Permeability of Concrete

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General

Permeability is defined as the property that governs the rate of flow of a fluid into a porous solid. Permeability is also can be defined ability to resist weathering action, chemical attack, abrasion, or any process of deterioration.

The permeability occurs in hardened concrete in two scenarios; firstly from the trapped air pockets from incomplete compaction and secondly from the empty space due to loss of mixing water by evaporation. Need for information on the permeability of concrete dates from the early 1930s. Designers of dams and other large hydraulic structures needed to know the rate at which water passed through concrete that was subjected to relatively high hydraulic pressures.

Today there is renewed interest in the permeability of concrete, but this interest does not center on the flow of water through concrete in water works structures, it deals mainly with permeability to deleterious substances such as chloride ions from sea water and deicing salts, sulfate ions, and other aggressive chemicals. The growing awareness of the role permeability plays in the long-term durability of concrete has led to the need for ways to quickly assess the permeability of concretes. The use of admixtures such as silica fume, latex emulsions, and high-range water reducers allows placement of highly impermeable concrete. More information on the effects of these admixtures, concrete mix design, and curing is needed so that low permeability concretes can be uniformly specified and manufactured. In 1986, construction technology laboratories researchers studied the effects of mix design, materials, and curing on permeability of selected concretes. The concretes studied had water- cement (w/c) ratios ranging from 0.26 to 0.75. Compressive strengths varied from 3580 psi to 15,250 psi at 90 days. Silica fume and high- range water reducers were used to produce the low w/c ratio concretes. Curing included 7-day moist- cure and 1-day moist-cure. After 90 days of air- drying, the concretes were subjected to tests. These tests included permeability to water and air, ponding with chloride solution, rapid chloride permeability, helium porosity, and volume of permeable voids.

Compressive Strength, Durability and Permeability:

The factors that allow concrete to obtain high compressive strength have been widely known and utilized in structures for many years. The strength of concrete was then further enhanced by the use of reinforcing steel, which allows for structures of many shapes and sizes to be built today. However, the factors affecting the durability of concrete **- many of which may affect the strength as well-** are not as recognizable. There is an approximately equal inverse relationship between penetrability and compressive strength.

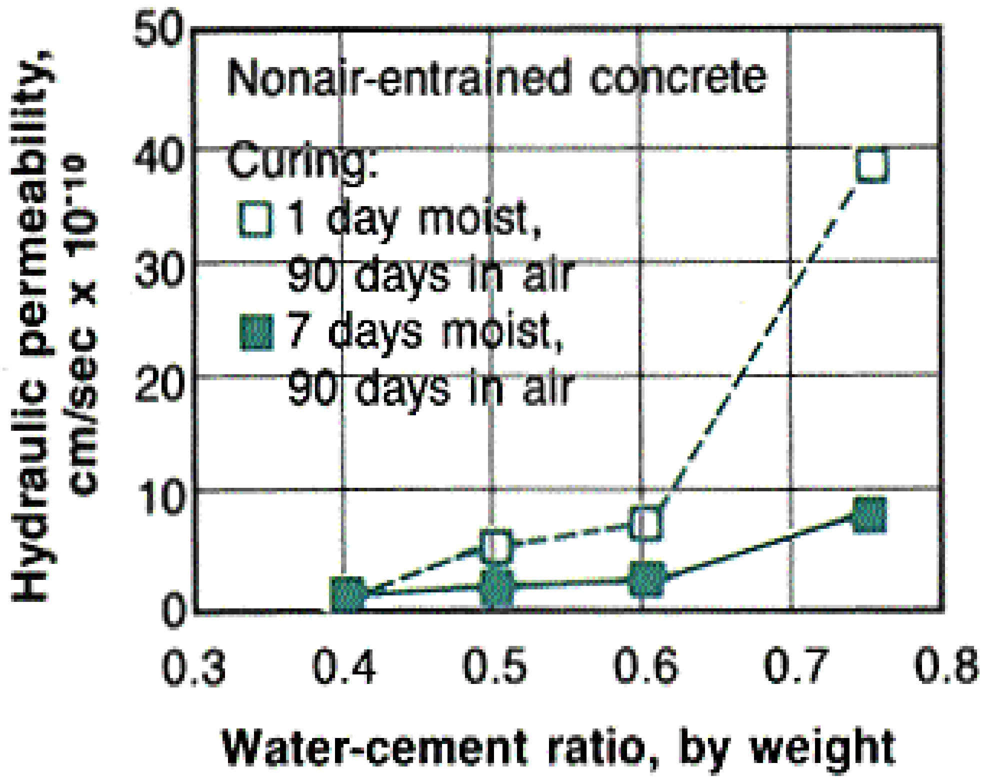
Durability of concrete is defined by the American Concrete Institute in ACI 116R as its ability to resist weathering action, chemical attack, abrasion, and other conditions of service. Durability of concrete can be also defined as the capability of the material by itself of keeping the original properties for a certain period; durable concrete may be defined as concrete that retains its original form, quality, and serviceability when exposed to its environment. In other words, durable concrete is concrete that in the particular environment of service resists the forces in that environment that tend to cause it to disintegrate without requiring excessive effort for maintenance during its service life. A multitude of factors affects durability of concrete either directly or indirectly. Some may be physical and perpetuate upon themselves, while others may be inherent to the properties of a specific mix design. Permeability of concrete is believed to be the most important characteristic of concrete that affects its durability. The principal result of the intrusion of an element into concrete is the corrosion of the reinforcing steel. Once this occurs, the structure will no longer maintain its structural integrity; the lifespan is reduced, and the general safety of the public is severely degraded. For reinforced concrete bridges, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. It is increasingly apparent that for many concrete members, the ability of the concrete to resist chloride penetration is an essential factor in determining its successful performance over an extended period. Concrete permeability will determine how quickly oxygen, water, and chloride ions will reach the layer of steel, the single most important factor affecting the rates of deterioration from reinforcing bar corrosion, carbonation, alkali-aggregate reaction, or freeze thaw cycles, all of which may be occurring simultaneously. The time-to-corrosion initiation and subsequent corrosion induced damage is related to the time that it takes chloride ions to reach a critical level at the steel.

