PCA Portland Cement Association

CONCRETE TECHNOLOGY Today

First Use of Ultra-High Performance Concrete for an Innovative Train Station Canopy

By V. H. Perry and D. Zakariasen, Lafarge Canada Inc.

Figure 2 (above). Half-canopy in steel form.

Figure 1 (above). Shawnessy Light Rail Transit Station, Calgary, Canada.

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Contents

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The Shawnessy Light Rail Transit (LRT) Station, constructed during fall 2003 and winter 2004, forms part of a southern expansion to Calgary's LRT system and is the world's first LRT system to be constructed with ultra-high performance concrete (UHPC). The innovative project, designed by Enzo Vicenzino of CPV Group Architects Ltd., is owned by the City of Calgary, managed by the Transportation Project Office (TPO), and constructed by general contractor, Walter Construction.

The Design

The station's twenty-four thin-shelled canopies, 5.1 m by 6 m (16.7 ft by 19.7 ft), and just 20 mm (0.79 in.) thick, supported on single columns, protect commuters from the elements. UHPC technology has a unique combination of superior technical characteristics including ductility, strength, and durability, while providing highly moldable products with a high quality surface aspect. The contract document specified a minimum requirement of 130 MPa (19,000 psi). In addition to the canopies, the components include struts, columns, beams, and gutters. The volume of material used totaled 80 m^3 (105 yd^3).

Manufacturing and Installation

The precast canopy components were individually cast and consist of half-shells, columns, tie beams, struts, and troughs. Table 1 summarizes test data from production of the twenty-four canopies.

The columns and half-shells were injection cast in closed steel forms (Figure 2). Troughs were cast through displacement molding, while struts and tie beams were produced using conventional gravity two-stage castings.

The columns were installed on the concrete platform first. Then, the right and left half-shells, along with the tie

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UHPC

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beams, were pre-assembled in the plant and transported to the site where they were lifted (by crane) over the railway tracks, for placement on the columns (Figure 3). Upon arrival at the site, the canopies were set on temporary scaffolding, and struts were attached to the shells and previously installed columns with welded connections.

Figure 3. Canopies ready for transportation.

Table 1. Test Results – LRT Canopies

Property	Mean value after 72 hours thermal treatment MPa (psi)	Standard development MPa (psi)
Compressive strength	152 (22,000)	6.2 (900)
Flexural strength	18 (2,600)	3.4 (500)

Conclusion

The material's unique combination of superior properties and design flexibility facilitated the architect's ability to create the attractive, off-white, curved canopies. Overall, this material offers solutions with advantages such as speed of construction, improved aesthetics, superior durability, and impermeability against corrosion, abrasion and impact—which translates to reduced maintenance and a longer life span for the structure.

This project was the first of its type in the world using this mix for thin, architectural, curved canopies. While this solution demonstrates many of the benefits of the material technology, it is apparent that the true benefits are not fully recognized. Furthermore, the material is still in its infancy, and, in the next few years, much progress is anticipated in the area of optimized solutions.

References

Lafarge North America Inc., *Technical Characteristics: UHPC with Organic Fibres*, National Building Code of Canada, 1995.

Perry, V.H., "Q&A: What Is Reactive Powder Concrete?" *HPC Bridge Views*, No. 16, July/August 2001, *http://www.cement.org/pdf_files/hpc-16julaug01.pdf*.

Lafarge North America Inc. Ductal® Website: *http://www.imagineductal.com*.

UHPC Symposium

International Symposium on **Ultra-High Performance Concrete**, September 13 - 15, 2004, Kassel, Germany

For more information and registration visit: ***www.uni-kassel.de/uhpc2004***

Ultra-High Performance Concrete (UHPC), also known as reactive powder concrete (RPC), is a high-strength, ductile material formulated by combining portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water, and steel or organic fibers. The material provides compressive strengths up to 200 MPa (29000 psi) and flexural strengths up to 50 MPa (7000 psi).

The materials are usually supplied in a three-component premix: powders (portland cement, silica fume, quartz flour, and fine silica sand) pre-blended in bulk-bags; superplasticizers; and organic fibers. The ductile behavior of this material is a first for concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking. The use of this material for construction is simplified by the elimination of reinforcing steel and the ability of the material to be virtually self placing or dry cast.

