

Some Thoughts on Realcrete, Labcrete, and Designcrete in Concrete Repair

By Alexander M. Vaysburd, Christopher D. Brown, Peter H. Emmons, and Benoit Bissonette

A large number of existing concrete structures are presently in a state of deterioration/distress. At the same time, many repaired concrete structures become severely deteriorated after only a few years of having been repaired. How can we halt the decay of the physical infrastructure? The durability of concrete repairs is at the present time a measure of its quality, much like strength and durability of new concrete structures. Durability must be ensured through the entire repair sequence, from the research, design, and material selection through construction practices and quality control. Every means of rendering concrete repair technology more reliable has an enormous engineering and economic significance considering the present day volume of deteriorated/distressed concrete structures.

Concrete repair is a complex process, presenting unique challenges that differ from those associated with new concrete construction. The repair process must successfully integrate new materials with old materials (Fig. 1), forming a composite system capable of enduring exposure to service loads, environment, and time.

Tremendous strides have been made in the understanding of durability of concrete, especially in severe environments, yet it still remains the foremost problem

facing the industry today. We have only to look at our newly repaired bridges, parking structures, and buildings to see that we do not yet have adequate answers. Spalling, cracking, rust staining, and corrosion of reinforcing steel are visible problems we are facing today (Fig. 2). But behind these visible manifestations of our shortcomings are more complex invisible problems. For some of them, it is worthwhile to look at them in detail and address the problem of “realcrete” versus “labcrete.”

It is an unfortunate fact that contemporary classification of concrete looks very different from what we were taught. It looks as follows:

- Bookcrete
- Labcrete
- Designcrete
- Machocrete (salespersoncrete)
- Legalcrete (mostly in the U.S.)
- Realcrete

Since the earliest use of concrete over seven millenniums ago, concrete repair started its history.¹ In recent years, the image of concrete has been shaken by durability problems, by often poor performance, and most of all, by concrete repair failures. The repair failures and endless “repair of repairs” made a substantial contribution to the

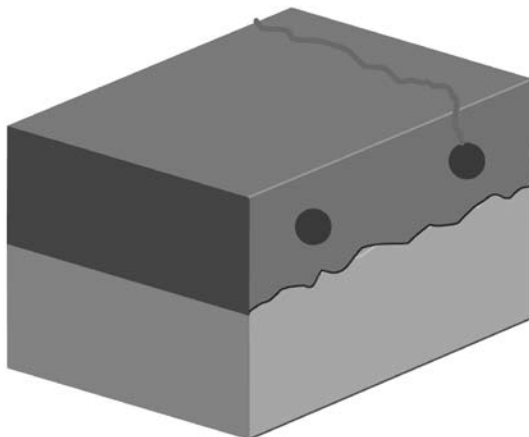


Fig. 1: Concrete repair composite system



Fig. 2: Concrete repair failure

current perceptions of concrete. Under the guise of producing high-performance materials, some of us frequently resort to the most extreme manipulations in blending binders, mixture design, the use of water, additives, and admixtures—manipulations that often defeat their purpose by diverting attention from simple but necessary basics of cement-based materials and result in unreasonably expansive materials with very questionable, if any, performance records.

We mix and we mold; we fumble and flounder. We develop and widely use—regardless of the situation—high-strength (“high-performance?”) concrete and repair materials; we unintentionally created an epidemic outbreak of self-desiccation and cracking. A discerning bacteriologist observed that the nose harbors more germs than any other portion of the body, and it was not until all noses had been amputated that he made another “great discovery”—the nose’s function is to be the intake strainer or trash rack for the body.

Existing research and testing methods used for evaluating the performance of concrete repair are clearly unsatisfactory. There are consistent inconsistencies in the reliability of laboratory test results. One of the reasons for this is that most of the tests are related to “labcrete” and cannot be synthesized into a complete understanding of in-place behavior and effects in repaired structures.

Cracking in a repair, caused by restrained volume changes, is one of the truly insidious phenomena of repair pathology, but permeability testing of materials using laboratory specimens disregards a dominating effect of cracking on permeability. The permeability of cement-based materials (realcrete) has very little to do with laboratory test data (labcrete), or with field permeability tests performed between cracks (foolcrete) (Fig. 3). Once a novice asked the great artist Rafael with what he mixed his paints. The master replied, “With brains.”² The same simple “method” should be employed by workers developing and using testing methods.

