Sand Filled Geotextile Containers in Australia - Is There a Future?

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Abstract
Australia was an early adopter of sand filled geotextile/geosynthetics containers (SFGC) for coastal structures and has been a global leader in application and the R&D of the technology. Large engineered “sandbags” were a natural progression from the small sandbags used, and still used, very effectively despite their low mass, for emergency wave erosion.

The SFGC technology has optimum applications and positive drivers for their use include:
- Increasing shortage and increasing cost of good quality rock.
- Suitability for emergency and temporary protection works.
- Providing soft, user friendly and safer structures for longer term works in high recreational use areas.
- Suitability for low crested structures.
- Environmental benefits as the geotextile provides a good substrate for marine growth.

Up to the early 2000’s the technology evolved rapidly facilitating innovative projects. However, the use of SFGC in Australia appears to be declining due to a number of issues including:
- Design; Being “soft” and flexible structures, they are more difficult to design for stability compared to traditional materials.
- The R&D and monitoring to date has provided a good understanding of failure modes and product-specific guidelines but there are still no comprehensive and widely accepted design guidelines such as the Rock Manual for rock.
- Construction; Contractors have tried, often unsuccessfully, to apply rock construction methods to SFGC structures resulting in construction delays, cost escalations and structural failures.
- Durability; Being relatively thin skinned and vulnerable to UV exposure, the life of the units and structure can be short, if not well designed, protected and maintained. Research into materials continues but the last significant improvement in material durability was in 2000 for Narrowneck reef.

Conclusion: The future widespread use of SFGC technology will depend on improved guidelines for design and construction as well as innovative development of more durable materials.

Keywords: geotextile, coastal structures, durability, innovation, climate change.

1. Introduction

Australia has over 35 years of experience with the manufacture of geotextiles and the design, modelling, construction and maintenance of coastal structures constructed using prefabricated sand filled geotextile containers (SFGC).

Australia is now recognised as a global leader in the manufacture, use and the R&D of the SFGC technology. However, the development of geotextiles used to fabricate SFGC has slowed and it appears, to the authors, that the popularity and use of SFGC in Australia is declining, raising the question of the future development and viability.

2. Background

High strength synthetic “filter fabrics” that were developed in the mid 1900’s and later named geotextiles and geosynthetics in the 1970s have gained widespread use in civil engineering and Australia was an early adopter of the use for coastal structures. As well as use of geotextile for filter layers, large engineered “sand bags” fabricated from geotextiles were a natural progression from the small hessian and similar natural textile sandbags used, and still used, very effectively despite their low mass, for emergency wave erosion [17] [20].

Geotextiles are also utilised to fabricate other container shapes such as tubes and mattresses. These various containers were generally filled with local or imported sand to construct coastal structures such as seawalls, groynes, breakwaters and reefs [11] [32].

Many generic and registered names are used to describe these fabricated forms. In this paper we will use the generic terms of geotextile and sand filled geotextile containers (SFGC) for sand filled

