# Bridge Views

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## HPC INTERNATIONAL SYMPOSIUM

*Henry G. Russell, Henry G. Russell, Inc.*

The Economical Solution for Durable Bridges and Transportation Structures was the theme for the second International Symposium on High Performance Concrete held September 25-27, 2000 in Orlando, Florida. With an attendance of over 1500, the symposium brought together experts from the United States and around the world to discuss the most recent applications and developments in high performance concrete. The symposium was sponsored by the Precast/Prestressed Concrete Institute (PCI), the Federal Highway Administration (FHWA), and the Fédération Internationale du Béton *(fib)* and was held in conjunction with PCI's 46th Annual Convention and Exhibition.

The symposium featured nine sessions covering General History, Marketing, and Implementation; Materials and Mix Design; Laboratory Research and Future Direction; Quality Concepts, Fabrication, and Transportation; Construction Techniques; Structural Design and Concepts; Structural Performance and Code Requirements; FHWA Showcase Projects and Case Studies; and *fib's* Approach to High Performance Concrete Structures.

In his opening remarks, Tony Kane, Executive Director of FHWA presented his top ten list of changes for the next 100 years. Number one on his list was high performance concrete in bridges with a projected service life of 100 years. He mentioned that 30 states have now used HPC in some of their structures and that, over the next 50 years, there will be major reconstruction of the urban infrastructure with the need for innovative construction methods using longer-lasting materials. Coupled with this is the need to construct quickly so as to minimize the impact to the traveling public.

### Technical Sessions

In the technical sessions, a wide range of topics was presented. With over 400 attendees from 42 foreign countries, there was ample opportunity to learn about developments from outside the USA. In a session devoted to *fib's* approach, one speaker emphasized that new codes should focus not only on design for strength and serviceability but also on design for durability. Another speaker emphasized that service life should be reliability based, in the same way that loads are currently treated. This approach is already being used for major European bridges.

There were presentations about applications of HPC in Belgium, Cuba, Denmark, France, Norway, and Thailand. Within the USA, there were presentations on bridge applications in Delaware, Louisiana, North Carolina, Virginia, and Washington.

Structural design and research was featured with a wide range of topics including shear capacity, composite action, flexural behavior, design optimization, rotational capacity of members, bond, and code applications.

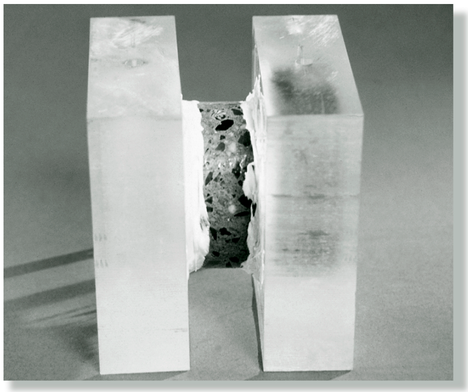
Durability and chloride penetration were popular topics and a major worldwide concern. Attendees were able to learn about corrosion modeling, the effects of concrete constituent materials on concrete durability, techniques to measure permeability, use of the maturity method, effects of curing on concrete properties, and high performance grouts for post-tensioned bridges.

Presentations on construction issues dealt with topics such as self-compacting concretes, repair and strengthening techniques, bridge deck overlays, cracking in prestressed concrete girders, and fiber reinforced concrete.

The symposium clearly illustrated the growing use and interest in HPC on a worldwide basis and the need to obtain a better understanding of its behavior through research. The constant evolution of new materials will continue to present opportunities for the future.

### Further Information

Copies of the proceedings of the symposium, as well as copies of the proceedings from the first symposium, held in New Orleans in 1997, are available from PCI at 312-786-0300; (fax) 312-786-0353; email info@pci.org. Both proceedings contain over 800 pages and a wealth of information.



Concrete specimen between two halves of the test cell

# THE RAPID CHLORIDE PERMEABILITY TEST

The rapid chloride permeability test (RCPT), identified as AASHTO T 277 or ASTM C 1202, is specified by many departments of transportation as a means to achieve a low permeability concrete. Consequently, HPC Bridge Views decided to ask three experts about various aspects of the test and its application in practice. The following answers were supplied by Doug Hooton (DH), University of Toronto; Mohamad A. Nagi (MAN), Construction Technology Laboratories, Inc. (CTL); and H. Celik Ozyildirim (HCO), Virginia Transportation Research Council (VTRC).

