Permeability of Concrete Block Pavements

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SUMMARY

This study sought to determine the runoff coefficients for trafficked pavements that have been in use for ten months. A Variable Intensity Portable Rain Simulator was used in 118 tests on nine areas on a pedestrian plaza and three areas on a vehicular street intersection. All areas were paved with "Unidecor" Pavers. Three rainfall intensity ranges were tested for each pavement type; 0 to 7 mm/hour, 7.1 to 15 mm/hour, and 15.1 to 30 mm/hour. For the three rain intensity ranges tested, runoff was signficantly different for each range. Unlike asphalt and concrete pavements, the runoff coefficients increased with rainfall intensity. This may be of some advantage in designing storm drainage systems and in reducing water pollution in runoff. The results on the vehicular street challenge the notion that concrete block pavements become impermeable over time. A runoff coefficient of 0.80 is recommended for interlocking concrete pavers, which is lower than 0.95 for 1.00 for asphalt or concrete.

1. INTRODUCTION

Roads and parking lots make up the largest percentage of manmade impervious surfaces in the world. Within the United States about 700-750 square kilometers of pavement are being developed annually (1). Large amounts of runoff contribute to wastewater treatment plant overloads and subsequent raw sewage dischares into rivers and lakes. High runoff rates reduce groundwater aquifer recharge, cause stream bed erosion, and flooding which frequently result in the loss of life, property and/or crop damage. High runoff rates also cause surface pollutants to be washed into storm sewers, streams and other waterway, causing damage to aquatic plant and animal life. Porous pavements are one of the tools which engineers and landscape architects may use to help reduce runoff. Porous pavements allow the stormwater to be managed "on-site" rather than quickly draining into sewers and transferring the water to another property.

In designing and drainage systems it is necessary to know the runoff coefficient for different land uses in the drainage area. Because of the increasing "on-site" management and control of stormwater runoff, there is a need for knowing the runoff coefficients of concrete block pavements for making runoff calculations.

Table 1 lists know runoff values for some pavement types.

Table 1
Runoff Coefficient Values for Paving Types

Type	Runoff Coefficient
Asphalt or concrete	0.95 - 1.0
Macadam, chip and seal	0.7 - 0.8
Gravel (compacted)	0.7
(loose)	0.3
Concrete grid pavement with grass	0.1 - 0.5

Smith (2) presented both laboratory and in-situ runoff data for concrete grid pavements. A runoff coefficient of 0.3 is considered to be useful in calculating drainage from concrete grid pavements. The only previous study on the permeability of solid concrete block pavements was done by Clark (1). His laboratory experiments were performed on a sample pavement in a shallow box, testing the permeability of newly laid blocks. Clark used a hand held watering can moving over a three square meter area of paving. This test method can create an uneven distribution of rainfall and hydraulic heads in the joints. Clark's tests found that for a newly laid pavement with freely draining base in slope of one percent, the infiltration (and absorption) was as high as twenty percent, i.e., the runoff coefficient was 0.80.

There are two differences between this investigation and Clark's tests. First, the pavement in this study had been subjected to traffic whereas Clark's tests tested in a laboratory were on pavers without traffic. Two pavement uses were studied in the following investigation; one designed for and subjected to automobile traffic, and one designed for and subjected to pedestrian use only.

considers a lower range of rainfall intensities than with Clark's work. This study applies rain intensities to concrete pavers that are typical to the eastern U.S. These intensities represent average storm events where the runoff can be managed "on-site" through infltration practices such as porous pavements. Furthermore, the test method created an even hydraulic head across all test areas, better simulating the interaction of rainfall and infiltration.

2. TEST SITES

Two test sites were located on Ball State University in Muncie, Indiana. See Figures 1 and 2. The average daily traffic load on Petty Road was 1,500 vehicles per day. On McKinley Road, and the remainder of the intersection which serves the campus of Ball State university and Muncie, the vehicle count was approximately 10,288 per day. Traffic on that portion of the intersection consisted of commercial, construction, and passenger vehicles.

Reconstruction of the area began in June of 1984 and was completed July 1, 1984. The soils underlying the test site are predominately loamy sands. The new street surface consists of a base of crushed limestone approximately 200mm to 300mm deep overlain with an approximate 25mm to 50mm layer of sand, on which 80mm thick pavers were installed. The slope of the intersection test plots ranged from 0.7% to 1.3%. Three test plots were located on the intersection.



