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Responsibility in Repair Construction

SP-332

Editors:

David VanOcker and Kevin MacDonald



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Responsibility in Repair Construction

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PREFACE

Responsibility in Repair Construction

Preface: The responsibilities for parties involved in a repair project may be significantly different than those traditionally encountered in new concrete construction. The new ACI 562 Code Requirements for Assessment, Repair and Rehabilitation of Concrete Buildings and corresponding ACI 563 Specifications for Repair of Concrete in Buildings identify requirements for the Licensed Design Professional and the contractor's Specialty Engineer during repair programs. Differing lines of authority in repair are presented through industry practice recommendations and case studies, along with identification of industry needs, informing parties engaged in concrete evaluation and repair projects.

David VanOcker and Kevin MacDonald
Editors

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Examining the Standard of Care for the Evaluation of Existing Structures

Keith Kesner, and Kevin Coll

Synopsis: Evaluation of an existing structure is a task commonly performed by licensed design professionals. An evaluation can be required by a façade inspection ordinance, as part of a due-diligence process prior to the purchase of a structure, or prior to the development of rehabilitation or repair measures. Each of these project types will have differences in the evaluation protocol and portion of the structure to be examined – but in each example, the licensed design professional is expected to provide a minimum “standard of care” to the client and to protect the public. Therefore, in developing the evaluation protocol, a critical question facing the licensed design professional is how much investigative effort is required to complete the evaluation and ensure the evaluation provides a minimum standard of care.

The standard of care for an evaluation of existing structures can broadly be defined as the level of effort that a reasonable and prudent licensed design professional would be expected to provide under similar circumstances. Given the range of structure types that can be encountered and the varying levels of damage and exposure conditions, determination of the scope of evaluation can be a difficult task for a licensed design professional. The following sections examine approaches used in industry codes and ordinances to help define a minimum standard of care for the evaluation of existing structures. Industry codes and ordinances to be examined will include the ACI 562-16 Code for Assessment, Repair and Rehabilitation of Existing Structural Concrete, FHWA bridge inspection requirements and building façade inspection standards and ordinances. Based upon these documents, items to be considered in establishing a “Standard of Care” in the evaluation of existing structures will be summarized.

Keywords: ACI 364, ACI 562, ASCE, ASTM E2270, standard of care, due diligence, professional liability, façade inspection.

ACI Fellow **Keith Kesner** is a Senior Project Manager at CVM Professional in King of Prussia, PA. He is a structural engineer with over 20 years of professional experience in the evaluation of existing structures. He is the author/co-author of over 100 publications and presentations on a variety of structural engineering topics. He currently serves as the Chair of ACI Committee 562, and as member of ACI Committees 318-C, 228 and 364.

Kevin Coll is a Senior Project Manager at CVM Professional in King of Prussia, PA. He is licensed engineer in the Commonwealth of Pennsylvania and has 25 years of experience in the assessment of existing structures and historic construction methods and materials. He has author/co-authored various publications on the inspection and analysis of older/transitional building systems. He currently serves as a member of ASTM E06.55 on Building Performance.

BACKGROUND

For several years, ACI Committee 364 – Rehabilitation members had a running discussion on what defines the “standard of care” for the evaluation of existing structures prior to rehabilitation, and what level of evaluation was necessary to satisfy the standard of care. These discussions were held in the context of revising the committee’s flagship document “Guide for Evaluation of Concrete Structures before Rehabilitation (ACI 364.1R) [1].” The broad topic of discussion was related to determining how ACI 364.1R and other guide documents for conditions assessments such as ASCE 11-99 [2] helped design professionals to determine the extent of evaluation required, and further how do the evaluation guides help define the standard of care. The following sections review the standard of care for the evaluation of existing structures and describe how various documents provide insight into the standard of care.

STANDARD OF CARE

Potential sources for standards of care to which design professionals may be exposed include (1) Code of Ethics defined by Professional Societies¹ (2) Legislative standards (codes, ordinances, etc.) (3) Contractual Agreements² and finally (4) those developed by the courts on a case by case basis.

The “Standard of Care” as it pertains to the practice of engineering is generally defined as “the degree of care that professionals of ordinary prudence would use under the same or similar circumstances”. This concept is rooted in English Common Law doctrine, which holds that the public has the right to expect those providing services do so in a reasonably careful and prudent manner, as tested or established by the actions of one’s own peers under like circumstances. (Professional Liability Agents Network , 2003) [3]. It is this definition that professional societies generally cite in their codes of ethics and to which contractual and legal expectations for the services provided by design professional are measured should a claim of professional negligence arise.

Contracts may raise this standard to inappropriately high levels. One recent example from our practice was a contract that included a contractual obligation for the design professional to “...provide professional services that reflect the highest standards of professional care”. Verbiage such as this can dramatically increase a client’s expectations and should problems arise on a project a design professional’s potential exposure. It has been our experience that Clients are amenable to revising these clauses if concern is raised to more standard verbiage. In the case of the above referenced contract the clause was reworded to “in a manner consistent with the level of skill and care used by comparable professional firms”.

The concept of understanding client’s expectations and defining an appropriate level of professional services is of particular importance for design professionals involved in the evaluation, repair and rehabilitation of existing structures. Unlike new construction, existing structures inherently involve hidden construction and unknown

¹ Such as the American Society of Civil Engineers (ASCE) Code of Ethics (2017).

² Such as the American Institute of Architect (AIA) Document B101 Standard Form of Agreement Between Owner and Architect.

conditions which will require a design professional's judgement to determine what level of assessment is warranted for a specific project. This aspect can be more difficult to define than one might think as the professionals opinion of what level of assessment may be needed to meet the Standard of Care regularly needs to be balanced with competing interests (i.e.; budget, impacts on operations/occupancy and schedule constraints). Recognizing this, different approaches to attempt to standardize the evaluation process have been developed by various parties (ASTM, ASCE, ACI, FHWA, etc.). These approaches for the most part can be categorized as either prescriptive or performance based, with each having relative merits and limitations. The following sections explore considerations unique to the evaluation of existing structures and various approaches to standardize the assessment process.

EVALUATION OF EXISTING STRUCTURES

The evaluation of existing structures is typically motivated by a need to confirm the condition of the structure (e.g. façade ordinance inspection), an observation of some type of damage or deterioration, or prior to rehabilitation. Regardless of the reason for the assessment an understanding of how the structure was intended to function is needed as it pertains to the focus of the assessment (i.e.; structurally, support of exterior cladding, means of water management for the building envelope assemblies, etc.). This is often in contrast to how it is actually functioning.

Development of an evaluation plan for existing structures requires the design professional to integrate available information with information that can be obtained during an investigation to make decisions about a structure. The question for the design professional is how much information and investigation is necessary given that nearly all investigations are limited in scope.

