# Concept Design of a Multipurpose Submerged Control Structure for Palm Beach, Gold Coast Australia

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## Abstract

Palm Beach has been identified as being one of the Gold Coast beaches currently under the greatest risk with regards to loss and damage to beach front properties due to beach erosion during significant wave events. Previous studies conclude that despite no prevailing erosional trend has been recorded; the beachfront developments are located too close to the beach inside the natural coastal buffer zone. The current beach width does not provide sufficient protection at many locations along Palm Beach. The land value alone of vulnerable beach front properties has been estimated to the excess of $406 million outlining the requirement for the implementation of an effective coastal protection strategy.

The City of Gold Coast commissioned DHI to carry out a concept design study for Palm Beach using state-of-the-art numerical modelling of to quantify changes to wave transformation, sediment transport and shoreline response. The study involved the assessment of three (3) potential shoreline protection strategies, which was completed in autumn 2014. Of the three strategies a solution involving 750,000 m$^3$ capital nourishment, seawall upgrades and a submerged control structure (SCS) was identified as the preferred solution.

This presentation will provide an overview of the design considerations that have gone into the concept design of the submerged control structure. The design will incorporate lessons learned from past similar projects and will present a selection of state of the art methods for assessing the performance of the SCS with regards to coastal response, surfing amenity and beach safety.

*Keywords: Coastal Structures, Beach Protection, Surfing Amenity, Numerical Modelling.*

## 1. Introduction

Previous studies have concluded that on a long term basis Palm Beach is a stable beach. However, high density infrastructure that exists in close proximity to the backshore has resulted in insufficient beach volume (‘buffer’) required to absorb potential short term fluctuations in the shoreline position; a natural response during storm events. Resultantly, infrastructure and beach front development could be susceptible to damage during large erosion events. Figure 1 shows the erosion at the most susceptible section of Palm Beach.

Figure 1 Example of erosion at Palm Beach

Palm Beach has been identified as being one of the Gold Coast beaches currently under the greatest risk with regards to loss and damage to community infrastructure and beach front properties due to beach erosion during significant wave events. The land value alone of vulnerable beach front properties has been estimated to the excess of $406 million outlining the requirement for the implementation of an effective coastal protection strategy.

The City of Gold Coast commissioned DHI to carry out a concept design study for Palm Beach involving the development and assessment of three (3) proposed shoreline protection options. All options assumed a comprehensive seawall upgrade and a targeted placement of ~750,000 m$^3$ of sand on the beach and nearshore consistent with the City’s Planning Scheme. Option 2 and 3 also included two alternative solutions for utilizing hard engineering structures for permanently stabilizing a wider beach along a sensitive section of the beach. Option 2 involved a nearshore submerged control structure aimed at enhancing coastal protection without causing impacts to visual beach amenity. Option 3 involved two low crested surface piercing artificial headlands, which from a coastal processes perspective provided a more conventional alternative to beach stabilization but at the expense of causing visual impacts to the beach. All potential options must provide maximum possible beach protection while also enhancing local surfing amenity.

A detailed assessment of the relative performance of each of the three (3) options can be found in Kaergaard *et al*., (2014).

Following a review of the costs and benefits of each option by an external panel of subject matter expert the City of Gold Coast reached the conclusion that a coastal protection option involving a combination of seawall upgrades, targeted sand placement and an innovative design of a submerged control structure was the preferred solution for improving coastal protection at Palm Beach. The purpose of this paper is to present the concept design and performance of this submerged control structure in its current stage as developed through numerical modelling while considering the lessons learnt from past experiences and apply these lessons in the SCS design for Palm Beach.

