Structural design of modular geocellular drainage tanks

Steve Wilson
The Environmental Protection Group Limited
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.
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Construction of a large soakaway using geocellular modular units
## Contents

Summary ................................................................. ii
Acknowledgements .................................................... iii
List of boxes .......................................................... viii
List of figures .......................................................... viii
List of tables ........................................................... xi
Glossary ............................................................... xii

1 Introduction .......................................................... 1
   1.1 Background ..................................................... 1
   1.2 Design standards .............................................. 4
   1.3 History ........................................................... 5
   1.4 The importance of appropriate structural design .......... 5

2 Geocellular structures .............................................. 7
   2.1 Types ............................................................ 7
   2.2 Materials ....................................................... 12
   2.3 Factors affecting structural performance .................. 13
   2.4 Quality and consistency of materials and manufacture ..... 19
   2.5 Implications for testing and design ....................... 20

3 Testing ............................................................... 22
   3.1 Introduction to testing ....................................... 22
   3.2 Static vertical load tests ..................................... 23
   3.3 Lateral load tests ............................................. 27
   3.4 Alternative lateral load test for flexible walled units .... 27
   3.5 Other tests ..................................................... 28
   3.6 Pavement tests – sub-base replacement systems .......... 29
   3.7 Full-scale tests ............................................... 31
   3.8 Dynamic/cyclic tests ........................................... 37
   3.9 Creep tests ..................................................... 41
   3.10 Durability tests ............................................... 43
   3.11 Characteristic design parameters ......................... 43

4 Structural design .................................................. 47
   4.1 Limit state design ............................................. 47
   4.2 Loads ............................................................ 51
   4.3 Vertical loads .................................................. 51
   4.4 Lateral loads ................................................... 56
   4.5 Flotation or uplift ............................................ 62
   4.6 Factors of safety ............................................... 64
   4.7 Creep ........................................................... 68
   4.8 Fatigue .......................................................... 71
   4.9 Minimum cover depth ........................................ 71
   4.10 Multi-layer tanks ............................................. 72
5 Detailed structural and finite element analysis ...........................................73
  5.1 Structural analysis .................................................................73
  5.2 Structural finite element analysis ..............................................75
  5.3 Geotechnical finite element analysis .........................................75
  5.4 Geotextiles and geomembranes .................................................76
6 Construction .................................................................78
  6.1 Installation .............................................................78
  6.2 Plant and materials ............................................................79
  6.3 Backfilling and compaction .....................................................80
  6.4 Abnormal loads .................................................................81
  6.5 Control of water .................................................................81
7 References ..............................................................87
Appendices ..........................................................89
  A1 Determination of loads for creep tests .......................................89
  A2 Basic test method for compressive strength and creep ....................90

List of boxes

Box 3.1 Factors to consider when determining test requirements ..............23
Box 3.2 Example of plate bearing test over a geocellular unit .................33
Box 3.3 Example determination of characteristic strength and deformation
  parameters .............................................................44
Box 4.1 Example calculation of characteristic backfill loads ..................52
Box 4.2 Example calculation of characteristic variable loads ..................56
Box 4.3 Example calculation of characteristic lateral load .....................62
Box 4.4 Example calculation of characteristic uplift force .....................63
Box 4.5 Example calculation of design loads .....................................65
Box 4.6 Example calculation of deflection (serviceability limit state) .......68
Box 4.7 Example creep calculations ..............................................70
Box 5.1 Example structural calculation ............................................74
Box 6.1 Example of side support provided to flexible perforated distributor
  pipe by geocellular units ...................................................86

