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Abstract: A 27-day field study was conducted to explore Retrogressive Breach Failures (RBF) at Amity Point, Queensland. Two events were documented over the course of the study, and videos and photographs were obtained of one event in progress. Beach profiles and recovering shoreline position were measured along with deployments of a simple penetrometer to obtain a proxy for surficial sand density. The sand appeared to be in a loose state prior to the second event, being controversial to theory of RBF. The recovering shoreline showed rapid accretion in the first 24-48 hours along with tidal erosion of the beach face. Wind speeds reached ~35 kilometers/hour out of the NNW on the day of each event, representing the only time these conditions were observed.

Introduction

Amity Point on North Stradbroke Island in Queensland, Australia features a sandy beach adjacent to a tidal channel (Rainbow Channel) that has been characterized by frequent and large volume erosion events for over 100 years (Figure 1). Beinssen et al. (2014) monitored the morphology and discussed the potential mechanisms behind the failures. They concluded that the failures represented a form of beach erosion known as a Retrogressive Breach Failure (RBF). RBF

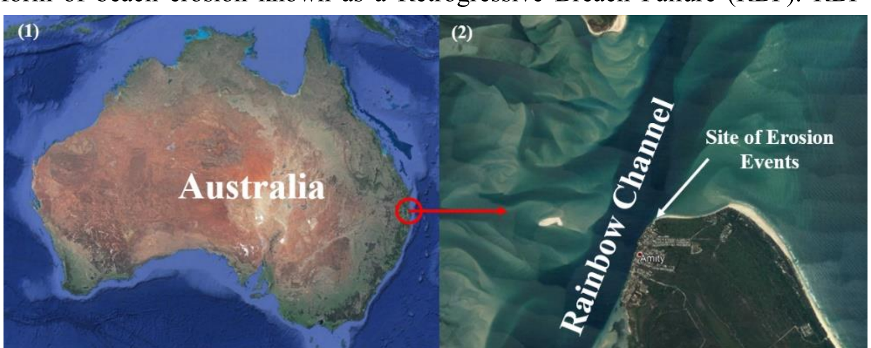

Figure 1: Site Location and Features (Source: Google Earth. 27°23'35.44"S and 153°26'24.32"E. (2): October 27, 2017, Accessed: May 28, 2018)

events are characterized by a near-vertical wall, retrograding onshore at a steady rate of approximately 0.8 meters per minute (Figure 2), leaving an amphitheater shaped scar (Van den Berg et al. 2002; Beinssen et al. 2014).

A number of site characteristics have been identified as typical for RBF events to occur. One of the most emphasized ones is sediment density. The sediment must be relatively densely packed, with void ratios less than 50%, as the dilative behavior of relatively densely packed soils governs the RBF process (You 2013, Beinssen et al. 2014). The combination of high density and low confining pressure leads to dilative response in soils (Duncan et al. 2015). For densely packed sands, the grains are in significant contact, and when shear is applied will either roll over each other or break. One factor determining particle translation versus breakage is the confining pressure in the soil mass. Under low confining pressure, the particles will roll over one another, increasing the pore volume (dilation), and decreasing the pore pressure. In the case of RBF events, the shear force on the vertical wall is gravity, and the low confining pressure on the grains allows dilation. Bolton (1986) reported that dilation can occur in soils with relative densities greater than 20%. Dilation decreases the pore pressure with respect to the adjacent hydrostatic pressure, and suction can hold the wall in place until the pore pressure differential dissipates (You 2013). This process can be repeated at different cross-shore locations, allowing the failure to progress onshore, and the

