

## The development of a plastic geo cellular subbase replacement system – laboratory structural trials

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**ABSTRACT:** The Charcon Permavoid geo cellular system is a plastic box system that has been designed to provide shallow stormwater storage within the pavement construction. It has been developed to be installed in place of traditional granular sub base materials immediately below the asphalt, concrete or block paving layers. The unique jointing system joins the boxes together to form a raft like structure to carry the structural loads from vehicular traffic.

The first phase in the development of the system was to undertake a series of laboratory trials to determine the design and performance parameters. This paper discusses the testing that was undertaken and reviews the results and design implications.

**KEY WORDS:** Sustainable Drainage Systems, Environment, Charcon Permavoid, Geo cellular System, Stormwater Storage

### 1 INTRODUCTION

The Permavoid geo cellular system is a stormwater storage system that comprises a series of 150mm thick plastic boxes that are clipped together to form a continuous raft that replaces open graded aggregate at shallow depth within a pavement construction (Figure 1).



**Figure 1 Permavoid unit within open graded gravel**

Once the initial concept was developed and prototypes manufactured a series of laboratory tests were commissioned to develop the design and performance parameters for the system. This started with simple compression tests on single units and progressed in stages to cyclic load tests on full scale pavements. Field scale tests have also been undertaken and are discussed in a separate paper (Wilson, Allen and Tomlinson, 2005).

The purpose of the testing was to provide answers to a number of questions that would be asked by designers and specifiers:

1. What load can the units support?
2. What deflections will occur?
3. What is the effect on the subgrade?

The results of the testing have been used to develop a set of design parameters and to confirm the design method for the system.

The system was developed to rationalise construction of stormwater storage systems and particularly to replace open graded aggregate storage layers below permeable or porous pavements. It is much more efficient than aggregate, with a 95% void ratio as opposed to about 30% for aggregate.

The system also has two major environmental advantages:

1. It uses recycled polypropylene rather than virgin raw materials.
2. It is lightweight and 430m<sup>2</sup> of 150mm thick sub base construction can be delivered on one 44 tonne truck compared to about 65m<sup>2</sup> of conventional aggregate on a 20 tonne truck.

## 2 LABORATORY TESTING OF COMPONENT UNIT

### 2.1 Test regime

The initial laboratory test regime was carried out to determine the properties of the individual units. The first phase of this testing comprised the following:

1. Vertical compression tests with the load applied via 300mm diameter steel plates at two different locations (over the centre and also over the joint of two units clipped together). The testing was undertaken for one, two and three layers of Permavoid (Figure 2a)
2. Lateral compression tests with the load applied via 300mm diameter steel plates
3. Long term maintained load creep tests (90 days duration).

Subsequently a further set of tests were undertaken to determine the following properties:

1. Tensile tests to determine tensile strength of a unit and a joint (Figure 2b)
2. Bending tests to determine the bending resistance of a unit and a joint.

During testing the load is applied automatically and the deflections of the load plate are recorded by transducers (Figure 2a).



