PAPER 13

SMALL COASTAL STORMWATER OUTLETS: LITERATURE REVIEW AND DESIGN GUIDELINES

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ABSTRACT

Stormwater usually drains into nearby rivers, lakes, pans, wetlands and the sea. Comprehensive manuals for stormwater management on land, and on coastal engineering have been published. However, only limited guidelines are available for coastal stormwater outlets. Funds for small and medium coastal outlets are often limited and therefore, must be used optimally, requiring design guidelines. The aim of this project was to provide general guidelines which should be used during design of small to medium sized coastal outlets. The project consisted of two phases.

Phase 1 mainly entailed a comprehensive literature survey (Schoonees & Theron, 2016). The aim of Phase 1 was to undertake a literature survey, to extract all relevant design guidelines for small and medium coastal outlets and to assess the applicability of these guidelines for South African conditions. Although the emphasis was on coastal factors impacting on stormwater outlets, mitigation measures described for the land factors (best management practices) are also briefly addressed because these practices affect the coastal design aspects. The Phase 1 report entails: a brief summary of the most important literature regarding small to medium sized stormwater outlets; it deals with the coastal issues and typical problems associated with coastal stormwater outlets; available best management practices for stormwater outlets are compiled, and the applicability of these practices for South African conditions is assessed. However, it was found that the limited existing guidelines are inadequate; therefore Phase 2 was initiated.

Phase 2 focused on drawing up comprehensive design guidelines for coastal stormwater outlets (Schoonees & Theron, 2018). If the number of failures of stormwater outlets and the associated costs are considered, it is clear that a detailed set of design guidelines are required. The limited existing guidelines for stormwater outlets were incorporated and significantly expanded by adding guidelines focusing on the coastal factors influencing the design of stormwater outlets and the problems caused by these factors. In the Phase 2 report, coastal processes and marine information relevant to the design of these stormwater outlets are briefly described. The guidelines cover: design methods; beach usages; aesthetics and location; shoreline changes and scour; protection of the outlet; water quality; and catalogue applicable legislation. Recommendations on the construction of small stormwater outlets are also provided regarding using favourable weather optimally, comments on the use of marine concrete, effects of sand transport and the protection offered by cofferdams. Both phases of the project were sponsored by IMESA.

1. INTRODUCTION

Limited funds are usually available for design and construction of small and medium coastal stormwateroutlets, despite considerable problems often being experienced. At the shoreline, not only land factors (e.g. ground slope, runoff), but also coastal factors like waves, currents and wind-blown sediment affect stormwater drains, thus necessitating innovative infrastructure solutions for sustainable outlets. Comprehensive manuals for (1) stormwater management on land; and (2) on coastal engineering have been published. However, only limited guidelines are available for coastal stormwater outlets.

Small to medium sized outlets are defined here to be outlets having diameters of less than 1 000 mm or rectangular (or square) outlets smaller than 1 000 mm by 1 000 mm. This project on small to medium sized coastal outlets has been divided into two parts, namely:

- **Phase 1: Literature survey**. Guidelines available in world literature were compiled the applicability of these guidelines to South African conditions was investigated (Schoonees & Theron, 2016). It was found that existing guidelines were inadequate.
- **Phase 2: Design guidelines**. Existing guidelines for stormwater outlets are presented and augmented by additional guidelines focusing on the coastal factors influencing the design of stormwater outlets.

Therefore the aim of this report (Phase 2) is to compile a set of design guidelines for small and medium coastal stormwater outlets applicable to South African conditions (of which the outlets around Mossel Bay serve as an example). A typical small to medium sized coastal stormwater outlet in shown in Figure 1. Furthermore, mitigation measures (widely called best management practices) for land factors have also been briefly addressed (refer to the Phase 1 report; Schoonees & Theron, 2016) because these practices affect the coastal design aspects. The land factors, which include the hydraulic and structural design of stormwater infrastructure and outlets, are not included in the scope of this study. Some recommendations on the construction of small stormwater outlets are also given. Furthermore, the most important applicable legislation is presented briefly.

Figure 1: A typical small to medium sized coastal stormwater outlet. (Photo: AK Theron)

The guidelines in this report are necessarily of a general nature. In certain cases, other measures may be more appropriate or more important based on local conditions and the characteristics of the particular site. IMESA, Stellenbosch University, IWEESU and the authors take no responsibility for the application of the guidelines in this report. A competent civil engineer needs to assess all factors and take full responsibility for his/her design and construction of a stormwater outlet.

2. COASTAL PROCESSES AND DESIGN INFORMATION FOR STORMWATER OUTLETS

The coastal processes that need to be considered and information required for design and construction of coastal structures include: (1) location of the site; (2) bathymetry and topography (from a conventional topographical, or a LiDAR survey and SANavy hydrographic charts); (3) nature of shoreline and seabed(including the characteristics of the foredune); (4) historic shoreline changes; (5) winds, waves and currents; (6) seawater-levels (including sea-level rise); (7) sediment transport: longshore, cross-shore, aeolian; (8) environmental issues; (9) effluents and water quality, circulation, dilution and dispersion; and (10) conflicting beach usages (Schoonees & Theron, 2018).