## 2. Coastal Processes on Palm Beach

Palm Beach is situated in the central region of the Gold Coast, Southern Queensland, Australia. Along with most Gold Coast beaches it hosts a high-energy open ocean wave climate not uncommonly experiencing 1-2 extreme wave events each year. Past wave records from the Gold Coast Waverider buoy illustrate several recordings of maximum wave heights ($H_{max}$) in excess of 10 metres (Queensland Government, 2015). Analysis of 6 years of wave measurements (Figure 2) reveal significant wave heights exceed 1.1 m 50% of the time and are larger than 1.9 m 10% of the time. Wave spectral peak periods exceeds 8 seconds more than 70% of the time.

As with all Gold Coast beaches the relative obliqueness of the wave climate at Palm Beach results in a northward net sand transport. Previous studies have estimated annual transport rates in the order of 500,000m$^3$ (BMT WBM, 2013) while transport modelling by use of DHI's 1D coastal model LITPACK derived over 2008 to 2012 ranged from 200,000m$^3$ in 2010 to 725,000m$^3$ in 2009, averaging at ~400,000m$^3$. Littoral transport was found to show significant inter-annual variation and to largely be driven by storm events predicted to transport up to ~55% of the annual transport over the duration of a single storm (~5 days). Subsequent detailed 2D modelling was able to quantify how various wave conditions caused sharp differences in longshore transport gradients along the beach sometimes resulting in simultaneous erosion and accretion processes to occur and effectively shift sand from one section of the beach to another.

Large wave events drive 'short term' offshore sediment transport leading to a reduced upper-beach width and subsequent reduced shoreline protection. During subsequent prolonged periods of small, long period waves, onshore transport prevails leading to upper beach recovery. The variability of the beach width due to these cross-shore processes was estimated from measurements to be around 60-80 m.

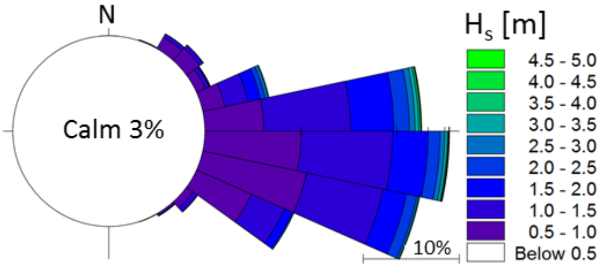

Figure 2 Wave climate (significant wave height, $H_S$ and peak wave direction, PWD) recorded by Gold Coast Wave Rider Buoy for the period 17/07/2007 to 01/05/2013. Predominant wave approach is from E and SE typically ranging between 0.5 and 1.5 m, at times exceeding 4m

## 3. Review of Lessons Learnt in Past SCS Design

To date, the construction and longevity of functional submerged control structures that meet and maintain the intended key design objectives have proved challenging. As a result a comprehensive review was undertaken that addressed seven (7) existing SCS worldwide in order to incorporate lessons learned into the Palm Beach SCS design. Following the performance of each structure with regards to a set of key criteria, performance grading was quantified with regards to both it short term and long term performance (Table 1). Of the seven selected structures Cable's, Boscombe, Pratte's, Opunake and Mount Maunganui were all built with surfing enhancement as the primary objective. Of these five (5) Cable's was the only reef constructed using rock, while the other reefs were constructed using geotextile containers. Kovalum and Narrowneck was categorised as multi-purpose artificial reefs built using geotextile containers and with coastal protection as a primary objective and with surfing amenity as a secondary objective.

Table 1 Performance scorecard of previous nearshore coastal control structures. Short term and long term performance is separated by an '/'. The performance scale ranges from 0 (failure to meet performance criteria) to 10 (exceptional performance). A score of 5 reflects acceptable performance. A '-' marks missing data

