Hitting the Mark

A case study of a pervious concrete quality assurance program

BY JOHN T. KEVERN AND JEREME MONTGOMERY

Research and experience have shown that pervious concrete mixtures proportioned to have 15 to 25% air void contents should have sufficient infiltration rates to limit storm water surface runoff and adequate strength to avoid raveling.[1] Until recently, however, there were no U.S. standards for the verification of air void content in fresh concrete or infiltration rates for in-place concrete. To help producers, contractors, and owners verify that their pavement projects will perform as needed, ASTM Committee C09.49, Pervious Concrete, has recently introduced Standard C1688, "Standard Test Method for Density and Void Content of Pervious Concrete"[2] and Standard C1701, "Standard Test Method for Infiltration Rate of Pervious Concrete."[3] These standards were used as part of the quality assurance program for the construction of a parking lot at the Metropolitan Community College (MCC) in Omaha, NE.

Using test placements to develop a compaction-density relationship, appropriate mixture properties could be defined without guesswork. Workability tests and unit weight tests per ASTM C1688 were used to screen loads to ensure that we placed only workable concrete that could be consolidated to achieve a target air void content.

UNIT WEIGHT AND AIR VOID CONTENT

Pervious concrete typically comprises a zero slump mixture with little to no fine aggregate and uniformly graded coarse aggregate. The workability of such mixtures can be highly sensitive to variations in moisture content and compaction effort, leading to large variations in the final void contents for a given pavement project. By mixing trial batches for the contractor to use in test placements of pavement, the producer can obtain unit weight data per ASTM C1688 and air void content V_{air} (in %) from cylindrical samples according to the procedure in Reference 4. V_{air} is given by

$$V_{air} = [1 - (W_D - W_S)/(\gamma_W \cdot V_T)] \times 100 \qquad (1)$$

where W_D is the weight of the oven-dried sample, W_S is the submerged weight of the sample (after tapping to release trapped air), γ_W is the unit weight of water, and V_T is the calculated volume of the sample using its measured diameter and length.

For the MCC project, six mixtures were prepared and samples were produced per ASTM C1688 during placement of the preliminary test panels (Fig. 1). Unit weight and air void content for each mixture were measured and plotted, and a linear regression analysis was used to determine the relationship between air void content and unit weight (Fig. 2). As one might expect, there is a linear relationship between void content and unit weight of pervious concrete mixtures, with a maximum unit weight (about 150 lb/ft^3 [2400 kg/m^3]) associated with zero air void content.

It must be noted that the ASTM C1688 procedure (filling a 0.25 ft^3 [7 L] cylindrical container in two lifts, with each lift consolidated using 20 blows from a standard Proctor hammer) will not produce the same air void content as would be produced in pavement. Our preliminary field determination for cores removed from the test panels indicated that a mixture with an air void content of 12% and unit weight of 133.5 lb/ft^3 (2140 kg/m^3) when tested per ASTM C1688 would have an in-place air void content (found per Eq. (1) using core sample data) of 17.5%. This in-place value was specified for the project.

QUALITY ASSURANCE PROGRAM

The owner recognized pervious concrete as a new product and thus made it very clear that, regardless if the

Fig. 1: To determine unit weight per ASTM C1688, concrete is consolidated using a Proctor hammer

product was successful or not, "we need to know why." The team was therefore expected to implement procedures within a set quality control program, including:

- Aggregate moisture tests conducted by the concrete producer before batching operations;
- Unit weight tests per ASTM C1688 conducted at the batch plant by the producer and at the job site on every load of concrete;
- Inverted slump cone tests (described in the following section) conducted at the job site by the owner's testing agency;
- Estimated unit weight test (described in the following section) conducted on site by the owner's testing agency;
- Unit weight tests (five total) using 4 in. (100 mm) diameter cores taken from the hardened pavement and tested using the procedure described in Reference 4 by the owner's testing agency; and
- Permeability tests (six total) per ASTM C1701, taken at the core locations (prior to coring) by the owner's testing agency (Fig. 3).

UNIQUE TEST PROCEDURES

Inverted slump cone test

The inverted slump cone test is qualitative, but it allows a rapid evaluation of workability. The procedure involves resting the small opening of a slump cone against a smooth, hard surface. The cone is then filled with fresh concrete in one lift, with no consolidation. Excess concrete is struck off, level with the large end of the cone, and the cone is then lifted. The fresh concrete is observed as it flows out of the cone. If the bulk of the concrete remains in the cone and can only be discharged by vigorous shaking of the cone, the mixture will be unworkable. Figure 4 shows two different mixtures after discharge. The concrete in Fig. 4(a) was discharged after tapping of the cone—the batch was remediated by increasing the water content. The concrete in Fig. 4(b) flowed freely from the cone and was approved for placement.