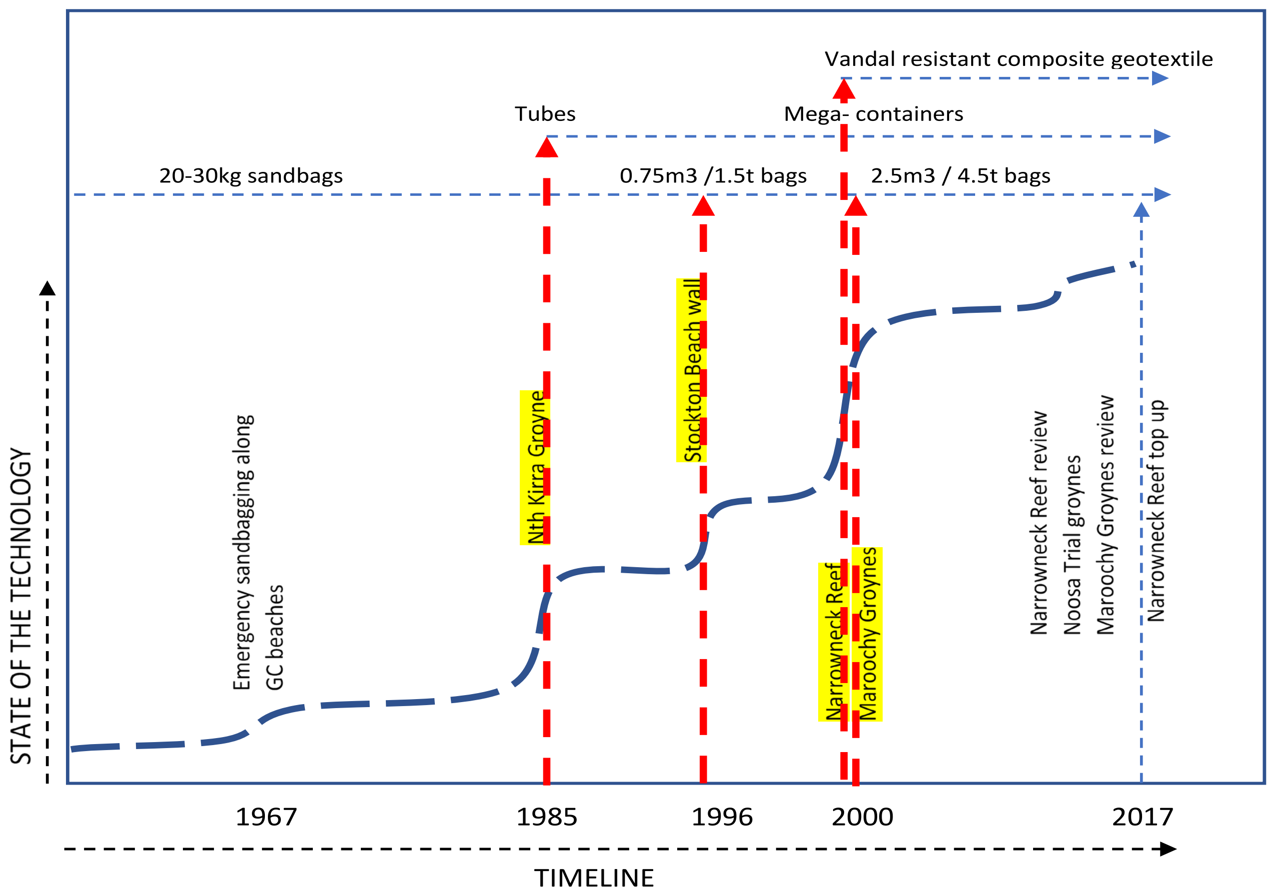

Figure 1 Timeline of evolution of SFGC technology in Australia showing innovative projects (highlighted) that proved advances to the technology. Source: [15].

geotextile bags, tubes, mega-containers and mattresses. The use of geotextile is also appropriate as does not exclude non-synthetic geotextiles.

From the early 1980's up to about the early 2000's the technology evolved rapidly facilitating innovative coastal projects. The development of the technology in Australia for open coast conditions is summarized in Figure 1, including innovative projects that significantly advanced the technology.

These projects have been monitored and well documented and their description and present condition is described below.

North Kirra (Gold Coast, Queensland) groyne was constructed in 1985 using stacked custom 1m dia x 100m long geotextile tubes stacked to provide a temporary groyne 5m high to provide temporary beach stabilisation protection for the SLSC [24]. Advantages were low cost (initial and whole of life), quick construction with low impact on surroundings, user-friendly and low crested. Disadvantages were damage by vandalism and associated repair costs. Practical repair methods were developed. Presently, it is buried under large scale beach nourishment [26].

Stockton Beach (Newcastle, NSW) seawall was constructed in about 1996 as temporary (6 month) protection to the SLSC [24]. This was the first use of 0.75m^3 SFGC in Australia and provided proof of concept. They were fabricated from standard (non-vandal deterrent) non-woven needle-punched staple-fibre geotextile. Advantages were quick construction, low impact on surroundings and user-friendly. Disadvantages were need for repairs due to minor damage by vandalism. ~~Presently, it continues to provide protection~~ [10].

