Resiliency of Existing Concrete Structures and Communities

How Can We Improve Long-Term Performance and Resiliency?

By

Keith Kesner and Tracy Marcotte

CVM Professional

King of Prussia, PA

Learning Objectives

- How resiliency is defined
- Need for resiliency of communities
- Improve resiliency of existing structures
- Contribution of codes and standards to resiliency

Resiliency - Definition

- Measure of the response of a system to a perturbation
- Perturbations????
- How is it measured?
  - Structural dynamics – impulse response function
    - Duhamel integral
    - Newmark method
    - Numerical integration

$$u(t) = \frac{1}{m\omega_D} \int_0^t p(\tau) e^{-\xi \omega_n t(t-\tau)} \sin[\,\omega_D (t-\tau)]\, d\tau$$

Resiliency - Definition

- Measure of the response of a system to a perturbation
- How is it measured?
  - Weebles
    - They wobble,
    - but they don't fall down

Resiliency - Definition

- How is it measured (cont.)?
  - Time to recovery of system
  - Restoration of services
  - Things back to “normal”
- Numerous resiliency “measures”
    - FEMA, NIST, NIBS, etc.

Resiliency

- Multi-scale problem
  - Individual structures, neighborhoods, full communities/cities
- How to improve???
  - Response to events
  - Structures – safe, **durable** and **sustainable**
  - Better codes and standards

Durability vs. Resiliency

- Durability
  - Long-term exposure to natural environment
  - Long-term exposure to man-made problems
  - **Minimal downtime for repair**
- Resiliency
  - Short-term exposure to environment / man-made problems
  - **Minimal downtime for restoration of services**

Sustainability vs. Resiliency

- Sustainability
  - Minimize impact on environment
  - Keep structures in service
- Resiliency
  - Keep structures operational / restorable
- **Co-equal goals**

Resiliency - Durability - Sustainability

- Not well understood by design professionals
- Not well understood by general public
- Highly inter-related
- Not mutually exclusive
- Critical to long-term performance of structures

Resiliency – Existing Structures

- Reality
  - We all can work to improve resiliency
- Things to strive for:
  - Less damage during events
  - Faster recovery time
  - Consistency in recovery protocols

Hurricane Michael, Mexico Beach, FL
Johnny Milano for NY Times, 2018

Design to resist: *begin with the end in mind*

- Reinforced concrete
- Pilings for storm surge
- Roof minimized against wind uplift
- Break-away walls at base & tear-away staircase

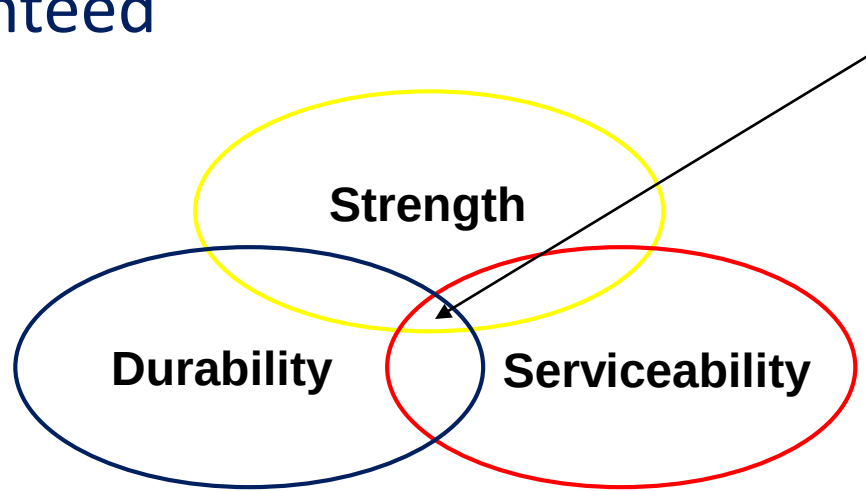
Rebuilding tear-away staircase
Johnny Milano for NY Times, 2018

Resiliency – How to improve it?