Laboratory and experimental testing should be designed to study repair-related issues of realcrete, paying more attention to the environment, repair location in the existing structure, its geometry, restraint, and nonuniformity. Various loading conditions need to be included in such testing programs. To give confidence to the technology, the science should provide a credible basis on which a prognosis of performance and longevity can be made.

A Glimpse of Repair Materials

Concrete repair is a complex process (Fig. 4). The greater the complexity, the greater the chance of errors, the greater the chance that something or somebody will sacrifice the quality. How can we solve this puzzle?



Fig. 3: Low permeability “labcrete”

Deterioration and distress of repaired concrete structures in service are a result of a variety of physical-chemical processes such as the corrosion of embedded reinforcing steel, chemical attack, and freezing and thawing. The most serious deterioration processes leading to repair failures are caused by the cracking of the repair material. When large, visible cracks become interconnected with micro-cracks, this network of cracks facilitates the transport of aggressive ions and gases to the embedded reinforcement, leading to premature corrosion and deterioration.

Concrete does not deteriorate by corrosion of reinforcement—it deteriorates by cracking. Corrosion, more cracking, and concrete spalling are effects, with initial cracking as the cause. It is not a question of what comes first—the chicken or the egg. It is a known cause.

The structure of cement-based materials is complex. The materials are a heterogeneous mixture of diverse components with widely varying characteristics and properties. It is a physical-chemical soup consisting of hydrated cementitious materials, aggregates, additives, and admixtures. Unquestionable progress has been made in the field of repair materials. But a material that has the required properties for a particular application is only one stage in the complex system that makes up the totality of concrete repair. The problem of durable concrete repair is more complex than it appears at first sight; it cannot be resolved only by selection of a good material. The whole issue needs to be approached from several angles.

Material, per se, does not perform, whether it is a concrete mixture in a truck or a repair material in a bag. Materials have a fundamental underpinning role in shaping industries. It follows that any considerations of materials needs and innovations