Factored Affecting Permeability of Concrete

1. W/C ratio: The mixing water is indirectly responsible for permeability of the hydrated cement paste because its content determines first the total space and subsequently the unfilled space after the water is consumed by either cement hydration reactions or evaporation to the environment.

Concrete will not be vulnerable to water-related destructive phenomena if there is a little or no evaporable water left after drying and provided that the subsequent exposure of the concrete to the environment did not cause to re-saturation of the pores. The latter, to a large extent, depends on the hydraulic conductivity, which is also known as the coefficient of permeability (K).

2. Curing: Moist- curing for the 7-day (minimum recommended in ACI 308, Standard Practice for Curing Concrete), resulted in a much more impermeable concrete. The following graph shows the relationship between permeability, w/c ratio, and initial moist-curing for 4x8-inch cylindrical concrete specimens tested after 90 days of air drying and subjected to 3000 psi of water pressure. Although permeability values would be different for other liquids and gases,



the relationship between w/c ratio, curing period, and permeability would be similar.

<u>3. The use of Admixtures</u>: Such as silica fume, latex emulsions, and high-range water reducers allows placement of highly impermeable concrete. More information on the effects of these admixtures, concrete mix design, and curing is needed so that low permeability concretes can be uniformly specified and manufacture.

4. Other Factors : There are few other factors that affect the permeability in concrete as the improper compaction and loss of mixing water, age of the concrete, increasing concrete age causes the permeability to reduce, this is because concrete is material that will continue to hydrate over a long period of time as long as there is a presence of un-hydrated lime. So with the presence of water, the hydration products will fill the empty spaces in the matrix. Another factor that improves the permeability is the fineness of cement. Finer cement particles will hydrate much faster; thus creating the impermeable concrete faster.

Permeability and Water Tightness

Generally, the same properties of concrete that make it less permeable also make it more watertight. The overall permeability of concrete to water is a function of the permeability of the paste (cement and water), the permeability and gradation of the aggregate, and the relative proportion of paste to aggregate. Decreased permeability improves concrete's resistance to re-saturation, sulfate and other chemical attack, and chloride ion penetration. A low permeability concrete requires a low w/c ratio and adequate moist-curing. Air entrainment aids water-tightness but has little effect on permeability.

The permeability of mature hardened paste kept continuously moist ranges from 0.1x10- 12 to 120x10- 12 centimeters per second for w/c ratios ranging from 0.3 to 0.7. The permeability of commonly used concrete aggregate varies from about 1.7x10- 9 to 3.5x10- 13 centimeters per second. The permeability of mature, good-quality concrete is about 1x10- 10 centimeters per second (reference 1).

