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Pervious Concrete: Guideline to Mixture Proportioning

NRMCA Engineering Division

National Ready Mixed Concrete Association

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This guideline accompanies a mixture proportioning spreadsheet to assist the user with establishing preliminary proportions for pervious concrete mixtures.

A research report also accompanies this package documenting some of the laboratory work that was used to validate this mixture proportioning guideline

Disclaimer: This mixture proportioning methodology has been experimentally validated for pervious concrete mixtures with portland cement, coarse aggregate and in many cases with hydration stabilizing admixtures. The guideline includes options to use sand as a portion of the aggregate, supplementary cementitious materials and other admixtures. These options have not been experimentally validated. Materials used for concrete vary significantly in various regions. No assurance is indicated that pervious concrete mixture proportions developed by these guidelines will result in an optimum mixture. As with any mixture proportioning procedure, this guideline provides preliminary mixture proportions that must be evaluated and adjusted with trial batches. Test placements with the intended placement tools and methods are also recommended.

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Introduction

Proportioning pervious concrete mixtures is different compared to procedures used for conventional concrete. When developing pervious concrete mixtures, the goal is to obtain a target or design void content that will allow for the percolation of water. The void content of a pervious concrete mixture will depend on the characteristics of the ingredients, how they are proportioned and how the mixture is consolidated. For pervious concrete mixtures it is even more important to verify through trial batches that the mixture achieves the characteristics assumed or targeted when developing mixture proportions. It should not be assumed that the mixture will achieve the target void content in actual mixtures. This should be verified by preparing and testing trial batches. Frequently one finds that even though the design void content is 20%, when the pervious concrete mixture is proportioned the experimentally measured void content is considerably different. This depends on the workability of the mixture and amount of consolidation.

Recently a new test method, ASTM C1688, *Standard Test Method for Density and Void Content of Pervious Concrete,* has been standardized to measure the density and void content of freshly mixed pervious concrete. Efforts continue to determine the density and void content of hardened pervious concrete for core samples that might be obtained from a pavement. It should be realized that the values obtained on a freshly mixed pervious concrete sample using standardized consolidation procedures can be significantly different from that measured on a pavement core. Various methods are used to place and consolidate pervious concrete in pavements. One should not expect equivalence of the measured densities by ASTM C1688 and that in hardened concrete cylinders or cores.

The challenge when proportioning a pervious concrete mixture proportioning is to ensure that when a design void content is targeted, a value that is close to that is attained when measured according to ASTM C1688. The other goal is to achieve an optimum paste of appropriate consistency. The workability of the paste should be tightly controlled with the appropriate amount of water to avoid a mixture that is too dry to prevent placement or too wet that would result in paste runoff (See Figure 3).

In this guideline a methodology to proportion pervious concrete mixtures for an ASTM C1688 design void content and optimum consistency is proposed. These concepts are used in the mixture proportioning spreadsheet that accompanies this document.

Mixture Proportioning Procedure

Pervious concrete is typically designed for a void content in the range of 15 to 30%. Generally as the void content decreases, the strength increases and permeability decreases. The following mixture proportioning approach can be used to quickly arrive at pervious concrete mixture proportions that would help attain void content of freshly mixed pervious concrete when measured in accordance with ASTM C1688 similar to the target value.

Step 1 – Aggregate Properties

- Select the size of coarse aggregate

  For most applications with pedestrian traffic, ASTM C33 No. 8 or No. 89 (nominal max size 3/8 in.) coarse aggregate is used. No. 67 (nominal maximum size ½ in.) or larger size can be used for applications that do not see much pedestrian traffic.

- Obtain or measure the relative density of the coarse aggregate by ASTM C127 and fine aggregate by ASTM C128 (if used).

  This value is needed to calculate the void content and for proportioning by absolute volume.

- Consider using fine aggregate

  While pervious concrete is generally defined as concrete with little or no fine aggregate, the use of sand can provide some advantages by increasing the strength of the mixture and improving its durability in locations with freezing and thawing cycles. Sand can improve how the mixture holds together and makes it easier to entrain air in the paste fraction of pervious concrete to resist freezing and thawing cycles. Use of sand will typically reduce the void content and permeability of pervious concrete but it would still be adequate for storm water design purposes. The sand content can vary from 5 to 10% by weight of the total aggregate.

