Practice Points NUMBER 16

Assessment of Historic Concrete Structures

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Concrete, a popular construction material, has been utilized by the modern construction industry for well over a century. Consisting of coarse aggregate (gravel and crushed stone), fine aggregate (sand), cement, and water, and in some cases augmented by additives to increase durability and flowability of the material, concrete has been used widely for paving, sidewalks, roads, bridges, tunnels, buildings, and other structures. Concrete quickly gained acceptance in twentieth-century construction because it offered the advantages of conforming to virtually any shape, was offered in various architectural finishes, and provided fire resistance superior to that of many other construction materials. Reinforced concrete offers the added benefit of reinforcing with steel for tensile strength, which enables concrete to be used far more extensively as a structural element. As development of new admixtures and additives continues, the possibilities of concrete construction appear limited only by the creativity of the designer.

Concrete quickly gained in popularity as a fireproof material, as cities expanded rapidly in the early twentieth century. Later, as understanding of its advantages and potential grew, concrete was used extensively not only for structural elements but also for architectural finishes on both the exterior and interior of buildings. Widely used in modernist architecture, concrete essentially defined the brutalist architecture movement, named after the French term *béton brut,* meaning raw concrete. Architects Le Corbusier, Erno Goldfinger, and others pioneered the brutalist movement. Other modernist architects, such as Louis Kahn, Tadao Ando, and Welton Becket, continued the use of concrete in architectural elements in their designs. Figures 1 through 3 illustrate the use of exposed concrete as an architectural component.

Fig. 1.
Exposed architectural-concrete facade and concrete elements at the Bailey School in Jackson, Mississippi, designed by architect A. Hays Town and built in the 1920s. Photograph 2016. All photographs by the authors unless otherwise noted.

Cast-in-place construction is defined as concrete placed while fluid into formwork constructed at the intended location of the concrete element. Once the concrete gains adequate strength, the formwork is removed, exposing the concrete surface. Precast construction is cast off site; once sufficient strength has been gained, the precast elements are transported to their final locations and installed. Both of these construction methods allow for variations in the final appearance of the concrete.

In using concrete as an architectural material, architects have paid attention to its material constituents,

Fig. 2.
Exposed concrete used as architectural finish at the Legislative Assembly in Chandigrah, India, designed by Le Corbusier, 2016.

Fig. 3.
Exposed concrete used as architectural finish at Salk Institute for Biological Studies, La Jolla, California, designed by Louis Kahn, 2016.

as well as to construction methods, as these factors directly impact the overall aesthetic. By varying the amount and type of material constituents, including the aggregates and cements, the material properties and color of the concrete can be adjusted. Construction methods and finishing techniques directly impact the final surface appearance and texture. Some of the various finishing techniques used historically, as well as today, include exposing the aggregates, retaining the texture from the formwork for a rougher finish (board form), and rubbing to create a smooth finish (Figs. 4, 5, 6, and 7).

Like other construction materials, concrete eventually deteriorates over time and with exposure to the environment. Primary causes of deterioration are usually related to the freezing and thawing of entrapped water, corrosion of embedded metal, problems with the material constituents, or problems during original construction, such as insufficient reinforcement. The nature and severity of each type of deterioration depends upon the climate and other conditions of exposure (such as pollutants and/or chlorides). Deterioration and distress can also be related to structural issues, such as overloading, or natural disasters, such as earthquakes. To address distress and deterioration, a rehabilitation strategy must be developed; this process also requires an understanding of the owner's intentions with the planned project.

It is important to note that historic structures designated or listed at the federal, state, or local levels will be subject to governing standards and requirements for reviews associated with preservation and rehabilitation. While similar processes and procedures are utilized for the assessment of any concrete structure, additional investigation may be necessary for historic structures; the development of repairs may be complicated due to the original construction methods, exposed finish, conservation of historic fabric, or other factors.

Expectations should be established with the owner at the beginning of the project. There may be situations in which the ultimate goals of the owner of a property designated as historic are not in line with governing standards, and it is the responsibility of the design professional to guide the project to develop goals, a rehabilitation strategy, and a maintenance program that are sensitive to the historic fabric and character of the building. Consideration of the significance of the concrete structure, preservation goals, and limitations on repairs and modifications must be addressed with the owner of an architecturally significant and historic property during the initial stages of the project.

