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Retrogressive Breach Failure Events at Amity Point, Australia and their Interaction with Built Defences

Konrad Beinssen and David T. Neil
School of Geography, Planning and Environmental Management, The University of Queensland St. Lucia, Queensland, Australia

ABSTRACT

A category of mass sediment transport in certain river and coastal settings is that of 'retrogressive breach failure' (RBF). Sand is carried away in a turbulent density current generated by the momentum of sand grains cascading off the face of a retrogressing, subaqueous near vertical wall of sand called a 'breach'. If such events retrogress onto the shoreline, they can cause serious damage to beaches, banks and manmade erosion defences. While a great deal of research effort has been applied to understanding the geotechnical nature of such events, particularly in the United States and the Netherlands, we have found that this mechanism of sediment transport is generally not well known to coastal scientists and engineers in Australia. This paper describes a site at Amity Point in Eastern Australia where successive RBF events have played a major role in coastal recession. Measures taken to stabilise the coast are described. The site serves as an unusual case study in coastal management.

KEY WORDS: Retrogressive breach; dilation; density current; erosion; sediment transport; seawall stability; channel slumping.

INTRODUCTION

Shoreline erosion has been an ongoing problem over many decades for the residents of the small village of Amity Point on Australia's east coast. Two quite distinct sediment transport mechanisms have driven this recession.

The first is the well recognised storm/calm weather cycle which removes sand from the beach to an offshore bar during large wave and high tide events and moves it onshore again during calm weather. In this mechanism, the energy which moves sand comes largely from the kinetic energy of wind, waves and currents. This mechanism plays a significant role at Amity Point, on both the ocean and estuary sides of the peninsula but will not be further discussed here.

The second mechanism is that of successive 'retrogressive breach failures' (RBF's) along the margins of a tidal channel which runs close to the Amity Point shoreline for about 1.5 kms (Fig. 1). These intermittent events are driven largely by gravitational potential energy and cause the rapid relocation of large quantities of sediment from the channel margins into deeper water by way of short lived density (turbidity) currents carrying entrained sand. These currents are generated by the momentum of sand cascading off a near vertical subaqueous retrogressing wall of sand called a 'breach'. The geotechnical nature of breaching has been described from flume tank experiments (Yao You, 2013; de Groot, Lindenberg, Mastbergen, van den Ham, 2012) and field observations made mainly in the lower Mississippi River (Torrey, 1995) and the Netherlands (Sylvis and de Groot, 1995).

Beinssen, Neil and Mastbergen (2014) describe observations of RBF events at Amity Point. Sequential events over many decades caused shoreline recession in the absence of defensive structures. Shoreline property owners have taken action to protect their land by progressively building a boulder mound seawall. This has been successful in preventing further coastal recession over the last 30 years. However, under conditions where the seawall foundations are shallower than the base of a retrogressing breach, the foundations are undermined and the seawall slumps or collapses. Building the seawall is an iterative process as each undermining moves the foundations deeper and extra rock is added to the top. Thus the wall has become progressively more stable over time.

The aim of this paper is to describe the unusual case history of Amity Point. First, coastal recession by the mechanism of successive RBF events along a tidal channel is unusual. Second, the fact that landholders (public and private) have individually taken on the task of coastal defence which has led to a collective solution, is unusual. Several incorrect hypotheses have been proposed to explain the observed erosion events and these will be discussed. It is hoped that this paper will contribute to a better understanding of erosion mechanisms and hence to more effective erosion management at this site.

BACKGROUND TO THE PROBLEM AT AMITY POINT

Site Location The coastal village of Amity Point is located on the NW tip of North Stradbroke Island on Australia's east coast (27^0 23' 35" S, 153^0 26' 23" E) as shown in Fig. 1.

Fig. 1:. Amity Point study location.

Site Description The isolated village is built on a low strand plain at the southern end of South Passage Inlet, a typical tidal entrance which connects the Tasman Sea to a wide shallow body of water (Moreton Bay). The entire spit consists of erodible, non-cohesive fine silica sand laid down in the Holocene to a depth of at least 5m below the water table. Indurated sand has not been found anywhere on the spit during investigations associated with this study.