See Addendum 1

Narrowneck reef "breakwater" was constructed in 1999-2000 as a key element of the Northern Gold Coast Beach Protection Strategy [24]. It was constructed using mega-SFGC filled in a hopper dredge and dropped into place. This was the first use of mega-SFGC. As well as proof of concept of the mega-SFGC and construction methods, during the project a composite heavy-duty geotextile for fabrication was developed. The mega-SFGC are now used routinely worldwide. The composite heavy-duty geotextile remains the benchmark for vandal resistance and has been adopted more broadly within the geotextile manufacturing industry. Underwater repair methods were also developed. Advantages were low initial cost, quick construction, low impact on surroundings, ability to settle to accommodate seabed changes, improved safe surf break for surfers and creation of a reef environment attracting fishermen and divers. Disadvantages were damage by anchors (from fishermen and divers) and associated repair costs. A top up and replacement of damaged bags and no-anchoring buoys was carried out in 2018 [27]. Presently, it continues to provide its primary function of coastal protection and secondary benefits of improved and safe surfing and diving [19] [21] [23].

Maroochydore groynes were constructed in 2001-2003 using the first 2.5m^3 SFGC that were developed for the exposed location [24]. Advantages were low initial cost, quick construction, low impact on surroundings, user-friendly and low crested construction. Disadvantages were damage by vandalism, displacement of individual units near the groyne head and associated maintenance costs. The groynes continue to provide their primary function of beach stabilisation, but the groynes are due for maintenance to restack and replace damaged and displaced crest bags [14]. Replacement with rock structures was initially considered to reduce future maintenance requirements but there is well-supported public campaign “Don’t Rock Maroochy” for retention of the user-friendly bags and repair with the same technology.

Improvements since 2000 have largely been incremental including further development of SFGC detailing, custom units [3], in-situ filling of smaller containers [3] and integration of hard elements to enhance recreational amenity and reduce damage [4] as well as novel applications, including partially submerged groynes [3] and river closures [4].

Some 18 years after the construction of the Narrowneck reef and Maroochydore groynes, the need for significant maintenance works led to an in-depth review of the commercially available SFGC characteristics and ongoing maintenance requirements to evaluate the options of repairing these structures using present day SFGC or replacing with rock.

The evolution of geotextile materials has slowed and despite the 18 years since the original construction of the Narrowneck reef, no significantly improved materials were commercially available from potential suppliers and the SFGC used for recent maintenance works was similar to the composite vandal deterrent SFGC developed during the initial construction [27].

With the extensive research, monitoring and development over the last 30 years many lessons, some unexpected, have been learned with respect to SFGC re:

- Stability design
- Construction methods
- Durability and repair methods
- Environmental benefits
- Safety and amenity
- Costs - project and whole of life

SFGC provide a possible alternate to rock. With increasing coastal urbanisation and the high value development along the coast, quarries with good quality rock are now often a long distance from the site of works and the rock needs to be trucked and/or shipped the long distances from the quarry with the final route to the construction site often on roads through urban developed areas causing adverse impacts on road infrastructure and the community amenity and safety.

However, rock structures are relatively simple to design and construct and remain as the most common material for construction of coastal structures and is the standard option against which other material options are generally measured against in Australia.

3. Characteristics

Geotextiles were initially developed and used to provide a robust filter layer at the structure – subgrade interface of coastal structures such as rock walls [29]. In this location within the structure, the geotextile replaces one [or multiple] rock filter layers and performs a critical function to avoid failure and needs the following general characteristics:

- High permeability while retaining fines
- High tensile strength and deformability (puncture resistance) to cope with initial rock placement and longer-term settlement and rock movements

As a filter layer the geotextile does not need to be resistant to UV, impact loads or vandals.

The type of geotextile material used for SFGC is important as it affects the tensile strength and permeability during construction and the durability, tensile strength and friction between modules of SFGC in operation. There are now a wide variety of engineered geotextiles with widely different characteristics, including those needed for SFGC.