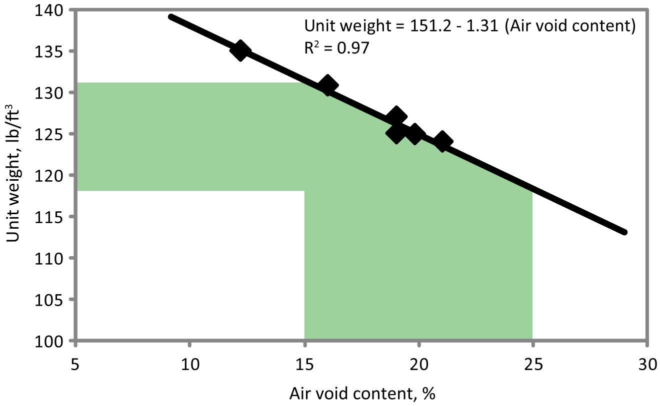


Fig. 2: Unit weight and air void content values for preliminary test panel concrete batches, measured per ASTM C1688. Note: 1 lb/ft³ = 16 kg/m³

Estimated in-place unit weight

In this procedure, a 0.25 ft³ (7 L) cylindrical container is filled with fresh concrete in one lift, with no consolidation. Excess concrete is struck off, level with the top of the container. The net weight of the concrete is determined and the unit weight of the test sample is calculated. The resulting value is multiplied by a compaction factor, which is based on observations that typical consolidation methods lead to a 1 in. (25 mm) reduction in thickness relative to the initial placement depth. Thus, for the 6 in. (150 mm) thick pavement required on this project, the compaction factor was 7 in./6 in. = 1.17. Estimated unit weight values were correlated with specific regions of the in-place pavement.

APPLICATION

Placement

The pervious concrete pavement was placed by directly discharging the concrete from mixer trucks onto an aggregate base. Concrete was raked into place and consolidated and finished using a hydraulic roller-screed operating directly on top of side forms. As per ACI 522.1-08, the concrete was covered with a polyethylene sheet immediately after finishing.[5]

The 5650 ft² (525 m²) paved area required 110 yd³ (84 m³) of concrete, which was delivered in 14 truckloads. Most of the placement was completed in 2 days, during which the average ambient temperature was 65°F (18.5°C) and the relative humidity was 70%.

Inverted slump testing showed that the first truck was not workable and additional water was added until the concrete had about 12% air void content as measured per ASTM C1688. The second truck had too much water added at the concrete plant and was held until the concrete had about 12% air void content per ASTM C1688. The water content for the third truck was acceptable, so concrete from this truck was placed while the second load was being held. Tests of subsequent loads indicated they also had acceptable water contents.

Pavement sections were installed with no reports of consolidation or finishing problems. Workers with previous experience with pervious concrete pavements reported, however, that the mixtures would have been considered too "wet" if evaluated by visual inspection only.

Fig. 3: Infiltration rate testing per ASTM C1701

Fresh and hardened properties

ACI 522.1-08 Section 1.6.2.1 requires that the unit weight of fresh concrete is within ±5 lb/ft^3 (±80 kg/m^3) of the specified fresh unit weight. ACI 522.1-08 Section 1.6.5.2.1.b requires that the unit weight of the hardened concrete is within ±5% of the approved hardened unit weight measured in test panels.

As indicated previously, the specified in-place air void content was 17.5%. Extending ACI 522.1-08 in-place density requirements to air void content, the allowable range would be from 12.5 to 22.5%. Air void contents measured using cores ranged from 13.4 to 21.6%—well within the allowable range. A comparison between estimated and in-place void contents is shown in Table 1. Even though the estimated in-place unit weight test is highly operator dependant, the mean of the test results was within 3% of the mean of the values measured using cores (Fig. 5).

Table 2 compares the air void contents of the fresh concrete (measured using ASTM C1688) and hardened concrete (measured using core samples). For all five cores, the void contents measured per ASTM C1688 were lower than the void contents found using the core samples.

Figure 6 shows the general relationship between void contents, as determined per ASTM C1688, and permeability, as determined per ASTM C1701. Permeability tests were not performed directly on the cores, as that ASTM standard is under development. Because the same equipment and methods were used to consolidate all pavement sections, Fig. 6 implies that initial workability, which influences compaction, also influences hardened permeability. The largest infiltration rate measured per ASTM C1701 was 2016 in./hour (51,200 mm/hour) and the lowest was only 62 in./hour (1600 mm/hour). While our observation of an exponential increase in permeability with increased void content is consistent with observations made by others, the multi-operator reproducibility of the test method is under evaluation.[1,6]

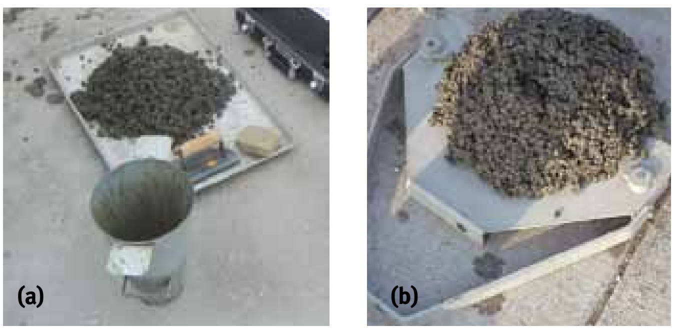


Fig. 4: Discharged concrete after inverted slump cone tests: (a) nonworkable mixture; and (b) workable mixture