Permeability Versus Durability

According to Mindness, Young, and Darwin, the parameter that has the largest influence on durability is the water/cement (w/c) ratio. The permeability of concrete and the permeability of the paste decreases as the w/c ratio decreases. Low w/c ratio means lower permeability, therefore lower voids in the concrete. This means that it is more difficult for water, and corrosives, to penetrate the concrete.

Concrete permeability influences durability because it controls the rate that moisture, which could contain an aggressive chemical, enters concrete and the movement of water. Decreasing the w/c ratio also increases concrete strength which further improves its resistance to cracking.

Tests of Permeability

Studies confirmed that several rapid-test procedures are available for estimating permeability instead of more complex flow testing. The following tests are some of these tests that pertain to the permeability and/ or resistivity of concrete, discussing the advantages and disadvantages of each method also clarified.

1. Chloride/ Salt-Ponding Test

Most direct method of measuring chloride penetration is the 90-day, salt-ponding test. This test subjects a concrete specimen to a chloride solution not under pressure for 90 days. A profile section of concrete is analyzed after this period to determine the penetration of the concrete. The 90-day chloride penetration test is considered the most accurate and informative test .A disadvantage of this method is that it is time consuming. Additionally, it may not allow sufficient time for low permeability concretes.

2. Rapid Chloride Permeability Test (RCP Test)

ASTM C1202, Standard Test Method for Electrical Indication of Concretes (Ability to Resist Chloride Ion Penetration) can be used to determine the relative permeability of the concrete specimens. At the end of the six-hour rapid permeability test, coulomb values representing the total current passed through the concrete slices over the testing period are obtained.

The area under the current versus time curve, i.e. the total charge passed in coulombs, correlates with the resistance of the specimen to chloride ion penetration. These values have been shown to be representative of the chloride ion permeability, which is an indirect indication of the permeability of concrete.

The rapid chloride permeability test (ASTM 1202) reliably and quickly assesses the relative permeabilities of a variety of concretes. In the next sections detailed procedure for this test clarified.

3. Migration Cells test

This test is similar to RCP, but one cell has a chloride solution while the other cell is chloride-free; the movement of chlorides to the chloride-free cell is then measured.

4. Surface Electrical Resistivity Test

There is a desire to replace the current standard for the measurement of concrete durability for several reasons. The RCP test, which is the current standard, is obviously not without fault. In addition to this fact is the condition that the RCP test is a three-day, time and labor-intensive test. The industry is looking for a suitable replacement to carry on the testing of concrete's durability. One of the most promising alternatives is electrical Surface Resistivity.

Rapid Chloride Permeability Test (Conforms to ASTM 1202 and AASHTO T 277 Test Standards)

main steps for this test summarized below:

1. Samples are collected consisting of three 4-inch by 8-inch cylinders comprising one sample set. Each cylinder in a set is labeled: A, B, and C, kept in a 100% humidity environment and trucked for testing location. Upon arrival, all samples entered a laboratory environment and are subsequently treated equally.

2. Sample Preparation: As samples arrived they were checked in and stored in a moist room sustaining 100% humidity until they are 26 days old. At that time the sample set is removed and samples A and B are cut on a concrete saw. Cutting consisted of the removal of a ¼ inch slice (Figure 1) to dress the top (troweled) edge and then cutting a 2 inch slice (Figure 2) required for testing. The remainder of samples A and B together with the uncut sample C were placed, submerged in a holding tank. The two, 2-inch samples were painted with Sikadur 32 Hi-Mod epoxy around their circumferences (Figure 3) and left to dry. Before close of business the two samples rejoined the rest of the sample set in the holding tank. This marked the end of day 26.

Figure 1. Cutting a ¼. Slice off the Sample to Dress the Troweled Edge.

Figure.2 Cutting the 2. Slice for Testing.

Figure 3 Application of Epoxy around the Samples Circumference

3. Pre-test Requirements: Day 27 began with removing the 2-inch samples from cylinders A and B and placing them in the desiccation chamber. Using an electric pump, a vacuum of pressure less than 1 mm Hg (133 Pa) was drawn for 3 hours. At that time de-aired water was introduced to the chamber (Figure 4) while keeping the vacuum until the samples are submerged and the pump is let to run an additional hour. At the conclusion of this 4-hour desiccation the chamber is returned to atmospheric pressure and the samples were left submerged in this state (over night) for 18 hours, plus or minus 2 hours. This concluded the activities of day 27.

