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The performance of geotextiles in concrete block permeable pavements

Literature review

for

Interpave

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Scope

Steve Wilson, Technical Director of Environmental Protection Group Ltd (EPG), has been engaged on behalf of Interpave, The Precast Concrete Paving and Kerb Association, to undertake a "desk top" review of known published literature relating to the biodegradation and structural performance of permeable pavements with a view to determine the if geotextile within a permeable pavement is necessary and/or desirable. EPG were also requested to provide a "Statement of Advice", based upon the findings of this work, on the use of geotextiles in such applications.

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1. INTRODUCTION

Geotextiles may be used in two locations in concrete block permeable pavements:

1. Between the laying course and the sub base (upper geotextile)

2. Between the sub base and subgrade (lower geotextile)

The upper geotextile was historically specified in the UK to prevent migration of the finer laying course material into the coarser sub base material. However, this geotextile can be omitted if the grading of the laying course and sub base is compatible so as to avoid migration of the laying course into the sub base. In the USA using appropriate gradings for these materials has always been used to prevent migration of material, and an upper geotextile is only used in a few cases. The latest edition of the ICPI's design manual for permeable interlocking concrete pavements does not require an upper geotextile.

The lower geotextile is almost always used in the UK to prevent the open graded subbase punching into the subgrade.

At present there is concern by some designers and manufacturers of concrete block permeable pavements that the upper geotextile may induce a potential structural weakness, especially where it is subject to heavy braking or turning. The reason for this concern is the reduced friction between the materials that occurs because of the geotextile. Pavement design assumes that there is full friction between all layers in the pavement.

There is also anecdotal evidence that the geotextile makes placing the laying course and laying the blocks more difficult which can cause poor installation. However there are some designers and manufacturers who consider the upper geotextile is essential for the pavements to remove pollution from the runoff. These differing opinions are causing confusion for the majority of designers and the purpose of this literature review was therefore to try and clarify the situation and determine the following:

- What evidence is there that the upper geotextile is detrimental to the structural performance of concrete block permeable pavement.

- What evidence is there to show that the upper geotextile is essential to remove pollutants from runoff.

The review that follows is split into two sections. The first section summarises the findings of papers that are related to the pollution removal performance of permeable pavements (both with and without an upper geotextile) and the second section summarises the findings of papers related to the structural implications of the upper geotextile.

The notation used in this summary is as follows:

General descriptions and summaries of information in a paper are in normal text.

Direct quotes from a paper are in italics.

Text added into a quote for clarification is in [square brackets].

{Comments on the findings of a paper are in brackets and bold text}.

2. PAPERS RELATING TO POLLUTION REMOVAL

Author(s)	Date	Title	Source
R Shahin	1994	**The leaching of pollutants from four pavements using laboratory apparatus**	Note this is a summary of research at Guelph University described in Uni Eco-stone guide and research summary by Uni Group.

This 180-page thesis describes a laboratory investigation of pavement leachate. Four types of pavements were installed in the engineering laboratory: asphalt, conventional interlocking pavers, and two UNI Eco-Stone pavements, to determine the effect of free-draining porous pavement as an alternative to conventional impervious surfaces. Runoff volume, pollutant load, and the quantity and quality of pollutants in actual rainwater percolating through or running off these pavements under various simulated rainfall durations and intensities were studied.

"[concrete block permeable pavement] *was found to substantially reduce both runoff and contaminants*."

"*The runoff collected from porous pavement in the laboratory showed very low concentrations in all water quality parameters, especially in oils and grease, phenols, heavy metals, and bacteria counts. Eco-Stone* (concrete block permeable pavement] *pavements showed the lowest concentrations in these parameters out of the three pavements*".

"*Percolation through the porous pavements' surface and underlying media slowed the water flow. The process of slowing the water allowed more time for oxidation of pollutants and the water had more time to react with other chemicals, such as chlorides, nitrates, and nitrites. Also, the pavement apparently filtered suspended solids and some other contaminants, such as sodium and sulphates*".

"*Porous pavement appears to have significant long-term benefits compared to conventional asphalt pavements in terms of its ability to reduce the quantity of stormwater pollutants. EC3 reduced the amount of stormwater pollutants more than the other porous pavement.*" [EC3 was a concrete block permeable pavement with 75mm aggregate subbase and joints filled with washed stone.]

The available evidence indicates that an upper geotextile was not included in the pavement construction. In North America an upper geotextile is only specified if the aggregates used for the laying course and sub base do not have compatible gradings and only a few projects have used an upper geotextile.

MK Thompson	1995	**Design and installation of test sections of porous pavements for improved quality of parking lot runoff**	Note this is a summary of research at Guelph University described in Uni Eco-stone guide and research summary by Uni Group.

This thesis examines four instrumented test pavements that were built in a parking lot at the University of Guelph including a concrete block permeable pavement.

"*Contaminant loads from asphalt surface were always greater than the other pavements and surfaces. This is mostly due to the asphalt being 100% impervious, which increases the amount of runoff and pollutants reaching the sewers and ultimately the receiving waters.*"

Author(s)	Date	Title	Source

"[Concrete block permeable pavement] *effectively reduces the amount of surface runoff. Runoff was only generated from the surface when the rainfall intensity exceeded the infiltration rates of the pavement.* [Concrete block permeable pavement] *proved to be an adequate porous pavement for reducing surface contaminant runoff loads.*"

An upper geotextile was not used in the pavement construction.

