Approach to Preservation of Historic Concrete

by Ann Harrer, Paul Gaudette, and Deborah Slaton

Fig. 1: Architectural precast concrete at the Bahai Temple in Chicago, Illinois, designed by Louis Bourgeois and John J. Earley

Concrete has been a popular construction material since antiquity and has been utilized by the modern construction industry for well over a century. Concrete gained acceptance in modern construction because it offered the advantages of conforming to virtually any shape and it was readily adaptable to various architectural finishes. As development of new admixtures and additives continues, the possibilities of concrete construction appear limited only by the creativity of the designer (Fig. 1). Historically, concrete was utilized not only for structural elements but also for architectural surfaces at both the exterior and interior of buildings, as well as for sculptural ornamentation (Fig. 2, 3, and 4). Many buildings and structures constructed with concrete are now reaching an age where they are considered historic as well as significant contributions to the built environment.

Primary causes of concrete deterioration are usually related to corrosion of embedded metal, freezing and thawing of critically saturated concrete, materials problems, issues related to original construction, structural issues, and inappropriate past repairs. The nature and severity of deterioration also depends upon the climate and other conditions of environmental exposure (such as pollutants and/or chlorides).[1]

To address distress and deterioration of a historic concrete structure, a rehabilitation strategy should be developed that accounts for the significance of the concrete structure, preservation goals, and limitations on repairs and modifications that need to be addressed as part of the repair design. While similar processes and procedures are utilized for the assessment and repair of any concrete structure, additional considerations pertain to work on architectural and historic structures. Often the approach to repairs may be complicated due to the original construction methods, need to match an exposed finish, conservation requirements for historic fabric, or other factors. These challenges are becoming more apparent as important early twentieth century and Modernist concrete structures from the 1930s through the 1960s are undergoing rehabilitation.

HISTORIC CONCRETE CHARACTERISTICS

Concrete was widely used by the ancient Romans to construct major engineering projects, such as coliseums, bridges, and aqueducts, which can still be seen in Europe today. Following this ancient use of hydraulic cement to produce concrete, the development of concrete slowed until the nineteenth century in Europe and the United States, when concrete became more widely utilized in the construction of civil structures such as the Erie Canal in New York, which incorporated natural hydraulic cement. The U.S. War Department constructed concrete buildings at western posts soon after the Civil War, and a system of fortifications in the 1890s along the Atlantic, Pacific, and Gulf coasts. Roads and bridges were also constructed of concrete at this time.

A patent for the use of reinforcement in concrete was obtained by S. T. Fowler in 1860, for the design of a reinforced concrete wall. Reinforcement manufacturers produced steel of varying strengths and shapes, and the re-

Fig. 2: Exposed concrete finish at the Legislative Assembly in Chandigarh, India, designed by Le Corbusier

inforcing systems also varied.[2] Following World War II, the materials, size, and strength of reinforcement bars were standardized through the work of the American Concrete Institute (ACI), Concrete Reinforcing Steel Institute (CRSI), and other organizations.

As the popularity of concrete as an architectural material grew in the early twentieth century, architects and engineers experimented with various possibilities for form, finish, and texture. In addition, precasters and sculptors also realized that concrete offered benefits and opportunities. 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 (Fig. 5). Some of the finishing techniques used historically, as well as currently, include exposing the aggregates, rubbing to create a smooth finish, and retaining the texture from the formwork in the finish (board form) (Fig. 6).

John J. Earley's work exemplified the creativity and aesthetics that can be achieved by utilizing exposed aggregates in architectural precast panels (Fig. 1). Architects such as Frank Lloyd Wright, Le Corbusier (Fig. 2), Louis Kahn (Fig. 3), and many others incorporated concrete as architectural elements in their designs.

ASSESSMENT

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. The goals and expectations for a rehabilitation strategy and maintenance program that is sensitive to the historic characteristics of the structure should be established with the owner at the beginning of the project.

The initial step in the development of a rehabilitation strategy is an assessment to evaluate existing conditions and determine causes of distress and deterioration (Fig. 7). The findings of the assessment provide the basis for development of a rehabilitation strategy that typically includes a repair and maintenance program. The condition assessment should include, at a minimum: identification of significant character-defining features, research and document review, field investigation, and (as appropriate) field and laboratory testing.