- Long-term durable structures
- Consistent reliability of existing structures
- Consistent repair procedures
  - Use codes and standards for repair
  - Support adoption of Codes and Standards for repair

Existing Structures

- Long-term performance of structures is not guaranteed



Long-term performance

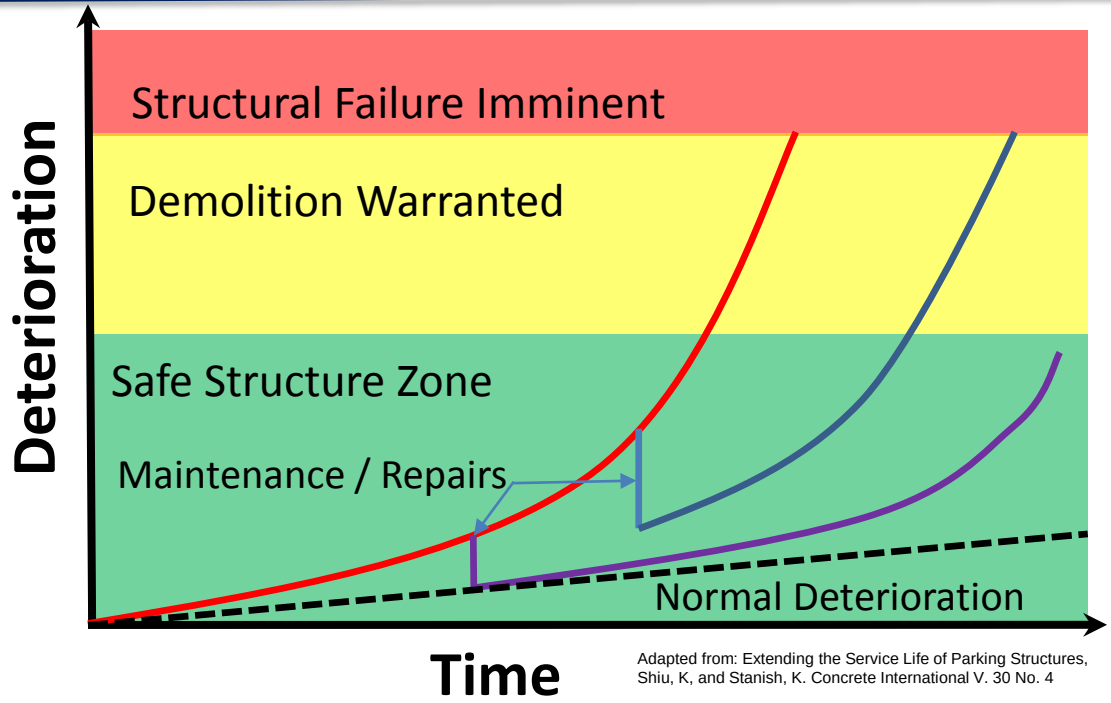
Durable;

Resilient;

Sustainable, etc.

Existing Structures - Performance

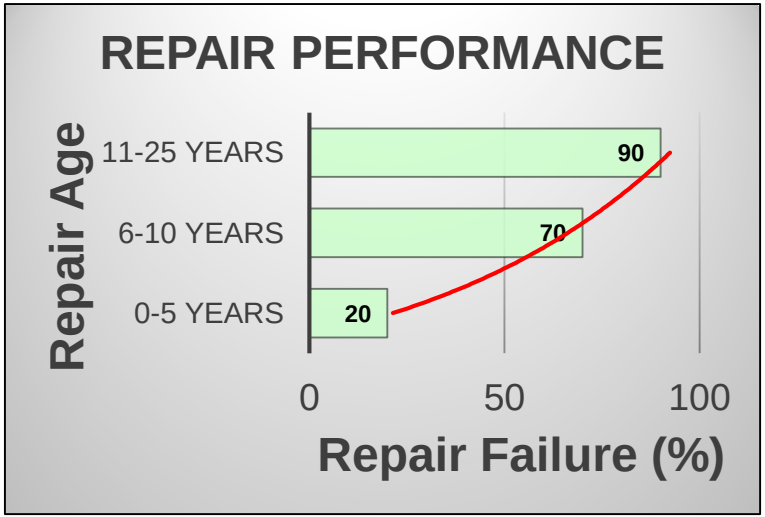
- Service life
- Repairs
- Execution of repairs
  - Timely fashion
  - Consistent manner



Adapted from: Extending the Service Life of Parking Structures, Shiu, K, and Stanish, K. Concrete International V. 30 No. 4

Existing Structures – Repairs

- Problems with concrete repairs?
  - Variations in practice
  - Variations in repair performance
  - Poor performance of repairs
  - Lack of quality control
  - Mis-diagnosis of problems



http://projects.bre.co.uk/conrepnet/pdf/newsletter3.pdf

What is wrong with concrete repair?

