DESIGN PROCESS OF A NEW CONCRETE BLOCK FOR PERMEABLE PAVEMENTS - LABORATORY TEST STUDIES

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SUMMARY

This paper presents the development of a new concrete block geometry specially designed for urban permeable pavements. In this project, the University of Cantabria worked with a local company of precast concrete and counted on the support of the local government. The main objective was to increase the use of permeable pavements as a Sustainable Urban Drainage System (SUDS) in the north of Spain.

The design process began taking different patterns and geometries into consideration. An initial theoretic comparison of factors such as void area, contact surface and aesthetic value helped to select one pattern with four different geometries of slots.

Then an experimental study was carried out in the Roads Laboratory of the Cantabria University in order to evaluate the hydraulic performance associated with the different slot shapes. There were two laboratory test studies. The first one consisted in trying different blockage states and gradients to identify the best geometry. The second one was an analysis of the runoff resistance of the permeable pavement constructed with the selected geometry of concrete block. With all the results, the company ordered the mould, produced the first series of this new concrete block and began to commercialize it.

The methodology followed for the design of this new concrete block for permeable pavements is only an approach with successes and errors and never pretends to be a guide, only a discussion topic for the enrichment of the technique.

1. INTRODUCTION

Permeable pavements are an important subset of Sustainable Urban Drainage Systems (SUDS) (Pratt et al., 2002), Stormwater Best Management Practices (BMPs), Low Impact Development or Water Sensitive Urban Design (WSUD). All around the world, countries are investing money to develop these techniques as part of the new tendency towards sustainability in urban drainage. The aim is to prevent and avoid problems like floods, diffuse pollution or water shortage.

Permeable interlocking concrete pavements (PICPs) (Smith and Burak, 2004) are one of the most used pervious surfaces because they offer a very good aesthetic and amenity value to fit in any urban context. Normally, applications of pervious paving are restricted to low volume parking areas or residential areas (Smith and Burak, 2004) although they can tolerate runoff from rooftop storage or adjacent conventionally impervious paved areas. Such surfaces have a high removal capacity of total suspended solids and pollutants in urban runoff, as well as enabling groundwater recharge and stream bank erosion control. Some other advantages of pervious surfaces are: low land requirements,

reduction or elimination of downstream conveyance systems, the preservation of the natural water balance at the site and the provision of surfaces with improved skid resistance, which reduces hydroplaning.

Pervious pavements cannot be used in areas where hazardous substances are likely to be washed into the subsoil, due to their filtration characteristics. Besides, their use may be restricted in cold or arid regions, regions with high wind erosion and areas of sole-source aquifers.

In normal circumstances, the most common factor causing failure of pervious surfaces is clogging (Pratt et al., 2002). Clogging can be defined as the accumulation of silt within the pavement structure due to sedimentation, thus reducing its filtering capacity (Dierkes et al., 2002). This blockage of the pavement is most likely to occur in the surface and in the geotextile layers, if these are used (Rommel et al., 2001).

The hypothesis was that the geometrical design of the concrete blocks influences the hydraulic performance of the permeable pavement, and the main aim of this work was to determine the most efficient block geometry among several selected. The specific objectives were to propose alternative paving block geometries and test and compare their hydraulic performance.

The hydraulic performance study was carried out using a specifically designed trials based on previous experience (Rodríguez et al., 2005a, Davies et al., 2002 and Rommel et al., 2001), trying to develop a protocol for testing permeable surfaces in order to analyse the effects of clogging and gradient. This design process is framed in the three-year research project "Development of New Structures of Pavements for the Biodegradation of Hydrocarbons" coordinated by the University of Cantabria, in Spain, and financed by the Spanish Ministry of Education and Science (reference REN 2003-05278/TECNO). Into this research project several permeable surfaces are being studied with the purpose of writing a Spanish Manual for the Construction of Permeable Pavements with Capability for Biodegradation of Hydrocarbons (Bayón et al., 2005). In this task the University of Cantabria is supported by the experience of the Coventry University, UK and counts on the collaboration of several companies. Then a parallel one-year project started: "Development of a new concrete block for permeable surfaces" This Project was collaboration between the Group of Investigation in Technology of Construction (GITECO) of the University of Cantabria and the local company Bloques Montserrat, with the support of SODERCAN (local authorities) inside the program for the Promotion of the Technology Development of Cantabria, Spain (2002-2006).