- Measure the oven dry bulk density (dry rodded unit weight) of the coarse aggregate by ASTM C29. If fine aggregate is used measure the oven dry bulk density of the combined aggregates by ASTM C29.

  When fine aggregate is used it should be in the same ratio as the mixture proportions and must be blended together thoroughly with the coarse aggregate using a scoop or shovel. The void content of the dry-rodded coarse or combined aggregates can be calculated as described in ASTM C29. For coarse aggregates the void content generally varies between 35% to 45% with lower void content for rounded gravel aggregates and higher void content for angular crushed stone aggregates. For combined aggregates the void content typically decreases with increasing amounts of fine aggregate. Coarse aggregates with a higher percent passing the No. 8 is likely to have a higher bulk density and a lower void content as the finer particles tend to fill in the voids between the larger particles.

- Obtain or measure the absorption of the aggregate and the total moisture content prior to batching.

  Monitoring moisture and its control is very critical to obtaining a workable pervious concrete mixture. The total moisture and absorption of the aggregate should be known to ensure that the correct amount of mixing water is added to the mixture during batching. This is similar to conventional concrete, but significantly more critical due to *the low workability and shorter delivery and working time available. It is important to ensure the correct amount of water is added during preliminary mixing to avoid jobsite retempering or waiting for a mix to "dry up".*

Step 2 – Calculate Required Paste Volume of Pervious Concrete

A recommended principle for estimating the required paste volume (*PV*) is as follows:

Required *PV* (%) = Aggregate Void Content (%) + *CI* (%) - Design Void Content (%)

CI = compaction index,
In tests at NRMCA it has been determined that choosing a value of 5% will result in an experimentally (ASTM C1688) measured void content that is close to the design void content.

The value of compaction index can be varied based on the anticipated consolidation to be used in the field. For greater consolidation effort a compaction index value of 1 to 2% may be more reasonable. For lighter level of consolidation a value of 7 to 8% can be used.

A higher value for CI will result in a higher paste volume.

In the experimental results with the laboratory trial batches reported in the accompanying research report CI = 5% was used since the aim was to have the design void content to match the experimentally (ASTM C1688) measured void content.

The use of sand in pervious concrete mixtures has not been evaluated in the research report and a recommended value for CI cannot be made at this point. After a preliminary trial batch is prepared, the paste content of the mixture can be evaluated and changed by the user in the accompanying software as appropriate. Alternatively a different value of CI can be established for subsequent mixtures with sand based on experience.

The required paste volume in percent is converted to required paste volume in ft^3, per cubic yard of pervious concrete:

PV, ft^3 = PV% × 27.

Step 3 – Determine water-to-cementitious materials ratio (w/cm)

Two approaches to select the appropriate w/cm are suggested:

- The first approach is to choose a w/cm value between 0.27 and 0.36 and evaluate the consistency of the mixture in trial batches. Normally lower values (0.27 to 0.30) are advisable when water reducing admixtures are used. When no water reducing admixtures are used a w/cm value between 0.31 and 0.36 can be selected.
- In the second approach, an evaluation of the paste consistency is suggested.

  Mix several batches of pastes of cementitious materials varying from 0.27 to 0.40 in increments of 0.02. Include the admixtures that will be used in appropriate dosages. Admixtures can include water reducing admixtures, set controlling admixtures, hydration stabilizing admixtures or viscosity modifying admixtures.

  The cementitious paste is mixed in a Hobart mixer in accordance with ASTM C305. The consistency of the paste is evaluated using the flow cone mold in ASTM C1437. The flow cone mold has a 2.75 in. upper diameter and 4 in. lower diameter as shown in Figure 1.

  Fill the cementitious paste in two equal layers with 5 tamps for each layer. After consolidating the second layer strike off the top of the flow cone mold with a straight edge and lift the flow cone vertically. The flow (spread) is calculated as the average of two measured diameters as shown in Figure 2. The measured flow is plotted against the *w/cm* of the cementitious paste batches. For portland cement paste choose a *w/cm* between 0 and 0.02 less than that value that gives a spread of 5 *in*. If the cementitious material includes a supplementary cementitious material (SCM) like fly ash or slag the same experiment can be carried out. However the optimal *w/cm* recommendation has not been experimentally validated.