List of figures

Figure 1.1 Large attenuation tank constructed from individual geocellular
  units ...............................................................1
Figure 1.2 Example of the consequences of failure of a modular geocellular tank
  after three years .......................................................2
Figure 1.3 Loads on modular plastic tanks .......................................3
Figure 1.4 Design requirements ....................................................4
Figure 1.5 Loss of use of car park spaces due to tank collapse ...............6
Figure 2.1 Internal view showing load bearing columns (a) and external
  framework (b) .........................................................8
Figure 2.2 Modular sub-base replacement tank below a car park ...........8
Figure 2.3  Honeycomb structures with rigid plates at top and bottom (a), and end view of honeycomb (b) ........................................... 9
Figure 2.4  Plate type unit: complete unit (a), and inside the unit with intermediate plates (b) .................................................. 10
Figure 2.5  Manufacture of profiled plastic sheet units .......................... 10
Figure 2.6  Profiled plastic sheet units: end view (a), and sheets separating under load test (b) .................................................. 11
Figure 2.7  Unit made up of a matrix of plastic strands .......................... 11
Figure 2.8  Polypropylene chain .......................................................... 12
Figure 2.9  Polyethylene chain ............................................................... 14
Figure 2.10 Creep failure ................................................................. 15
Figure 2.11 Load against time to failure ............................................... 15
Figure 2.12 Regression of strength of PVC materials under cyclic loading .... 16
Figure 2.13 Fatigue in a plastic member subject to repeated bending ......... 17
Figure 2.14 Failure of block paving due to excessive deflection of underlying plastic geocellular tank (intentionally tested to failure) ............. 17
Figure 2.15 Bending in box structure (a), testing to measure bending resistance (b) .............................................................. 18
Figure 2.16 Bending and tension in structural members ............................ 21
Figure 3.1  Example locations for load plate .......................................... 24
Figure 3.2  Different test configurations on a plastic geocellular structure: via a rectangular platen to whole unit (a) via a 300 mm circular platen (b) .............................................................. 24
Figure 3.3  Laboratory testing to simulate loads on column type units ......... 25
Figure 3.4  Laboratory testing to simulate loads on plate type units .......... 25
Figure 3.5  Bending tests over void in a unit ......................................... 26
Figure 3.6  Typical stress – strain curve for compression tests .................. 26
Figure 3.7  Alternative lateral load test ............................................... 28
Figure 3.8  Air bag used to apply lateral load. Test layout (a) and photograph of test (b) .............................................................. 28
Figure 3.9  Creep test with load applied on all sides ............................... 29
Figure 3.10 Testing of a full-scale pavement over a plastic modular geocellular tank (sub-base replacement) .................................. 30
Figure 3.11 Measurement of pavement deflection .................................. 30
Figure 3.12 Insulation around a unit being tested at low temperature .......... 31
Figure 3.13 Installation of full-scale trial .............................................. 31
Figure 3.14 Surface settlement over the tank when loaded ....................... 32
Figure 3.15 Testing results for stacked units ......................................... 33
Figure 3.16 Flotation due to groundwater levels .................................... 34
Figure 3.17 Results of flotation test .................................................... 34
Figure 3.18 Lateral load test layout ..................................................... 35
Figure 3.19 Construction of lateral load test ........................................ 35
Figure 3.20 Results from full-scale load test ....................................... 36
Figure 3.21 Laboratory tests on a flexible unit ...................................... 36
Figure 3.22 Cyclic loading test ........................................................... 37
Figure 3.23 Results of cyclic loading test ............................................ 38
Figure A2.1 Position of load tests on plastic geocellular stormwater storage units .....................................................94
Figure A2.2 Plastic geocellular stormwater storage units axis subject to vertical load tests ...............................................94
Figure A2.3 Plastic geocellular stormwater storage units axis subject to lateral load tests ..............................................94

List of tables

Table 2.1 Typical material properties tested during manufacture .................20
Table 4.1 Implication of geotechnical categories on design and construction of geocellular tanks .................................................49
Table 4.2 Characteristic loads for different land-use .................................54
Table 4.3 $\phi'_{\text{crit}}$ for clay soils (from BS 8002:1994) ...........................59
Table 4.4 $\phi'$ for granular soils (from BS 8002:1994) .............................60
Table 4.5 Partial load factors (based on EN 1997-1:2004) .......................64
Table 4.6 Partial factors of safety for materials, $\gamma_m$ ..........................65
Table 4.7 Minimum cover depths to geocellular units to provide restraint and protect geomembranes .................................72
<table>
<thead>
<tr>
<th><strong>Glossary</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attenuation system</strong></td>
</tr>
<tr>
<td><strong>Characteristic load</strong></td>
</tr>
<tr>
<td><strong>Characteristic strength</strong></td>
</tr>
<tr>
<td><strong>Crate</strong></td>
</tr>
<tr>
<td><strong>Creep</strong></td>
</tr>
<tr>
<td><strong>Design load</strong></td>
</tr>
<tr>
<td><strong>Design strength</strong></td>
</tr>
<tr>
<td><strong>Geogrid</strong></td>
</tr>
<tr>
<td><strong>Geomembrane</strong></td>
</tr>
<tr>
<td><strong>Geotextile</strong></td>
</tr>
<tr>
<td><strong>Honeycomb type</strong></td>
</tr>
<tr>
<td><strong>Infiltration system</strong></td>
</tr>
<tr>
<td><strong>Lateral load</strong></td>
</tr>
<tr>
<td><strong>Limit state</strong></td>
</tr>
</tbody>
</table>
**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](image-url)

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).

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.
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 (i.e. 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*