The superior durability characteristics are due to a combination of fine powders selected for their grain size (maximum 600 micrometer) and chemical reactivity. The net effect is a maximum compactness and a small, disconnected pore structure.

The following is an example of the range of material characteristics for UHPC:

STRENGTH	
Compressive	120 to 150 MPa (17000 to 22000 psi)
Flexural	15 to 25 MPa (2200 to 3600 psi)
Modulus of Elasticity	45 to 50 GPa (6500 to 7300 ksi)
DURABILITY	
Freeze/thaw (after 300 cycles)	100%
Salt-scaling (loss of residue)	< 60 g/m^2 (< 0.013 lb/ft^3)
Abrasion (relative volume loss index)	1.7
Oxygen permeability	<10^{-20} m^2 (< 10^{-19} ft^2)
Cl$^-$ permeability (total load)	< 10 C
Carbonation depth	< 0.5 mm (< 0.02 in.)

Decorative Concrete: Exposed-Aggregate Finishes

Exposed-aggregate concrete is a popular decorative finish for concrete slabs because of its durability and wide range of texture and color in unlimited applications. The finish is ideal where concrete slabs are cast horizontally for sidewalks, driveways, patios, pool decks; and in countless other residential, commercial, industrial, and public works applications.

There are three ways of obtaining exposed-aggregate finishes on fresh concrete slabs: (1) the *seeding technique*, where a select aggregate is pressed into the concrete surface; (2) the *monolithic technique*, where a select aggregate, usually gap-graded, is mixed throughout the batch of concrete; and (3) a *topping course technique*, which exposes gap-graded aggregates in a special overlay.

Seeded Exposed-Aggregate Concrete

In this method select aggregate is carefully seeded by shovel, hand, or mechanical means to cover the entire surface of unhardened concrete with one layer of stone. The seeded aggregate is normally embedded in the concrete by tapping with a wooden hand float, a darby, or a bullfloat. Sometimes a straightedge or rolling device such as a large diameter pipe is used. Final embedment can be obtained with a magnesium float or darby until a layer of mortar about 2 mm (1⁄16 in.) thick completely surrounds and covers all particles.

In general, exposing the seeded aggregate should be delayed until the slab will bear the weight of a concrete finisher on kneeboards with no indentation. At this time the slab is lightly brushed with a stiff nylon bristle broom to remove excess mortar. Next, brushing combined with a fine water spray can begin. Soft and hard bristle brooms and special exposed-aggregate brooms with water jets are available to complete the job. Occasionally, wire bristle brooms may be needed for a particularly stubborn area, but such brooms should be used with caution as they may stain the aggregate.

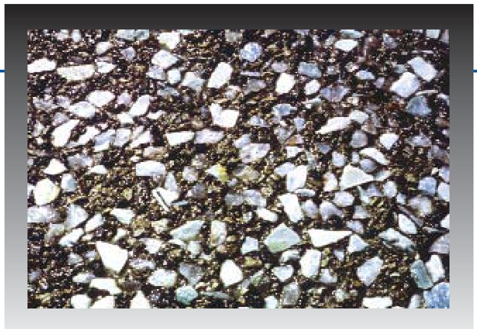


Figure 1. Exposed-aggregate concrete.

Surface set retarders may be used to advantage on large jobs or during hot weather to delay the time of washing and brushing. When using smaller aggregate sizes, it is desirable to delay the time of set of the surface matrix by using a surface retarder to allow the base concrete to attain its initial set. This procedure will help prevent dislodgment of the small-size aggregate. The retarder is sprayed over the surface according to the manufacturer's recommendations with an ordinary, low-pressure garden sprayer after the seeded concrete is floated. After the concrete sets, the procedure of washing and brushing the surface is performed to expose the aggregate.

Monolithic Exposed-Aggregate Concrete

In this method the select aggregate to be exposed is mixed throughout the concrete during batching. Placing, striking off, bullfloating, or darbying follow the usual procedures. Care should be taken not to overfloat the surface, as this may depress the coarse aggregate too deeply. The aggregate is ready for exposing when the water sheen disappears, the surface can support a finisher's weight on kneeboards without indentation, and the aggregate is not dislodged by washing and brushing.