CJ Pratt	1997	**Design guidelines for porous/permeable pavements**	Sustaining water resources in the 21st Century. September 7 – 12 1997, Malmo, Sweden pp196 - 211

This paper is a general discussion of various aspects of the performance of permeable pavements including pollution removal. The paper identified that permeable or porous surfaces reduce the volume of runoff {**note that this may reduce the overall pollution load**}

"*Observations in the laboratory and in the field by a number of researchers have shown that pollutants washed in pervious constructions tend to accumulate within the structure. In the case of construction with porous macadam surfacing, the pollutants have been found mainly on the geotextile at the base of the construction…*" The base of the construction is taken to mean between the subbase and the subgrade. Later in the paper it clarifies that porous macadam pavements do not usually have an upper geotextile.

"*Studies on full scale laboratory models and in the field on a permeable pavement surfaced with CeePy blocks have shown that pollutants are also concentrated on the geotextile but, because of the different level in the construction at which the geotextile is located, the pollutants are retained towards the top of the construction where retrieval or treatment might be easier and less costly*" {**This suggests that the pollution removal performance of the geotextile is the same whether it is located at the top or bottom of the pavement construction**}

A study of a CeePy block pavement which has an upper geotextile showed a reduction in suspended solids (SS).

The paper also discusses laboratory tests at Coventry University "*with 84% of the oil being retained on the internal surfaces of the construction, the majority* [of this] *(68%)* [was] *on the geotextile.*" However no testing was carried out to directly compare the performance of pavements with and without an upper geotextile.

The paper suggests that "*as oils seem to be predominantly retained on the geotextile, as shown by laboratory experiment [Pratt and Bond] , it seems advisable to specify the inclusion of a geotextile layer within the top 100 – 200mm of all pavement types.*"

Author(s)	Date	Title	Source
PC Bond and CJ Pratt	1998	**Developments in permeable /porous pavements, observations on mineral oil bio-degradation**	Standing Conference on Stormwater Source Control, XV, 1998, Coventry University

This paper discusses a study into biodegradation of oils in permeable pavements carried out by Coventry University. The purpose of the study was to determine the role that biodegradation plays in reducing the concentration of hydrocarbons in outflow from permeable pavements.

The laboratory study used concrete blocks bedded on clean gravel with a geotextile below (Terram 1000). The subbase below the geotextile comprised 600mm thickness of 20 -50mm crushed granite. There was also a basal geotextile between the subbase and subgrade.

There was no testing on a pavement without an upper geotextile to give a comparison of the performance with and without an upper geotextile.

Oil and rainfall events were applied to the pavement and the concentration of oil in the effluent was measured. Fertiliser was also added to provide nutrients. Carbon dioxide and oxygen concentrations were measured in the subbase.

"*A noticeable rise in structure temperatures, particularly within the subbase*", was noted and the authors interpreted this as indicating increased bacterial metabolic activity (ie biodegradation) was occurring within the subbase.

"*Data from gas temperature and dipslide observations suggest that active breakdown of hydrocarbons was occurring, concentrated within the subbase*".

CJ Pratt, AP Newman and PC Bond	1999	**Mineral oil bio-degradation within a permeable pavement: long term observations**	Water Science and Technology, Vol 39 No 2 pp103-109

This paper discusses the research pavement test set up from previous paper (Bond and Pratt 1998) which was monitored for a further period of 300 days.

It reports the same conclusions as the previous paper.

M Legret and V Colandini	1999	**Effects of a porous pavement with reservoir structure on runoff water: water quality and fate of heavy metals**	Water Science and Technology, Vol 39 No 2 pp111-117

The paper discusses monitoring of the water quality in a full scale trail of a porous asphalt surface. The construction was:

60mm of 0/14 porous asphalt

Author(s)	Date	Title	Source

200mm of porous bituminous bound aggregate

350mm of 10/80 aggregate

Geotextile over formation

It did not have an upper geotextile within the construction.

The results found that heavy metals and suspended solids were removed from runoff by the pavement. Most of silt was trapped in the surface and did not reach the subbase. {**Although this study was for porous asphalt it is likely that a similar effect will be seen with concrete block permeable pavement if the jointing aggregate has an appropriate grading**}.

CJ Pratt	1999	**Developments in permeable pavements: further observations on mineral oil degradation**	Standing Conference on Stormwater Source Control, XVII, 1999, Coventry University

This paper reports additional data from experiments at Coventry University in the same test rig reported by Pratt (1997) and Bond and Pratt (1998). The test was extended from 450 days to 735 days. The test pavement included an upper geotextile (Terram 1000). There was no comparative testing to determine the performance of pavements with and without an upper geotextile. The paper reports that the original work was looking at shock loading of oil and this paper looks at continuous low level loads.

The study measured the temperature, carbon dioxide and oxygen levels in the laying course and subbase. There were only minor variations from normal atmospheric conditions in the bedding layer but much higher carbon dioxide concentrations in the subbase. **{In the paper by Pratt and Bond 1998 the authors interpreted this as indicating that biodegradation of oil was occurring in the subbase}**.

The temperature increase was greatest in the subbase zone "*where the bulk of the bio-degradation is believed to occur.*" "*the internal characteristics of the sub-base better support the degradation processes …*"

The pavement was taken apart after the tests and it was found that "*the geotextile layer separating the bedding gravel from the sub-base stone had retained large quantities of the total applied oil*" "*….oil found on the other construction materials which was only some 11 and 22% respectively*".
{There was no comparative testing to determine if the other construction materials would retain oil if the upper geotextile was absent}.