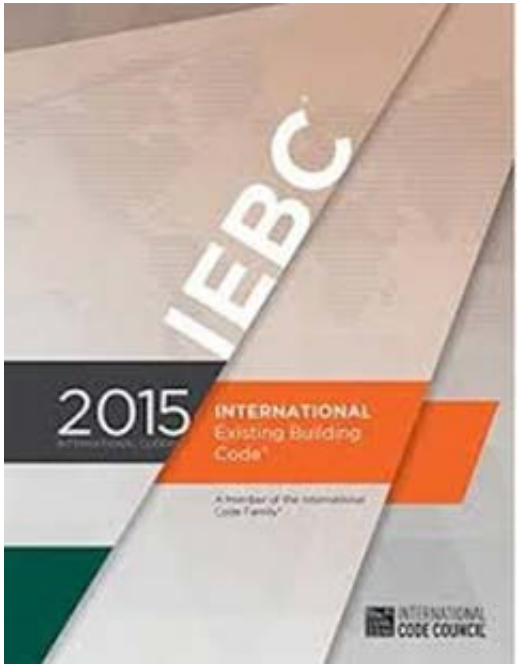
- Many design professionals do not consider repair a distinct area
  - Limited evaluation of structures
  - Lack of understanding of durability
- Lack of contractor focus on quality
- US national codes
  - IBC – comprehensive document for new design
  - IEBC – does not establish a clear standard of care for repair

What is wrong with concrete repair?

- Lack of formal education in existing structures
  - Limited coursework on existing structures
    - ACI Faculty Network – 21 US universities have 1 course
  - Limited course materials on repair
  - Academic “preservation” is not repair

What is wrong with the IEBC?

- The how of minimum evaluation requirements
  - How bad is a structure?
  - Analysis considerations?
- Reliability of repaired structures?
- Durability considerations?
- Consideration of service life
- Construction quality assurance



What is wrong with the IEBC?

- Missing standard of care
- Standard of Care - “level of effort a prudent LDP would be expected to provide on a project”
  - Determined from codes, industry standards, guidelines, tradition, etc.

What is wrong with the IEBC

- Confusing definitions

UNSAFE. Buildings, structures or equipment that are unsanitary, or that are deficient due to inadequate means of egress facilities, inadequate light and ventilation, or that constitute a fire hazard, or in which the structure or individual structural members meet the definition of "*Dangerous*," or that are otherwise *dangerous* to human life or the public welfare, or that involve illegal or improper occupancy or inadequate maintenance shall be deemed unsafe. A vacant structure that is not secured against entry shall be deemed unsafe.

[BS] DANGEROUS. Any building, structure or portion thereof that meets any of the conditions described below shall be deemed dangerous:

1. The building or structure has collapsed, has partially collapsed, has moved off its foundation, or lacks the necessary support of the ground.
2. There exists a significant risk of collapse, detachment or dislodgement of any portion, member, appurtenance or ornamentation of the building or structure under service loads.

- What is needed?
  - Clear path to identify unsafe conditions

Concrete repairs – How to improve?

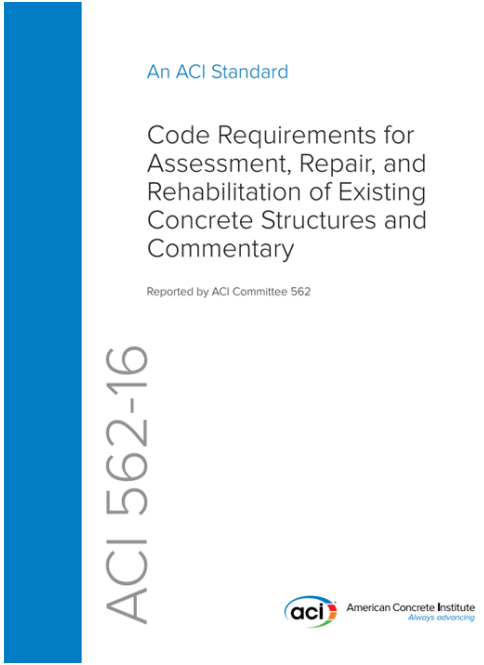
- Establish a clearer standard of practice
  - Minimum standards
  - Durable repair design
- Reliability of repaired structures
- Fully developed supporting documents

