THE DESIGN OF PERMEABLE PAVEMENTS FOR RETAIL DEVELOPMENT IN IRELAND

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SUMMARY

The paper describes an ongoing project to install permeable paving for access roads and parking areas at 50 retail developments in Ireland. It explains how different levels of trafficking are accommodated and how the permeable pavements manage rainfall falling on the pavers as well as on the remainder of the sites. The paper includes cost information which is used to compare the cost of permeable paving with that of conventional paving. It is concluded that in addition to flood relief benefits, both for the site itself and for neighbouring properties, it is often the case that a permeable pavement reduces cost.

The paper also explains why permeable pavements are capable of sustaining loads applied by heavy traffic, even though their roadbase comprises unbound granular material.

Examples are presented of tanked systems where the water is detained within the permeable pavement and of exfiltrating systems where the water exfiltrates into the subgrade below. Examples are included showing installation by both hand laying and by machine.

1. INTRODUCTION

The Paper describes the Authors' experience of the design and construction of over 50 permeable paving projects at retail developments in Ireland, all similar to the one shown in Figure 1. The projects are being installed over a seven years period and each has several similar characteristics. In each case, the development site is of area approximately 10,000m^2 and the local drainage authority is requiring that the discharge from the development should not exceed the outflow of the previous green field site. Ireland is a leading country in the implementation of sustainable drainage schemes.

Although its population was only 4 million at July 2005 (less than Singapore), it has become a significant market for manufacturers of permeable pavers. In fact, more permeable pavers are installed in Ireland than in England where the population is over 50 million. All new projects require an active sustainable drainage statement. This means the discharge is limited to between 2 litres/sec/hectare and 6 litres/sec/hectare (this simplifies matters because each site is approximately one hectare). Typically, the site comprises 1,000m^2 of soft landscaping, which is allowed to look after itself, 4,500m^2 of car parking, 1,500m^2 of other hard landscaping and 3,000m^2 of buildings. Experience with early schemes led to the conclusion that the most cost effective solution is to install permeable paving over the entire

4,500m^2 of car parking and to drain the impermeable hardstandings and the roof into this permeable car park.

Some of the schemes are "tanked" whereby the water is detained within the roadbase material and others allow the water to exfiltrate from the pavement directly into the underlying subgrade material. Exfiltration is usually the preferred solution because of its cost effectiveness and simplicity. However, it is frequently the case that the underlying subgrade material is unsuitable for one or more reasons. It may be too fine to allow the infiltration of water. In its saturated condition, it may be unable to support the weight of traffic. The water table may be too high or the authority may be reluctant to permit potentially contaminated water to enter the ground. One of the benefits of a tanked solution is that it allows the water to pass through a fuel interceptor.

There are several factors which have driven the move towards permeable pavements for retail development in Ireland. Firstly, the cost analysis which follows shows that they represent a cost effective solution in cases where the drainage authority requires attenuation. The cost study presented applies to a tanked scheme. An alternative is an exfiltration scheme which is even more cost effective. However, many sites are not suited to exfiltration as described in the last paragraph.

In supermarkets, owners prefer permeable pavements for reasons in addition to their cost effectiveness. Firstly, permeable pavements ensure that ponding is avoided even during the most intense storms. Secondly, they allow perfectly flat pavements to be installed. This greatly facilitates the handling of supermarket trolleys. Maneuvering trolleys against, down or across a gradient can lead to difficulties particularly on windy days and especially in the case of poorly maintained trolleys. Also, with conventional paving built to falls, discarded trolleys can become runaways which cause damage to parked vehicles and can be a danger to children and the elderly. Thirdly, owners find a permeable paving surface to be attractive. A perfectly flat surface has an attraction per se which is added to by the texture, pattern and colour of the permeable pavement surface.



Figure 1. Typical retail development involving permeable paving in Ireland and detail of permeable paver used.

2. PAVEMENT SECTION DESIGN PARAMETERS

The pavement section has to be designed both in terms of hydraulic requirements and in terms of traffic loads using the following method.