As soon as the surface water sheen has disappeared, a surface set retarder is sprayed over the surface and then the concrete is covered with plastic sheeting to continue curing. The same washing and brushing procedure for aggregate exposure used in the seeding method is used to expose the aggregate in the monolithic method.

Topping Exposed-Aggregate Concrete

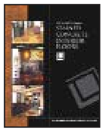
In this method, a thin topping course of concrete containing the select aggregate is placed over a base slab of conventional concrete. The topping normally is 25 mm to 50 mm (1 in. to 2 in.) thick depending on the aggregate size. The base slab is struck off low so that the final floated surface of the topping will be at finish grade. The topping thickness must be at least three times the diameter of the maximum coarse aggregate size used in the topping concrete mixture.

The surface of the base course should have a rough broomed finish and be firm enough to support a finisher's weight before the topping is placed. The topping concrete is a specially designed mixture of select gap-graded aggregates and masonry sand. The same washing and brushing procedure of aggregate exposure is used in this type of construction as with the seeding method.

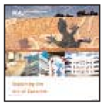
More on Decorative Concrete

For extensive illustration and discussion of decorative concrete applications refer to:

Finishing Concrete with Color and Texture
PA124, 2004.



Bob Harris' Guide to Stained Concrete Floors
LT283, 2004.



Exploring the Art of Concrete
CD028, 2003.

All three items can be purchased at *www.cement.org/bookstore*.

Cement-Treated Subgrade Paves Way for Cement Plant Haul Road

By Donald H. Taubert, Capitol Cement

Nearly ten years ago, Capitol Cement determined that it was time to build a new entrance/haul road into its portland cement plant. The road was to be approximately 275 m (900 ft) long and 12 m (40 ft) wide with a 30-year design life for a minimum of 160 cement trucks with 80,000 lb gross vehicle weight (gvw) daily.

Drash Consulting Engineers of San Antonio designed the pavement using procedures from PCA's *Thickness Design for Concrete and Street Pavements* (1984). It was determined that 230 mm (9 in.) of non-reinforced concrete pavement would be required. This was to be placed directly on a cement-modified clay subgrade. No separation layer—e.g., flex-base or asphalt-treated base—was necessary.

Subgrade Treatment

Figure 1. Subgrade treatment with slurry placement.

The subgrade was bored and tested. Subsequent analysis of California Bearing Ratio (CBR) values resulted in a value of 3 for the raw subgrade. With the addition of 4% portland cement, the value was raised to 20.

Further testing on the clay subgrade determined it to be a highly expansive Class CH (fat clay) within the Unified Soil Classification System (USCS), approximately 1 m (3.5 ft) deep, with Plasticity Indices (PI) ranging from 38 to 43. Atterberg Limit tests showed that 5% cement, or about 12.5 kg/m^2 (21 lb/yd^2), would lower the PI to an acceptable level. Subsequent field testing showed PI was reduced to 12.

The subgrade was prepared to a depth of 150 mm (6 in.) by Olmos Construction Company using cement mixed into slurry. Olmos has developed a slurry truck with an external centrifugal pump for mixing and circulation (Figure 1). All subgrade work (scarifying, cement spreading, pulverization, grading, and compaction) was completed within four hours. Density was determined to be 1500 kg/m^3 (94.2 pcf), with an optimum moisture content of 23.6%. All construction equipment used the prepared subgrade for travel at the end of the day.

