CONCRETE RETAINING BLOCK WALLS

Project Review - Hydraulic Applications

Existing applications are still performing well after 30 years

CONCRETE MANUFACTURERS ASSOCIATION
Quality cast in concrete

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CONCRETE RETAINING BLOCK WALLS IN HYDRAULIC APPLICATIONS

The use of concrete retaining blocks in hydraulic applications requires special detailing and design to take into account hydraulic forces, saturated backfill and environmental effects.

INTRODUCTION

The need to protect the banks of rivers, attenuation pond walls, beaches and other water-courses against erosion, dates back to early civilisation. The response to this need has been development down the years of many methods of protection, often using naturally occurring materials, which today exist alongside modern materials and engineered systems. New materials and new systems are continually being developed. Some of these have been specifically developed for bank protection, while others have been adopted for this use as a spin-off from their intended use.

Two factors are of particular importance in bank protection. Firstly, irrespective of the materials and form of construction, the bank/beach protection forms a part of natural environment, and effectiveness of the design must be judged in environmental as well as engineering terms. Secondly, the development of an adequate design requires a clear understanding of factors affecting the stability of the existing bank/beach, or likely to affect the stability of protection.

Concrete retaining blocks are relatively new to this application but are now the forefront of development in erosion protection, coastal protection and general hydraulic structures where traditional reinforced concrete is visually unacceptable. The blocks have a more natural appearance due to their patterned, uneven face and their ability to be vegetated and all but hidden. Their versatility lends them to some very aesthetic layouts and on larger protects best results will be gained from a multi-disciplinary approach incorporating professionals in the fields of hydraulics, soil mechanics, landscape architecture, horticulture and wildlife.

The use of concrete retaining blocks in hydraulic applications can be divided into three distinct areas: attenuation ponds, river bank protection and coastal protection. River banks are subjected to regular floods and although this may only occur once or twice a year, the effects are quite devastating. Beaches on the other hand are subjected to wave action, which is more predictable and regular.

RIVER BANK PROTECTION

River bank erosion can occur in channels which are stable or unstable. Stable channels experience some local erosion and deposition particularly in meander bends. Changing land use such as rapid urbanisation can cause stable channels to become unstable due to the increase in the run-off pattern. Unstable channels undergo systematic morphological changes along their entire length in an attempt to achieve regime condition.

The nature of rainfall in South Africa, particularly in the interior, promotes instability due to high volume, short duration precipitation with considerable dry spells between rainfall events. Attempts to protect the section of bank without looking at the total catchment are likely to fail and the engineer must consider all possible effects of the proposed protection on the overall stability of the channel.

Erosion occurs when erosive forces exceed the resistive forces of the bank. This initial erosion often destabilises a section of bank leading to mass failure. The main processes responsible for erosion are illustrated in figure 1.