An optimum w/cm is critical for pervious concrete. Too low w/cm can result in poor workability, difficulty in attaining good consolidation and therefore can result in higher void contents than that required by design. These mixtures will be more susceptible to raveling in the field. Too high w/cm will result in paste run down, and possibly sealing of the voids. The workability is typically assigned a visual rating as shown in Figure 3 by holding a handful of the fresh pervious concrete and compacting it with both hands into a ball.

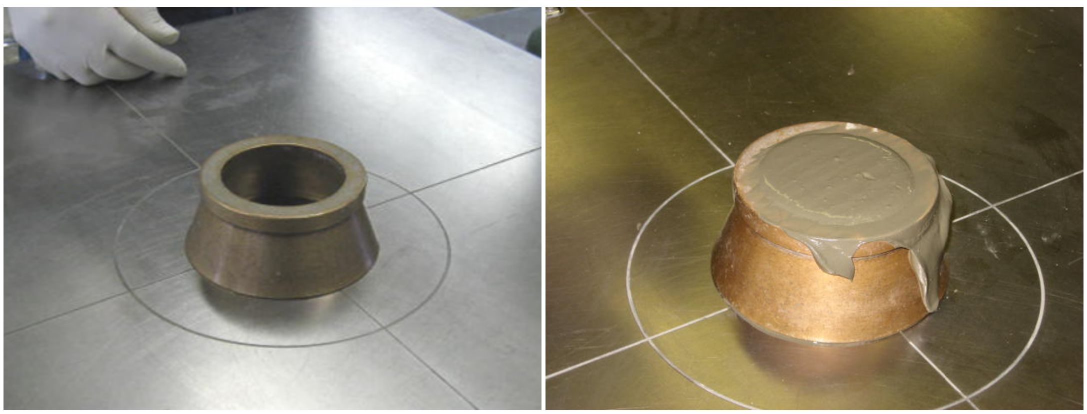

Figure 1 Flow Cone Mold

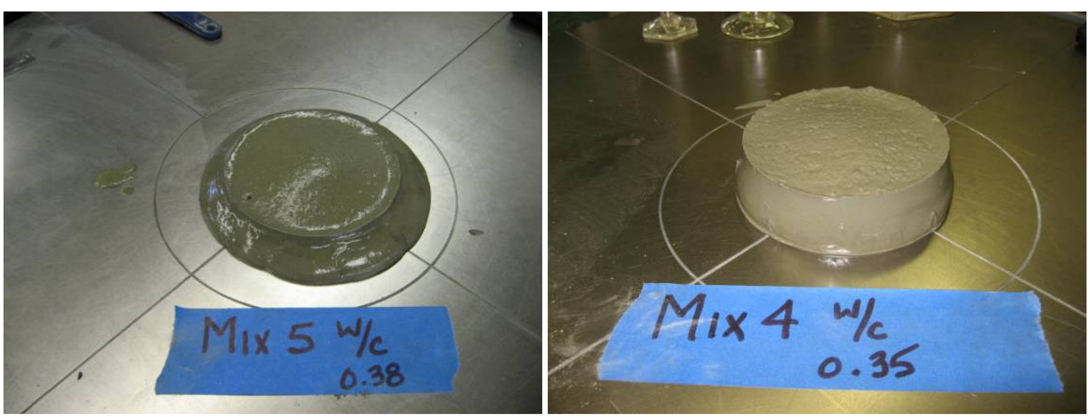

Figure 2 Cementitous Paste Flow Test Specimens

1	2	3	4	5
(Dry)	(In-Between)	(Optimum)	(In-Between)	(Wet)

Figure 3 Pervious Concrete Workability Visual Rating (1-5)

Step 4 – Estimate the cementitious, water, and aggregate weights

The following calculations are performed in the accompanying spreadsheet.