Today, the village consists of about 320 houses, a coastal caravan park and other infrastructure. It has a population of about 350 residents; considerably more during holiday times. The vulnerable land which directly fronts onto the channel is both privately and publicly owned (about 50% each). There are 26 blocks of private land with a combined value of about $A30 million so the cost of defense is considered justified by owners.
RBF events occur along the 1.5 km strip of coastline adjacent to the tidal channel which has a thalweg up to 22 m deep about 300 m offshore.

Problem Definition Coastal recession is of little consequence to humans if property or infrastructure is not threatened. However, where past uninformed decisions have been made to place infrastructure or privatise land too close to a receding coast, technical, financial and legal problems will eventually arise. Such 'legacy issues' must then be dealt with on a case-by-case basis and very often in a legal environment.

At Amity Point, land was subdivided by the Queensland State Government in 1886, to create a new township and as a way of raising revenue. Leasehold land was sold at a public auction and this land was later converted to freehold. Initially, a 40 to 80m wide esplanade of public land separated auctioned land from the coast. Over time, without action to defend it, this esplanade has eroded. The coast inevitably reached and eroded into private property, public roads and recreational parks. Foreshore property owners (public and private alike) then faced a stark choice; defend against channel encroachment or lose the land.

Dean and Dalrymple (2002) state; '*Seawalls are controversial. The statement has been made that 'seawalls cause erosion'. However, seawalls are almost only built on eroding shorelines, and thus the converse of the statement is definitely true; erosion can cause seawalls'!* Such is the case at Amity Point.

A seawall has been progressively and opportunistically (after RBF events) built and maintained over thirty years. Property owners have each paid for seawall construction in front of their land. In section, the wall is a pyramid shaped boulder mound and has been built from the upland side by tipping boulders from a truck.

The mechanism of coastal recession by sequential RBF events was not understood for many years. In the absence of this knowledge many incorrect hypotheses have been proposed. Incorrect dogma has developed and still influences coastal planning decisions. These misconceptions need to be corrected if management is to have a sound process basis.

Summary of the Geomechanics of RBF Events The geomechanical nature of RBF events at Amity Point has been comprehensively described in Beinssen, Neil and Mastbergen (2014) and is briefly summarized below.

When medium to densely packed (dilatant) fine sand exists on a subaqueous slope, it is potentially unstable and vulnerable to a failure mechanism termed 'retrogressive breach failure' (RBF). This failure can be initiated by a small triggering event which creates a small scarp on the subaqueous sandy slope and which then sets a positive feedback erosion event in motion. The momentum of sand falling off the vertical face of the scarp generates a sand/water density current which flows downslope and transports entrained sand into deeper water offshore.

The vertical face of the subaqueous wall of sand (the breach) can remain dynamically stable via a geotechnical property of sand known as 'dilation'. A shear force close to the breach, generated by the sand wall's tendency to collapse under gravity, causes the grain structure to 'dilate' (the void ratio to increase). This creates an under-pressure in the pore water (relative to surrounding hydrostatic pressure) which temporally 'sucks' the grains together and stabilises the wall as it retrogresses upslope from its starting point.

As the breach continues upslope, its wall height will increase if the event's runout angle is less than the slope angle of the seabed. A growing wall height will increase the momentum of the event and this will enhance scouring at the base of the wall and hence further reduce the runout angle, leading to an even greater wall height. Positive feedback (ignitive growth) increases the event's vigor (de Groot and Mastbergen, 2006).

As the wall height grows, events at Amity Point usually develop into 'dual mode failure' where the failure mechanism switches back and forth between breaching and sliding (Yao You, 2013). Dual mode greatly increases the rate of sediment release and so boosts the density current. Such events are particularly vigorous with a wall height of up to 7m and a retrogression rate of 0.8m per minute.

After each RBF event finishes, it leaves behind a characteristic 'amphitheatre' shaped morphology at its upslope end including a 'choke' which concentrates the density current during the active phase. At its lower end, a long tongue or fan of sand is deposited downslope and offshore as the density current loses momentum and its entrained sand settles. This 'signature' morphology can be used to identify RBF sites after the active phase has ended and before sand infilling.