2. METHODOLOGY AND MATERIALS

1.1 Theoretical study

The basic design was done attending to conditions of easy production and use considering three main factors:

- Hydraulic performance and maintenance.
- Resistance and bearing capability.
- Aesthetics and amenity.

The conditions fixed by the company for easy production and use were simple geometries with symmetry, easy handle and variety of layouts. So the initial condition was: an easy geometry pattern with as much symmetry as possible.

1.1.1 Hydraulic performance and maintenance

The design should have a good hydraulic performance along the time minimizing the maintenance. The considered options were two:

1. Voids filled with permeable material.
2. Slots completely empty.

In the first alternative, permeability depends on the filler, commonly gravel or grass. This filler is directly affected by the silt accumulation in the surface causing the blockage. The needed maintenance to avoid this problem is complicate and involves substitution or raking.

The second alternative, with the slots completely empty, without any filler, the hydraulic performance depends on the slots working as drains and on the permeability of the bedding layer. The empty space acts like reservoir for water and silt accumulation but the size of the silt is limited by the geometry of the slots (Rodríguez *et al*., 2005b). The blockage of the slots could be avoided through sweeping or vacuuming. Considering these reflections, the first decision was to use concrete blocks with empty slots.

1.1.2 Resistance and bearing capability

The concrete characteristics for these blocks were the same than for normal blocks, thus the resistance of the material was not in consideration. Only geometrical characteristics that could influence the bearing capability were considered.

About the depth of the block three possibilities were considered:

- Under 100 mm: normally used for pedestrian paths.
- Around 100 mm: able to bear middle intensity of traffic.
- Over 100 mm: able to bear high intensity of traffic.

The contact surface between concrete blocks is very important to ensure the bearing capacity of the pavement. In this point the blocks with filler could behave better than the ones without it. So the design of the blocks without any filler in their disposition should take into account the real contact surface between blocks and the possibility of concentrated efforts in any irregularity of this surface. Also, it is important to try to avoid weak points like sharp corners or edges and maintain sufficient surface in the cross sections. For these reasons, the contact surface should be the maximum, the edges should be bevelled and the slots should not penetrate too much weakening the cross section.

1.1.3 Aesthetic and amenity

Ease and elegance were considered as important issues to ensure the aesthetic of the pavement constructed with concrete blocks. The colour should be inside the normally used ones but as dark as possible in order to hide the likely stains in the parking bays. To complete the aesthetic considerations, it was stipulated that the concrete block should permit as many dispositions as possible.

Walking conditions were assessed from an amenity point of view. It was important that the voids or slots were not very wide in order to offer a continuous surface for the step and avoid, as much as possible, the problems with high-heeled shoes, walking sticks and crutches.

Summarizing, the initial considerations stay like these:

- Initial condition: Easy geometry with symmetrical design.
- Hydraulic performance and maintenance: Blocks with empty slots enabling to sweep or vacuum.
- Resistance and bearing capability: Maximize the contact surface between blocks minimizing sharp edges and irregularities.
- Aesthetics and amenity: Blocks with narrow slots and multiple combinations for the construction of urban pavements.

1.2 Laboratory studies

After the theoretical study, the selected blocks were tested in the Laboratory of Roads and Airports of the University of Cantabria. Two trials were designed to assess the hydraulic behaviour of the concrete blocks using the same equipment: an infiltration-meter with rain simulator. The infiltration-meter with rain simulator (Figure 1) makes possible the checking of the hydraulic performance of the pervious pavements under different conditions of rain, runoff, blockage and surface gradient. The results that this device offers are runoff generated and amount of water infiltrate through the surface of the sample (Rodríguez et al., 2005a).

