EFFECTIVENESS OF ADAPTIVE COASTAL PROTECTION IN MANAGING WAVE OVERTOPPING AND RETAINING BEACH VIEWS AT THE CREST OF SEABEE SEAWALLS

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Abstract

Seabee armoured seawalls have been constructed at a number of sites globally, the North Cronulla seawall being well known. Seabee armour units have high structural resistance, are cost effective in fabrication and construction but suffer from high wave runup leading to increased wave overtopping or need for higher crest levels.
With projected sea level rise of the order of 1 m over the next 100 years, higher extreme water levels and wave heights will impact our coastlines leading to increased wave runup and overtopping of existing structures beyond safe limits. Adaptive methods of coastal protection are required.
Within this study, wave deflectors, back beach wave washout zones and the staggering of Seabee seawalls have been physically modelled in wave flume testing at WRL to determine their effectiveness in reducing wave overtopping rates in present and future conditions. Combinations of these adaptive coastal protection measures have been shown to eliminate unsafe levels of wave overtopping that may occur with climate change.
In protecting our coastline we must avoid distancing ourselves from it and in so doing diminish the value of beach amenity. As well as holding great economic wealth within the tourism and residential industries, beach views have overwhelming social and emotional importance to the everyday lives of coastal communities and beach users. Within this study various beach user communities at several beaches have been surveyed as to the value of horizon, shoreline and sandy beach views. As well as highlighting strong desires for close beach proximity, survey responses stress the importance of maintaining a strong visual connection with the coastline as opposed to obstructing it through extreme measures of coastal defence. The study emphasises that effective adaptive coastal protection requires an essential compromise between the need for structural integrity and overtopping safety and the communities' desire for proximity and visual connection with the beach.

Keywords: seawalls, wave overtopping, sea level rise, climate change adaptation, beach amenity

Introduction

Seabee seawalls are a form of seawall defence currently implemented globally from Cronulla beach Australia to the coastal town of Rada Tilly in Argentina. In certain locations they are a practical form of coastal protection against storm waves due to their interlocking high structural resistance, increased drainage, and cost effectiveness in fabrication and construction. While structurally sound, due to their uniform surface design Seabee seawalls contain decreased roughness and therefore suffer from high wave runup and increased wave overtopping.

With a predicted sea level rise of approximately 1m over the next 100 years, storm water levels and wave heights impacting our beaches and seawalls will rise leading to increased wave overtopping beyond safe limits. Therefore adaptive forms of coastal protection are required to ensure the long term safety of coastal communities against future wave overtopping caused by large storm events.

Within this study various adaptive upgrade options for Seabee walls including wave deflectors, back beach washout zones and Seabee unit staggering were physically modelled in order to determine their effectiveness in reducing wave overtopping rates under present and future conditions (Figure 1). All physical modelling was performed within the 3m flume at UNSW Water Research Laboratory in Manly Vale.

