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Portland Cement Pervious Concrete: A Field Experience from Sioux City

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Abstract: Portland Cement Pervious Concrete (PCPC) is becoming more utilized across the U.S. due to increased requirements for stormwater management. This paper details the experience of the installation of a PCPC test section/parking area in Sioux City, Iowa. In order to evaluate a large number of mixture designs, the test section incorporated five different mixtures, each placed with and without air entraining agent, for a total of ten sections. Cylinder samples were prepared during construction and compared with core data. The samples were tested for void ratio, permeability, unit weight, compressive strength development with time, and spatial distribution of material properties across the pavement profile. The results show a high degree of variability in material properties between the top and bottom layers, especially in the bottom five cm (two in.). Strong relationships between unit weight, permeability, strength, and void ratio suggest that void ratio criteria determined from unit weight testing has the potential for use as QA/QC criteria for pervious concrete field placement.

INTRODUCTION

Portland Cement Pervious Concrete (PCPC) pavement has been in use for over 30 years in the United States, and an experimental road was constructed in England in the 1960's [1, 2]. PCPC has seen widespread use in Europe and Japan, although not for stormwater improvements. Some highways use a surface course of PCPC to improve skid resistance and reduce traffic noise [3]. Recently, PCPC applications have been extended to cold climate regions, such as Iowa.

The primary utilization for PCPC in the United States (U.S.) is for stormwater benefits. Current PCPC is most often used in the U.S. for parking lots and recreational pathways and, more increasingly, low-volume roads [4]. Parking lot applications allow stormwater to infiltrate, and reduce or eliminate the need for additional control structures, such as retention ponds. The large internal surface area of the pervious concrete system catches a majority of the pollutants in the stormwater and allows microbes to naturally reduce the concentration. Instead of accumulating in nearby surface waters, the pollutants are degraded or trapped in the pavement system, thereby increasing overall water quality. Other uses include tree grates in sidewalks and hydraulic erosion control structures. In this paper, the field experience of a PCPC project conducted by a local ready mixture company at Sioux City, Iowa is summarized. The field placement and quality control tests are discussed and recommendations are proposed for the future improvement of pervious concrete projects.

PROJECT SITE DESCRIPTION

The project was located in Sioux City on the western side of Iowa and was placed on September 28, 2005. The test site consisted of an 46 cm (18 in.) deep drainable aggregate base and PCPC slab dimensions of 3 m (10 ft.) wide by approximately 40 m (130 ft.) long, with a 46 cm (8 in.) pavement thickness. Once completed, the site was intended for heavy vehicle storage which resulted in the increased pavement thickness above the standard 15 cm (6 in.) depth. Placement occurred in one 46 cm (8 in.) lift. The pavement was placed by a rear-discharge ready mixed concrete truck and leveled to an elevation slightly above the forms. A hydraulic roller-screed was used for compaction and finishing operations. Immediately following the roller-screed, a standard white-pigmented curing compound was applied and the surface was covered with plastic for seven days. The temperature at the time of placement ranged from 4ºC to 16ºC (40ºF to 60ºF) and the average wind speed was over 16 kph (10 mph), the low temperature during the first night was below freezing. Over the first seven days, the average high temperature was 26ºC (80ºF) and the average low of 11ºC (52ºF), with an average relative humidity of 67%.

MIXTURE DESIGN DEVELOPMENT

The mixture designs were based on research results from Iowa State University (ISU), presented by Kevern [5]. To evaluate a large number of concrete mixtures, five different mixture designs were used, both with and without air entrainment, for a total of 10 different mixtures. Of the ten mixtures, six were similar proportions to published ISU mixtures, with the exception of slag and fly ash replacement for cement. Two more of the mixtures were similar in proportion to ISU mixtures with the exception of slag and fly ash replacement for cement and crushed quartzite aggregate instead of river gravel. The final two mixture designs were provided by the Nebraska Concrete and Aggregate Association.

The project used two sizes of narrowly graded pea gravel (#4PG and 3/8PG) and one gradation of crushed quartzite, with the majority of the aggregate passing the 12.7 mm (½ inch sieve) (P1/2QTZ). The river gravel had a specific gravity of 2.62 and absorption of 1.7%. The quartzite had specific gravity of 2.7 and absorption of 1.1%.

