WATER INFILTRATION THROUGH CONCRETE BLOCK PAVEMENTS UP TO 26 YEARS OLD

Madrid, G.G., Giraldo, E.A. and González, G.A.

Germán G. Madrid Consulting; Cl 37 No.66-15 (502), Medellín, Colombia.
E-mail: germanmadrid@epm.net.co

ABSTRACT

It has been recognised that concrete block pavements (CBPs) allow the ingress or a certain percentage of surface water into the bedding sand, particularly when new; but over a period of time, infiltration is reduced to a point that could be assumed close to zero. This infiltration is one of the main concerns of road engineers and developers because of the potential damage that it could cause to the base, subbase and subgrade, and the need to build drainage systems to evacuate this water.

This paper describes a study of the infiltration of water in to CBPs, and its relationship to pavement age, two parameters assumed to be related but not much studied in the past. The work was conducted through a Graduate Student Project in the School of Civil Engineering of the University of Medellín.

It was found that there was an excellent agreement between the rate of water infiltration (expressed in terms of mm^2 or joint area) and the age of CBPs, with the infiltration decreasing exponentially, independent of paver thickness and joint sand composition. A less precise relationship was obtained when infiltration was expressed in terms of m^2 of CBP. This relationship would be valid for the standard construction procedures and materials, and pavements in good condition, with filled joints and no surface level distress or large amounts of vegetation.

The influence of joint width was found to be higher than the influence of slope, as long as there was water on the pavement surface. Surface conditions such as oil and grease help make the pavement more impermeable. Stepping, due to structural deformation, or the presence of roots under the paver layer, and a large amount of vegetation (grass), could dramatically increase the permeability of a CBP.

The results obtained in this study were generally in line with the findings of earlier studies.

1. INTRODUCTION

It has been recognised that concrete block pavements (CBPs) allow the ingress or a certain percentage of surface water into the bedding sand, particularly when new; but over a period of time, infiltration is reduced to a point that could be assumed close to cero. This infiltration is one of the main concerns of road engineers and developers because of the potential damage that it could cause to the base, subbase and subgrade, and the need to build drainage systems to evacuate this water.

This paper describes a study of the infiltration of water in to CBPs, and its relationship to pavement age, two parameters assumed to be related but not much studied in the past.

The work was conducted through a Graduate Student Project in the School of Civil Engineering of the University of Medellín by Giraldo and González (2002).

2. LITERATURE REVIEW

The first published evaluation of water infiltration through CBPs was reported by Clark (1979), who evaluated the initial infiltration of rainwater into a small area of pavers. This laboratory constructed panel was laid on a concrete tank, with a gravel filtering layer over the concrete, and the bedding sand and pavers on top of it, following the conventional construction methods.

For a simulated rainfall, ranging from 22 mm/h to 53 mm/h (applied water flow), the surface water flow and the laying course (infiltrated) water flow were measured, to take into account the water absorbed by the pavers (very constant at around 4% of the applied flow, with values twice as high for a better joint sealing). The results showed that there was very little influence of the CBP slope (1% or 2,5%); the water infiltration was proportional to the amount of rainfall (water head); the presence of fines in the jointing sand had a great influence on the reduction of infiltration; very soon after the infiltration commenced, the infiltration rate became constant, at least for the first hour, with no clear indication of how it varies thereafter; runoff coefficients were 70% to 90%; and the water infiltration was 3,5 L/m^2h to 9,5 L/m^2h, measured for periods of 40 to 90 minutes.

Clifford (1982) conducted tests to characterize the absorption of water by the pavers and the infiltration of water through the joints, both in the laboratory and in the field. He used an open cylinder sealed to the pavement and filled with a head of water and measured the decrease in the water level. Although the test results had different formats, the infiltration rate was about 3,0 L/m^2h.

Some of his conclusions were that water infiltration changed with the age of the pavement, and it becomes almost completely sealed after some time and that the absorption of water by the pavers was important in controlling the initial intake of water through the complete pavement surface.

Hade (1987) evaluated one a pedestrian and a vehicular area, some months old, using a portable rain simulator, to find the runoff coefficient of a CBP surface. The infiltrations were 4,5 L/m^2h for the pedestrian area and 8,2 L/m^2h for the vehicular area, which was contrary to what had been expected by the author.

Hade and Smith (1988), based on Hade's research, concluded that "the runoff coefficient for CBP increases with increasing rainfall intensity (from 0 to 5 mm/h)". This finding coincided with Clark's finding regarding a constant infiltration rate with time. Al runoff coefficient of 0,8 was recommended to be considered for rain intensities of 30 mm/h to 50 mm/h.

The laboratory-based research by Shackel and Yamin (1994), conducted very much in the same way as Clark's, confirmed (among many other things) that the intuitive notion that the joint width (area) had a direct influence on the water infiltration for a certain area was true: 30% to 35% of the applied water could infiltrate into a newly laid CBP (65% to 70% runoff coefficient), for an non-trafficked and sand-sealed condition.

Yaron, Bensabath and Ishai (1996) examined infiltration from the point of view of the permeability of the composite section. Using Darcy's law, they showed that the influence of the depth of water on the surface on the potentially infiltrating water was very small, so changing the runoff from 45 mm/h to 15 mm/h, or the surface's slope, should not significantly affect the infiltration.