Concrete Mix Design

The specified flexural strength (third point) was 4.5 MPa (650 psi) with a compressive strength of 35 MPa (5000 psi) as the governing control criterion. Air entrainment was specified to be 4% to 6%, and slump to be 75 mm to 125 mm (3 in. to 5 in.). The 28-day design strength was achieved in 7 days. Capitol performed compressive, flexural, and splitting tensile tests at 3, 7, 28, 56, and 90 days. Both flexural and compressive strengths exceeded design strength by a large margin, with

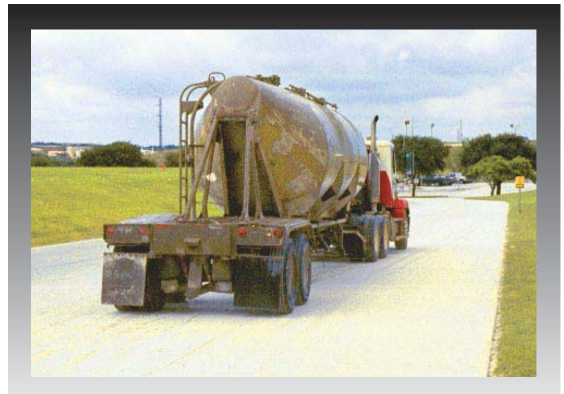


Figure 2. Capitol Cement plant haul road.

90-day flexural at about 5.2 MPa (755 psi) and 90-day compressive at about 47 MPa (6800 psi). Splitting tensile tests, ASTM C 496, exceeded 4.1 MPa (600 psi) at 90 days, though this was not a required value.

Concrete Pavement Construction

Construction called for the concrete to be placed one lane at a time, with a delay of one week between placements. The concrete was to be 225 mm (9 in.) thick, non-reinforced, and with keyed longitudinal joints. Transverse construction joints were every 18 m (60 ft), dowelled with 0.43 m (17 in.) long, 32 mm (1.25 in.) diameter bars, placed on 300 mm (12 in.) centers. These dowel bars were pre-positioned using a basket system, ensuring their proper placement and perpendicularity to the concrete and subgrade. Contraction (control) joints were spaced at 4.6 m (15 ft) intervals and sawed to a depth of 50 mm (2 in.). The contraction joints were sealed with pourable, elastomeric joint sealant as soon as possible.

All paving operations were done by Zachry Construction Company, headquartered in San Antonio. The concrete was delivered and placed with conventional ready-mix trucks and struck off using a vibratory strike-off screed. Curing was done with an ASTM C 309 curing compound.

Pavement Performance

The pavement was closely monitored for eight years on an annual basis. Loading data on trucks, empty and loaded, were calculated and converted to Equivalent

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Cement-Treated Subgrade Paves Way for Cement Plant Haul Road

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Single Axle Loads (ESALS), a method to establish the fatigue factor. Fuel trucks, raw materials, and machinery and equipment trucks have been included in these totals. Since 1996, the pavement received ESALS of 83,000 to 297,450.

Countless cars, small trucks, and other light-duty vehicles have traversed this road, further adding to the ESAL load. Original design data anticipated 212,000 ESALS annually. Even with the additional 150,000 lb gvw trucks, the pavement is still on track with its design life performing with no problems.

Reference:

R. G. Packard. *Thickness Design for Concrete Highway and Street Pavements*. EB109.01, PCA, 1984.

PCA Soil Cement Website: *http://www.cement.org/pavements/pv_sc.asp*

Internationalization and Environmental Benefits Prompt Change to ASTM C 150

The predominant cement standard for the U.S., ASTM C 150—Standard Specification for Portland Cement, made a change in May 2004 to permit the use of up to 5% limestone in portland cement. This now makes ASTM C 150 consistent with European, Canadian, Mexican, and other cement standards around the world that have taken advantage of this technology for 20 to 30 years. No change was made to existing chemical or physical requirements in the standard. Extensive research[1] and field practice has demonstrated that cements containing up to 5% limestone provide workability, durability, and strength at least equivalent to cements without limestone and also provide significant environmental benefits.