Figure 1 - Location of Muncie, Indiana

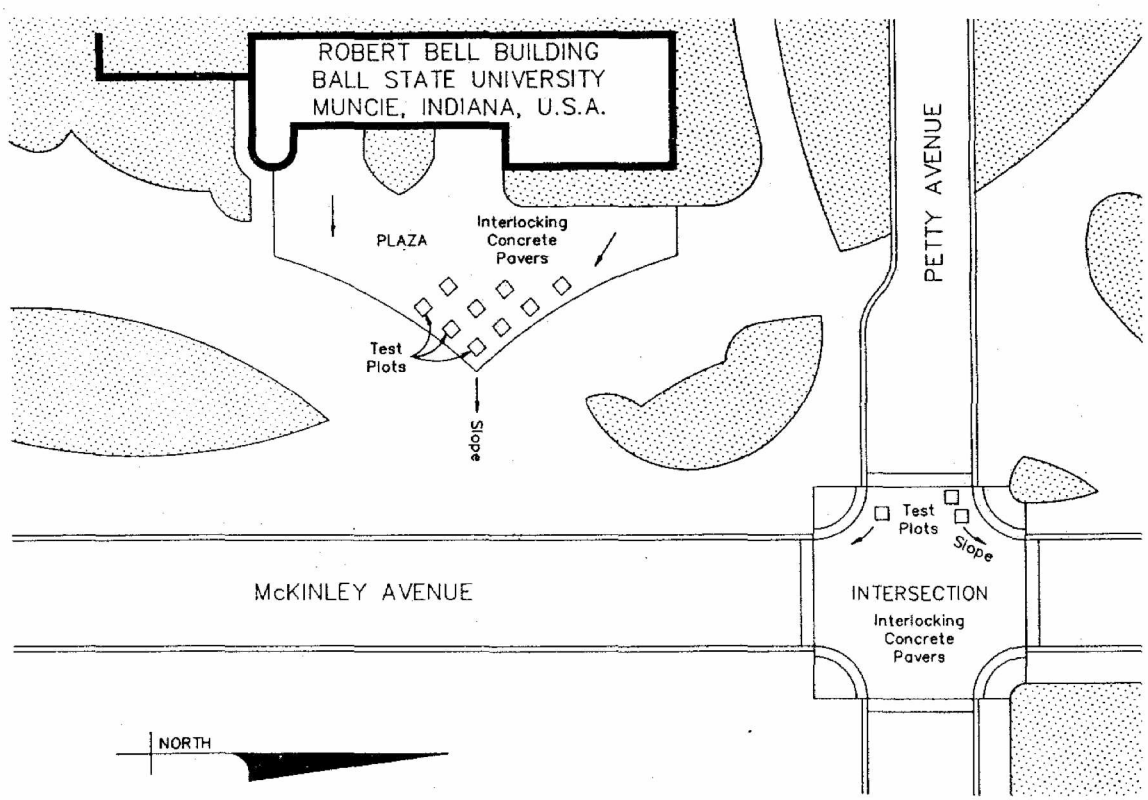


Figure 2 - Plan of Test Areas. Scale = 1:600 (approximately)

The plaza area was construcred in a similar manner except that approximately 100mm to 150mm of gravel were used for the base. A total of nine plots were located on the plaza area and 60mm thick pavers were installed. The plaza is primarily for pedestrian use with a few delivery vehicles frequenting the area. The slope of the plaza test plots ranged from 3.7 to 4.9%.

Table 2 gives the results of a sieve analysis on a sample collected from the supply of sand used in the joint and bedding. The construction specifications from the contract for intersection was for 50mm of sand and gave no grading specifications.

Table 2
Sieve Analysis of Joint and Bedding Sand for the Intersection and Plaza

Screen Size	Percent Passing
4.72mm	99
2.36mm	99
1.18mm	98
300um	31
75um	0.5

Within the intersection, on the western apron where the testing occured, the joint sand was within two millimeters from the bottom edge of the chamfer of the block. In the wheel paths of McKinley Avenue the sand was drawn as much as 40mm from the bottom of the chamfered edge.

