ARI	100 ARI	Reference / method
Still water level	SWL	m AHD	1.24	1.35	1.44	Interpolated from [20]
Offshore significant wave height	Hs SSE	m	6.4	7.7	9.3	Interpolated from [20]
Peak wave period	Tp	S	11.0	12.1	13.0	[18]
Wave transformation coefficient	K @6.5 m	-	0.44	0.44	0.44	[18]
Local breaking wave height	Hsb	m	2.8	3.4	3.6	Interpolated from [20]
Wave setup at shore	Setup	m	0.4	0.5	0.5	15% of Hsb
Setup water level	Setup WL	m AHD	1.7	1.9	2.0	15% of Hsb
Wave runup level on beach	R2%	m	3.1	3.4	4.0	[13]

Table 3: UAS survey monitoring dates

Survey descriptor	Date
Pre-construction	14th August 2015
Mid-construction	12th September 2015
Post-construction	3rd November 2015
3 month post-construction	25th February 2016
6 month post-construction	29th May 2016
Post East Coast Low (ECL) storm	29th June 2016
1 year post-construction	25th October 2016

Storm events where significant wave heights exceeded 4 m are shown in Table 4. Notably, this period includes the East Coast Low (ECL) storm event in June 2016 which had recorded significant wave heights of up to 6.5 m from the east. This combined with spring high tide water levels to allow large waves to propagate into usually sheltered areas of the coastline, however Ettalong Point is somewhat sheltered from this direction.

5.2 Ground based monitoring

RTK-GPS ground surveys were sampled in a continuous profile along the crest centreline to assess potential settlement or slumping. The data shows that the crest experienced settlement of approximately 0.05 - 0.1 m in the first three months following construction (Figure 3). The western half of the wall maintained its elevation between February 2016 and May 2016, while the eastern portion of the wall settled a further 0.05 m. The October 2016 survey shows a consistent total settlement of 0.2 m since construction. The cause of this settlement is difficult to ascertain. Possible causes are settlement of sand foundation due to the weight of the seawall, rotation along the slip plane of the structure, or most likely due to settlement of the sand within individual containers. This dataset provides a valuable insight into the settlement of GSC structures and the potential for

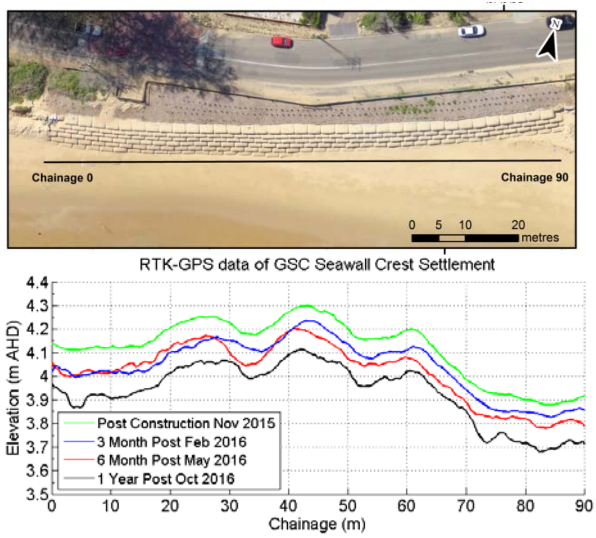

Figure 3: RTK-GPS data of Crest Settlement

reductions in performance to parameters such as wave runup. These preliminary results suggest that GSC seawall crest levels should be designed with a sufficient factor of safety to account for settlement over the design life of the structure. Site investigations also identified that exposed courses of geocontainers have slightly deformed by “tilting forwards” (Figure 5). This is likely caused by the redistribution of sand within individual containers under wave action. Minor deflation and localised slumping of geocontainers has also been observed which is attributed to vandalism.

5.3 UAS Monitoring

The use of UAS surveying as a survey tool has matured such that it is now routinely used to collect high quality datasets [7], [19]. WRL completed UAS surveys using a Sensefly eBee RTK which is an autonomous survey-grade drone that uses photogrammetry to provide elevation data.