The evaluation plan must consider structural redundancy, potential for the structure to display distress prior to failure and the consequences should a failure occur. Consider the cantilever retaining walls that form a flood control channel shown in Figure 1. The top posts were added as a retrofit due to concerns about the capacity of the wall sections. During probing, significant corrosion of the reinforcing steel was observed at a construction joint near the base of the wall (Figure 2). The structurally significant corrosion was only visible after extensive probing. Previous experience (Kesner, et al. 1999) [4] has indicated these types of wall sections can fail with only limited evidence of displacement or structural distress prior to failure.



Figure 1- Cantilever wall sections forming a flood control channel.



Figure 2 - Reinforcing steel corrosion damage at the base of wall section.

The cantilever retaining wall represents one example of a non-redundant structure, in which significant damage can occur with only limited outwardly visible evidence of structural distress. On these types of structures, an evaluation limited to a visual inspection with material sampling limited to core samples to confirm concrete strength may miss the critical deficiency in the structure. The damage to the structure can only be identified with probes or with extensive use of nondestructive test methods.

A similar situation can exist in façade construction. Terra cotta façade elements [5] are commonly hung from hidden structural supports (Figures 3 and 4). Water infiltration can result in corrosion of the support members with very limited outwardly visible signs of distress on the façade. The condition of internal supports is typically only identified by probing.



Figure 3 - Projected terra cotta façade elements exhibiting damage consistent with failure of internal supporting steel structure.

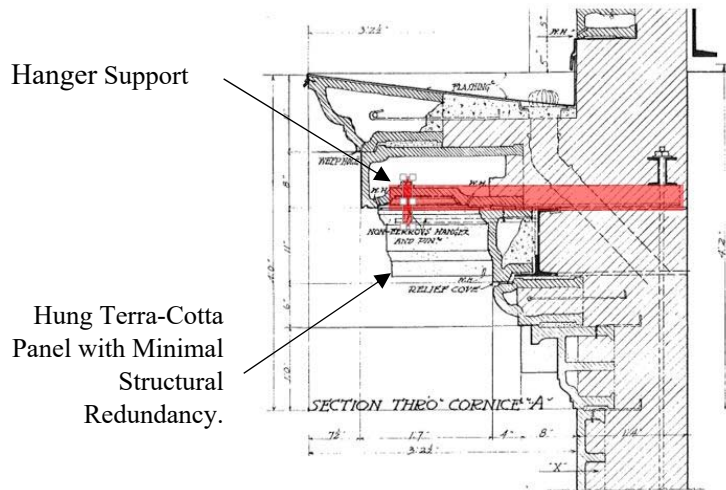


Figure 4 - Typical Detail 1927 Terra-Cotta Manual (supporting structure highlight added).

The basis of design for the flood control channel described above and structural support for the terra cotta assemblies are quite different. These examples were selected to highlight the wide range of building types and systems that can be encountered during assessments, each with relative merits and limitations that must be understood. In both of these situations, a failure can occur with limited warning as the underlying defects are often concealed and lack structural redundancy.

The investigation plan to evaluate these types of conditions must anticipate the behavior of the structure and consequence of a failure. In the flood control channel example, failure may have widespread affects with either minimal impact should it be located in a rural setting or potentially life threatening impacts in an urban setting. For the distressed terra cotta façade element, the immediate hazard to pedestrian traffic below this area was mitigated by closing the sidewalk section beneath until stabilization measures were completed. The examples briefly described above are intended to highlight some of the pitfalls that can occur in the evaluation of existing structures.

In broad terms, design professionals rely primarily on visual examination and some level of probing to expose/assess hidden assemblies to further their understanding of the construction or to diagnose factors contributing to observed areas of distress. To the degree that existing documentation pertaining to the original design (drawings/specifications/shop drawings/submittals) is available, these can be of great use. However, these documents are often incomplete and may not accurately represent the as-built conditions (i.e.; were all of the framing members installed as detailed, were flashings omitted, were post-tensioned cables located & stressed properly, etc.)

Given the level of uncertainty inherent in any structural investigation, what insight can be obtained from ordinances, codes and industry guidelines on how the standard of care can be satisfied? Specifically, how can a design professional use various industry documents to develop structural investigation protocols that are likely to identify potential hidden conditions and other types of damage?

HOW TO ENSURE STANDARD OF CARE IS MET

Two different approaches have been adopted in various ordinances, codes and guidelines to help ensure the standard of care is satisfied in a “typical” condition evaluation. In broad terms, prescriptive standards delineate the items to be reviewed and mechanism to complete the review, while performance standards describe the performance level that must be satisfied.

Prescriptive Based Evaluation

A good example of a prescriptive based guidance to conduct an assessment can be found in ASTM E2270 Standard Practice for the Inspection of Building Facades for Unsafe Conditions, Annex A1.1 [6]. This document attempts to standardize the level of assessment needed for a particular façade considering both the age and type of construction. Older facades of certain types such as terra-cotta require relatively more invasive effort to meet a minimum standard of care. In this instance the requirement of an increased quantity of detailed (hand's on) inspection and a minimum number of probes/tests to assess concealed assemblies. In a similar vein various localities have adopted façade inspection ordinances, most notably New York City, Chicago and Philadelphia. These ordinances require periodic inspections of building facades for unsafe conditions within certain height parameters, and provide minimum requirements on the frequency of inspections and on the scope of visual and tactile inspections.

Another example of a prescriptive evaluation requirement is National Bridge Inspection Standards mandated by the Federal Highway Administration (FHWA) and State DOT's (NBIS) [7]. Similar to the façade inspection standards discussed above they also provide requirements on inspection frequency (biennial) and inspection scope (tactile inspection possibly supplemented with NDT of fracture critical elements with limited/no redundancy).

In both instances the standards and ordinances are useful in setting minimum requirements on the frequency and scope of needed assessments, but continue to rely on professional judgement in the development of the project-specific assessment scope and render primarily qualitative results.

Performance Based Evaluation

The ACI 562-16 [8] code for repair of existing concrete structures has largely adopted a performance-based approach to the evaluation of existing structures, in contrast to the prescriptive approach used in the façade ordinances and FHWA Standards. The performance-based approach in ACI 562-16 is integrated with demand / capacity ratios that define unsafe conditions and delineate when repairs must satisfy new code requirements. The performance-basis requires the design professional to evaluate the structure to determine if the observed behavior of the structure is adequate for the current or proposed loading. Specifically, investigations and evaluations are required when:

- The structure exhibits signs of damage, displacement, deterioration, structural deficiency or behavior that is inconsistent with available design documents or code requirements in effect at the time of construction - ACI 562-16 Section 6.2.1-1
- When a preliminary evaluation indicates strengthening is required - ACI 562-16 Section 6.2.1-2
- There is a reason to question the capacity of the structure and insufficient information is available to determine if the structure is capable of resisting design demands – ACI 562-16 Sec. 6.2.2
- When repairs are required to an individual member in a structure, it shall be determined if similar members throughout the structure also require evaluation – ACI 562-16 Sec. 6.2.3

These provisions require the design professional to determine when a structural evaluation is required based upon the observed conditions of the structure. Compared to a prescriptive provisions, the performance based provisions place a greater onus on the design professional to understand the expected behavior and what constitutes a deviation from expected behavior.