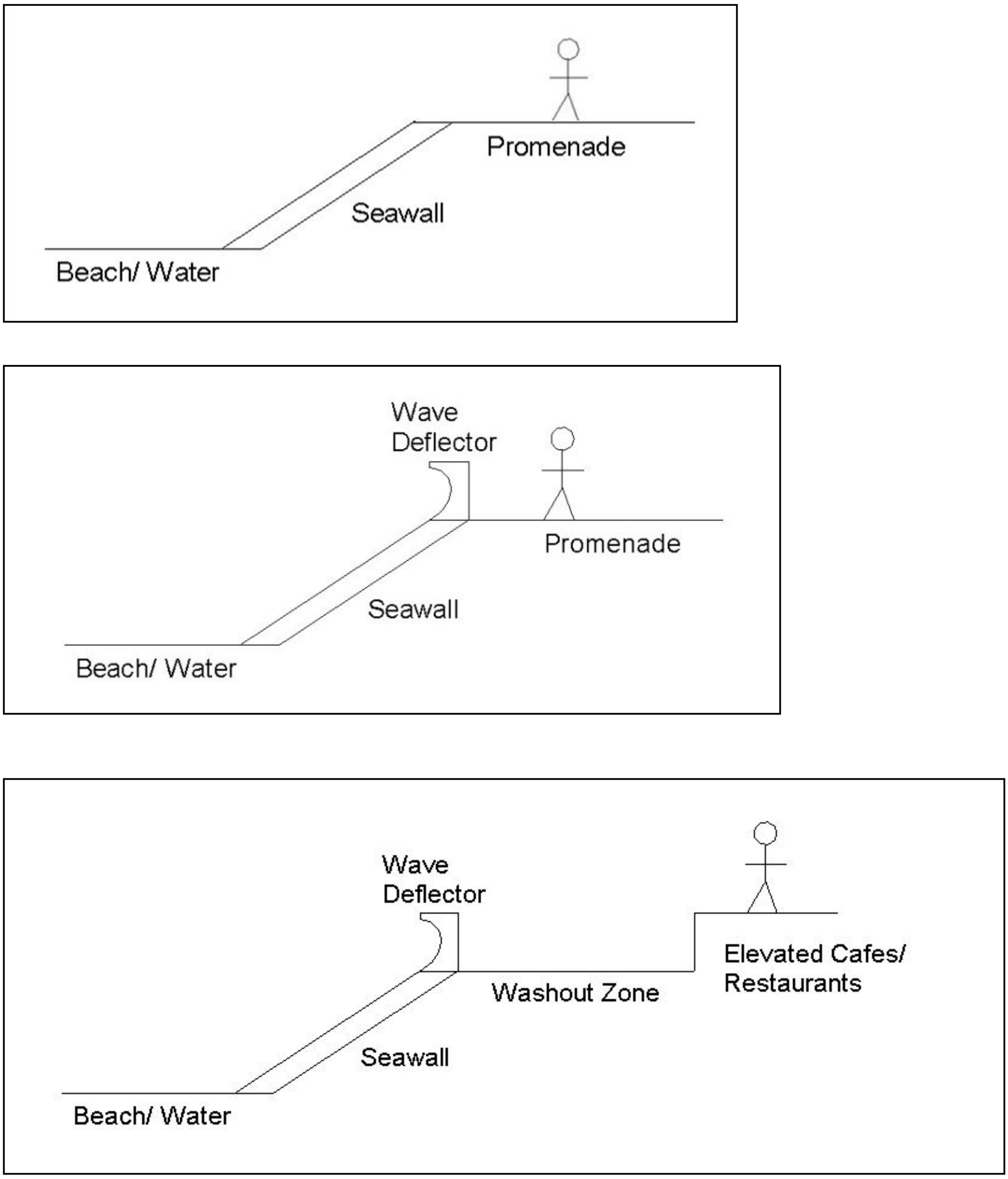

Figure 1 Idealised section profiles showing wave deflectors and washout zones

Wave flume testing

All laboratory wave flume testing was undertaken at a Froude length scale of 1:15. A storm eroded beach with a toe level of -1 m AHD was adopted. Present day base condition tests were undertaken with a storm water level (tide plus surge) of +1 m AHD. A prototype seawall with a slope of 1:1.5 comprising nominal 1 tonne Seabee units (prototype diameter of 900 mm with height of 510 mm and a central void of diameter 495 mm) and crest height of +4.5m AHD was adopted to emulate beach bank conditions along the NSW coastline where communities are predicted to be at great risk due to projected sea level rise. Testing for future sea level rise values of 0.5 m and 1 m was carried out at water levels of 1.5 m and 2 m AHD.

Each test ran for a random wave spectrum of 1000 waves; equating to 30 mins of testing time and 116 mins prototype storm wave exposure. A range of wave heights were tested across each water depth by varying the amplitude of the flume paddle's drive signal. A 3 probe array was installed seaward of the wall to monitor incident and reflected wave heights and ensure results remained valid and consistent.

The volume of water overtopping the crest of the Seabee seawall (with various adaptation protection options) was collected and measured in metal trays landward of the crest as shown in Figure 2.

Figure 2. Laboratory Testing Setup – shows wave deflector and back beach washout zone with overtopping collection trays

Wave flume test results – no adaptation

As seen within Figure 3, without the addition of adaptive coastal protection, likely sea level rises will result in significant increases in wave overtopping rates. Results obtained through physical modelling of a 1 m sea level rise infer a predicted wave overtopping rate of 122 L/s/m in prototype scale. This is over 2400 times the EurOtop Manual (2007) recommended safe overtopping limit of 0.05 L/s/m, equating to over 7300 L or 7.3 m^3 of water striking a pedestrian behind the crest of the seawall every minute.

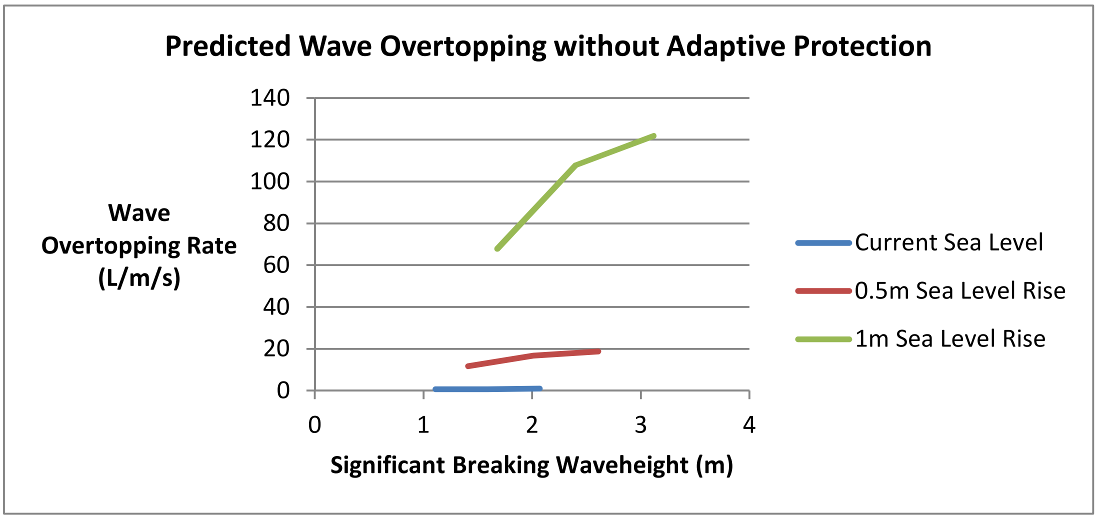

Figure 3. Comparison of Wave Overtopping with no Adaptive Protection

As shown in Figure 4, even with current sea levels it is evident that in the occurrence of large storm events overtopping rates are unsafe for pedestrian activity. With predicted sea level rises, overtopping rates will only become more dangerous, therefore placing heavy dependence on the need to improve current seawall defences by introducing adaptive protection such as wave deflectors.

