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Structural design of modular geocellular drainage tanks

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The Environmental Protection Group Limited

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Summary

Stormwater attenuation tanks constructed using modular plastic geocellular units are commonly used as part of sustainable drainage and rainwater harvesting systems. This guide discusses the different types of unit that are available and the differences in their structural performance. It provides information on many full scale trials that have been carried out on various different systems and gives a detailed assessment of the factors that affect their structural performance. It also includes guidance on appropriate testing and structural design together with a discussion of the practical issues that should be considered in construction.

There is a wealth of information now available about the performance of plastic geocellular tanks. Those that are designed and constructed in accordance with normal structural and geotechnical principles should provide a safe and durable solution for storage of stormwater below ground.

Modular geocellular units are lightweight and easy to handle

Structural design of modular geocellular drainage tanks

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SUDS, surface water management, development, the provision and maintenance of surface water drainage to new and existing developments	AVAILABILITY	Unrestricted
	CONTENT	Instruction manual, recommendations
	STATUS	Established knowledge
	USER	Developers, contractors, consulting engineers, landscape architects, architects, local authorities, highway authorities, sewerage undertakers, drainage product manufacturers, environmental regulators, planner, sewerage undertakers, contractors and other organisations involved in the provision or maintenance of surface water drainage to new and existing developments.

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Steve has over 20 years practical experience of geotechnical and environmental design for civil engineering and building structures including drainage design and redevelopment of contaminated land. He is co-author of CIRIA publication C582 *Source control using constructed pervious surfaces* and C609 *SUDS. Hydraulic, structural and water quality advice relating to SUDS techniques*. He has helped develop structural testing and design protocols for plastic modular tanks and has undertaken extensive research on several different types. Steve provides design and construction advice to major suppliers of these types of tanks. He has also provided expert independent advice to clients that have suffered failures.

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Throughout this guide reference is made to various trade names for geocellular units. Note that all these names are registered trademarks. In particular stormcell is often used as a generic term for modular plastic stormwater tanks but Stormcell is in fact a trademark of Hydro International Limited.

The guidance document has been developed in partnership with The Environmental Protection Group Limited and CIRIA.

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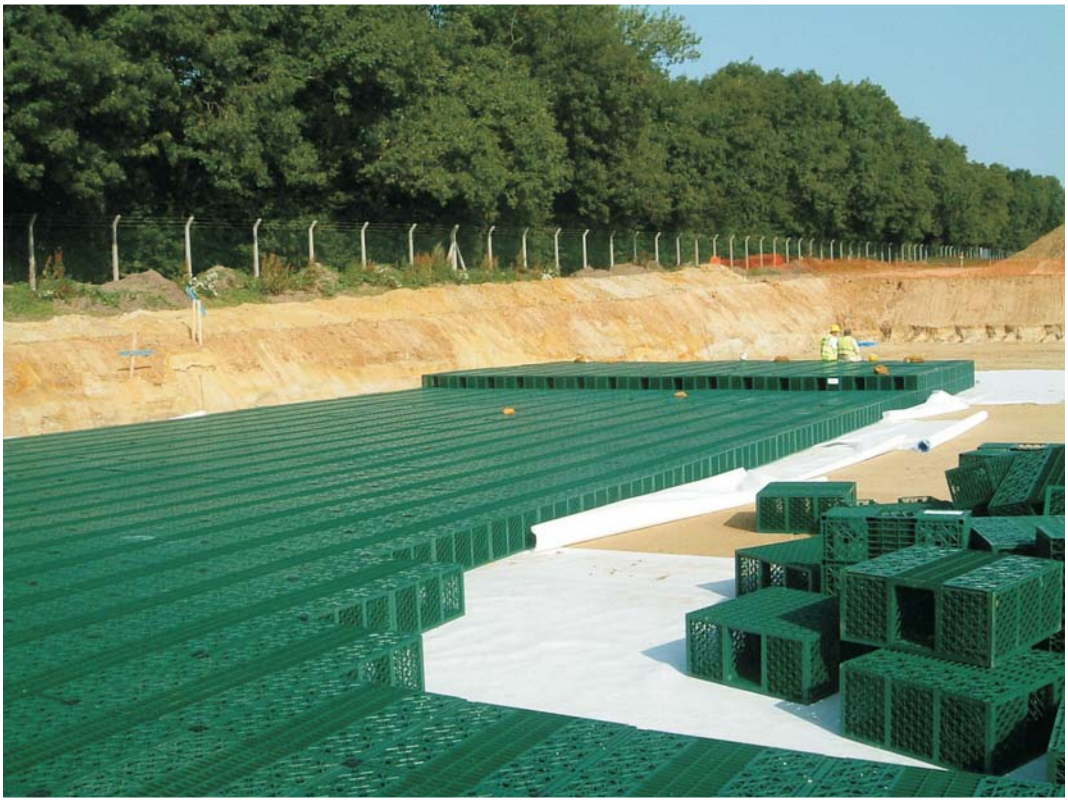

