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PERMEABLE PAVEMENTS FOR HEAVILY TRAFFICKED ROADS – A FULL SCALE TRIAL

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands.

Summary

The paper describes a full scale trial in which four test items each of width 4m and length 6m were trafficked by Heavy Goods Vehicles (HGVs) in order to assess the performance of different pavement sections. Each of the four test items comprised tanked permeable pavements in which water was detained within the pavements. The purpose was to compare the performance under traffic of permeable pavements with the following types of base:

- Type 1: Unreinforced 20mm / 6mm Coarse Graded Aggregate.
- Type 2: 20 mm/6 mm Coarse Graded Aggregate stabilised with 3% cement.
- Type 3: Dense Bitumen Macadam with 5% 50 Penetration bitumen.
- Type 4: Coarse Graded Aggregate reinforced with two layers of geogrid.

The reason for selecting those four base types is that they are each used commonly in the United Kingdom (UK). In particular, Types 1, 2 and 3 are included in the UK Interpave document “Guide to the design, construction and maintenance of concrete block permeable pavements” Edition 5 2 and also in the permeable pavements British Standard BS7533: Part 12: 2009 [BSI, 2009].

Both the Interpave Guide 2 and the British Standard 3 define six Load Categories of traffic. Load Categories 1 and 2 cover lightly trafficked pavements and recommend Type 1 bases. Load Categories 3 to 6 comprise pavements subjected to increasing levels of heavy traffic, right up to 1 000 HGVs per week in the case of Load Category 6 and recommend Type 2 or Type 3 bases. Type 4 bases are frequently specified in the UK as an alternative to the Interpave guidelines for all traffic Categories.

The purposes of the full scale trial were as follows:

1. To check whether the range of Load Categories for which unbound Coarse Graded Aggregate can be used can be extended beyond Load Category 2.
2. To compare the performance of the four base types.
3. To assess the accuracy of the Interpave/British Standard Guidelines.
4. To examine whether more cost effective pavements can be installed.

1. PRESENT UK STRUCTURAL DESIGN GUIDANCE

Current UK permeable pavement design guidance is set out in BS7533: Part 13: 2009 [BSI 2009] which was published in March 2009. The guidance was based upon Interpave's previously published data[2] which is shown in Tables 1 to 3 and Figures 1 and 2. BS7533 includes a few presentational changes but arrives at the same design sections. Both documents are based upon full scale experiments undertaken at Newcastle University in 1999-2000 [Knapton, Cook and Morrel, 2002]. Those experiments focused upon Coarse Graded Aggregate bases. Since then there has been a massive increase in the use of permeable paving in the UK which has been driven by Sustainable Drainage (SuDS) legislation and by a general awareness of the need to ensure that all development is carried out in an environmentally sensitive manner. As a result of this, permeable pavements are being specified in increasingly heavily trafficked situations so there is a move towards cement stabilisation, bitumen stabilisation and geogrid reinforced Coarse Graded Aggregates.

Table 1 illustrates the six loading classifications and includes examples of each. The designer has the choice between using a number of large goods vehicles per week or a cumulative number of standard axles. Figure 1 shows resulting design sections for infiltration pavements and Figure 2 shows resulting design sections for tanked (detention) pavements. Those design sections comply with BS7533: Part 13: 2009 [BSI, 2009].

Figures 1 and 2 apply in the case of pavements to be installed over subgrades of California Bearing Ratio (CBR) 5% and greater. For pavements to be installed over weaker soils, Table 2 shows the adjustments to be made to the thickness of the Coarse Graded Aggregate (in the case of infiltrating pavements) or the Capping Material (in the case of tanked/detention pavements).

Figures 1 and 2 show that for Load Categories 1 and 2, the pavement base comprises Coarse Graded Aggregate but for Load Categories 3, 4, 5 and 6, a course of hydraulically bound (i.e. cement bound) Coarse Graded Aggregate is required to stiffen the pavement. This means that for pavements trafficked by one or more large goods vehicles per week, the hydraulically bound course is required by BS7533: Part 12: 2009. The sections shown in Figures 1 and 2 were originally derived from the full-scale research described in [BSI, 2009].