Figure 4 Desiccation Chamber

4. Run Test and Collect Data:

Day 28 was the actual testing day, the 2-inch samples from cylinders A and B were removed from the desiccation chamber and either wiped dry or allowed to surface dry. They were then siliconed into an acrylic test cell (Figure 5) comprised of two sides: one positive and one negative. The samples were placed into their respective cells ,top of the sample into the negative side and the 90° joint sealed with silicone between the surface of the acrylic and the surface of the epoxy all the way around the circumference, and on both sides. A schematic diagram provided by David Whiting is pictured here in Figure.6. The silicone was then allowed to cure (approximately 2 hours).

During curing, the positive and negative test leads in addition to the thermocouples were connected (Figure 7) as well as the information necessary to initiate the test entered into the software responsible for data collection during the test. After the silicone dried enough to prevent leaking, the cells were filled with hand mixed chemical solutions. The positive side was filled with a 0.3 N sodium hydroxide solution (NaOH) and the negative side with a 3% by mass sodium chloride solution (NaCl). At this time the test was begun and run for 6 hours, the software taking readings every 5 minutes. The particular program used in this project recorded the time, temperature, charge passed and current. It determined the cumulative charge passed during the 6-hour test in coulombs (ampere second) by measuring the area underneath the curve of current (in amperes) versus time(in second).

Figure.5 Siliconning Sample into the Test Cell

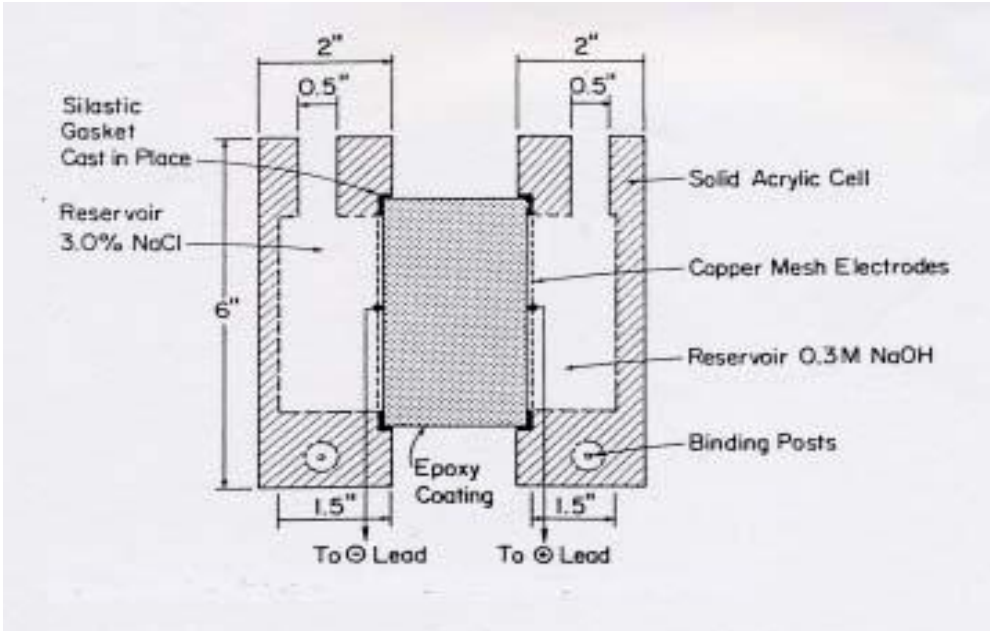


Figure 6 Schematic of RCP test set up from David Whiting

Figure.7 The Complete Testing Configuration (Sample A and B)

5. Clean Up

The post-test day entailed separating the samples from the reusable acrylic cells using a utility knife (Figure 8) and cleaning those cells. Cleaning the cells required the removal of all silicone and dipping them in a muratic acid bath before rinsing and drying until their next use. The previous days test results were also printed and cataloged for record. The 2-inch samples were discarded and the remaining portions of the A and B cylinders awaited their 91-day test date to repeat this battery.

Figure 8 Disassembly of the Test Cells

Figure 9 Test Cells Cleaned and Ready for Next Test

References

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