**Q1.** *The RCPT has been criticized because its results have poor correlation with those from ponding tests (AASHTO T 259). Is there sufficient correlation between the results of the two tests for mixes incorporating fly ash, silica fume, ground granulated blast furnace slag (GGBFS), or combinations thereof to justify using the RCPT in bridge specifications?*

**DH** The relationship between RCPT data and diffusion coefficients calculated from ponding tests is quite good and appears to hold for a wide variety of concretes including those with fly ash and GGBFS,[1] silica fume,[2] and metakaolin.[3] The reports of poor correlation mainly result from the use of poor (too thick) test samples and the flawed integrated chloride analysis procedures used in generating the T 259 data, as described in Reference 4. If a more useful rate of penetration value is used instead, the correlation improves dramatically.[5] The correlations aren't perfect, but the relationship is clear.

**MAN** Although each test measures a different parameter, a correlation coefficient exceeding 0.95 was achieved in earlier studies with portland cement concrete. In the case of concrete incorporating silica fume, fly ash, or GGBFS, correlation between the two methods can be good, especially when the modifications of AASHTO T 259 used by researchers in recent years are implemented. These include extending the test time to 180 days to accommodate low permeability concretes, using the profile grinding technique, and calculating diffusion factors instead of integral chloride contents. As for the available data, a comprehensive study sponsored by the Portland Cement Association and currently underway at CTL will provide a wealth of data for both methods with concrete containing fly ash, GGBFS, or a combination of both.

**HCO** Many expect a high statistical correlation between results from the RCPT and the ponding test. However, RCPT results are generally obtained after 28 days of moist curing; whereas, those from the ponding tests are obtained after two weeks of moist curing, four weeks of air drying, and 90 days of ponding. It is obvious that the curing conditions and test ages are different. Such differences become very important when supplementary cementitious materials are used in the concrete. However, a qualitative relationship has been shown by research work done at the Virginia Department of Transportation (VDOT)[6] and elsewhere.[2,5]

Concretes that yield low RCPT values, also show a high resistance to chloride penetration. VDOT cures specimens for one week at 73°F (23°C) and for three weeks at 100°F (38°C) and tests them at 28 days. Also, T 259 specimens are ponded for one or more years rather than the standard 90-day period to discern the differences.

**Q2.** *Is the RCPT an accurate, consistent, and reliable test to evaluate the permeability of concrete that has been placed in an actual bridge?*

**DH** If the user is aware of the parameters that affect the RCPT test results, then the test can be used to evaluate in-place concrete. If the bridge has been exposed to chlorides, then the core samples that are used must be taken below the depth of chloride penetration. In-situ chlorides raise the pore fluid conductivity and the RCPT is largely a measure of conductivity. This precludes its use for evaluating the near-surface, curing-affected zone of the bridge—but this would be the same for ponding tests. However, if the concrete contains calcium nitrite corrosion inhibitor, the resulting higher pore fluid conductivity gives RCPT values that are too high—this is one of the limitations of the RCPT that is mentioned in the ASTM C 1202 version of the test.

**MAN** The accuracy of the RCPT is influenced mainly by the presence of materials in the concrete that influence its electrical conductivity, such as admixtures. However, the test gives a reliable indication of concrete permeability. The precision statement in ASTM C 1202 shows relatively high variations. However, these variations were partially caused by deviations from details of the test procedures and round robin instructions when the tests were conducted in 1985. If the round robin tests were repeated today, with the use of more reliable and commercially available equipment at laboratories that now have long-term experience with the test, variations would be much less.

**HCO** Yes. The issue is whether chlorides in the concretes affect the test results to a large degree. Concretes in actual bridge structures that have been exposed to deicing chemicals contain chlorides. Research performed in Virginia has shown that specimens from field concretes yield values comparable to those from laboratory specimens. Also, VTRC sometimes retests concretes. Such retesting shows that subsequent values are within 10 percent of the values from previous tests.

**Q3.** *Why are different coulomb values specified for precast concrete and cast-in-place concrete?*

**DH** I see no reason to have different specified values for precast concrete and cast-in-place concrete. In fact, if the values for precast concrete are less than those of cast-in-place concrete, then a lower RCPT value should be achievable on a day-to-day basis.