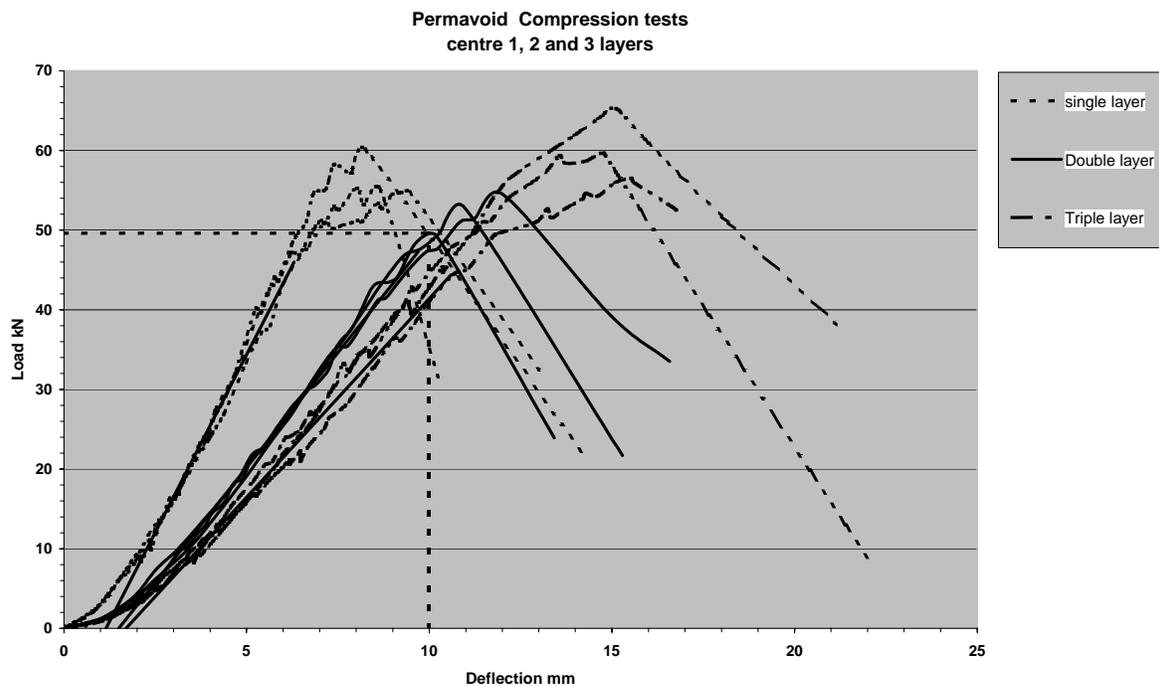
**Figure 2a, Compression testing**



**Figure 2b, Tensile test at failure**

## 2.2 Results

The plastic units are complex structures and it is important to realise that the use of compression tests is used to simplify the design process. However because of this, a cautious approach is adopted when analysing the results. Typical results for the vertical loading are summarised in Figure 3.



**Figure 3 Typical results – vertical compression**

The results show that after the initial seating deflections the units behave in a generally elastic manner until they begin to yield and then fail. The failure loads are similar for one, two and three layers, but the rate of deflection increases as the number of layers increases. Because the units are complex structures, when yield begins to occur there is actual failure of some structural members. For this reason the strength is taken at the point when yield occurs rather than when ultimate failure or collapse occurs.

On the basis of the test results the following design parameters (table 1) can be determined for the units:

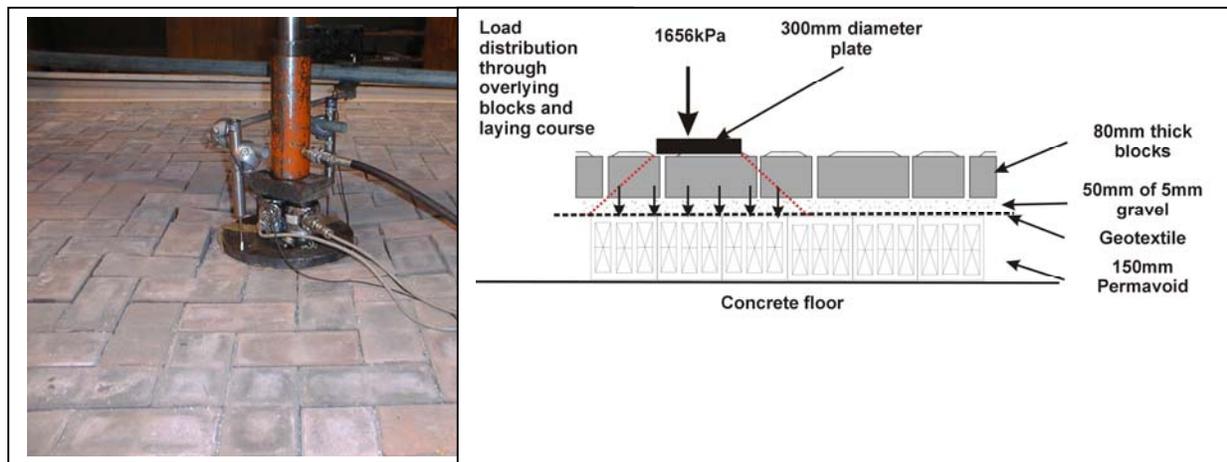
**Table 1, Typical Physical Properties of the Geocellular Units:**