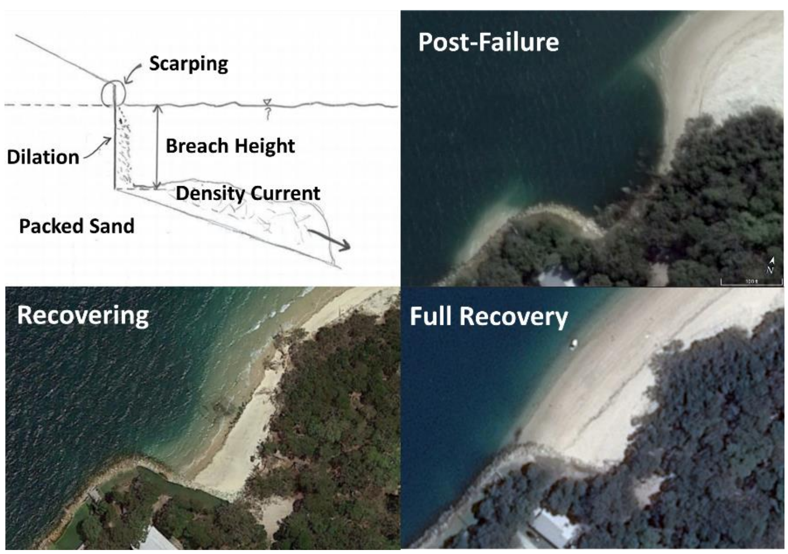

Figure 2: Mechanics or RBF Events (Top Left), Representative Beach States: Post-Failure (Top-Right), Recovering (Bottom-Left), Full Recovery (Bottom-Right). Google Earth Pro V 7.3.2.

vertical wall to retrograde (Beinssen et al. 2014). Note in Figure 2, dilation merely shows the location of the process, not the full mechanism.

Beinssen et al. (2014) documented more than 40 RBF events over a 20-month period at Amity Point. Grain size analysis was performed on samples, documenting a fine sand with a median grain size of 150-250 µm, which matched characteristics of sediments from other RBF sites (Beinssen et al. 2014). Post-event, the initial beach morphology is rebuilt rapidly, taking 24 hours to 4 weeks to rebuild the entire beach via longshore transport (Beinssen et al. 2014). Previous studies have aimed for the understanding of the mechanism of RBF events with emphasis on processes following the initiation of failure, based on both laboratory experiments (DeGroot et al. 2012, You 2013) and from field observations (Torrey 1995, Beinssen et al. 2014). However, the actual initiation of failure is still poorly understood, and rarely investigated. Masterbergen and Van den Berg (2003) suggested that RBF events could be initiated by the scarp of a small shear failure, and Beinssen et al. (2014) proposed, along with other events that disturb the sediment enough to produce failure, that small liquefaction events may be to blame. Liquefaction or fluidization of sediments in subtidal and intertidal environments have been associated to wave forcing, leading to the reorganization of particles and excess pore pressure build up (residual liquefaction), as well as to pressure gradients (momentary liquefaction), and internal flow processes (fluidization) (Turner and Nielsen 1997; Sumer 2014).

The current lack of in-situ data from Amity Point represents an additional difficulty regarding the identification of a specific type of subaqueous slope failure or failure trigger. Most importantly, no density profile of the beach is available at this point. This issue is significant, because the observed high sedimentation rate at the beach suggests a loosely packed soil mass, which is in stark contrast to the requirement for RBF events (Atigh and Byrne 2004). Beinssen et al. (2014) point out that the beach can support heavy machinery, and that poorly-graded sediments tend to pack densely, especially under the influence of waves. This may indicate a denser soil mass at the beach. However, the lack of in-situ density data prevents the proof of either theory.

To investigate the RBF events at Amity Point further, a field survey was carried out over a 27-day period in June/July of 2018. The goal of this study was to examine the role of soil bulk density. A simple penetrometer was designed to test local density variations at the site, and by doing so, to gain information about possible trigger mechanisms. Additionally, the site was monitored so that in the case of any events, the failure and recovery processes could be documented. This paper presents the data collected at the site, including the penetrometer results, beach profiles, and surveys completed to monitor the two observed RBF events.

Methods

Beach Profiles and Surveying

Two cross-shore transects were measured approximately every other day during the study (daily after RBF events), sampling at 1-5 meters per point depending on the necessary resolution. An engineering level and staff were used to measure the

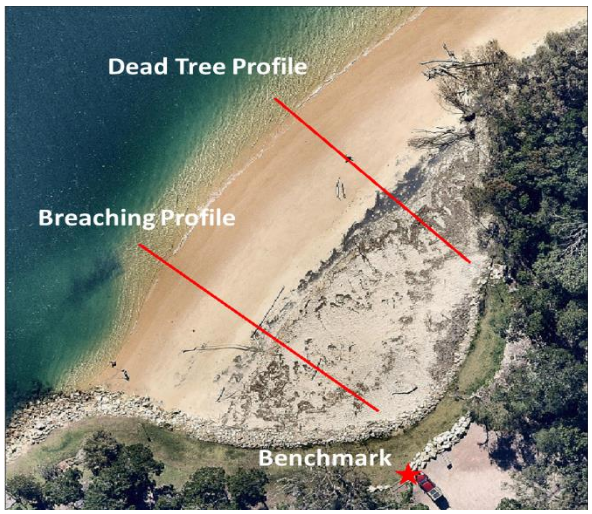

Figure 3: Survey Layout for Beach Profiles

profiles in relation to a benchmark at the site (Figure 3). Post-event, the edge of the sub-aerial beach was measured at low tide using a Total Station Instrument (TSI) to document the recovery.