The sample of pavement was compound by a geotextile under a bedding layer and a surface of concrete blocks. The geotextile was nonwoven polyester with a mass of 150g/m^2. The aggregate of the bedding layer was limestone of 5mm and the concrete blocks were the prototypes of the selected geometries, especially built for these trials. The depth of the whole sample was 130mm corresponding to the bedding layer 50mm (Rodríguez et al., 2005b).

The first test maintains the same conditions of rain and runoff varying the blockage scenario and the surface gradient. The rain intensity simulated was 50mm/h and the runoff entering the sample was the equivalent to the one generated by an equal impervious surface over the sample under the same rain intensity. Three different blockage scenarios were simulated checking four different slopes each time.

- Scenario 1: New pavement.

In this scenario, the concrete block is just put in place and there is not any kind of silt which could disturb the infiltration of the water.

- Scenario 2: Maintenance at middle level.

The amount of silt to use was over the half of the amount of silt needed to clog completely the pavements constructed with the selected pavers. This could be considered as a normal level of maintenance.

These two scenarios were the same for all the blocks, this permitted direct comparison of them under the same clogging conditions, new and middle clogged.

- Scenario 3: Surface completely clogged.

In this case, the amount of silt added to the surfaces is different for each kind of block depending on the need to fill completely all the gaps and slots. Under these conditions, the block behaviour is analysed, already knowing which one is the easiest one to clog.

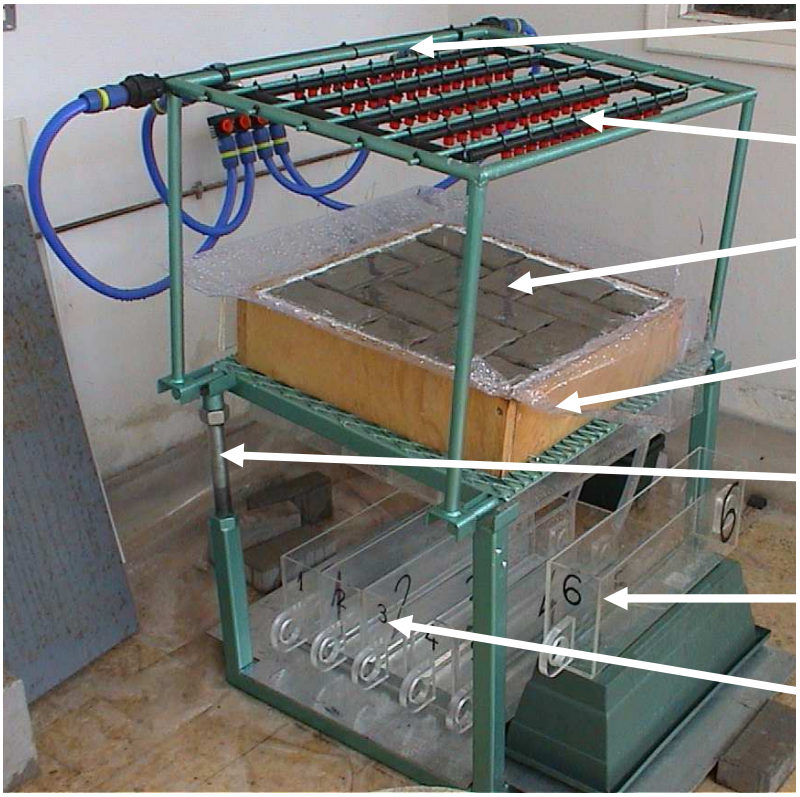


Figure 1. Infiltration-meter with rain simulator

Each scenario was tested varying the gradient of the surface controlling the infiltration through the surface and the runoff generated. The surface gradients were four:

- 0%: Sample completely horizontal enabling the temporal accumulation of water.
- 2%: A commonly used gradient in the urban pavements.
- 5%: An over the average slope in the urban pavements.
- 10%: An extreme gradient that facilitates the formation of runoff.

The second hydraulic test maintained the same conditions of blockage and gradient of the surface varying the runoff entrance without rain simulation. The blockage in this case corresponded to the scenario 3, the worst possible, and the gradient was 2%, the most common one. The rain simulator was no used this time so the water entered to the sample area only like runoff on the top. The amount of runoff was varied in order to assess the efficiency of the permeable pavement under these conditions and the variation of the drainage path (Gonzalez-Angullo, 2005).