Element	Value	Unit
Short Term Compressive Strength		
- Vertical	715	kN/m <sup>2</sup>
- Lateral	156	kN/m <sup>2</sup>
Short term deflection		
- Vertical	1mm per 126kN/m <sup>2</sup>	mm per kN/m <sup>2</sup>
- Lateral	1mm per 15kN/m <sup>2</sup>	mm per kN/m <sup>2</sup>
Ultimate tensile strength of a single joint	2.25	kN
Tensile strength of a single joint at 1% secant modulus	1	kN
Bending resistance of unit	0.71	kNm
Bending resistance of single joint	0.16	kNm
Minimum Void Ratio	95	%

### 3. FULL SCALE LABORATORY PAVEMENT TESTS (STATIC)

#### 3.1 Test regime

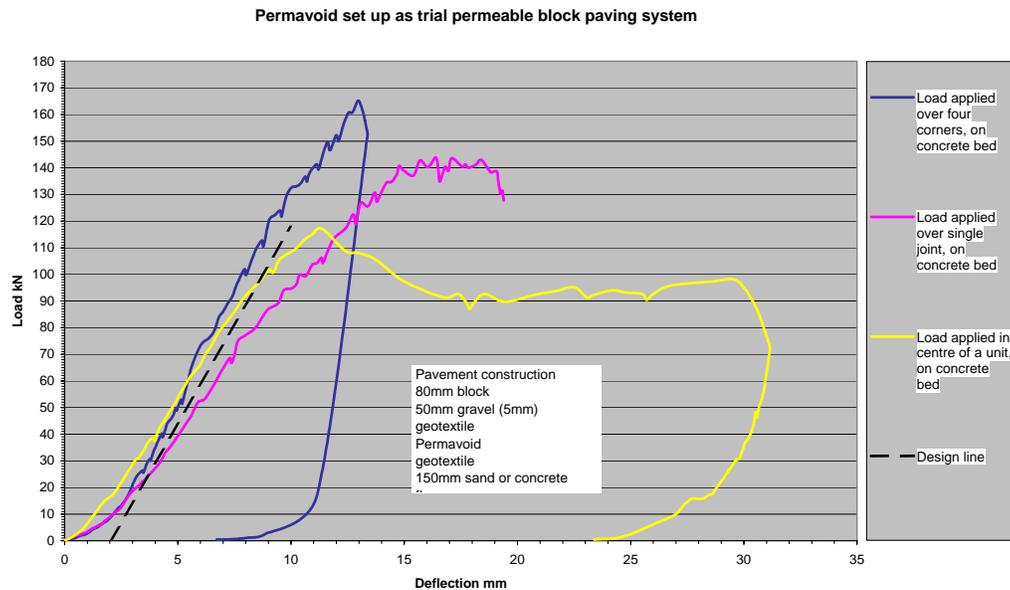
Using the design parameters determined from the initial phase of testing a full scale pavement trial was designed to confirm the performance below a permeable block paving (Figure 4). One of the aims of this was to determine the deflection profile of the system under loading. The load was applied in various locations over the units to obtain worse case results.



**Figure 4 Full scale test below block paving**

### 3.2 Results

Graphs of load against deflection have been obtained from the full scale tests (Figure 5).



Comparison of the results for the pavement test with those on a single box shows the load spread through the upper layers is around 2 vert to 1 horiz. In order to limit pavement deflections to 1mm (from the Permavoid only) the applied load at the surface needs to be limited to 16kN on the 300mm diameter plate (or 225kPa). Using the results from the tests on the boxes the maximum load to limit deflections to 1mm was estimated to be 260kPa. The difference between the two tests is probably due to the load being concentrated onto a small area of box when the blocks deflect in the full scale test, which gives a greater recorded deflection. These limiting pressures are similar to those typically applied by car tyres (up to about 245 kPa).

The results also indicated that the radius of deflection around the load application is very small and that the deflection is concentrated in a small area around the load plate.

## 4 FULL SCALE LABORATORY PAVEMENT TESTS (CYCLIC)

### 4.1 Test regime

The final phase of laboratory testing was to undertake cyclic loading tests on a full scale pavement. The laboratory experiment comprised the construction and testing of a 1:1 scale pavement section incorporating Permavoid boxes as a sub-base. The pavement was surfaced with conventional concrete block pavers. The cyclic load was transferred onto a load cell and then onto the block surfacing using a 300mm steel plate. The load cell was linked directly to a data logger to allow continual monitoring of the load being applied to the pavement.