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Table 1. Mixture Proportions

Mixture Identification	Coarse Aggregate	Sand	Cementitious Binder				
			PC	GGBFS	FA	H_20	w/b
	kg/m³ (pcy)	kg/m³ (pcy)	kg/m³ (pcy)	kg/m³ (pcy)	kg/m³ (pcy)	kg/m³ (pcy)	
#4PG[A]-B21-SL19-FA7	900 (2600)	-	140 (400)	40 (100)	10 (40)	60 (160)	(0.29)
#4PG-B21-SL19-FA7	900 (2600)	-	140 (400)	40 (100)	10 (40)	60 (160)	(0.29)
P1/2QTZ[A]-B22-SL-29-FA7-S5	860 (2470)	40 (120)	140 (410)	40 (110)	10 (40)	60 (170)	(0.30)
P1/2QTZ-B22-SL-29-FA7-S5	860 (2470)	40 (120)	140 (410)	40 (110)	10 (40)	60 (170)	(0.30)
3/8PG[A]-B21-SL19-FA7-S7	870 (2500)	60 (170)	150 (430)	40 (110)	10 (40)	60 (180)	(0.31)
3/8PG-B21-SL19-FA7-S7	870 (2500)	60 (170)	150 (430)	40 (110)	10 (40)	60 (180)	(0.31)
3/8PG[A]-B21-FA7-S7	870 (2500)	60 (170)	180 (530)	-	10 (40)	60 (160)	(0.28)
3/8PG-B21-FA7-S7	870 (2500)	60 (170)	180 (530)	-	10 (40)	60 (160)	(0.28)
#4PG[A]-B21-FA7-S7	870 (2500)	60 (170)	180 (530)	-	10 (40)	50 (130)	(0.24)
#4PG-B21-FA7-S7	870 (2500)	60 (170)	180 (530)		10 (40)	50 (130)	(0.24)

The mixtures used a combination of Type I Portland cement, class C fly ash, and ground-granulated blast furnace slag (GGBFS). The admixture combination included a standard mid-range water reducer dosed at 3.3 mL/kg (5 oz/cwt) and a hydration stabilizer dosed at 4 mL/kg (6 oz/cwt) of cementitious material.

The following mixture identifications describe the supplementary cementitious materials included in the test placement; blast furnace slag (SL), and class C fly ash (FA). Table **1** lists the design mixture proportions; an example identification for mixture (P1/2QTZA-B22-SL29-FA7-S5) includes 12.7 mm (½ inch) quartzite aggregate, (A) air entrainment, (B22) 22% binder to aggregate by weight, (SL29) 29% slag by weight of binder, (FA7) 7% fly ash by weight of binder, and (S5) 5% sand by weight of coarse aggregate.

SAMPLE PLACEMENT AND TESTING PROCEDURES

On the day of placement, cylinder samples were placed in three lifts by rodding each layer 25 times and vigorously tapping the side of the cylinder after rodding. The cylinders were 10 cm (4 in.) diameter by 20 cm (8 in.) length and were covered and cured on-site. At 7-days all the cylinders were demolded and triplicate samples tested for compressive strength. The cylinders not tested at seven days were placed in a standard curing room, 22.8ºC ±1.7ºC (73ºF ±3ºF) > 95% R.H., for 21-day and 28-day testing.

At 7-days, 10 cm (4 in.) diameter cores were also taken from the field slab. One set was used to determine compressive strength, according to ASTM C39 [6], and a second set was used for void ratio and permeability analysis. The cores were stored in a standard curing room until compressive strength was determined at 28-days time. In order to produce failure surfaces similar to standard concrete specimens, all compressive strength samples were sulfur capped according to ASTM C617 [7]. Core samples for permeability and void ratio analysis were cut horizontally into two halves, 10 cm (4 in.) diameter by 10 cm (4 in.) length top and bottom samples. Void ratio was determined by measuring the displacement of the sample underwater compared with the oven dry weight using the procedure developed by Montes *et al.* [8].

The permeability of the specimens was determined using the falling head permeability test apparatus shown in Fig. (**1**). Flexible sealing gum was used around the top perimeter of a sample to prevent water leakage along the sides of a sample. The samples were then confined in a latex membrane and sealed in a rubber sleeve which was surrounded by adjustable hose clamps. The average coefficient of permeability (k) was then determined following Darcy's law and assuming laminar flow regime.

