

# Renovation of the Concrete Repair Industry

by Fred Goodwin

**C**oncrete rarely suffers catastrophic failure. When this occurs, preventative measures are included by revising the building code, documented in the literature, and standardized in other industry publications. Even with these preventative measures, however, many problems still occur with concrete construction that will require repairs sooner or later. Estimates from the Vision 2020 report state that “The annual cost to owners for repair, protection and strengthening is estimated between \$18 billion and \$21 billion in the U.S. alone.” In 2005, the ASCE report card estimated that an expenditure of \$1.6 trillion was needed over the next 5 years to restore the infrastructure in the U.S. to a grade point average of C (refer to Fig. 1). Some estimate that up to 50% of concrete repair occurs during new construction (refer to Fig. 2). Examples of these noncatastrophic or near-miss failures include inadequate cover for reinforcing steel, formwork movement, honeycombing, and other “just a few minor cracks” or “close enough” situations. While

many observable defects are corrected, other times the defect is not detected and failure does not occur for some time. In any case, repairs are made. Estimates from the U.S. Army Corps of Engineers (USACE) as well as the CONREPNET reports estimate that about 50% of repairs to concrete fail. The failure rate of repaired concrete greatly increases with time because most repairs are less durable than the original concrete (refer to Fig. 3).

Concrete is a relatively difficult material to remove, but demolition and replacement of the structure is frequently the only option if repairs are delayed until the repair becomes cost prohibitive. Concrete requires repair due to the combined results of the three Ds:

- Design and construction errors;
- Deterioration; and
- Damage.

Concrete repairs are thought to be correcting the observed problems that exist in the concrete such

*Fig. 1: The American Society of Civil Engineers 2005 report card on America's infrastructure<sup>1</sup> was compiled by a team of 24 of the nation's leading civil engineers analyzing hundreds of studies and surveying more than 2000 engineers. Letter grades from A = Excellent to F = Failure are assigned based on condition and capacity, amount of funding versus the need, and other factors. For example, if 77% of roads were found to be in good or better condition, a grade of C would be assigned. In 1998—the first year of this report—a grade of D was assigned. In 2001, additional funding improved the grade to a D+ with an estimate of \$1.3 trillion investment needed over the next 5 years to restore the U.S. infrastructure to a C grade. The latest estimate from 2005 rates the infrastructure at a D grade and estimates that \$1.6 trillion is needed for restoration*

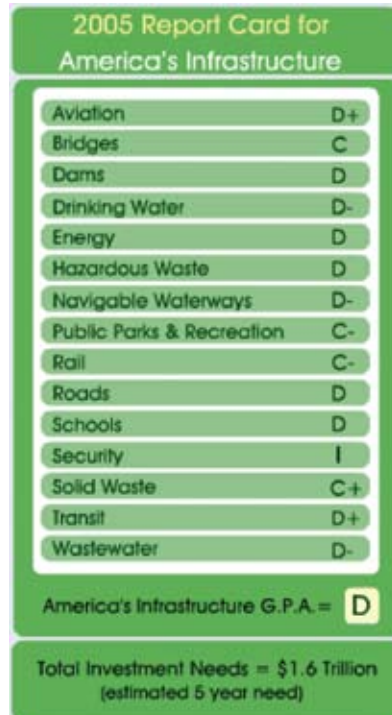


Fig. 2: Concrete failure occurrence<sup>2</sup>



Fig. 3: Failure rate of repairs based on elapsed time since the repair was performed<sup>3</sup>

as leakage, settlement, deflection, wear, spalling, disintegration, and cracking. Performing the repair without determining the root cause of the need for the repair nearly always forces another repair of the repair to occur. Determination of the cause for the repair, performing a condition survey, and developing a repair analysis are needed before implementation of a repair strategy. Frequently these additional steps are viewed as expensive and time consuming when the objective is to just patch or fill in the damaged area to most rapidly return the concrete structure to service.

There is a need for renovation in the concrete repair industry. One definition of the word renovate is to restore to life, vigor, or activity. In this sense, the concrete repair industry is renovating itself because of recent activities regarding development of repair specifications, industry guidelines, repair material understanding, and improved durability of repaired structures.

Concrete repair is a process (refer to Fig. 4). Consideration of safety, structural, functionality,

environmental protection and contamination, and aesthetic issues must be addressed. A maintenance plan should be included in the repair design to satisfactorily extend the life of the structure. There are five perspectives to be considered in the concrete repair process. They are:

1. The structure—cause and effect;
2. The owner—repair-required owner criteria;
3. The engineer—condition-survey engineering criteria;
4. The contractor—repair strategy; and
5. The manufacturer—material selection.