Considering the cantilever retaining wall example above, Sections 6.2.1-1 and 6.2.2 of ACI 562-16 are both potential triggers for a more detailed evaluation to confirm the capacity of the wall sections. The means and methods of the investigation still must be determined by the design professional. The commentary to ACI 562-16 provides insight and references on how to develop the investigation protocol.

To provide a uniform level of reliability in existing structures, ACI 562-16 provides a series of demand / capacity ratios that delineate the level of repairs required based upon the current capacity the structure (Sec. 6.2.4 of ACI 562-16). The analysis is based upon:

- As-measured structural member section properties and dimensions.
- The presence and effect of any alterations to the structural system.
- Loads, occupancy, or usage different from the original design.

The intent of the performance-based approach in ACI 562-16 is to allow the design professional the flexibility to determine the extent of evaluation required, and to proceed directly to repair design when the capacity of structure is not in question. To help the design professional with the evaluation process, the commentary to ACI 562-16 provides insight on the intent of the code and extensive references on the evaluation process.

SUMMARY AND CONCLUSIONS

Both prescriptive and performance based standards for the evaluation of existing structures have been developed for design professionals. While these standards can provide useful procedural guidance on defining the parameters of an evaluation it remains the licensed design professional's judgement as to if and when an appropriate standard of care is met. As every project and structure are unique so should be the development of individualized assessment protocols that consider these differences. Some key points for design professionals to consider when establishing assessment protocols that will meet the standard of care are:

- Sources of Information: Codes, ACI, ASCE, ASTM, Ordinances, etc.
- Limitations of the standards and other documents used to develop the assessment protocol.
- Understand the expected behavior of the structure; including the level of redundancy and consequences of failure.
- Balancing of the assessment with potentially competing limitations (budget, use, schedule) and client expectations
- Regardless of the approach the design professional remains the final person responsible for assessing the integrity of the structure, and therefore the design professional must ensure that the assessment protocol satisfies a standard of care.

REFERENCES

1. American Concrete Institute 364.1R-07 - Guide for Evaluation of Concrete Structures before Rehabilitation
2. American Society of Civil Engineers, "ASCE 11 - Guideline for Structural Condition Assessment of Existing Buildings".
3. Cavnag Associates, "What is the Standard of Care", Professional Liability Update, September, 2003. <http://www.cavnag.com/publications/professional-liability-update-what-is-the-standard-of-care/>
4. Kesner, K.E., Poston, R.W., Salmassian, K., and Fulton, G.F., "A Case Study in Sustainable Restoration: The Marina del Rey Seawall Repair Project," Concrete International, December 1999, Vol. 21, No. 12.
5. National Terra-Cotta Society, Architectural Terra Cotta Standard Construction Manual, 1927 Edition.
6. American Society of Testing and Materials, "ASTM E2270 - Standard Practice for Periodic Inspection of Building Facades for Unsafe Conditions".
7. NBIS – National Bridge Inspection Standards (<https://www.fhwa.dot.gov/bridge/nbis.cfm>)
8. American Concrete Institute 562-16 – "Code Requirements for Assessment, Repair and Rehabilitation of Existing Concrete Structures."

Responsibility in Evaluating and Repairing Existing Concrete Structures An Environmental Structure Case Study

Pericles C. Stivaros, Ph.D., P.E., FACI

Synopsis:

A successful concrete repair project requires a close coordination of efforts between the three major parties involved: the owner, the licensed design professional (LDP), and the contractor. Lack of coordination and clear understanding of the professional and contractual responsibilities, as well as the expectations, of each party involved in a concrete repair project could result in long legal disputes to attempt to sort out the responsibilities of each party. The greatest victim of the dispute is usually the structure itself. The American Concrete Institute (ACI) has led the effort to develop responsibility guidelines in concrete construction. ACI 132 identifies and suggests allocation of responsibilities to various parties involved in concrete construction. ACI 132 document is applicable to general concrete construction, and it does not consider the particularities of evaluating and repairing existing concrete structures. ACI 562 provides minimum requirements for assessment, repair and rehabilitation of existing distressed concrete structures, including a discussion on the responsibilities of the licensed design professional for the evaluation and repair of concrete structures. This paper discusses the responsibilities of the licensed design professional, the contractor, and the owner through a repair case study. The paper demonstrates the need to expand ACI 132 and/or ACI 562 to include responsibility guidelines for concrete repair projects.

Keywords: concrete repair, responsibility, quality control, quality assurance, structural assessment, structural evaluation, nondestructive testing

ACI Fellow **Pericles C. Stivaros, Ph.D., P.E.** is a Vice President of GEI Consultants Inc., P.C., New York, N.Y. His professional experience includes construction failure investigations, testing, evaluation, and rehabilitation of distressed structures. He is a member of several ACI Technical Committees, including the Technical Activities Committee (TAC) (past), the TAC Construction Standards Committee, member and past Chair of ACI 347 - Formwork, ACI 350 Environmental Engineering Concrete Structures, ACI 364 – Rehabilitation, ACI 351 Foundations for Equipment and Machinery, and ACI 362 - Parking Structures.

INTRODUCTION

Identification and assignment of responsibility in concrete construction is a key factor for a successful project. ASCE “Quality in the Construction Project”¹ discusses the roles, responsibilities, requirements, and limits of authority of participants in the design and construction process. ACI Committee 132 “Responsibility in Concrete Construction” has summarized the responsibilities of the various members of a construction team. The ACI 132R-14 “Guide for Responsibility in Concrete Construction”² document was developed primarily for new concrete construction. Evaluation and repair of existing concrete structures presents different challenges than new construction, and the responsibilities of the repair construction team vary from the general responsibilities associated with new construction. ACI 562 “Code Requirements for Evaluation, Repair, and Rehabilitation of Existing Concrete Structures and Commentary”³ briefly outlines the responsibilities of the licensed design professional (LDP) of a repair project.

The responsibilities of each party are not independent from each other; they are interrelated. The owner cannot define the objectives of a project without knowing the nature and extent of the problem and the repair alternatives. Not only does the design professional need to investigate and identify the problem, but also understand the owner’s needs, as well as meet minimum design code requirements and constructability and serviceability issues. The contractor’s decision on construction means and methods depends on the design decision made by the LDP and the decisions made by the owner with respect to the extent of work, access to work areas, maintaining means of egress, compliance with environmental regulations and site safety. Thus, a concrete repair project has an even stronger need for design and construction interdependence and owner involvement than new construction.

The key to a successful repair project is understanding the owner’s needs and the needs of the structure itself. Some owners have the expertise and resources to identify and determine the extent of the problem, while others do not. It is the responsibility of the LDP to educate the owner on the type, cause, and extent of the problem, the extent of the required repairs, and the associated construction cost. The LDP should develop alternate repair methods and materials, with an emphasis on cost effectiveness and long-term service life.