3. GUIDELINES

3.1 Beach usages, aesthetics and location

The outlet structure should be as small as possible, yet be functional. Public access along the beach must be maintained. Sharp edges and unnecessarily protruding structural elements (especially, metal bars, etc.) should be avoided to reduce possible injuries, especially if the structure is submerged at times. Conflict must also be avoided as far as possible with other "beneficial coastal zone uses": that is, direct contact recreational activities (for example, swimming), indirect contact recreational activities (for example, sunbathing), collection of filter feeders (such as shellfish), marine protected areas, port and industrial facilities, mariculture (including abalone farms), and undeveloped and pristine coastal environments. The discharge from stormwater outlets is sometimes highly polluted and can result in human health or environmental issues if the discharge location is too near any of the before mentioned "beneficial coastal zone uses".

Some typical site selection criteria for a small coastal outlet have been summarised and guidance regarding elevation of the end of the outlet structure has been provided in Schoonees & Theron (2018). The particular circumstances and local site characteristics have to be considered in each case. The design approach regarding location, layout and detailed design, should be to "work with nature". An outlet should be as unobtrusive as possible by making it blend in with the surrounding area. For example, by: (1) covering the outlet with irregularly placed rock; (2) burying it where feasible; (3) avoiding regular and angular shapes; and (4) do not use bright colours. Because of marine growth, there is no point in colouring or painting an outlet below about the high-tide mark.

Numerous outlets over a short longshore length of shoreline will make the coastal zone to appear artificial. Where possible, different smaller outlets should be combined into a larger outlet for hydraulic and cost reasons. The same principle applies for aesthetic reasons. It is also recommended to incorporate and hide the outlet into coastal structures such as jetties, piers, promenades, look-out platforms, seawalls, groynes, revetments, breakwaters, boat ramps, etc.A coastal structure that has more than one function will not only save cost but will, in total, have a reduced visual impact compared with more than one structure. A landscape architect can also be consulted to make the outlet(s) less obtrusive.

An outlet should, wherever possible, not obstruct people from using the beach. Means to safely walk across or around an outlet should be provided where necessary. This crossing point can be higher up the beach so that the railing at the crossing point will not be subjected to wave forces. Note that kelp, seagrass and other material can become entangled on railing, thus resulting in large forces. By providing a small, raised platform as a lookout area at the crossing point, the structure of the crossing point can have a dual function.

3.2 Shoreline changes and scour

If there is a significant *long*-term eroding trend of the shoreline, a conservative estimate of the erosion rate is extrapolated for the design lifetime; usually, 50 (or 100) years. This constitutes the horizontal distance that the outlet should ideally be placed landward of the present sandy shoreline to provide for long-term shoreline erosion. Typical *short*-term horizontal shoreline variations along exposed South African beaches are of the order of 30 m to 80 m (to perhaps 90 m in the most extreme cases), to less than 30 m in more sheltered locations. The long-term and short-term horizontal distances should be added together for placing the outlet.

Typical vertical variations on very exposed South African beaches are of the order of 2 m to 6 m during the most extreme storm erosion and progressively less than 2 m for less exposed locations. Hard structures, including stormwater outlets that are located on sandy shorelines and positioned within reach of the sea, are also subject to scouring of the toe of the structure or underscouring of the foundations. Outlets structures must be designed to cope with the maximum expected scouring in addition to the natural vertical beach profile changes discussed above. Thus, the structure must be able to span between adjacent supports without relying on any support from the beach sand in between spans.

A number of options exist to combat underscouring of stormwater outlets due to wave action. These options include locating (or in some instances relocating existing) outlets higher up on the beach away from the sea, or using rigid or flexible protection for the outlet structure as described Schoonees & Theron (2018).*In any event, the outlet should have adequately dimensioned and well-constructed back and side walls and a well-founded floor. Good quality materials should also be used* as the structures are located in the aggressive coastal environment. These measures will protect the outlet and prevent damage to the concrete itself. The protection of pipes (encasing) to increase structural strength and durability may be an option, but only if properly designed, including adequate foundation support and scour protection where required.

3.3 Protection of the outlet

3.3.1 General

An outlet structure can be protected by different permanent methods, namely: (1) concrete structures; (2) rock protection; (3) sand bags; (4) grout and block mattresses; (5) gabions and Reno mattresses; and (6) other methods.

3.3.2 Concrete structures

Concrete of a high quality and strength and low permeability should be used for marine works; for example, to limit corrosion of reinforcing steel. Adequate cover and crack control for the concrete (including painting with a bitumen mixture) are very important.

By locating the stormwater outlet structure in the lee of rock, wave forces and cost can be reduced significantly. Generally, concrete outlets need a firm, stable foundation. Thus, use the beach profile and nature of the seabed to reduce cost. On a rocky or a mixed rocky and sandy coast, the pipeline can be placed in a gully, fixed to the rock with dowels and/or concreted over to cover it.

Rock levels above and under the seabed are required. Furthermore, weathering of the bedrock needs to be assessed in foundation design.

It is recommended to anchor marine structures firmly to bedrock where possible. If the bedrock is located deeper down, end bearing piles can be considered. If the bedrock is below the expected extreme scour level, then a stone screed layer can be place on top of the bedrock in order to obtain a level surface. For shallower bedrock, concrete placed over dowels (anchored to the seabed) should be used. If it is not feasible to use the bedrock as foundation, then rock or other protection measures should be considered.

3.3.3 Rock protection

General

Because a rock revetment is usually the cheapest option to protect the stilling basin of a small outlet from wave and current action, other options should be compared with a rock revetment in terms of functionality, lifetime and cost. Figure 2 illustrates a typical cross-section of a rock revetment. The design wave and water-level condition(s) at the rock revetment can be determined based on depth-limited conditions and/or by wave transformation modelling.