TABLE 1: Estimated in-place and core sample air void contents

Estimated in-place air void content, %	Core sample air void content, %	Difference between estimated and core sample air void content, %	Estimated in-place unit weight, lb/ft^3
14.5	13.4	1.1	132.8
16.5	18.9	−2.4	128.6
17.5	15.8	1.7	129.5
19.5	13.8	5.7	133.1
18.0	21.6	−3.6	125.1

Note: 1 lb/ft^3 = 16.018 kg/m^3

TABLE 2: Air void contents for fresh (per ASTM C1688) and hardened concrete mixtures

Air void content			Unit weight
Fresh concrete per ASTM C1688, %	Hardened concrete data (from cores), %	Difference between fresh and hardened concrete, %	Fresh concrete values per ASTM C1688, lb/ft^3
13.0	13.4	−0.4	134.6
11.5	18.9	−7.4	136.7
15.1	15.8	−0.7	130.8
12.9	13.8	−0.9	133.5
16.6	21.6	−5.0	127.5

Note: 1 lb/ft3 = 16.018 kg/m3

INDICATIONS

Our work for the MCC pavement project (Fig. 7) indicates that:

- Air void and unit weight tests per ASTM C1688 can be used to predict in-place air void content;
- The inverted slump cone test is a good predictor of mixture workability and provides a rapid method for culling mixtures that will have unacceptably low unit weights; and
- A requirement that the in-place unit weight is within ±5% of the specified unit weight (as per ACI 522.1-08) is appropriate and achievable.

For workable mixtures that passed the inverted slump cone test, estimated in-place unit weights correlated well with measured in-place air void contents. Mixtures that met the specified unit weight of 133.5 lb/ft^3

(2140 kg/m^3) were very workable, although they might have been considered too "wet" if evaluated by visual inspection only.

Fig. 5: Core tests were taken to verify density of in-place concrete

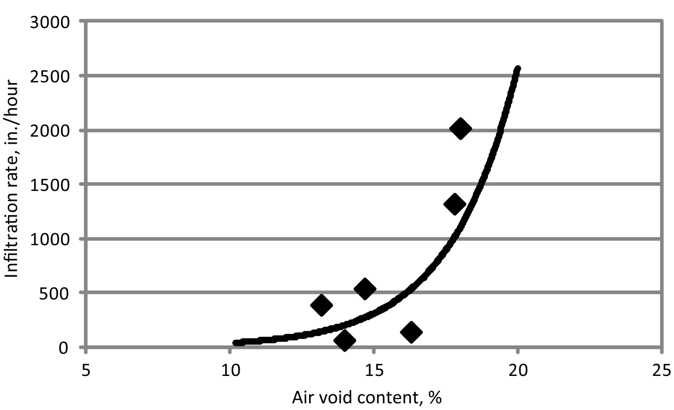


Fig. 6: Infiltration rate as a function of air void content. Note: 1 in. = 25.4 mm

Fig. 7: View of completed pavement

PROJECT CREDITS

Owner: Metropolitan Community College
Designer: HDR, Inc.
General Contractor: Sampson Construction
Concrete Producer: Consolidated Concrete, LLC
Concrete Contractor: AVAS Construction Company, Inc.
Testing Agency: Thiele Geotech, Inc.

References

1. Schaefer, V.R.; Wang, K.; Suleiman, M.T.; and Kevern, J., "Mix Design Development for Pervious Concrete in Cold Weather Climates," A Report from the National Concrete Pavement Technology Center (CP Tech Center), Iowa State University, Ames, IA, 2006, 85 pp (available at www.ctre.iastate.edu/reports/mix_design_pervious.pdf).

2. ASTM C1688, "Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete," ASTM International, West Conshohocken, PA, 2008, 3 pp.

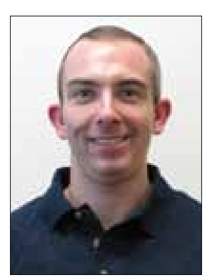
3. ASTM C1701, "Standard Test Method for Infiltration Rate of In Place Pervious Concrete," ASTM International, West Conshohocken, PA, 2009, 3 pp.

4. Montes, F.; Valavala, S.; and Haselbach, L.M., "A New Test Method for Porosity Measurements of Portland Cement Pervious Concrete," *Journal of ASTM International*, V. 2, No. 1, ASTM International, West Conshohocken, PA, 2005, 13 pp.

5. ACI Committee 522, "Specification for Pervious Concrete Pavement (ACI 522.1-08)," American Concrete Institute, Farmington Hills, MI, 2008, 7 pp.

6. Kevern, J.T.; Schaefer, V.R.; and Wang, K., "Predicting Performance of Pervious Concrete using Unit Weight," *Proceedings of the 2009 NRMCA Concrete Technology Forum,* Cincinnati, OH, 2009, 11 pp.

Selected for reader interest by the editors.



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