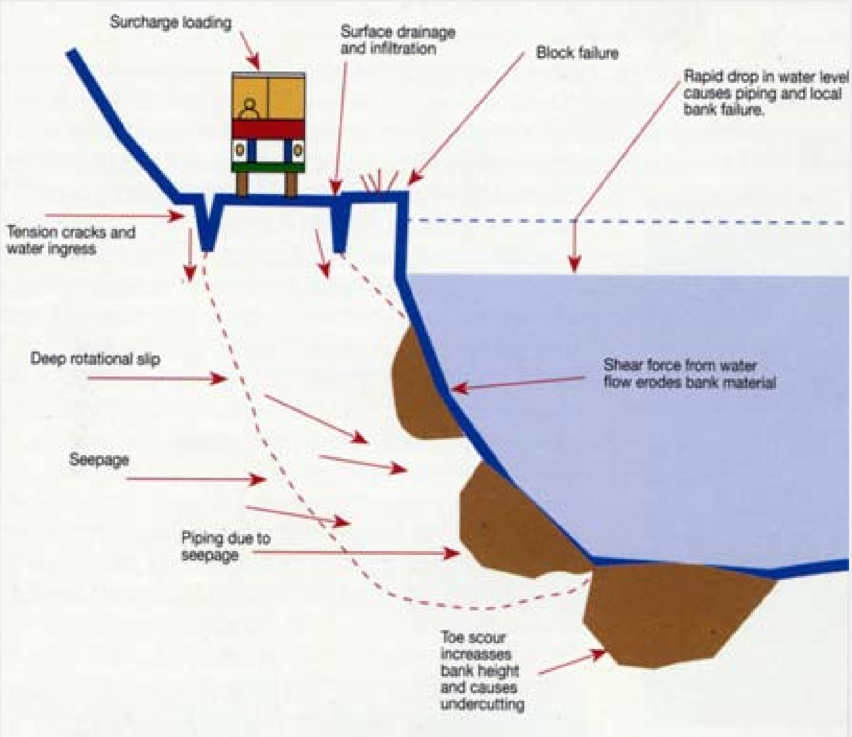
CRESTA CENTRE RANDBURG

Continued erosion of a stream embankment in Randburg posed a serious threat to buried municipal services. An Enviro-Wall earth retaining structure was chosen and installed to protect these services and allow the stream to meander along a defined water course, thus maintaining existing vegetation.

The stream bed was further protected by lining it with an Armorflex erosion protection system.

Photograph 1 *Stream embankment - Randburg*

Figure 1: *Erosion forces on channel bank. Apart from the erosion by current flow, erosion can be generated by the following factors:*



- *Wave action: boat or wind driven waves wash against bank causing removal of material.*
- *Seepage: groundwater flow, depending on hydraulic gradient and permeability, causes piping, and uplift from pore water pressure.*
- *Surface run-off: this causes gullying and removal of bank supporting vegetation.*
- *Effects of local features: large rocks in stream bed or hydraulic structures can drive the flow against a bank increasing the shear force on the bank.*
- *Desiccation: wetting and drying in clays can cause deep cracking, weakening the soil and leading to block failure.*
- *Animal and man: traffic along the bank destroys soil retaining vegetation while burrowing animals can destabilise the bank.*
- *Sudden water level fluctuation: rapid rise in water level causes uplift forces on the bank, while rapid drawdown causes temporary high pore pressure in the bank which can lead to minor block failure.*

JOHANNESBURG BOTANICAL GARDENS

A tributary of the Braamfontein Spruit runs through the Johannesburg Botanical Gardens into the Emmarentia Dam. At the top end of the Botanical Gardens the stream was suffering considerable erosion and flooding damage. It was therefore necessary to line the stream and improve its geometry to eliminate erosion and limit flooding.

Photograph 2 *River bank protection - Johannesburg Botanical Gardens*

The area is extremely environmentally sensitive and the decision was made to use Terraforce and Terrafix blocks because of their plantability. Although unproved in rapidly flowing rivers, this project was to serve as an experiment to test these products under fast flowing water (8m/s). The banks around the bends were protected with Terraforce blocks while straight sections were lined with Terrafiix on 1:3 slope to allow access to and through the stream. Longitudinally, the stream was stepped at 10m intervals to reduce the grade and hence velocities. The blocks were fixed into concrete cross beams at 5m centres. These beams were anchored to the stream bed with duckbill anchors to prevent uplift and roll up. The top two rows of Terrafix were filled with no fines concrete to give a rigid lip to allow the stream to overflow its banks in large storms. A typical cross section of the stream is shown in figure 2 over the page

Continuous monitoring of the stream lining during the 1993/94 rainy season revealed that apart from a few problems related to construction errors, the lining performed very well. The rainy season in question included numerous medium and a number of large storms where the stream overflowed its banks. The blocks were easy to plant and substantial growth took place very soon after construction. Critical details for blocks when used in streams and rivers are the shear keys between blocks. Extensive use of geotextiles, both to reinforce the fill embankment as well as prevent piping from the embankment is also critical. The backfill behind the blocks must be on a free draining nature to prevent build up of hydrostatic pressure. Vegetation of the blocks with deep rooting evergreen plants as soon as possible is critical to the success.