Rock properties

Equations for basic rock properties such as median mass and rock layer thickness have been presented. The minimum thickness of gravel, stone or rock layers is 300 mm. Design methods are applicable for rock with standard narrow gradings. If rock has be used that does not adhere to a narrow grading, it means that special physical model tests are essential to substantiate a design.

Rock revetments should have a minimum crest width of 3 to 4 times the nominal rock diameter. Typical rock slopes for revetments and breakwaters range from 1: 1.5 to 1: 3. Slopes steeper than 1: 1.5 should not be used for rock revetments. The flatter the slope of a rock revetment, the more stable the rock will be. However, smaller, but considerably more rock, will be required.

The relationships between rock sizes in adjacent layers have been given in Schoonees & Theron (2018); rock in a lower layer should be 10 to 15 times smaller (in terms of mass) than the rock in the layer above. It is recommended to use the factor 10 because it is somewhat conservative. If the rock placed during construction deviates slightly from the specified rock, the rock should still be within acceptable limits.

Design approach

For small coastal outlets, it is recommended to design rock slopes to be statically stable. Failure modes for a rock revetment have been discussed in Schoonees & Theron (2018). The design approach for a rock revetment to protect a small coastal outlet can be summarised as follows(Schoonees & Theron, 2018):

- Decide on the usage of the area in the lee of the revetment.
- Choose rock as armour and the revetment slope; usually, 1: 1.5 to limit the rock volume.
- Calculate the wave run-up and/or tolerable overtopping rate. For small coastal outlets, very little overtopping should be allowed so as not to damage infrastructure.
- Determine the crest height based on the wave run-up and/or the allowable overtopping.
- Choose the wave (or notional) permeability (P).
- Choose the allowable damage. Use Sd = 2 ("start of damage") so as to minimise maintenance.
- Compute the median size of the armour rock.
- Calculate the thickness of the armour layer based on the size of the armour rock.
- Determine size and thickness of the underlayer, filter layer and core rock.
- Design the toe of the revetment.
- Decide on whether a mass capping is required based on access to the outlet by crane or truck for maintenance. A crown wall is expensive and normally it should not be necessary.
- Construction methods. End tipping is usually carried out to deliver rock for a revetment.
- The bearing capacity of the seabed soil must be sufficient to support the revetment. It may be necessary to excavate soil to reach a better foundation and/or gravel to fill the excavated soil.
- Rock and other construction material must be locally available. For rock, it is necessary to consider sizes and whether sufficient quantities can be obtained.

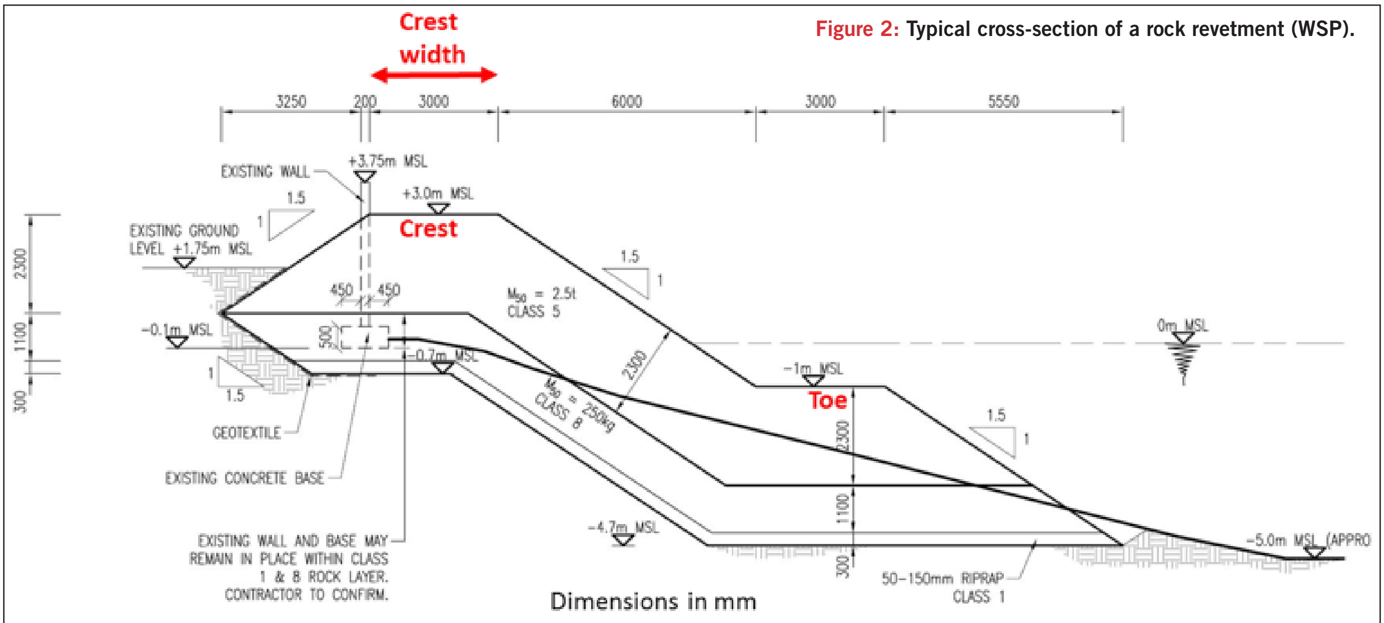


Figure 2: Typical cross-section of a rock revetment (WSP).

Wave run-up

Equations for computing the wave run-up have been presented for impermeable and permeable rock slopesin Schoonees & Theron (2018).