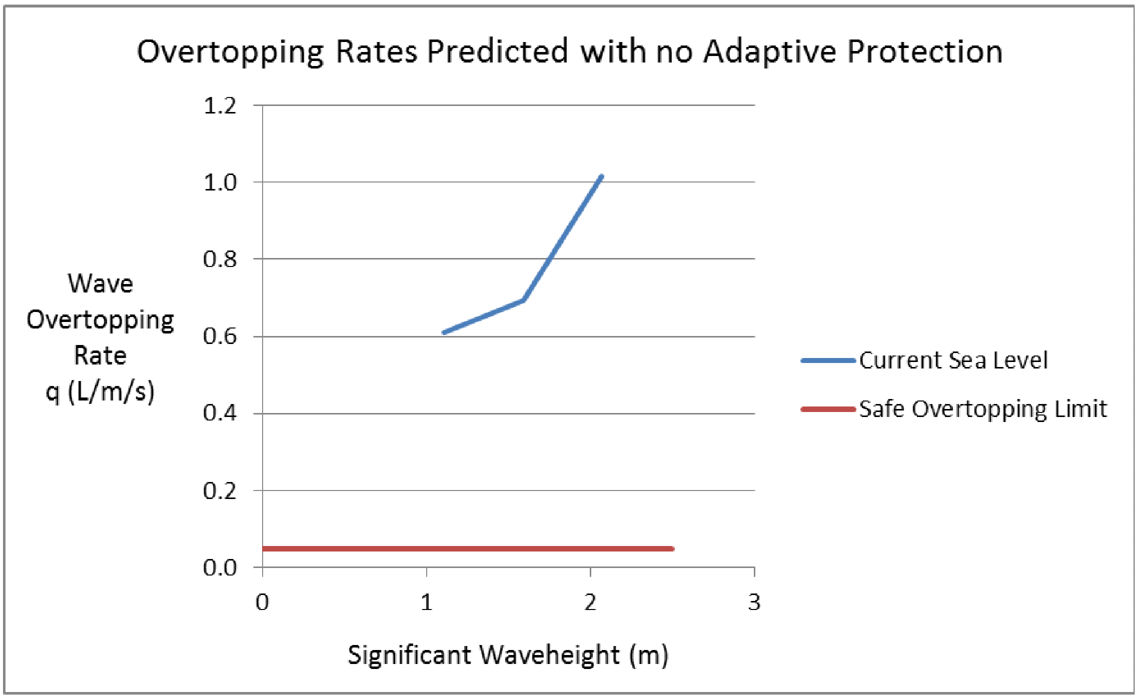

Figure 4. Wave Overtopping with Current Sea Level.

Wave flume test results – wave deflector adaptation

Wave deflector prototype heights of 0.6, 0.9 and 1.2 m were adopted for physical model wave testing as these heights correspond to the architectural secondary uses of sitting, leaning and pure vision purposes respectively. All wave deflectors were carved out of solid grey PVC in a log spiral shape, which was concluded by Pohl (1992) as the most effective deflector shape in reducing wave overtopping.

The addition of wave deflectors was found to effectively reduce unsafe wave over topping rates dramatically by reflecting incident waves 180 degrees. With current sea levels, implementing even the shortest 0.6 m wave deflector eliminated all unsafe overtopping levels and so further testing at this water depth was deemed unnecessary.

If designing for 0.5 m sea level rise as depicted within Figure 5, the 0.9 and 1.2 m high deflectors are sufficient to reduce overtopping rates to safe levels; while the 0.6 m deflector still resulted in overtopping approximately 8.5 times that of the safe limit.

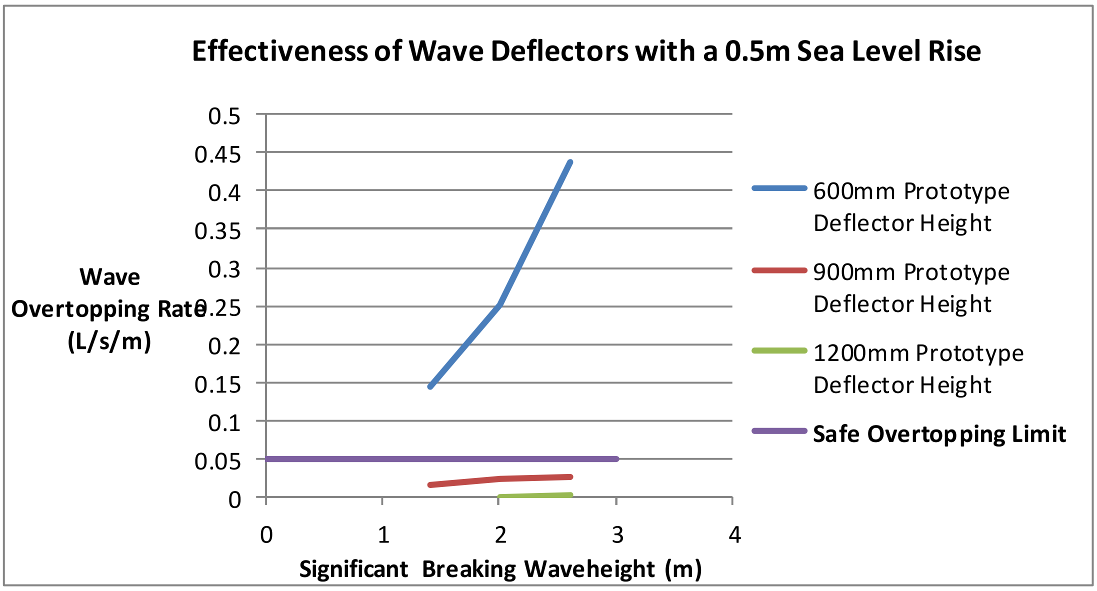

Figure 5. Analysis of Wave Deflector Effectiveness with a 0.5m Sea Level Rise.

As evident within Figure 6, results show that with a 1 m sea level rise even the highest 1.2 m wave deflector is not a sufficient form of protection as it is only effective in preventing unsafe overtopping against smaller wave heights.