The research by Qvist and Kirk (1996) was focused on the development of equipment (the Infiltrometer) and a testing method, to consistently evaluate the infiltration of water into CBPs by adjusting the water head over the surface and avoiding the loss of water by evaporation. But the diversity of the pavements tested (gravel as joint material or sealed joints) made it difficult to use the information efficiently. Despite this, the authors reported an average infiltration of 3,6 L/m^2h.

In 1988, Shackel presented an update of his 1994 study, where several sands were evaluated and a 25% water penetration (75% runoff) was observed. Several other interesting conclusions were also reached.

3. BACKGROUND TO RESEARCH PROPOSAL

Most of the research discussed in the previous section dealt mainly with runoff values, or made the infiltration a function of a certain simulated rain. Since the normal rainfall generally creates a very low water head over the pavement, it was assumed that the existence of water on the surface would be equivalent to rainfall for the same duration of the permanence. It was therefore proposed that a permanent water head be created over the pavement and that the infiltrated water be measured at regular intervals up to 2 hours.

The second aim of the study was to express infiltration as a function of the joint area. All CBPs have a different joint area/paver area relationship, due to the different sizes of the units and the different joint widths; and the infiltration should be proportional to this relationship. With this in mind, data expressed in terms of mL/mm^2 of joint area would be a net value, and not depend of any other variable. The equivalent infiltration values in terms of mL/m^2 of CBP are also provided, in order to compare them to the values given by other authors.

The infiltration information would then be correlated with the age of the pavement. Observations have shown that new CBPs tend to stay wet after rainfall for longer periods than older CBPs, the theory being that, over time the joints become sealed, or almost sealed, due to physical phenomena and deleterious materials. However, due to the difficulties associated with studying many variables such as joint material, paver thickness, etc., it was decided to limit the variables to infiltration, joint area and age, and to see if consistent results could be obtained without considering them.

4. DETAILS OF RESEARCH PROGRAM

4.1 Equipment

The equipment consisted of a transparent, 280 mm outer diameter, acrylic cylinder, opened at the bottom, with a circular opening at the top side and a plastic bottle, graduated in 20 ml steps up to a capacity of 1 litre. The diameter of the top opening of the cylinder allowed the bottle to rest, upside-down, with the tip (now at the bottom) at a height of 40 mm above the CBP's surface. The top side of the cylinder has another very small opening for pressure compensation (Photo 1).

4.2 Testing Procedure

Once the test site is determined, it is cleaned with a soft brush, in order not to damage the top of the jointing sand.

The characteristics of the pavement are registered (site, use, age, interventions, location of the testing site, surface condition, shape and size of the pavers, etc.). The environmental conditions are also registered, as well as any other facts that could introduce an error into the testing.

The acrylic cylinder is placed over the selected site, and its perimeter is marked on the CBP.

The joints inside the testing area are measured using a caliper (measuring each fraction of joint in length and width), and the total length and area is calculated. Additionally, the length of the joints in a square metre of CBP (mm/m^2), the average joint width (mm), and the joint area in a square metre of CBP (mm^2/m^2) are registered.

The surface of each paver, including the chamfers, inside the testing area, is covered with synthetic modeling clay (Photo 2). This product is impermeable and easy to remove from the pavers after the test, without leaving any stain on them. It performed much better than paints and waxes.

The acrylic cylinder is placed over the sealed area, and bound and sealed by the outer side, using a generous amount of the same synthetic clay (Photo 3).

The sealed cylinder is filled with water, using the graduated bottles, until the 40 mm water head is reached (Photo 4). The last bottle stays in place, vertical (Photo 5), and the level of the water inside it is registered. Readings are taken every 15 minutes up to a period of 2 hours (initial, 15, 30, 45, 60, 75, 90, 105 and 120 minutes).

Observations are made when there is any type of wetting or water flow through the joints, below the bottom seal of the acrylic cylinder (Photo 6). Once the test is finished, the clay is removed by hand and with the help of a brush.

Photo 1. Equipment and tools.

Photo 2. Sealing the paver's surface.

Photo 3. Sealing of the cylinder.

Photo 4. Filling the cylinder up to 40 mm.

Photo 5. Leveling of the marked bottle.

Photo 6. Test after a 2 h run.

Table 1. Details of Test Sites.