The paper also reports on studies to measure the oil retaining capacity of all the materials used in the pavement. The results are summarised in a table and quoted as the maximum retention capacity per m^2 of pavement area:

"*Concrete blocks – 1171g oil /m^2*

Bedding gravel and stones - 2782g oil /m^2

Geotextile - 465g oil /m^2

Granite subbase - 5124g oil /m^2"

Author(s)	Date	Title	Source

The results show that the geotextile has the greatest oil retention per unit weight of material.

"*36g of oil per kg of bedding gravel*
3189g of oil per kg of geotextile
7g of oil per kg of granite subbase"

{However because the geotextile is so thin and light compared to the subbase aggregate in the full size pavement the subbase will hold the most oil (in the pavement there is only about 0.146kg of geotextile so it only holds 0.146kg x 3189 = 465g of oil/m^2 and there is about 77.3kg of aggregate in the bedding gravel so the oil retention is 36 x 77.3kg = 2782g of oil/m^2}.

{These results tend to suggest that if the geotextile is not present the subbase will retain oil. These results do contradict the earlier conclusions from the trial tests but it is difficult to draw any firm conclusions as there was no comparative testing to compare the performance of pavements with and without geotextiles}.

Author(s)	Date	Title	Source
C Dierkes, L Kuhlmann, J Kandasamy, G Angelis	2002	**Pollution Retention Capability and Maintenance of Permeable Pavements**	Not known

The main objective of the study presented was to determine the behaviour of pollutants in the pavement, the roadbed and the soils below permeable pavements. Laboratory studies in test-rigs and field investigations of full size pavements were carried out. The pavements only had a lower geotextile between the bottom of the subbase and the subgrade.

"*The concentrations of heavy metals and mineral oils, which are the most important harmful substances on traffic areas, are determined in the whole structure and in the underlying soil. If pollutants migrate through the structure, their concentrations are expected to be increased in the roadbed and the underlying soil.*"

The conclusions from the laboratory tests were:

"*There are big differences in the ability of the pavers and joint fillings to trap the heavy metals. Most metals in seepage were found where the infiltration was carried out only through the joints.*"

"*Pavements with large joints or apertures for infiltration must be equipped with a suitable joint-filling, otherwise pollutants can pass the pavement and get into the underground more easily.*"

"*Most structures show no danger of a possible groundwater contamination during the tests, so porous pavements made of concrete blocks could be used without fear of a breakthrough of metals for a period of at least 50 years.*"

The field investigations studied a car park in a supermarket in Germany.

Author(s)	Date	Title	Source

"The *pavement of the car park consists of the porous* [concrete] *pavers with the joint filling (1 mm to 3 mm), a bedding with a depth of 5 to 8 cm (2 mm to 5 mm) and a 20 to 25 cm thick subbase of crushed stones (8 mm to 45 mm).*"

"*The highest copper, zinc and cadmium concentrations were found in the pavement (paving stones, joint filling and bedding). The permissible limits* [German] *for playgrounds are not exceeded. All metal-contents were in the range of natural background concentrations of German soils. No significant increase of the heavy metal concentrations in the underlying soil was observed.*"

"*At the mineral oil type hydrocarbons (spillage) an input can be seen. Highest concentrations were found in the joint filling. In the subbase and the soil the concentrations are also elevated. Highest concentrations with 28 mg/kg are very low. A significant increase but no endangering of the soil could be observed. PAH could not be detected at all.*"

Author(s)	Date	Title	Source
A.P. Newman, C.J. Pratt, S.J. Coupe and N. Cresswell	2002	**Oil bio-degradation in permeable pavements by microbial communities**	Water Science and Technology Vol 45 No 7 pp 51–56 IWA Publishing 2002

The research was carried out on the same concrete block permeable pavement structure as previously described (Pratt *et al.*, 1996; Bond *et al.*, 1999) which included an upper geotextile. It looks at the microbe populations on the upper geotextile but did not look at populations on any of other materials in the pavement, not on the development of microbe populations within pavements without an upper geotextile for comparison.

Author(s)	Date	Title	Source
W James	2002	**Green Roads: Research into Permeable Pavers**	Stormwater. March/April 2002

This paper presents a general discussion of full scale and laboratory trials of the pollution removal of Uni Ecoloc block paving. The discussion indicates the pavement was successful in removing pollutants.

The pavement did not include an upper geotextile.

Author(s)	Date	Title	Source
C Pratt, S Wilson and P Cooper	2002	**Source control using constructed pervious surfaces. CIRIA Report C 582**	Construction Industry Research and Information Association (CIRIA)

This provides information on all types of pervious surface.

"*Pollutants that are conveyed in association with sediment, may be filtered from the percolating waters. This may occur through trapping within the soil or aggregate matrix, or on geotextile layers within the construction.*"

"*The pollutants are trapped with the construction at various locations according to the type of pervious construction. In cases where a geotextile is installed, much of the pollution is retained on it. In some cases the geotextile is situated in the upper layers of the construction (as with porous/permeable concrete block surfacing bedded on gravel); in others it is used as a separation layer at the subgrade.*"

Author(s)	Date	Title	Source

"*Positioning a geotextile near the surface of the pervious construction should enable pollutants to be trapped and retained close to the surface of the construction. This retention has disadvantages and advantages. The main disadvantage is that the filtering of sediments and their associated pollutants at this level may hamper percolation of waters and can eventually lead to surface ponding. One advantage is that even if eventual maintenance is required to reinstate infiltration, only a limited amount of the construction needs to be disturbed, since the sub-base below the geotextile is protected.*"

"To assist with pollution control, it is helpful to include a geotextile in the upper layers of the pavement."