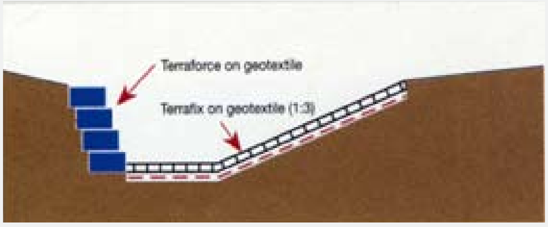


Figure 2a: Typical cross section at bends

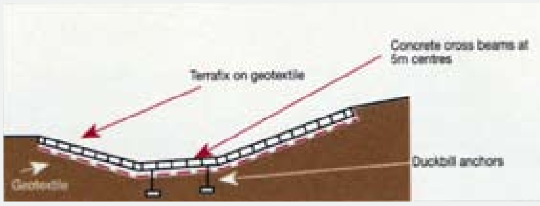
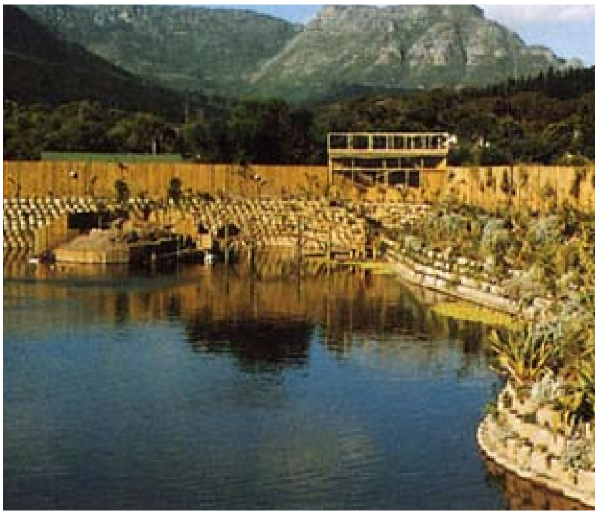


Figure 2b: Typical cross section on straights

HOUSE RUBEN - HOUT BAY



Photograph 3 *Artificial Lake - House Ruben - Hout Bay*

Concrete retaining blocks have also been used to construct artificial lakes; in this case at House Ruben, Hout Bay.

The lake is situated in soft, easily erodible, alluvial soil with a rapidly rising and falling water table.

The requirements to overcome this problem were as follows:

- *The soil had to be retained at a steep angle without much fuss and delay immediately after excavation.*
- *While being fully permeable to prevent the build-up of hydrostatic pressure, the migration of soil through the structure had to prevented.*
- *Finally, the wall was to be plantable in order to present an attractive, environmentally acceptable elevation.*

Terraforce was chosen for this project. The closed vertical surface structure combined with open horizontal structure of this system is permeable and does not inhibit the penetration of primary root systems. Furthermore, the system is interlocking both vertically as well as horizontally and offers maximum mass per square metre when completed.

After excavation, a gravel foundation was placed on a geotextile separation layer. Terraforce was constructed directly on to this foundation and filled with a mixture of gravel and soil up to the high water mark. Topsoil was used to fill the elements above this level. A geotextile filter layer was placed behind the blocks. Due to the flexible nature of the system, no settlement problems were encountered.

The versatile reversible nature of these elements allowed the construction of various interesting features. A set of steps leading to a landing platform for small boats was fashioned. A number of sharp curves, combined with terraces were integrated into the structure to create interesting variations.

After completion, units above the high water mark were planted with suitable plants and within a short period the basic structure was no longer visible.

EMBANKMENT PROTECTION – SECUNDA

Due to its interlocking action, Enviro-Wall blocks were chosen to protect a river embankment in Secunda.

In the closed configuration, the blocks provide a hydraulicly smooth section doubling in this instance as culvert headwalls.

Greening of Enviro-Walls in hydraulic applications is easily achieved by simply opening the blocks above top-water level to provide growth pockets.

Photograph 4 *River bank protection - Secunda*

COASTAL PROTECTION

Coastal erosion is caused predominantly by wave action which is aggravated by the tides, especially spring tides. Ocean currents and the local topography also play an important role, as these factors will dictate the scour/deposition patterns of the sand on the beaches. Beach sand which is cohesionless and single sized is very susceptible to scour. Changing ocean currents can have a devastating effect on beaches, not only threatening structures along the coast, but also affecting the leisure potential of beaches which is an important source of income for coastal resorts.