Design method for armour rock size in shallow water

The Van Gent equation (CIRIA, CUR, CETMEF, 2007) can be used to calculate the required size of the armour rock on a straight section of a revetment in **shallow water**. In this equation, the $D_{n50,core}/D_{n50}$ factor = 0 if a geotextile is applied (as for a revetment). If the outlet is in deeper water, then CIRIA, CUR, CETMEF (2007) should be consulted for alternative design formulae. It also needs to be checked that the wave height used is possible; that is, the depth-limited scenario. Unless a detailed storm analysis has been carried out, the maximum number of waves should be assumed; namely, N= 7500.

Toe design

Usually, rock toes are designed to be flexible; that is, limited rock movement is allowed whereby rock falls into the start of a scour hole but without this rock movement affecting the armour rock layer. A typical cross-section of a rock toe that can be built on a rocky seabed is illustrated in Figure 3 (CIRIA, CUR, CETMEF, 2007). The toe is anchored in an excavated trench. Another possibility is to construct a toe beam that is anchored to the seabed by means of piles. A special toe has been proposed for sandy seabeds with a severe scour potential (Figure 4; CIRIA, CUR, CETMEF, 2007). Typically, sandy South African shorelines have a severe scour potential.

Geotextiles

Usually two types of geotextiles (filter fabrics) are applied in the marine environment, namely: (1) woven geotextiles; and (2) non-woven (or needle-punched) geotextiles. The filtration function of geotextiles is most important for revetments. The water permeability has to be maintained during the life of the revetment. A criterion for a geotextile to be sand tight has been specifiedin Schoonees & Theron (2018).

Soil has to be properly prepared by removing loose objects so that the ground is even and that the geotextile can lie flat. Note that the dumping of large rocks and stones (> say, 50 kg) directly onto a geotextile can damage it. Therefore, a filter layer (s) may be required on top of the geotextile to protect it against falling stones and rocks. Usually, the geotextile is rolled down the slope to place it. It may be necessary to initially place stones or a small heap of gravel on the geotextile to keep it in position until the correct filter layer can be placed on top of it. Different seams (joints) for geotextiles have been listed in Schoonees & Theron (2018). It is recommended that seams be used to connect different strips of geotextiles. Overlapping without stitching is not recommended (Rankilor, 1994). A hand-held sowing machine can be applied on site to do the stitching.

It is recommended that specifications about different characteristics and suitability of the geotextile for the application be obtained from manufacturers. Characteristics like the mass of geotextile per unit area, pore sizes, water permeability, puncture resistance, tensile strength, stretching during tensile loads, etc. should be provided (Ingold & Miller, 1988).

General comments on rock design

The layout of the revetment has to be considered carefully to assess possible vulnerable sections and to evaluate the 3-dimensional effects of the revetment (including the effect on the adjacent shoreline). Vulnerable sections of the revetment are corners of the revetment and transition areas. Smooth transition areas are required. It may be necessary to increase the rock size at bends and corners; or use the larger rock in the grading at the corners.

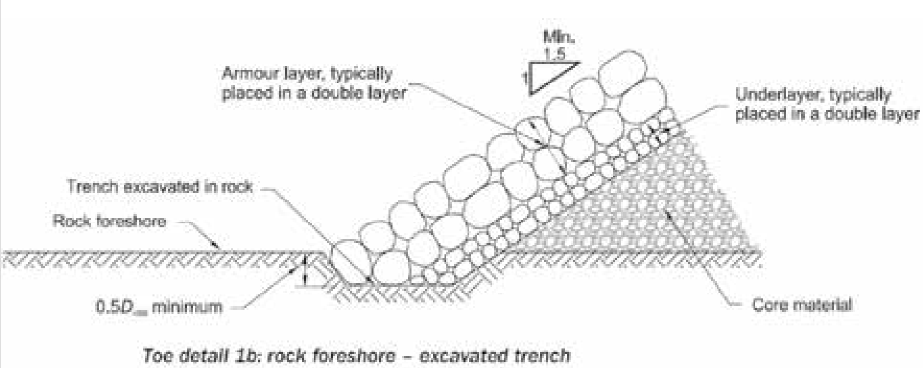
3.3.4 Sand bags

Large sand bags filled with sand, grout or concrete have been applied all over the world and in South Africa (Langebaan and KwaZulu-Natal) to combat coastal erosion. Of the measures using geotextile sand-filled containers, sand bags are the best suited to protect small coastal stormwater outlets in the long term. For short-term usage, refer to Section 4.

The most important failure mechanisms for sand bag protection have been listed in Schoonees & Theron (2018). The design of a sand bag revetment must include the durability of the geotextileand thestability of the structure. Regarding *durability*, a sand bag can, clearly, only be effective as shore protection as long as its contents remain in the bag. A significant advantage of sand bags is that the material (sand) for fill is available at the site. There are a number of ways in which the sand fill can be lost from the bags, namely:

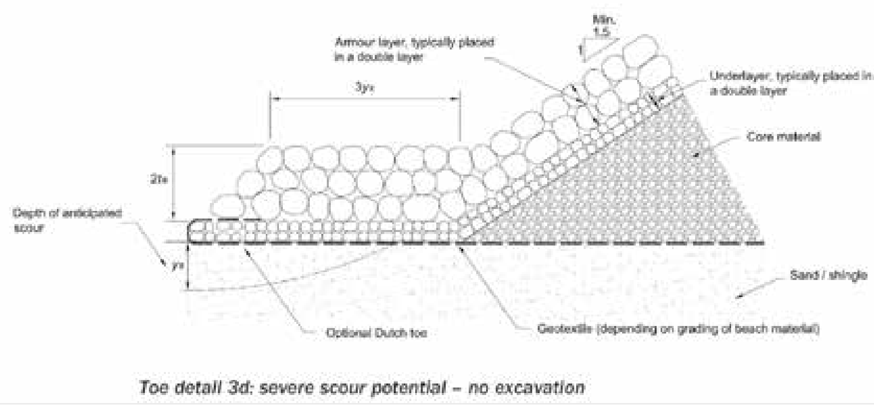
- The bags can tear or burst open. Partially filled bags are particularly at risk.
- Abrasion of the bag fabric by sediment, debris, boats and pedestrians can cause failures.
- Despite added inhibitors, the ultra-violet light of the sun can degrade the fabric of the bags.
- Vandals can cut and damage the bags.