RESPONSIBILITY AND AUTHORITY

Responsibility and authority go hand-in-hand. Fulfillment of contractual responsibilities requires some degree of authority to make decisions during the process of performing design and construction work. The ultimate authority and responsibility rests with the owner. The owner delegates part or all authority and assigns responsibilities to the design professional and to the contractor. The transfer of authority and responsibility is done through a contract between the owner and each party. This process should be done in a straightforward way, leaving no misunderstandings about the degree of the delegated authority and responsibility that comes with it. Otherwise, the construction process fails and may end up in litigation. Better definition of authority and responsibility leads to better quality control, which in turn leads to successful projects and minimized conflicts.

GENERAL RESPONSIBILITIES OF THE OWNER

Maintain a Safe Structure

The owner is the ultimate authority on any concrete repair project. The owner has a legal or equitable interest in their properties. Building codes usually designate the owner as the responsible party for maintaining the safety of the buildings or nonbuilding structures. Stemming from this responsibility, owners should perform periodic condition surveys of their structures to identify damaged areas requiring repairs. Damaged areas should be evaluated, and repair design and construction should be initiated if required. Owners who lack this expertise typically assign all or part of their responsibilities to LDPs to execute the technical portion of the work, and to contractors to perform the construction of the repairs. The LDP also serves as an advisor to the owner in the decision-making process and

informs the extent and type of required repairs.

Establish Scope and Objectives

It is the owner's responsibility to establish the purpose and objectives of the repair. Based on the results of the structural assessment, the owner, with the help of the LDP, should establish the objectives and extent of the repair program. Are the repairs necessary to restore the structural safety of the structure? Are the repairs needed to maintain the serviceability and long-term durability of the structure? Are the repairs mandated by the governing codes and regulations, i.e., required to maintain the safe status of the building or structure? What are the repair alternatives and cost-effective analyses for each? Answers to these questions can provide the owner with a good decision-making basis. Owners should set realistic expectations for a successful project. A repaired structure cannot become new; it may look like new, but its remaining service life is decreasing as it ages.

Environmental Assessment

Existing buildings that were built before hazardous material regulations came into effect may contain hazardous materials, such as asbestos and lead. The owner is responsible for conducting an environmental assessment to identify hazardous materials and remove such materials.

Funding and Payment

A prerequisite for every project, including a repair project, is funding. The owner is responsible for making payments associated with the repairs. Repair work is funded with different motives than new construction. Usually, new construction begins after securing funding through economic planning. Funding of repair work is often done under distressed conditions and sometimes within a limited timeframe. Repairs related to the safety of a structure require immediate attention irrespective of economics. Local authorities can order the evacuation of unsafe buildings and require owners to restore the structural safety within a limited timeframe. The owner should decide on the type and extent of repair work that can be accomplished with available funds, conducting at least the minimum work necessary to maintain the structural safety of the structure.

GENERAL RESPONSIBILITIES OF THE LICENSED DESIGN PROFESSIONAL

The responsibilities of the LDP in a repair project start and end with their contract with the owner. Anything that is not included in the contract remains the responsibility of the owner. Furthermore, the LDP is responsible for performing these services within the requirements of the codes and regulations, as well as the standard of care, applicable to the location of the project.

It is the responsibility of the LDP to educate the owner on the repair process and the expectations for the scope and quality of the repairs. A clear understanding of the condition of the structure and the alternate repair options must be presented to the owner for their decision.

The general responsibilities of the design professional for a concrete repair project include:

- Understand owner's requirements, objectives and expectations
- Evaluate structural conditions – condition survey, nondestructive testing, laboratory testing
- Design following the governing codes and standards – establish basis of design compliance
- Maintain the standard of care – develop QA/QC program
- Perform repair design, develop specifications – prepare contract documents
- Perform field observations
- Perform or delegate inspections and tests
- Inform owner of maintenance requirements, some of which may be the result of workmanship and material warranties by the repair material manufacturers
- Identify unsafe conditions and report to the owner and the jurisdictional authorities

Professional Services

According to ACI 562³ Section 1.1.4, the LDP for a project “is responsible for and in charge of the assessment or rehabilitation design, or both.” To be “in-charge” of the investigation is not enough for the LDP to perform the complex work that is usually required in repair and rehabilitation projects. The LDP should not only have the

responsibility, but they should also have the decision authority for all aspects of the investigation and repair design for a damaged concrete structure.

The LDP should first understand the owner's needs and requirements, and second understand the structure. First, the owner's requirements and responsibilities are delegated to the LDP through a contract. Understanding the structure is the basic responsibility of the LDP. The LDP identifies the problem, evaluates and understands the problem, determines the cause of the problem, develops repair details, and develops a maintenance program for the repairs.

Compliance with Codes and Regulations

The investigation and design work must comply with the governing codes and standards while maintaining the standard of care. The question is which code should govern the repair. Is it the current code or the code under which the structure was originally designed? The LDP should establish the design-basis criteria and determine applicable code for the repair design following ACI 562³. The ACI 562³ code provides minimum requirements for the assessment and repair design of existing concrete structures and outlines the responsibilities of the LDP in a concrete repair project.

Maintenance Requirements

A concrete repair project does not end with the final inspection of the repairs. Just as existing structures require maintenance and protection, repairs require special maintenance and protection as well. The LDP, within the extent of their contractual obligations, should develop a maintenance program, including type and frequency of actions, that is necessary to ensure a satisfactory performance of the repair during the structure's remaining service life. The LDP should notify the owner on any additional maintenance items resulting from warranty requirements.

Unsafe Structural Conditions

It is the duty of the LDP to protect the public from unsafe structural conditions. Should unsafe conditions be discovered during the assessment phase, the LDP is responsible for reporting them to the owner. Also, several jurisdictions require unsafe conditions be reported to the appropriate authorities. To the extent of their contractual obligations, the LDP should develop stabilization measures to ensure the temporary safety of a distressed structure until permanent repairs are designed and implemented.

GENERAL RESPONSIBILITIES OF THE CONTRACTOR

The only task of the contractor is to fulfill the requirements described in the contract documents. This contractual responsibility should be accompanied by the authority for the contractor to make decisions on the construction process, means and methods. The general responsibilities of the contractor include:

- Implementation of the requirements of the contract documents
- Development of construction means and methods, specialty techniques, and sequence of construction
- Review contract documents, identify discrepancies, tolerances, and compatibility issues
- Provide and install required materials
- Maintain structural stability
- Provide required labor and equipment
- Initiate and maintain site safety
- Develop and maintain a quality control program for the construction procedures and site safety
- Provide the owner with the material and workmanship warranties as per the contract documents

In a concrete repair project, the contractor is responsible for meeting the concrete repair performance requirements. The contractor, together with the repair material manufacturer, is responsible for the proper surface preparation and installation of the repair materials. A thorough understanding of the repair design intent by the contractor can lead to the proper implementation of the repair program.