Figure 4 Construction of the GSC seawall. Clockwise from top left: the erosion scarp in August 2015; placement of 2.5 m^3 containers using modified rock grab; aerial view of completed GSC seawall after 3 months in operation.

Table 4: H_s events exceeding 4 m during monitoring

Date	$H_{s,\ max}$ (m)	Direction
22nd October 2015	4.0	S
14th – 15th January 2016	4.1	ENE
4th February 2016	4.1	E
19th – 20th March 2016	4.6	S
5th - 6th June 2016	6.5	ENE

Figure 5: Evidence of minor deflation and "forward tilting" of geocontainers (photo taken 29th June 2016)

The accuracy of the UAS derived data used in this study is considered to have a nominal accuracy of +/- 7 cm which is more than adequate for analysis of beach volume change [19]. Surveys were conducted at low tide to maximise coverage of the beach profile which resulted in data generally extending to a minimum level of 1.0 m AHD.

6. Data Analysis

Erosion intensity maps were generated from the UAS data to examine elevation changes between surveys thereby identifying zones of accretion and erosion (Figure 6). Profile data was also extracted in the vicinity of the GSC seawall to further analyse sediment movement (Figure 7). These profiles were extrapolated down to the 0 m contour to enable calculation of the volume of sand above 0 m AHD using the dune schema described in [15] as well as examining the movement of the 1.5 m AHD contour.

6.1 Discussion

The erosion intensity maps and analysis of the vegetation line movement indicate that significant erosion occured at Ettalong prior to and following the construction of the seawall with the dune face eroding/receding up to 13 m in three months (Figure 6 A). There was a prolonged period of larger than average waves (in excess of 2.5 m) originating from a SSE direction at the end of August 2015 which likely caused this erosion.