METHODS

Background information RBF events can occur anywhere along the 1.5 km margin of the tidal channel at Amity Point. In particular, it was known that frequent erosion events occurred at the beach at the northern end of the Amity Point seawall (Fig. 1). A program to systematically monitor the beach here was started on 1st July 2012 and continued for 26 months to 31st August 2014.

Field Methods The beach at the study site was sketched in plan, videoed and photographed almost daily during the study period.

When an active RBF event was noticed by residents living at the site, the first author was called to video and measure its progress. Events which were not observed in the 'active phase', could be subsequently identified because all leave behind an amphitheatre shaped geomorphic 'signature'. In this way, every event which reached the bank at the site over the 26 months was identified and recorded.

Periodic bathymetric scans were made using a Lowrance HDS 10 plotter/sounder and DrDepth computer package to draw maps to show the underwater morphology of selected RBF events.

Daily rainfall was measured using a standard rain guage and tide data recorded using a pressure logger installed near the site.

Regular surveys to assess the stability of the boulder mound seawall were conducted. The survey points were marked with numbered tags epoxy glued to rocks along the crest of the wall to identify where the survey staff was to be placed at each survey. Levels were measured relative to a number of stable reference points further inland. The instrument used was a GeoMax ZDL 700 digital auto level.

The level of 82 points on the crest of the seawall along its 800m length were monitored between August 2012 and September 2014; a maximum period of 774 days between first and last surveys. The average vertical movement per year of each point was calculated using the first and last level measurements for that point and the results were then pooled.

RESULTS OF FIELD OBSERVATIONS AT AMITY POINT

Beinssen, Neil and Mastbergen (2014) describe field observations of RBF events made at the Amity Point study site. The following points add to those already reported.

Every event which occurred at the study site (Fig. 1) over 26 months from July 2012 to August 2014 was recorded. In that period, 52 RBF events occurred; one each 14 days on average. Of these events, 21 could be accurately timed so that a tidal direction could be assigned. Of these 21, 15 occurred on the flood tide and 6 on the ebb tide, which represents a significant difference (chi squared p=0.036).

Of the 52 recorded events, 48 reached the rock wall but none of these destabilised it. However, after some of these events more rocks were added to re-enforce or extend the wall.

The mechanism which triggers RBF events is still not well understood and requires further research. Sylvis and de Groot (1995) state that, '*there will always be a initiation mechanism: a sudden, local change in water pressure due to waves from a passing ship or a wind wave, an increase in outflowing groundwater during an extreme low tide, a quickly changing soil pressure due to a local shear failure or due to dredging activities, vibrations caused by pile driving, and so on*'. They suggest there may be multiple trigger mechanisms.

The data set was analysed using linear regression to examine the effect of both tidal velocity and rainfall on the occurrence (triggering) of events. First, frequency and magnitude of events (response variables) in relation to lunar cycle (as a proxy for tidal velocity) were tested. The explanatory variable used was the number of days from the date of each event to the date of the closest spring tide. The results indicate that tidal velocity is not a predictor of either frequency (R^2=0.07, p=0.53) or magnitude of events (R^2=8E-4, p=0.403). Second, frequency and magnitude of events in relation to rainfall in the three days before the event were tested. Again, the results showed that rainfall is not a predictor of either frequency (R^2=0.55, p=0.09) or magnitude (R^2=2E-5, p=0.97) of events. We conclude that neither tidal velocity or rainfall (within the range of the 52 recorded events) trigger RBF events at this site.

We tested the relationship between the magnitude of events (measured planform area at termination) and number of days to the following event. Magnitude of events was positively related to the number of days to the next event (R^2=0.42, p=9.6E-8), explaining 42% of the variability in the dataset (Fig. 2). This indicates that the larger the event, the longer it takes to rebuild the beach with sand brought to the site in the longshore current to set the conditions for the next event to be triggered. Beach infilling is a function of the rate of sand delivery to the site and time.

