A Review

Of

National Concrete Pavement Technology Center, Iowa State University
Final Report, February 2006

"Mix Design Development for Pervious Concrete in Cold Weather Climates"

Presented to
VRMCA Technical Committee

The following is a summary of key elements and conclusions of the materials property requirements for pervious pavements as determined in research at the National Concrete Pavement Technology Center at Iowa State University. The summations herein are intended for education and discussion purposes for the VRMCA Technical Committee and any interpretations of the writer are based on a thorough review of the referenced research paper but may not necessarily reflect the full extent of the reported work. A PDF file of the full report can be obtained at www.ctre.iastate.edu. search "pervious". A copy of the Executive Summary from the titled report is included as an appendix.

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April 18, 2007

The research reported in the "Mix Design Development for Pervious Concrete in Cold Weather Climates" by the National Concrete Pavement Technology Center, Iowa State University (herby referred to as the Iowa Report) focused on identifying materials, mix proportioning, and mixing procedures that would provide a pervious pavement with sufficient drainability and at the same time have sufficient mechanical properties to be suited to carry the design loadings. Following is a brief synopsis of characteristics that the writer found to be of interest.

<u>Mixing Procedure/cycle and Effect on Paste-Aggregate Bond</u>: In the Iowa work, it was found that differences existed in the paste-aggregate bond based on the batching sequence employed. Dry mixing about 5% of the cement with the aggregate before adding the batch water (and admixtures) improved bond strength compared to a more conventional batch sequence of adding the aggregate + water first then followed by the cement.

<u>Binder-Aggregate Ratio</u>: An optimum binder-aggregate ratio was found to be 0.21. This binder-aggregate ratio can be used to establish the maximum and minimum cement content for a given set of aggregates.

<u>Water-Cement Ratio</u>: An optimum W/C was found to a values of 0.27

<u>Utilization of Fine Aggregate</u>: The introduction of a small quantity of fine aggregate in the mix increases the strength of the pervious concrete.

<u>Void Ratio</u>: The key element controlling the mechanical properties of pervious concrete is the void content.

<u>Compressive Strength & Void Content</u>: Below is a graph from the Iowa Report showing the relationship between the void content and compressive strength.

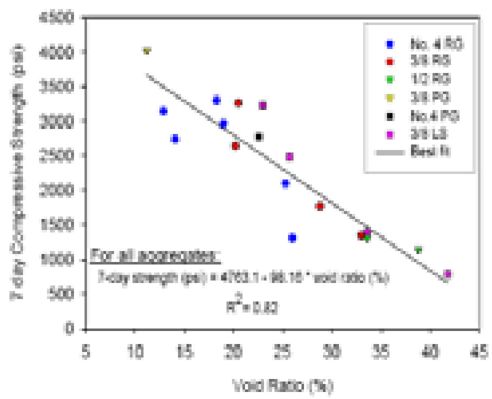

Figure 13. Relationship between void ratio and seven-day compressive strength for all mixes placed using regular compaction energy

As can be seen, there is a reasonably good correlation between the %void content and compressive strength. A void content of from 15% to 20% provided compressive strengths that would correspond to the minimum values that may be used in conventional concrete paving (3000 to 3500 psi).

Void Content & Compacted Unit Weight:

The graph below from the Iowa Report shows the relationship between % void content and compacted unit weight. As would be expected, the void content and unit weight are inversely proportional; as the void content increases the unit weight decreases and conversely as the void content decreases the unit weight increases.