The geotextile materials presently used for fabrication of SFGC have evolved considerably from the hessian and similar natural textile “sandbags”. Types include:

- Woven
- Non-woven
- Composite woven and non-woven
- Composite non-woven vandal-deterrent

From the long-term monitoring and observation of SFGC structures, the key characteristics of SFGC compared to rock are as below.

Modularity:

- Wide range of uniform sizes 40kg -300t of SFGC that can be fabricated to specification can provide for higher stability than rock as rock

boulder supply now limited to about typically 3-6t grading requiring flatter slopes for larger wave conditions or overtopping.
- Large modules are able to resist overtopping forces and can be used for low crested structures
- Cost per unit volume generally decreases with size whereas rock costs increase with size such that unit rates using large modules can be much lower than rock
- Fill ratio and type of fill affects shape and stability due to density, interlocking friction and flexibility.
- Individual SFGC modules can, in many cases, can be stacked at steeper slope and achieve a smaller footprint than equivalent rock designs.

Flexibility / deformability:
- Able to accommodate settlement, particularly with the use of a flexible toe (similar to rock structures if suitably designed).

Interlocking:
- Flexibility and friction of the geotextiles provides high level of interlocking and stability.
- Able to accommodate overtopping (where adequately sized) so better than rock for low crested overtopped structures.

Permeability:
- Modules absorb some energy internally, but sand fill will migrate if not filled tightly and poorly filled SFGC may fail due to fatigue of loose material or loss of weight and reduced stability.

Constructability:
- Only empty SFGC forms need to be imported to site reducing transport impacts.
- Rock often needs to be transported hundreds of km by road causing traffic hazards and damage to roads.

"Soft":
- More user friendly and safe for recreational use.
- Good substrate for marine growth and habitat.
- Less durable than good quality rock although poor quality rock can split and deteriorate.

4. Design

There are many variables in the design of SFGC structures. The geotextile, individual units and the structure as a whole need to be designed very differently to rock as well as for both construction and operational loads.

Construction filling and placement loads can be significant for the geotextile. SFGC under about 2.5m^3 are generally filled with sand in a frame on site, hydraulically compacted, sealed and transported into place. Larger containers are generally hydraulically filled in-situ or in a split hull hopper barge with a sand pump or dredge. When filled in a hopper barge the SFGC are dropped into place, deforming through the vessel opening before impacting with the seafloor. The tensile loads on the SFGC material and seams of larger SFGC during filling and placement using this method are often higher than the loads in service [24].

For design of individual units, in service wave forces generally dominate. Australian use of SFGC in exposed coastal locations necessitated designs that could be suitable for large waves and the outer section of Narrowneck reef that is in 10m of water has been subjected to storms with H_{max} of about 12m recorded at the nearby waverider buoy off the Southport Spit [19]. For walls, wave heights are typically depth-limited but can still be substantial depending on location and condition of the beach and this typically drives the selection of container size and configuration. During service, four typical failure modes have been identified from monitoring and modelling of SFGC structures [22]. For walls these are as per Figure 2.

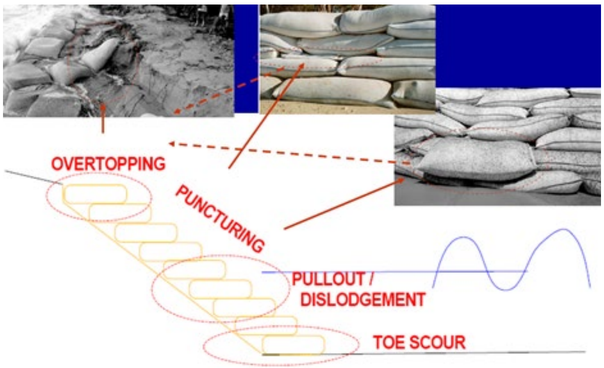

Figure 2 Examples of the four typical failure modes for SFGC walls. (Source: [22])

For design of SFGC, a number of variables unique to SFGC need to be considered. As an example, Figure 3 shows the variables involved in the pull out failure mode.