Construction of a large soakaway using geocellular modular units

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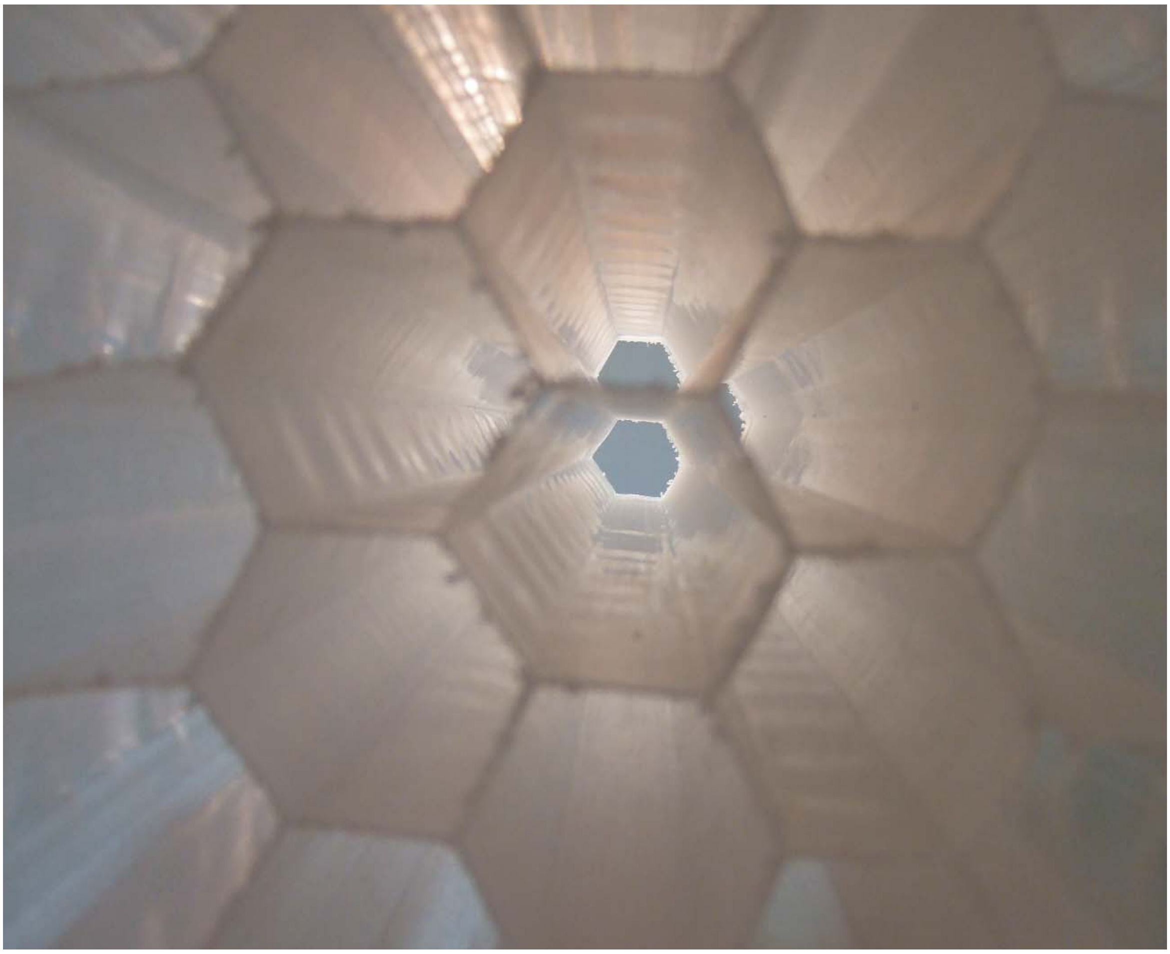
Glossary