A condition survey should be performed to evaluate the root cause of the repair, determine the quantity of the repairs, and document them as found. The repair analysis must take into account the owner's needs: the urgency of the repair completion, the budget considerations, the service life of the repaired structure, and the aesthetics. Engineering criteria must also be met; not just the structural requirements, but the environmental constraints, the constructibility, and safety issues before, during, and after the repair. The

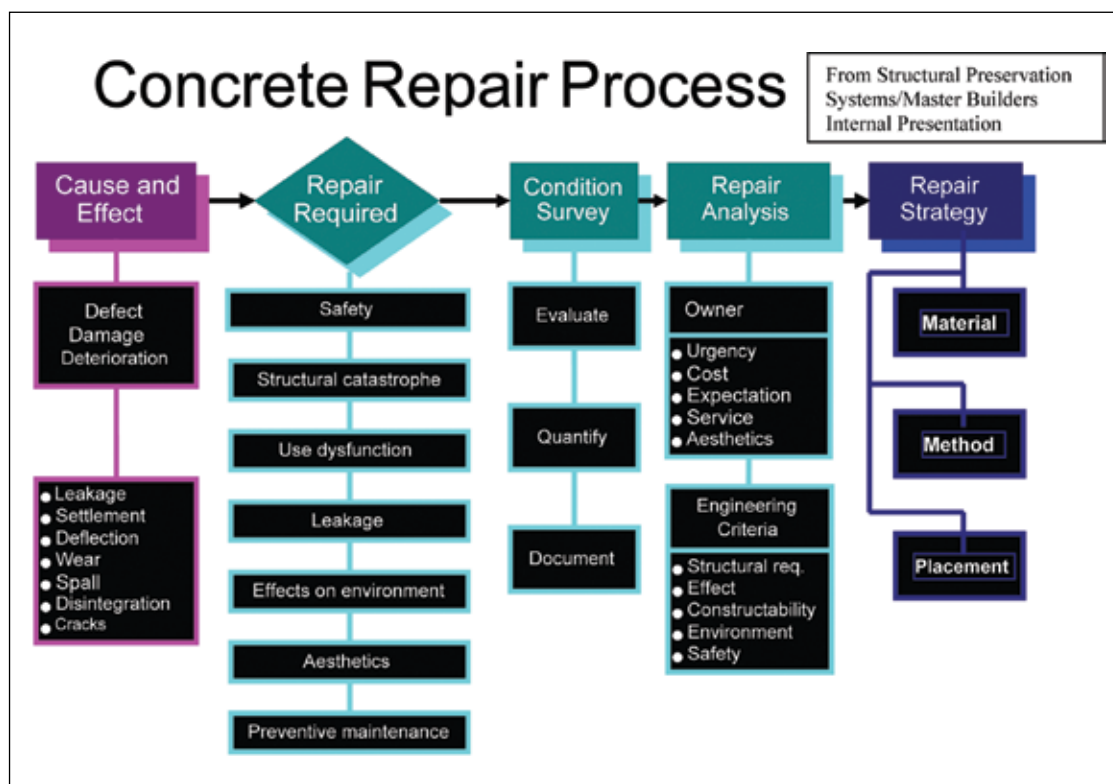


Fig. 4: The steps of the concrete repair process involve observing the effects of defects, damage, and deterioration causing leakage, settlement, deflection, wear, spalling, disintegration, and cracking. Determination of the need for repairs must consider safety, structural integrity, usage dysfunction, leakage, environmental contamination, aesthetics, and a plan for continued preventative maintenance. The result of this determination is all too frequently replacement of the structure (as repair is no longer possible) or minimization of the repairs to sell the structure. A condition survey is needed to evaluate the necessary areas for repair, quantify repairs for estimation purposes, and document these findings, usually in a proposal. The needs of the owner and engineer as well as other involved parties must be addressed to develop a repair strategy. Note that the three parts of the repair strategy must be considered together—the constraints of the material, the application method, and the implementation methods of the repair

strategy for the repair must be designed to be compatible with the concrete substrate, the environment of the structure, and the application constraints.

Several lists of repair material properties exist, correlating the repair material properties with the concrete substrate; however, often only the ultimate material properties are considered. Cementitious materials in particular undergo significant changes during curing. The substrate concrete has usually reached its final properties of volume change, strength development, and acclimatization to the environment. When applied, most repair materials must be of a consistency suitable for the application method and achievement of bond and consolidation. Development of the final physical properties occurs over time and often involves shrinkage, changes in modulus, heat evolution, and other physical and chemical changes to occur during the transition from application to service properties. Achievement of compatibility of the repair material with the substrate, the application, and the environment must be a series of informed compromises.