Significance

The first step in the assessment is to research the history and significance of the building, its character-defining features, and the concrete.[3] Research should include collecting and reviewing as much information as possible regarding the original construction, use, previous assessments, repair, and maintenance of the concrete. This initial step allows the design professionals conducting the assessment to become familiar with not only the original construction but also previous repair and maintenance.

Fig. 3: Exposed concrete finish at the Salk Institute for Biological Studies in La Jolla, California, designed by Louis Kahn

If a Historic Structure Report (HSR) exists, it will likely contain valuable information pertaining to the history, construction, and maintenance of the building. In addition, if available, landmark nomination reports, Historic American Building Survey (HABS) and Historic American Engineering Record (HAER) documentation, archival drawings and photographs, and other documents can yield information regarding the building. If only limited documentation is available, a more detailed field investigation may be necessary to understand the existing design and construction.

Fig. 4: Exposed concrete surfaces and sculpture at the Bailey Magnet School, Jackson, Mississippi

Fig. 5: Exposed aggregate at a historic concrete balustrade

Fig. 6: Variations in formwork and finish at a historic concrete facade

Field Investigation

The next step is to perform field investigation and testing.[4] The investigation starts with a visual condition survey and comparison of the as-built construction with the gathered documents and information, and documentation of the existing conditions of the concrete, 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 (Fig. 8). The condition survey can also yield information about original construction such as placement techniques and finishing procedures, as well as potential construction deficiencies including poor consolidation of the concrete during placement.

Field investigation of the concrete often includes various types of nondestructive testing, inspection openings, and removal of concrete samples for laboratory studies. The reinforcement embedded within concrete often requires investigation beyond the visual survey to understand the as-built construction and 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; however, selective inspection openings are necessary to confirm the findings of nondestructive evaluation.[5]

Inspection Openings

As conditions that contribute to deterioration and distress within concrete structures are often not visible, the use of inspection openings can verify conditions from the visual survey, sounding, and nondestructive testing. Locations for inspection openings should be representative of the various conditions noted during the survey and should be unobtrusive if possible, especially on historic structures. Locating inspection openings in areas of existing distress (cracks or spalls) can provide information while minimizing the removal of material (Fig. 9).

Laboratory Studies

Laboratory studies provide information on the characteristics of the concrete and causes of deterioration that are especially important in repair of historic concrete. Samples, preferably concrete cores of the size as required by ASTM C42,[6] or as required for other laboratory testing, can be removed from representative locations. If concrete core samples cannot be obtained due to access, architectural sensitivity, or other limitations, fragments or incipient spalls can yield information, although limited by the uncontrolled nature of a fragment. Additional information on available laboratory testing is provided in ACI 364.1R-19.[4]

Petrographic examination (ASTM C856),[7] the detailed analysis and study of concrete using stereomicroscopy, provides valuable information regarding concrete composition, original concrete mix, and potential causes of observed distress. Information gathered through materials studies helps identify causes of distress and also assists in the development of the repair design, such as specifying compatible and aesthetically matching concrete mixes.

CONSERVATION APPROACH

Through evaluation of the assessment findings, taking into consideration the owner's project goals, a conservation approach can be developed that addresses existing deterioration while being sensitive to the preservation of the historic fabric.

The conservation approach needs to consider technical issues, characteristics of the original concrete, and aesthetic considerations such as matching the original concrete elements. Similar to any assessment, the findings are studied to determine the underlying causes of observed deterioration and distress to develop an appropriate scope and extent of repairs. The owner's intended use and maintenance of the structure, as well as the significance of the structure, should also be understood. In some cases, structural assessment and analysis may be necessary. Most importantly, the conservation approach should address the underlying causes of the distress or deterioration of the concrete to minimize continued deterioration or premature failure of the repairs.[8]

Repairs to the concrete should be durable and extend the service life of the concrete structure. It is therefore important that the repair approach includes surface preparation of the substrate to achieve bond of the repair material to the original concrete substrate. This may require removal of some historic fabric as part of the repairs, such as where removal of concrete to access all sides of a corroded bar is necessary to mitigate ongoing corrosion and to key-in and mechanically anchor the repair to the substrate concrete (Fig. 10). The characteristics of the original concrete should be considered in selecting the repair material and designing the repair.[9] For example, the compressive strength and modulus of elasticity of the repair material need to be compatible with the original or substrate concrete. In addition, the depth and shape of the repair should be selected to provide durable service life for both the repair and the substrate concrete.