Firstly, consider drainage. Most Irish drainage authorities allow between 2 and 6 litres/sec/hectare to be discharged into the downstream sewerage. On a typical retail development there will be approximately 5,000m^2 of permeable pavement representing approximately 50% of the total site area. Therefore, assume that the development is allowed an outflow of approximately 6 litres/sec, i.e.24, 000 litres/hr or 576,000 litres/24hr-day. Assuming that a 1hr storm generates 20mm rainfall and with an r-value for Dublin of 0.33, the 48hr storm generates 60mm, the total volume falling in 1hr is 120m^3 (120,000 litres)and the total volume in 48hr is 360m^3 (360,000 litres). This means you will need storage capacity for 120,000-24,000=96,000 litres after the 1hr storm and negative storage after the 48hr storm. In fact, a detailed analysis shows that the critical time is between 2hr and 4hr when you will need to store 240,000 litres of water in 5,000m^2 of permeable paving. Assuming 300mm thickness of Coarse Graded Aggregate roadbase with a void ratio of 0.32, the total storage volume in the entire pavement is 3000 x 0.3 x 0.32 = 288m^3 = 288,000 litres. By comparing the figure of 240,000 litres required with the figure of 288,000 litres provided, it can be seen that 300mm thickness of Coarse Graded Aggregate roadbase achieves the requisite storage capacity.

Secondly consider traffic loads. In supermarket developments, most of the permeable paving will need to withstand light vehicles in the car park but some areas may need to support delivery vehicles. Normally, the thickness of Coarse Graded Aggregate developed for hydraulic reasons is sufficient to withstand the light traffic. Delivery vehicles can be accommodated by adding cement to the upper 200mm thickness of the Coarse Graded Aggregate roadbase to create no-fines lean concrete. Although this diminishes the water storage capacity of the material from 32% to 25%, it provides significantly enhanced stiffness and allows typical supermarket delivery traffic of say one or two heavy vehicles per day.

Permeable pavements contravene many of the traditionally accepted principles of pavement design. In particular, one of the objectives of a conventional pavement is to create an impermeable surface so that moisture ingress cannot weaken components of the pavement or the underlying subgrade. Many highway pavement specifications are predicated upon the requirement to keep the specified materials dry. The deliberate cascading of water through highway construction materials requires a radical approach to the selection of material thickness and properties. This impacts two areas of design. Firstly, an alternative approach is required for the assessment of loading. Secondly, material properties need to be selected taking into account the flow of water vertically downwards and the retention of water within the material. This means that the traditional structurally beneficial effects of fine materials will have to be foregone and an alternative methodology will be required to ensure stability, strength and durability.

Levels of traffic loading need to be assessed so that the pavement can be placed into one of five load categories as shown in Table 1.

Table 1. Classification of Vehicles

Load Category	Maximum Axle Load (kg)
Category 1 - Domestic (GVW = 2000kg)	1000
Category 2 - Light (GVW = 3500kg) **Supermarket Car Park**	2000
Category 3 - Commercial (GVW = 7500kg)	5000
Category 4 — **One/two delivery vehicle(s) per day (GVW = 21,000kg)**	8,000
Category 5 - Heavy (GVW = 44,000kg)	11,000

Car parks fall into Load Category 2 and Load Category 4 includes supermarket delivery vehicles. Now take the load appropriate to the load category and multiply it by the Load Partial Safety Factor from Table 2. From their experience of over 20 completed supermarkets in Ireland, the Authors feel able to use a load Partial Safety Factor of 1.2.

Table 2. Load Partial Safety Factors. (*For Category 4 vehicles, maximum Load Partial Safety Factor = 1.1)

Level of Certainty of Load	Load Partial Safety Factor
Certain	1.0
Well informed value	**1.2***
Anecdotal information	1.5*

Now proportion the pavement section from Table 3.

Table 3. Pavement Course Roadbase Design Thicknesses. Note these need to be adjusted for ground conditions and for material partial Safety Factor. Two conditions are highlighted. One is for a car park subject to light vehicular loading only and the second is for the situation where occasional delivery vehicles also traffic the car park.

Factored Load (kg)	Course Thickness (mm)	
	Cement stabilized open graded crushed rock	Open graded crushed rock
1,400	-	150
1,600	-	150
2,000	-	175
2,800 – supermarket car park	**-**	**200**
3,200	-	250
4,000	-	300
6,000	-	350
8,000	-	450
10,000 – supermarket delivery route	**200**	**150**
15,400	300	150

If the subgrade CBR is greater than 5%, the above roadbase material can be installed directly above the subgrade. In poorer ground conditions, a conventional DTp Type 1 granular sub-base should be installed between the subgrade and the roadbase. In most design situations, an impermeable membrane should be provided between the roadbase and the sub-base courses. The thickness of the sub-base required is shown in Table 4.

Table 4. DTp Type 1 Sub-base Thickness Required

Subgrade CBR (%)	Thickness of DTp Type 1 sub-base material (mm)
>5	0
5	150
4	250
3	350
2	600
1	Subgrade improvement required

Finally, apply the Material Partial Safety Factor as follows. The stability of the open graded crushed rock material should be assessed according to Table 5 and the thickness of this course should be multiplied by the appropriate factor from Table 5.