| **Coastal** | **Performance (Short term/long term)** |
|---|---|

| **Control Structure Performance (Short term/long term)** | Volume ($m^3$) x$10^3$ | Coastal Protection | Surfing Amenity | Marine Ecology | Structural Integrity | Safety | Cost (AUD\$/$m^3$) |
|---|---|---|---|---|---|---|---|
| Narrow-neck | 65 | 9/3 | 7/3 | 7/7 | 5/4 | 6/9 | 43 |
| Boscombe | 13 | 4/4 | 5/2 | 7/7 | 4/3 | 6/0 | 390 |
| Cables | 5 | 0/0 | 7/7 | 8/8 | 9/9 | 9/9 | 302 |
| Maunganui | 6.3 | 6/6 | 8/2 | 7/7 | 3/3 | 9/9 | 233 |
| Pratte's | 1.5 | 1/0 | 2/0 | 4/0 | 1/0 | 9/9 | 261 |
| Opunake | 3.4 | 1/0 | 2/0 | -/- | -/- | 9/9 | - |
| Kovalam | 4 | 6/- | 8/- | 6/- | 2/- | -/- | 370 |

Cable’s Reef was considered successful in producing a significant increase in surfable waves on an annual basis in the short [2] and in the long term [11] (scoring ‘7’ for both time scales Table 2). The use of granite stone to modify an existing limestone platform at Cables has proven to create a stable artificial surfing reef that has continued to function according to design specification. There has been no report of maintenance required since construction (scoring ‘9’ for both time scales).There were issues regarding the accuracy of initial placement with some rock rolling off the existing limestone platform [2]. Nevertheless, such difficulties should not be experienced if deployed onto a shallow gradient sand bottom bed such at Palm Beach.

Geotextile sand containers were used for all of the multi-purpose artificial reefs discussed. For each application negative reports outlining either one or more of the following were discussed; placement inaccuracies, reported at Narrowneck [10], weight induced container settlement, reported at Narrowneck [7], settlement due to storm bar movement, reported at Narrowneck [7], tearing causing damage beyond repair resulting in the loss of sand, reported at Mount Maunganui [10] and at Pratte’s Reef [3] and [9], container movement, reported at Narrowneck [6], Boscombe [12] and at Mount Maunganui [10] and [6], fill valve failure resulting in the loss of sand, reported at Mount Maunganui [10], material degradation and fragmentation, reported at Kovalam Reef [5] and at Boscombe [12] and anthropogenic induced damage (for example by anchors, propellers and spear guns), reported at Narrowneck [7].

For all geotextile designs the containers were reported to be prone to moving, settlement and failing structurally. The resulting impacts were in some instances due to the complexity of the initial reef design being too difficult to build or, if built to specification, the shape was not upheld over time.

If a reef alters from the specific design then the reef will no longer perform to the design specification and will therefore pose a risk of not continuing to meet the intended project objectives. When such failures have occurred at existing geotextile multi-purpose reefs, costly on-going maintenance work has been required, for example: Narrowneck (2001 - 2006) [6], Boscombe (2010 - 2012) [12] and Mount Maunganui (2007 – ongoing) [1]. Several stability issues arose in a number of previous projects due to the reef being position too shallow and placed in the active highly mobile profile causing the containers to shift, sink and alter from the design shape (Narrowneck [7] and Mt. Maunganui [6]), thus reducing functionality. All geotextile container designs have experienced significant problems with breakage, burial and shifting of containers commencing from the time of construction. For Narrowneck, Maunganui and Boscombe the surfing quality at all three reefs has diminished over time due to structural changes in the initial design shape.

An advantage of geotextile containers is that they have no sharp edges and a forgiving exterior. With no reported injuries at Narrowneck induced by the containers [4] they are considered to be safe for surfers and swimmers. However, under wave action the containers at Boscombe have been found to move creating large gaps between the containers big enough to cause a potential threat to users. For this reason Boscombe Reef remains closed to the public from 2012 [12]. Using rock will provide a harder surface compared to geotextile bags and great care must be taken in further studies to assure that this does not pose an added safety risk. On the other hand the smaller unit sizes of rock may greatly reduce the potential gap size and risk of entrapment compared to geotextile bags. To the authors understanding no surf accidents involving hitting the bottom has been reported at Cable’s Reef.