Penetrometer

A simple penetrometer was devised using a sharpened speargun bolt. This rod was attached to a fishing line and reel and dropped from a kayak into the seabed, and more specifically, the channel slope (Figure 4). See Figure 6 for a map of

Figure 4: Penetrometer Setup

deployments. The penetrometer was 0.91 meters long, 4 millimeters in diameter, and had a mass of 359 grams. Coating the tip in a waterproof lubricant allowed to estimate the penetration depth, along with the GPS location for each drop. Experiments with Portable Free Fall Penetrometers have showed that penetration depth correlates well with sediment strength (Bilici et al. 2018). Assuming that the sediment within the study area represented the same type of sand with similar grain size distributions makes bulk density a key parameter controlling sediment strength and resistance (Duncan et al. 2015). Thus, changes in penetration depth can be related to changes in bulk density. Over 200 deployments were conducted, and sporadic water depths were measured using a portable echosounder (Deeper Smart Sonar Pro Fishfinder) when conditions allowed.

Results

Two RBF events (Event 1 & Event 2) occurred during the study period. Event 1, on July 6th, occurred while the research team was on site, which allowed for video recording, drone photographs, and erosion rate measurements to be taken. During this event, the beach retrograded at approximately 0.5 meters/minute and eroded approximately 200 square meters of beach. Event 2 occurred two weeks after the first, and eroded 300 square meters of the beach. This event happened over night, so only drone photographs were used to document the site (Figure 5).

Figure 5: Typical Pre-Failure (Left) and Failed (Right) Beach, Source: NearMap & Drone Imagery

Penetrometer Measurements

Figure 6 displays the deployments recorded in the first 4 days after Event 1 (Top), and in the 4 days before Event 2 (Bottom). Penetration depths ranged between 3.5-15 centimeters. Since the penetrometer was not calibrated, the data only serves as a qualitative measure of bulk density relative to other deployments during the study. A majority of the deployments right after the first event achieved small penetration depths (cooler colors), compared to right before the second event, when deeper penetration depths were reached (warmer colors). This shows that the penetrometer went deeper into the soil for these deployments, and that the slope was looser right before Event 2 than after Event 1.

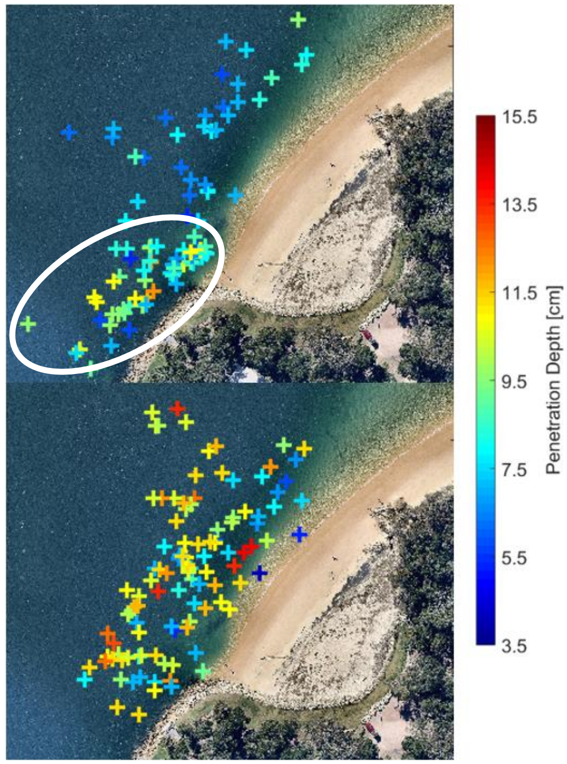

Figure 6: Penetrometer Drops Taken during the Recovery Stage (Top) July 7-11th, and the Stable Period (Bottom) July 14-19th, Area of Post-Failure Deposition is Circled

Post-Event Recovery

Following each event, the shoreline was measured daily using a TSI (Figure 7).