Specifications attempt to define important material properties, test methods for evaluation of those properties, and minimum acceptable values for the properties. Unfortunately, each repair situation is different and specifications developed for one situation may not be appropriate to another situation. Furthermore, specifications drive compliant materials toward commodities, hindering innovation—if a material is compliant with a specification, it is viewed as equal to others and price becomes the differentiating factor.

## New Industry Protocol

Recently, a new type of document has been adopted by ICRI. The ICRI Technical Guideline No. 03740, “Inorganic Repair Material Data Sheet Protocol,” was developed through a balanced task group of specifiers, researchers, and materials producers to provide a means of fairly comparing cementitious repair materials with documented test methods suitable for cementitious repair materials, as well as producing a mechanism for verification of the material’s performance by applicators and specifiers. This document defines the important properties for cementitious repair materials and provides guidance for test methods and modifications to standard methods to make them appropriate for concrete repair. Unlike a specification, minimum performance values are not listed. This allows for evaluation of material characteristics as appropriate for a repair situation, verification of material performance, and forces innovation based on technical characteristics rather than just on price. ACI 546.3R-06, “Guide for the Selection of Materials for the Repair of Concrete,” provides more detailed explanation of different tests and is harmonized with the ICRI document. Also under development is a

document by ACI Committee 364, Rehabilitation, to serve as a guide to the ICRI document.

Failures of concrete repairs tend to be more readily accepted than failures of the parent concrete. Few corrective feedback mechanisms are currently in place to improve the industry practice such as those that exist with new concrete construction. Recent developments arising from Vision 2020 and increased visibility of the concrete repair industry through organizations such as ICRI have resulted in many initiatives to improve this situation. Development of a repair code (similar to the ACI 318 Building Code used for new construction) is underway at ACI under the newly formed ACI Committee 562, Evaluation, Repair, and Rehabilitation of Concrete Buildings, with an objective to issue a code of concrete repair by 2012. Reference specifications will be developed by ACI Committee 563, Specifications for Repair of Structural Concrete in Buildings, and guide specifications are being developed in the ICRI Guide Specifications committee to supplement the code from ACI Committee 562.

Another very interesting document is under development by ISO TC71 that focuses on inspection and prevention to minimize the life-cycle cost of concrete structures. Prevention of repair through quality of the initial construction, preventative maintenance, and addressing minor problems before they progress to major issues in the structure can significantly extend the life cycle of structures, produce fewer interruptions in usage, and cost much less over the life of the structure.

Different structures are first assigned levels of criticality according to maintenance categories. Examples of two extreme cases are the severity of failure of a residential sidewalk compared with that of a nuclear reactor. In the case of failure of the sidewalk, replacement is obviously the preferred remedy for such disposable structures. On the other hand, failure of a nuclear reactor is not an option and every step to prevent such an occurrence is worth consideration. A maintenance plan is an integral part of the project design, whether for new construction or major rehabilitation. A maintenance classification system is shown in the following based on the impact to society for different structures with increasing attention to prevention and diagnosis as the importance of the structure increases. The final category of noninvestigative maintenance is for special cases that do not fit within the other categories.

A hierarchy of inspections is also described in the ISO document under development. Any significant structure should undergo an initial inspection with issuance of a “birth certificate” including as-built plans, baseline measurements, and certification of compliance to the project specifications. Subsequent repairs would renew and update this birth certificate. For critical structures, the proposed document

## Maintenance categories

<b>Category A</b>	<b>Preventative maintenance</b> <ul style="list-style-type: none"> <li>• Very important structures (that is, many occupants, service life of &gt;100 years)</li> <li>• Establish long-term monitoring system; initial, routine, and periodic inspections</li> <li>• Preventative measures at design and construction (that is, cathodic protection)</li> </ul>
<b>Category B</b>	<b>Normal maintenance</b> <ul style="list-style-type: none"> <li>• Normal structures (that is, service life of &lt;100 years, restored when needed)</li> <li>• Initial, routine, and periodic inspections; visual and with simple instruments</li> </ul>
<b>Category C</b>	<b>Investigation maintenance</b> <ul style="list-style-type: none"> <li>• Temporary buildings (that is, service life of &lt;20 years)</li> <li>• Routine inspections</li> <li>• When signs of deterioration occur, either simple repair or demolish</li> </ul>
<b>Category D</b>	<b>Noninvestigation maintenance</b> <ul style="list-style-type: none"> <li>• Offshore structures</li> <li>• Underground and underwater structures</li> </ul>

provides for monitoring and routine inspections. Monitoring can consist of imbedded strain gauges, movement indicators, ambient condition documentation, and corrosion sensors. Routine inspections can be thought of as a security guard's or control room operator's logs. Monitoring and routine inspection are further supplemented with regular inspections, conducted on a periodic basis, with the intent of early detection of problems. Extraordinary inspections are conducted in the event of a damaging event to determine the extent of emergency repairs and provide preliminary findings for a detailed inspection. The detailed inspection is a focused forensic investigation to develop a repair strategy.