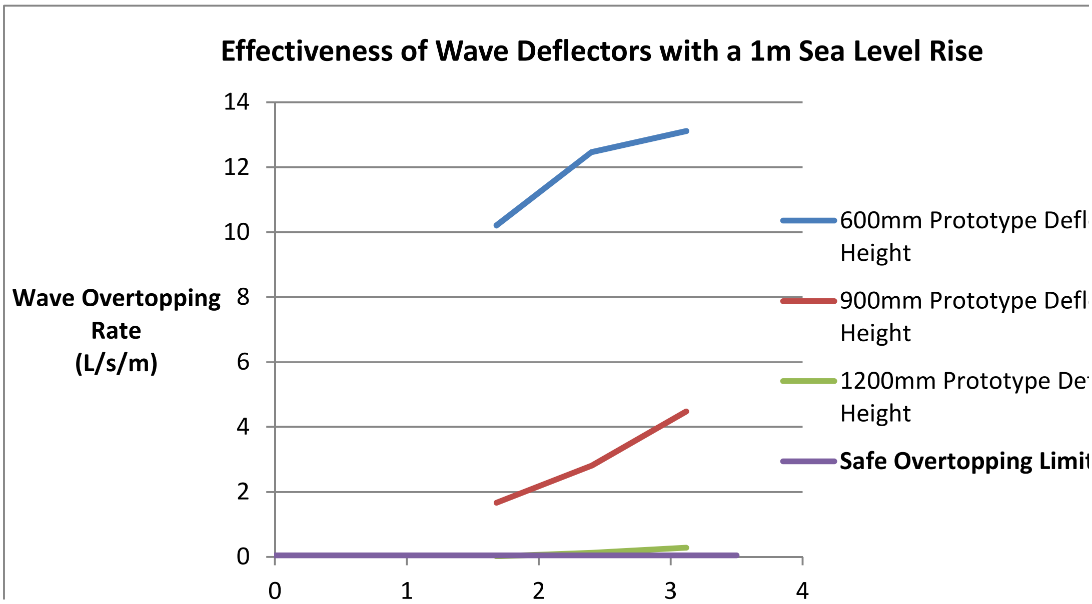

Figure 6. Analysis of Wave Deflector Effectiveness with a 1m Sea Level Rise.

It can easily be inferred that one way to achieve the necessary effectiveness of wave deflectors is to increase their height until they fulfil all safe overtopping requirements; but in our attempts to protect our coastline we must also ensure we do not distance ourselves from it.

As well as holding great economic wealth within the tourism and residential industries, beach views have overwhelming social and emotional importance to the everyday lives of coastal communities. As detailed later, the value of horizon, shoreline and sandy beach views was surveyed at the tourist popular Bondi Beach, the local community Newport Beach, as well as externally online. Across all survey locations, responses highlighted strong desires for close beach proximity and stressed the importance of maintaining a strong visual connection with the coastline as opposed to obstructing it through extreme measures of coastal defence. Hence in order to prevent predicted unsafe wave overtopping, wave deflectors need not be heightened to unrealistic levels but must be accompanied with further adaptive protection such as that provided by introduced back beach wave washout zones.

Wave flume test results – wave deflector and washout zone adaptation

As shown schematically in Figure 1, wave washout zones are promenade areas behind the crest of the seawall such that in large storm events, wave overtopping escaping introduced wave deflectors is contained and prevented from reaching restaurants, cafes or residential housing elevated behind. To ensure essential beach views remain unobstructed to those both using the promenade and those safely elevated behind it, the height of the wave deflector was chosen to be a constant 0.9 m as necessary for better sight lines to the water and horizon from restaurants and cafes behind the washout zone.

Washout zone widths of up to 9 m and back land heights up to 1.8 m were physically modelled against a 1 m sea level rise and a maximum test breaking wave height of 3.12 m. As shown in Figure 7, only the smallest washout zone of width 3 m and height 0.9 m produced unsafe wave overtopping whilst all other proposed washout zones successfully reduced wave overtopping rates landward of the washout zone well beneath that of limits for safe pedestrian activity.

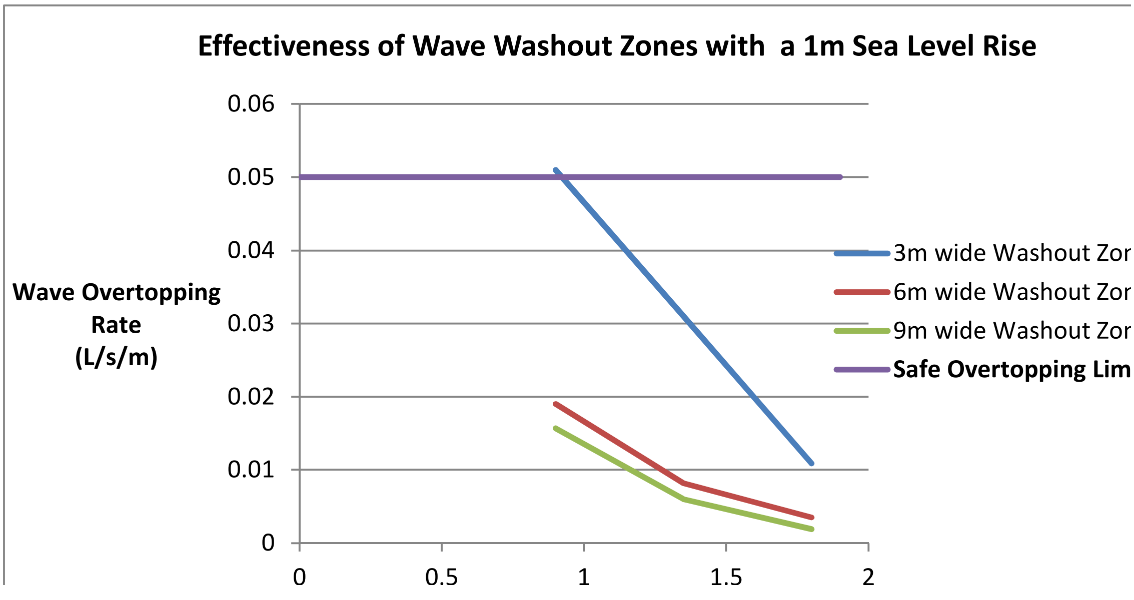

Figure 7. Back Beach Wave Washout Zone Effectiveness with 1m Sea Level Rise

As expected the largest reduction in wave overtopping resulted from the biggest washout zone of width 9 m and back height 1.8 m, allowing only 3.8% that of the safe overtopping limit. Throughout testing, water overtopping the 0.9 m wave deflector was seen to slosh within the washout zone, only to be confined by the back land height until it drained away through drainage paths at the back of the seawall.
Testing showed that reduction in wave overtopping rate was largely governed by increases in back land height as opposed to increases in washout zone width.