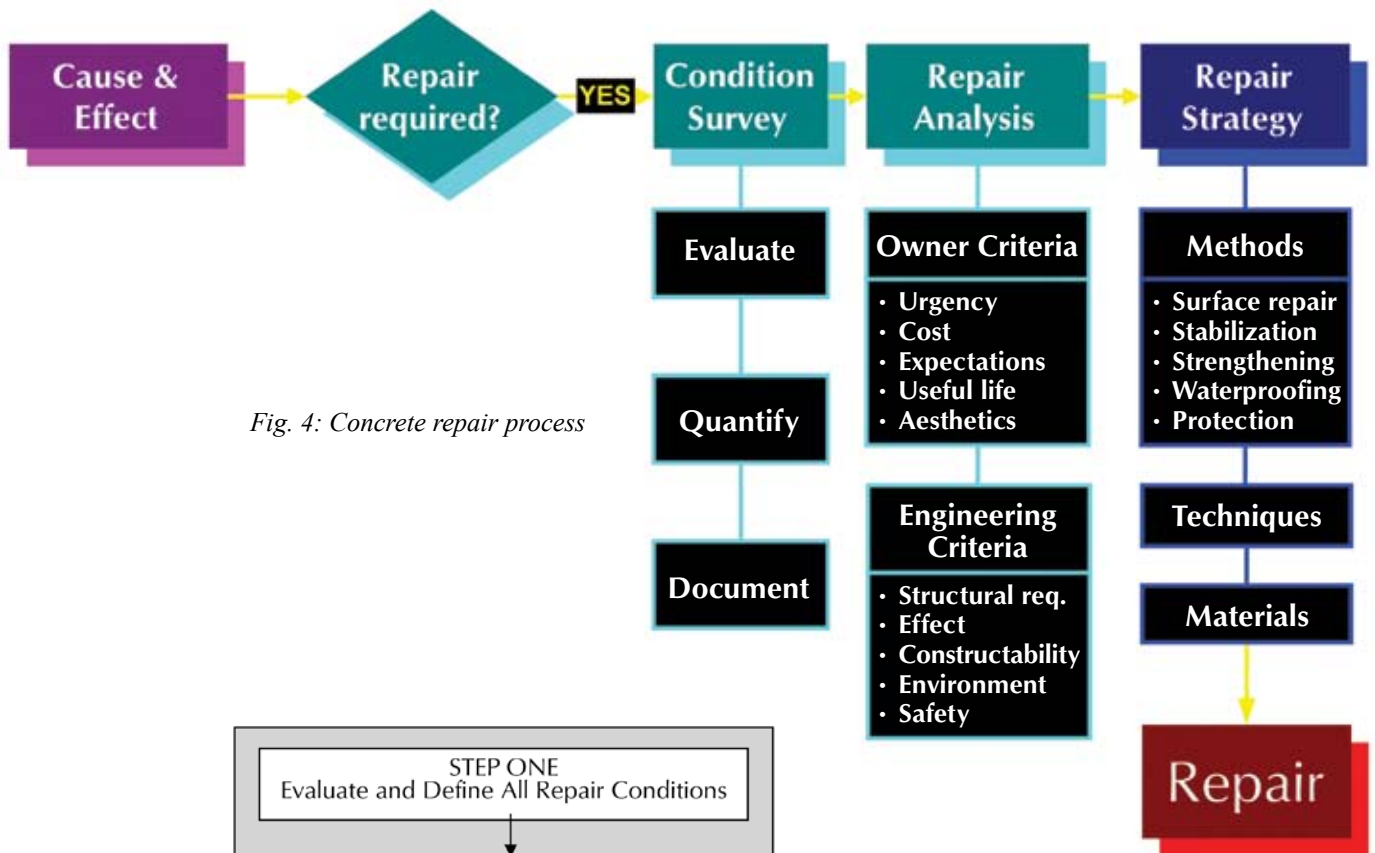


Fig. 4: Concrete repair process

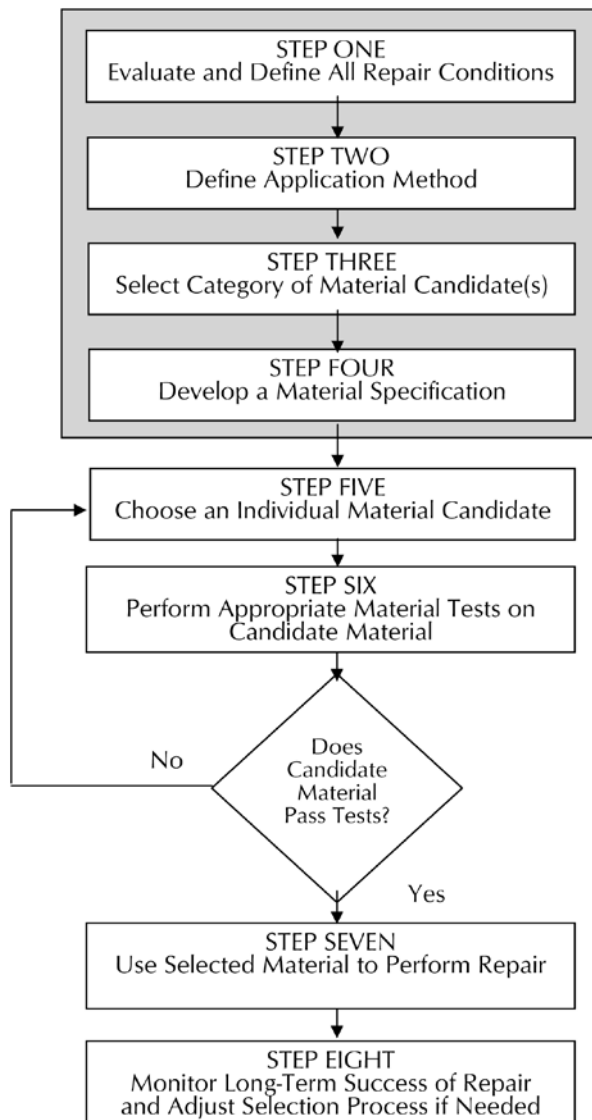


Fig. 5: Material selection procedure

should relate to the functions of the final engineering product. In stating this we are not reinventing the wheel. It was known even in Epictetus' time, 50 to 100 AD. He wrote in his discourse, "Materials are indifferent; but the use we make of them is not a matter of indifference."³ So, if material does not perform, how can we call it high-performance material? What do we really mean by a high-performance material—high performance for what? The answer to this is anything but obvious. High-performance concrete (HPC) presents itself as the solution to the problems it has created. It may sound cynical but we would like to make the following observation. For the past decade, the concrete industry has been engaged in the production and often unjustifiable use of high-strength concrete and similar cementitious materials, referred to by the opportunistic term "high performance." The major task of the next few decades will be to repair or replace the structures constructed of and repaired with so-called high-performance materials during the past 10 years.