Of all the multipurpose geotextile reefs reviewed, shoreline response of the Narrowneck Reef is the best documented with independent reports confirming leeward shoreline accretion of at least 20 m up to 3.5 years after construction [13]. The Maunganui reef has also been reported to cause the formation of a salient [14]. Documented reports of shoreline responses for remaining reefs has been sparse or with conflicting conclusions. No confirmed reports of downstream erosion problems caused by the reefs have been documented. Both geotextiles and rock have been found to provide ecological enhancement at all locations applied [7], [1] and [2].

## 4. Palm Beach SCS Design

It was a requirement that the SCS for Palm Beach must incorporate coastal protection, surf amenity enhancement and beach safety. Based on the lessons learned from the review of past structures and using state-of-the-art numerical methods for benchmarking and optimization a new and novel SCS design was developed.

When designed correctly a SCS is capable of forming a salient it its lee which can provide increased coastal protection to shoreward properties. The phenomenon is caused by wave breaking on the SCS which weakens the longshore transport occurring in its lee. In order to be effective the SCS must be located offshore the ambient surf zone and with a crest height shallow enough to cause wave breaking on a regular basis. In order to provide a noticeable protection effect on a sufficiently wide section of beach the structure has to be relatively large in order to provide enough perturbation to the longshore transport. Due to the potential risk of downstream erosion it was imperative that the SCS was constructed at a location where downstream beaches were able to cope with a minor recession.

With regards to the SCS providing surfable waves it was highly important that the relative alignment of the structure compared to the predominant wave directions allowed for suitable wave peel angles to occur. The offshore facing slope of the toe of the structure would have to be designed so that large waves do not break abruptly on the crest as was the case at Mount Maunganui and Boscombe [6].

A detailed investigation of the naturally occurring coastal processes of Palm Beach presented in [8] was carried out in order to adopt the best possible ‘working-with-nature’ approach for incorporating all of these constraints into the concept design. It was found that the large natural Palm Beach reef produced a number of wave focusing zones which resulted in discrete areas of locally enlarged wave heights along the central section of the beach.

It was chosen to place the SCS landward of the northern most focusing zone located off 19th avenue. The site was chosen in order to dissipate the naturally enlarged waves further offshore, which would enhance the structures ability to generate a large salient in its lee with a coastal stabilization effect extending south towards the 11th Ave. groyne. As an added benefit the natural wave focusing would provide valuable wave preconditioning with respect to surfing quality before the waves reach the toe of the structure.

Any minor downstream erosion would be absorbed north of 23rd Ave, where the beach is wider compared to south of 19th Ave, where the average beach volume is critical during storm events.

The offshore toe of the SCS was placed 560 m offshore in 11.4 m water depth in order to assure that the structure was located offshore the ambient surf zone in all but the most extreme wave events. A second reasoning behind the offshore location is that bed mobility in this water depth (approximately 1.6 m deeper than the depth of closure) is greatly reduced compared to previous designs, which limits risk of post construction settling. Constructing the SCS foundations below the existing bed level, excavated prior to infilling may be an additional option for further mitigating post construction settlement.

The crest level was chosen to be -1.5 m AHD. This level was chosen to assure that the structure remained fully submerged during even the lowest tides, while still inducing frequent wave breaking.

The offshore section of the SCS was designed as a curved wave focusing platform aimed at focusing wave energy towards the crest. Using this method it was found that local wave heights could be increased by more than 40% which further increased the frequency of wave breaking on the structure and improved its resilience to minor settlement of the crest. At the same time the wave focusing platform would form a significant wave peak providing an ideal take-off zone for surfers.

A moderate gradient of 1:12 was selected for the offshore slopes of the SCS to enable gradual shoaling processes and moderate intensity of plunging waves upon breaking. As the offshore toe of the structure extends from 11.4 meters below the surface, the offshore slope of the structure is approximately 120 meters long making it comparable in size to a typical wave length at this depth. As a result incoming waves will have time to gradually adjust to the changing bathymetry, which causes wave breaking to occur along the slope in a proportionate water depth to its height as opposed to collapsing violently into a shallow crest which could prove hazardous for experienced surfers. Along landward slopes of the SCS the slopes do not affect the incoming wave train and could be made much steeper.