It is recommended to use a double layer geotextile for the bags (Hornsey et al, 2009). Apart from being stronger and resistant against abrasion, the outer layer protects the inner layer against ultra-violet light. Furthermore, sand grains are trapped in the outer layer, which makes it considerably more difficult to cut with a knife and thus, reduces vandalism. The material used for EnviroRock by Kaytech (2017) in South Africa had similar properties. Saathoff et al (2007) and Rankilor (1994) give a good description of the required characteristics and tests to be conducted of the geotextile to be used



CIRIA, CUR, CETMEF (2007)

Figure 3: Typical cross-section of a rock toe that can be built on a rocky seabed.



CIRIA, CUR, CETMEF (2007)

Figure 4: **Special toe proposed for sandy seabeds with a severe scour potential.**

for making sand bags. Kaytech (2017) lists the characteristics and tests done for EnviroRock.

A typical cross-section of a sand bag revetment is depicted in Figure 5. It is recommended to use a double layer of sandbags and to place the sand bags with their long axes perpendicular to the shoreline. Sand bags of 2.5 m³ are recommended; however, do not use bags smaller than 1 m³ or bags much bigger than 2.5 m³. Sand bags should be filled to capacity, but not be overfilled. The bags should be closed by stitching. Sand bags should not to be damaged during construction. Old conveyor belts can be used to protect the placed sand bags from construction vehicles.

Excessive wave overtopping can damage infrastructure and even be dangerous for pedestrians and cars (EurOtop, 2007). It is recommended that the sand bag revetment be built high enough to prevent significant wave overtopping. Nevertheless, attention should be given to the possible lateral flow of overtopped water during conditions exceeding the design condition. For example, placing a few bags in rows on top of the structure to form little groynes or spurs at regular intervals alongshore, should limit lateral flow and allow the overtopped water to drain through the structure.

The best slope based on present research is 1: 1 (Figure 5). A design graph for 2.5 m³ sand bags for different slopes is contained in Schoonees& Theron (2018). It is not recommended to use slopes steeper than 1: 1. The design procedure by Recio (2007) and Recio & Oumeraci (2008) is recommended for the design of sand bag revetments. It is recommended that two or more sand bags as a flexible toe be placed directly on the sand seawards of the bottom of the slope (additional to the toe shown in Figure 5). The orientation of these bags should be alongshore.

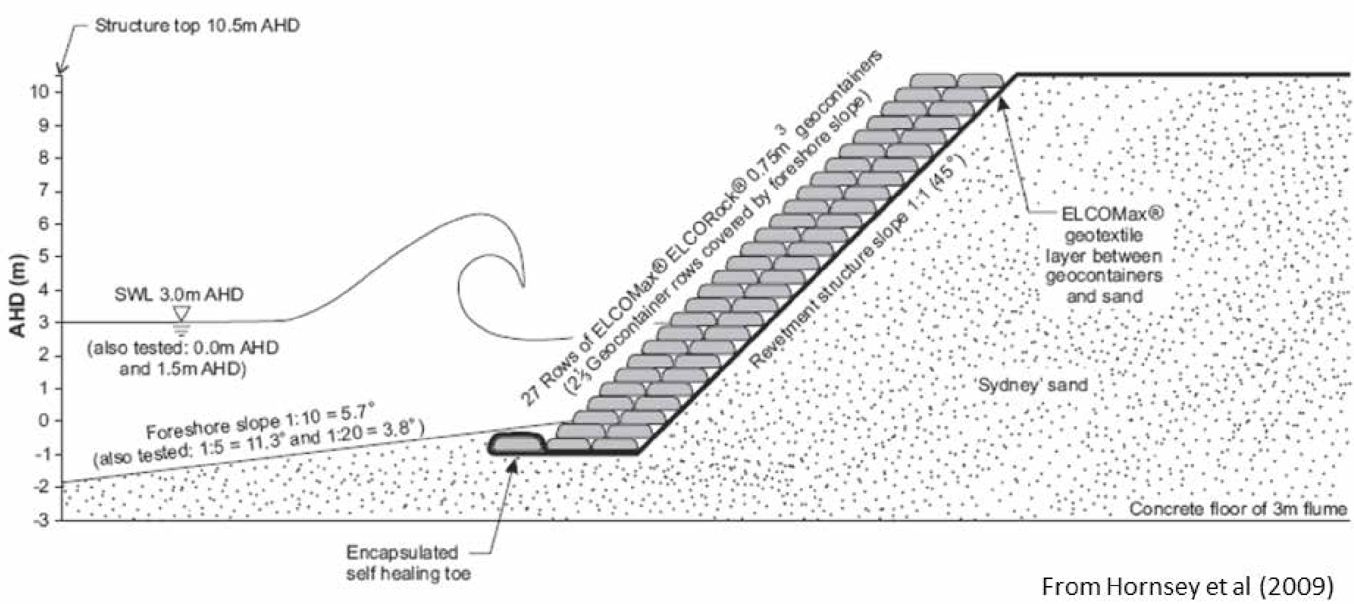
The planshape and 3-dimensional aspects of a sand bag revetment should be considered carefully. The sand bag protection should enclose the outlet structure; or else, the revetment should continue sufficiently far landwards so that the outlet is not attacked by waves from behind (the land side) after the adjacent beach had been eroded. There should be no sharp corners in the sand bag revetment.