BS7533: Part 13: 2009 provides an alternative design in which a course of Dense Bitumen Macadam (DBM) is included, either as a replacement for the hydraulically bound Coarse Graded Aggregate (for Load Categories 3, 4, 5 and 6) or as an additional course in the case of Load Categories 1 and 2. The reason for the DBM alternative is that contractors often prefer to traffic the permeable pavement during the construction phase. The inclusion of a DMB course protects the Coarse Graded Aggregate (CGA) below from contamination in this circumstance and is therefore commonly installed in, for example, housing developments. When DBM is installed for this reason, it would seem wrong to ignore its undoubted structural contribution to the pavement. Therefore, BS7533: Part 13: 2009 includes Table 3 which shows the DBM thickness required for different trafficking levels. Of course, DBM is insufficiently permeable to allow its use in a permeable pavement, indeed it is often used in circumstances where its waterproofing properties are advantageous. Therefore, BS7533: Part 13: 2009 requires that 75 mm diameter holes are punched through the DBM on a 750 mm grid to allow the continued flow of water downwards through the pavement (The holes are filled with 6mm grit to prevent the loss of laying course material.)

A significant issue which frequently occurs in the design of permeable pavements is where the cut-off point should be for the inclusion of hydraulically bound CGA. This is a particularly relevant matter because experience indicates that many permeable pavements fall into Load Category 3 (one large goods vehicle per week). Presently, such pavements require the inclusion of a hydraulically bound course. One of the objectives of this full scale trial was to establish whether Load Category 3 pavements can dispense with the hydraulically bound course.

Therefore, BS7533: Part13: 2009 includes CGA, hydraulically bound CGA and DBM as the three possible base materials for permeable pavements. A fourth type of base used commonly in the UK is CGA reinforced with geogrid materials. This option was omitted from the Interpave and BS documents but is an alternative which interests those involved in UK permeable pavements. Therefore, geogrid reinforced CGA was added as the fourth Test Item in the full scale trial.

Table 1. UK classification of permeable pavements by loading.

1 DOMESTIC PARKING	**2 CAR**	**3 PEDESTRIAN**	**4 SHOPPING**	**5 COMMERCIAL**	**6 HEAVY TRAFFIC**
No Large Goods vehicles	Emergency Large Goods Vehicles only	One (1) Large Goods Vehicle per week	Ten (10) Large Good Vehicles per week	One hundred (100) Large Good Vehicles per week	One thousand (1 000) Large Good Vehicles per week
Zero standard axles	One hundred (100) standard axles	0.015 msa*	0.15 msa*	1,5 msa*	15 msa*
Patio	Car parking bays and aisles	Town/city pedestrian street	Retail development delivery access route	Industrial premises	Main road
Private drive	Railway station platform	Nursery access	School / College access road	Lightly trafficked public road	Distribution centre
Decorative feature	External car showroom	Parking area to residential development	Office block delivery route	Light industrial development	Bus station (bus every five (5) minutes)
Enclosed playground	Sports stadium pedestrian	Garden centre external display area	Deliveries to small residential development	Mixed retail / industrial development	Motorway Truck Stop
Footway with zero vehicle overrun	Footway with occasional overrun	Cemetery Crematorium	Garden centre delivery route	Town square	Bus stop
	Private drive / footway crossover	Motel parking	Fire station yard	Footway with regular overrun	Roundabout
		Airport car park with no bus pickup	Airport car park with bus to terminal	Airport landside roads	Bus lane
		Sports centre	Sports stadium access route / forecourt		
msa* = Millions of standard 8 000 kg axles.					