It is important to note that the contractor should have no direct responsibility for engineering design required by building codes. The contractor should not be responsible for design, except for specialty item design work, which the contractor assigns to a specialty licensed design professional. Specialty items may include: design of precast concrete members and their connections to existing structures, formwork, or shoring/bracing design. It is equally

important to note that the contractor has no direct responsibility for structural assessment and evaluation of existing concrete structures. This responsibility belongs to the LDP. However, it is the responsibility of the contractor to report new conditions encountered during the repair process to the owner and to the LDP.

REPAIR PROCESS AND RESPONSIBILITIES

Concrete repair process usually consists of three phases:

- a. Problem identification, structural assessment and evaluation
- b. Repair design and contract document development
- c. Construction of repairs

Structural Assessment and Evaluation

The structural assessment and evaluation responsibility belongs to the owner, who in turn delegates this responsibility to a licensed design professional. ACI 364⁴ provides general procedures for the evaluation of concrete structures before rehabilitation and repair. ACI 562³ codifies the minimum requirements for assessment, repair, and rehabilitation of existing structures. The LDP is responsible to inform and advise the owner on the required scope of the investigation and the expectations of the repair program.

The assessment and evaluation process include the development of the investigation program, condition surveys, nondestructive testing, material laboratory testing, and structural analysis and design. The assessment report should include information on the type, cause and extent of damage, repair alternatives with service life evaluations, and required future maintenance and monitoring. Improper assessment can lead to inappropriate repair design details and material specifications, which may lead to premature failure of the repair or accelerate damage to other non-damaged portions of a structure.

Sometimes, due to budget and time constraints, an owner may decide to limit the scope of investigation to the minimum and confine the investigation to only limited areas of the damage structure. Such decisions by the owner could affect the quality and the results of the investigation. For example, the elimination of non-destructive testing to identify hidden concrete faults (internal cracking, voids and delamination) will affect the estimation of the cause and extent of the damage. The elimination of laboratory testing of concrete samples deprives the investigation of crucial information on the strength and long-term durability characteristics of the existing concrete. Also, the restriction of the investigation to only certain parts of the damaged structure is in direct conflict with ACI 562³, which requires the LDP to determine if evaluation and repairs are required to similar members elsewhere in the structure. For these reasons, the contract between the owner and the LDP becomes a very important instrument. The contract should spell out the extent of investigation, including the areas to be investigated, as well as the expectations of the investigation. It must be made clear to the owner that unless the structure is properly investigated, and all known defects are repaired, problems will continue to exist.

Repair Design - Contract Document Development

Based on the assessment report, and in consultation with the owner, the LDP should develop the required repair design and details. The LDP should determine the applicable codes and standards of the original building design and construction, as well as the repair design-basis code.

As per ACI 562³, the repair design should address the strength (load carrying capacity of the damaged members), structural serviceability (such as overall stability, fire resistance, deflection, cracking and excessive vibration), and the long-term durability (ability of the structural elements to resist deterioration). The restoration of member strength is usually mandated by the governing building codes. A structure should be restored to its originally designed load-carrying capacity. Some durability requirements, such as a concrete cover, are also mandated by the code. Other durability requirements, such as protective coatings, are not required by the code. The owner should decide to what extent durability measures should be implemented in a repair design project. However, the LDP should advise the owner on the consequences of durability measures on the service life of the structure.

Construction Cost Estimates

An important aspect of the assessment is to determine the extent of the repair work required and to estimate the

quantities and approximate construction cost. For some projects, the LDP may delegate estimation to a professional construction cost estimating firm. Varying and continuously changing cost requirements during a project can cause serious issues among the construction team members. Underestimation of the extent of damage can place burdens on the owner and may result in incomplete and/or inferior repairs.

Engineering cost estimates for repair work are usually based on previous cost experiences of similar projects in the same general area. Repair costs also depend on the volume and extent of repairs, site conditions and accessibility, level of expertise required, and other site-specific requirements (i.e., noise and odor control, protection of tenants, and maintaining means of egress). Actual construction costs may be obtained only after preparing construction contract bid documents and obtaining firm bids from contractors.

Hidden Conditions – Control of Repair Quantities

Unknown hidden conditions can change the original bid significantly. For this reason, the LDP is responsible for developing a control program for unknown hidden conditions. This can be achieved by developing repair criteria for various types and levels of damage. For example, the LDP should specify the limit of loss of steel reinforcement due to corrosion before replacement or addition of more steel. As they become exposed, hidden conditions should also be evaluated by the LDP.

Control of the quantities can also be achieved by specifying the method and equipment for the removal of damaged concrete. Though this suggestion appears to interfere with the contractor's means and methods, it is necessary to avoid removing areas of good concrete. A mock-up of removal and repair is recommended.

Construction of Repairs

The construction process for concrete repair projects often presents challenges that are not encountered in new construction. It requires close coordination between the owner, the LDP, and the contractor. Although the repair work is outlined in the contract documents, the scope of work may change as new conditions are uncovered. The contractor must be watchful for any new conditions observed and must be cautious not to damage existing good areas. Also, the contractor must be cautioned to make continuous observations of the existing structure for possible movements, additional cracking, and deflections, and to observe the overall stability of the structure.

The LDP has a contract only with the owner. The LDP cannot direct the contractor to perform additional work as the actual existing conditions dictate, or direct the contractor on safety, shoring and bracing issues. Thus, it is the responsibility of the LDP to establish criteria for the various damaged conditions requiring repairs. These criteria should be included in the contract between the owner and the contractor, thus becoming enforceable by the LDP. Examples of such criteria include the minimum crack width requiring repair or defining the spalling depth of a slab requiring either repair or complete replacement.

Temporary Shoring and Bracing

A repair project commonly requires that portions of a structure are supported before repair. The question is: who is responsible for the design and construction of temporary shoring and bracing? The answer is very clear: the design should be performed by a licensed design professional (other than the LDP of record for the repair), and the installation should be performed by the contractor. The LDP for the shoring design, sometimes called a specialty engineer, should be retained by the contractor. A conflict may result if the LDP for the repair design is the same professional for the shoring design, since the shoring is part of the contractor's means and methods, unless it is agreed with all the parties.

Having a general statement on the repair drawings for the contractor to “provide and install shoring as required” is a recipe for disaster. The repair LDP, as the one familiar with the deteriorated condition of the structure, is responsible for providing information on the required shoring, including:

- Areas of the structure requiring shoring and bracing before and during the repairs
- Design loads on the shoring system
- Temporary environmental loads, such as snow, wind and ice, should be taken into consideration as required by the authorities having jurisdiction. Action plan should be specified in the event of occurrence of such loads.
- Required quality control for installing and maintaining the shoring

- Specific jacking requirements
- Special inspections, field observations, and testing requirements
- Anticipated changes of the structure during the demolition and repair process that can affect the shoring system placement or the shoring loading

Quality Assurance

The effectiveness and longevity of a concrete repair depends very much on the surface preparation, repair material application, protection and curing of the repair. Thus, a strict quality assurance program should be developed, and inspection procedures should be specified in the contract documents by the LDP. The quality assurance program should include provisions for inspection and testing to verify the quality of workmanship and repair materials.