Instrumentation was set up in an array across the pavement and load plate to measure deflections of the pavement surface under load. The transducers were also linked to the data logger to allow real time monitoring of the surface displacement. The test set up is shown in Figure 6.

The testing was undertaken in sets of cycles, starting with approximately 36 cycles per hour, increasing to approximately 360 cycles per hour. The first 144 cycles were undertaken at 36 cycles per hour, equating to a cycle duration of approximately 100 seconds. The remainder of the cycles were undertaken at a frequency of approximately 360 cycles per hour, equating to a cycle duration of approximately 10 seconds (it took 10 seconds for the full load of 55kN to be applied to the pavement and then fully removed again).

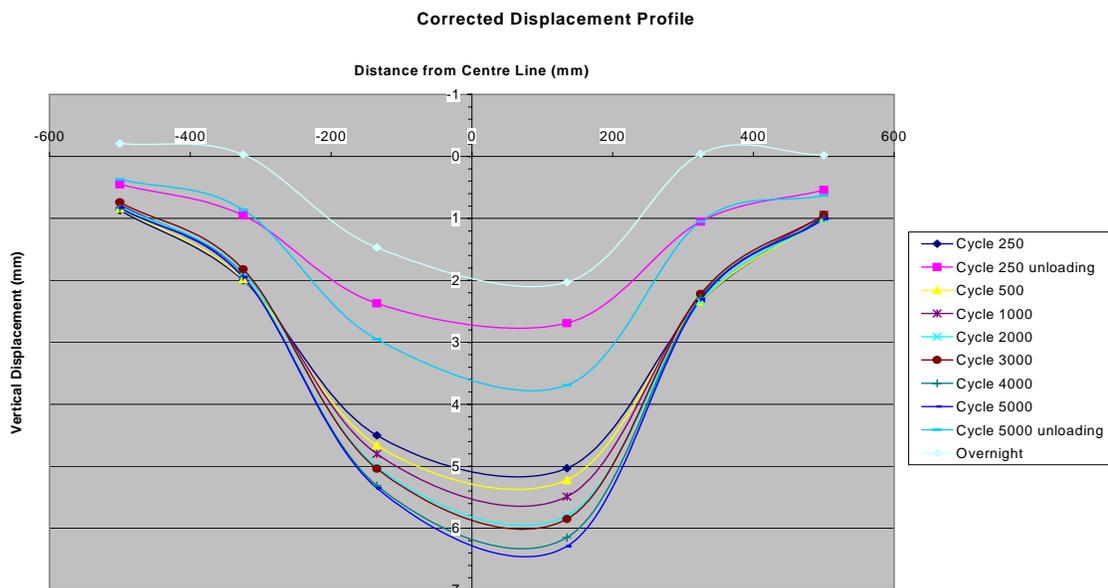


**Figure 6, Cyclic loading test**

The applied load of 55kN is equivalent to the wheel load of a tractor-unit for a heavy goods vehicle (774kPa pressure). The number of cycles for this experiment was based on the use of the system under areas with infrequent HGV loading (it equates to a 50 year design life for a refuse collection vehicle with a frequency of 1 per week).

#### 4.2 Results

On the basis of the observed displacement patterns and examination of the data, it was considered that it is reasonable to apply a correction to the data. A graph plotting cycle number against permanent settlement was produced. This clearly indicated that there is a bedding in effect of about 10mm, which is approximately complete after 108 cycles. This was due to the geotextile deflecting into the spaces in the surface of the Permavoid and compaction of the laying course. In practice in a full scale construction these will be removed by compaction during construction of the block paving which was not fully achieved in the confined laboratory test space. As such, the correction applied is to remove the permanent displacement recorded after the 108th cycle. The corrected displacement profiles are shown in Figure 7.