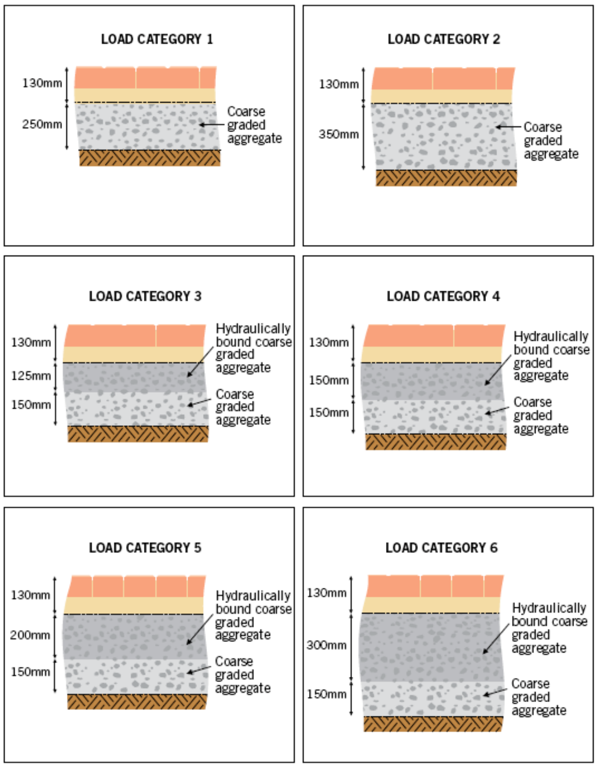

Figure 1. UK recommended sections for infiltrating pavements in which the water infiltrates into the subgrade.

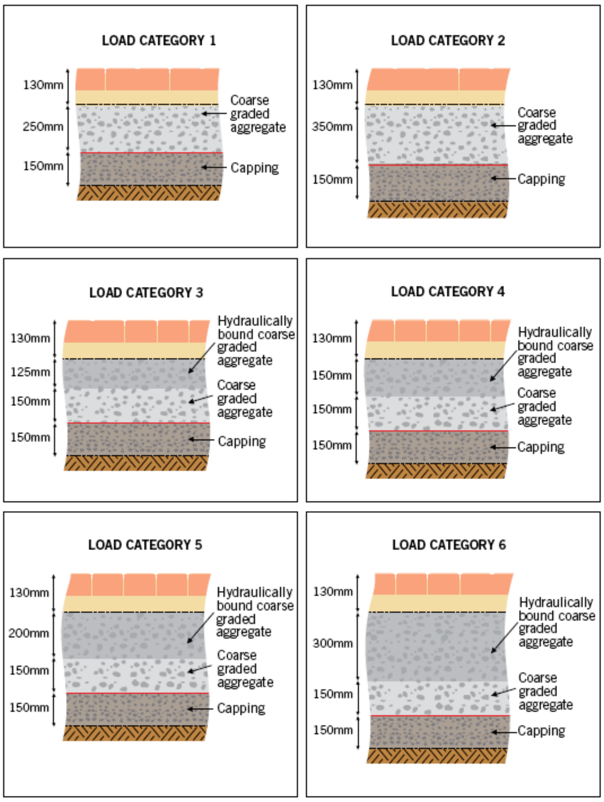

Figure 2. UK recommended pavement sections for tanked pavements according to traffic levels. The waterproof membrane is installed directly above the Capping layer.

Table 2. Adjustments to Coarse Graded Aggregate or Capping Material thickness for pavements designed on soils of CBR less than 5%.

CBR OF SUBGRADE (%)	ADJUSTMENT TO THICKNESS OF COARSE GRADED AGGREGATE IN CASE OF SYSTEM A AND SYSTEM B (INFILTRATING) PAVEMENTS (mm)***	TOTAL THICKNESS OF CAPPING MATERIAL IN THE CASE OF SYSTEM C (DETENTION) PAVEMENTS (mm)
1	+300*, **	600*
2	+175**	350
3	+125**	250
4	+100**	200
5	Use thickness in Design Chart	150
8		
10		
15		

* Expert guidance should be sought in the case of pavements constructed over subgrades of CBR less than 2%.
** Subgrades of CBR less than 5% are often too fine to permit sufficient infiltration.
*** Note that the additional coarse graded aggregate values in this column can be applied, in the case of System C pavements, instead of the enhanced capping thickness show in the middle column.

Table 3 Thickness of Dense Bitumen Macadam when such material is used as a roadbase.

Total Traffic (Site plus in-service) (Cumulative Standard Axles (msa)	Thickness of Dense Bitumen Macadam (mm)
Up to 1.5	**130**
1.5 to 4.0	**145**
4.0 to 8.0	**170**
8.0 to 12.0	**185**

msa* = Millions of standard 8 000 kg axles.