The concept design of the SCS is illustrated in Figure 3. It has a total volume of 53,000 m3 and has a 60 m long crest oriented 105° to true north, which will result in wave breaking to occur with a peal angle of approximately 40° - 45° depending on wave conditions.

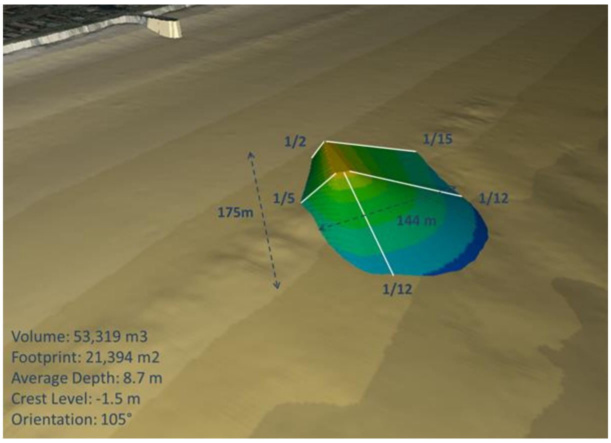

Figure 3 Dimensions and form of the SCS comprised of a curved shoaling platform designed to refract and focus waves to form a peak and the crest aligned to the prevailing wave direction to enable optimum peel angle during most frequently occurring wave directions

With regards to the choice of construction material, the structural performance of geotextile containers and rock used for submerged control structures was considered. To meet project requirements with regards to design specifications and demonstrating long term durability, a rock solution was adopted. This solution is considered as a baseline reference deign to demonstrate feasibility and performance of the coastal protection scheme, and identify design requirements and constraints. Future design phases will further investigate the performance of alternate materials and their ability to satisfy long term project objectives. For the reference design preliminary estimates using Van Der Meer formula indicates a rock armouring size of approximately 3 t with a d50 of 1.1 m. Given the very mild slope of offshore part of the structure it is considered plausible that actual rock size requirements may be less, subject to further detailed studies using 3D scaled physical modelling. In order to obtain sufficient accuracy rock placement should be carried out by a barge mounted GPS fitted excavator similar to that previously used for construction of the Cable's Reef. With regards to environmental impact it is important that no burial of important habitat is occurring. With the natural high porosity of rock it is expected that the SCS in time will provide an extraordinary habitat for local marine flora and fauna. “

## 5. Numerical Modelling

State of the art numerical modelling was undertaken to assess the performance of the Palm Beach SCS. Long term coastal response and associated salient formation were assessed using the MIKE21 Shoreline model. Surf amenity impact assessment and beach safety was assessed using MIKE21 BW Boussinesq model coupled with DHIs in-house surf amenity analysis software OPTISURF.

The Shoreline Model was applied to predict the shoreline response to the SCS design along with two alternatives with respectively larger and smaller crest length. A more comprehensive description of the Shoreline model is provided in [8]. The three SCSs are summarised in Table 2. Coastal response presented in Figure 4 compared to the relative performance of an option only including sand nourishment or nourishment stabilized by two headlands. The SCS design developed in section 4 is in this context named SCS B. It is observed how the larger SCS A generated the largest salient but also causes substantial downstream beach recession. SCS C only causes a slightly reduction in shoreline perturbation compared to B despite a 50% reduction in crest length. The reason for this is due to the substantial wave focusing and subsequent dissipation effect caused by the curved focusing platform which is identical for all three structures.