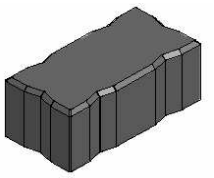
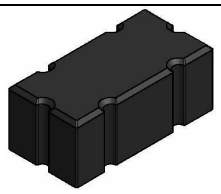
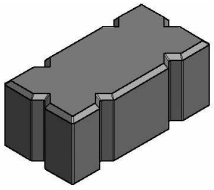
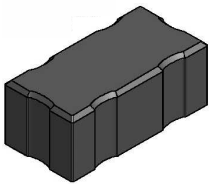
The increasing runoff corresponded to the one originated by an equivalent area of impervious surface over the sample under a growing rain intensity. This could be explained too as the runoff coming from an increasing impervious area under a constant rain intensity of 50 mm/h, draining to the permeable surface of the sample.

The silt used in all the trials was construction debris with a size distribution similar to the urban silt used in other experiences (Davies et al., 2002 and Rodríguez et al., 2005a). The rain and runoff simulations had always 20 minutes of duration in all the trials (Rodríguez et al., 2005b).

3. RESULTS AND DISCUSSION

Among the various models extracted from the theoretical study, 4 were preselected attending to the highest level of symmetry which allows multiple combinations and the lowest number of sharp edges and irregularities (Table 1).

Table 1. Preselected designs.

Geometry of the slot	B1: Rhomboidal	B2: Circular	B3: Square	B4: Elliptic
Model view (Castro et al., 2005)				

The 4 preselected designs were compared in detail under the three considerations.

- Hydraulic performance and maintenance.

The 4 geometries were adapted to have infiltration areas of 600 mm^2 and allow the direct comparison of the influence of the different geometries in the hydraulic behaviour (HB) through the laboratory tests.

- Resistance and bearing capability.

The contact surface between blocks was assessed by means of its perimeter called contact perimeter (CP) and the percentage respect of the total perimeter of the block. The other parameter considered was the minimum wide (MW) of any cross section of the concrete block.

- Aesthetics and amenity.

To ensure the best walking conditions, the maximum slot width (SW) in any combination was indicated and scored.

The only parameter to assess in laboratory was the hydraulic behaviour (HB). To do this the four geometries were tested in the infiltration-meter with rain simulator. The test studies were carried out in the Laboratory of Roads and Airports of the University of Cantabria with the described infiltration-meter with rain simulator. The 4 geometries were tested following the indications of the first trial, variation of blockage and gradient, obtaining the following results for each scenario.

- Scenario 1: New pavement.

No silt was used to simulate the clogging. In this situation all the blocks work perfectly for all the gradients tested. The best one was B1 with 95% of infiltration at 10% slope and the worst was B3 with 91% of infiltration at 10% gradient. Blocks B1 and B4 worked slightly better than B2 and B3.

- Scenario 2: Maintenance at middle level.

The blockage simulated is the one caused by 2kg of silt in $1m^2$ of pavement for all the geometries. This meant 500g of silt in the $0.25m^2$ of the sample. In this situation blocks B1 and B2 offered better results with infiltrations over 87% with the worst gradient of the surface.

- Scenario 3: Surface completely clogged.

The amounts used for the blockage were between 2.5 and 3.5kg of silt per m^2 of permeable pavement, depending on the concrete block analysed. Blocks B2 and B3 were clogged easily because they accept bigger sizes in the slots and not so many fines were required like in B1 and B4 where the narrowed slots were clogged only with fine particles. This meant a better hydraulic behaviour of block B2.

Blocks B1 and B2 present 60% of infiltration rate with a gradient of 2% worsening quickly with higher gradients.

From the comparisons in scenarios 1 and 2, the 2 best pavers were B1 and B4, so they were tested again to compare them in detail. The parameter to assess the hydraulic behaviour (HB) was the value of the average percentage of infiltrated water of all the tested situations. From the detailed comparison of B1 and B4, it could be appreciated that B1 was slightly better than B4 with reference to hydraulic behaviour (Table 2).