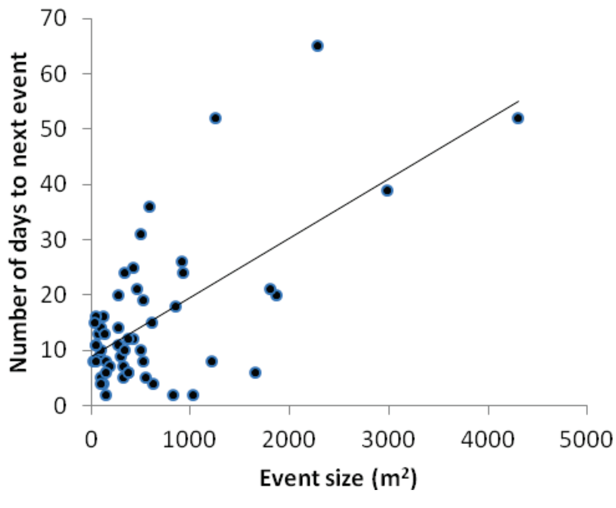

Fig: 2: Regression of event size (explanatory variable) by days to the next event (response variable) for the study site at Amity Point.

The active phase of each event ends when the density current carrying the entrained sand loses momentum so that sand cascading off the breaching wall settles closer to the base of the wall and the natural maximum angle of repose of the subaqueous sand (about 30 to 35 degrees) is established. Two factors help to explain how events abruptly end. First, at the study site events often slow to single mode failure (Yao You, 2013) as they retrogress up the beach into more densely packed sand and this reduces the release of sand from the breach and hence the momentum of the density current. Second, the sand wall height decreases as the relatively flat beach is encountered and the runout angle of the RBF event becomes larger than the inclination angle of the beach. This acts to progressively decrease the sand wall height and hence the rate at which sand is released into the density current.

Recognizing RBF Sites Active RBF events start unpredictably, are short lived and occur underwater so they have rarely been witnessed by scientists. However, because they leave behind such characteristic morphologies, RBF sites can often be identified from remote imagery in clear water conditions, bathymetric scans or by direct observation from the shore. Some examples are shown below.

An image (Google Earth) acquired 18.8.2014 shows an RBF site at Amity Point (Fig.3) which was witnessed and monitored in the field on the previous day starting at 11pm. This event encountered the seawall but did not undermine its foundations so the wall remained stable. The event's active phase lasted about 1.5 hours. The typical post-event 'amphitheatre' morphology is evident. Sand infilling by longshore drift from NE at this site is rapid and in this case, the pre-event beach profile was restored within a month.

Fig. 3: Image (Google Earth) of an RBF 'scar' at the Amity Point study site. Note the pre-event line of beach.

Another image (Google Earth) aquired on 17.10.2004 shows an RBF site at Amity Point at $27^0$24'12.49"S, $153^0$26'11.93"E (Fig. 4). The date on which this event occurred is unknown. Note that the event occurred between two groynes but did not impact the subaerial beach. This site can still be identified on Google Earth images over 10 years later because longshore drift carrying sand is minimal here so sand infilling is slow.

Many similar sites can been identified on satellite images in eastern Australia.

A bathymetric scan recorded at the study site on 18.10.2014 about 17 hours after an RBF event (Fig. 5) shows the typical morphology on the upper beach and also the tongue of sand deposited offshore by the density current.

Fig. 4: Site of an RBF event between groynes at Amity Point.

An image acquired at the study site on 6.5.2008 about 8 hours after an RBF event (Fig. 6) shows the typical post-event 'amphitheatre' morphology at ground level. The pre-event height of the beach can be seen by the line of sand still adhering to the seawall.

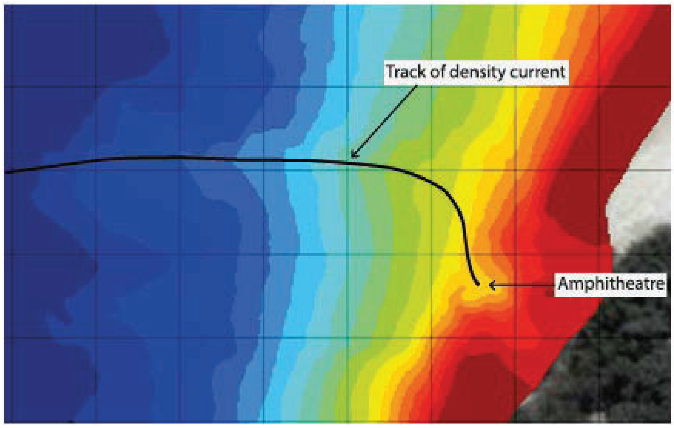

Fig. 5: Bathymetric scan following an RBF event at the Amity Point study site. Grid lines are 40m apart.