Attenuation system	A system designed to control the peak flow from a given site by providing a facility for the temporary storage of stormwater.
Characteristic load	The expected loads to be supported by a structure.
Characteristic strength	The load at which a unit under test begins to yield (ie rate of deflection begins to increase). The lowest value from a series of tests is usually taken as the characteristic strength.
Crate	Commonly used term for plastic modular geocellular storage units. Also known as plastic crates.
Creep	Increase in deflection (and possible loss of strength) over time under a constant load applied to a geocellular structure.
Design load	The characteristic load multiplied by the partial factor of safety relevant to the limit state being considered.
Design strength	The maximum load at which the product will provide continuous long-term structural performance. This value is derived from the characteristic strength divided by a partial factor of safety.
Geogrid	A regular grid structure of polymeric material formed by joined intersecting ribs. They are used to reinforce (increase the strength) soil, rock, earth, or other similar material.
Geomembrane	An impermeable material often wrapped around structures to create a watertight tank. An extra geotextile layer may be wrapped around the membrane to reduce punching stresses caused by loading on sharp points of contact.
Geotextile	A permeable material often wrapped around the structure to prevent soil entering, or silt passing out of, the storage units. Also used to protect geomembranes.
Honeycomb type	Plastic modular unit manufactured with a honeycomb structure for storing excess stormwater. Honeycomb type units are extruded.
Infiltration system	A system designed to provide an underground storage facility in which stormwater is stored temporarily before it soaks into the surrounding soil. Commonly known as soakaways.
Lateral load	The horizontal load applied to the vertical face of the product due to the surrounding ground, groundwater and super imposed loads.
Limit state	A set of performance criteria (eg deflection, strength, stability) that must be met when a geocellular structure is subject to loads.

Modular plastic geocellular storage units	Any cuboid plastic structure that has been designed to create an underground void for storing stormwater or to act as an infiltration system. The large void is formed by placing and stacking many units together. Often referred to as crates.
Partial factors of safety	Factors applied to both the strength of the modular unit and the loads imposed on it. They provide a degree of security to the tank and allow for creep and fatigue. There are many uncertainties associated with detailed structural design including simplifications in representing the geocellular structure for analysis, accidental overloading of the structure, variations in material properties and variations in dimensions from those assumed or specified. The factor of safety allows for these uncertainties.
Permanent load	Loads that remain on a structure for its entire life. An example is the weight of backfill over a tank.
Plastic crate	See *Crate*.
Porosity	Ratio of useable storage volume to total volume (void ratio is often confused with porosity).
Rainwater harvesting system	A system designed to provide a temporary underground storage facility from which stormwater is pumped for reuse.
Serviceability limit state	To satisfy the serviceability limit state criteria, a geocellular structure must remain functional for its intended use subject to routine loading.
Soakaway	See *Infiltration system*.
Sub-base replacement	Geocellular units that are specifically designed to be placed at a shallow depth in the pavement construction and replace aggregate sub-base. The units achieve this by acting as a flexible raft with sufficient strength to distribute the applied loads.
Transient load	Loads that may be applied and removed over the design life of a structure, for example traffic load.
Ultimate limit state	To satisfy the ultimate limit state, a geocellular structure should not collapse when subjected to the peak design load.
Ultimate strength	The maximum load that a unit can support without failure.
Vertical load	The axial load applied to the upper surface of the unit due to the self weight of backfill and transient loads.
Void ratio	The ratio of useable storage volume to volume of solid material.