In discussing the subbase it states that "*these layers represent the site of long term chemical and biological pollutant retention and degradation processes. The construction materials should be selected, in addition to their structural strength properties, for their ability to sustain such processes. In general this means that materials should create neutral or slightly alkaline conditions and they should provide favourable sites for colonisation by microbial populations. Materials could range from natural soils to man-made plastic, load-bearing void formers. The structure formed of the material should be open-textured to facilitate drainage and aeration, but should ideally have sites where percolating waters may be ponded or held by surface tension, thus delaying through-flow.*"

Dierkes, Carsten, Lothar Kuhlman, Jaya Kandasamy, George Angelis.	2002	**Pollution Retention Capability and Maintenance of Permeable Pavements**	9th International Conference on Urban Drainage, Portland, Oregon. 8-13 September 2002

The purpose of the research discussed in this paper was to study the pollution retention capacity and to assess the success of cleaning clogged permeable pavements. Fifteen years after construction a permeable paver grocery store parking lot it remained permeable and still filtered pollutants. Details of the pavement construction are not provided and it is not clear whether an upper geotextile was present.

B Shackel, J Ball and M Mearing	2003	**Using permeable eco-paving to achieve improved water quality for urban pavements.**	Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003)

This paper discusses the study of a full scale demonstration project in Manly, New South Wales, Australia. The construction of the pavement was:

Uni Ecoloc Blocks

Bedding layer 2-5mm aggregate

Subbase 20mm open graded

Geotextile

There was no upper geotextile in the construction. The study found that the permeable pavement reduced the volume of runoff and this reduced the ability of the pavement to transport contaminants.

Author(s)	Date	Title	Source

{Note this will happen regardless of the presence of geotextiles because the reduction in runoff is influenced by the nature of the construction (the blocks, bedding layer and subbase soak up water.}

W James, WRC James, and H Von Langsdorff	2003	**Computer aided design of permeable concrete block pavement for reducing stressors and contaminants in an urban environment**	Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003)

The paper discusses modelling of runoff from permeable pavements using stormwater management software.

"*Another important pollutant that is removed or reduced by permeable pavement is related to turbidity, viz. the concentration of settleable or suspended solids (James and Thompson, 1996; James and Shaheen, 1997).*"

The available evidence indicates that an upper geotextile was not included in the pavement construction. In North America an upper geotextile is only specified if the aggregates used for the laying course and sub base do not have compatible gradings and only a few projects have used an upper geotextile.

AP Newman, A Shuttleworth, T Puehmeier, K Wing Ki and CJ Pratt	2003	**Recent developments in oil retaining porous pavements**	Proc Second National Conference on Sustainable Drainage, Coventry University, June 2003pp 81 -89

"*The important role of the* [upper] *geotextile in this type of device* [concrete block permeable pavement] *is well documented (Newman et al 2001) and is felt to be very important in the design of pervious pavement invented by Pratt in 1994.*" **{the only reference listed in the references is Newman et al 2002, not 2001. This paper (Newman, Pratt, Coupe and Cresswell is discussed above and did not discuss any testing that proves the upper geotextile is required. Therefore this statement cannot be proven.}**

The paper discusses discrepancies in the total oil sorptive capacities of individual materials and the results of lab testing at Coventry where most of oil in test rigs was in [upper] geotextile.

"*…as much as 90% of the oil might have been retained on the* [upper] *geotextile and the importance of this element of the structure is greater than would be indicated by the sorptive capacities alone.*" However there is no reference to comparative testing to determine what happens if the upper geotextile is absent.

The paper puts the pollution removal performance down to the breakthrough head of the geotextile used, which holds water above the geotextile layer and allows oil to sorb onto the fibres of the geotextile.

It states that permeable pavements can deal with low levels of oil pollution but allow oil through the construction if large spills occur.

Author(s)	Date	Title	Source
S Wilson, AP Newman, T Puehmeier and A Shuttleworth	2003	**Performance of an oil interceptor incorporated into a pervious pavement**	Engineering sustainability, Proceedings of ICE, Vol 1 No 1, 2003

The paper discusses testing on a model concrete permeable pavement with an oil separator below. Oil was observed to spread on to the upper geotextile below the laying course and a large proportion was retained there.

However the test was carried out with plastic cells as subbase, rather than aggregate. It did show that the oil would not flow quickly through the plastic cells that formed the subbase. **{If the subbase was aggregate the oil would have absorbed onto the particles as it passed.}**

In addition there was no comparative testing done without a geotextile to see what the performance would be. **{it was not possible with the plastic box structure and it was not the purpose of this test}.**

Author(s)	Date	Title	Source
EZ Bean, WF Hunt, DA Bidelspach and RJ Burak	2004	**Study on the surface infiltration rate of permeable pavements**	1st Water and Environment Specialty Conference of the Canadian Society for Civil Engineering Saskatoon, Saskatchewan, Canada June 2-5, 2004 / *2-5 juin 2004*

The paper discusses full scale trials of the pollution removal in a Uni Ecoloc pavement.

"*Permeable pavement has also been shown to act as a filter of such pollutants as lead and automotive oil (Brattebo and Booth,2003; Pratt, 1995)*"

The results showed that zinc was removed by the pavement and the authors also suggested that the pavements would remove copper and Phosphorous. They indicated that there was no trend suggesting removal of suspended solids, but the data was limited.

Details of the pavement construction are not provided and it is not clear whether an upper geotextile was present.

Author(s)	Date	Title	Source
D Newton G Jenkins and I Phillips	2004	**Design of conjunctive pervious/impervious pavement systems for optimal stormwater management performance**	Novatech 2004, Sustainable techniques and strategies in urban water management. 5th Int Conference, Lyon, France June 2004 pp 779 - 786

This paper discusses a study of suspended solids removal by permeable paving. The study used concrete lattice blocks on a 2-7mm gravel bedding layer on a 5-20mm subbase.