Location	Test	Shape of pavers	Age yrs	Site description	Condition	Humidity	Joint Vegetation	Slope %
1	1	"I"	13	Downtown street, side	Good	Dry		
	2	"I"	13	Downtown street, center	Good	Dry		
2	3	"I"	15	Parking space in a building	Good	Dry	Yes	
	4	"I"	15	Sidewalk adjacent to 3	Good	Dry	Yes	15
3	5	Wave	17	Gas station	Good	Oil, gas		
	6	Wave	17	Gas station	Good	Dry		
4	7	Cross	7	Shopping Center	Good	Dry	Yes	
5	8	Cross	26	Parking space in a building, side	Good	Grease	Yes	
	9	Cross	26	Parking space in a building, center	Good	Dry	Yes	
6	10	"I"	15	Pedestrian plaza	Good	Dry		7,5
7	11	Rectangle	17	Parking space, enclosed subdivision	Good	Dry	Yes	7,5
	12	Rectangle	12	Parking space, enclosed subdivision	Good	Dry	Yes	7,5
8	13	Rectangle	7	Pedestrian plaza, shopping area	Good	Dry		
9	14	Rectangle	14	Street, commercial area, side	Good	Dry		8,8
	15	Rectangle	14	Parking space, adjacent to 14	Chipping	Dry	Yes	9,8
10	16	"I"	11	Parking space, enclosed subdivision	Stepped	Dry	Roots	
	17	"I"	11	Street, adjacent to 16, side	Eroded	Dry		
11	18	Rectangle	2	Street, enclosed subdivision, side	Repaired			4,4
	19	Rectangle	12	Street, enclosed subdivision, center	Chipping		Yes	4,4
12	20	Cross	15	Residential street, center	Good	Dry	Little	13,8
	21	Cross	15	Residential street, side	Good	Dry	Little	13,8
13	22	Wave	14	Gas station	Good	Dry		
14	23	Cross	25	Pedestrian & exhibition plaza	Good	Dry	Little	
	24	Cross	0	Same as 23, repaired	Good	Dry		

4.3 Test Sites

Twenty-four tests were conducted at 14 locations, covering different applications, and ages from cero (just repaired) to 26 years old, the oldest in the country. General details of the test sites are presented in Table 1. The dimensional characteristics of each CBP are presented in Table 2, with maximum and minimum values for most of the columns, showing a great variation among CBPs.

Table 2. Dimensional Characteristics of CBPs at Each Location.

Location	Test	Paver Length (mm)	Paver Width (mm)	Paver Area (mm^2)	Joint Length (mm)	Joint Width (mm)	Joint Area (mm^2)	Joint Length (mm/m^2)	Joint Area (mm^2/m^2)
1	1	280	93	24.568	980	3,68	3.606	16.030	58.946
	2	250	96	23.876	980	3,84	3.763	16.030	61.573
2	3	195	72	14.524	940	4,13	3.882	15.376	63.552
	4	195	72	14.524	1.140	2,44	2.782	18.646	45.552
3	5	195	104	21.641	930	4,22	3.925	15.212	64.180
	6	195	104	20.789	930	4,18	3.887	15.212	63.571
4	7	250	210	43.975	860	7,01	6.029	14.067	98.540
5	8	235	205	41.475	880	5,76	5.069	14.394	82.869
	9	235	205	41.475	840	5,52	4.637	13.740	75.780
6	10	205	110	26.100	1.140	2,91	3.317	18.646	54.283
7	11	190	85	16.150	740	10,71	7.925	12.104	129.636
	12	190	85	16.150	760	6,46	4.910	12.431	80.351
8	13	190	95	18.505	910	4,03	3.667	14.885	59.912
9	14	185	85	15.725	830	2,93	2.432	13.576	39.789
	15	195	100	19.500	920	2,44	2.245	15.048	36.680
10	16	205	75	17.750	940	2,08	1.955	15.375	31.959
	17	205	75	17.750	945	2,35	2.221	15.457	36.265
11	18	185	90	16.650	850	3,41	2.899	13.903	47.445
	19	185	80	14.800	870	2,93	2.549	14.231	41.707
12	20	201	185	31.305	780	5,67	4.423	12.758	72.369
	21	200	190	31.316	790	4,94	3.903	12.922	63.872
13	22	205	111	23.057	700	3,74	2.618	11.450	42.842
14	23	220	205	37.900	760	9,78	7.433	12.431	121.578
	24	205	185	37.856	770	10,33	7.954	12.595	130.042
Maximum		280	210	43.975		10,33		18.646	130.042
Minimum		185	72	14.524		2,08		11.450	31.959

The infiltration readings taken every 15 minutes up to a period of 2 hours are shown in Table 3.

Table 3. Infiltration (mL/mm^2) for each 15 Minute Period (20 tests).