It is important to note that attention should be given to details of a sand bag revetment because experience has shown that failure can occur because of small issues regarding the design. It is recommended that physical model tests be conducted to optimise the design of a sand bag revetment.

3.3.5 Concrete block and grout mattresses

Concrete block mattresses are solid or perforated concrete blocks that are usually connected by means of wire or polyester rope. For marine applications, strong, polyester rope is preferred. These mattresses are placed on a geotextile that covers the ground, allows water flow through the mattress and prevents or limits soil leaching out from underneath the geotextile. Sometimes the concrete blocks are cast directly onto the geotextile with fabric loops. Concrete block mattresses are flexible so that the mattresses can follow the ground contours and allow for settlement. It is customary to fix the mattresses on steeper slopes by using stakes hit

Figure 5: **Typical cross-section of a sand bag revetment.**



From Hornsey et al (2009)

into the ground. Perforated blocks can either be filled with gravel or coarse sand to restrict vegetation growth or filled with topsoil to stimulate plant growth. Pipelines are regularly protected by placing concrete mattresses over them.

A *grout mattress* consists of two connected geotextile sheets, one on top of the other but closed at the edges. At regular intervals in both directions, these two sheets are woven together in spots, thus forming permeable weep holes. After preparation of the soil, the grout mattress is laid out and sometimes fixed to the soil by means of stakes (especially on steeper slopes). The geotextile sheets act as formwork when the geotextile sheets are pumped full with grout from the lower elevations of the geotextiles sheets to the higher points. The weep holes remain intact, allowing water flow back and forth. Excess grout should not clog the weep holes. The weep holes that force the grout into a rounded rectangular shapes throughout the mattress, also make the grout mattress flexible. Clearly, exposure to ultra-violet light from the sun will result in degradation of the geotextile. Therefore, grout mattresses should preferably be covered.

Proper design of concrete block and grout mattresses must include the following:

- Ensure that the mattresses will be stable during extreme conditions.
- The geotextile must remain functional during its design life. The geotextile must be permeable; not allow the leaching out of soil from underneath the mattresses; and must not tear.
- The applicability of construction methods has to be considered. Practical issues to be evaluated include joints and seams of the geotextile.

The Rankilor (1994) graph that can be used for conceptual design of *concrete block mattresses* has been presented in Schoonees & Theron (2018). This graph enables the determination of the required thickness of the mattress. The slope at which the concrete mattress is placed must be flatter than 1: 2.1 (25 degrees) and that a maximum wave height 1.2 m applies (Rankilor (1994). Furthermore, a thick geotextile and/or a granular underlayer should be used to reduce hydraulic pressure underneath the grout mattress (Rankilor (1994).

The Rankilor (1994) conceptual design method for *grout mattresses* has been discussedin Schoonees & Theron (2018). Rankilor (1994) states that a thick geotextile and/or a granular underlayer should be used to reduce hydraulic pressure underneath the grout mattress. The design methods by Klein Breteler & Pilarczyk (1998), Rankilor (1994) and PIANC (1992, 2011) can be applied for the hydraulic stability of mattresses. Pilarczyk (2000) provides further information on the use of geotextiles. Klein Breteler&Pilarczyk (1998) stressed the importance of the geotechnical properties of the foundation soil. In evaluating the stability of the mattresses against sliding and possible lifting of the mattresses, the following geotechnical conditions should be adhered to: (1) elastic storage; (2) softening (liquefaction) of the foundation soil; and (3) a drop in the water-level.

In general, the requirements for a suitable geotextile should at least include the following (Ingold & Miller (1988), Rankilor (1994), Pilarczyk (2000) and PIANC (2011)):

- The geotextile should be very permeable to water (especially for wave up- and downrush).
- The geotextile must have a high strength and should not stretch excessively.
- Sediment should be contained underneath the geotextile and should not wash out.

Note that the use of grout mattresses in the coastal zone in shallow water is restricted to maximum significant wave height less than 1 m. For higher waves, the required thickness of the mattress becomes too large and then either rock or armour units is/are a better solution.

Special attention must be given to fixing the mattresses to the outlet structure and also to the edges of the mattresses. These edges should be buried so that they are more stable whilst also making it more difficult for thieves and vandals to access the edges of the mattresses. In the case of concrete block mattresses without an inbuilt geotextile, the edges of the mattresses should be without geotextile. These strips of mattresses without geotextile should be far enough from the outlet structure so that the stability of the outlet structures is not detrimentally influenced by the local sinking of the mattresses along the edges.

Geotextile normally come in rolls with a given width. To cover the required area, different strips of geotextile have to be properly joined by either a strong, sown joint or by gluing the strips together. Overlapping of geotextile strips should be avoided if possible. Industrial sewing machines are available for easy joining in the field. Where possible, the orientation of the geotextile strips should be at right angles to the shoreline.

For grout mattresses, care have to be taken that grout is not lost through the geotextile. Furthermore, the geotextile should be filled to capacity throughout the mattresses. This will ensure stability and prevent flapping of a half-filled mattress.