"*The use of gravel for the bedding layer eliminated the need for a geotextile between the subbase and bedding layers*".

Author(s)	Date	Title	Source

"*Numerous studies have identified clogging of the geotextile layer as an important mechanism for particulate removal. This is also the primary mechanism for the reduction in infiltration capacity which is the principal operational concern for all forms of porous pavement. Hence a key objective of the experimental program was to determine the effectiveness of a system relying on coarse media filtration and sedimentation for particulate removal rather than filtration through the geotextile layer.*"

"*Despite the absence of a geotextile layer Figure 1 indicates that the constructed pavement can provide effective removal of particulate material even under high hydraulic loadings.*"

Suspended solids removal was between 91% and 94% and occurred by filtration and sedimentation during vertical flow through the pavement. Further treatment in the subbase was considered to be a second order effect.

"*The absence of a geotextile layer within the pavement can minimise the potential for clogging by making the full pavement depth available for sediment storage rather than a thin clogging layer above the geotextile.*"

Note that again there was no testing of pavements with an upper geotextile in order to give a direct comparison.

S Fach and WF Geiger	2004	**Effectiveness of the pollutant retention capacity of permeable pavements to road runoffs**	Novatech 2004, Sustainable techniques and strategies in urban water management. 5th Int Conference, Lyon, France June 2004 pp 779 - 786

This paper looked at the performance of different subbase and laying course materials (Limestone 0/45, crushed basalt 2/5 and crushed brick 2/5). There were no geotextiles in the pavement construction.

The results showed that permeable pavements without geotextiles effectively removed heavy metals from runoff (> 90%).

BK Ferguson	2005	**Porous pavements**	CRC Press

This is a text book about all forms of pervious pavements.

It discusses geotextiles on Page 86, but only in relation to preventing migration of fines between non compatible materials. It does identify upper and lower geotextiles but there is no mention of a requirement for pollution removal.

On Page 155 onwards it discusses the pollution removal performance of pervious pavements.

"*A porous pavement traps solid particles on the pavement surface along with the metal ions adsorbed to the particles….*"

"*Particles that pass through the surface pores are likely to continue to the bottom of the pavement.*

Author(s)	Date	Title	Source

They can settle on the pavement's floor or discharge through a drainage pipe if one is present. On the whole, solids accumulate most at the surface of a pavement or at the bottom, the smallest accumulations tend to be in the middle."

A lot of the discussion about pollution removal is mainly based on studies of porous asphalt pavements, but it does include reference to the work at Coventry University.

The book suggests that the numerous internal surfaces in the pavement support the microbiotic community that biodegrades oils.

It refers to the research work at Coventry University and the biodegradation of oil on a geotextile, but it also refers to other studies (porous asphalt) where biodegradation was also observed. It is not clear if upper geotextiles were present in the other studies and the author has been contacted to clarify this. The text emphasises that a reduction in pollutant load can occur as a result of reduced runoff from permeable pavements. **{This will not be influenced by the presence of an upper geotextiles and occurs in all permeable pavements}**.

SJ Coupe, T Lowe, HG Smith and IW Westwood	2005	**The effects of nutrients on the biodegradation of used and unused oil in permeable pavement systems**	Proc Third National Conference on Sustainable Drainage, Coventry University, June 2005pp 222 -231

This paper discusses research work at Coventry University that included a study of the colonisation of Inbitex geotextile (this appears to be a very similar specification to Terram 1000) by microbes. The research only looked at the upper geotextile and not any of the other materials in the pavement. There was no comparative testing carried out to see how the pavements perform if there is no upper geotextile present.

A Beeldens and G Herrier	2006	**Water pervious pavement blocks: The Belgian experience**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

This paper provides a review of research into performance of permeable pavements carried out in Belgium.

"*To ensure the stability of the structure, contamination between layers must be prevented, if necessary by separating them with a geotextile. However, this should be avoided as much as possible, to prevent one layer from sliding over another under the action of traffic.*"

{Note it is a fundamental concept of the structural design of pavements that full friction develops between different layers of materials. An upper geotextile will reduce the friction between materials significantly.}

Author(s)	Date	Title	Source
T Van Seters, D Smith, G MacMillan	2006	**Performance evaluation of permeable pavement and a bioretention swale**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

The paper discusses a full scale study of a concrete block permeable paving without an upper geotextile. It reports that stormwater concentrations of motor oil, dissolved copper and zinc in the infiltrated runoff were significantly less than in the runoff from a conventional asphalt control area (Brattebo and Booth, 2003). Motor oil was detected in the samples of runoff form an asphalt surface but not in samples collected from subsurface runoff beneath the permeable pavements.