Research was carried out at Stellenbosch University where models were built to test the effect of wave action on the crb walls. As a result of this research, a method of construction was specifically developed for coastal protection. The method of construction is shown in figure 3 and includes the following:

(1) Galvanised plastic coated Gabion Baskets (Packed with mass handstone): *The baskets are use to form a firm footing on the bedrock wall below the lowest mean sea level. They also fulfil the vital functions of mass drainage due to the ground water and overtopping in times of heavy seas and a levelling medium on which to ground the walls concrete foundation.*

(2) Concrete foundation set on Gabion Baskets: *This concrete foundation typically consists of 25 MPa strength concrete, 200 mm thick shuttered to a width of 900 mm. Waterloffel blocks are then placed on the wet concrete and set for line and level.*

(3) Ballast drain: *20 mm Graded stone ballast drain must be formed from the centre compartment of the Waterloffel extending upward to 300 mm behind the walls and encapsulated in geo-fabric. This ballast is essential to allow free drainage behind the wall, especially when the wall is being overtopped by heavy seas.*

(4) Waterloffel (Block weight 72 kg and 12 blocks per m^2) *After placing in the wet concrete of the foundation, the Waterloffel block is packed with its unique wings interlocked. The length of each wing governing the actual spacing between each block when packed tightly together.*

(5) Geotextile: *The geofabric is placed stating at the bottom of the first Gabion basket and extending upwards across the back of the Gabions and following the line of the waterloffel blocks, to the in situ concrete capping on the top of the wall where it is locked in between the last two blocks. The geo - textile is very important, firstly as a barrier allowing free flow of water, while restricting the fines and the secondly, providing vertical stability and lateral strength through the back of the wall.*

(6) Backfill: *The void between the toe of the dune and the top of the wall behind the waterloffel construction should be filled with clean, coarse, free drain sea sand which is normally taken from the low tide mark.*

(7) In situ concrete cappingledge beam: *It is essential that a concrete capping be used on top of the wall, firstly for stability, in that acting with the foundation concrete, it provides the framework, locking the entire construction together and secondly, in the event of overtopping, the ground water returning over the top of the wall is unable to erode the soil behind the blocks which might failure of the wall. The in situ concrete edge beam also provides a handy means of fixing uprights for a balustrade should one be required.*

Capping	*20 MPa concrete - Laid in panels 200 mm thick and 1. 5m wide with expansion joints every 4. 5m*
Edge beam	*20 MPa concrete - 300 mm thick and 700 mm wide*

The method of construction has been used successfully at Umhlanga Rocks (see photograph), Umdloti, Isiphingo, Lagoon, Margate, Dairy Beach, Durban and Cave Rock, Brighton Beach.