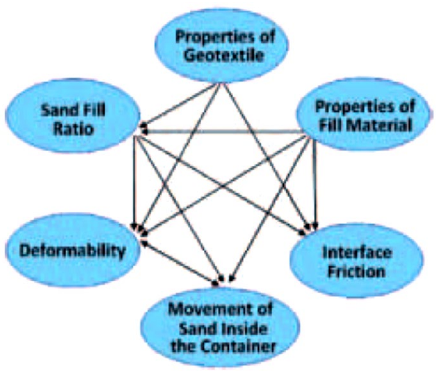

Figure 3 Variables determining stability against the pull out failure mode of SFGC structures (Source [30]).

SFGC can be very stable as very large and cost-effective units can be filled in-situ providing a very high deadweight. Even smaller sand bags, if well stacked, can provide effective protection well beyond its design limits and is easy to restack.

Even relatively small SFGC units, with good stacking and interlocking, have been found to outperform rock on a gross weight basis even with a significantly lower SG [1]. Examples of this are:

- the 0.75m^3 SFGC seawall constructed in about 1996 at Stockton Beach (NSW).
- the 0.75m^3 SFGC seawalls constructed in about 2000 at Maroochydore (QLD) and Belongil (NSW).
- The 2.5m^3 SFGC seawall constructed in 2016 at Collaroy.

However, being "soft" and flexible with the potential for sand migration within the containers, resulting in loss of stability SFGC structures are more difficult to design for stability than rock and require different construction methods.

While there are no "simple" formulae such as developed by Hudson and Van der Meer and guidelines such as the USCE "Coastal Engineering Manual" or the European "Rock Manual" that are available to assist rock structure designers and contractors there are a number of comprehensive text books and references for designers for SFGC sizing and specification for SFGC designers [2] [7] [12] [13] [30] [31].

Australian Standards for geotextiles are available but these are for testing and geotextile design, in general, and SFGC design remains a specialist area of expertise. It is still common to see geotextile specifications linked to a specific product rather than to the specific needs of the project.

As a result of design challenges, SFGC options are often quickly dismissed by designers without this specialist expertise.

5. Construction

Construction is not difficult but generally requires different equipment and methods to rock construction. Filling of containers requires sufficient sand to provide a firm and tight geotextile in order to eliminate the potential for geotextile failure due to fatigue without overfilling which can cause bursting and compromise stability. For mega-containers, filling to about 80% is required to optimise volume and stability. Fill material is also important to overall container dimensions and the use of material with significant fines has the potential for slumping over time. Handling, placing and manipulating of container shape is also essential to achieving good interlocking, stability and aesthetics. As a result, SFGC options are often poorly constructed by inexperienced contractors.

6. Maintenance

Approvals generally require structures to be designed for a 30 to 50 year design life. Whilst this can be achieved with appropriate maintenance, a higher level of maintenance is generally required for SFGC compared to rock. In areas with potential vandalism the need for monitoring and maintenance will be increased. Maintenance costs need to be factored into whole of life costs.

Coastal Councils are generally responsible for the construction and maintenance of coastal management works. Major works and maintenance are generally outsourced leading to pressures to reduce any monitoring and maintenance requirements.

The need for maintenance and associated costs may be considered more acceptable in cases where lower capital cost or user friendliness are key design criteria. This is not dissimilar to a sports ground or play area where grass or similar soft cover is often selected over other ground covers to provide aesthetic and safety outcomes, but requires constant maintenance, increasing whole of life costs. Certainly this has been the case for Narrowneck reef [28] and Maroochydore groynes where the benefits of "soft" user-friendly outcomes has resulted in continued adoption of SFGC for ongoing maintenance works despite the desirability of lower maintenance options.

7. Summary

There is over 35 years' experience with the design, construction and maintenance of SFGC in Australia. Over this time, the technology has proven to have advantages and disadvantages and like other materials, there have been failures due to inappropriate use, poor design or lack of maintenance.

Advantages include:

- Cost; Large SFGC generally have a significantly lower cost than rock and maintenance can be relatively low in areas not subjected to vandalism.
- Constructability; Relatively quick to construct and / or remove making SFGC structures suitable for temporary and/or emergency structures until long term solutions can be implemented.
- Stability; Large SFGC can resist large wave forces and overtopping.
- Low crested; SFGC are suitable for low crested (low visual impact) structures.
- Safety; SFGC provide a hydraulically smooth, soft, user friendly and safer structures for works in high recreational use areas [6].
- Environmental benefits as the geotextile forms a good substrate for marine growth [5].