Table 5. Open graded crushed rock thickness adjustment for Material Partial Safety Factor

Nature of open graded crushed rock material	Partial Safety Factor
As stable as DTp Clause 803 material ("Type 1")	0.9
As stable as graded 20mm crushed rock to BS882	1.0
As stable as rounded 20mm graded gravel to BS882	1.3

By applying the factors shown in Tables 1 to 5, the Authors would normally recommend design sections as follows. The sections below assume a subgrade CBR of 3%, typical for sandy silty clays in Ireland.

A/ Car park
80mm thickness Hydropave permeable pavers
50mm thickness 6mm single sized grit
300mm thickness Coarse Graded Aggregate (particle size range 20mm to 5mm)
Layer of 2000 gauge polythene
150mm thickness “Clause 804” crushed rock
250mm thickness capping material

B/ Delivery route
80mm thickness Hydropave permeable pavers
50mm thickness 6mm single sized grit
200mm thickness Cement Stabilised Coarse Graded Aggregate (particle size range 20mm to 5mm)
150mm thickness Coarse Graded Aggregate (particle size range 20mm to 5mm)
Layer of 2000 gauge polythene

150mm thickness “Clause 804” crushed rock
250mm thickness capping material

3. DESIGN CONCEPT

The crucial issue in the structural performance of permeable paving is the stability of the Coarse Graded Aggregate which comprises both the roadbase and the water detention medium. The Authors have found that contractors and others who are new to permeable paving sometimes express concern that the Coarse Graded Aggregate forming the roadbase and water detention medium will be unable to sustain traffic loads. Figure 2 shows a typical 20mm to 5mm Coarse Graded Aggregate. Although some materials are more angular than the one shown in Figure 2, the Authors have found rounded materials to remain stable under traffic once the pavers have been installed.



Figure 2. Typical 20mm to 5mm Coarse Graded Aggregate. In this instance, the material comprises rounded uncrushed gravel.

The reason for suspicion regarding the stability of Coarse Graded Aggregate is that the material is uncompactable during site operations; it pushes and can form a bow wave ahead of construction plant. The Authors have found that once 80mm thickness pavers are installed over the stone, the self weight of the pavers provides the stability which the aggregate needs as is now explained.

The stone below the permeable pavers would normally comprise a 20mm to 5mm aggregate. The individual stones carry the load by physically locking together. However, this interlock is not enough –

they can easily be pushed aside. The way in which pavers introduce stability can be understood as follows. In order to make the mechanics easy to understand assume that the stones are all of one size and are all spherical.

First, just consider the round stone particles with no pavers installed as shown in Figure 3. The weight of each stone particle is shown by a small arrow acting downwards. A typical 15mm diameter particle weighs 4.2 grams. Each particle rests on two or more round particles occupying the row below. The weight of the top particle is resisted by the inclined forces shown at the contact points between particles in different layers. The inclined forces can be calculated to be 2.42 grams. At the same time, friction between neighbouring particles allows shear forces to develop and it is these shear forces which provide strength and stability to the pavement. The shear forces can be calculated by multiplying the inclined forces by the coefficient of friction between the particles, which is usually about 0.6. Therefore, the shear forces are about 1.45 grams between each particle. This is quite small and will not provide stability, hence the unstable nature of the material prior to the installation of pavers.