		Infiltration (mL/mm^2)										
Test	Age	Singular Reading (At minute …)								Min	Max.	Average
No.	yrs	15	30	45	60	75	90	105	120	In a 15 min period		
1	13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
2	13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	15	0,0000	0,0167	0,0347	0,0193	0,0489	0,0296	0,0270	0,0309	0,0000	0,0489	0,0259
4	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1970	0,0000	0,0000	0,1970	0,0246
5	17	0,0000	0,0025	0,0000	0,0013	0,0000	0,0000	0,0000	0,0000	0,0000	0,0025	0,0005
6	17	0,0039	0,0013	0,0000	0,0013	0,0000	0,0013	0,0026	0,0000	0,0000	0,0039	0,0013
7	7	0,1046	0,0290	0,0573	0,0647	0,0232	0,0465	0,0531	0,0515	0,0232	0,1046	0,0537
10	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
11	17	0,0669	0,0555	0,0492	0,0592	0,0315	0,0114	0,0120	0,0107	0,0107	0,0669	0,0371
12	12	0,0000	0,0000	0,0326	0,0366	0,0020	0,0020	0,0020	0,0000	0,0000	0,0366	0,0094
14	14	0,0000	0,0411	0,0021	0,0308	0,0493	0,0370	0,0329	0,0308	0,0000	0,0493	0,0280
15	14	0,0602	0,0000	0,0580	0,0000	0,0535	0,0000	0,0446	0,0000	0,0000	0,0602	0,0270
17	11	0,0631	0,0406	0,0451	0,0677	0,0000	0,0000	0,0361	0,1443	0,0000	0,1443	0,0496
18	2	0,1689	0,1310	0,1086	0,0983	0,0896	0,1051	0,0310	0,0845	0,0310	0,1689	0,1021
19	12	0,0000	0,0000	0,0020	0,0471	0,0000	0,0000	0,0392	0,0039	0,0000	0,0471	0,0115
20	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0011	0,0396	0,0000	0,0000	0,0396	0,0051
21	15	0,0000	0,0402	0,0000	0,0435	0,0000	0,0000	0,0205	0,0205	0,0000	0,0435	0,0156
22	14	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
23	25	0,0000	0,0000	0,0114	0,0000	0,0175	0,0000	0,0148	0,0000	0,0000	0,0175	0,0055
24	0	0,1164	0,0478	0,1110	0,0928	0,0404	0,0686	0,1117	0,0457	0,0404	0,1164	0,0793
Minimum	0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000		
Maximum	25	0,1689	0,1310	0,1086	0,0928	0,0896	0,1051	0,1970	0,1443		0,1970	
Average		0,0292	0,0203	0,0256	0,0281	0,0178	0,0151	0,0332	0,0211			0,0238

Table 4 shows the accumulated infiltration, i.e. the addition of the infiltration of the previous reading to the next one.

Table 4. Accumulated Infiltration (mL/mm^2) (20 tests).

	INFILTRATION (mL/mm^2)								
Test	Age	Accumulated reading (Σ after minute …)							
(No.)	(years)	15	30	45	60	75	90	105	120
1	13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
2	13	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	15	0,0000	0,0167	0,0514	0,0707	0,1196	0,1492	0,1762	0,2071
4	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1970	0,1970
5	17	0,0000	0,0025	0,0025	0,0038	0,0038	0,0038	0,0038	0,0038
6	17	0,0039	0,0052	0,0052	0,0065	0,0065	0,0078	0,0104	0,0104
7	7	0,1046	0,1336	0,1909	0,2556	0,2788	0,3253	0,3784	0,4299
10	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
11	17	0,0669	0,1224	0,1716	0,2308	0,2623	0,2737	0,2857	0,2964
12	12	0,0000	0,0000	0,0326	0,0692	0,0712	0,0732	0,0752	0,0752
14	14	0,0000	0,0411	0,0432	0,0740	0,1233	0,1603	0,1932	0,2240
15	14	0,0602	0,0602	0,1182	0,1182	0,1717	0,1717	0,2163	0,2163
17	11	0,0631	0,1037	0,1488	0,2165	0,2165	0,2165	0,2526	0,3969
18	2	0,1689	0,2999	0,4085	0,5068	0,5964	0,7015	0,7325	0,8170
19	12	0,0000	0,0000	0,0020	0,0491	0,0491	0,0491	0,0883	0,0922
20	15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0011	0,0407	0,0407
21	15	0,0000	0,0402	0,0402	0,0837	0,0837	0,0837	0,1042	0,1247
22	14	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
23	25	0,0000	0,0000	0,0114	0,0114	0,0289	0,0289	0,0437	0,0437
24	0	0,1164	0,1642	0,2752	0,3680	0,4084	0,4770	0,5887	0,6344
Average		0,0292	0,0495	0,0751	0,1032	0,1210	0,1361	0,1693	0,1905

5. DATA ANALYSIS

The accumulated infiltration is compared with CPB pavement age in Figure 1. When fitting a regression curve to this data, there are four points that appear to be outliers: one at age seven years, with no infiltration (Test 13, known for being built on concrete), one at age 11 years with the highest infiltration measured (Test 16, stepped, with roots), and two at age 26 years, also with a high infiltration (a very seldom trafficked parking area, with much vegetation). These data were deleted and further analysis conducted, as shown in Figure 2. It can be seen that there is now a very good correlation between the data.