Because the exterior facade of historic concrete structures is often exposed concrete, the conservation approach should also consider matching the existing overall aesthetic of the concrete including color, texture, and finish. Research and consideration of available cements, aggregates, and potential admixtures to develop a compatible mix that is a match to the original in color and texture is necessary. Locally available materials may have been used during original construction and may be available for

Fig. 7: Ongoing condition assessment of a historic concrete building facade

Fig. 8: Due to variations in formwork and finishing techniques, there are visible differences in texture, even after a coating has been applied

Fig. 9: Delamination and spalling at exposed concrete are examples of distress and deterioration that should be documented as part of a visual condition survey

Fig. 10: Removal of concrete beyond the corroding reinforcement bar to allow for removal of corrosion product and to address the underlying distress mechanism

Fig. 11: Completion of off-building trial samples and mock-ups prior to the start of repairs to confirm appropriate performance of the concrete mix design, placement procedures, and finishing techniques

repairs; however, material removed from the same quarry but from a different depth or location may not be similar to the original constituents. If materials from the original source (such as locally quarried aggregates) are not available, research will be needed to find a similar material for use in the repairs. Mineral pigments and admixtures can be considered to achieve a color match; however, the durability and colorfastness of the materials needs to be understood. Matching the geometry and finish of the existing components may affect the constructability of the repair—another factor that needs to be considered.

MOCK UPS AND REPAIR IMPLEMENTATION

The results of architectural concrete repair work are dependent to a great extent on the experience and craftsmanship of the craftsman performing the work. As craftsmanship is critical to the overall technical performance as well as the final aesthetic of the repairs, it is imperative that the desired level of craftsmanship be established prior to the start of work through mock-ups and a trial repair program. Mock-ups and trial repairs are also necessary to confirm the developed conservation approach, provide an opportunity to refine the repair process, and provide an opportunity for the owner, design team, and contractor to review examples of the completed repair (Fig. 11).

The design of the concrete repair mix design needs to be developed to meet the technical specifications as well as to match the adjacent original concrete, in accordance with the conservation approach. The mix development, review, and approval process can require quite a bit of time and should be included in the construction schedule. The concrete mix should be designed for constructability to allow for placement and be compatible with the characteristics of the original concrete. Typically, formed concrete repairs are preferred to trowel-applied mortars. Concrete repair materials with coarse aggregate, utilized in formed concrete repairs, will typically have characteristics more similar to the substrate concrete and the formwork will allow for proper consolidation. In order to achieve compatible, durable, and aesthetically matching repairs, the creation of formwork, placement procedures, and finishing procedures should be practiced and finalized through a series of off-building samples and mock-ups.[10] During the off-building samples and mock-ups, mixes, placement, and finishing procedures can be fine-tuned and modified without resulting in unacceptable repairs on the building that will require removal.

Following the successful completion of mock-ups demonstrating the required level of craftsmanship, the ability to achieve the necessary technical characteristics, and match to the aesthetic details of the existing structure, production repair work can begin. During implementation of the concrete repairs, craftsmanship should be maintained at a high level to achieve an acceptable final result. Quality control during the repair work should include monitoring the batching and mixing of the concrete repair materials with slump, air content, unit weight, and other typical quality control testing, as well as visual review of the work. In addition, hammer sounding of the repairs, once adequately cured, should be performed to detect any areas of unsound or unbonded repair materials. Additional quality control testing, including tensile bond testing, can also be performed. If any repairs deviate from the approved mock-ups, are unsound, or do not match the adjacent concrete, these should be removed and replaced.

CONCLUSION

Although a durable material, concrete is susceptible to deterioration as a result of various distress mechanisms, from environmental exposure to problematic original design and construction. Historic structures in which concrete is used as both an architectural and structural material present specific challenges with developing and implementing repairs. Understanding the significance of a historic concrete structure and conserving the character-defining features are vital to the preservation of these structures. The conservation approach needs to address the underlying deterioration or distress mechanisms while matching the existing original color, finish, and texture of the concrete structure. While the conservation of concrete presents challenges, through a detailed condition assessment, collaborative conservation approach development, and mock ups, repairs utilizing a high level of craftsmanship can be completed that match the overall design aesthetic of the structure.

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