- **Initial inspection:** Investigation of structures and examination of construction documents to detect initial defects noncompliant with design requirements;
- **Routine inspection:** Normal (that is, daily) visual examination of structures;
- **Monitoring:** Recording of data from systems incorporated into the structure;
- **Regular inspection:** Periodic investigation to detect signs of deterioration;
- **Extraordinary inspection:** Investigation and evaluation of damaged structures; and
- **Detailed inspection:** Investigation and determination of level of damage and deterioration in a structure.

Another standard that is due to be finalized by the end of 2008 is a new European standard that has been under development over the past 15 years. The European Standard EN 1504, "Products and Systems for the Repair and Protection of Concrete Structures," is aimed at all those involved with the repair of concrete. EN 1504 deals with all aspects of the repair and/or protection process including:

- Definitions and repair principles;
- The need for accurate diagnosis of deterioration causes before specification of the repair method;
- Detailed understanding of the needs of the client;

- Product performance requirements and test methods;
- Factory production control and evaluation of conformity, including CE-marking; and
- Site application methods and quality control of the manufacturing facility.

The standard consists of 10 parts, each covered by a separate document.

- EN 1504-1 describes terms and definitions within the standard;
- EN 1504-2 provides specifications for surface protection products/systems for concrete;
- EN 1504-3 provides specifications for the structural and nonstructural repair;
- EN 1504-4 provides specifications for structural bonding;
- EN 1504-5 provides specifications for concrete injection;
- EN 1504-6 provides specifications for anchoring of reinforcing bars;
- EN 1504-7 provides specifications for reinforcement corrosion protection;
- EN 1504-8 describes the quality control and evaluation of conformity for the manufacturing companies;
- ENV 1504-9 defines the general principles for the use of products and systems, for the repair and protection of concrete; and
- EN 1504-10 provides information on site application of products and quality control of the manufacturing facility.

Documents that specifically relate to products and systems deal with product specifications. Performance characteristics are defined as either for "all intended uses"—this provides the minimum technical performance parameters that have to be met for each and every application—or for "certain intended uses"—these characteristics ensure that the repair system can withstand the many harsh conditions that may have caused the original defects. Performance requirements define the

minimum quantitative values that a product must achieve when tested under standardized test methods and conditions. A great deal more information about the EN1504 standard that is beyond the scope of this document is available.

## Cracking

The most common failure mode documented for concrete repairs is cracking. While it is frequently thought that the cracking of repair materials is caused only by drying shrinkage, other types of failures, such as reinforcing steel corrosion, alkali-aggregate reaction, improper load transfer through the repair, and sulfate attack, evidence themselves as cracking (refer to Fig. 5). Furthermore, only in rare cases of very fine cracks in moist environments do the cracks ever close due to autogenous healing; generally, small cracks become larger, continue to propagate, and contribute to further deterioration by allowing ingress of deleterious agents (that is, chlorides, water, and carbonation) that provide for acceleration

of deterioration. The root cause of nearly all cracking of cementitious materials is that the relatively low tensile capacity of the cementitious material has been exceeded. Tensile creep can help equalize stresses of restrained shrinkage, yet there is no standardized test to quantify tensile creep.

Recently a test method was adopted as ASTM C1581 that allowed comparison of the cracking resistance by combining the effects of drying shrinkage (and to some extent, autogenous shrinkage), tensile strength, and tensile creep. In this test, a ring-shaped specimen is cast around a central restraining ring that has strain gauges mounted to record movement. The bottom of the ring rests on a plastic film that prevents drying and minimizes restraint. The top of the ring is waxed so that drying occurs only from the outside of the ring, which then compresses the inner restraining ring and is recorded from the strain gauges. The inner restraining ring provides sufficient restraint so that creep effects in the material being tested can be considered (refer to Fig. 6). As in repair situations, the driving force for cracking is drying shrinkage and lower shrinkage materials produce less stress on the ring. The higher the tensile strength and tensile creep of the material, the more drying shrinkage stress can be accommodated. The ASTM C1581 test assumes that materials dry uniformly, does not consider thermal effects, and is limited to materials containing less than 1/2 in. (13 mm) diameter top-size aggregate. Despite these limitations, it appears that much useful information can be gained by comparing the cracking resistance of different repair materials using this method.