The paver under test were those shown in Figure 3. The average joint width on the pavement under testing was found to be 3.11mm, which gives an open area of 3.5%. The average joint widths in the street area were larger than those measured on the tested areas of the intersection.

3. .TESTING DEVICE

A Variable Intensity Portable Rain Simulator was constructed which operates on the principle of a double ring infiltrometer. Figures 4, 5 and 6 describe the operation of the simulator. Figure 7 shows the simulator on the test site. Two frames seal the perimeter of a one square meter area of pavement and deliver a prescribed quantity of water over a thirty minute period. The droplets were applied in a 5cm grid from height of approximately 30cm. This allowed for even distribution of water over the test surface. A vacuum pump, in concert with other components, collected the runoff from the lowest corner of the inner retaining frame. Water was also applied to the area between the inner and out frame to equalize the hydrostatic pressure on the soils within the perimeter of the inner frame. The difference between the amount of water applied

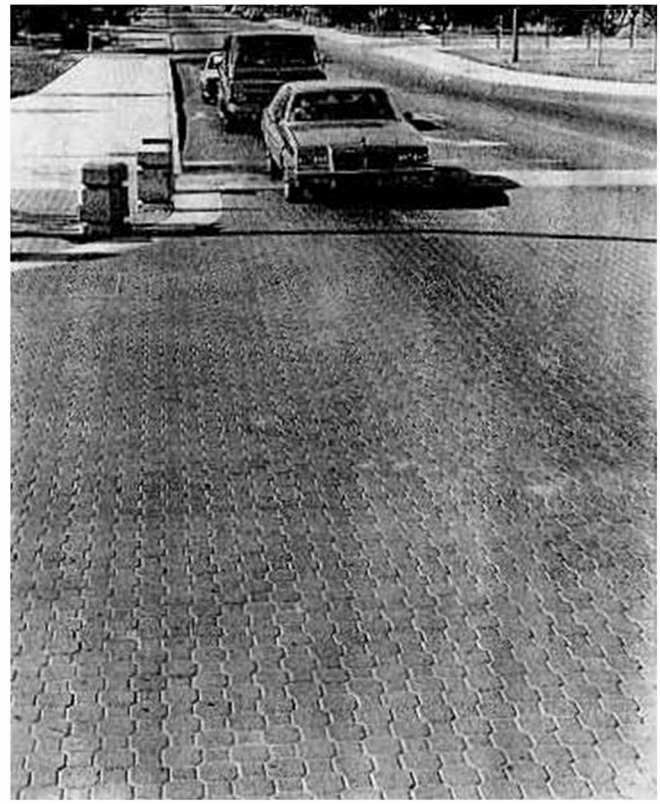


Figure 3 - "Uni-decor" pavers in the intersection test areas.