STRUCTURAL ASSESSMENT OF ENVIRONMENTAL STRUCTURES

Unlike building structures, environmental structures are built to last and, in fact, some municipalities require a service life of well over 100 to 200 years for some types of structures. Unless treatment plants, pipelines, and other environmental facilities are properly designed, constructed, and maintained over their life cycles, they cannot sustain the needed levels of service. Caring for these structures is the key to their sustainability and successful performance.

As water supply and wastewater treatment structures age, failure rates will increase, and capital needs could escalate if water, wastewater, and stormwater systems require renewal at the same time. Such a situation can create a huge economic burden for many municipalities. Thus, a need arises to develop maintenance and repair programs and service life evaluations.

LDPs are consulted by public agencies to assess and evaluate the structural integrity of environmental infrastructure. The LDP is responsible to undertake the investigation program, identify the required concrete repairs, develop service life cost analyses, and develop repair plans and details to meet the owner's management plan and expectations.

As discussed earlier, it is the responsibility of the LDP to understand the objectives and expectations of the owner. Public owners usually operate with rigid standard operating procedures, expecting their consultants to follow such procedures. Also, long-term capital plans and budget allocations do not have the flexibility for budget adjustments that are usually expected in repair/rehabilitation projects. It is therefore crucial for the LDP to identify the required repair quantities as close to reality as possible. Excessive variations in the repair quantities and budget can put the public agency in an undesirable position; such an undesirable position can also lead to political turmoil.

The assessment, evaluation, and repair of environmental structures present some distinct differences as compared to studies for building type structures. The severe exposure conditions, with continuous attack from the elements; the continuous presence of water and other liquids; the continuous attack from chemicals; and the surface erosion from liquid movement are some of the differences that separate environmental structures from other structures. Furthermore, both the investigation and repair construction require tight scheduling to ensure adequate water supply or water treatment.

Case Study: Wastewater Treatment Plant Assessment

A 275 million gallon per day (MGD) wastewater treatment plant in a major US city was constructed in the 1930s, and after several decades in operation it needed repairs. The concrete primary and final settling tanks of the plant displayed extensive deterioration in the form of surface erosion, cracking, spalling, reinforcement corrosion, and other signs of distress and deterioration. The plant has approximately 50 settling tanks of varying sizes. Most of the tanks are consecutive and have common walls. The owner required the structural evaluation of the concrete tanks to determine the general condition, the extent of damage, the type and cost of needed rehabilitation repairs, and the remaining useful service life of the concrete tanks.

The owner, with the help of the LDP, developed the objectives of that study as follows:

- Identify type and extent of damage
- Approximate quantities of damage

- Determine concrete quality and strength
- Assess the effect of damage on the structural integrity
- Identify and evaluate repair options

To achieve the above objectives, the following concrete assessment, evaluation, and repair program was developed:

- Condition surveys - visual inspections
- Nondestructive testing
- Laboratory testing
- Structural assessment - service life evaluation
- Repair design
- Repair construction

It is the responsibility of the LDP to develop the methodology to perform the various repair tasks. Fortunately for the professionals, there are several codes, industry standards, and guides providing information on how to tackle the complex issues of a repair program, especially for environmental structures.

These codes, industry standards, and guides include:

- ACI 350⁵ Code Requirements for Environmental Engineering Concrete Structures and Commentary
- ACI 364.1R⁴ Guide for Evaluation of Concrete Structures before Rehabilitation
- ACI 201.1R⁶ Guide for Conducting Visual Inspection of Concrete in Service
- ACI 224.1R⁷ Causes, Evaluation and Repair of Cracks in Concrete
- ACI 228.2R⁸ Report on Nondestructive Test Methods for Evaluation of Concrete Structures
- ACI 546R⁹ Guide to Concrete Repair
- ACI 562³ Code Requirements for Evaluation, Repair, and Rehabilitation of Existing Concrete Structures and Commentary
- ICRI No. 210.4¹⁰ Guide for Nondestructive Evaluation Methods for Condition Assessment, Repair, and Performance Monitoring of Concrete Structures
- ICRI No. 310.1R¹¹ Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

Additionally, public owners may have their own standard operating procedures, including specifications and standard repair details for evaluating and repairing environmental structures.

Condition Surveys - Visual Inspections

This task includes field visits to perform a condition assessment by visual observations of the concrete tanks. The visual observations were performed in accordance with ACI 201.1R “Guide for Conducting a Visual Inspection of Concrete in Service.”⁶ The observed conditions, such as cracks, spalls, exposed aggregates and surface erosion, exposed reinforcement, reinforcement corrosion, and damaged expansion joints, were identified and recorded on drawings. Typical defects identified included: concrete cracking and spalling, steel bar corrosion, joint failures, and surface erosion. Photographs of typical conditions observed, and repairs are illustrated in Figures 1 to 6.

During the condition survey, a few concrete column and wall elements exhibited advanced states of deterioration requiring special attention. The owner was informed on such conditions.

Nondestructive Testing

Nondestructive testing was performed at selected locations to confirm the soundness of the concrete, identify internal faults, identify potential reinforcement corrosion, and detect location and depth of reinforcement. Nondestructive testing methods included:

- Pachometer Testing: Location and depth of reinforcing steel bars
- Impact-Echo: Identify internal faults
- Impulse Response: Identify general weaken areas
- GPR: Identify internal faults, rebars, hidden piping
- Half-Cell Potentials: Measure of corrosion potential

Photographs of nondestructive testing and results are illustrated in Figures 7 to 10.

Laboratory Testing

Concrete core samples were taken from the tank walls and floors for laboratory testing. The purpose of the laboratory testing was to determine the strength and quality of the concrete, detect any chemical attacks, and determine long-term durability characteristics of the concrete. The laboratory testing included:

1. Compressive Strength Testing
2. Petrographic & Chemical Analyses
 - Identify concrete properties & quality: water/cementitious ratio, air content
 - Chemical attack (Alkali-silica reactivity, sulfates)
 - Chloride content
 - Carbonation (pH levels)
 - Freeze-thaw damage

Service Life Evaluation

Technical service life for a concrete member is the time in service until a defined unacceptable state is reached (i.e., spalling of concrete, safety level below acceptable standards, or failure of elements). Deterioration of reinforced concrete structures is mostly due to the corrosion of the reinforcing steel embedded in the concrete. Steel corrosion is usually attributed to the ingress of chlorides and other corrosive chemicals within the concrete mass. In general, the service life evaluation of a concrete structure is based on probabilistic models that predict the time required for contaminants to reach the embedded steel in concrete and initiate corrosion. The analysis is based on the specific characteristics of the concrete and the local environmental conditions. Commercially-available computer software was employed to simulate the progress of contaminant ions (chlorides, sulfates, hydroxides) through the concrete by considering the chemical and physical properties of concrete.