Once the paste volume and *w/cm* is known the quantities of cementitious materials, water, and aggregate weights for 1 cubic yard of pervious concrete can be calculated as follows:

The following notations are used in the calculations:

M_w = weight of water, lb/yd^3
M_c = weight of cement, lb/yd^3
M_{scm} = weight of supplementary cementitious material, SCM (if any), lb/yd^3
x = ratio of the weight of SCM to the weight of the total cementitous content
y = ratio of the weight of sand to the weight of the combined aggregate
V_w = volume of water, ft^3
V_{cm} = absolute volume of total cementitious material, ft^3
V_{agg} = absolute volume of combined SSD aggregate, ft^3
V_{void} = Design void volume, in percent or ft^3
$DRUW$ = Dry rodded unit weight of aggregate (combined if more than one is used), lb/ft^3
RD_c = relative density (specific gravity) of cement (3.15 for portland cement)
RD_{scm} = relative density of supplementary cementitious material (if any)
RD_{cm} = relative density of the total cementitious material
RD_{ca} = SSD relative density of coarse aggregate
RD_{sand} = SSD relative density of sand (if any)
RD_{ca}(dry) = Dry relative density of coarse aggregate
RD_{sand}(dry) = Dry relative density of sand (if any)
RD_{agg} = SSD relative density of the combined aggregate
ρ_w = density of water (62.4 lb/ft^3)

The void content of the aggregate is calculated from the measured dry-rodded unit weight (DRUW) in accordance with ASTM C29 (note that as per C29 for this calculation, ρ_w = 62.3 lb/ft^3):

$$Agg_{void} = 1 - \left(\frac{DRUW}{RD_{ca}(dry) \times 62.3} \right)$$

The dry relative density of aggregate is calculated from the SSD value and the aggregate absorption.

When 2 aggregates are used and the dry rodded unit weight is measured, the void content of the aggregate is calculated by:

$$Agg_{void} = 1 - \left[\frac{DRUW}{62.3} \times \left(\frac{(1-y)}{RD_{ca}(dry)} + \frac{y}{RD_{sand}(dry)} \right) \right]$$

The relative density of the total cementitious material is,

$$RD_{cm} = \frac{RD_c \times RD_{scm}}{[(1-x) \times RD_{scm}] + [x \times RD_c]}$$

When only one cementitious material is used $RD_{cm} = RD_c$ (3.15 for portland cement)

The relative density of the combined aggregate is,

$$RD_{agg} = \frac{RD_{ca} \times RD_{sand}}{[(1-y) \times RD_{sand}] + [y \times RD_{ca}]}$$

When only one aggregate (coarse) is used $RD_{agg} = RD_{ca}$

The water to cementitious weight ratio is,

$$(w/cm)_w = \frac{M_w}{[M_c + M_{scm}]}$$

The water to cementitious volume ratio is,

$$(w/cm)_v = (w/cm)_w \times RD_{cm}$$

The paste volume, PV, in step 2 is the sum of the volume of water and the total cementitious material

$$PV, ft^3 = V_w + V_{cm}$$

The absolute volume of total cementitious material is determined by,

$$V_{cm}, ft^3 = \frac{PV}{[1 + (w/cm)_v]}$$

The volume of water,

$$V_w, ft^3 = PV - V_{cm}$$

The absolute volume of SSD combined aggregate (V_{agg}) is:

$$V_{agg} = 27 - (PV + V_{void})$$

Convert the volumes to weights of ingredients per cubic yard and for trial batches:

Cement (*lb/yd*^{3})	$= V_{cm} \times RD_{cm} \times \rho_w \times (1 - x)$
SCM (*lb/yd*^{3})	$= V_{cm} \times RD_{cm} \times \rho_w \times x$
Water (*lb/yd*^{3})	$= V_w \times \rho_w$
SSD Coarse Aggregate (*lb/yd*^{3})	$= V_{agg} \times RD_{agg} \times \rho_w \times (1 - y)$
SSD Fine Aggregate (*lb/yd*^{3})	$= V_{agg} \times RD_{agg} \times \rho_w \times y$

Step 5 – Determine the type and dosage of admixtures to be used

Admixtures can include water reducing admixtures, set controlling admixtures, air entraining admixtures, hydration stabilizing admixtures or viscosity modifying admixtures. Admixtures are typically dosed on the basis of fl.oz./100 lb of cementitious materials.

Water reducing admixtures or superplasticizers can improve the consistency of the paste and reduce the quantity of water.

Set controlling admixtures might be used as they are in conventional concrete. The use of accelerating admixtures is discouraged as it will accelerate the rate of stiffening.

Air entraining admixtures may be used for pervious concrete that will be subject to cycles of freezing and thawing to protect the integrity of the paste. However it is not possible to measure the entrained air content in the paste. ASTM C231 pressure meter test used for normal concrete is not applicable. Researchers have attempted using microscopic measurements.