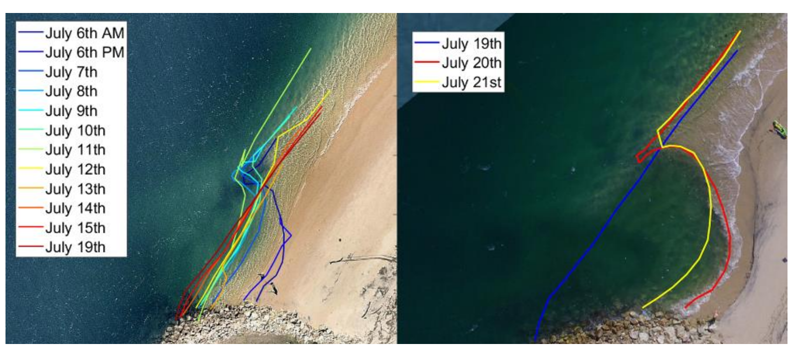

Figure 7: (Left) Event 1 Recovery Cycle, (Right) Event 2 Recovery Cycle

The shoreline recovered quickly in the first 24-48 hours post-event, after which the rate of accretion slowed until the original shoreline was restored. This process took around 5 days for the first event, and the position did not vary significantly for the remaining 9 days until the Event 2. The field study concluded two days after the Event 2, preventing more data acquisition on the second event's recovery.

Wind Observations

Wind speeds were also documented using data available from the Australian Government Bureau of Meteorology, measured on the Eastern side of the island, 10km from the site. It was noted from field observations that the predominant wind direction was strong out of the North-Northwest (NNW) on the day of each event. Further exploration of wind data from … over the study period showed that this was indeed the case: on both event days, the wind was blowing at ~35 kilometer/hour out of the NNW. Not only was the wind magnitude and direction

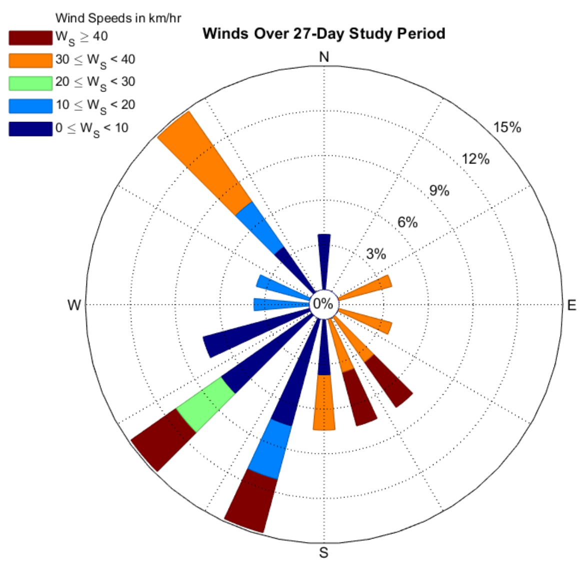

Figure 8: Wind Rose for Wind Speeds, Directions, and Frequency over the Study Period

the same on both days when an event occurred, but these were the only two days that this wind pattern was observed over the 27-day period (Figure 8).

Discussion

The 0.5 meters/minute observed erosion rate for Event 1 was slower than the 0.8 meters/minute value reported by Beinssen et al. (2014). Those authors examined over 40 events of varying erosion volumes and took an average of the erosion rates. While event observed here was smaller than the average suggested by Beinssen et al. (2014), it was within the reported 0.3 – 0.8 meters per minute reported range.

Penetrometer Measurements

It is important to note that since the penetrometer was not calibrated to any specific density or velocity considerations, any data can only be compared to other deployments within the study and is merely a qualitative measure. Nevertheless, the results (Figure 7) suggest that the sand became generally looser in the days leading up to Event 2, while being denser after Event 1. At this time, it is unknown what could cause this process to occur. DeGroot et al. (1988) showed that hydraulically placed fills tended to pack loosely on slopes. While this represents a different setting, similar processes may apply also for deposition from longshore transport. It would also explain why the area where sediments were deposited post failure appeared looser than the sediment in other areas of the channel (circled portion of top figure). However, Beinssen et al. 2014 stated that dense sand is required for RBF events. Furthermore, since penetrometer drops were not conducted before the first event, it remains unknown how loose or dense the sand mass was before the first event. The soil mass appeared generally denser after the first event, which would imply that the RBF event affects the soil on the entire surrounding channel slope, not just the failure area. The results highlight the complexity of sand reorganization, and thus, in situ bulk density variations at this site, and the need for more sophisticated equipment to accomplish this task. Since density is an important factor in RBF events, understanding the role of density at the Amity Point site will be a major point of future work. One possible pathway could be to deploy a more sophisticated free fall penetrometer with on-board sensors to explore in-situ density in more detail, following an approach as demonstrated by Albatal et al. (2019), for example.