High-performance concrete is another excuse not to address the real problems. In reality, "high-performance" requires a combination of adequate research, laboratory testing, quality design, materials, and workmanship. A flowchart of a proposed material selection process is presented in Fig. 5.

Design and Construction Objectives, Detailed Design

The design objectives, detailed design, and workmanship have the greatest impact on the performance of a repaired structure. The majority of faults and problems in the concrete repair field are caused by failure to establish realistic project objectives, lack of attention to detail in design, poor in-place workmanship, and inadequate quality control. King⁴ showed that, in the construction field, 99% of quality-related defects were due to poor design, detailing, specifications, workmanship, and management. At the global level, one can conclude that even with substantial advances in the field of repair materials, the industry will still have an unacceptably high level of defects and failures.

It is sometimes surprising to observe that a designer tends to have a rather hazy idea of the materials he is supposed to specify. He merely recognizes materials according to their slump, water-to-binder ratio, compressive strength, and how fast this strength is achieved as measured from some artificially made and artificially cured specimens. Design codes seemed to encourage this apparently narrow-minded attitude by translating every material performance into its compressive strength. Concrete repair design problems are almost always open-ended. They do not have a unique or correct solution, although some solutions are clearly better than others. They differ from the analytical problems with formulae used in mechanics, and structures, which generally have single correct answers. The first tools the repair designer needs is knowledge of what he is doing and an open mind, as well as the willingness to consider all facts. The designer has to know the subject matter, and has to look far beyond the "black box." He needs a better understanding of concrete repair as a unique composite system of materials exposed to the complex combination of interior and exterior environments.

In new structures, there is a well-defined structural system demonstrated in technical documentation. In repair and rehabilitation, one has only problems—symptoms, and if lucky, causes, often without any information about the anatomy of the structure to be dealt with. The following are some of these problems:

- What caused the failure or deterioration/distress?
- What is the remaining service life of the structure (durability capacity)?
- What is the present load carrying capacity of the structure?
- How will the repair treatment affect the overall structure (side effects)?
- Which materials and methods will offer the best (technical and economical) solution?

There is an increased need to pay more attention to constructibility issues during the development of

specifications and a higher level of knowledge in concrete technology, including field experiences in practical aspects of this technology for engineers developing such specifications. The design must contribute to the solution and not be the major problem. Geometry, access, amount and spacing of reinforcement, climatic conditions, available equipment, local engineering and labor skills, quality control, and economical considerations have to be analyzed.

The repair specifications are often a mixture of referenced standards and cut and paste clauses from previous projects. Often they tend to be based on borrowed wisdom as opposed to documented performance; mythology is used instead of methodology and misconceptions prevail over concepts.

The analysis of premature deterioration highlights the very essential role played by the construction process in providing the quality needed for a concrete structure to resist its environment. On-site workmanship is a crucial element in the repair's success or failure. Poor workmanship results in unacceptable variability in the concrete industry. Variability leads to premature failures due to various destructive processes. Variety may be the spice of life, but variability is a curse to the concrete industry. Variability derives from lack of control of processes, materials, and the environment. All good intentions in a rational design and material selection will fail if not supported by quality workmanship and quality control during construction.

Research and Laboratory Testing

Much research work on the durability of concrete is based on short-term laboratory testing in highly artificial conditions. Because it is not possible to simulate the field service conditions by accelerated laboratory tests, these test methods have a limited value for prediction and control of repair durability.

For many years there has been a search for small-scale tests that predict the occurrence and propagation of cracks in engineering structures. Prediction of cracking behavior in full-size repairs is usually associated with small specimen behavior in laboratory testing. Laboratory tests are usually inadequate because of one or more of the following basic reasons:

- (a) The small size does not allow the full constraints to be developed, and the critical tensile stress is not achieved;
- (b) General yielding of the small specimen during the cracking process clearly negates the fracture mechanics approach occurring in full-size repairs;
- (c) The strain rate does not reproduce that associated with a propagating crack in the full-scale repair, where cracks usually propagate at high speeds by absorption of elastic strain energy; and

(d) It is impossible to model the combined effects of an in-place environment on the small specimen under controlled conditions.