"*In a laboratory study in Guelph, Shahin (1994) reported that concentrations of zinc and iron were much lower after infiltration through a permeable pavement installation.*"

"*Overall, discharge from the permeable pavement and bioswale under drains met Ontario receiving water standards for most constituents analyzed.*"

"*Oil and grease (solvent extractable) was detected in 100%, 38% and 56% of control, permeable pavement and bioswale samples, respectively. The source of oil and grease in infiltrate samples requires further investigation.*"

{Note that sampling was from a point 1m below the pavement in natural soils which would have improved filtration and pollution removal.}

Author(s)	Date	Title	Source
AP Newman, SJ Coupe and K Robinson	2006	**Pollution retention and biodegradation within permeable pavements**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

"*The subbase on which these blocks have been laid (63-10 mm size grading) has invariably utilised a polypropylene geotextile between the load bearing/water storage layer (usually 50mm granite or similar) and the upper bedding layer (5 or 10mm granite or 10mm split pea gravel). This polyalkane geotextile plays an important role in both retention and biodegradation of hydrocarbons (Pratt et al. 2001).*"

{But there is no comparative testing of pavements with and without an upper geotextile to demonstrate this. The statement relating to the use of the geotextile only refers to UK practice.}

"*The two most significant items of note are the fact that around 31% of the added oil was degraded in 78 days and that on breaking down the structure at the end of the experiment 49 % of the oil added was found on the geotextile. Given that Bond was also able to demonstrate that the geotextile was the main region of biodegradation (Bond 1999) it would seem logical that around 70-80% of the added oil is intercepted by the geotextile.*"

Author(s)	Date	Title	Source

{This statement contradicts the earlier work of Bond and Pratt, 1998 and Pratt, Newman and Bond, 1999 that reported biodegradation of oil was in the subbase. Again there is no comparative testing with and without an upper geotextile to support the statements in this 2006 paper.}

"*In the work described above heat bonded, non-woven geotextiles had been used. It was not proven that this was optimum and indeed it was probably a fortuitous choice at the time the experiments stated. Woven geotextiles are cheaper than non-wovens of the same strength but a theory had arisen from our previous experience that the retention of hydrocarbons was, in part, due to the higher water breakthrough head exhibited by the non-wovens. The proposal was that in a rainstorm water would pool on the geotextile forming a temporary gravity separator for free phase oil washed down from above. At the end of the storm water would penetrate the geotextile until the depth of water was less than the breakthrough head".*

{Note that if a geotextile is already wet (saturated) and water has flowed through it the break through head effect may be removed until it dries out again. This means that once break through has occurred the water may flow through until there is no more water above the geotextile, so the hypothesis made by the authors is not entirely correct.}

"The water would then evaporate from the upper layers and when the oil encounters the geotextile it will have virtually zero velocity and insufficient energy to penetrate the geotextile. The hydrocarbon would then have the opportunity to interact chemically and physically with the polyalkane geotextile. In subsequent rain events hydrocarbons not strongly attached to the geotextile will again float on the water pool. The process is also likely to encourage the spread of hydrocarbons across the geotextile surface encouraging the formation of oil degrading biofilm over the geotextile surface. This experiment compared a traditional non-woven geotextile with a thicker, felt like, non-woven and a typical woven type."

{It is assumed that the traditional non woven is a thermally bonded non woven such as Terram 1000 and the felt like non woven is a 300g/m^2 needle punched non woven which may not have a breakthrough head.}

"*In each group, 5 models were produced using the traditional construction system (geotextile separating 50 mm granite subbase from 10 mm pea gravel bedding layer) previously used in the pervious pavement research at Coventry University (Pratt et al., 1999), and 5 were used to study the effects of siltation by incorporating a 5 mm layer of simulated silt just above the geotextile. The models used were 110 mm in height and with a diameter of 125 mm.*"

{This seems to imply that the blocks and jointing material were missing from these tests. If that is the case they do not replicate real life where a lot of pollution is trapped in the joints.}

"*It can be seen clearly that the woven geotextile gives a poorer performance than the non-wovens and that, for this product, the presence of silt makes a significant difference to the retention of oil. Whether this is due to sorption on the trapped particulates or because the particulates increase the breakthrough head is unclear. It is also important to note that the choice of geotextile has important*

Author(s)	Date	Title	Source
microbiological consequences."			
Various	2006	**Various**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

Note that there are several other papers from Coventry University researchers in the 2006 conference that look at specific aspects of microbial action on geotextiles. The papers focus entirely on the geotextile and make no attempt to see if the processes occur in pavements without geotextiles.

3. PAPERS ON STRUCTURAL PERFORMANCE

Author(s)	Date	Title	Source
CB Elvidge and GP Raymond	1999	**Laboratory survivability of non woven geotextiles on open graded crushed aggregate**	Geosynthetics International 1999, Vol 6, No 2

This paper reviews the results of a study into the damage caused by open graded aggregates to geotextiles. The results, in terms of damage to the geotextile, show:

(i) the smaller the compaction energy the less geotextile damage occurs
(ii) the greater the mass per unit area, or thickness, of the geotextile the less geotextile damage occurs
(iii) the smaller the particle size of the aggregate overlying the geotextile the less geotextile damage occurs.

The testing was limited to needle punched polyester geotextiles.

J Knapton, I Cook and D Morrell	2002	**A new design method for permeable pavements surfaced with pavers**	Highways and Transportation January/February 2002.

This paper discusses the results of structural testing of concrete block permeable paving under a rolling wheel test rig at Newcastle University. Three different pavement construction s were tested to give a comparison and included pavements with and without an upper geotextile.

"*The testing was continued to 16,000 ESAs and rutting developed to a depth of 4mm in the Cloburn 6mm washed crushed micro–granite. Where the Cloburn material was separated from the underlying coarse graded gravel by a knitted* [woven] *geotextile, the rut depth was 11mm. The zone installed over 4mm washed natural gravel deformed by 9mm.*"

"*The development of significantly greater levels of rutting in the zone including the knitted geotextile had not been expected. Following the testing, an investigation revealed that the reason for this enhanced rutting value is the pressing of the roadbase material into the geotextile during loading. Effectively, during the construction phase, the geotextile spanned from high point to high point over the roadbase particles and the trafficking then stretched the geotextile, pressing it down into the depressions between the roadbase aggregate particles.*"

S Omoto, T Yoshida and M Hata	2003	**Full scale durability evaluation of interlocking block pavement with geotextile**	Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003)

This paper discusses the structural testing of pavements in Japan.