Wave flume test results – Seabee unit staggering

The last form of adaptive coastal protection physically modelled was the implementation of Seabee unit staggering as proposed by Walker (1996). It must be noted that the staggering of Seabee units cannot be retrofitted to existing Seabee seawalls like the addition of wave deflectors and wash out zones previously discussed. This adaptive form of protection would need to be incorporated into the design of new staggered Seabee seawalls which allow for increased runup and wave overtopping due to projected sea level rises.

Staggers of 30% and 40% standard Seabee unit height were tested against current and future sea levels in row and diagonal pattern placement. The results shown in Figure 8 indicate that Seabee staggering alone is not sufficient to reduce overtopping levels below safe limit criteria, reductions of up to 62% can be obtained when using optimised staggering of 40% height with row pattern placement. It was noteworthy that with current sea levels pattern placement of staggering governed overtopping reductions, while in contrast, when testing future increased sea levels, incident waves were resisted by considerably less surface area of staggering and therefore % stagger height governed the overtopping reduction.

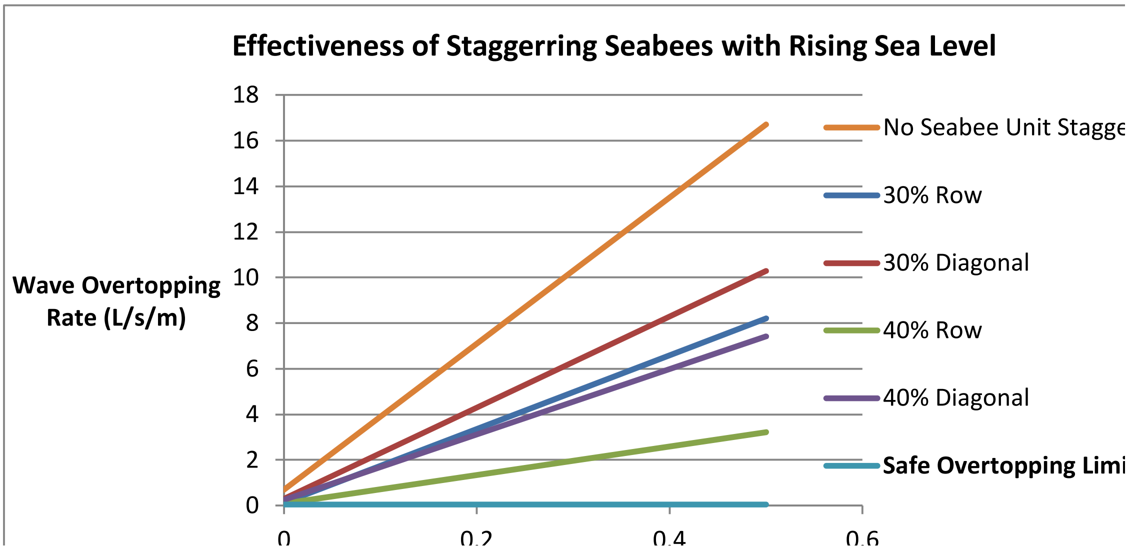

Figure 8. Wave Overtopping Reductions with Seabee Staggering

Discussion - wave flume testing and adaptive protection

It has been demonstrated how coastal protection can be adapted for sea level rise to effectively limit wave overtopping below safety limit criteria for pedestrian activity. It must be noted that although results shown are valid for a Seabee seawall slope of 1:1.5 and a crest height of +4.5m AHD, further testing is required to form relationships with corresponding results of differing slopes and crest height and/or armour units other than Seabees.

Value of a beach view - the consequences of raised seawall options

Wave deflectors alone have the potential to limit unsafe levels of wave overtopping. It has been shown above that to be effective against a 1m sea level rise on a Seabee seawall, wave deflectors alone would need to be higher than 1.2m. Such high wave deflectors would obstruct and block existing beach views of the sand, shoreline and horizon as depicted within Figure 9.