When considering the performance of realcrete (actual structures), the current laboratory tests on durability should be used with caution because the performance behavior of cementitious materials is highly dependent on environmental conditions, specimen geometry, curing history, and very much on the human factor—workmanship. Laboratory specimens (labcrete) are relatively small, produced by experienced technicians in controlled artificial conditions; usually they are not restrained against volume changes. It is easy for labcrete to yield low permeability values. The same material mixture when used in field structures may not prove to be durable due to the shrinkage cracking, exposure to frequent freezing and thawing, wetting and drying, and heating and cooling. Research has to concentrate on developing an inexpensive and relatively rapid, reliable method of evaluating repair material in regard to its future in-place performance, and thus establish a rational yardstick for selecting and specifying repair materials for which strength is of secondary importance.

Part of the reason that we still do not have an answer to the question “Should we protect or not protect reinforcing steel exposed in the repair area by applying an additional protection system?” is caused by the shortcomings in laboratory investigations of the corrosion performance of different protective systems. Steel bars and tendons within a repaired structure usually constitute an electrically continuous system. For unknown reasons, most of the research and laboratory evaluation carried out to date have been conducted by exposing the reinforcement in more or less uniform exposure conditions. Thus, the effect of the simultaneous

existence of diverse exposure condition with respect to various segments of the reinforcement in repair situations has not been fully understood and has not been evaluated.

To illustrate this point, consider the commonly used method for the evaluation of various reinforcement protection systems in chloride environments by the saltwater ponding test (Fig. 6). The method is being widely used for testing of concrete mixtures, chemical additives, inhibitors, and pozzolanic materials for resistance to chloride ion penetration. This test is useful for evaluating corrosion protection in new construction, if an unrealistic assumption is made that the concrete is crack-free and the chloride ion transport mechanism is by diffusion.⁵ Unfortunately, this method is being unjustifiably referred to and specified for evaluation of corrosion protection of reinforcement in repair systems. This test does not take into consideration the presence of the three phases of a composite system (existing, repair, and transition zones between them), the differences in permeability of existing and repair phases, or the effect of interior environmental variables such as the pH of solutions, presence of aggressive ions, the steel stress condition, and humidity.

No correlation has ever been established between the ponding test results and the corrosion protection in service. Therefore, it is not surprising that some systems failing the ponding test give good performance in service and vice versa. It might be argued that at least this test gives some general understanding of the protective capabilities of tested systems. The complex situation of chloride attack in concrete repair illustrates that, when dealing with corrosion problems in repaired structures, simplifications and generalizations are very dangerous.