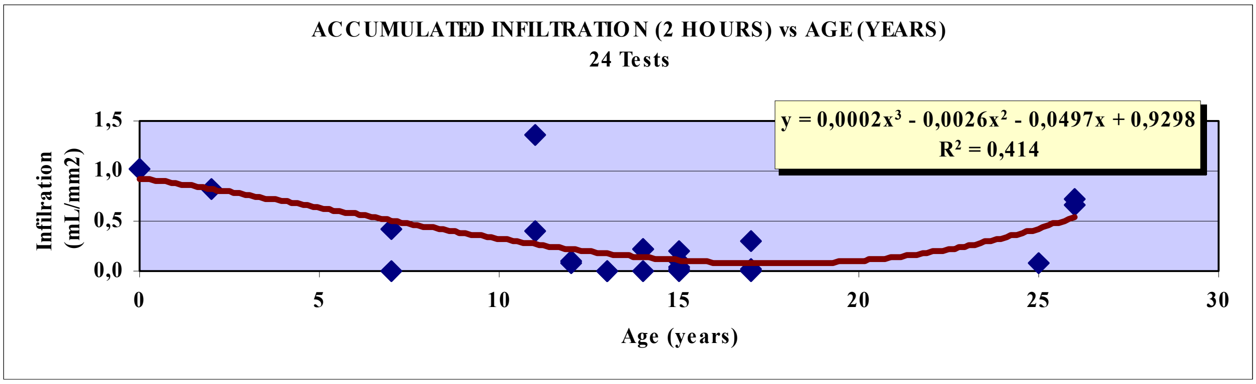

Figure 1. Accumulated infiltration (mL/mm^2) vs. Age (years); (24 tests).

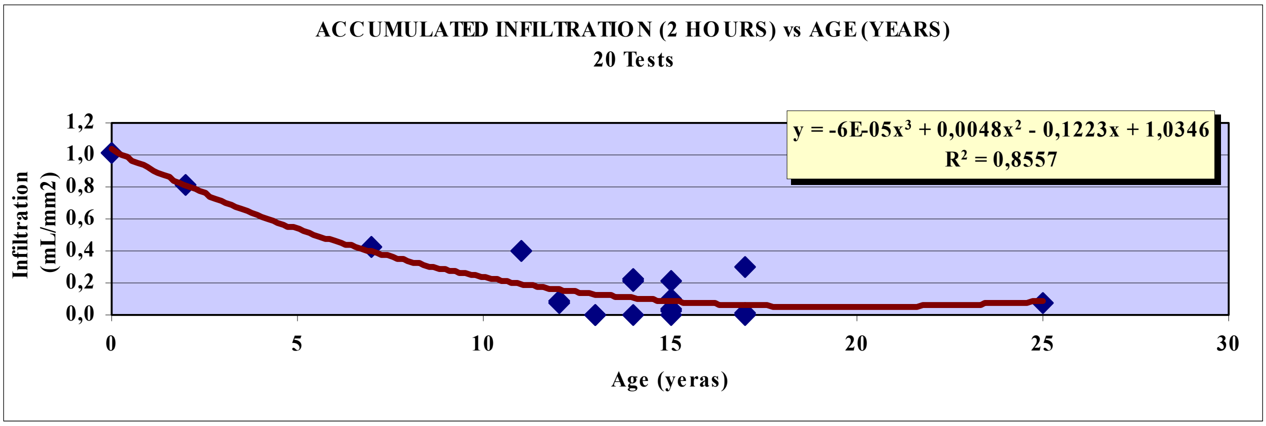

Figure 2. Accumulated infiltration (mL/mm^2) vs. Age (years); (20 tests).

Figures 3 and 4 compare the infiltration, in L/m^2 of CBP, with pavement age. The trend is surprisingly the same, although not with such high regression values.

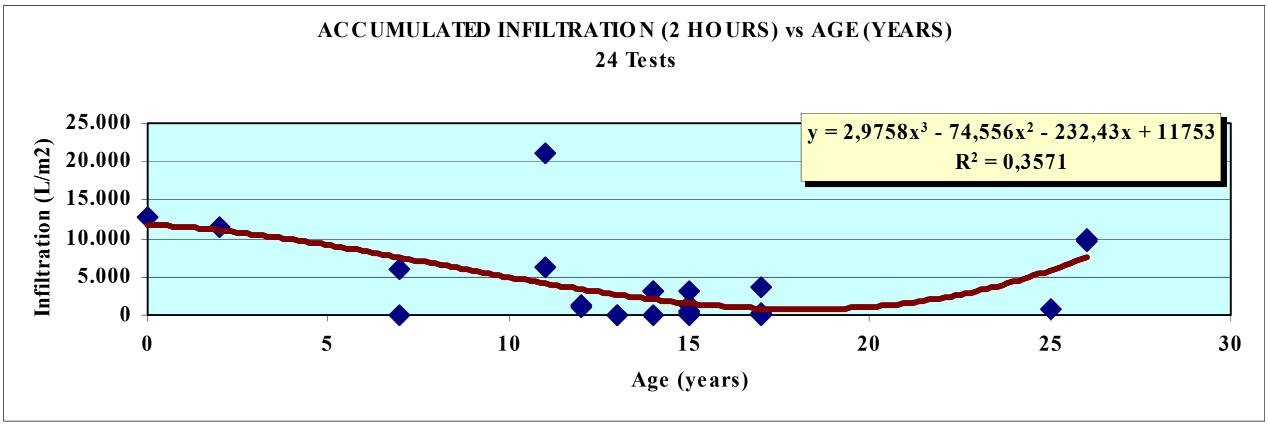

Figure 3. Accumulated infiltration (mL/m^2) vs. Age (years); (24 tests).