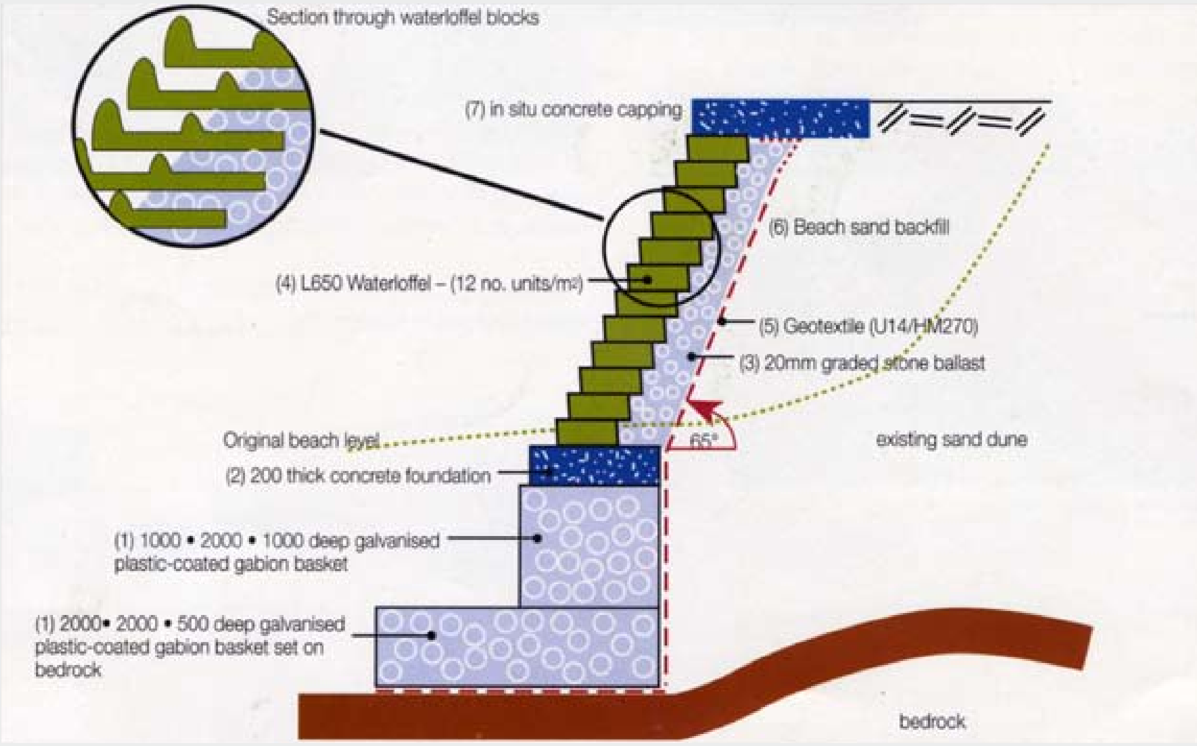


Figure 3: Typical section of Waterloffel wall used for coastal protection on Natal beaches

UMHLANGA ROCKS SEA WALL

Sections of the southern part of Umhlanga Rocks beach wall collapsed as a result of erosion and scour of the supporting dune sand. The Borough decided to repair the damage by building an artificial dune using concrete Waterloffel blocks.

The decision to use the Waterloffel block system follows extensive research by CSIR at the University of Stellenbosch on the technical viability of the system.

A foundation for the wall was constructed using large (1m x 5m x 2m) Gabions founded on the bed rock. Once the Gabions were in place, concrete was cast on the Gabions to form a foundation for the Waterloffel blocks.

The new wall was built to a height of 4m from the bed rock and forms the foundation of the beach walk. (See photograph 4)

Because of the retaining wall is founded in bed rock, the risk of scour and wave action undermining the walls is eliminated, and further collapse of the beachwalk avoided.

To make the wall more attractive, indigenous dune vegetation was planted in sandfilled blocks.

Photograph 5 *Concrete retaining wall - Umhlanga Rocks*

LAGUNA BEACH RECREATION FACILITIES

Photograph 6 *Laguna Beach - Under construction*

The design of the earth retaining structure at Laguna Beach Recreational Facility required certain considerations, relevant to projects involving the force of water, which had to be taken into account:

- *Anticipated depth of scour and erosion protection at foundation level.*
- *Dissipation of hydrostatic pressure by means of effective backfill design and drainage measures.*
- *Prevention of leaching by providing a closed vertical surface structure.*
- *Sufficient strength to withstand occasional extreme coastal conditions.*

A minimum crb element mass of 38kg (790 kg/m^2 constructed mass including top soil) was specified. For durability in the aggressive coastal environment, a cement content of 300kg/m^3 concrete, was used in making the units.

After excavating the beach to a foundation level of 1.5m below m.s.l., (also the level of water table), a 1100x250 mm foundation of 25 MPa concrete was cast.

The bottom 3 m of this structure, which is normally situated below beach level, was constructed with Terraforce elements filled with 15 MPa concrete and hot dip galvanised dowels locking individual rows together. Selected coarse backfill and weepholes were provided.

As a front line of defence in case of severe erosion of the beach, a Gabion mattress apron topped with sand (4% cement — 1,5 m wide and 1,5 m high) was placed on top of the concrete foundation. The contractor then constructed the wall to its full height of 6m above foundation level with the units filled with plant supportive topsoil. The structure is curved to match the radii of paddling pools above, and an existing stormwater outfall was incorporated to form a functional, yet attractive spillway onto the beach.