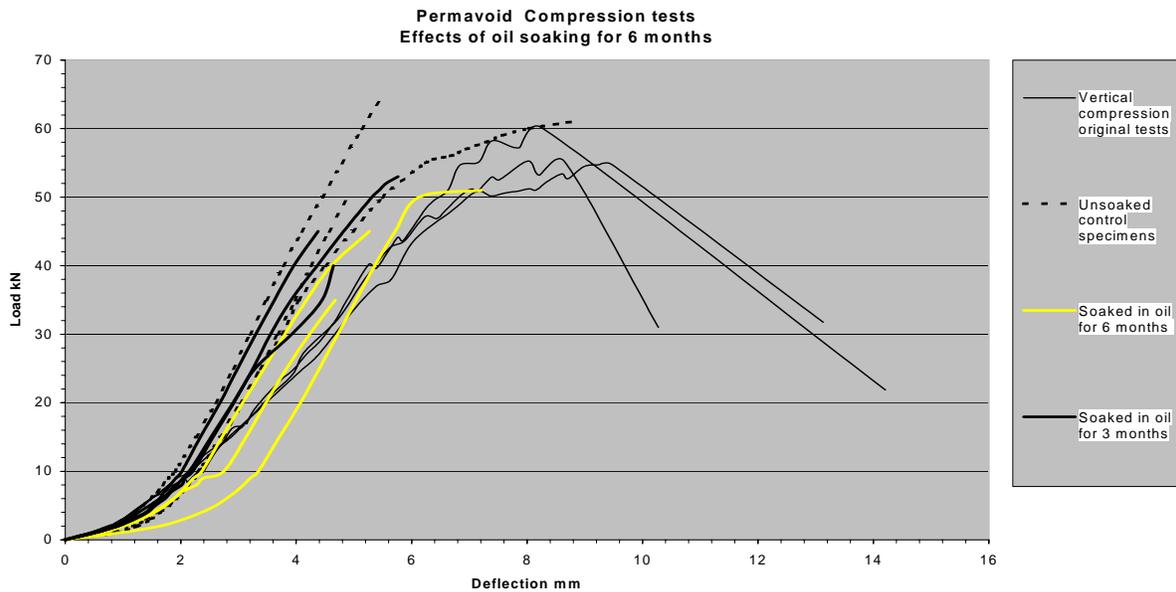


**Figure 7, Cyclic loading results**

On completion of the testing there was no evidence of any damage to the block paving surface. As can be seen, the permanent deflection is up to about 3.5mm by cycle 5000. Elastic deflections on each load cycle were about 2mm to 3mm.

## 5 OIL SOAKED TESTS

Testing of samples was carried out at Coventry University to determine the effect of prolonged contact with hydrocarbons on the structural capacity of the units. The units were completely immersed in used engine oil and then the vertical compression strength was measured at one, three and six months. This is a very onerous test and far in excess of the exposure that would occur in practice where exposure would be to a film of oil on any water surface.



**Figure 8, Summary of Oil soakage tests on Permavoid at Coventry University**

The results of the testing are summarised in Figure 8. The test results for the units that have been exposed to oil have been super imposed on the original vertical compression test results. After soaking in used engine oil for one month there was no loss of strength in the units or change in behaviour under loading.

After three months soaking in used engine oil there was again no indication of any change in strength in the units or change in behaviour under loading. Any observed variations are within the scatter of the unsoaked results. After six months soaking the results indicate that there may be a change in the behaviour of the units. The initial set in the test appears to be greater although this may be due to variations in the test set up, because there is no change in the stiffness of the Permavoid once the elastic part of the graph is reached. There is no change in the load deflection characteristics within the design range. Complete failure (transition from ductile to brittle behaviour) appears to occur at around the same load as the yield point is achieved in the original unsoaked samples. In practice this is not considered significant because the applied loads are maintained well below the yield point to reduce the effects of creep.

Thus in practice the units could be left immersed in oil for up to six months with no significant practical effect on their performance.

## **6 SUMMARY**

A series of laboratory tests have been undertaken in order to determine the design parameters for a geo cellular system (Charcon Permavoid) that is used in place of open graded sub base for storm water storage below road pavements.

The testing has been undertaken to determine the compressive strength of the units and their performance below block paved areas. Tests to determine the effects of oil that may be present in stormwater have also been undertaken.

The results indicate that the units will be suitable for use under areas such as car parks or access roads where there is infrequent HGV traffic with a cover of block paving and laying course. The presence of oil pollution in stormwater is unlikely to effect the structural performance of the system.

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