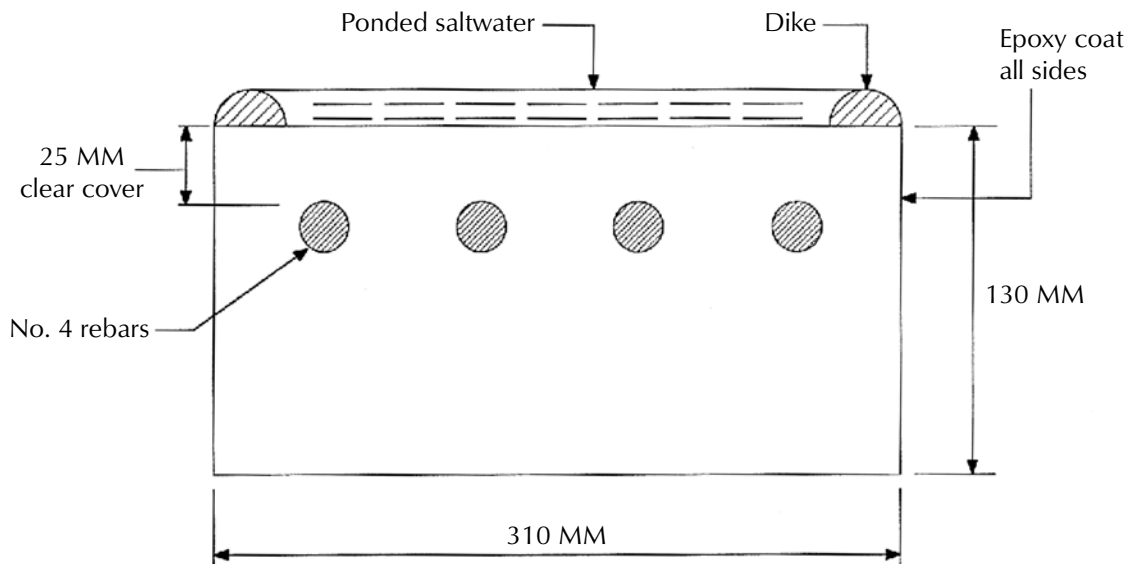


Fig. 6: Corrosion test specimen

Most likely, some of the researchers feel that it is up to the designer and contractor to control the conditions in field and, if this is not done, it is not their problem. Site condition is not perceived to be within the researcher's scope of work. The speed of construction nowadays also affects the researchers. There is no time devoted for the underbrush of misinterpretation and the resulting misinformation that has to be cleared before the research report is published.

One realizes that long, slow, and expensive field testing procedures conflict with the commercial factors involved and, therefore, a compromise testing program should be devised. But, facing the fact that existing laboratory tests do not satisfy the needs of the industry by lack of applicability to real-life situations, site testing becomes a necessity. The advantages of site testing are that the measurements made are specific to the test environment, the level of confidence is high, and the test results can be used to set up reliable, accelerated laboratory tests.

Looking to the Future

We know the answers to about 60% of the questions needed to perform concrete repairs properly—and can't wait to get the other 40%. Until then, we must do the best we can with what we have and make performance tests reliable. The tests will give us the right answers if we ask the right questions. According to Leonardo da Vinci, "Experiments do not ever err; it is only your judgement that errs in promising results which are not caused by your experiments."

It is hoped that the few thoughts highlighted here will contribute to a better understanding of concepts in concrete repair by enlightened researchers, educators, designers/specifiers, material manufacturers and contractors, so that many of the misconcepts that prevail presently can be avoided.

The most successful formula for the future in the concrete repair field is:

DESIGNCRETE = LABCRETE = REALCRETE

References

1. Stenly, C.C., *The History of Concrete*, Cement and Concrete Association (C&CA), United Kingdom, 1979.
2. Cross, H., *Engineers in Ivory Towers*, McGraw-Hill Book Company, 1952.
3. Vaysburd, A.M.; Bissonnette, B.; and Brown, C.D., "Durability of Concrete Repair—Field Analysis Versus Laboratory Results," *Proceedings of the 5th International Conference on Industrial Floors 2003*, Esslingen, Germany, January 21-23, 2003, V. 2, pp. 103-114.
4. King, N.P., "Efficient Concreting Practice: A Review of Current Procedures," *Proceedings of the International Conference—2000*, E&FN Spon, 1993, pp. 177-265.
5. Emmons, P.H., and Vaysburd, A.M., "Corrosion Protection in Concrete Repair: Myth and Reality," *Concrete International*, V. 19, No. 3, Mar. 1997, pp. 47-56.

This Viewpoint article has been selected by the editors as an offering to the interest of our readers. However, the opinions given are not necessarily those of the International Concrete Repair Institute or of the editors of this magazine. Reader comment is invited.



Alexander M. Vaysburd, FACI, is a principal of Vaycon Consulting, a Baltimore, Maryland-based consulting firm that specializes in concrete and concrete repair technology. He is also an associate professor at Laval University, Quebec City, Quebec, Canada. In 1996, he was awarded ACI's Wason Medal for Most Meritorious Paper. In 2000, Vaysburd received two ACI recognitions: the Cedric Willson Award and the Construction Practice Award.



ACI member **Christopher D. Brown** is President of Conproco Corp., Dover, New Hampshire, a pioneer in manufacturing fiberglass-reinforced cements for surface-bonded construction. Recently the company was awarded a contract for the development of a crack-resistant durable concrete repair material for Navy concrete structures. Conproco is active in ACI, ICRI, SWRI, and the Concrete Repair Engineering Experimental Program.



Peter H. Emmons, FACI, is President and CEO of the Structural Group. He is presently the Chair of the Strategic Development Council, Past President of ICRI, and Chair of ACI Committee 364, Rehabilitation. In 2000, he received ACI's Arthur R. Anderson Award for outstanding contributions to concrete technology and also was a co-recipient of the ACI Construction Practice Award.



ACI member **Benoit Bissonnette** is an associate professor at Laval University. He is actively involved in research on durability properties of repair materials. He is the author and co-author of more than 60 technical papers in the concrete materials field. Bissonnette is also active in various professional organizations such as ICRI and RILEM.