While internationalization of ASTM C 150 provided the impetus for changes to the standard, a more significant factor is the environmental benefits afforded by the use of limestone in portland cement. These include a reduction in use of raw materials, reduced energy consumption, and reduced green-house gas emissions, while ensuring required product performance. Assuming (based on experience in Canada) that cement is made with an average of 2.5% limestone, annual environmental benefits nationwide would be:

- Reduction in raw materials use of over 1.6 million tons
- Reduction in energy use of over 1.25×10^{13} kJ (11.8 trillion BTU)
- Reduction in carbon dioxide emissions of over 2.7 million tons
- Reduction of cement kiln dust waste of over 190 thousand tons

This reduction in environmental impact is approximately equivalent to two one-million ton cement plants. Record-level cement consumption demands enhance the benefits and highlight the timeliness of the change. The carbon dioxide reduction of roughly 2.6% is particularly relevant and is a significant component of the cement industry's voluntary commitment to reduce CO_2 emissions by 10% (from a 1990 baseline) per ton of cementitious product sold by 2020. It is for this reason that the environmental benefits of the provision were endorsed by the EPA. The use of limestone in cement is part of the cement industry's plan to reduce CO_2 emissions which includes:

- Improved manufacturing process efficiency
- Product formulation using less calcined materials
- Development and promotion of sustainable solutions using concrete products

Reference:

[1]*The Use of Limestone in Portland Cement: A State-of-the-Art Review*, EB227, PCA, 2003, 38 pages.

For more information, please contact: John Melander, PCA, 847-966-6200, jmelander@cement.org

What Changed in C 150?

The primary change to ASTM C 150 is new language that states: "5.1.3 Up to 5.0% limestone by mass is permitted in amounts such that the chemical and physical requirements of this standard are met. The limestone shall be naturally occurring, consisting of at least 70% by mass of one or more of the mineral forms of calcium carbonate." The standard also requires that when limestone is used in cement, the manufacturer shall report in writing the amount used, and, when requested, provide data on physical and chemical properties of cement with and without limestone. Provisions are included for determining limestone content of cement and correcting Bogue potential phase composition calculations. The example mill test report in the Appendix of ASTM C 150 has been updated to illustrate how to report limestone content of cement, and calcium carbonate content of limestone. **No changes were made to the existing chemical and physical requirements of ASTM C 150.**

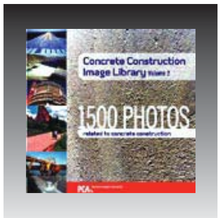
ASTM C 150-04 is available in either electronic or print format from ASTM in West Conshohocken, PA, 19428, Ph: (610) 832-9585 or online *www.astm.org*.

New Information Products

Save 30% to 90% on bulk orders. Contact Pat Schardt at 800.868.6733 or pschardt@cement.org.

The following information products are now available. To purchase them in the United States, contact the Portland Cement Association, Customer Service, 5420 Old Orchard Road, Skokie, IL 60077-1083, telephone 800.868.6733, fax 847.966.9666, or Web site ***www.cement.org***. In Canada, please direct requests to the nearest regional office of the Cement Association of Canada (Halifax, Montreal, Toronto, and Vancouver—***www.cement.ca***).

Concrete Construction Image Library Volume 2, CD043



Over 1500 photos show fresh and hardened concrete, concrete construction techniques, and concrete testing according to ASTM standards. Images include concrete airports, buildings, bridges, dams, tunnels as well as defects and repairs. Concrete construction is shown in pavement and flatwork projects, bridges and buildings, each including images of the individual placing, finishing, and curing techniques. All images are available in high-resolution quality (1536 x 1045 or higher) for use in publications, presentations, and Web sites.

Spanish Language Publications; Design and Control of Concrete Mixtures- Book (EB201) and CD (CD201)

Diseño y Control de Mezclas de Concreto

By: S.H. Kosmatka, B. Kerkhoff, W.C. Panarese, and J. Tanesi

Spanish edition of PCA's premier publication includes translation of the popular 14th U.S. edition of *Design and Control of Concrete Mixtures* (EB001.14) plus information on construction practices and standards used in Latin America. From the basics to specifics of materials, mixing, placing, testing, and new developments, this manual on concrete technology covers almost every aspect of the most widely used construction material in the world. Units in Metric and Inch-Pound.

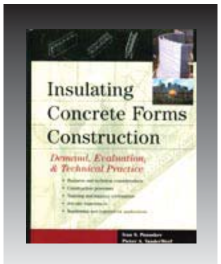
Content of the CD version includes comprehensive glossary, links to cement and concrete resources on the Web and metric conversion. The entire book is indexed and can be searched using keywords or phrases. PowerPoint slides are available for each of the book's 18 chapters.