"*The authors constructed a 30-m-long pavement test site consisting of six pavement zones with*

Author(s)	Date	Title	Source

different cross-sectional dimensions in the pavement test field (circuit length: 628 m) of the Public Works Research Institute of the Ministry of Land, Infrastructure and Transportation. The pavement zones were constructed with or without geotextile having the fiber area weight of 60 g/m² or 130 g/m², either on the granular crushed-stone base course or the permeable bituminous stabilized base course."

"*The results confirmed that with either base course, geotextile helped prevent the cushion sand from migrating into the base. It was also proved that in zones with the permeable bituminous-stabilized base course, geotextile helped reduce the rutting depth and rate of block breakage, maintaining a good level of pavement serviceability. Because the fiber area weight of geotextile made no difference to the pavement serviceability, geotextile having the fiber area weight of 60 g/m² was deemed adequate.*"

{This paper looks at bedding sand migration which should not be problem with correctly specified laying course and subbase in concrete block permeable pavements. The effects of sand on a geotextile are also much less severe than from open graded laying course or subbase.}

C Y Kang	2006	**Performance reviews of Hong Kong International Airport and Yantian International Container Terminals.**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

This paper includes a review of the performance of a concrete block pavement at Yantian International Container Terminals in the People's Republic of China. It is a review of impermeable block paving but does have some useful information regarding the performance of geotextiles at high level in a pavement construction.

The concrete block paving is used in the container storage areas with high loads from stacked containers and the plant used to move them.

The pavement construction was:

- 100mm thick concrete blocks
- 25mm sand laying course
- Non woven geotextile (450g/m²) impregnated with bitumen emulsion
- 500mm of lean mix concrete base
- 200mm subbase

The report discusses the maintenance of the pavement and states

"*When they removed blocks in defective areas, maintenance personnel found that:*

1. Most of the jointing and bedding sand had been washed away.

2. If geotextile was present, it was breaking down……"

Author(s)	Date	Title	Source
M. Huurman and W. Boomsma	2006	**Mechanical behaviour of a permeable base and bedding material and the rutting behaviour of permeable CBPS in which they are applied.**	8th International Conference on Concrete Block Paving, November 6-8, 2006 San Francisco, California USA

This paper discusses pavement tests carried out at TRL on Aquaflow pavements (assumed to have an upper geotextile present). These tests seem to indicate that the structural performance is adequate, although it is not clear if the finite element analysis discussed in the paper included an upper geotextile in the model.

4. SUMMARY

4.1 Pollution removal

There is evidence that water quality will improve when it flows through a concrete block permeable pavement, without the use of a geotextile layer. However, there is some evidence that the use of geotextile between the laying course and the sub base, may assist in enhancing pollution removal and biodegrading of pollutants, although this evidence is by no means definitive.

A lot of the research into the performance of permeable pavements with upper geotextiles has been carried out at Coventry University, particularly before the method of paving became well established. The early work at Coventry University was carried out to investigate the level of oil retention and bioremediation in permeable pavements. Initial observations (Pratt 1997, Bond and Pratt 1998, Pratt et al 1999) were that biodegradation was occurring in the subbase and that the subbase had the greatest oil retention capacity.

However on breaking down the pavements they found most of the oil trapped in the pavement was on the upper geotextile. Based on this observation they subsequently focused on the process of biodegradation on the geotextile. They have also put forward a hypothesis as to why the upper geotextile is important in pollution removal, that is based on the breakthrough head for the geotextile (the geotextile used in the tests requires a 23mm head of water on top of it before water will flow through it).

This hypothesis has never been proved because there has never been any comparative testing carried out on permeable pavements that do not have an upper geotextile in order to categorically demonstrate the benefits of including one. Some limited comparative testing of different geotextiles was reported by Newman et al 2006 but this was not conclusive as it used "10mm pea gravel bedding layer [laying course]" which is likely to retain less oil than the 2/6.3 crushed rock laying course specified in the Interpave design manual. It does not appear to have used blocks above the laying course in the test. It does indicate that non woven geotextiles may be less effective at removing pollution. The felt like non woven is thought to have been a 300g/m^2 needle punched non woven geotextile fleece which does not have a break through head.

There are a numerous studies from the USA, Australia and Europe (for example Legret and Colandini 1999, Shackel et al 2003, Shahin 1994, Thompson 1995, Ferguson 2005, Newton et al 2004) that have tested concrete block permeable pavements that do not include an upper geotextile. They have found that CBPP is effective at removing pollutants when the upper geotextile is not present and seems to give similar levels of pollution as the tests undertaken elsewhere with the upper geotextile. However again there is no comparative testing so it is not possible to determine if the pavements would perform better or if there would be greater biodegradation with an upper geotextile.

It is however likely that biodegradation will occur in pavement without an upper geotextile because the prerequisites for the process will still be there either in the subbase or at the lower geotextile, ie:

- Oxygen – the oxygen levels at 350mm below the surface will be similar to those at 130mm below in these open permeable structures.
- Microrganisms – these are naturally occurring and will be present regardless of the geotextile. The aggregate provides a suitable substrate for the microorganisms if an upper geotextile is not present.
- Nutrients – these may be present in the aggregate and in rainfall runoff. The geotextile does not provide the nutrients.
- Moisture – although the upper geotextile can hold moisture it is closer to the surface so may dry out quicker than moisture that passes deeper into the subbase. This is unlikely to be a limiting factor if the geotextile is not present.
- pH – the geotextile will not change the pH and the aggregates used are likely to have a near neutral pH providing crushed concrete is not used.
- Temperature – biodegradation is temperature dependent and increases at higher temperatures. The temperature variations in the pavement reduce with depth so in summer biodegradation on an upper geotextile may be slightly greater than deeper in the subbase, but in winter the opposite may be true.
- Absence of toxicity, removal of metabolites and absence of competitive organisms – none of these will be improved by the presence of the upper geotextile.