This article has provided a brief glimpse into some of the improvements to our industry. There is plenty of concrete in need of repair and information is becoming available to show how

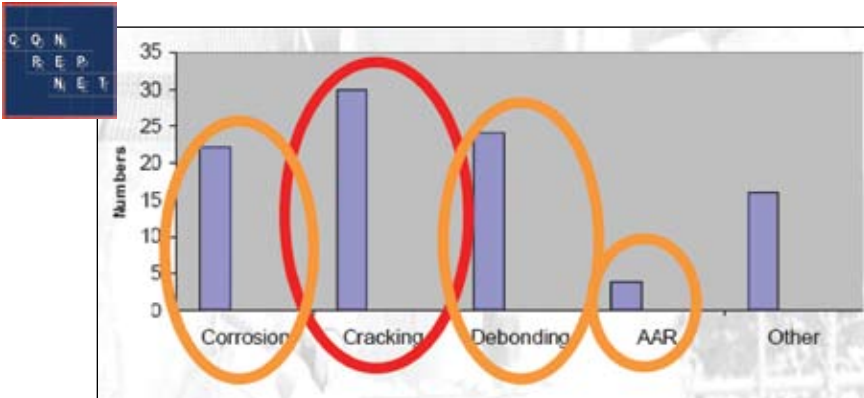


Fig. 5: The CONREPNET study found that cracking was the most common failure mode of concrete repairs. Corrosion, debonding, and alkali-aggregate reaction are also commonly associated with cracking

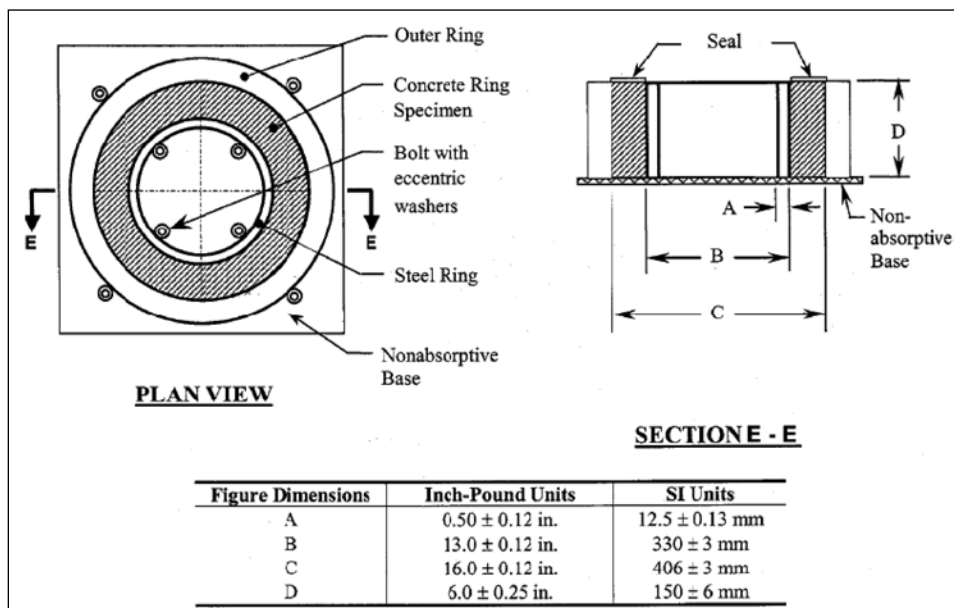


Fig. 6: ASTM C1581, "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage," combines the effects of drying shrinkage, tensile creep, and tensile strength to provide comparative information about the cracking resistance of cementitious materials under standard laboratory conditions. The inner steel restraining ring is intended to provide sufficient restraint so that most materials crack within 28 days after the initiation of drying (removal of the outer mold)



durable concrete repairs can be beneficial to our society. A recently published book, *The Economics of Historic Preservation* by D. Rypkema (published by the National Trust for Historic Preservation), compiles statistics from many sources to show that restoration of historic structures is beneficial both to the local economy as well as to the environment. Sustainability initiatives of which LEEDS is perhaps the best known show not only that the building of structures can be optimized for environmental benefits, but also how keeping our existing structures useful over a longer life cycle is the largest benefit to resource use and impact to the environment. When one considers the amount of knowledge currently available concerning concrete technology, the increasing usage of

concrete in our most significant structures, and the desire for continued improvements in the quality of our lives, concrete repair will continue to evolve and become integral to providing sustainability for our future.

## References

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