The structure is fully covered with indigenous vegetation and has experienced many severe storms in the past eight years without any evident damage (see photograph 7).

Photograph 7 *Laguna Beach - After vegetation*

GIANT WAVES MAKE LITTLE IMPACT ON WATERLOFFEL WALLS

March 2007 saw turbulent seas and extraordinarily high tides, which wreaked havoc on large stretches of beach on the north and south coasts of KwaZulu Natal, but resulted in only slight damage to those sections of the coast protected with Waterloffel sea walls.

Incoming wave amplitudes as high as 12 metres were recorded from Richards Bay to Port Edward, and beaches in Durban, Umhlanga, Umdloti, Ballito and Umkomaas were particularly hard hit. Many remained closed over the Easter holidays due mainly to health concerns about ruptured sewage pipes and a lack of sand.

This was not the case at unprotected beaches, for instance, Ballito, which were severely damaged. Large sections of unprotected boardwalk were completely destroyed and some buildings, for example, the popular holiday resort, Santorini, were undermined by the force of the water.

Some walls using the system were damaged by the heavy seas, the reason for this is that they were built with foundations on sand instead of bedrock. Standard designs for the correct installation of Waterloffel walls must ensure that they are founded on bedrock. They must also incorporate specially designed behind-the-wall drainage and selected free-draining backfill material such as beach sand. The current designs were developed jointly by Infraset and Kaytech, and have proven extremely effective.

South Africa's beaches are a major tourist attraction and revenue earner, and like other eco-sensitive areas it is vitally important they are protected for our future generations.

Waterloffel sea walls have been built along selected sections of the KwaZulu Natal coast, in Knysna and in Cape Town, over the past 15 years. They were first introduced after research conducted by the Civil Engineering Department of the University of Stellenbosch in the early 1990's demonstrated conclusively that their shape and configuration dissipated wave energy and vastly reduced the destructive power of wave action, while at the same time contributing to a redepositing of sand on the protected beaches.

Waterloffel retaining walls are also used to create marinas, protect embankments in estuaries and as scour protection on river banks. They and other Loffelstein retaining wall systems are registered as a global trademark for which Infraset Landscaping Products holds the licences worldwide.

ATTENUATION POND APPLICATION, CHILLI LANE SHOPPING CENTRE, SUNNINGHILL, JOHANNESBURG

Controlling the flowrate of stormwater discharge off new developments in Gauteng has become a JRA requirement. Terraforce L11 blocks were used to create a pond with wall heights of 5,5m. The design incorporated 19mm stone infill to the blocks and a 200mm stone drain between the rear of the blocks and the cut face, with a separation geofabric to prevent fines clogging the stone drain.

BIOFILTERS

Biofilters: Sewerage effluent water treatment tanks have utilised concrete retaining block walls to retain the ballast stone infill. The voids between the blocks allow air to ventilate more efficiently, the block walls with geogrid reinforcing placed 4m deep into the ballast, limit movement caused by temperature induced settlement of the ballast stone, giving tanks a longer life.

CONCLUSION

Concrete retaining blocks are ideally suited to hydraulic applications, particularly for bank/beach erosion protection, and new attenuation ponds. Their successful applications is dependent on a detailed and systematic design process. Particular attention to the hydraulic forces, is necessary, especially ground water and its effect on overall stability and adequate drainage. Attenuation ponds on the other hand require an effective drainage behind the blocks, when water levels draw down, to allow quick drainage.

The design engineer must give careful attention to the detail in the scheme, especially to protect the toe from scour, the top of the bank from run-off and over topping and reinforcement of the backfill. The design approach must be holistic and take into account the environmental impact of the retaining wall.

The retaining system is an integral part of the environment and must be made to complement and support the existing conditions. It is necessary for any scheme to be visually accepted as most watercourse and beaches enjoy substantial public use. Early vegetation of the scheme should be carried out, general performance monitored and remedial measures done as a matter of urgency.

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