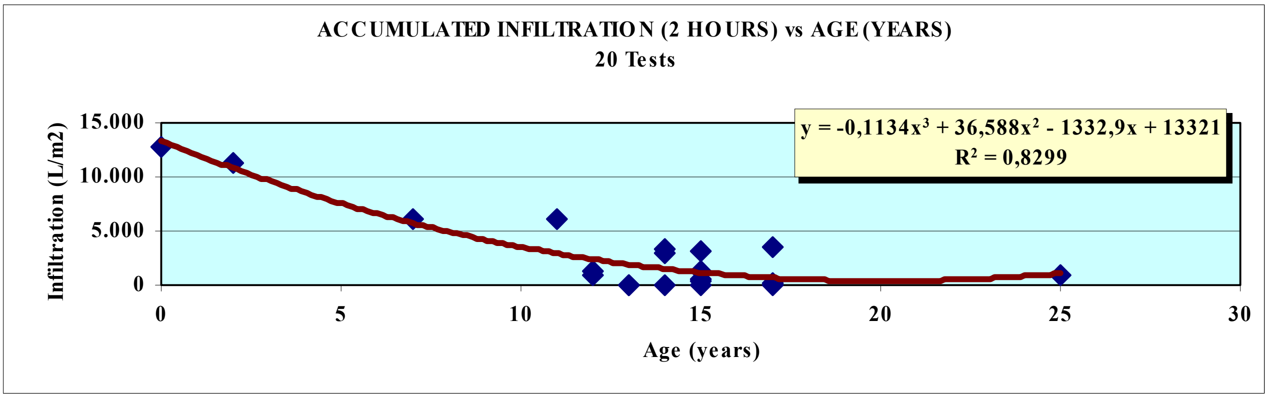

Figure 4. Accumulated infiltration (mL/m^2) vs. Age (years); (20 tests).

Using the data for the 20 tests, Figure 5 shows the curve as in Figure 2 (accumulated infiltration after 2 hours), plus the corresponding curves for 15, 30 and 60 minutes (doubling the time from one to the next). It can clearly be seen that the trend is well established since the first reading, and maintains its proportionality up to 2 hours.

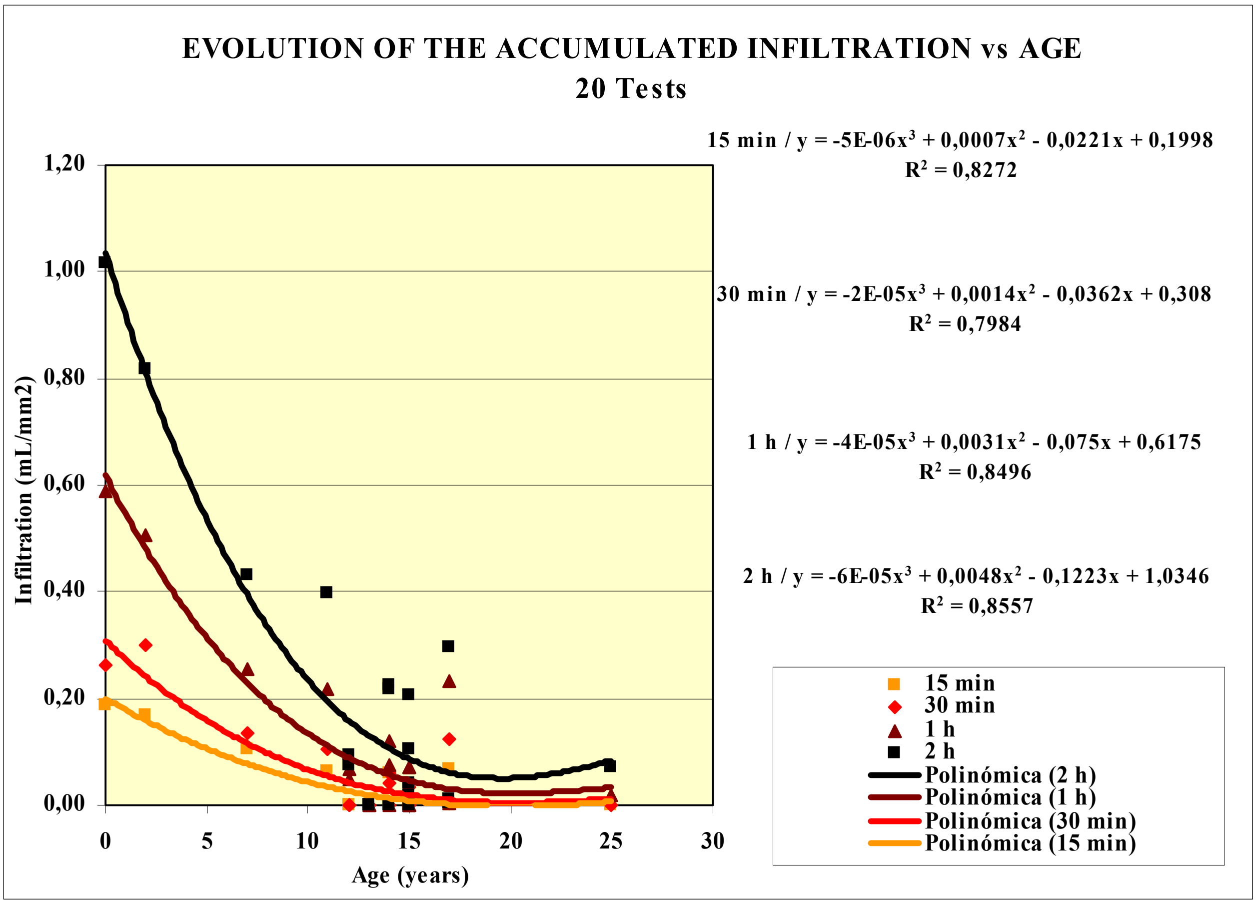

Figure 5. Accumulated infiltration (mL/mm^2) vs. Age (years) every 15 min; (20 tests).