2. DETAILS OF FULL SCALE TEST SITE

The whole 24 m x 4 m test site was excavated to a depth of 730 mm below the existing surface level. The 24 m long trial comprised four pavement Test Items, each of length 6m. It was tanked by installing 2 000 gauge polythene over the sub-base material and bringing it to the surface at the sides and ends. To simulate the most adverse conditions, water was introduced into the pavement. Figures 4 to 9 illustrate the installation of the full scale trial pavement.

Before commencing installation, three CBR tests were carried out in each of the four sections (12 tests in all). Soaked CBR values (96 h soaking) varied between 4% and 7%, with several values congregated around 5% which was therefore taken to be the effective value.

The test site was installed during January 2009 to allow trafficking to take place during February and March 2009.

The area was trafficked by an eight wheel rigid truck shuttling backwards and forwards over each Test Item at a speed of approximately 10 mph (16 kph) (see Figure 11). The truck was loaded beyond its normal limit to achieve the following axle loads:

- Axle 1 (first steering axle) 7 200 kg.
- Axle 2 (second steering axle) 8 000 kg.
- Axle 3 (first rear axle) 13 580 kg.

- Axle 4 (rearmost axle) 11 100 kg.

Taking a damaging power factor of 3.75 (often referred to as the Fourth Power Law), the above values suggest that each pass of the truck applies 12 standard axles. This does not take into account wheel load interaction, dynamic load magnification effects or load redistribution between axles by truck suspension. Therefore, it may represent a conservative estimate such that the true effective trafficking levels may exceed the stated values. Whilst the above axle loads are greater than those commonly encountered on a highway, they are nonetheless within the anticipated range of loads applied from time to time by overloaded large goods vehicles.

	6.00	6.00	6.00	6.00	
Section	No.1	No.2	No.3	No.4	
80 mm	Hydropave	Hydropave	Hydropave	Hydropave	2000 Gauge Polyth
50mm	6mm Grit	6mm Grit	6mm Grit	6mm Grit	
150mm	20/6 C.G.A.	20/6 C.G.A. with 3% cement	Dense Bitumen Macadam	20/6 C.G.A.	Netlon Tensar 5540
200mm	20/6 C.G.A.	20/6 C.G.A.	20/6 C.G.A.	20/6 C.G.A.	
150mm	6F1	6F1	6F1	6F1	Pipe for Water Test
					I No at each end
	1	2	3	4	

Figure 3. Course thicknesses for Test Items 1 to 4. Note that "6F1" refers to a category of Capping Material as defined in UK Highways Authority's "Specification for Highway Works". The term 20/6 C.G.A. refers to Coarse Graded Aggregate with particles within the range 20 mm to 6 mm. "Hydropave" is the proprietary name of the permeable pavers used to surface each Test Item.

Figure 4. The test area has been excavated to reveal alluvium clay with a California Bearing Ratio of 5%.

Figure 5. 150mm thickness of compacted Capping Material was installed throughout the test zone prior to installing polythene tanking.

Figure 6 (left). 2000 gauge polythene was installed to achieve tanked conditions for each Test Item.

Figure 7 (right). Test Item 4 required the installation of two layers of a geogrid material known as Tensar SS40. The lower layer is shown here directly over the polythene membrane. The second layer was installed between two courses of Coarse Graded Aggregate..

Figure 8. Prior to the laying of pavers, a 50mm thick course of 6mm single sized grit was installed in each Test Item.

Figure 9. Permeable pavers were installed to a 45° herringbone pattern.

Figure 10 (left). Values of permanent deformation were measured at locations as marked on the board. Each measurement point occupied a similar position in relation to the paver laying pattern. Measurements were taken by inserting the calibrated wedge between the pavement surface and the straight edge. An initial set of readings was taken prior to trafficking and all reported readings are obtained by first subtracting the initial data set.

Figure 11 (right). Trafficking was by means of an overloaded eight wheel truck which shuttled back

and forth at a constant speed of approximately 10 mph (16 kph).

Figure 12. Typical rut in Test Item 1 after several thousand standard axles.