Fig. (1). Permeameter for PCPC.

Table 2. Results from Samples Placed On-Site

Mixture No.	Mixture ID	Cylinders				
		Voids	Unit weight	7-day fc'	21-day fc'	28-day fc'
		(%)	kg/m^3 (pcf)	MPa (psi)	MPa (psi)	MPa (psi)
1	#4PG^A-B21-SL19-FA7	12.6	2150 (134)	23.7 (3440)	28.1 (4080)	27.2 (3950)
2	#4PG-B21-SL19-FA7	14.9	2120 (132)	22.4 (3250)	30.9 (4480)	36.1 (5230)
3	P1/2QTZ^A-B22-SL-29-FA7-S5	27.9	1830 (114)	11.1 (1620)	13.9 (2020)	13.2 (1910)
4	P1/2QTZ-B22-SL-29-FA7-S5	28.1	1850 (115)	14.3 (2080)	16.5 (2400)	15.7 (2280)
5	3/8PG^A-B21-SL19-FA7-S7	11.6	2280 (142)	21.6 (3140)	49.1 (7120)	47.8 (6930)
6	3/8PG-B21-SL19-FA7-S7	13.9	2160 (135)	27.3 (3960)	35.7 (5180)	32.0 (4640)
7	3/8PG^A-B21-FA7-S7	12.4	2230 (139)	23.9 (3460)	41.3 (5980)	26.6 (3860)
8	3/8PG-B21-FA7-S7	17.0	2100 (131)	16.7 (2420)	16.2 (2360)	20.6 (2990)
9	#4PG^A-B21-FA7-S7	14.9	2120 (133)	24.1 (3490)	30.1 (4360)	27.7 (4010)
10	#4PG-B21-FA7-S7	5.0	2310 (144)	25.0 (3630)	44.9 (6510)	55.0 (7980)

* All values represent average of triplicate testing

Table 3. Results from Core Samples

Mixture No.	Mixture ID	Cores		
		Voids	Unit weight	28-day fc'
		%	kg/m^3 (pcf)	MPa (psi)
1	#4PG^A-B21-SL19-FA7	24.4	1870 (117)	8.1 (1180)
2	#4PG-B21-SL19-FA7	30.3	1790 (112)	10.2 (1490)
3	P1/2QTZ^A-B22-SL-29-FA7-S5	36.1	1650 (103)	4.4 (630)
4	P1/2QTZ-B22-SL-29-FA7-S5	35.4	1670 (104)	6.4 (930)
5	3/8PG^A-B21-SL19-FA7-S7	11.4	2200 (138)	30.1 (4370)
6	3/8PG-B21-SL19-FA7-S7	29.6	1850 (116)	10.5 (1520)
7	3/8PG^A-B21-FA7-S7	28.0	1920 (120)	7.3 (1060)
8	3/8PG-B21-FA7-S7	18.4	2100 (131)	14.7 (2140)
9	#4PG^A-B21-FA7-S7	22.4	1950 (122)	14.3 (2070)
10	#4PG-B21-FA7-S7	8.5	2220 (139)	16.8 (2430)

RESULTS AND DISCUSSION

The results from test cylinders are shown in Table **2**. The mixture designs which contained air entraining agent are identified with a superscript "A" in the aggregate designation. Water-permeable voids ranged from 5.0% for the small-sized rounded pea gravel to 28.1% for a mixture containing larger crushed quartzite. Correspondingly, the unit weight and compressive strengths were highly variable with unit weight ranges of 1829 kg/m^3 (114.2 pcf) to 2305 kg/m^3 (143.9 pcf) and compressive strength between 11.1 kPa (1616 psi) and 55.0 kPa (7,975 psi) although, the extremely high strength cylinders were not permeable on the order required for stormwater management, >30 cm/hr (12 in./hr).