It was suggested by the LDP to perform a service life evaluation of each type of liquid-containing tank or other suspect concrete elements throughout the entire plant. Concrete cores were extracted from the tank structures, and wastewater samples were collected for laboratory testing. The concrete cores were tested to determine the ionic and moisture transport properties of the concrete. The wastewater sample was tested for pH and various metal concentrations. The data collected from the concrete and water testing were used in the service life evaluation of concrete.

Two repair alternates were simulated:

- a) Perform the minimum required repairs, including repair of cracks, spalls, expansion joints, and corroded reinforcing steel bars.
- b) Perform the minimum required repairs as in Item (a), apply a ½" thick cementitious silica fume mortar, and apply a protective epoxy coating on all tank surfaces.

The simulation results indicated that the chloride contaminants could reach the 2-inch depth and cause the reinforcing steel to corrode in approximately seven to ten years. Steel bars located close to the surface in less than 2" will start corroding in much less time. For bars located in more than 3" within the concrete, the chlorides will require 20 to 40 years before they affect the steel bars. When a protective mortar layer and epoxy coating is introduced into the simulation, the time over which corrosion initiation of rebars is expected to increase well beyond 40 years.

Structural Assessment and Evaluation

The results of the condition surveys, nondestructive testing, laboratory testing, structural design evaluation, and service life analyses were summarized in a comprehensive engineering report. The structural evaluation included recommendations with respect to the repair or replacement of extensively damaged concrete areas, as well as approximate budget analysis of alternate repair programs. Although the general condition of the tanks was sound, the observed damaged conditions required repairs to prevent further deterioration and damage that could eventually compromise the structural integrity of the concrete tanks. Additionally, the state of deterioration had jeopardized the durability qualities of concrete and needed to be restored.

Two repair alternatives were suggested:

1. Perform minimum required repairs.
2. Perform the full repair program outlined in the investigation report.

Alternative No. 1 included only those repairs considered necessary to control further deterioration and extend the service life of the existing structures for the next 10 to 20 years in combination with bi-annual structural assessments. This alternative included major repair items such as patching of concrete spalls, sealing of cracks, repair of failed expansion joints, repair of exposed steel reinforcing, repair of damage steel embedment and holes, repair of columns, repair of concrete troughs, and repair of concrete walkways.

Alternative No. 2 included all the repairs proposed under Alternative No. 1, plus the coating of all exposed tank surfaces. Alternative No. 2 is expected to extend the service life of the existing structures for approximately 30 to 40-years. The concrete surface coating was expected to restore and protect the concrete from the abrasive effects of water flow and chemical attack. Surface coating would also reduce the potential for moisture, chloride and other chemical migration into the concrete, which could potentially damage the steel reinforcing.

Repair Design

The owner evaluated the recommendation of the evaluation report and decided to implement repair Alternative No. 1. The philosophy of the repair design for this project was two-fold: restoration of the structural integrity of the concrete tanks; and ensuring their future long-term durability after the repairs. Design methods used in the rehabilitation of the tanks incorporate durability characteristics in the repair materials selected to ensure continuing long-term serviceability of the tanks. Other factors, such as cost and construction schedules to meet the plant's operations requirements, were incorporated into the repair design.

The repair design was based on the local building code, ACI 350⁵ and ACI 562³ Codes, and other special site-specific design requirements established by the owner.

Repair Construction

The repair construction presented several challenges. Considering the large scale of recommended repairs, in combination with the plant operation requirements and budget, it was recommended to develop a general plan on the construction sequence and tank availability. In consultation with the owner, a protocol was developed to determine the safe number of tanks out of service for repair purposes without disturbing the plant's operations. Other challenges included:

Common wall repairs with through cracks and leaking expansion joints required the common wall to be dry on both sides to best ensure the proper installation and effectiveness of the repair. Thus, two consecutive tanks were required to be out of service at the same time. However, due to plant operations it was not possible to have dry walls at all tanks. Thus, the crack repair detail was changed from epoxy injection to injection of hydrophobic polyurethane foam grout at the leaky cracks.

Considering the need to have the repairs completed within specified time limits while keeping the plant's operations undisturbed, the work needed to be unobstructed from weather conditions. It was suggested by the owner to require a temporary roof cover on the tanks so that repairs could proceed in any weather conditions. Heating and ventilation should be provided as required for both personnel safety, as well as curing of the concrete repair work.

Escalation of repair quantities are controlled with close supervision of the contractor's work by the owner's design engineering team. The project specifications require that the removal of the damaged areas be carefully controlled; thus, no good material is removed. Furthermore, water blasting pressures for surface cleaning must be calibrated to remove only loose and soft surface material. No steam pressure cleaning or sandblasting is allowed. Also, no toxic cleaning materials are allowed.

Concrete repair is a specialty construction work requiring experience and qualification to install certain repair materials. The contractor must be an approved applicator by the material manufacturer. Also, a manufacturer's representative is required to be on-site to ensure proper mixing, surface preparation, and application of the repair materials. To ensure the quality and uniformity of the repairs, the contractor is required to perform mock-up repairs for all typical repair types. The mock-up repairs should be performed to the satisfaction of the owner and the LDP.

Quality Assurance

Considering the peculiarities of this project, including the strict quality assurance requirements established by the owner, the repair drawings and specifications included measures to assure quality and uniformity of construction. Such measures included:

- Require proof of concrete rehabilitation experience of all contractors and subcontractors.
- Require proof of approved applicator qualifications of the contractors furnished by the repair material manufacturers.
- Require presence of the material manufacturer and certification by the manufacturer that the materials have been mixed and applied properly and that surfaces were prepared as per the manufacturer's requirements.
- Require mock-up repairs for all typical repair items; minimum mock-up repair quantities, testing and acceptance criteria were specified.
- Establish a protocol for the removal of damaged concrete to avoid removal of good concrete. Additional areas not specified in the drawings requiring removal are to be inspected by the LDP.
- Establish criteria for the minimum deteriorated condition requiring repairs or replacement.
- Require pull-out testing for the repaired spall areas. Acceptance criteria were also specified.
- Review of material submittals.
- Specify special inspections required by the local authorities. These inspections are done by a qualified inspection agency retained by the owner.
- The LDP is to perform additional observations of the work in progress to ensure that the work meets the design intent.
- Require the contractor to provide a guarantee of the work for a set number of years (a five-year period is a reasonable time) against failure of crack and patch repairs.

CONCLUSIONS

This study presented a brief discussion of the responsibilities of the construction team members—owner, licensed design professional, and contractor—during a concrete repair project. Currently, there is no single existing document similar to ACI 132R² outlining these responsibilities.