Alternative Hypotheses to Explain Erosion Mechanisms While 'channel slumping' has been identified as causing erosion at Amity Point, its geotechnical nature has only recently been recognised (Beinssen, Neil and Mastbergen, 2014). RBF events now scientifically explain all field observations. Other explanations which have been put forward over many years are described below.

1. Tidal current induced bank erosion. The most often quoted explanation for the observed 'channel slumping' events comes from correspondence of the Beach Protection Authority, the Government agency responsible for erosion planning in Queensland between 1968 and 2003. In a letter to Redland City Council the BPA states *'the cause of the slumps are the tidal currents which undermine the steep nearshore batter of the adjacent Rainbow Channel'*. Channel margin collapses were diagnosed as shear failures of an over-steepened bank caused by tidal current erosion.

Fig. 6: The study site at Amity Point, viewed towards the South, showing the post-event morphology of an RBF.

Related to the above, is the interpretation that the built seawall is not smoothly aligned and hence the laminar tidal flow in the channel causes eddies along the channel margins which 'auger' out sand and collapse the seawall. This does not account for the fact that erosion events frequently occur at times when there is little or no tidal current.

2. Collapse of indurated sand strata. A privately commissioned engineering report of a seawall collapse which happened in calm conditions in 1989 proposes that the wall has been built on a shelf of indurated sand which was progressively undermined by tidal currents and suddenly collapsed; in other words a shear failure. The report states; *'A possible explanation of the collapse is the presence of a layer or layers of indurated (cemented) sand which supports the seawall rock in front of the Chadwick property (site of the event). The tidal flows continued to attempt to erode the shoreline which resulted in the undermining of the indurated sand shelf. At some stage the extent of undermining was such that the indurated sand shelf could no longer support the rock above it and it collapsed'*. This hypothesis also proposes a form of shear failure and has led to decades of unhelpful speculation that caves may exist under indurated sand and that houses built close to the seawall could crash vertically through at any time.

A search for indurated sand at this site was conducted during the present study. A bore was put down to a depth of 11 m (7 m below the water table) and unconsolidated sand only was encountered to that depth. No indurated sand was found.

3. Hyper-compaction of sand. A geotechnical report from 1999 puts forward the hypothesis that hyper-compaction of sand on the upland side of the seawall causes the failure. This report quotes; '*your problem is the hyper-compacted organo-sand, which is an old layer of sand and organic debris which has been compacted to a state of fragility by the passage of very heavy vehicles over a period of time. This is dangerous and is the probable cause of the last (erosion) event, in that this hypercompaction allows for sudden shear of a face with rapid and massive slump'*. Once again, a form of shear failure was diagnosed, in this case with a 'slip surface' on the upland side of the seawall.

4. Groundwater outflow under the seawall. The first author of this paper speculated that 'piping' of groundwater outflow (submarine groundwater discharge) either from the freshwater aquifer or caused by tidal drawdown (or both together) might undermine the seawall and cause the observed events. Investigations began by setting up a series of experiments to study the dynamics of the water table adjacent to the seawall. It was during this study that retrogressive breaching was discovered in the scientific literature as the explanation for the field observations.

All the above speculative hypotheses are incorrect. They have distracted the coastal planning process and should all now be acknowledged as incorrect and discarded.

BUILT EROSION DEFENCES AT AMITY POINT

History Early attempts to stabilise the coast involved the local community, with encouragement from Government, building wooden groynes, placing car bodies at the sites of events and even placing an old vessel on the beach to act as a groyne.

In the 1970's, rock from a local quarry became available. Ten shore-normal rock groynes were constructed by both Government contractors and local community labour and funded both privately and by way of Government grants. Three of these groynes still exist today and these were upgraded by Government in 2010 by adding more rock.