Core sample results are reported in Table **3**; due to the coring schedule, only 28-day compressive strength was tested. Core sample voids ranged from 8.5% to 36.1%. Unit weight values ranged from 1647 kg/m^3 (102.8 pcf) for the highest void ratio sample to 2223 kg/m^3 (138.8 pcf) for the lowest void ratio sample. Core sample compressive strength values follow a similar trend with the highest strength produced from the lowest void ratio. It was observed that the cores containing voids above 25%, when tested for compressive strength, failed solely through the paste fraction, while

Table 4. Permeability Results for Core Samples

Mixture No.	Mixture ID	Location	k	Voids	Unit Weight
			cm/hr (in/hr)	(%)	kg/m³ (pcf)
1	#4PG[A]-B21-SL19-FA7	Top	1836 (723)	27.0	1850 (116)
		Bottom	2484 (978)	30.4	1790 (112)
2	#4PG-B21-SL19-FA7	Top	2591 (1020)	29.9	1800 (113)
		Bottom	7236 (2849)	35.2	1700 (106)
3	P1/2QTZ[A]-B22-SL-29-FA7-S5	Top	7991 (3146)	35.5	1670 (104)
		Bottom	13320 (5244)	42.1	1520 (95)
4	P1/2QTZ-B22-SL-29-FA7-S5	Top	6335 (2494)	35.3	1680 (105)
		Bottom	10655 (4195)	40.1	1560 (97)
5	3/8PG[A]-B21-SL19-FA7-S7	Top	0 (0)	13.9	2160 (135)
		Bottom	8 (3)	18.3	2080 (130)
6	3/8PG-B21-SL19-FA7-S7	Top	719 (283)	35.5	1700 (106)
		Bottom	7559 (2976)	38.7	1590 (99)
7	3/8PG[A]-B21-FA7-S7	Top	1331 (524)	25.3	1950 (121)
		Bottom	4247 (1672)	32.8	1770 (110)
8	3/8PG-B21-FA7-S7	Top	122 (48)	16.3	2150 (134)
		Bottom	1440 (567)	25.2	1940 (121)
9	#4PG[A]-B21-FA7-S7	Top	145 (57)	19.4	2010 (125)
		Bottom	2268 (893)	27.4	1850 (116)
10	#4PG-B21-FA7-S7	Top	0 (0)	11.8	2170 (135)
		Bottom	3 (1)	13.6	2120 (132)

the samples with voids below 25% failed more often through the aggregate.

Data presented in Table **4** show the test results for the top and bottom portions of the core samples. Each sample was divided into top and bottom portions to determine variability across the slab profile. In all cases the unit weight was higher in the top portion due to surface compaction, producing lower voids and permeability. Generally, the river gravel mixtures that contained slag had less vertical variability in void ratio than the river gravel mixtures which only contained cement and fly ash. The average difference in void ratio between the top and bottom was 4.1% for mixtures containing slag and 6.6% for those mixtures without slag.

COMPARISON OF TEST RESULTS FROM FIELD PLACED AND CORE SAMPLES

Comparing the 28-day compressive strength results from the cylinder samples placed at the site (Table **2**), with the core samples taken from the site (Table **3**), the cylinders placed on-site produced higher compressive strength and lower voids than the corresponding core samples. The difference in compressive strength is likely due to higher compaction levels in the cylinder placement versus the *in-situ* conditions. This can be attributed to a lack of placing experience and lack a standard placing procedure. The cylinders placed on site had a large variation in the strength values, with an average difference between the highest compressive strength and lowest compressive strength being 11.7 MPa (1,692 psi). The highest strength cylinder samples often did not occur at 28-days, indicative of variability in cylinder specimens.

Fig. (**2**) shows a typical core specimen where, even visually, concrete in the region close to the slab surface was denser than the concrete near the bottom of the sample. The core samples generally had a higher void ratio than the field placed cylinders. The non-uniform compaction of the field pavement may be the major cause of the low strength of the field core samples which was placed in a single lift. As a result, two-lift PCPC construction/compaction may be required to improve the field uniformity and strength of thick > 15 cm (6 inches) pervious pavement.

Fig. (**3**) shows that for the cylinders and the core data, unit weight decreased linearly with increased void ratio. The best fit lines show good agreement with R^2 greater than 0.95. This strong relationship between PCPC unit weight and voids obtained from the field samples is also consistent with that of previous lab studies [9, 10]. These results indicate that the sample unit weight test can be used as a PCPC quality control (QC) test for prediction of voids.