The owner is the ultimate party responsible for the maintenance and repair of their structure. The owner may delegate this responsibility to licensed design professionals, contractors or construction managers. The owner should make their objectives and expectations clear to the other team members. Otherwise, the objectives and expectations will remain unfulfilled.

The responsibilities of the licensed design professional start and end with the contract requirements between the LDP and the owner. The role of the LDP is to inform the owner of the actual condition of the structure and protect the owner by advising them on the appropriate course of action with respect to the structural assessment and repair needs.

The contractor is the party that implements the repair program. Satisfactory repair work requires a good understanding of the design intent, as well as a quality control program.

Effective communication and understanding of the nature of the damage and the repair design alternatives can prevent misunderstandings and unrealistic expectations among the construction team members.

The ACI 132R² document is applicable to general concrete construction, primarily for new project construction, and it does not consider the special process of evaluating and repairing existing concrete structures. Therefore, there is a need for a new ACI document addressing the special responsibilities stemming from the particularities of concrete repair projects.

REFERENCES

1. Quality in the Construction Project, A Guide for Owners, Designers, and Constructors,” ASCE, Third Edition, 2012, 302 pp.
2. ACI Committee 132 “Guide for Responsibility in Concrete Construction (ACI 132R-14),” American Concrete Institute, Farmington Hills, Michigan, 2014, 11 pp.
3. ACI Committee 562 “Code Requirements for Evaluation, Repair, and Rehabilitation of Existing Concrete Structures and Commentary (ACI 562-16)” American Concrete Institute, Farmington Hills, Michigan, 2016, 86 pp.
4. ACI Committee 364 “Guide for Evaluation of Concrete Structures before Rehabilitation (ACI 364.1R-07),” American Concrete Institute, Farmington Hills, Michigan, 2007, 18 pp.
5. ACI Committee 350 “Code Requirements for Environmental Engineering Concrete Structures and Commentary (ACI 350-06),” American Concrete Institute, Farmington Hills, Michigan, 2006, 485 pp.
6. ACI Committee 201 “Guide for Conducting Visual Inspection of Concrete in Service (ACI 201.1R-08),” American Concrete Institute, Farmington Hills, Michigan, 2008, 15 pp.
7. ACI Committee 224. “Causes, Evaluation and Repair of Cracks in Concrete (ACI 224.1R-07),” American Concrete Institute, Farmington Hills, Michigan, 2007, 22 pp.
8. ACI Committee 228 “Report on Nondestructive Test Methods for Evaluation of Concrete Structures (ACI 228.2R-13),” American Concrete Institute, Farmington Hills, Michigan, 2013, 82 pp.
9. ACI Committee 546R “Guide to Concrete Repair (ACI 546R-14),” American Concrete Institute, Farmington Hills, Michigan, 2014, 70 pp.
10. ICRI No. 210.4 Guide for Nondestructive Evaluation Methods for Condition Assessment, Repair, and Performance Monitoring of Concrete Structures
11. ICRI No. 310.1R Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion



Figure 1 – Cracked and spalled concrete columns and repairs.

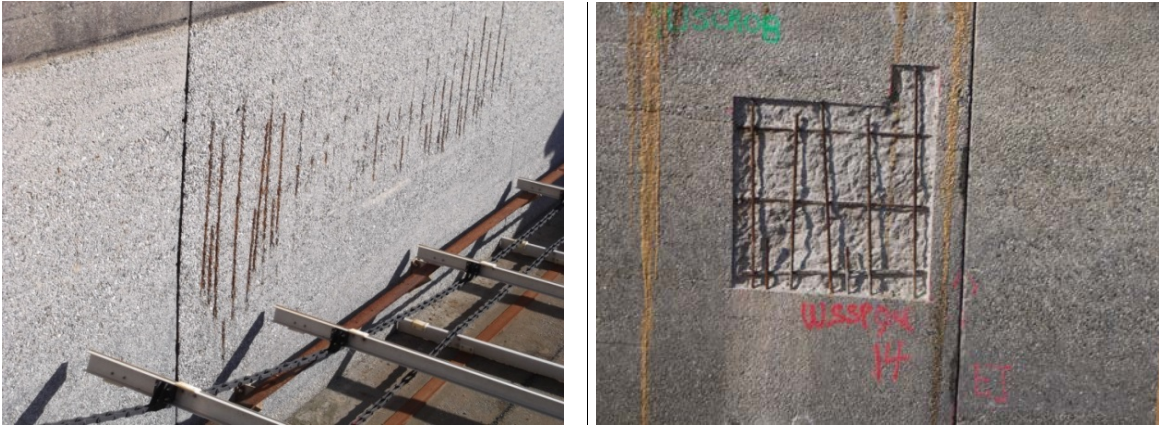


Figure 2 – Exposed corroded reinforcing steel bars and repairs.



Figure 3 -Eroded concrete surface and repairs



Figure 4 - Spalled concrete and repairs



Figure 5 - Cracked tank wall. Water leaks from adjacent tank. Chemical grout injection.



Figure 6 – Cracked troughs and repairs.



Figure 7 – Impact-Echo testing: Identify internal defects



Figure 8 - Impulse Response: Identify general weakened areas



Figure 9 - GPR: Identify internal faults, rebars, hidden piping



Figure 10 - Half-Cell Testing: Measurement of corrosion potentials

UNRAVELING RESPONSIBILITIES IN A PARKING STRUCTURE FLOOR SLAB FAILURE

William O. Wilson, PE and Daniel E. Moser, PE, SE, PTI Fellow

Biography:

ACI member **William Wilson** is a Restoration Consultant at Walker Consultants. He is both a Purdue University and University of Illinois graduate and has been with Walker for 5 years. He is a member of ACI Committees 231 (Early-age Properties), and 365 (Service Life). His career focus is on infrastructure repair with a focus on structural repair of parking structures.

Daniel Moser is a Principal and Director of Restoration at Walker Consultants. Dan is a University of Illinois graduate and has been in the industry for 30 years. Dan is a Registered Professional Engineer and a Licensed Structural Engineer and has performed structural investigations and practical repair and strengthening designs for structures of all types and materials throughout his career. Dan is a PTI Fellow and is very active in the post-tensioning repair community.

ABSTRACT

This is a case study involving an aging parking structure that deteriorated to the point where the structural floor slab failed. The lines of responsibility between parties involved with owning, managing and repairing the existing, exposed structures are not always clear, based on contractual language. This case ended in litigation to determine who was responsible for repair costs when the structural slab reached the end of its service life, taking into account the root cause of the slab failure. In this case study we review the field and background information obtained for this case as well as the court interpretation of lines of responsibility and contract language regarding parking structure maintenance and normal wear and tear.

Keywords: post-tensioning repair; button head post-tensioning; litigation; slab failure; parking structure repair; normal wear and tear; lines of responsibility.