An appropriately sensitive rehabilitation strategy addresses existing distress, including structural concerns, with compatible materials and repair procedures and without unnecessary removal or modification of significant elements. As an initial step in the development of a rehabilitation strategy, an assessment of the structure should be performed to evaluate existing conditions and determine causes of distress and deterioration. The findings of the assessment provide the basis for development of a rehabilitation strategy, which typically includes a repair and maintenance program. The assessment should also include identification and documentation of historically or architecturally significant components. An understanding of the original construction, as well as of deterioration mechanisms, provides information to support development of the repair and maintenance program.

Research

The first step in any assessment is gathering information relevant to the original construction, use, maintenance, and modification of the structure. This

Fig. 4.
Smooth-form concrete finish.

Fig. 5.
Board-formed concrete finish.

Fig. 6.
Board-formed concrete finish.

Fig. 7.
Exposed-aggregate concrete finish.

initial step allows the design professionals conducting the assessment to become familiar with not only the original construction but also the previous repair and maintenance of the structure. For reinforced-concrete structures, an understanding of the design and behavior of the structural system may be necessary, depending on the goals of the project. The designed structural system, as well as the construction materials and methods, will have an impact on the repair design, as well as on the performance of the structure. In addition, it is important to understand the conditions of the original construction and materials utilized. For example, a document review may indicate that the mixture design for concrete placed during the winter may include an accelerating admixture that may contain chlorides. If limited documentation is available, a more detailed field investigation may be necessary to understand the existing design and construction.

Original construction drawings are often available. In some cases specifications or other construction-related correspondence, such as field reports, submittals, requests for information, construction quality-control records, and manufacturer's information related to installed products may also be available for review. Archival photographs can also provide information regarding the construction methods and use of the building. News articles from the time of construction may also be a resource for structures, particularly if the structure is prominent to the community or considered noteworthy for its architecture. Information can also be found in documentation from previous investigations and prior repair and maintenance work, as well as through interviews with the owner, facility managers, and maintenance staff. It is important to verify information obtained through research and interviews against actual conditions. If the original construction drawings are not available, information on proprietary reinforcement and formwork systems may be available in manufacturers' catalogs or product data.

If a historic structure report exists, it likely will contain valuable information pertaining to the history, construction, and use of the building. In addition, if available, landmark-nomination reports, Historic American Building Survey (HABS) and Historic American Engineering Record (HAER) documentation, or other documents can yield information regarding the building.

Field Investigation

The next step is the field investigation, which includes a condition survey and comparison of the as-built construction with the documents and information obtained during the research. In addition, the field investigation should be utilized to identify and confirm the architecturally or historically significant elements.

Fig. 8.
Delamination and spalling in exposed concrete, documented as part of the visual condition survey. Photograph by Adrienne Goetz, WJE.

Fig. 9.
Freezing- and thawing-related distress at a historic exposed-concrete monument, Wyoming, 2008.

The field investigation typically includes visual observations, documentation, and measurement of elements of interest, as well as nondestructive testing, inspection openings, and removal of samples for laboratory testing, as further discussed below. The condition survey is the most important part of the field investigation because it provides the baseline information for further analysis and development of a rehabilitation approach. Modifications or repairs not mentioned in documents should be investigated, as they could have an impact on the behavior of structural elements or could potentially contribute to deterioration. In addition, modifications to historic structures may need to be evaluated in order to determine their significance. In the case of reinforced concrete, as-built conditions may not be visible since the reinforcement bars are encased in concrete; therefore, it is likely that additional testing, nondestructive evaluation, or inspection openings will be needed to confirm concealed conditions.