Beach Recovery

Consistent with observations by Beinssen et al. (2014), the beach rebuilt rapidly after each event. Since the two observed RBF events were small compared to the entire beach area, they rebuilt in a matter of days. Beinssen et al. (2014) reported that the rapid rebuild is due to longshore transport. However, results from the current study show that this may not reflect the complete picture. After each event, beach profiles showed a distinct decrease in elevation of the entire beach face. Figure 9 details this change in topography for the day before (19-Jul) and day after (21-Jul) Event 2. Only the Breaching Profile (Figure 3) is shown for clarity, but this decrease in elevation was consistently observed across both profiles after both events.

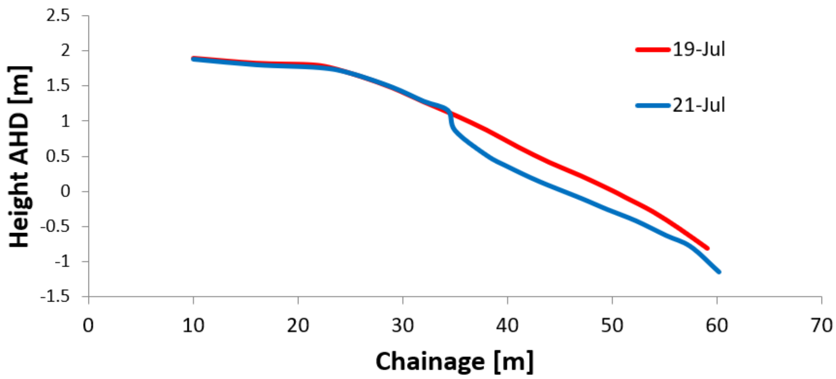

Figure 9: Profile Showing Topography Change Due to RBF Event

The decrease in elevation was around 0.3 meters along the breaching profile (closest to the event scar) and around 0.1 meters along dead tree profile. Using the known area of the beach face from drone imagery, it was estimated that approximately 100 cubic meters of sand eroded from the beach face in the first 24-48 hours after the event. Using drone photographs of the erosion scar, the TSI measurements of the recovering shoreline (Figure 7 – Right), and water depth measurements from the echosounder, the amount of accretion in the first 24-48 hours post-event was also estimated to be around 100 cubic meters of sand.

This result explains the rapid accretion seen initially after the event. Tides erode the upper portion of the beach face, and this sand fills the hole left behind. Once the initial erosion is finished, all that is left to fill the hole is longshore transport, which explains why the accretion slows after the first 2 days.

Wind Observation

Perhaps the most important finding of the study came from observation of the wind. Wind measurements were not originally planned, but once noticed, it became clear that the wind was an important factor for both events. Strong winds of ~35 kilometers/hour out of the NNW were observed and documented on the days of both events and on no other day during the study (Figure 8). This raised an important question regarding the role of the wind during RBF events at Amity Point.

Due to the predominant longshore transport direction (Figure 10), sand that is not deposited on the channel slope at the site is deposited in the channel and moved away by the tidal currents. The site is well protected from waves, as the

Figure 10: Wind and Transport Direction at the Site

predominant wave direction from sea swell is on the other side of the island to the Southeast. However, on days when the wind is strong out of the NNW, the wind points directly at the beach, increasing the height of the waves, and encouraging more transport and deposition onto the channel slope at the site. This increased transport could over steepen or overload the slope, causing a shear failure similar to that proposed by Masterbergen and Van der Berg 2003. Also, the increased waves could induce liquefaction processes (Turner and Nielsen 1997; Sumer 2014).

These proposed mechanisms are purely speculated and will require further research/testing. Still, finding that the wind direction is a constant factor in two observed events is an important step, and gives future researchers a starting point.

Conclusion

This paper presents the results of a 27-day field experiment conducted to study RBF events at Amity Point, Queensland. Researchers observed two events during the study and made daily measurements to document the behavior of the site before, during, and after the events. Results showed that a simple penetrometer provides a purely qualitative measure of apparent soil density. Nevertheless, the data suggest that the sediment was relatively loosely packed preceding an event, a mechanism that will be an area of future research. Initial accretion in failure zone appears to be driven by tidal erosion of the beach face in the first 24-hours. Finally, wind was ~35 kilometers/hour out of the NNW on the day of both events, and these were the only times during the study that these wind conditions were observed. The findings of this study have given researchers more specific questions to answer about the processes that trigger RBF events, added to the knowledge base of how RBF events work, and discovered possible reasons for events to occur that had not yet been noted.

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