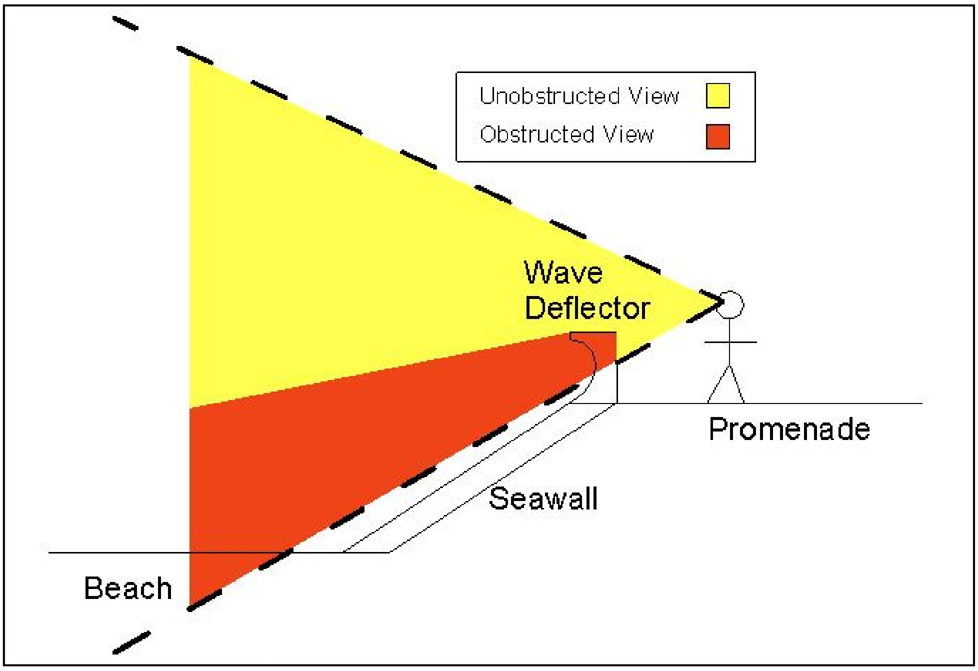

Figure 9. Blocking of valued beach views with wave deflector adaptations

If society does not sufficiently value their existing beach views then the addition of wave deflectors alone proves to be an efficient and viable option for protecting coastal communities against projections of sea level rise and unsafe wave overtopping. However, what if society does value beach views highly such that obstructing them through coastal adaptation options consequently destroys the beauty and meaning of the very thing we are trying to protect?
In assessing adaptive coastal protection options it is essential to consider the importance of unobstructed beach views and their significance to an individual's overall beachside experience.

Value of a beach and view - survey of beach users

Within this study, surveys were performed at the tourist popular Bondi Beach and the local community Newport Beach in order to determine the emotional and architectural value of various beach views. The survey was performed at various times on weekdays, weekends and on a public holiday so as to cover a large representation of beach users. As it was inappropriate to survey people on the sand, beach survey responses were obtained from surveying pedestrian paths of transit as well as adjacent parks and promenades overlooking beach views at Bondi and Newport as shown within Figures 10 and 11 respectively.

In addition an external online survey was conducted to ensure responses were not limited to people that visited the beaches on coincident days but also covered a larger representation of society including those that may not visit the beach frequently.

Figure 10. Bondi park - valued views of sandy beach, shoreline and the horizon

Figure 11. Newport Beach Adjacent community park – valued views

Responses highlighted a strong desire for close beach proximity and unobstructed views of the shoreline, horizon and sandy beach. 318 responses were obtained in total with 103 responses from Bondi Beach, 101 responses from Newport Beach and 114 external responses online.

The distribution of respondents is given in Figure 12. Bondi Beach is a popular beach destination for not only locals but also for residents from all over Sydney. As a result, survey participants understandably contain an approximate 1:1 ratio between local and day tripper responses. This contrasts with the smaller local community beach at Newport where the local resident to day tripper ratio was a much larger 3:1.

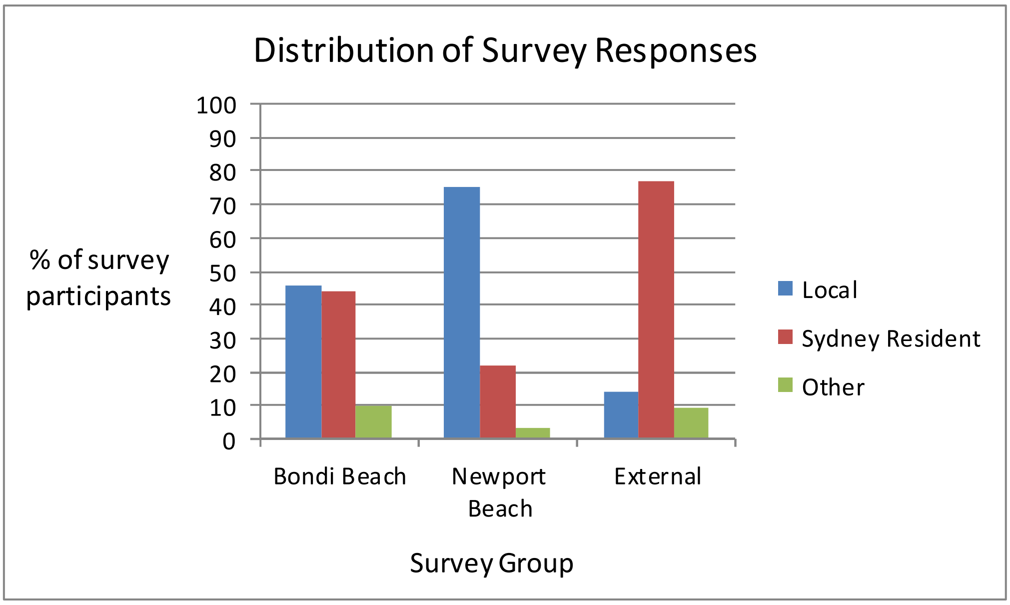

Figure 12. Distribution of survey respondents across survey groups

As also concluded by Lazarow and Raybould (2009) in their survey of the Gold Coast, beach proximity of survey participants was found to be a major factor in the frequency of participant beach visits. 91% of Newport respondents were locals visiting the beach at least once a week. Only 62% of the more diverse Bondi Beach respondents visited on a weekly basis. With a much larger proportion of locals at Newport Beach it was found that 52% of respondents visit the beach daily as part of their everyday routines such as morning or sunset walks with pets. This is a significant difference from the external on line survey results representing the wider population which found that 35% of people only go to the beach on a monthly basis and 43% of people only visit the beach at most once every 3 months over the course of a year.

Value of a beach and view – attracting factors

Across all survey locations it was found that beach atmosphere is the most "attracting" factor with more than 80% of respondents on average attracted to values such as beach views, other people and the sun as shown in Figure 13. This finding is supported by Morgan's surveying on 50 UK beaches in 1999 which concluded scenic quality as the most important factor amongst users of the beach environment (Morgan, 1999).