The condition survey starts with a visual survey and the documentation of the existing conditions of the concrete components, including the structural and architectural elements and the original concrete finish and texture. Coatings or membranes applied to the concrete and the condition of these systems should also be investigated and documented. Documentation of observed deterioration, including spalling and cracking, typically includes photographs, notes, and annotations on plans or elevations to indicate locations and sizes of observed deterioration and distress. Cracking is not an unusual condition; however, the investigation and documentation of cracking can provide information regarding why the cracking occurred. The condition survey can also yield information about original construction such as placement techniques, poor consolidation of the concrete during placement, and other issues. Spalls that expose corroded reinforcement are of particular interest, as this is a primary deterioration mechanism, and can also provide information on reinforcement (Fig. 8).

The use and exposure of the structure should also be documented (Fig. 9). For example, as chlorides can induce corrosion of the reinforcement, it is important to note any potential external chloride sources; these sources may include salts used on adjacent sidewalks or driving surfaces in the winter to reduce snow and ice or the proximity of the structure to the ocean. The location of the building and source of materials present may yield information regarding the original construction. For example, local sand or soil with characteristics unique to the location may have been used as fine aggregates, which can impact the performance of the concrete. If deterioration appears unique to, or particularly prominent at, one portion of the structure (for example, where guardrails are attached), these conditions should be documented. Localized or unique deterioration may be indicative of inappropriate construction practices at a portion of the structure, structural concerns, incompatibility of materials, deterioration related to use of the structure, or other distress mechanisms affecting only a specific component or area of the structure.

Field and Laboratory Testing

To confirm and augment the findings of the visual investigation, nondestructive testing, inspection openings, and laboratory studies are useful in locating and determining the extent of deterioration and distress conditions in the concrete, confirming as-built conditions, assessing causes of deterioration and distress, and providing information regarding the concrete materials. The reinforcement embedded within concrete often requires investigation beyond the visual survey to understand the as-built construction or to verify information shown in construction documents.

Nondestructive evaluation can provide some information regarding the location of reinforcement, properties of the concrete, and the location and extent of distress. The most common type of nondestructive testing is sound testing, which involves tapping the concrete surface with a hammer or other hard instrument or by dragging heavy chains over horizontal surfaces to identify areas of delaminated and unsound concrete; these areas will sound hollow or dull. Sounding is a simple and valuable field-testing technique and should be utilized in most concrete structure-condition surveys. Other nondestructive-testing techniques involve passing ultrasonic or radar waves through the concrete and measuring the response; changes in wave frequency or speed can indicate embedded components or distress within the element not visible at the surface. Ground-penetrating radar and cover meters are commonly used to confirm as-built conditions, such as dimensions, when only one side of the concrete element is accessible; these techniques also help identify the location of reinforcement and other embedded or encased items (Fig. 10). Exploratory openings are used to confirm results from nondestructive testing.

As conditions that contribute to deterioration and distress within concrete structures are often not visible, the use of inspection openings and field testing to verify conditions from the visual survey, sounding, and nondestructive testing are often an important part of the assessment. For example, to determine the extent of carbonation, testing samples removed from the structure with phenolphthalein is necessary; determining the extent of carbonation of the concrete is important, as carbonated concrete loses its inherent ability to passively protect the embedded reinforcement from corrosion. Locations for inspection openings should be representative of the various conditions noted during the survey and should be as unobtrusive if possible, especially on historic structures. Existing distress may provide information and minimize the requirement for additional removal of material. For example, existing spalls provide an opportunity to examine concealed conditions with only minor additional removals. Inspection openings can reveal the size and spacing of reinforcement, depth of concrete cover, information on concrete mix, depth of deterioration, and other information.

Laboratory studies can provide information regarding the characteristics of the concrete and the causes of deterioration. Samples, preferably concrete cores of the size as required by the prescribed laboratory, can be removed from representative locations. Locations of cores should be selected to avoid areas with reinforcement locations unless it is necessary to confirm conditions of the reinforcement. A structural engineer should be consulted if reinforcement is to be damaged during the sampling. If core samples cannot be obtained due to budget, access, or other limitations, fragments or incipient spalls yield some information, although limited by the uncontrolled nature of a fragment. Laboratory testing can determine the compressive strength of the concrete, chloride content, air content, specific constituents (through chemical analysis), and other information. Petrography, the detailed analysis and study of concrete using stereomicroscopy, provides valuable information regarding concrete composition, original concrete mix, and the potential causes of observed distress. Information gathered through materials studies helps identify causes of distress and also assists in the development of the scope of work for repairs, such as specification of compatible and aesthetically matching concrete-mix designs.