3.3.6 Gabions and Reno mattresses

Experience in Southern Africa has clearly indicated that the life of gabions in the sea is limited because of abrasion, corrosion, failure of the wire and the stone being washed out. The use of gabions and Reno mattresses in the sea is generally **not** recommended. However, if gabions and Reno mattresses are very seldom (less than once a year) exposed to wave and current action for a short time and buried for the rest of the period, they can be used in the coastal environment. Nevertheless, it should in these instances still be evaluated whether loose rock will not be a better option. Note that gabions can be very handy to place a filter layer of rock to drain water away. That is, a gabion lined with a geotextile and filled with gravel can easily be placed around a structure. This means that the gabion is used for: (1) ease of construction (and its strength is not required after deployment); and (2) to limit the volume of gravel.

3.3.7 Other methods

Placing the stilling basin of the outlet very high up on the beach may make it unnecessary to protect the outlet against wave action. The best management practices described in Schoonees & Theron (2016) such as exfiltration, should be used to reduce or eliminate any outflow, even during floods. Typical consequences of an outlet discharging landwards of wave action, include a pool of stagnant water at the end of the outlet and potential aeolian sand transport problems.

By building a large pier or jetty to support the outlet above any wave action, is another possibility. Another option is to incorporate the whole outlet in a groyne, seawall or breakwater. These options are very expensive and most probably only financially feasible if the structure are built for other purposes as well.

3.4 Water quality

3.4.1 General

In general, prevention is better (and cheaper) than cure. The following guidelines and recommendations have been presented in Schoonees & Theron (2016) in this respect, namely:

- Pollution associated with stormwater outlets relates to: (1) pollution in the sea near the outlet; (2) stagnant pools formed at the seaward end of the outlet; and (3) debris and litter. All of these problems are ideally alleviated by following best management practices on land.

- Ponding of runoff at the terminal end of the outlet can be prevented or reduced by means of effective outlet structures or by incorporating infiltration components in the outlet system.
- Similarly, litter generated inland should rather be dealt with in the terrestrial domain. Litter traps or mechanisms require significant maintenance to prevent blockages or overspill of litter and are also susceptible to vandalism and theft of metal components.
- Street cleaning is cost effective to remove heavy metals and pesticides close to the source of contamination rather than requiring treatment at the receiving end.
- Exfiltration involves the extraction of a part of the stormwater flow and letting the water infiltrate the soil by means of a perforated pipe and/or a trench. The first flush is usually treated in this way. Exfiltration is also effective to decrease pollution levels, recharge aquifers and to limit the underground intrusion of seawater towards land.

Blockage of stormwater drains can result in stormwater drains overflowing. For drains situated on steep slopes, this overflowing water can cause significant erosion of the steep embankments, which can endanger nearby infrastructure. This has happened at Santos Beach (Mossel Bay) in which the erosion and possibly the associated pollution, severely impacted on the status of this blue flag beach (P Myburgh, Mossel Bay Municipality, pers.com., 2018). The most effective means of alleviating such problems are to address the issues upstream of the coastal area, for example, by means of upstream pollution control at stormwater inlets.

3.4.2 Dispersion and dilution

If the contamination of stormwater cannot be prevented, one or more of the following measures can be taken, namely:

- Ideally, the **effluent should be treated** to acceptable water quality standards before discharging into the coastal zone. However, this option is very expensive and usually requires continuous operation.
- **Keep people and animals** away from the impact zone. A distance of at least 100 m alongshore on either side of the discharge point should be regarded as the impact zone unless detailed studies have more accurately indicated the extent of the impact zone. Management measures in this category include:
  - Put up information boards telling beach users to warn them against bathing, swimming, water sports and the collection of mussels, oysters and other filter feeders.
  - Police these impact zones by means of lifesavers or other beach personnel.
  - Close parts of the beaches in during times of first flushes.
  - Monitoring of water quality is required by analysing water samples on a regular basis.
- The stormwater outlet must be **designed to maximise mixing and dilution** and to minimise the impact zone. If possible, a stormwater outlet should not be placed on a bathing beach or alternatively, that the impact zone would be away from the swimming area.

3.5 Pipe materials for small stormwater outlets in the coastal zone

In general, all pipe materials and workmanship should comply with the relevant official standards such as SANS 2001 (CC2, DP1, DP5, etc.). Good quality materials should also be used as pipes and stormwater structures located in the coastal zone are subject to an aggressive environment resulting in both corrosion and structural challenges. Pipes and fittings should be installed according to manufacturers' instructions. Where stormwater pipes are lain down steep coastal slopes, special care should be taken in the design and construction to ensure as little movement as possible and also to prevent scouring along the pipe. In addition, in such circumstances, joints must be well sealed and the pipes should be properly anchored. In the coastal zone fibre reinforced concrete pipes can be used, but steel reinforced concrete pipes are not recommended. Butt welded HDPE pipes with diameters from 280 mm and larger are robust and well suited for coastal outlets. Small diameter (up to 300mm) PVC pipes are suitable for use in some smaller coastal stormwater applications, although pipes of less than about 300mm diameter are not generally recommended. In Mossel Bay it was also found that the spirally wound type of pipe was better suited for use on steep slopes, as the joints could be better sealed and the pipes could be anchored (P Myburgh, pers.com., Mossel Bay Municipality, 2018). Polypropylene, GRP, steel or vitrified clay pipes are not generally appropriate for coastal outlets.