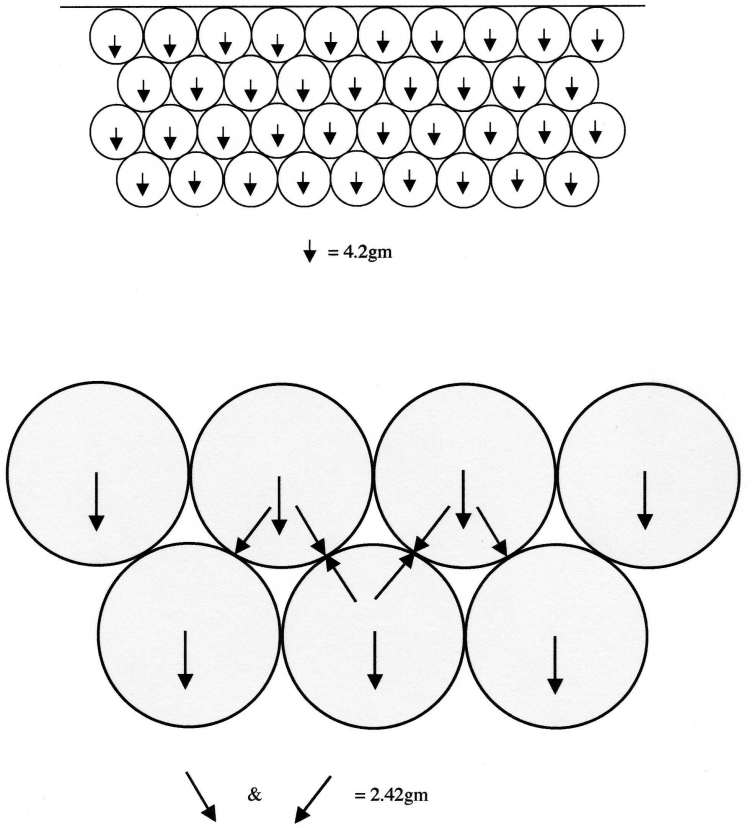

Figure 3. Forces developed between 15mm diameter Coarse Graded Aggregate particles before pavers are installed

Now consider the situation which develops when permeable pavers are installed as shown in Figure 4. Each particle at the surface of the stone now has to support the weight of part of the paver. In the case of a 15mm diameter particle, it has to support 45 grams of paver in addition to its own weight of 4.2 grams. If we now go through the same calculations as before, we find that the normal forces grow to 28 grams and the corresponding shear forces between neighbouring particles grow from 1.42 grams to 17 grams. In other words, installing permeable paviors

increases the strength of the stone by twelve times. This explains why permeable pavements can be used for heavily trafficked roads, i.e. roads trafficked by a relatively low number of heavy vehicles.

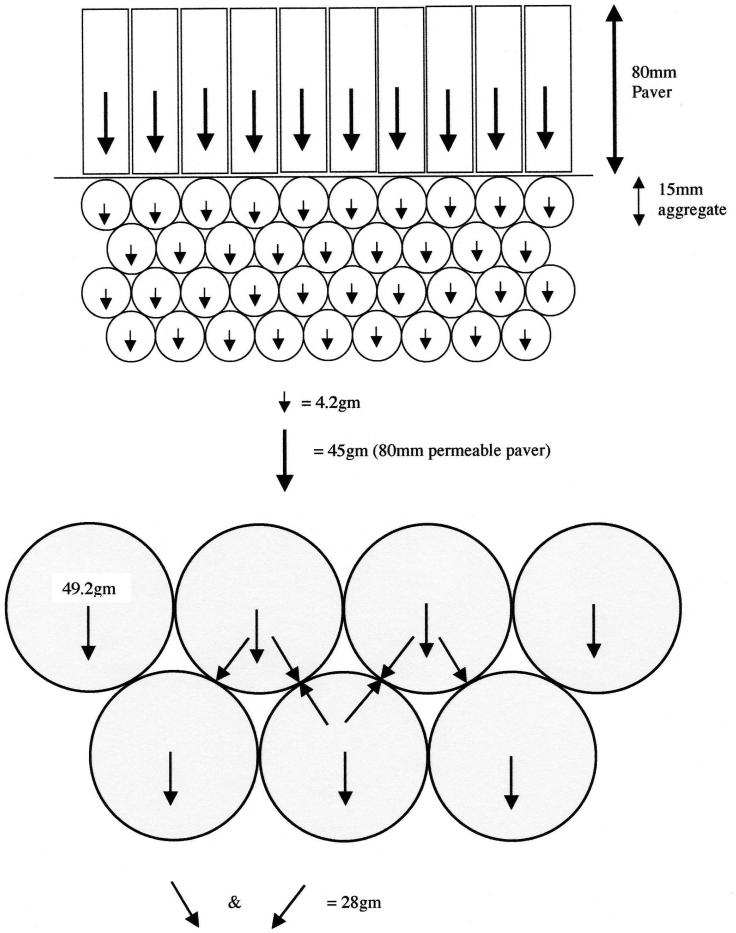

Figure 4. Forces developed between 15mm diameter Coarse Graded Aggregate particles after 80mm thickness pavers are installed

As this analysis shows, the friction forces which develop between the stones below permeable paving should ensure that the material remains stable when trafficked by heavy vehicles. Nonetheless, the Authors prefer to add cement to the upper 200mm thickness of coarse graded aggregate to enhance the stability of the pavement. Although this is unnecessary from the perspective of structural mechanics, the Authors do recognize that their designs are being installed by Irish contractors whose reputation sometimes goes before them.