Table 2 Selected properties of the three SCS designs versions tested using the MIKE21FM Shoreline Model

| Name | Crest length [m] | Offshore Depth [m] | Nearshore Depth [m] | Volume [$m^3$] | Max. Width [m] | Max. Length [m] |
|---|---|---|---|---|---|---|
| SCS A | 190 | 11.6 | 4.7 | 96,248 | 154 | 309 |
| SCS B | 60 | 11.4 | 6.6 | 53,319 | 144 | 175 |
| SCS C | 30 | 10.6 | 6.9 | 37,112 | 138 | 142 |

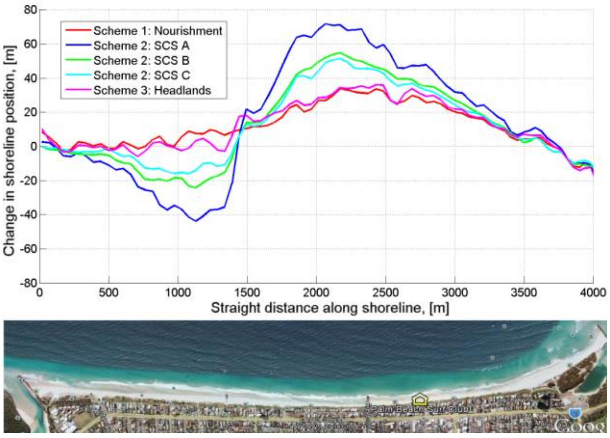

Figure 4 Predicted coastal response due to the different management options including SCS A, B and C.

It is noticed that reducing the SCS size from 96,000 $m^3$ to 53,000 $m^3$ decreases the amount of downstream erosion by 50% while the maximum width of the salient is only reduced by 20%. Compared to scheme 1 and 3 the numerical model indicates that the SCS option provides the most beach protection south of 19th Ave but in exchange for potential shoreline recession to the north, which would have to be mitigated in subsequent detailed design.

Based on long term records of nearshore wave conditions four (4) representative wave scenarios were selected to undergo detailed surfing amenity impacted investigations by comparing the SCS layout versus the (no SCS) baseline. The wave boundary condition for each event was modelled in the non-linear Boussinesq wave model using representative directional wave spectra at the offshore boundary. An instantaneous model output from the Palm Beach Boussinesq wave model is shown in Figure 5.

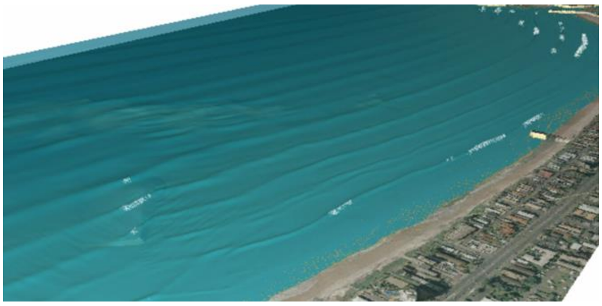

Figure 5 BW model results showing weakly nonlinear waves breaking on the SCS (lower left corner of image). The local wave conditions for the presented scenario: $H_s$ 1.7 m, $T_p$ 12 s and Dir 73°

The program OPTISURF was used to calculate key surfing amenity parameters, including number of surfable waves, maximum length and wave height of each surf ride, from the calculated one hour wave field for the ‘with’ and ‘without’ SCS cases. An example of model output is provided in Figure 6 illustrating the superposition of all possible surf rides occurring during the course of 1 hour of wave action. OPTISURF utilises the instantaneous wave field output to track the moving transition point between unbroken and broken waves. Each of these points is referred to as a pocket point and marks the zone adjacent to the breaking section of the wave; the optimum position for a surfer during a wave ride. For each time step, each pocket point was tracked back to its previous position if it exists. The vector length between the two points describes the minimum average speed the surfer would have had to maintain in order to keep surfing the wave. If the average speed exceeds 10 m/s, the particular section of the wave is considered non-surfable and the surf ride is terminated (known in the surfing community as a ‘closeout section’). Subsequently, a new ride is initialised for the new pocket point.