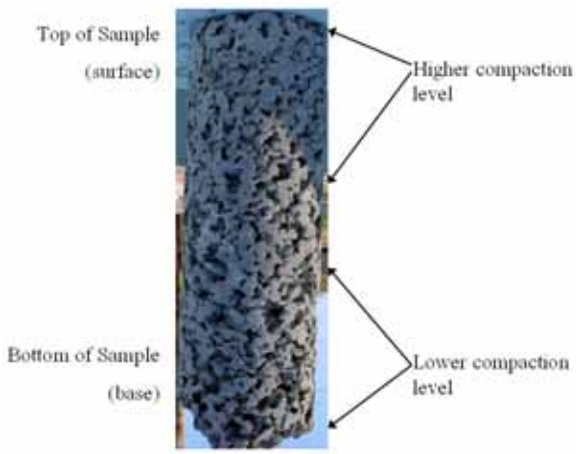

Fig. (2). Void distribution across a core sample.

The maximum and minimum compressive strength values obtained from field placed cylinder samples represent the total variability of the QC samples. When the maximum, minimum cylinder strength data and core compressive strength data from the 28-day tests are plotted against the void ratio (Fig. **4**), the best fit line for the field-placed cylinder data are greater than that for the core samples. Since the lowest strength hand-placed cylinder samples were stronger than any core samples, the standard rodding technique produced a greater level of densification than typical field compaction activities. The best fit line for the lowest field placed compressive strength cylinders have similar slope values to the core samples, as seen in Fig. (**4**). The large difference between cylinder strength values, within each mixture and curing age, suggests that compressive strength data from cylinders taken at the site is more sensitive than that of normal concrete due to the lack of a standard placing technique.

Since there was a visual difference in void ratio from the top to the bottom of the samples (Fig. **2**), the core samples were divided into two groups based on their locations, either from the top or the bottom of the slab. Void ratio, unit

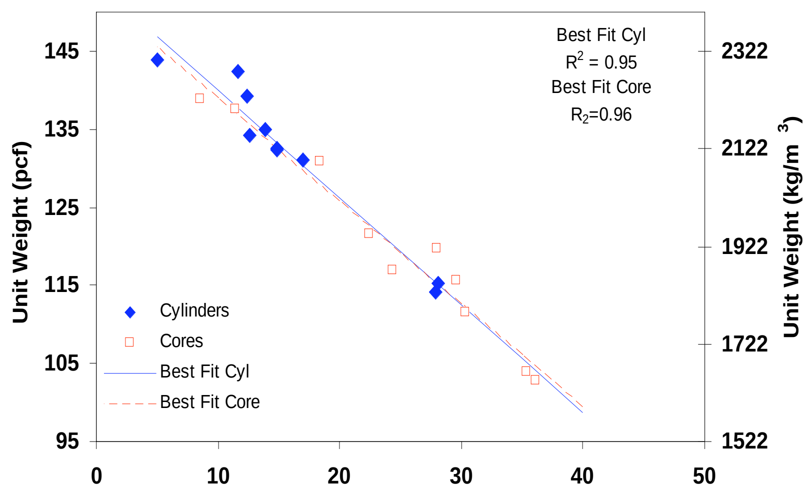

Fig. (3). Relationship between unit weight and void ratio.

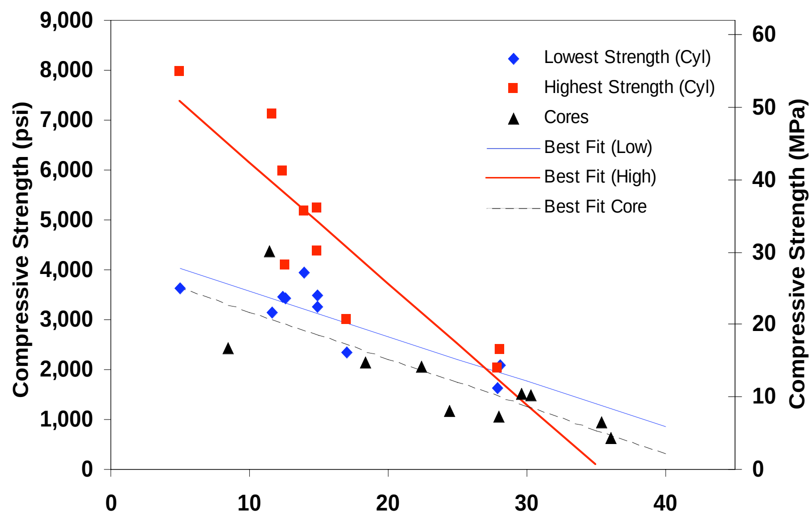

Fig. (4). Relationship between compressive strength and void ratio.