Hydration stabilizing admixtures can help delay the rate of stiffening for pervious concrete mixtures and maintain its workability for a longer period. These admixtures are also reported to facilitate faster discharge from truck mixers.

Viscosity modifying admixtures are reported to make the mixture more robust, i.e. more water can be added without causing the paste to drain down.

Synthetic fibers at dosages typically used in conventional concrete have also been used.

Admixture volumes and weights are assumed to be negligible for mixture proportion calculations.

Step 6 – Determine batch quantities for trial batches and modify mixture proportions

As with conventional concrete, the most important step of developing mixtures for pervious concrete is to make trial batches in the lab and evaluate the characteristics of the mixture.

Measure the total moisture content of the aggregates prior to preparing the batch.

Calculate batch quantities of wet aggregates and added water based on the free moisture content of the aggregates. These calculations are similar to those used for conventional concrete. Note that the mixer should be "buttered" prior to mixing the trial batch or add the typical amount of mixer holdback to the paste quantities.

In the laboratory mix the concrete in accordance with ASTM C192 in a 3-3-2 mixing sequence. Use prolonged mixing if necessary.

Measure and record the density of the pervious concrete and calculate the void content in accordance with ASTM C1688.

Evaluate the consistency of the mix by the visual rating indicated in Figure 3. The paste should be of adequate quantity to coat aggregates and of the proper consistency to prevent early drying or paste flow down.

Perform strength tests if there are strength requirements in the project. Note that there is no standard test method to prepare strength test specimens for pervious concrete at this time. A similar consolidation procedure as used in ASTM C1688 might be used.

Make appropriate changes to the quantities of the mixture ingredients based on the evaluation of the trial batches.

The accompanying mixture proportioning spreadsheet provides a means of calculating batch quantities for laboratory and production size batches. Input required is the total moisture content of the aggregates and the batch size.

Numerical Example

Develop proportions for a pervious concrete mixture with the following:

Design void content = 20%

No. 8 gravel aggregate
Aggregate relative density (dry) = 2.65
Absorption = 1.1%

No sand.
Use portland cement only
w/cm = 0.34.

Step 1

No. 8 gravel

Bulk dry RD_{ca} = 2.65
Absorption = 1.1%
Dry rodded unit weight, lb/ft^3 = 100 lb/ft^3
SSD RD_{ca} = (2.65 × 1.011) = 2.68

No sand, so y=0 and $RD_{agg} = RD_{ca}$

Aggregate voids content = $1-\left(\frac{100}{2.65\times 62.3}\right)$ = 39.5%

Step 2

Required *PV* (%) = Aggregate Void Content (%) + *CI* (%) - Design void content (%)
= 39.5 + 5 – 20 = 24.5%

Paste volume *PV*, ft^3 = 0.245 × 27 = 6.62 ft^3

Step 3

$(w/cm)_w$ = 0.34 (given)
No SCM, so x=0 and $RD_{cm} = RD_c$

Step 4

Ingredient weights

$(w/cm)_v$ = 0.34 × 3.15 = 1.07 (*RD* of cement = 3.15)

Volume of cement $V_{cm}, ft^3 = \frac{PV}{[1+(w/cm)_v]} = \frac{6.62}{[1+1.07]} = 3.20 ft^3$

Volume of water, $V_w, ft^3 = PV - V_{cm}$ = (6.62 – 3.20) = 3.42 ft^3

Volume of voids, V_{void}, ft^3 = 0.20 × 27 = 5.40 ft^3

Absolute vol. of aggregate = 27 - ($PV + V_{void}$)
= 27 – (6.62 + 5.40)
= 14.98 ft^3

Weight of cement, lb/yd^3	= 3.20 × 3.15 × 62.4	= 629
Weight of water, lb/yd^3	= 3.42 × 1.00 × 62.4	= 213
Weight of SSD aggregate, lb/yd^3	= 14.98 × 2.68 × 62.4	= 2505

Summary

A simple pervious concrete mixture proportioning methodology to attain a design void content similar to the value measured in accordance with ASTM C1688 is proposed. The methodology involves calculating the paste volume based on the aggregate void content, a compaction index factor, and the design void content of the pervious concrete mixture. *w/cm* is estimated using a simple paste experiment to evaluate its consistency. From this the pervious concrete mixture proportions are estimated. It is emphasized that the characteristics of the mixture be evaluated in trial batches and modified as needed.

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