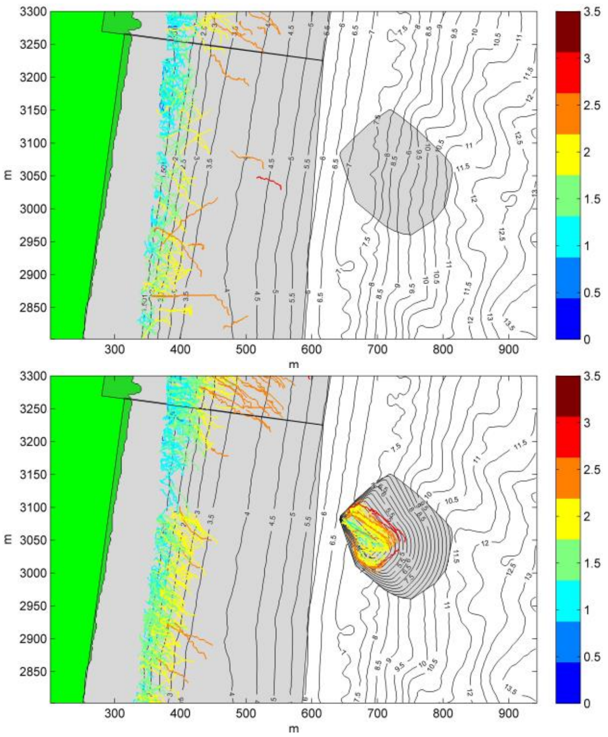

Figure 6 OPTISURF results including the total number of possible surf rides during one hour for the without-SCS (top) and the with-SCS (bottom) layouts. The colour bar to the left marks the maximum wave height [m] experienced during each ride. It is noticed that the largest ridable waves experienced are confined to the SCS.

The surfing impact assessment study for SCS B resulted in expected surfable rides of 50 – 70 m on a regular basis and at times to exceed 90 m.

For all four wave events a considerable amount of wave focusing is created by the SCS structure. The significant wave height at this location is 27% - 53% larger than if the SCS had not been present.
The strong focusing characteristics of the SCS results in a sheltered wave shadow zone with a width of approximately 300 metres extending from 100 meters south of 19th Avenue to the 21st Avenue groyne. The sheltered zone is expected to experience a significant reduction in wave heights during most conditions suitable for surfing. The sheltered zone will be followed by an approximately 200 m wide transition zone to the North and South, where the wave field will be subject to minor changes due to wave diffraction into the sheltered zone. The remaining wave field of Palm Beach should not experience any impact as a result of the SCS.
The SCS B layout was found not to cause any hazardous near-shore currents affecting swimmers during any of the events tested.

## 6. Conclusion and Recommendations

The Palm Beach SCS concept design considerations have been carefully assessed through a highly thorough review of past attempts of SCS design forming a tried and tested foundation of knowledge which we can learn and progress from. Application of the latest technologies in numerical modelling has enabled the concept design to be tested and optimized with an unprecedented level of accuracy. At the current stage of the project it is considered plausible that the SCS design could potentially help stabilizing one of the most vulnerable sections of Palm Beach while also providing an overall increase in surfing amenity. It is however of utmost importance to highlight that several key aspects of the design processes are still subject to further investigations before the overall performance assessment can be finalised.

As the SCS could have the potential to cause downstream erosion it is essential that this will be mitigated to acceptable by the design layout of the beach protection scheme incorporating the northern area of Pam Beach, where beach volume has been historically stable and adequate to provide a buffer.
The stability and rock size requirements are of key importance with regards to projected construction cost and detailed physical modelling would be required to confirm that previous estimates have been conservative. The high porosity of rock will on its own most likely result in some level of wave dissipation which may affect both performance with regards to coastal protection and surfing and most likely be accounted for once a final rock sizing has been determined.

Safety involving the use of the SCS for surfing as well as the structure's influence on the safety of other stakeholders such as boat users and divers are paramount and will have to be investigated in further detail to assure that the structure under no circumstances causes an unacceptable risk to the public.

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