Fig. 10.
Use of nondestructive testing to determine location of reinforcement steel during an assessment of a concrete structure.

Evaluation of Findings

The findings from the document review, field investigation, and laboratory testing are then studied to determine the underlying causes of observed deterioration and distress. In some cases, structural assessment and analysis may be necessary, if, for example, as-built conditions are found to be different than anticipated (e.g., less reinforcement in the structure than shown in construction documents). The cause(s) of observed deterioration and distress must be understood in order to develop an appropriate scope and define the extent of the repair design. The owner's intended use and maintenance of the structure, as well as its significance and value, should also be understood and considered during the evaluation. Through evaluation of the assessment findings and the owner's project goals, an approach can be developed to address the owner's concerns while being sensitive to the preservation and conservation of the historic fabric. Typically, the evaluation concludes with the preparation of a report for the owner summarizing the findings of the assessment and recommendations for repair, with recommendations for further investigation as required. The report also serves as a basis for development of a mockup or trial repair program and construction documents for the repairs.

In Conclusion

The use of concrete as both an architectural and structural material has created challenges, particularly in cases where the concrete is an exposed architectural element. Concrete can suffer from various distress mechanisms, ranging from environmental exposure to problematic original design and construction. The first step in the rehabilitation of a historic concrete structure is an assessment to identify architecturally or historically significant characteristics, understand as-built construction, and determine the extent and cause of distress and deterioration. The assessment should gather as much information regarding the original construction, maintenance, and use, as well as about cause and extent of any deterioration. The assessment should include research and document review followed by on-site field investigation and field and laboratory testing. The resulting data informs a report that serves as a summary of findings and, taking into consideration the owner's project requirements and significance of the structure, provides the basis for the development of a rehabilitation approach. A sensitive rehabilitation approach addresses existing distress and deterioration with compatible and durable repairs, while retaining historic fabric wherever possible, and maintaining or restoring aesthetics.

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Additional Reading

American Concrete Institute. *Guide for Conducting a Visual Inspection of Concrete in Service*. American Concrete Institute Committee 201, ACI 201.1R-08.

American Concrete Institute. *Report on Nondestructive Test Methods for Evaluation of Concrete in Structures.* American Concrete Institute Committee 228, ACI 228.2R-13

American Concrete Institute. *Guide to Evaluation of Concrete Structures before Rehabilitation.* American Concrete Institute Committee 364, ACI 364.1R-07.

American Concrete Institute. *Concrete Repair Guide.* ACI Committee 546, ACI 546R-14.

Custance-Baker, Alice, Gina Crevello, Susan Macdonald, and Kyle Normandin. *Conserving Concrete Heritage, An Annotated Bibliography.* Los Angeles, Calif.: The Getty Conservation Institute, 2015.

Gale, Frances and Doris Eichberg, guest eds. "Concrete." Special issue on Concrete, *APT Bulletin* 48, no. 1 (Spring 2017). Springfield, Ill.: Association for Preservation Technology, 2017.

Gaudette, Paul, and Deborah Slaton. *Preservation of Historic Concrete.* Preservation Brief 15. Washington, D.C.: National Park Service, Heritage Preservation Services, 2007.

Jester, Thomas C., ed. *Twentieth-Century Building Materials: History and Conservation.* Los Angeles, Calif.: The Getty Conservation Institute, 2014.

Macdonald, Susan. *Concrete Building Pathology.* Oxford, England: Blackwell Science, Ltd., 2003.

Meinheit, Donald, and Anthony Felder. *Vintage Steel Reinforcement in Concrete Structures.* Schaumberg, Ill.: Concrete Reinforcing Steel Institute, 2014.

Standard Practice for Petrographic Examination of Hardened Concrete. ASTM C856. West Conshohocken, Penn.: ASTM International, 2014.

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