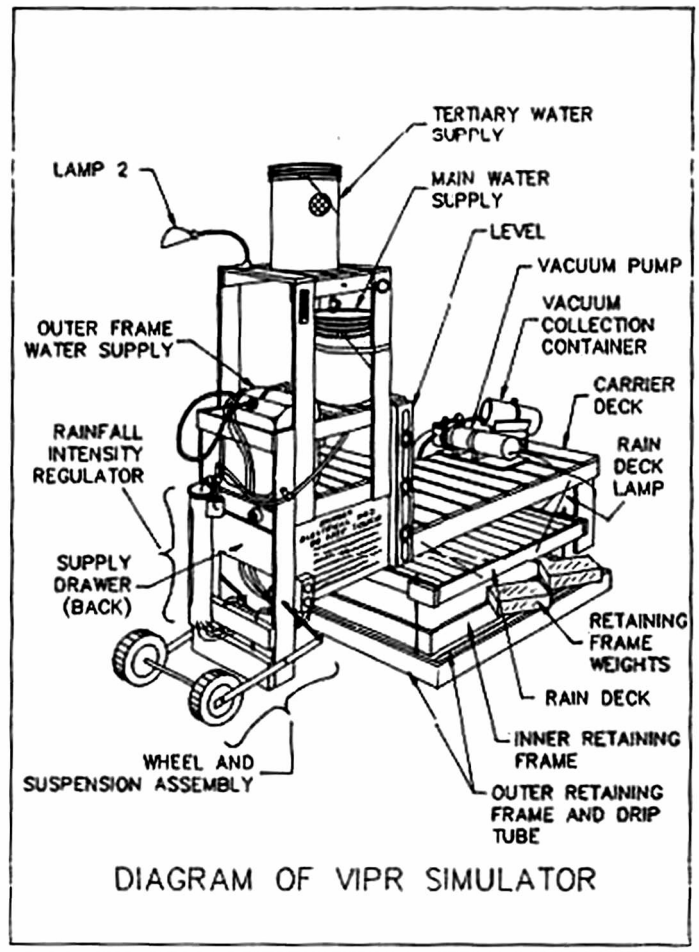


Figure 4 - The Variable Intensity Portable Rain (VIPR) Simulator

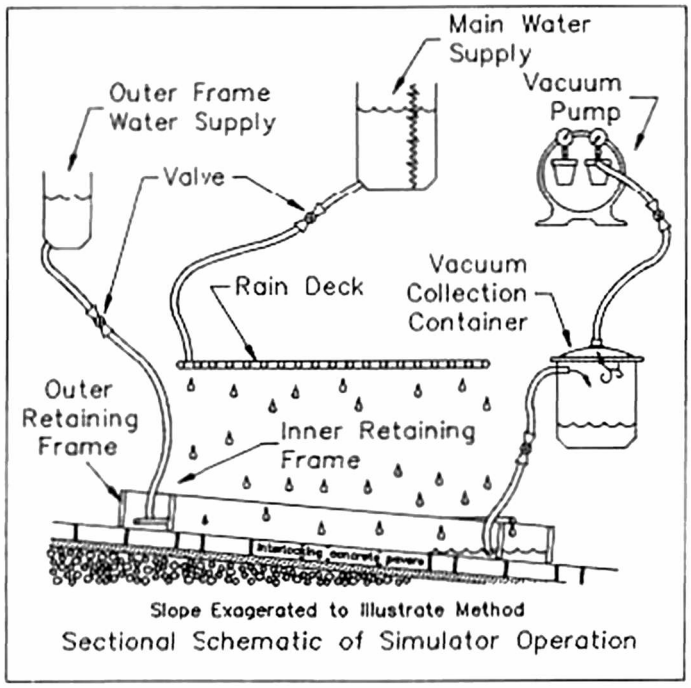


Figure 5

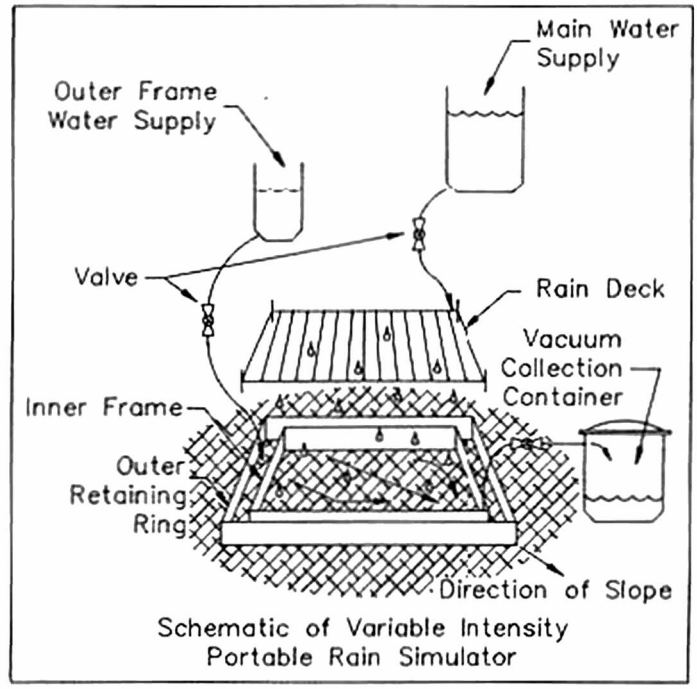


Figure 6

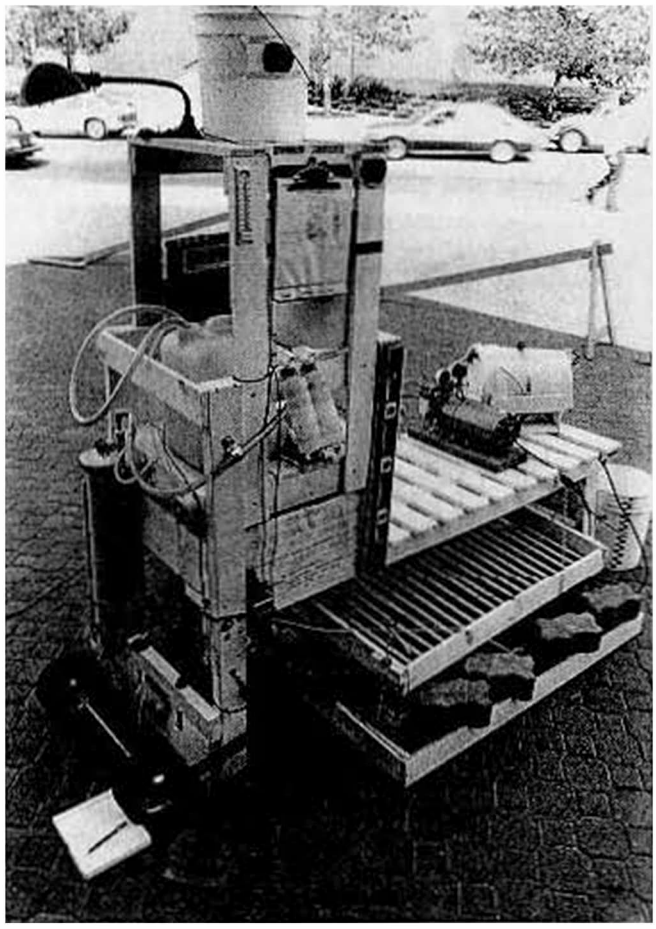


Figure 7 - The Simulator on the Plaza Test Area

to the inner frame and the amount withdrawn from it was assumed to be infiltrated and absorbed. Evaporation was considered negligible.

In preparation for testing, the plots were lightly swept to remove stones and debris that would prevent the retaining frames from sealing against the pavement. The inner retaining frame was placed over the plot and the crevices between the block under the frame edges were sealed with a pliable compound. The Simulator (carrying the outer frame and rain deck) was positioned over the inner frame, then the outer frame was lowered and sealed against the pavement. The rain deck was realeased from the carrier and lowered onto its legs over the inner frame. Pavers were used as weights on the retaining frames to ensure the seal. The raindeck was leveled by adjusting the length of its legs.

Water was placed in the 20 liter primary supply bucket. The air temperature and other atmospheric conditions were recorded. The vacuum container was placed outside the lowest corner of the frames and the vacuum hoses placed inside the inner frame at the low corner, perpendicular to the pavement surface. The container for the outer frame drip tube was filled with water and engaged. The raindeck and vacuum systems were then engaged. During the course of the test the rainceck was adjusted to compensate for uneven rainfall