2002-2004 PCA Research and Technical Reports, MS375

This document provides a list of PCA research reports from the last two years. The reports are categorized by research projects with respect to their market or technical area. Categories include Engineered Structures, Residential, Public Works, Product Standards and Technology, Energy and Environment, and Manufacturing Technology.

Insulating Concrete Forms Construction: Demand, Evaluation & Technical Practice, LT282

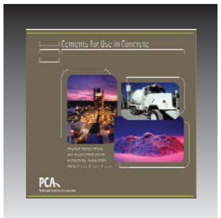
By: P. VanderWerf



This invaluable book walks contractors through both business and technical considerations in evaluating and adopting ICFs for both the residential and commercial markets. Published by The McGraw-Hill Companies.

Cements for Use in Concrete , CD050

By: M. Thomas and P. Tennis



The latest release in PCA's highly-regarded series of training programs on cement and concrete technology, this CD provides a comprehensive overview of cements for use in general concrete construction.

Topics include:

- Historical development of cement and concrete
- The cement manufacturing process, including raw materials, grinding, pyroprocessing, cooling, and finish grinding
- Cement classification; portland and blended cement
- Basic cement chemistry and hydration reactions
- The primary effects cement characteristics have on fresh and hardened concrete properties
- Applicable specifications for cements for general concrete construction: ASTM C 150, ASTM C 595, ASTM C 1157 and the new CSA A3000 specification
- An overview of cements for masonry.

This fully-narrated, self-paced course on cement technology will be an invaluable resource for cement manufacturers, ready-mix concrete producers, concrete contractors, consultants, architects, specifiers, and other design professionals dealing with the use of cement and concrete as building materials.

In-Situ Field Permeability Testing

By Charles A. Ishee, P.E., Structural Materials Research Engineer
Florida Department of Transportation

Ideally, durability and performance of concrete could be accurately predicted with a simple test procedure. In the mid 1980s, there was a strong desire to adequately assess the optimum level of in-place concrete permeability to gain a better understanding of long-term durability. In 1986, the Florida Department of Transportation and the Federal Highway Administration funded a project managed by the University of Florida, to develop a standardized test that could be performed in the field to determine the permeability of concrete. The result of that research was the field permeability test (FPT)[1].

Testing Procedure

The Field Permeability Test uses a portable apparatus for rapid and convenient determination of in-situ water permeability of in-service concrete. The basic procedure is to drill a hole in the surface of the concrete, insert an FPT probe (Figure 1) into the hole, seal off the top and bottom of that hole, and force high-pressure water to radially permeate through the probe into the surrounding concrete. By measuring the rate of flow into the test hole, the coefficient of permeability can be determined by means of the Packer/Lugeon equation, which is based on Darcy's Law.

The coefficient of permeability, K, for the FPT can be calculated as:

$$K = \frac{Q}{2\pi L_o h} \sinh^{-1}\left(\frac{L_o}{2\pi}\right), \text{ where:}$$

L_o = length of test section,

$2r$ = diameter of test hole,

h = applied head pressure, and

Q = rate of flow.

Typical values for the permeability using the FPT in the laboratory ranged from 1 x 10^{-11} m/s to 5 x 10^{-11} m/s.

Various Equipment Applications

To validate the equipment, an extensive laboratory testing program was conducted to investigate the permeability of concrete made with multiple aggregate sources and types, a wide range of water to cementitious materials ratios, Class F fly ash, silica fume, and extended moist-curing durations. The results were correlated to the Rapid Chloride Permeability (RCP) test in that K = 1.22 x 10^{-12} + 1.05 x $10^{-15}C$, where K is the value for the FPT (in in./s) and C is the value for the RCP test (in Coulombs).

Figure 2. FPT equipment.

Field tests have also been conducted on in-place concrete on several bridges throughout Florida. A total of 57 FPTs were run on 13 bridges. The lowest permeability coefficient registered had a value of 9.4 x 10^{-12} m/s. Overall, the permeability coefficients of the tested site concrete were two to four times higher than coefficients obtained from the laboratory. Cores from the various structures were also tested for RCP. The results from the RCP validated the conclusion that some of the concrete did not have low permeability and thus might be expected to have lower service life.