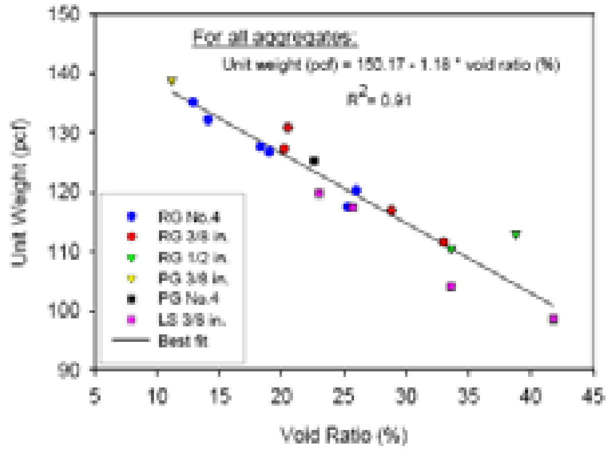

Figure 17. Relationship between unit weight and void ratio for all mixes placed using regular compaction energy

Because of the very strong correlation between unit weight and void content, the unit weight of a pervious concrete can be used as a convenient indirect measure of its void content.

Void Content & Permeability: Figure #18 from the Iowa Report shows the relationship between % voids and the coefficient of permeability (drainability).

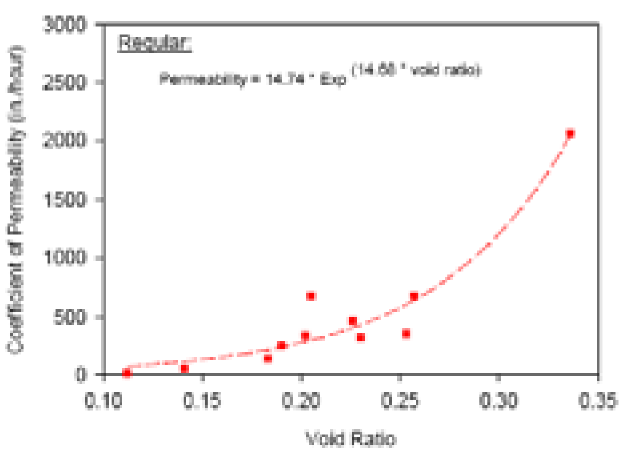

Figure 18. Relationship between pervious concrete void ratio and permeability for all mixes placed using regular compaction energy

As reported, a void content between 15% and 19% will provide a permeability of from 135 inches/hour to 240 inches/hour. These levels of infiltration should be more than adequate to handle any design storm event.

Optimization of Void Content-Unit Weight-Strength-Permeability:

To achieve a satisfactory performance of a pervious pavement the relationship of the void content-unit weight-strength-permeability must be balanced. The Iowa Report shows that **a unit weight in the range of 127 to 132 lbs/cu.ft. is optimum for both strength & permeability.**

Compaction & Freeze Thaw Resistance:

Although other factors contributed to F/T resistance the conclusion of the Iowa Report was that "compaction has an important effect on the PCPC strength and freeze-thaw resistance and needs further investigation."

Strength vs. Age:

Figure 12 from the Iowa Report shows that there is very little strength gain beyond an age of 7-days. Therefore, it must be inferred that both evaluation and acceptance testing should be based on a 7-day strength, not 28-day as would be the case with conventional concrete.

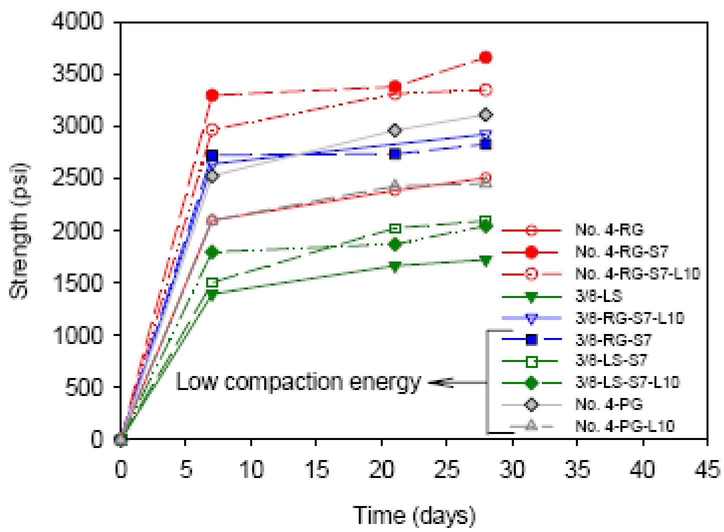

Figure 12. Strength development with time

COMMENARY:

1. **<u>Mix Development/Design</u>**: Although not specifically stated, it can be inferred that the development of a satisfactory pervious mix will be predicated upon achieving a "target" unit weight for the mixture with a given set of materials to provide a void content within the recommended ranges. In order to achieve this, it will be necessary to first establish a standardized means of compaction, which at this time has not been addressed. Nonetheless, pre-construction evaluations of the proposed mixtures should be conducted on the compressive or split tensile strength of cylinders prepared at varying levels of compaction to provide a range of unit weights, from which a unit weight-strength relationship can be established. Then a mix proportion could be selected to achieve both satisfactory strength and drainability.

2. **<u>Unit Weight of Plastic Concrete</u>**: The measurement of the unit weight of the plastic concrete in accordance with ASTM C 29, Jigging Procedure, as suggested by reference 1-3 and the tolerance of +/- 5 lbs/cu.ft. permitted would appear to be of only limited significance. Based on the reported unit weight-strength relationship shown in the Iowa report, the unit weight of the concrete (as place) would have to be controlled within a much greater degree of precision than +/- 5 lbs/cu.ft., perhaps on the order of +/- 2 lbs/cu.ft. or less.

3. **<u>Construction Conformance</u>**: **The most essential key to a successful pervious concrete pavement installation will be to achieve a level of consolidation of the concrete during construction to provide an in-place unit weight commensurate with that determined necessary in the pre-construction testing to provide sufficient strength and drainability.**

4. **<u>CHALLENGES</u>**:

   a. **<u>Unit Weight (density determination):</u>** As cited in the other sources (ref 1,2,3) the in-place density is to be determined based on the testing of core samples in accordance with ASTM C 140. However, the hardened density of a sample of pervious concrete <u>cannot</u> be determined by the "water displacement method". Due to the interconnectivity of the void space within pervious concrete, the test method (either ASTM C 140 or C 642) can only measure density of the solid volume of the concrete sample; i.e. it "air free unit weight". The void content of pervious concrete is so pervasive that a "bulk density" cannot be determined via a water displacement method. (Note in reviewing information from the Florida Concrete & Products Association they likewise reference ASTMC 140, but it can be inferred that they only intend to utilize the 1-minute drain period before determining the specimen weight as described in C 140.

Unit weight calculations are then based on a specimen volume calculated based on measurement of the specimen versus it weight.

b. **<u>SSD Determination</u>**: It is virtually impossible to bring a hardened sample of pervious concrete to a saturated-surface dry condition. The exposed surfaces of the paste & aggregate particles within the interstitial void space will retain a sufficient water film so as to significantly impact any determination of the SSD weight of a sample in air. This fact negates the possibility of accurately determining the density based on a calculated sample volume from specimen measurements vs weight. Therefore, consideration must be given to developing a standard moisture conditioning regimen (such as oven dried) of both pre-construction specimens and cores to be able to accurately determine the in-place density based on a calculated volume of core specimens. (Note, again the FC&PA uses the 1-minute drained condition. However this could result in an artificial increase in the indicated unit weight due to the excess water film present. Although this artificial increase may only account for a calculated increase on the order of perhaps only 2 to 3 lbs/cu.ft. this would be sufficient error to possibly jeopardize the assessment of the void content)

c. **<u>Construction Consolidation</u>**: The ultimate challenge will be to find a test method that can be used to monitor the degree of compaction (unit weight) of the in-place concrete during installation. This is needed to assure that the installation techniques are providing an in-place density within the prescribed range as determined in pre-construction testing.

Other References:

Portland Cement Pervious Manual, Florida Concrete & Products Association, 3030 Dade Avenue, Orlando, FL 32804

Text Reference for Pervious Concrete Contractor Certification, National Ready Mixed Concrete Association, Publication #2PPCRT, 900 Spring Street, Silver Spring, MD 20910.

Mix Design Development for Pervious Concrete in cold Weather Climates, National Concrete Pavement Technology Center, Iowa State University, 800 Lincoln Way, Ames IA 50010.