The smell of fresh air accompanied with stunning sunrise and sunset views of the horizon and shoreline was highlighted as daily moments of tranquillity for respondents; holding major importance in their lives. Many retired locals surveyed at Newport Beach also commented that they walk to the beach daily just to sit on adjacent park seats and watch the waves break into the shoreline.

Recreation is also a highly attractive influence to beaches as shown in Figure 13, with approximately 60% of all respondents attracted to the idea of walking, jogging or running in the presence of priceless beach views as opposed to exercising throughout neighbourhood streets or gyms. It was also found that many parents bring their children to the beach on the weekend as family outings; enjoying priceless beach views while having picnic lunches on adjacent beach parks overlooking the water.

With much further to travel on average to their nearest beach, external online participants rated the attractiveness of beachside restaurants and cafés significantly higher than corresponding responses from the Newport and Bondi Beach respondents.

This is understandable as most external respondents rarely go to the beach and therefore plan an entire day with more emphasis placed on enjoying great food while overlooking priceless views of the water.

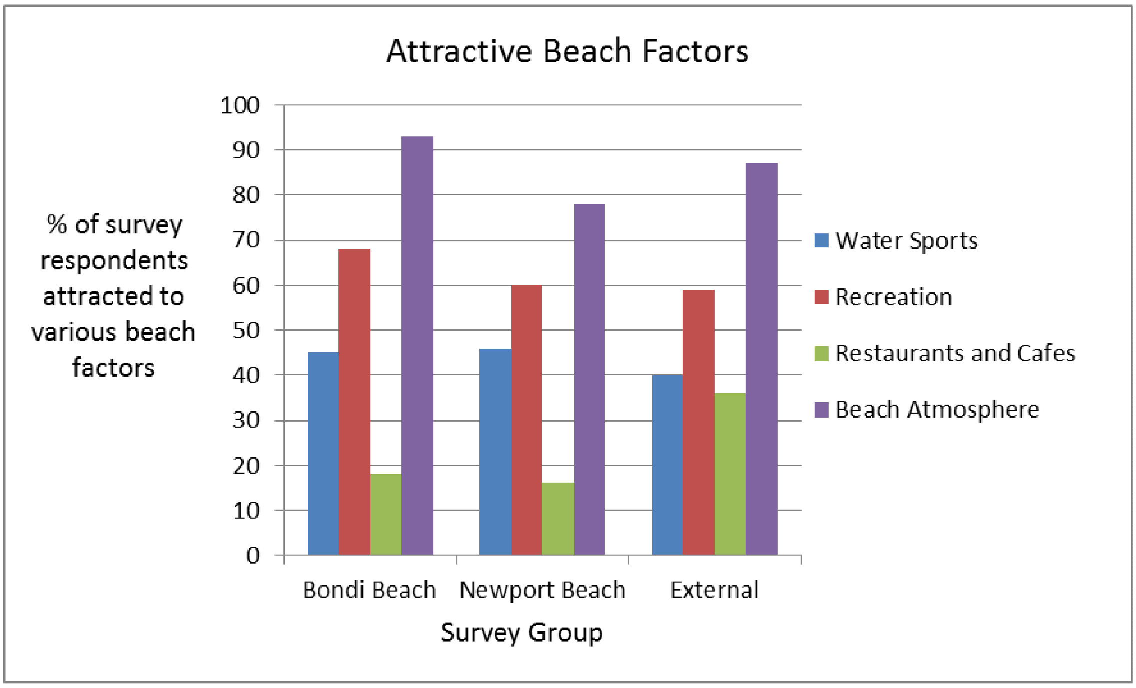

Figure 13. Responses for attractive beach factors across survey groups

Value of a beach and view - the importance of unobstructed views

An unobstructed view of the shoreline, horizon and sandy beach was highlighted through the majority of all survey responses as essential to one's positive beachside experience. Shoreline views were consistently rated the most important unobstructed view, closely followed by views of the horizon and then the sandy beach.

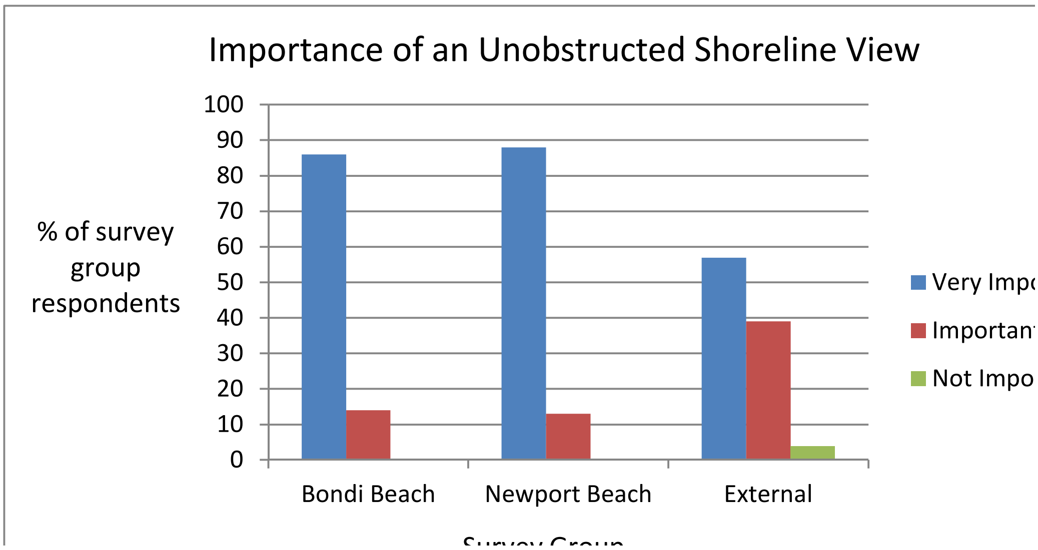

Figure 14. Importance of unobstructed shoreline views across survey groups

As seen in Figure 14, responses from Newport and Bondi Beach consistently rated the importance of unobstructed beach views significantly higher than corresponding external on line survey responses. While both Beach surveyed groups concluded all unobstructed views essential to beachside enjoyment, 11% and 12% of external respondents thought the respective obstruction of horizon and sandy beach views would not negatively impact their beachside experience.