**MAN** One of the reasons is that the precast concrete has better quality control than cast-in-place concrete. Therefore, it is expected to yield lower RCPT values than cast-in-place concrete for a given mix design. Construction practices, such as consolidation, influence concrete permeability.

**HCO** The specification of different values for precast and cast-in-place concrete is related to the practical achievability of such values and the importance of the various bridge elements. For example, in Virginia, lower values are required in precast, prestressed concrete members than in bridge decks because the prestressed concrete members are load-carrying elements that are more difficult to replace than the bridge decks. Also, precast, prestressed elements are prepared in plants where more control is possible and lower RCPT values can be achieved. The exposure conditions are also important. Precast, prestressed members can be exposed to equal or worse conditions than decks through ocean spray and leaking joints.

## Q4. *How are recommended RCPT values influenced by local sources of concrete constituent materials?*

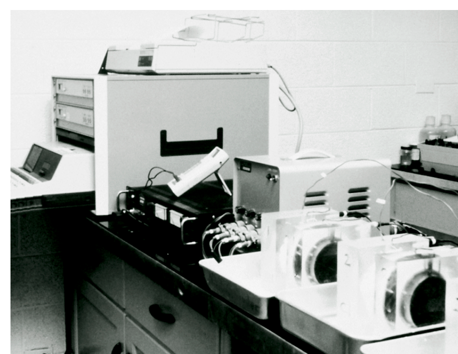
**DH** As with most tests, results for a given concrete mixture vary to some extent with local raw materials. Some important issues for the RCPT, and chloride resistance in general, are the effects of local materials on the unit water content of the concrete (even at a fixed water-cementitious materials ratio), as well as the type of pozzolan or GGBFS available.

**MAN** The source and gradation of aggregate influence concrete permeability. The sources and properties of pozzolanic materials may also have an effect. Changes in air content lead to changes in concrete permeability. RCPT values for fly ash concrete are usually higher at early ages and decrease with time. There are cases where fly ash concretes failed to meet the specified RCPT values when tested at 28 days. The same concretes would easily meet the specified values when tested at a later age such as 90 days.

**HCO** Some aggregates may have iron-bearing components, steel fibers may be present in the concrete, and some admixtures, such as calcium nitrite, may contain ions that affect the charge passed. Trial batches usually indicate whether problems can be expected. Ingredients that are conductive, such as steel fibers, can cause the coulomb values to be too high.

## Q5. *How do exposure conditions influence the recommended or specified RCPT values?*

**DH** Most of the specifications that I have seen, appear to be using RCPT limits, regardless of the value selected, to help ensure long service life for concrete exposed to chlorides from a marine environment or deicing salts. I don't think a lot of thought has gone into many of the actual values specified, in terms of relating them to a specific life in a specific environment. A value of 1000 coulombs is often referred to, and there is not much point going lower in terms of being able to achieve those values in practice consistently. In fact, one of the benefits of specifying any RCPT value is to get concrete producers and, hopefully, contractors, to pay attention to durability properties in addition to strength.



*A complete setup for the rapid chloride permeability test*

**MAN** Exposure and curing conditions, especially temperature, affect the concrete properties. Increases in curing temperature may lead to lower permeability. Optimum moist-curing will produce concrete with lower permeability. Formation of microcracks that can occur because of exposure conditions will influence concrete permeability as well.

**HCO** Severe exposure conditions justify the use of lower values. VDOT specifies lower coulomb values for deck concretes than for concretes placed in the substructure.

## Q6. *Do all low permeability concretes have low RCPT values and do all concretes with low RCPT values have low permeabilities?*

**DH** What people usually mean by low permeability is a high resistance to the penetration of some aggressive fluid such as a salt solution. This usually involves diffusion and other processes and not just a pressure gradient that the term "permeability" implies. A better term would be low penetrability. But regardless, for a wide range of concretes, low RCPT values are related to low penetrability. The major exception, which is mentioned in ASTM C 1202, is when a calcium nitrite corrosion inhibitor is used. This raises the pore fluid conductivity enough to raise the RCPT values significantly, even though chloride penetration resistance may be quite good. The RCPT is a rapid index test that is mainly providing a measure of conductivity. Conductivity will be affected by the volume, size, and connectivity of the pores as well as the pore fluid conductivity. Some have tried to use this argument to claim that this causes silica fume concrete to benefit unduly from low RCPT results, but we have looked at this and all our results using long-term ponding tests, show the same relative level of improvement with silica fume as is indicated by the RCPT.[1] Therefore, it may be that the pore fluid conductivity must have to increase greatly, to have a significant impact on the result.