Silvis and de Groot (1995) report that a technique called the 'fixed point method' of groynes was tried in Holland around 1880. They report that '*history has shown that this was not a good solution*' and that '*Groynes were eventually connected in 1965 providing a continuous foreshore protection'*. This experience has been mirrored at Amity Point.

The seven most northerly groynes at Amity Point were ineffective in that RBF events continued to impact the beach between them. From the mid 1980's RBF erosion events started to be repaired using rock placed in the depressions left behind. In this opportunistic way an 800m long substantial seawall was constructed over the ensuing 10 to 15 years.

The rhyolite rock is won from a local quarry and is ordered and paid for by both public and private landowners individually to protect their strip of coast. Construction has been essentially by one contractor. An estimate of cost to date to private landowners is about \$A1.8 million (today's dollar value) which equates to \$A2500 per linear metre of seawall. The seawall contains about 50 m^3 of rock per linear metre.

This seawall has proven to be effective in preventing any further loss of land over the last 30 years, as observed by long-time local residents and by reference to aerial photographs. However, many localised slumps or collapses have occurred as deep RBF events have undermined its foundations. An understanding of the mechanics of RBF events now explains how they impact the seawall and cause the observed slumps.

Events which are triggered offshore retrogress upslope until the seawall is encountered. If the base of the approaching breach is above the foundations of the seawall, it remains stable. In this case the event simply stops because it runs out of sand. If the base of the breach is deeper than the foundations of the seawall, the breach continues under the wall and destabilises it. When this happens, the rock foundations move deeper and repairs are made by adding rock to the top. The seawall so becomes progressively less vulnerable to future events. Seawall building has proven to be an iterative process. Experience also shows that repairs after seawall slumps caused by RBF events must be quickly carried out to avoid secondary erosion of exposed sand scarps.

As an example, a 22m wide slump of the seawall (Fig. 7) occurred during an RBF event on 7.12.2014. This slump was repaired within two days by the addition of 140 m^3 of rock. Observers report the RBF event which caused it remained active for over an hour.

Fig. 7: A 22m wide seawall slump at Amity Point occurred 7.12.2014.

Amity Point Seawall Stability Measurements The results of the program to monitor the stability of the 800 m seawall showed that of the 82 reference points initially monitored, 4 were lost. These 4 points were sited at two locations where minor slumping requiring some repairs had occurred. The other 78 sites showed an average upward movement of 6.1mm (standard deviation=11.9mm) per year which can be explained by measurement error.

There is no evidence for overall slow subsidence of the seawall over time due to tidal current undermining.

SUMMARY AND CONCLUSIONS

At Amity Point, a 1.5 km strip of coast adjoining a tidal channel has been impacted by erosion events for over a century (Beinssen, Neil and Mastbergen 2014). Sequential events over many years led to consistent coastal recession until an effective seawall was progressively built. There has now been no further loss of foreshore land for thirty years.

The geotechnical nature of erosion events is explained by retrogressive breach failure (RBF) of medium to densely packed fine sand on a subaqueous slope. Entrained sand is carried in a density current from the channel margin into deeper water. Such events are natural phenomena at Amity Point and are not caused by built erosion defenses.

There have been a number of alternative hypotheses put forward over the years to explain the mechanism of observed erosion events. Most propose shear failure due to over-steepening of the channel margin by tidal current. All should now be abandoned in favor of the RBF explanation.

Understanding the nature of RBF events now helps to explain the nature of seawall slumps and collapses. During most RBF events, the base of the breaching wall of sand is above the foundations of the seawall and so its stability is unaffected. However, when the breach is deep enough to undermine the seawall's foundations, it slumps or collapses. Such events happen rapidly, are limited in extent and move the rock foundations deeper. Timely repairs are required if secondary damage is to be avoided.

Over 2015, an 'Amity Point Shoreline Erosion Management Plan' will be developed by Government, in consultation with the local community. The planning process will provide an opportunity to canvas a wide range of issues (philosophical, physical, social, ecological, legal and financial) to do with coastal defense at Amity Point. A good understanding of the geomechanics of RBF events, their role in driving coastal recession in the past and how they now impact the seawall at Amity Point will be particularly important.

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