distribution. The outer frame drip system was adjusted to keep the pavement equally wet on both sides of the inner frame. Each test was conducted for a half hour. After the raindeck was disengaged, the vacuum system was allowed to continue operating until more runoff was being collected.

cylinder for measurement. The liters applied and liters removed were recorded.

4. RESULTS AND DISCUSSION

One hundred eighteen tests were conducted for three rainfall intensity ranges (0-7mm/hour, 7.1-15mm/hour, 15.1-30mm/hour) on the pedestrain plaza and on the vehicular intersection. Eighty-seven tests were conducted on the plaza and thirty-one were conduced on the intersection. The average time between each test on each plot during a two week testing period for the plaza was 12 hours and 22 hours for the intersection. Table 3 lists the characteristics of each site. Tables 4 and 5 show the runoff coefficients for each intensity range.

automobile traffic on the plaza had some effect on decreasing the runoff coefficients when compared to the higher coefficients on the plaza. The lower coefficients measured on the trafficked pavement may have been due in part to the storage capacity caused by the sucking and removal joint sand by automobile tires as well as the low slope (0.7% to 1.3%). The observed speed of automobile, while not measured, appeared to be over 50 kilometers/hour. Speeds over 50 km/hour tend to cause sucking and removal of the joint sand. Sucking may also help maintain a lower density of the joint sand which may increase infiltration. Larger sand particles remaining in the joints subject to lateral forces are not likely to move.