The same trend can be seen en Figure 6, when the maximum and minimum readings, for each test and period are compared rather than the accumulated infiltration.

Taking the information of the 20 tests, extracting average values for the accumulated infiltration, and assuming the 2 hour infiltration as being 100 %, Figure 7 shows how constant the water flow is, aligning, almost perfectly, with a linear regression.

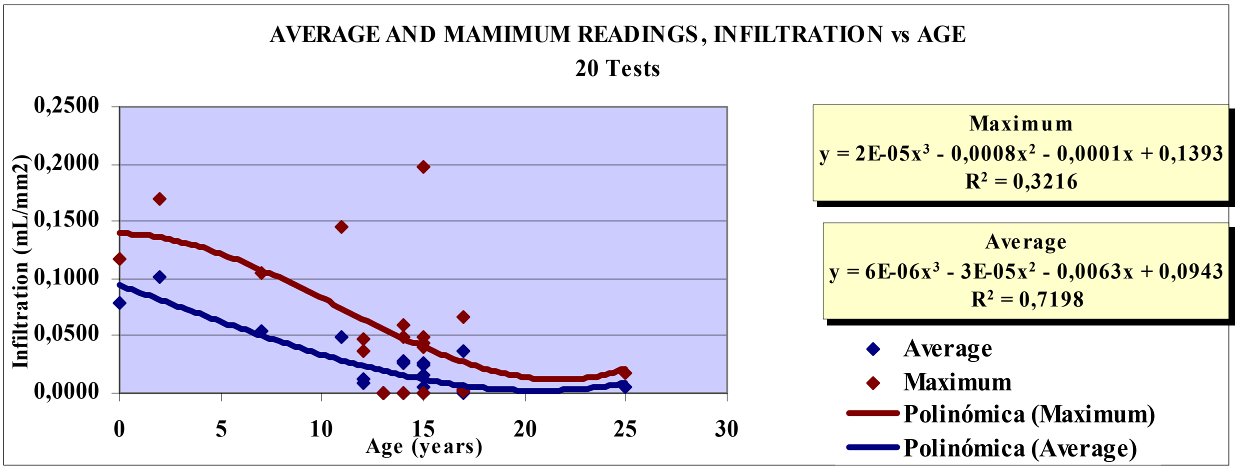

Figure 6. Average and maximum readings of infiltration vs. Age; (20 pavements).

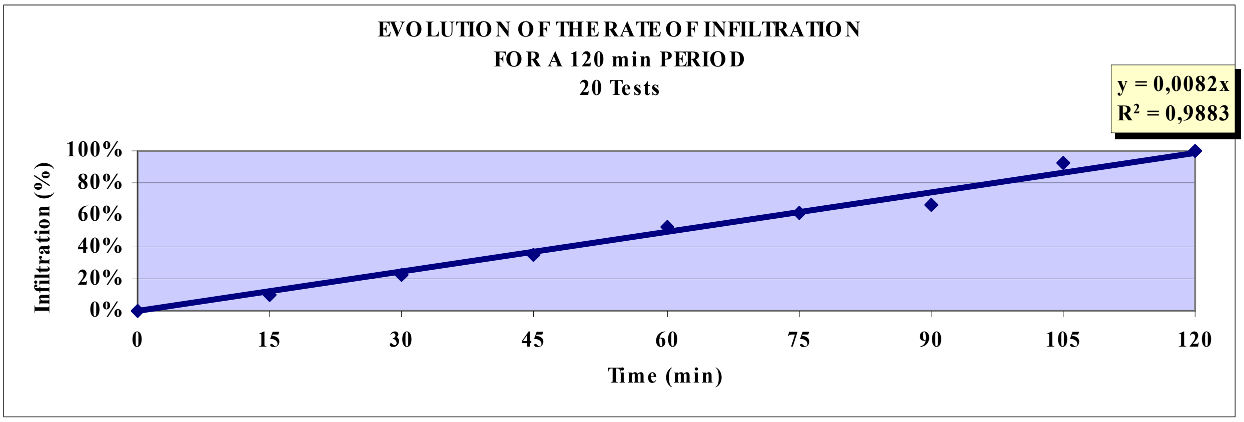

Figure 7. Average and maximum readings of infiltration vs. Age; (20 pavements).

The average infiltration, for a 1 hour period of rainfall, varied from 0,6175 mL/mm^2 in new pavements to 0,0375 (or even 0) mL/mm^2, in 20 year old CBPs. For rectangular units (200 mm x 100 mm) and 2 mm joints (joint area = 30.000 mm^2/m^2), those figures are equivalent to 18,5 L/m^2 and 1,1 L/m^2. The equations in Figure 5 can be used to calculate the infiltration, base on the rain duration, the age of the pavement and the area of joints, in a square metre of CBP, for the areas presented in Table 5.