While eating at a beachside restaurant or café, 77% and 69% of Bondi and Newport respondents respectively said they would be negatively affected if their views of the sandy beach, shoreline and/or horizon were obstructed. Although external responses rated unobstructed beach views less essential to their overall beachside experience, with a result of 79%, external respondents indicated they would be the most negatively affected group by obstructed beach views while eating at a beachside café or restaurant. Since Sydney resident day trippers on average have to travel much further to the nearest beachside café or restaurant it is understandable that their beachside experience would be affected most negatively by obstructed views while dining. As locals generally experience beach views on a regular basis, survey responses show it is not as critical for them to have perfect views while enjoying food or beverages at beachside cafes or restaurants.

As shown in Figure 15, when given the choice between beach views or atmosphere, 70% of external respondents preferred to sit higher with unobstructed views within a beachside café or restaurant as opposed to sitting lower with obstructed views but increased beach atmosphere. Corresponding preferences for higher positions with better views from Bondi and Newport Beach were found to be less with only 65% and 51% respectively.

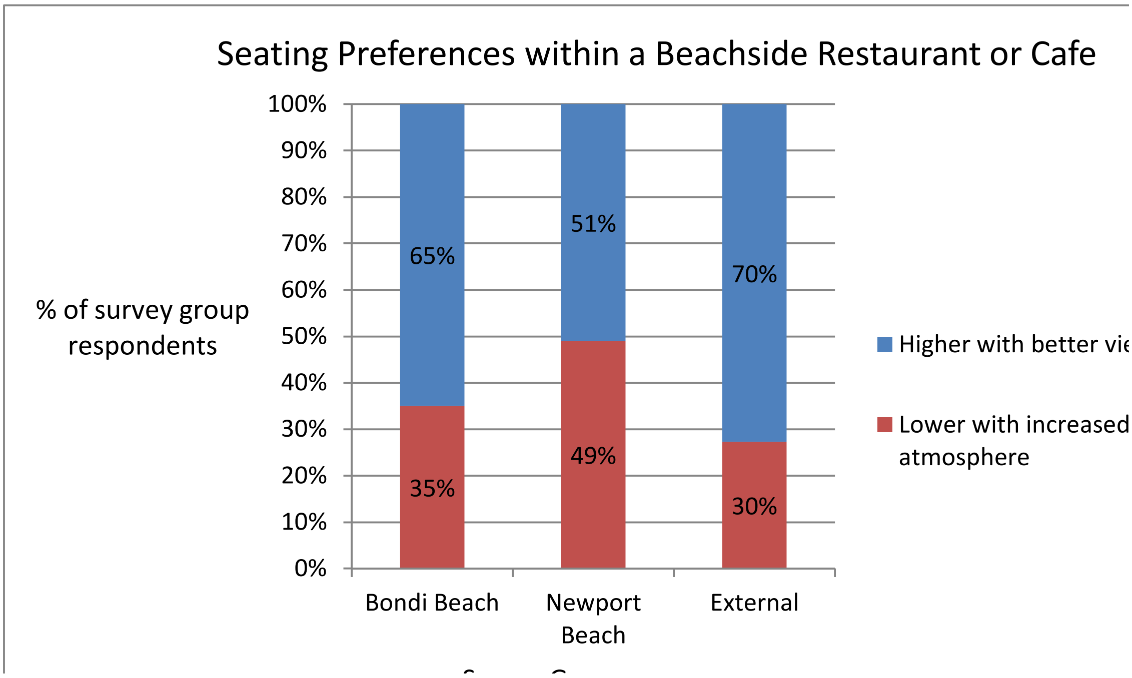

Figure 15. Seating preferences within a beachside restaurant or café

Concerns for erosion of sandy beach

In general there was large concern for possible future erosion of beaches from all survey respondents, both local residents and day trippers. Although unobstructed views of the sandy beach were considered the least critical to a positive beachside experience, approximately 90% of all survey groups concluded that they would be greatly affected by a complete loss of all beach sand since it is an integral part of all beaches.

Responses from both Bondi and Newport Beach survey groups showed similar concern rates of 84% and 81% respectively for a 50% reduction in sandy beach width. External survey participants were concerned significantly less about a 50% reduction in sandy beach width with only 47% of survey participants concluding they would be negatively affected. Across all 3 survey groups there were consistent trends for those least concerned with the loss of sandy beach width due to erosion to be those who rarely go on the sand or visit the beach less often.

Conclusion – adaptive protection options and beach views

While it is clear that adapting current seawalls is an essential option to the future protection of community interests, the need to preserve precious beach views has been voiced by various coastal communities, therefore emphasising a necessary compromise between one's need for safety and their desire for aesthetic wealth.

Overall it has been demonstrated through surveying at Bondi Beach, Newport Beach and externally online how unobstructed shoreline, horizon and sandy beach views hold overwhelming social and emotional importance to the everyday lives of coastal communities. The need to preserve unobstructed beach views has been outlined with responses stressing the importance of maintaining a strong visual connection with the coastline as opposed to obstructing it through extreme measures of coastal defence.

Therefore in order to prevent unsafe wave overtopping predicted with a 1m sea level rise as well as ensure unobstructed beach views, seawalls and/or wave deflectors should not be heightened to unrealistic limits. Alternative adaptive coastal protection options including back beach wave washout zones need to be considered.

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