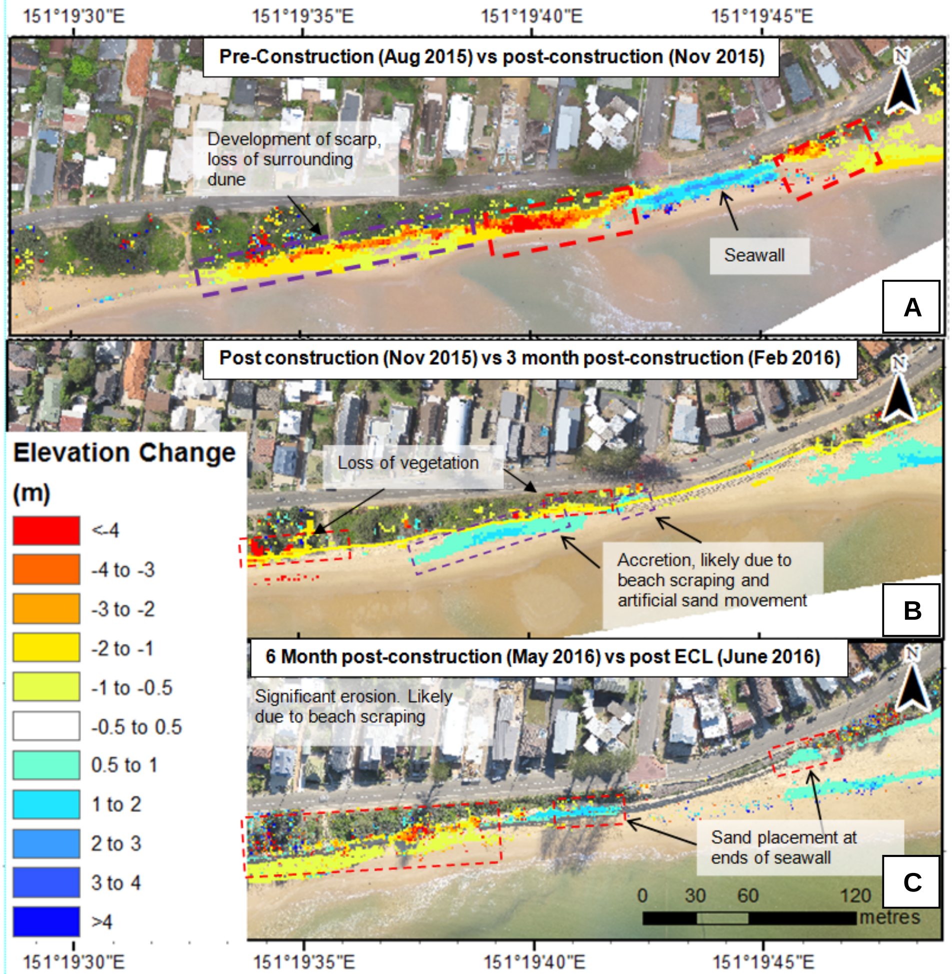

Figure 6: Erosion Intensity maps showing beach change between UAS surveys; pre-construction vs post-construction (top), post-construction vs 3 month post-construction (middle) and 6 month post-construction vs post ECL (bottom)

In the three months following the seawall construction (November 2015 to February 2016), erosion rates abated in the vicinity of the seawall (Figure 6 B). Sand accretion measured at the western end of the seawall during this period is attributed to beach scraping undertaken by Council. The minimal erosion in this period is likey due to the propensity for milder wave condition in NSW throughout summer months. While Ettalong is predominately exposed to waves from the SSE, the easterly waves produced by the June 2016 ECL storm event still caused moderate erosion at the site (Figure 6 C). In the 3 week period between the pre and post ECL storm survey, Council completed extensive beach scraping to mitigate the effects of the storm. Despite this, it is evident that the storm caused the vegetation line to recede by up to 7 m. During this period, Council also placed sand in the zones immediately west and east of the seawall to reduce the erosion end effects caused by the structure, which is also visible in Figure 6 C. Analysis of the available storm demand and movement of the 1.5 m contour data also yield interesting observations. Figure 7 indicates that the beach located to the east of the structure towards Ettalong Point (Profile 5 and Profile 6) has been accreting and widening since construction of the seawall. Approximately 1,500 m^3 of sand was harvested from this area to fill the geocontainers which is likely to be partially responsible for the observed volume loss between August and November 2015. Sand volumes at Profile 3 (immediately to the west of the seawall) have remained relatively stable since construction of the seawall which is likely attributed to Council's continued beach scraping efforts. Profile 2 located 75 m west of the seawall has generally eroded and narrowed throughout the survey period. Empirical relationships suggested by [14] indicate that Profile 2 is at the extreme western location where end effects from the seawall could impact upon sediment movement. Comparing the trends of recession and erosion for an additional profile located 150 m west of the seawall indicates a similar rate of recession and erosion. Based on this it is likely that the recession at Profile 2 is largely due to natural erosion and ongoing tendencies of the site, rather than directly caused by the seawall. Since the one year post construction survey in October 2016, sand has continued to accrete at the seawall such that five out of a total of eight courses of geocontainers have been buried.