**MAN** For most cases, the answer is yes. However, there are cases when relatively high dosages of chemical admixtures are used that RCPT values will be higher, even though the concrete has low permeability. The presence of these admixtures increases the conductivity of concrete leading to relatively higher coulomb values.

**HCO** The VTRC has used the RCPT for more than 15 years. Low permeability concretes have yielded low RCPT values, and vice versa. However, we have seen or heard of higher RCPT values with some concretes that are expected to yield low values. But, we have not been able to duplicate such concretes. Subsequent preparation of identical concrete mixes yielded the expected low values. Low permeability concretes containing conductive ingredients may have unrealistically high RCPT values.

*Q7. What improvements would you make to the RCPT procedure?*

**DH** There are several improvements that can be made. Many involve simplifying the saturation procedures and the cell configurations to make the test easier to perform. In addition, one of the real issues that affects the relationship of the results with those of the ponding test is the heating that occurs in concretes yielding higher coulomb values during the six hours of the test. An increase in temperature raises the conductivity of the pore fluid and raises the measured RCPT value. One suggestion[(4)] has been to multiply the 30-minute reading by 12 to get a six-hour RCPT value that is unaffected by this heating. This doesn't affect values less than 1500-2000 coulombs significantly, but corrects the heating effect on higher coulomb concretes.

Since the RCPT is really a measure of conductivity, it would be faster, easier, and cheaper to measure conductivity or resistivity directly, but there are no standard ASTM methods for these properties of concrete yet, and users would have to get accustomed to a whole different set of units and values. It would be preferable to have a rapid test that measures the chloride penetration resistance directly and allows calculation of a diffusion value that could be used in predictive service life models. At the University of Toronto, we have been working on this approach as part of an FHWA-funded research program. However, it will take some time to have the modifications accepted in ASTM and AASHTO standards.

**MAN** Improvement may be needed to ensure an optimum seal between specimens and cells, especially when the diameter of the specimen is slightly different than the diameter of the cell.

**HCO** Permeability of concrete declines over time. Therefore, 28-day results are not necessarily true indications of the potential of the concrete. A curing procedure that provides equivalent later-age RCPT values at 28 days would be useful. A curing procedure using a higher temperature accelerates the reduction in RCPT values, allowing values normally measured at later ages—6 months and beyond—to be determined at 28 days.

## References


1. McGrath, P. F. and Hooton, R. D., "Influence of Binder Composition on Chloride Penetration Resistance of Concrete," Durability of Concrete, Publication SP-170, American Concrete Institute, Farmington Hills, MI, 1997, pp. 331-347.
2. Hooton, R. D., Pun, P., Kojundic, T., and Fidjestøl, P., "Influence of Silica Fume on Chloride Resistance of Concrete," Proceedings, PCI/FHWA International Symposium on High Performance Concrete, New Orleans, Oct. 20-22, 1997, pp. 245-256.
3. Hooton, R. D., Gruber. K, and Boddy, A. M., "The Chloride Penetration Resistance of Concrete Containing High-Reactivity Metakaolin," Proceedings, PCI/FHWA International Symposium on High Performance Concrete, New Orleans, Oct. 20-22, 1997, pp. 172-183.
4. McGrath, P. F. and Hooton, R. D., "A Re-Evaluation of the AASHTO T 259 90-Day Salt Ponding Test," Cement and Concrete Research, Vol. 29, 1999, pp. 1239-1248.
5. Hooton, R. D., "Discussion of Durability Aspects of Precast, Prestressed Concrete – Parts 1 and 2," PCI Journal, Vol. 42, No. 3, May-June 1997, pp. 65-66.
6. Ozyildirim, C., "Permeability Specifications for High-Performance Concrete Decks," Transportation Research Record 1610, Concrete in Construction, Transportation Research Board, 1988, pp. 1-5.


### IN MEMORIAM

We are sorry to inform you that David A. Whiting died on September 25, 2000, after a battle with cancer. We will miss Dave's quiet professionalism. He developed the rapid chloride permeability test under an FHWA-sponsored project with Construction Technology Laboratories.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