The literature review clearly shows that there is no proven case that an upper geotextile improves the pollution removal performance of CBPP. The only way this can be proven is to undertake comparative testing of identical pavement structures with and without an upper geotextile.

There are also many papers regarding clogging and cleaning of CBPP. These all indicate that clogging occurs in the top few cm of the joints. This is the reason why they can be cleaned. If the majority of the clogging (and thus silt removal) was occurring on the geotextile it would be virtually impossible to regenerate the infiltration capacity of a clogged pavement using road sweepers.

4.2 Structural performance

There has been limited structural analysis of CBPP. The limited data that is available is conflicting. Knapton et al 2002 found that a geotextile was detrimental to the structural performance of a CBPP when compared to a pavement without one. Kang 2006 found evidence that a geotextile can be damaged when placed high in a pavement construction. However Huurman and Boomsma 2006 indicate that a pavement with an upper geotextile can carry a high number of passes from heavy axle loads based on TRL testing of the Aquaflow pavement system.

The upper geotextile will reduce the friction between the laying course and the subbase, which is a critical factor in the strength of a pavement. A geotextile can reduce the friction between the layers by up to 26%. It is difficult to relate this to a reduction in design strength of the pavement, but it will have some effect.

What is clear is that if a geotextile is to be used high in a pavement construction (between the laying course and subbase) it will be subject to very high forces, especially where there is HGV traffic. Therefore the geotextile must be specified to deal with the conditions and the evidence suggests that the heavier the weight of a non woven geotextile the more durable it will be (Elvidge and Raymond 1999).

Therefore if an upper geotextile is required it is suggested it is limited to lightly loaded pavements such as car parks or where there is only occasional heavy goods vehicle traffic. In applications where there will be frequent trafficking by HGV's, buses, etc, or the pavement is subjected to a large number of breaking and accelerating forces, the upper geotextile should be omitted and the grading of the laying course and sub base designed to avoid migration of materials.

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5. CONCLUSION

There is conflicting evidence that the upper geotextile is critical to the biodegradation and filtration performance. The decision to use a geotextile between the laying course and the sub base is a balance between durability and structural performance of the pavement and possible improvements in water quality. Further research is required to clarify the pollution removal benefits and structural performance when using a geotextile in this location.

6. STATEMENT OF ADVICE

Based upon the findings of the literature review the following statement is suggested for inclusion in Interpave design information and other publications:-

USE OF GEOTEXTILES IN PERMEABLE PAVEMENTS

Geotextiles may be used in two locations in concrete block permeable pavements:

1. Between the laying course and the sub base

2. Between the sub base and subgrade.

The locations of the geotextiles are shown in Figure 1.

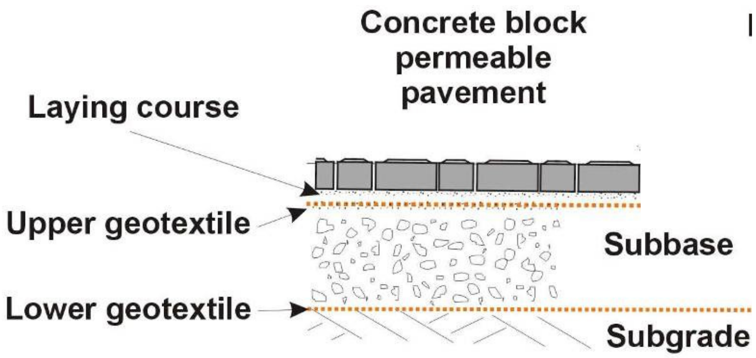

Figure 1 Geotextiles in a permeable pavement

Geotextile (Upper Geotextile) Between The Laying Course And The Sub Base

An upper geotextile can be used to prevent migration of the finer laying course material into the coarser sub base material . However, this geotextile can be omitted if the grading of the laying course and sub base is compatible so avoiding migration of the laying course material into the sub base. The Interpave design guide provides information on how to achieve this.

There is evidence that water quality will improve when it flows through a concrete block permeable pavement, without the use of a geotextile layer. However, there is also some evidence that the use of geotextile between the laying course and the sub base, may assist in enhancing pollution removal and biodegrading of pollutants, although this is by no means definitive.

There is also evidence that when geotextile is used between the laying course and the sub base it may possibly be detrimental to the structural performance of the pavement, although again evidence is by no means definitive.

Worldwide studies of full size pavements installed with and without an upper geotextile suggest that there is no difference in water quality performance in practice. See EPG Ltd Report, "The Performance of Geotextiles in Concrete Block Permeable Pavements, May 2007" for a critique and summary of studies published on this topic.

The decision to use an upper geotextile between the laying course and the sub base is a balance between durability and structural performance of the pavement and possible improvements in water quality. It is therefore recommended that the designer consults the concrete block manufacturer for specific guidance relevant to the project and local conditions, on the use of geotextiles.

Geotextile, Between the Sub Base and Subgrade,

Geotextiles can be used in this location to act as a separator to prevent the sub base punching into the subgrade soils and causing clogging of the sub base. Where water infiltrates to the ground this geotextile will also act as a filter and may support biodegradation.