3. RESULTS

Figures 10, 11 and 12 illustrate the application of the test load and the recording of permanent deformation resulting from that loading. The loading took place during February 2009 and March 2009. Deformation readings were taken pre-loading then at the following number of standard axles: 120, 360, 600, 1 200, 1 800, 2 400, 3 000, 3 600, 4 200, 4 800, 6 000. For each Test Item, permanent deformations were recorded at the first quarter point, the centre and the second quarter point.

For each of Sections A, B and C a chart was produced for each of the four Test Items (12 charts in all), each showing 11 rut profiles, one for each of the above 11 levels of trafficking. The numbers shown on the horizontal axis of each chart correspond with the numbers marked on the straight edge shown in Figure 10 – the difference between each measurement point reflects the paving module and is 290 mm for the paver and laying pattern adopted.

For each of the Test Items, the maximum rut depth can be read from the corresponding chart on the following four pages. Note that in the case of Test Items 1 and 4, i.e. those including unbound CGA, the initial 600 standard axles produce significantly greater levels of deformation than do subsequent trafficking. This suggests that a degree of conditioning is taking place, possibly reflecting additional compaction being achieved by the test vehicle. The Test Items were all installed to normal UK compaction standards. Therefore, these enhanced deformations should be regarded as representing a realistic expectation of deformations which can be anticipated in construction contracts where large goods vehicles traffic the pavement in a channelized manner.

Taking the above into account, the maximum rut developed in each of the test sites at 6 000 cumulative standard axles of trafficking is:

- Test Item 1: 37 mm.
- Test Item 2: 10 mm.
- Test Item 3: 6 mm.
- Test Item 4: 32 mm.

The increase in rutting between 3 000 and 6 000 cumulative standard axles can be used as a means of extrapolating the results from the 6 000 standard axles achieved to say 25 000 standard axles. This is considered to be a reasonable level of extrapolation for the following reasons. Firstly, the level of channelization applied in this test is such that some design approaches would consider that three times 6 000 standard axles had been applied, e.g. the British Ports Association Heavy Duty Pavement Design Manual4. Secondly, no account was taken of wheel proximity or dynamics in the test, both of which could be expressed in terms of an enhanced level of standard axles. Thirdly, in each chart, the incremental rut growth after 3 000 cumulative standard axles was consistent.

Based upon the above, the extrapolated rutting at 25 000 cumulative standard axles is:

- Test Item 1: 73 mm.
- Test Item 2: 22 mm.
- Test Item 3: 18 mm.
- Test Item 4: 66 mm.

Over a 20 years design life, a Load Category 3 pavement would need to withstand 1 000 Large Goods Vehicles which would apply say 2.5 standard axles each, i.e. say 2 500 cumulative standard axles. The corresponding rut depths would be:

- Test Item 1: 30 mm.
- Test Item 2: 7 mm.
- Test Item 3: 5 mm.
- Test Item 4: 27 mm.

The failure criterion for a flexible pavement is often taken to be 40mm rutting. On this basis, it would be reasonable to conclude that Test Items 1 and 4 and are suitable for Load Category 3 pavements but not for Load Category 4 pavements. Likewise, Test Items 2 and 3 are confirmed as being suitable for Load Category 4 pavements. This also suggests that the design sections shown in Figures 1 and 2 are all correct since for greater levels of trafficking, thicker courses are recommended in line with the normal relationships between course thickness and levels of trafficking for hydraulically stabilized materials. Furthermore, the trial also confirms that the UK recommendations for the use of DBM set out in Table 3 are also correct by similar reasoning.

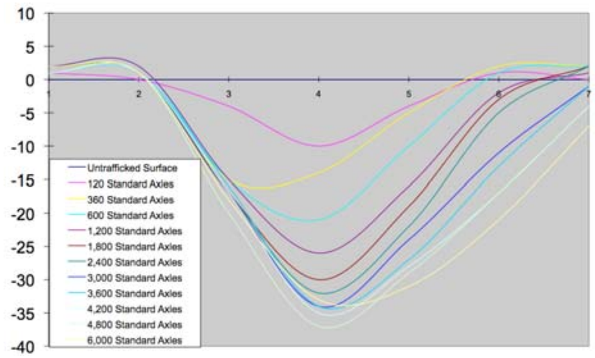

Figure 13. Test Item 1. Unreinforced 20 mm / 6 mm Coarse Graded Aggregate at centre of Test Item.