3.6 Applicable legislation

The main legislation applicable are the following: (1) National Environmental Management Amendment Act (#62 of 2008), the updated EIA Regulations (2014), and latest (2017) amendments; (2) Integrated Coastal Management Act (ICM Act #24 of 2008) and ICM Amendment (#36 of 2014); (3) Local Government Act: Municipal Systems (2000); and (4) National Water Act (1998). Policies on the disposal of waste water, as well as other legislation, may be applicable depending on the specific site.

4. CONSTRUCTION GUIDELINES

Wave conditions are generally severe around the South African shoreline. These conditions make working from the sea difficult and expensive. Furthermore, the duration of calm weather is limited. As a result, small coastal outlets will almost exclusively be constructed using access from land. Thus, either: (1) an embankment and/or a cofferdam; or (2) a jetty with or without a cofferdam will be used.

The following general guidelines for construction of small to medium coastal stormwater outlets (Schoonees & Theron, 2016) should be considered, namely:

- **Use favourable weather optimally** by limiting the construction period in the sea. Therefore, all equipment and material must be available and stored close to the construction site. Furthermore, precast concrete elements should be used where possible. In this way, construction can progress quickly during calm and favourable sea and weather conditions. Construction can follow the water-level down as the tidal water-level starts dropping towards low-water spring tide (LWST). Note that for about 2 hours before and 2 hours after low tide, construction above the low tide level can usually be undertaken with little interference from wave and current action and quickset cement can set.
- **Concrete** can be mixed at the work area or supplied by concrete trucks. Concrete can also be placed by using a bucket which is swung by a crane. Alternatively, concrete can be pumped from land to an inaccessible working area by supporting the concrete supply pipeline on scaffolding. Columns or supports for outlet structures can be fixed to a rocky bottom by: (1) placing a concrete manhole ring on the seabed; (2) excavating the sand inside of the ring; (3) drilling holes

into the bedrock; and (4) fixing dowels with epoxy in these holes. The concrete ring acts as formwork and protection against wave action for quick set concrete. It is important to protect the upper surface of the wet concrete in the ring.

- A cofferdam or the abutment leading up to a jetty forms an obstruction to the longshore **transport of sand** at the site and therefore accretion will form on the updrift side and erosion on the downdrift side. This accretion can result in re-excavation of sand while the downdrift erosion may endanger the stability of embankments. Cross-shore sand transport will quickly erode a cofferdam and therefore, protection of a cofferdam is usually needed. Aeolian sand transport is usually only a nuisance during construction. If a trench is excavated for the stormwater outlet, then sand is usually transported into the trench at a considerable rate. Thus, it is recommended to limit the inflow of sand from the sides and to close off the trench at the seaward end for as long as possible. A trench can be excavated by earthmoving equipment or by using a grab operated from a crane on a jetty.
- A temporary **cofferdam** can be: (1) a wall of sand; (2) a sand wall protected by sand bags or sand filled geotextile containers; (3) a rock wall; or (4) a sheet pile wall. Dewatering equipment can also be installed. Sheet piles will reduce the seepage of water into the working area. Timely maintenance of such a temporary structure is important.

A cofferdam consisting of only sand will normally only be feasible if the works area is high up the beach so that wave run-up rarely reaches the cofferdam. It is recommended to apply sand bags (1 m^3 bulk bags) for short-term protection of a cofferdam. It is *not* recommended to: (1) use sand bags smaller than 1 m^3; or (2) to place bulk sand bags on top of each other. The lower rows of bags on the slope of the cofferdam to be protected, should be placed directly on the sand. It is recommended that the bags be closed using cable ties and that the lifting loops be tied together after placement. To remove the bags, the bag material can be cut and pulled out (or picked up later along the shoreline).

Rock together with a geotextile can also be used effectively to protect the outer slopes of cofferdams. It must be ensured that the rock will be stable. Usually rock has to be removed after construction. This is easy on rocky or mixed rocky/sandy seabeds, but difficult on sandy beaches. Flatter outer slopes of the cofferdam will be more stable than steeper slopes, but require more space and rock.

5. CONCLUSIONS AND RECOMMENDATIONS

Limited funds for design and construction of small and medium coastal stormwater outlets, often lead to small and inadequate outlets, requiring relatively expensive repairs and additional maintenance. At the shoreline, considerable problems are often experienced,thus necessitating innovative infrastructure solutions for resilient outfalls. The design approach regarding location and layout of outlets should be to "work with nature". The outlet structure should be as small and unobtrusive as possible, yet be functional. Public access along the beach must be maintained. Where possible, a number of different smaller outlets should be combined into one large outlet for hydraulic, cost and aesthetic reasons.

An outlet structure can be protected by different permanent methods, namely: (1) concrete structures; (2) rock protection; (3) sand bags; (4) grout and block mattresses; (5) gabions and Reno mattresses; and (6) other methods. Design methods and typical cross-sections are presented for these protection measures. Properly designed and well-built concrete and rock structures have the longest expected life, while mattresses, geotextile and gabion structures will not last as long. *Other methods* include exfiltration, building a large pier to support the outlet, and to incorporate the whole outlet in a groyne or seawall. Some of these options are very expensive.

Guidelines have been presented with regard to water quality. In general, pollution should rather be prevented from reaching the seashore by applying "best management practices". If the contamination of stormwater cannot be prevented, the effluent should be treated, people and animals should be kept away from the impact zone of the pollution and/or the stormwater outlet must be designed to minimise the impact zone. Applicable legislation has also been addressed briefly.

Construction guidelines are provided regarding using favourable weather optimally, comments on the use of marine concrete, effects of sand transport and the protection offered by cofferdams.

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