Disadvantages include:

- Cost; Smaller SFGC generally have higher initial cost than rock. Maintenance costs of larger SFGC can be significant.
- Design; SFGC specification is more complex than for rock. Without comprehensive guidelines it has been a specialist area in Australia.

- Durability; Being relatively thin skinned and soft, the life of the units and structure can be shortened if not well designed, properly constructed, protected and / or maintained. SFGC generally require more maintenance than rock structures.

Considering the advantages and disadvantages, SFGC can provide good solutions in areas where:

- there is high public usage and safety is a major design criteria.
- there is preference for low crested solutions for structures such as groynes, breakwaters and reefs.
- temporary structures that can be easily removed are required.
- emergency structures that can be quickly, safely and economically constructed are required.
- there is low likelihood of vandalism or regular inspections and maintenance are feasible.
- safe truck access for rock and construction equipment for rock is not available or is prohibitively expensive.

The use of SFGC for emergency protection can be a two-edged sword as in New South Wales “sand bags” are specified as 0.75m^3 with a height of only 1.5m high [8]. This size container with the limited wall height is designed to fail on exposed NSW beaches and not be a long-term solution. This results in damage and total failure.

Even with the increasing scarcity of good quality rock and increasing need for user friendly and safe coastal management structures, future widespread use and development of SFGC now appears to be at a cross road and declining due to a number of issues including:

- Design; Being “soft” and flexible structures, they are more difficult to design for stability compared to traditional materials and design of SFGC coastal structures is a specialized field of coastal engineering and these structures need different design, construction and maintenance methods.
- The R&D and monitoring to date has provided a good understanding of failure modes but there are still no widely accepted design guidelines such as the Rock Manual for rock.
- Construction; Different construction methods and equipment are required. Contractors have tried, often unsuccessfully, to apply rock construction methods to SFGC structures resulting in construction delays, cost escalations and structural failures.
- Durability; Being relatively thin skinned, the life of the units and structure can be short if not well designed, protected and maintained. The need for ongoing maintenance has been a significant concern to some authorities responsible for existing SFGC structures. Unfortunately, there have been no significant advances in durability over the last 18 years.
- Poorly designed, constructed and/or maintained structures have resulted in some SFGC failures. As a result, SFGC options are often quickly dismissed during concept design stage.

8. Conclusions

The future widespread use of SFGC technology in Australia is likely depend on both development of more durable materials and also improved guidelines for design and construction.

9. Recommendations

The following actions are recommended:

- Further development of geotextiles suitable for fabrication of robust and durable SFGC, preferably using non-synthetic products.
- SFGC should only be used where their unique characteristics provide benefits and whole of life costs can be justified.
- Provision for suitable monitoring and maintenance needs to be included over the design life of SFGC structures.
- Development of alternate products using non-synthetic materials for SFGCs, such as basalt fibre [9].
- Compilation of comprehensive Sand-Filled Geotextile Container Design Manual outlining the different types of geotextile, opportunities for use, advantages and disadvantages, case studies as well as existing design resources and additional R&D and monitoring of a range of real-world structures.

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ADDENDUM 1 - Correction and Additional Timeline Data re Stockton Beach Wall

CORRECTION: The wall is no longer in service - it was replaced in about 2017 (after 21 years) with a designed rock wall.

TIMELINE

1996: Constructed as temporary wall (6 month design life) to protect SLSC.

2010: Erosion and wall was extended northward with similar size (0.75m3) bags.

2016 (June); The wall was damaged (bags displaced but wall still functional)

2017: The wall was replaced with a rock wall. This rock wall subsequently was damaged in 2018 and there were reports of injuries to beach users due to collapse and scattered rocks on beach (see: https://www.newcastleherald.com.au/story/5691472/junior-lifesaver-badly-injured-as-erosion-seawall-crumbles/).