Honeycomb geocellular structure

1 Introduction

1.1 Background

Modular plastic geocellular units are commonly used as a cost effective method of providing stormwater infiltration (soakaways) and attenuation tanks for new developments (Figure 1.1). Geocellular tanks are usually constructed using modular units that are cuboid plastic structures with a high porosity typically in excess of 90 per cent (note this is often incorrectly referred to as the void ratio of the units). The individual units or boxes are placed together to form a large tank surrounded by either a geomembrane or a geotextile. Since the early 1990s, they have been used to construct stormwater attenuation tanks and soakaways worldwide.

There is very little understanding within the construction industry of the different types of modular units that are available and the effect that the form of the units has on their structural performance. In the past there has been very little independent guidance on the structural design and performance of such tanks, with many consultants and contractors relying solely on the advice of manufacturers.

Figure 1.1 *Large attenuation tank constructed from individual geocellular units*

This book provides guidance on the structural design and construction of geocellular stormwater drainage tanks. Information about testing components and carrying out design calculations are provided along with worked examples. It does not cover other design issues such as hydraulic performance, siltation etc. There is extensive guidance on such matters provided in C697 *The SUDS Manual* (CIRIA, 2007) and by British Water (2005).

Frequently engineers, architects and clients rely on manufacturers' claims regarding the load carrying capacity of these types of tank. However, it is important to realise that these tanks are structures and should be designed by competent engineers using sound structural and geotechnical principles as they may be used below areas that are trafficked by heavy goods vehicles that can impose significant loads on them.

Appropriate analysis is required to ensure they do not collapse under the imposed load.

Geocellular units are not all the same. There are various types of box units that have different structural forms. Laboratory testing and design calculations should take account of these differences, for example a specific method of laboratory testing used on one type may not be appropriate for another because it may not replicate how the box performs when installed in the ground. In the worst case inappropriate laboratory testing can overestimate the strength of the units.

Engineers who are responsible for approving tank designs should undertake their own independent structural design calculations and should ask manufacturers for the necessary test data to allow them to do so.

There have been failures of modular geocellular tanks (Figure 1.2) both in the UK and elsewhere (Wendebourg, 2006 and Paul and Wieland, 2006) but, from the available evidence, none have been caused by problems with materials or quality of manufacture of the units or tanks.

The four main contributing factors to most failures are:

1 Inadequate design, often not taking account of particular ground conditions on a site, or not allowing for creep of the units.

2 Lack of understanding of the performance of the tanks, leading to overloading, for example by running heavy plant across tanks that were not designed to carry such loads, or by using unsuitable backfill, for example containing boulders.

3 Lack of appreciation of the influence of groundwater levels or the effect of surface water flows into excavations during construction.

4 Inappropriate laboratory testing that overestimates the strength of the units.

If these issues are addressed then plastic geocellular tanks constructed using any of the available units can provide a safe and durable solution for the storage of stormwater below ground.

Figure 1.2 ***Example of the consequences of failure of a modular geocellular tank after three years***

Plastic modular tanks are subject to numerous loads and the testing and design regime should consider all of them to ensure that an installation will be safe and serviceable (Figure 1.3).