Codes and Standards for Repair

- 562 – Code for Repair of Existing Structures
  - First published in 2013
  - Third version in Spring 2019
- 563 – Specifications for Repair
  - First published in 2018
  - Parallel document to ACI 301

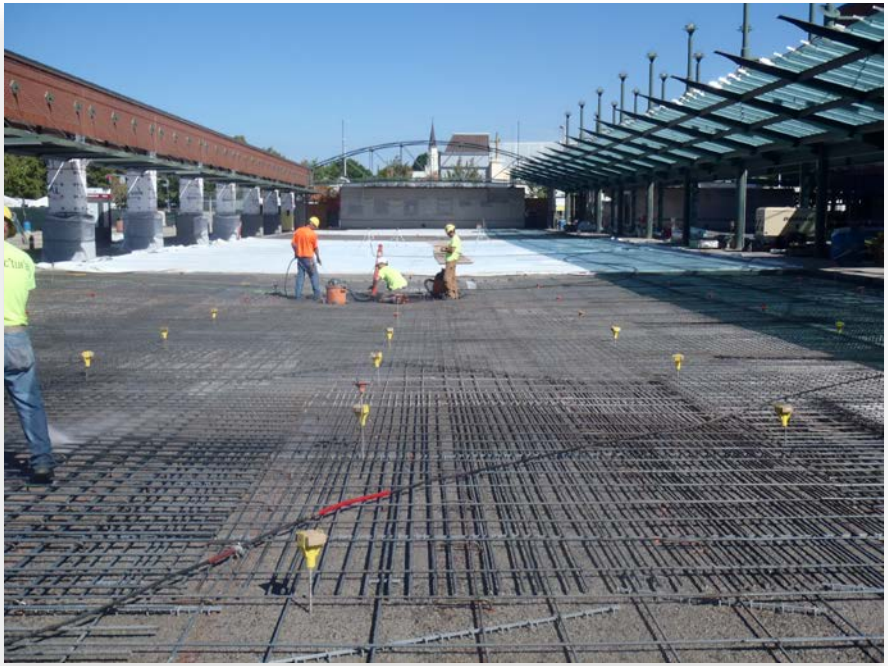
ACI 562

- ACI Standard
  - Sets the minimum requirements for repair
- Provides clear requ. for strengthening
  - Based upon damage present
  - New vs. existing code requirements
- Fully developed support documents



ACI 562 – Major Sections

- Applicability / General
- Loads
- Evaluation
- Repair design
- Durability
- Construction & QA/QC

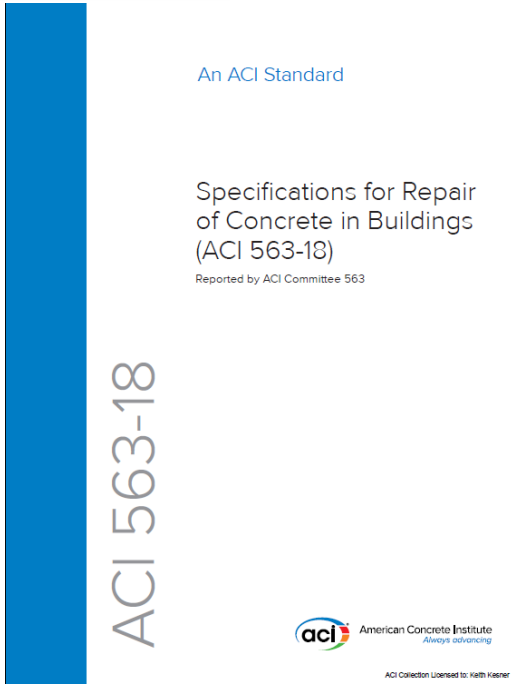


Standard Repair Specifications

- Instructions to contractors
- How to execute project requirements
- Material requirements
- Consistency of repairs
- Improved repair performance