Table 3
Pavement Characteristics

Pavement Characteristics	Plaza	Intersection
Test area	1 sq. m.	1 sq. m.
Block thickness	60mm	80mm
Average joint width	3.11mm	over 3.11mm
Slope range	3.7% - 4.9%	0.7% - 1.3%
Sand thickness	50mm	50mm
Sand gradation	- See Table 1 --	
Base thickness (gravel)	100 - 150mm	300mm
Average time between tests	12 hours	22 hours
Sand drawn out of joints	No	Yes, some
Automobile traffic	None	15,000 - 10,000+ vehicles/day

Table 4
Runoff Data for Plaza
Length of Each Test = 30 Minutes

Rainfall Intensity Range mm/hour	Number of Tests	Average Coefficient	Standard Deviation	r^2 Coefficient *
0 - 7	31	.510	.150	0.27
7.1 - 15	29	.633	.099	0.04
15.1 - 30	27	.794	.091	0.22
for all ranges		.639	.120	0.54

Table 5
Runoff Data for Intersection
Length of Each Test = 30 Minutes

Rainfall Intensity Range mm/hour	Number of Tests	Average Coefficient	Standard Deviation	r^2 Coefficient *
0 - 7	12	.130	.098	0.002
7.1 - 15	9	.418	.226	0.47
15.1 - 30	10	.660	.112	0.14
for all ranges		.385	.145	0.73