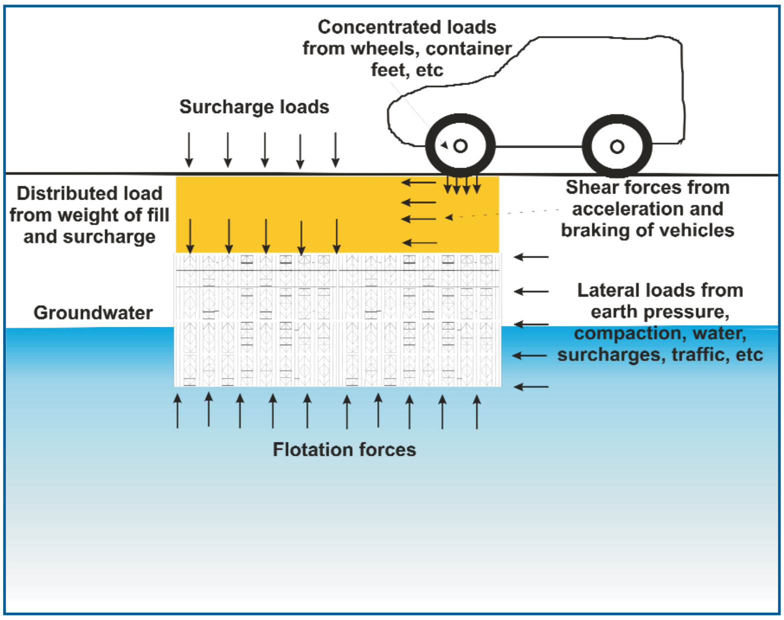


Figure 1.3 ***Loads on modular plastic tanks***

Design of tanks constructed using modular geocellular units should:

- take account of all the applied loads, including accidental loading (for example by delivery vehicles in a car park)
- be based on appropriate laboratory tests
- use appropriate partial factors of safety
- analyse all appropriate limit states (or failure modes).

The design requirements for a safe and serviceable tank installation are summarised in Figure 1.4.