ACI 563 – Specifications for Repair

- Developed to be parallel to ACI 301
- Contents
  - Shoring / bracing
  - Formwork
  - Conv. concrete
  - Prop. materials
  - Shotcrete (ACI 503.7)
  - Removals
  - Reinforcement
  - Handling / placement
  - Crack repair – epoxy

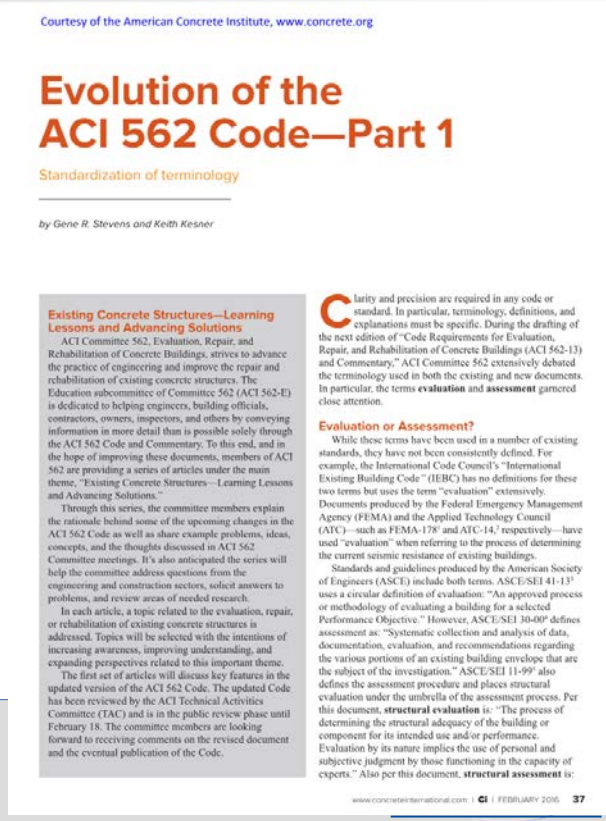


ICRI 030130 – Structural Concrete Repair

- Stand-alone specification
  - Concrete removal — Repair layout
  - Material selection — Placement
  - Pay basis — QA/QC
- Not coordinated
  - ICRI CRST — ACI 562 / ACI 563

Supporting Documents

- ACI/ICRI Guide
  - Worked examples
- CI Article series
  - 11 parts
  - Code explanations
- Webinars
  - ACI / ICRI



Courtesy of the American Concrete Institute, www.concrete.org

Evolution of the ACI 562 Code—Part 1

Standardization of terminology

by Gene R. Stevens and Keith Kesner

Existing Concrete Structures—Learning Lessons and Advancing Solutions

ACI Committee 562, Evaluation, Repair, and Rehabilitation of Concrete Buildings, strives to advance the practice of engineering and improve the repair and rehabilitation of existing concrete structures. The Education subcommittee of Committee 562 (ACI 562-E) is dedicated to helping engineers, building officials, contractors, owners, inspectors, and others by conveying information in more detail than is possible solely through the ACI 562 Code and Commentary. To this end, and in the hope of improving these documents, members of ACI 562 are providing a series of articles under the main theme, "Existing Concrete Structures—Learning Lessons and Advancing Solutions."

Through this series, the committee members explain the rationale behind some of the upcoming changes in the ACI 562 Code as well as share example problems, ideas, concepts, and the thoughts discussed in ACI 562 Committee meetings. It's also anticipated the series will help the committee address questions from the engineering and construction sectors, solicit answers to problems, and review areas of needed research.

In each article, a topic related to the evaluation, repair, or rehabilitation of existing concrete structures is addressed. Topics will be selected with the intentions of increasing awareness, improving understanding, and expanding perspectives related to this important theme.