*Regression of rainfall intensity and runoff coefficient

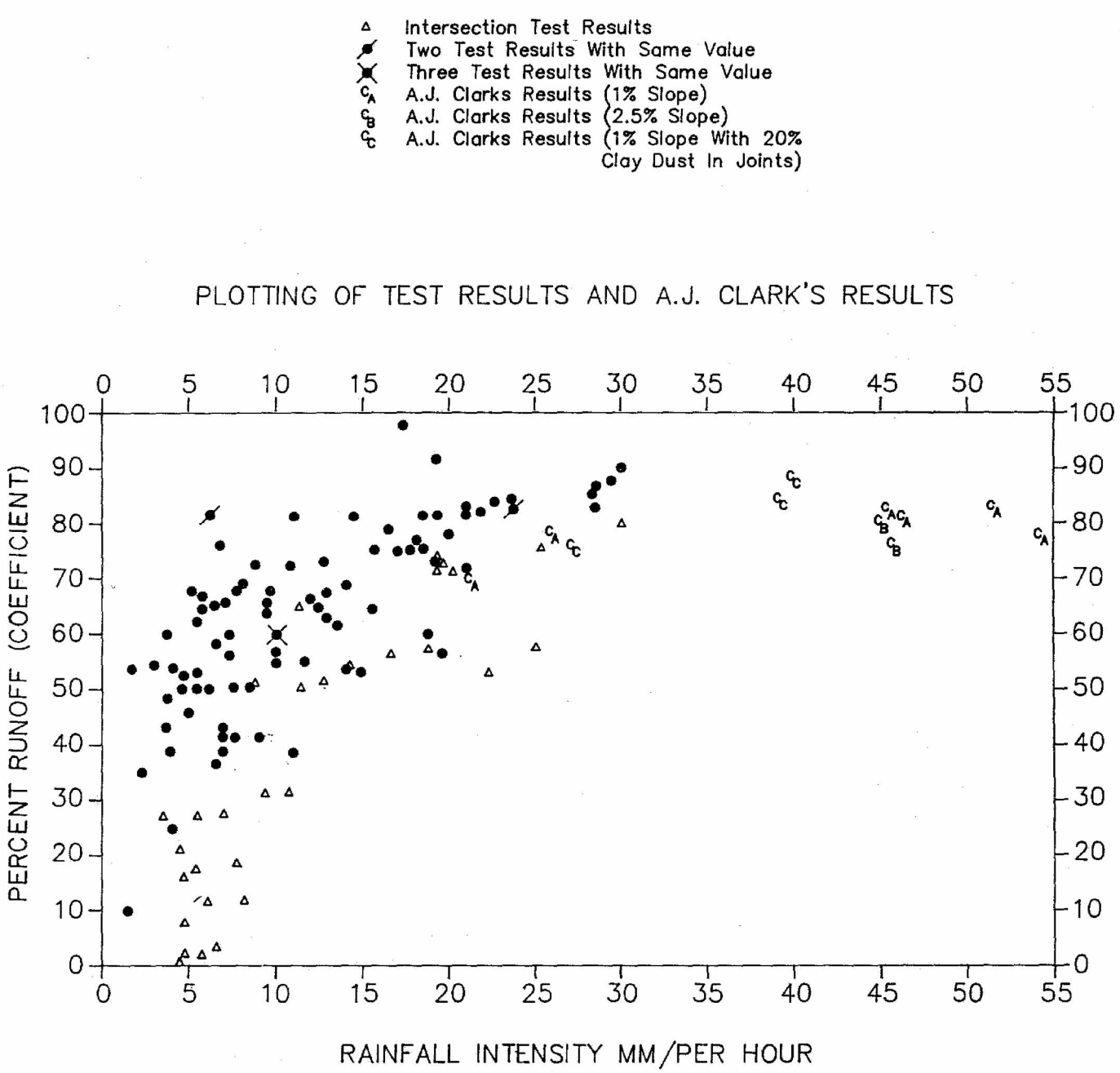


Figure 8 - Plot of Test Results Compared to Plot of Data from Clark's Tests

Figure 8 charts the results from this study and Clark's which was on 3 sq. meters of newly laid pavement on 1% and 2.5% slopes. Most of the rain intensities used in Clark's test were higher than 30mm/hour. Three of the resultant runoff coefficients in Clark's study are close to the coefficients generated by the 15-30 mm/hour intensity range.

5. CONCLUSIONS

1) The runoff coefficient for CBP increases with increasing rainfall intensity (from 0-5 mm/hour). CBP does not exhibit a constant coefficient at varying intensities like asphalt or poured concrete pavements. Therefore, drainage calculations should account for this, especially when dynamic runoff models are used for sizing storm sewers in large areas of CBP.

2) Since runoff coefficients increased with rainfall intensity, CBP may reduce the "first-flush" effect, i.e., the washing of pollutants into the drainage system that occurs in the first 30 minutes of the storm. The

the "first=flush" is often higher than raw domestic sewage. This "first-flush" often flows directly into streams and lakes that are sources of drinking water and for recreation.

3) CBP placed on a sand and gravel base, trafficked by automobiles, does not always have the joints fill over time with detritus (generating a high runoff coefficient). The sealing action of sediment and detritus in the joints may be negated or even reversed by the sucking and pumping action of automobile tires on the CBP.

4) Clark's results are logical continuation of the runoff coefficients from this study, even with the longer rainfall periods used by Clark (48-90 minute versus 30 minute periods in this study).

5) For the purposes of drainage design, a runoff coefficient of 0.80 is recommended for drainage calcuations based on rain intensities of 30 mm/hour to 50 mm/hour. This runoff coefficient is suggested for pavers on a sand bed and compacted gravel base, and does not apply to pavers placed on asphalt or concrete bases. This is lower than the 0.95 to 1.00 recommended for asphalt or concrete.

6) Spacer bars on pavers are experiencing increased use, especially with mechanical installation. Spacer bars could be extended to as much as 5-6mm, to lower runoff while maintaining interlock. This may increase infiltration and should be studied further. Sand gradation should transfer loads while allowing water to flow downward through the joints.

7) Further studies should explore the differences in runoff coefficient in relation to paver shape, percent of open area and total joint length.

(1) Thelen, E., Grover, W.C., Haiburg, A.J., Haigh, T.I., Investigation of Porous Pavements for Urban Runoff Control, the Franklin Institute Press, Philadelphia, Pennsylvania, U.S.A., 1973.

(2) Smith, David R., "Evaluation of Concrete Grid Pavements in the United States, in the Proceedings of the Second International Conference on Concrete Block Paving, Technical University of Delft, Delft, the Netherlands, April, 1984, pp. 330-336.

(3) Clark, A.J. "Water Penetration through Newley Laid Concrete Block Paving", Cement and Concrete Association of England, Wexham Springs, Technical Report No. 529, 1985.