Table 5. Area of Joints per m^2, for Different Paver Sizes and Joint Widths.

Paver Size (mm x mm)	Length of Joints (mm)	Area of Joints (mm^2/m^2) for 2 mm wide joints	Area of Joints (mm^2/m^2) for 3 mm joints
100 x 100	20.000	40.000	60.000
100 x 200	15.000	30.000	45.000
200 x 200	10.000	20.000	30.000
250 x 250	8.000	16.000	24.000

6. CONCLUSIONS

This paper has described a study of the infiltration of water in to CBPs, and its relationship to pavement age, two parameters assumed to be related but not much studied in the past. The work was conducted through a Graduation Project in the School of Civil Engineering of the University of Medellín.

It was found that there was an excellent agreement between the rate of water infiltration (expressed in terms of mm^2 or joint area) and the age of CBPs, with the infiltration decreasing exponentially, independent of paver thickness and joint sand composition. A less precise relationship was obtained when infiltration was expressed in terms of m^2 of CBP. This relationship would be valid for the standard construction procedures and materials, and pavements in good condition, with filled joints and no surface level distress or large amounts of vegetation.

As long as there was water on the surface of the pavement, the infiltration rate was almost constant, at least up to a period of 2 hours.

The influence of joint width was found to be higher than the influence of slope, as long as there was water on the pavement surface.

Surface conditions such as oil and grease help make the pavement more impermeable. Stepping, due to structural deformation, or the presence of roots under the paver layer, and a large amount of vegetation (grass), could dramatically increase the permeability of a CBP. The results obtained in this study were generally in line with the findings of earlier studies. A more comprehensive series of tests could be performed, to add more points to the equation, especially for recently-constructed CBP and old pavements.

7. ACKNOWLEDGEMENTS

The authors thank the Instituto Colombiano de Productores de Cemento - ICPC (Colombian Institute of Cement Producers) for sponsoring the tests, leading to the production of this paper.

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WATER INFILTRATION THROUGH CONCRETE BLOCK PAVEMENTS UP TO 26 YEARS OLD

Madrid, G.G., Giraldo, E.A. and González, G.A.

Germán G. Madrid Consulting; Cl 37 No.66-15 (502), Medellín, Colombia.
E-mail: germanmadrid@epm.net.co

PROFESSIONAL CURRICULUM VITAE (Resume)
GERMÁN G. MADRID

He was born in 1955 in Medellín, Colombia.
Civil Engineer form the University of Medellín, Medellín, Colombia, 1979.
Master of Sciences in Civil Engineering from Carnegie-Mellon University, Pittsburgh, USA, 1981.
Concrete Technologist from the City and Guilds of London Institute, London, United Kingdom.

From 1981 to 2002 he was Director of the Technical Department and Director of Precasting of the COLOMBIAN INSTITUTE OF CEMENT PRODUCERS - ICPC, focusing in the development of the uses of cement through precast concrete.

For this purpose, he wrote and published a large amount of papers, booklets and books on concrete block paving and concrete masonry. Among them, he is coauthor of the Handbook for the Design and Construction of Elements of Public Space – MEP, published by ICPC and the Pontifical Bolivarian University - UPB, and the Handbook for the Construction of Concrete Masonry.

Throughout his professional career, he has been lecturer in many seminars and curses, and has presented papers in several national and international events, like the International Conferences on Concrete Block Paving, from 1988 to 2003 (Rome - Italy, Auckland - New Zealand, Tel-Aviv - Israel, Cartagena - Colombia, Tokyo - Japan and Sun City - South Africa). His professional activities in consulting for precast concrete producers and for engineering projects, has taken him to lecture and work in 75 cities in 19 countries.

From 1995 to 2003 was the President of the Precast Concrete Committee of the Colombian Standards Institute - ICONTEC, developing more than 20 standards. He is the representative, for Latin-America, in the International Committee of Technologists in Small Element Paving - SEPT, which coordinates the International Conferences and activities on concrete block paving, and he was the organizer of the Third International Workshop on Concrete Block Paving in Cartagena, Colombia, in 1998.

Since March 2002, he set-up his private consulting (GERMÁN G. MADRID Consulting), within the same working line developed before and with emphasis in the development of public space. He acts as permanent advisor for ICPC and is actually working for companies and institutions in Brazil, Colombia, Costa Rica, United States and Panama.

He has been the translator, to Spanish, of several of ICPI's publications and is the author of the booklet (in Spanish) on the Construction of Concrete Block Pavements, among the titles being sold by ICPI.

GERMÁN G. MADRID
Civil Engineering, MScCE
GERMÁN G. MADRID Consulting
Calle 37 No. 66-15, Ap. 502, A.A. 52458
Medellín, **COLOMBIA**
Tel: +57 (4) 2651888, Fax: +57 (4) 3502730, Cel: +57 (3310) 4623824
E-mail: germanmadrid@epm.net.co