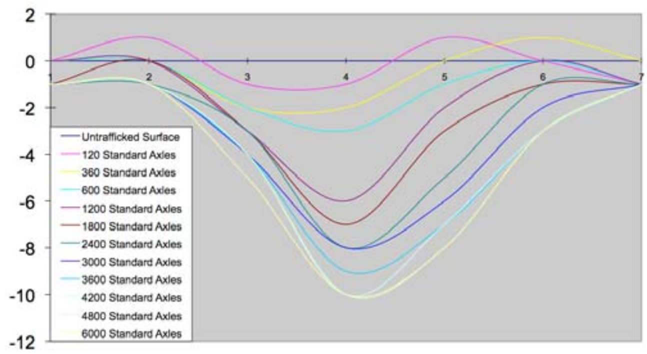

Figure 14. Test Item 2. 20 mm / 6 mm Coarse Graded Aggregate stabilised with 3% cement at centre of Test Item.

4. CONCLUSIONS

The following conclusions can be drawn from the full scale testing.

1. Each of the four materials commonly used in the UK as the main structural course in a permeable pavement have been subjected to full scale trafficking in a controlled test and have

been found to develop rutting when subjected to traffic of different amounts according to the following list which is ordered from least rutting to most rutting:

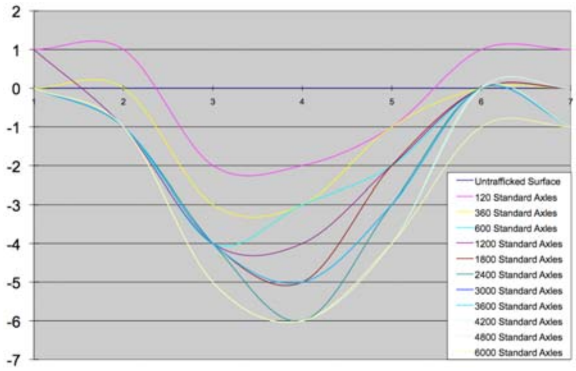

Figure 15. Test Item 3. Dense Bitumen Macadam with 5% 50 Penetration bitumen at centre of Test Item.

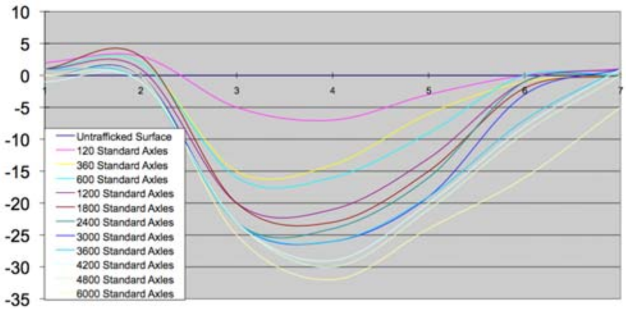

Figure 16 Test Item 4. Coarse Graded Aggregate reinforced with two layers of geogrid at centre of Test Item.

- Dense Bitumen Macadam.
- Hydraulically bound Coarse Graded Aggregate.
- Geogrid Reinforced Coarse Graded Aggregate.
- Coarse Graded Aggregate.

2. Whereas UK recommendations require that Load Category 3 pavements (i.e. pavements trafficked by one large goods vehicle per week) should include a cement or bitumen bound base, this has been shown to be a conservative requirement and providing all of the materials are correctly specified and installed as set out in Refs 2 & 3, the cement or bitumen bound course can be omitted for Load Category 3 pavements and instead the thickness of Coarse Graded Aggregate can be increased to 350 mm.

3. The present UK recommendations are safe but for Load Category 3 pavements, cost and time savings may be possible by adopting Conclusion 2.

4. There is a distinct difference in performance between, on the one hand cement and bitumen stabilized structural layers and on the other hand Coarse Graded Aggregate, whether reinforced or not. Typically, for a given level of trafficking, ruts in the unbound structural courses are between three and four times those which occur in pavements which include a bound structural course.

5. Even when trafficked by overloaded fully channelized highway vehicles, permeable pavements perform well in that there is no indication that they fail structurally under such load, but rather they progressively deform and develop ruts in line with conventional flexible pavements.

5. REFERENCES

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