Table 2. Comparison of parameters

	B1: Rhomboidal	B4: Elliptic
HB	**55.6 %**	**54.2 %**
CP	360 mm (60%)	408 mm (68%)
MW	90 mm (90%)	92 mm (92%)
SW	10 mm (10%)	8 mm (12%)
Score	**53.9%**	**56.55%**

However, there were other parameters to consider and B4 had better indicators of resistance, bearing capability, aesthetics and amenity (Table 2). Thus, the elliptic slots offer better conditions in sum. But more hydraulic characterization was carried out and B4 was tested to runoff resistance to know exactly how good it was. B4 was tested with runoff enters corresponding to an equal surface under a rain intensity from 50mm/h up to 175mm/h (Gonzalez-Angullo, 2005).

The worst result was 30% of infiltration with a gradient of 2% and the surface completely clogged. This could be expressed as $1m^2$ of permeable area receiving runoff from $3.5m^2$ of impermeable area under a rain intensity of 50mm/h during 20 minutes (once every 25 years in Cantabria) assuring a water infiltration of 30 %.

These results were given to the company and the four industrial designs were patented (Castro et al., 2005) and started with the production of B4. Now the first real applications are being constructed and the University of Cantabria will check periodically the characteristics of the pavements built with these concrete blocks to validate the design process.

4. CONCLUSIONS

In conclusion, the design process of a new concrete block for permeable pavements was successful. The three main analyses to be made during the design process were:

- Hydraulic performance and maintenance
- Resistance and bearing capability
- Aesthetics and amenity

Laboratory test studies showed differences that allowed the selection among different models and their hydraulic characterization. These tests showed very good results in extreme conditions of blockage, gradient, rain and runoff for the blocks with longer and narrower slots, rhomboidal and elliptic. However, the final decision not only depended on the laboratory results. The block with rhomboidal slots was selected because of the influence of other considerations. The next work to be done is to check in the real applications how this concrete block design works and compare these results with the laboratory ones.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Bayón, JR, Rodríguez, J and Castro, D, 2005. Pervious Pavement Research in Spain. Third National Conference on Sustainable Drainage, Coventry University, pp. 396-404.

Castro, D, Rodríguez, J, Bayón, JR, Ballester, F and González-Angullo, N, 2005. Request of patent of the industrial designs applied to concrete blocks for pavement. Expedient number: D0502335; 1-4. Priority date: 11th November 2005.

Davies, JW, Pratt, CJ and Scott, MA, 2002. Laboratory study of permeable pavement systems to support hydraulic modelling. Proceedings of the 9th International Conference on Urban Drainage (9ICUD)

Dierkes, C, Kuhlman, L, Kandasamy J and Angelis G, 2002. Pollution Retention Capability and Maintenance of Permeable Pavements. ; 9th International Conference on Urban Drainage (9ICUD)

González-Angullo, N, 2005. Hydraulic Performance of Permeable Pavements. MSc in European Construction 2004-2005 Project.

Pratt, CJ, Wilson S and Cooper P, 2002. Source control using constructed pervious surfaces. Hydraulic, structural and water quality performance issues. CIRIA C582, RP637. CIRIA. London.

Rodríguez, J, Castro, D, Calzada, MA and Davies, JW, 2005. Pervious Pavement Research in Spain: Structural and Hydraulic issues. Proceedings of the 10th International Conference on Urban Drainage (10ICUD)

Rodríguez, J, González, N, Castro, D and Ballester, F 2005. Selection of concrete blocks for permeable pavements. Proceedings of the Third CIWEM National Conference. NJ Horan. Volume II pp. 275-284

Rommel M, Rus M, Argue J, Johnston L, Pezzaniti D, 2001. Carpark with 1 to 1 (impervious/permeable) paving: performance of Formpave blocks. NOVATECH'2001, Sustainable Techniques and Strategies in Urban Water Management, 4 International Conference; Lyon: Graie; pp. 807-814

Smith, DR and Burak, R, 2004. Construction of permeable interlocking concrete pavements. Interlocking Concrete Pavement Magazine. May 2004. Volume 11 Number 2. pp. 22-30.