4. COST ANALYSIS OF PERMEABLE PAVEMENTS

The Authors have assessed the costs of two alternative drainage methods for a 10,000m^2 site in Dublin as follows. The cost of a conventional pavement constructed from Dense Bitumen Macadam (DBM) (called asphalt concrete in the US) over a crushed rock sub-base was compared with that of a permeable pavement solution. In each case, the drainage authority required that outflow from the site did not

exceed 6 litres/second. In the case of the DBM pavement, a holding tank comprising proprietary plastic units was included in the cost exercise.

In the case of the permeable paving, detention was by way of 325mm thickness of 20mm to 5mm Coarse Graded Aggregate tanked with 2000 gauge polythene. The conventional scheme required 14 manholes, 20 road gulleys and 611m of 300mm diameter pipe at a depth of 1m, all of which were eliminated in the case of the permeable pavement solution. The costs are listed below and show a slight saving in the case of permeable paving. Of course, the conventional solution would have been less costly than the permeable pavement had there been no need for detention. Nonetheless, the cost exercise shows that permeable paving represents a cost-effective solution when water detention is required as part of a sustainable drainage project.

Table 6. Details of cost comparison for permeable and conventionally drained pavements

HYDROPAVE COST COMPARISON				
	UNIT	QUANTITY	UNIT PREICE £UK	TOTAL PRICE £UK
STANDARD ROAD				
130 standard road comprising Dense Bitumen Macadam	m^2	3065	9.00	£27,585.00
Clause804 crushed rock sub-base	m^3	690.3	11.00	£7,593.30
Trench 1m deep	m	611	7.00	£4,277.00
300 mm dia. Pipe	m	611	18.30	£11,181.30
Geotextile lining	m^2	1530	2.00	£3,060.00
Pea gravel	M	611	8.00	£4,888.00
Manholes	nr	14	840.00	£11,760.00
Road gullies	nr	20	100.00	£2,000.00
Excavate for storage units and dispose off site	m^3	100	12.00	£1,200.00
Storage Units				£18,000.00
TOTAL FOR REPUBLIC OF IRELAND STANDARD ROAD				**£91,544.60**
ROAD SURFACED WITH PERMEABLE PAVERS				
80th Permeable Pavers	m^2	3065	18.90	£57,929
50th 6mm grit	m^2	3065	3.00	£9,195
325mm thickness 20mm - 5mm grit	m^3	996.125	11.00	£10,957
2000 gauge visqueen	m^2	3065	1.37	£4,199
225 hardcore	m^3	690.3	11.00	£7,593
TOTAL FOR REPUBLIC OF IRELAND PERMEABLE ROAD				**£89,873**

5. CONCLUSIONS

Although small in population, Ireland is a leading country in the implementation of sustainable drainage schemes. All construction projects require an active sustainable drainage statement. In general, Irish drainage authorities require that a new development should discharge no additional water as compared with the green field levels. In practice, this means that all Irish developments are required to discharge no more than a figure set by the drainage authority which is between 2 litres/se/hectare and 6 litres/sec/hectare.

It is concluded that where drainage authorities require that rainfall is attenuated on site, permeable paving represents a cost effective solution. Pavers can be used in car parks and access roads subject to either light traffic or to occasional heavy vehicles. The authors have found that in the case of sites of total area approximately10, 000m2, a 4,500m^2 permeable pavement car park can be used to attenuate the drainage for the entire site, including the roofs of buildings.

In the case of retail developments, the owner finds several benefits in using permeable paving. Firstly, it is of low initial and maintenance cost. Secondly, the absence of standing water is considered to be beneficial. Thirdly, permeable pavements can be installed entirely flat. This is beneficial in supermarket car parks where conventional falls impede the handling of supermarket trolleys. On windy days, supermarket trolleys can be difficult to maneuver on slopes and damage is frequently inflicted on vehicles by out of control trolleys, either during handling or after they have been discarded.

The Authors have developed a hydraulic and structural design methodology based initially upon nationally published guidelines but modified by their experience to give the result as set out in the design example presented. In particular, they have recognized the potential difficulties inherent in designing permeable car parks subjected to occasional heavy traffic. Their solution is to include cement within the upper part of the coarse graded aggregate and to then account for loss of water retention void in this material.

The Authors have found that rounded aggregate is suitable as a roadbase material, even though it is difficult to handle during installation. The weight of the permeable pavers adds stability to the stone which can then accommodate heavy delivery vehicles in retail developments. In cases where regular heavy traffic is anticipated, the Authors have found that introducing cement into the upper 200mm of the Coarse Graded Aggregate is beneficial in eliminating rutting.