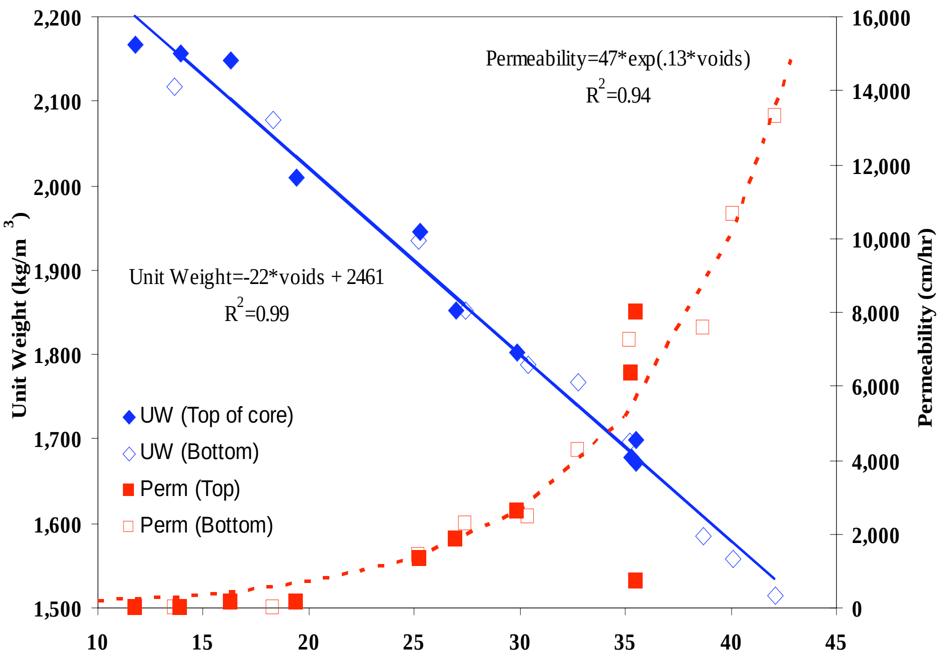

Fig. (5). Relationship between unit weight, permeability, and void ratio.

weight, and permeability were performed for each group of samples. It was observed that the void ratio of the bottom samples increased by an average of 5.8% across the slab, although the increase ranged from 2% to 9% depending on mixture workability. The increase in void ratio caused an average decrease in unit weight of 128 kg/m^3 (8 pcf), ranging from 48 kg/m^3 to 208 kg/m^3 (3 pcf to 13 pcf). The permeability increased an average of 500%, although the lower surface permeability value would control the infiltration rate. Fig. (**5**) illustrates the relationship between unit weight, permeability, and void ratio for both the top and bottom core samples. The trends of unit weight decreasing linearly with void ratio and permeability increasing exponentially are consistent with the previous finding from the PCPC placed and tested in the laboratory [11]. The results in Fig. (**5**) show that the bottom sample data points have higher permeability and lower unit weight than the data points from the top of the slabs.

CONCLUSIONS AND RECOMMEDATIONS

The following conclusions and recommendations are drawn from the Sioux City field test results.

1. Unit weight decreased linearly with void ratio and permeability increased exponentially with void ratio. Because unit weight is a simple and reliable test method, it can be used as a PCPC quality control test in the field to predict void ratio.
2. The level of field PCPC compaction varied along the pavement profile, with the highest compaction at the surface and the lowest compaction near the base. As a result, two-lift construction and compaction may be required or more compactive effort may need to be exerted in the field to improve PCPC pavement uniformity and strength of thicker placements.
3. The overall void ratio of field core samples was much higher than that of field placed cylinder samples. Also, the lack of standard procedures for PCPC cylinder sample preparation (compaction) resulted in a large variation in strength test results as well as a large difference in the compressive strength from the field core samples. A standardized cylinder placement technique should be developed to produce void ratios which correlate with *in-situ* pavement.

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