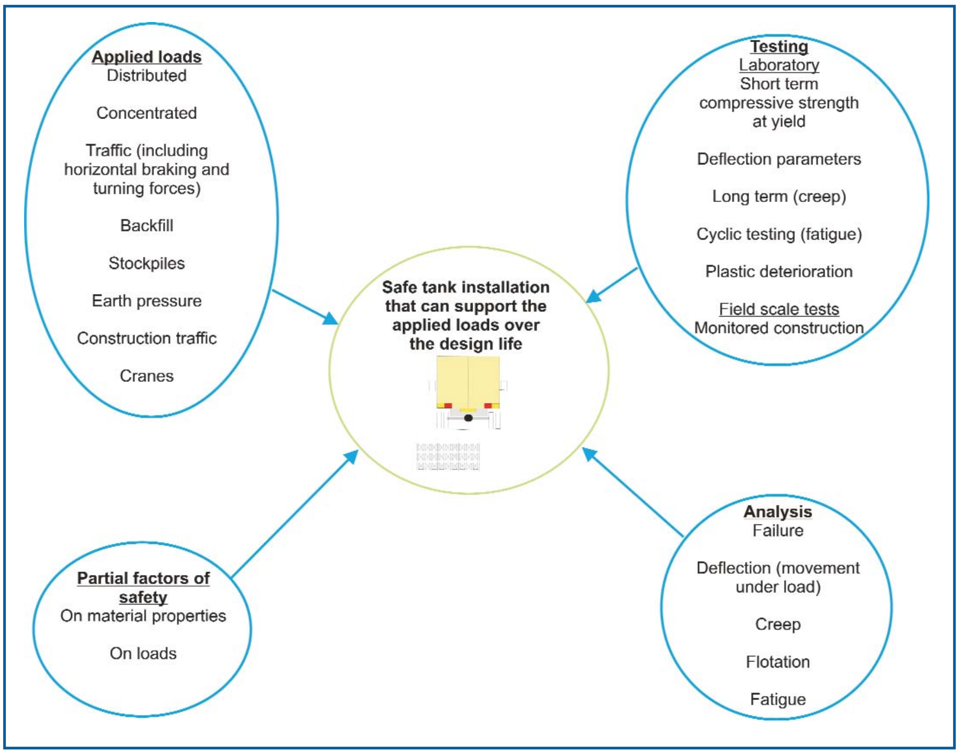


Figure 1.4 ***Design requirements***

1.2 Design standards

Geocellular modular units may be considered as geotechnical structures from a design point of view because they act as retaining structures and support earthworks materials. The design philosophy proposed in this guide follows the requirements for geotechnical design practice as described in BS EN 1997-1:2004.

Eurocode 7 defines three Geotechnical Categories that may be used to establish geotechnical design requirements. These range from Category 1 which covers the most small and relatively simple structures up to Category 3 which covers complex and large geotechnical structures or difficult ground conditions. The Geotechnical Categories are discussed in more detail in Chapter 4 but most geocellular tanks that support vehicles are likely to fall into Category 2. Small tanks in landscape areas may fall into Category 1 if there is only a negligible risk associated with failure and the consequences will be minor.

For Category 1 structures the requirements of Eurocode 7 can be met based on experience and qualitative geotechnical investigations. For Category 2 structures quantitative geotechnical data and analysis is required to ensure that the fundamental requirements of the Eurocode are satisfied (ie the design of the geocellular tanks should include calculations that are based on site investigation data). The designs should be supervised by a qualified engineer with relevant geotechnical training and experience (Department for Communities and Local Government, 2007).

Another concept introduced in Eurocode 7 is the geotechnical design report. This document provides a record of the assumptions, methods of calculation and the results of the verification of safety and serviceability. It should also include details of the supervision required during construction and a note of items to be checked or requiring maintenance or monitoring. The level of supervision will depend on the geotechnical category, with the requirements increasing with increasing category.

The design report should be provided to the contractor and client so that they know what assumptions have been made during the design of the tank, for example maximum vehicle loads. Further information is provided in Chapter 4 of this publication and in BS EN 1997-1:2004. Further information on the implications of the geotechnical categories and geotechnical design report is also provided in Chapter 4. Provision of the design report will help prevent the kind of failures that have occurred with geocellular tanks.

1.3 History

In the mid 1980s plastic honeycomb structures were first used for stormwater storage in mainland Europe, below permeable pavements. This was possibly the first use of modular plastic tank structures to manage stormwater runoff. Their use became more widespread in the early 1990s and in the late 1990s honeycomb attenuation structures were introduced into the UK.

Since then there has been an explosion in the number and different types of box units available and they are now widely used for attenuation storage and infiltration in stormwater drainage systems. The units can be used to construct tanks to replace traditional solutions such as perforated manhole rings in soakaways or oversize pipes and pre-cast concrete box culverts in attenuation systems.

Despite this widespread use, consulting engineers still tend to rely on manufacturers to provide structural designs and there seems to be little understanding of the variation in structural performance of these tanks within the construction industry. This has led to failures that could have easily been avoided.

This book aims to address these issues and allow consistent and transparent designs to be undertaken.

1.4 The importance of appropriate structural design

Apart from the obvious health and safety implications of a collapse and the cost of replacing a tank, there are other implications that should be considered:

- the cost of replacing overlying construction such as car parks and the resulting costs because of loss of use can be far more than the cost of replacing the tank (Figure 1.5)
- the reputation of the designers and/or suppliers and relationships with clients will be damaged
- failures will lead to increased professional indemnity premiums where designers may be responsible
- the acceptance by the industry of modular plastic geocellular units for such use will be undermined
- the consequence of tank collapse can be far reaching and appropriate structural design should be a high priority for both consultants and suppliers, in the same way that it is for other geotechnical structures.

Figure 1.5 *Loss of use of car park spaces due to tank collapse*