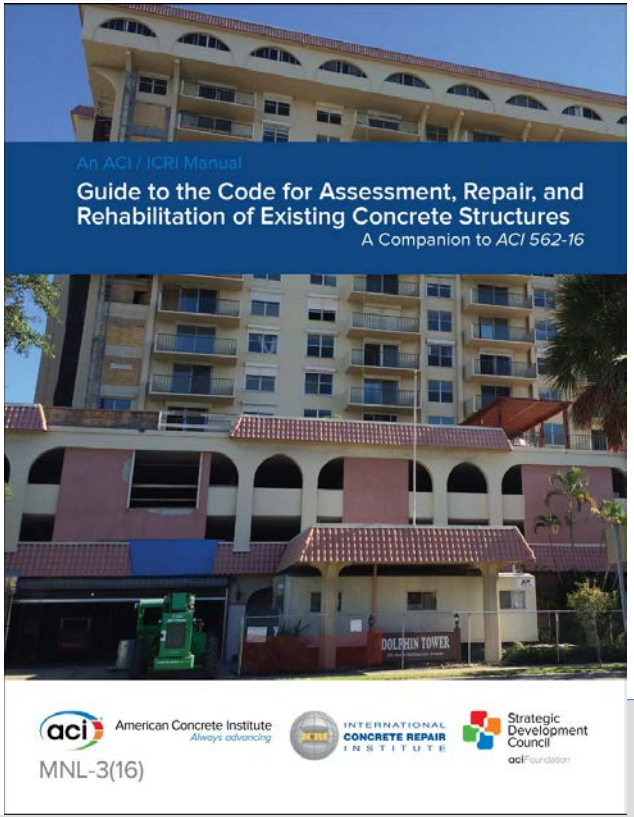
The first set of articles will discuss key features in the updated version of the ACI 562 Code. The updated Code has been reviewed by the ACI Technical Activities Committee (TAC) and is in the public review phase until February 18. The committee members are looking forward to receiving comments on the revised document and the eventual publication of the Code.

Clarity and precision are required in any code or standard. In particular, terminology, definitions, and explanations must be specific. During the drafting of the next edition of "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary," ACI Committee 562 extensively debated the terminology used in both the existing and new documents. In particular, the terms **evaluation** and **assessment** garnered close attention.

Evaluation or Assessment?

While these terms have been used in a number of existing standards, they have not been consistently defined. For example, the International Code Council's "International Existing Building Code" (IEBC) has no definitions for these two terms but uses the term "evaluation" extensively. Documents produced by the Federal Emergency Management Agency (FEMA) and the Applied Technology Council (ATC)—such as FEMA-178[1] and ATC-14,[2] respectively—have used "evaluation" when referring to the process of determining the current seismic resistance of existing buildings.

Standards and guidelines produced by the American Society of Engineers (ASCE) include both terms. ASCE/SEI 41-13[3] uses a circular definition of evaluation: "An approved process or methodology of evaluating a building for a selected Performance Objective." However, ASCE/SEI 30-00[4] defines assessment as: "Systematic collection and analysis of data, documentation, evaluation, and recommendations regarding the various portions of an existing building envelope that are the subject of the investigation." ASCE/SEI 11-99[5] also defines the assessment procedure and places structural evaluation under the umbrella of the assessment process. Per this document, **structural evaluation** is: "The process of determining the structural adequacy of the building or component for its intended use and/or performance. Evaluation by its nature implies the use of personal and subjective judgment by those functioning in the capacity of experts." Also per this document, **structural assessment** is:



INTERNATIONAL CONCRETE REPAIR INSTITUTE

ICRI – CSRT Program

- Certified repair inspectors
- Written and field training
  - QA / QC procedures
  - Understand
    - Why and how of good repair practices

Codes and Standards - Resiliency

- Establish standard of care
- Raise the bar for performance
  - Reliability
  - Durability
- Repaired structures
  - Resistance to further damage
  - Capable of long-term performance

ACI 562 Adoption

- Statewide adoption in OH and HI
- Working on 2021 IEBC Adoption
- IEBC Alternate procedure
- Why ACI 562?
  - Use a standard for design of repairs
  - IEBC is not sufficient
  - Current practice is not working

[A] 104.11 Alternative materials, design and methods of construction, and equipment. The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design, or method of construction shall be approved where the *code official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method, or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety. Where the alternative material, design or method of construction is not approved, the *code official* shall respond in writing, stating the reasons the alternative was not approved.

2015 - IEBC

How to support ACI 562 adoption?

- Use it on projects
- Encourage NCSEA EBC to support
- Talk to code officials
- www.concrete.org/adopt

Summary

- Resiliency of communities
  - Starts with durable existing structures
  - Hard to quantify actual resiliency
- Repair Codes and Standards
  - Current repair process is not working
  - Needed to improve process
  - Code adoption is critical step