Conclusions

The field permeability test can be used as an indicator of concrete permeability. The FPT can provide a relative measurement of permeability, which can be used

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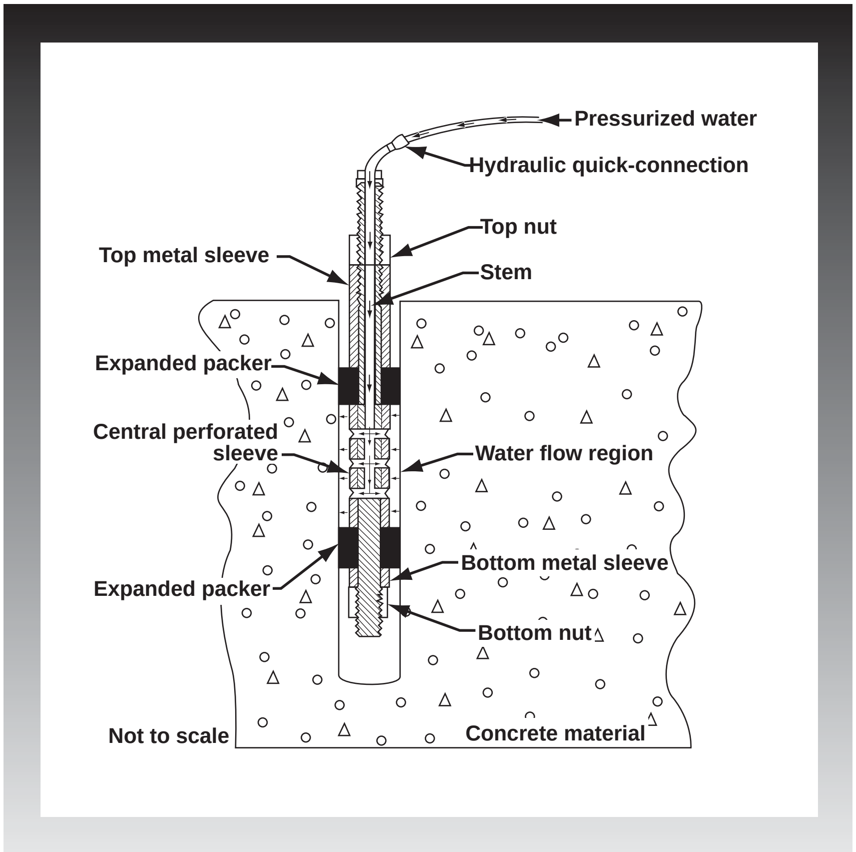

Figure 1. Schematic of an FPT probe in a concrete structure.

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In-Situ Field Permeability Testing

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as a measure of quality to define the performance characteristics of structural concrete. With additional research, the FPT could be one of several tools routinely used to accept concrete based on performance.

Reference:

1. M. Tia, D. Bloomquist, M.C.K. Yang, P. Soongswang, C. A. Meletiou, P. Amornsrivilai, E. Dobson, and D. Richardson. *Field and Laboratory Study of Modulus of Rupture and Permeability of Structural Concrete in Florida*, FL/DOT/SMO/89/361, FLDOT and FHWA, 1990.

Education & Training

PCA will conduct the following courses at PCA's Skokie, IL facility. Customized, off-site, and web-based courses are also available. For more information or to register, contact Julie Clausen (jclausen@cement.org).

Skokie courses:

Kiln Process—October 4-7, 2004

Mill Grinding—October 18-20, 2004

Concrete: Principles & Practices—November 1-4, 2004

Aggregates, Admixtures, & Supplementary Cementing Materials for Use in Concrete—November 8-10, 2004

Troubleshooting: Solutions to Concrete Field Problems—November 15-17, 2004

Microscopy of Clinker & Cement—November 15-19, 2004

Logistics for the Cement Industry—December 6–8, 2004

Cement Manufacturing for Process Engineers—December 6-9, 2004

CT042

CONCRETE TECHNOLOGY *Today*

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