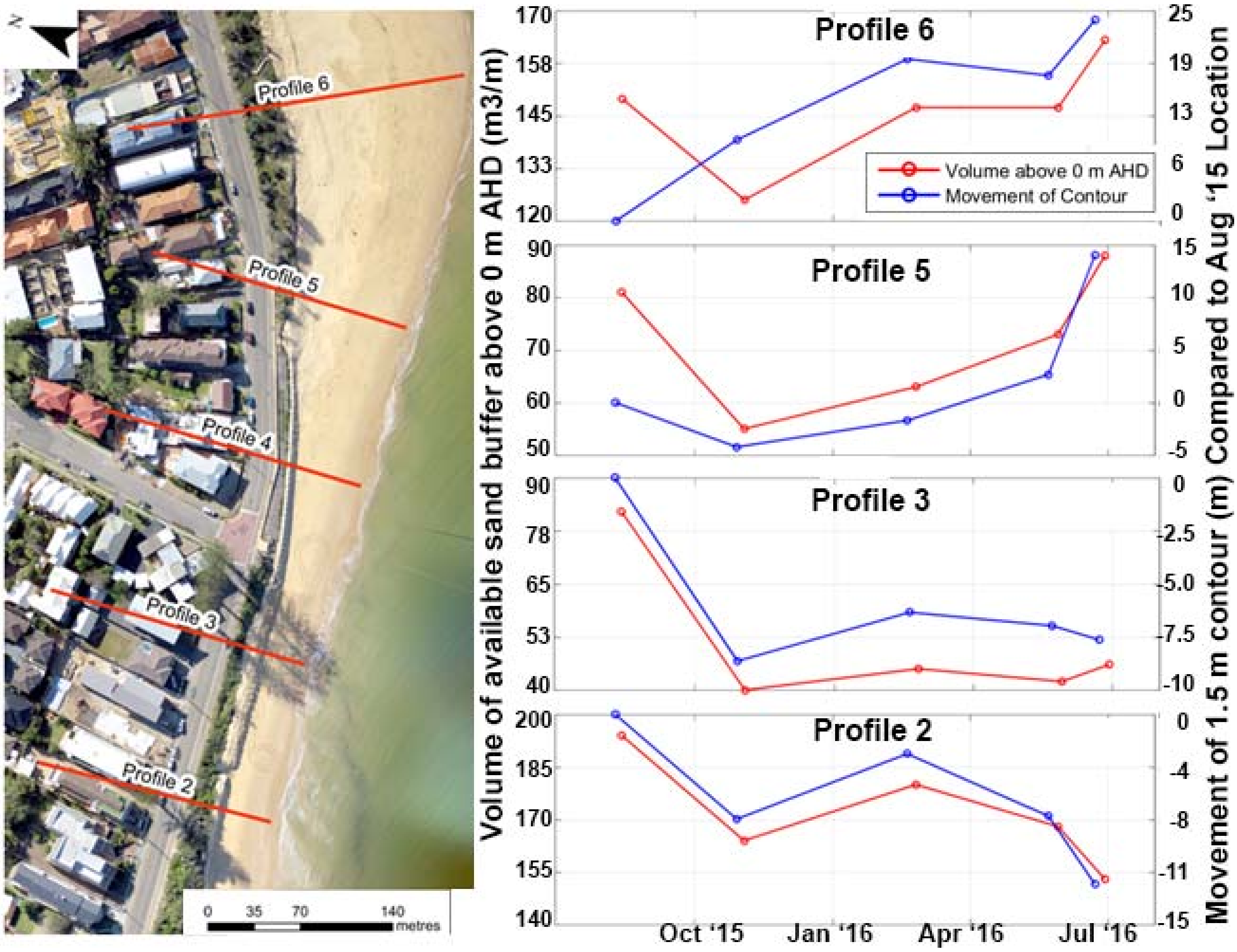

Figure 7: Analysis of volume about 0 m AHD and movement of 1.5 m contour for profiles in proximity to GSC seawall

6.2 Conclusions

This paper has presented an example of best practice design for a soft interim structure needed to prevent the loss of a road and allow it to be reopened. Based on visual observations and preliminary analysis of data from an ongoing UAS survey monitoring program, the seawall combined with beach scraping have thus far been successful at managing the risk of the road being undermined (Figure 8). However, the underlying natural tendency for erosion at this site may continue which could require additional coastal engineering works. Interesting observations of the seawall performance include the development of a "forward tilt" of the geocontainers and a settlement of 0.2 m in the first 12 months since construction. Both these phenomena are likely caused by the redistribution of sand within individual containers under wave action. Results indicate that is necessary to continue monitoring the performance of the structure and the adjacent beach in the short term until the long term coastal management strategy for the site is developed and implemented.

Figure 8: Photo of the CSG seawall looking west after one year in operation (Photo date:25/10/2016).

7. References

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