American Concrete Institute

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Guide to ACI 562-16 Repair Code:
Example of Precast/Prestressed Double-Tee Repair

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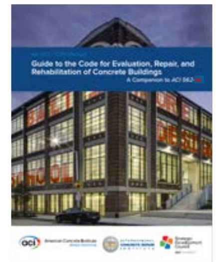
November 11, 2016

ACI 562-16 Repair Code and Guide



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Facility Description

- Water treatment plant (WTP)
- Precast double-tee roof beams
  - 24 and 28 in. depths
  - 59 to 72 ft. spans
  - Dapped ends
- Cast-in-place concrete framing

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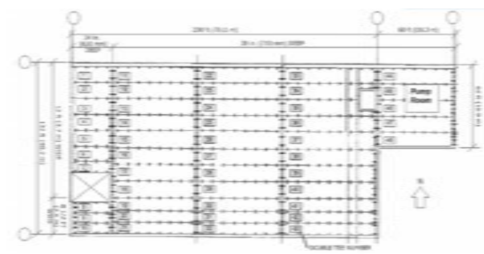
Facility Description



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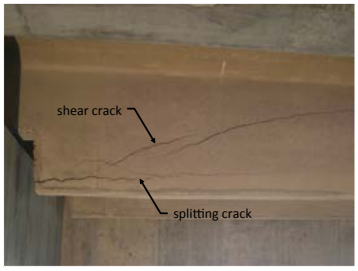
Project Initiation

- Wide diagonal crack observed in double-tee stem shortly after construction
- Temporary retrofit designed and installed as an emergency safety measure
- Licensed design professional (LDP) retained to:
  - Determine cause of cracking
  - Assess structural implications
  - Develop long-term repair details

Project Initiation



Project Initiation

Preliminary Evaluation - ACI 562-16 1.7.1

- …shall include investigation and review of the structure, plans, construction data, reports, local jurisdictional codes, and other available documents of the existing structure.
- Existing in-place conditions shall be visually or otherwise investigated to verify existing geometry and structural conditions.

Preliminary Evaluation

- Precast concrete shop drawings reviewed to:
  - Confirm layout and dimensions of double tees
  - Determine prestressed and mild reinforcement details
- Visual inspection completed to establish existing concrete condition
  - Inspected from walkways and catwalks
  - Binoculars and ladders used where appropriate
  - Over 75 percent of double tee stem ends observed

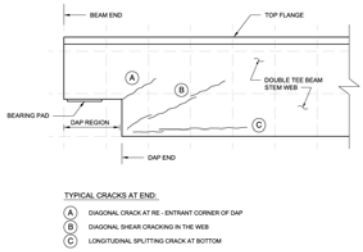
Preliminary Evaluation

- Design calculations reviewed to:
  - Confirm design loads conformed to the original building code as permitted by ACI 562-16 1.7.3
  - Confirm that as-designed shear strength was adequate for the design loads per ACI 562-16 4.5.1

Preliminary Findings

- Double tee stems adjacent to daps had apparent concrete shear cracking problem
  - Only one stem end with wide diagonal crack
  - Many other stem ends with fine diagonal cracks
- The as-designed shear strength was confirmed to be adequate for the design load effects
- Unclear if diagonal cracking a result of unusual structural behavior or a structural deficiency

Preliminary Findings - Typical Cracking



Structural Assessment - ACI 562-16 6.2.1

An investigation and structural evaluation shall be performed if an existing structure 1) exhibits signs of damage, displacement, deterioration, structural deficiency, or behavior that is inconsistent with available design and construction documents or code requirements in effect at the time of construction, or 2) preliminary evaluation indicates strengthening is required.

Structural Assessment

- Owner notified that diagonal cracks might be a safety concern per ACI 562-16 1.7.2
- LDP recommended further assessment in accordance with ACI 562-16 6.1.1 to include:
  - Structural Investigation
  - Structural Evaluation and Analysis
- Periodic visual monitoring recommended
- Temporary shoring deemed unnecessary given expedited assessment schedule

Structural Assessment - ACI 562-16 6.1.1

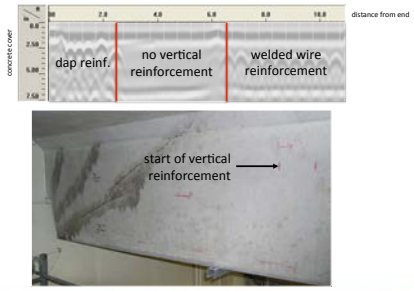
The structural assessment shall compromise… an investigation to establish the in-place condition of the structure in the work area, including environment, geometry, material strengths, reinforcing steel sizes and placement and signs of distress…

Structural Investigation

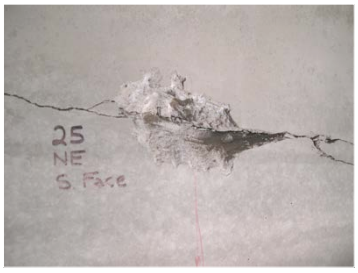
- Field measurements made per ACI 562-16 6.2.4 to determine:
  - Span lengths, flange thicknesses, flange widths, stem depths and stem widths of double tees
  - Reinforcement spacing and cover in double tee stems
- Double tee flange thicknesses, reinforcement spacing and cover determined with ground penetrating radar (GPR) and confirmed via exploratory openings

Structural Investigation

Structural Investigation



Structural Investigation

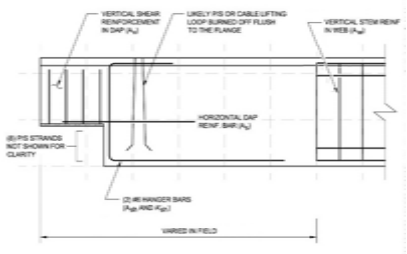


Structural Investigation

Structural Investigation

- Forty-one stem ends surveyed with GPR
- Location of vertical reinforcement varied greatly
  - 5 of 41 ends: vertical reinforcement started within 10 in. of dapped end
  - 36 of 41 ends: vertical reinforcement started 18 to 91 in. from dapped end
- GPR survey demonstrated that vertical reinforcement was mislocated or missing relative to the precast concrete shop drawings

Structural Investigation



Structural Investigation

- Material properties obtained from precast concrete shop drawings per ACI 562-16 6.3.1
  - Assumed conformance to specified grades of steel
  - Reviewed concrete cylinder test data
  - No observed deterioration or associated effects on performance (ACI 562-16 6.3.4)
- Other potential sources include:
  - Historical values in ACI 562-16 Tables 6.3.1a to 6.3.1c
  - Physical testing in accordance with ACI 562-16 6.4

Structural Assessment - ACI 562-16 6.1.1

The structural assessment shall compromise… an evaluation to define the causes of distress, goals of the rehabilitation, and criteria for selection of rehabilitation strategies…

Design-Basis Code – ACI 562-16 1.2.4.2

- Original building code defined as design-basis code criteria as determined by:
  - ACI 562-16 Chapter 4
  - International Existing Building Code
- ACI 562-16 used in conjunction with original building code to evaluate structure and design repairs.

Structural Evaluation

- Shear capacity of as-built double tees evaluated in relation to design shear forces
  - Load factors, combinations and resulting shear forces defined by original building code
  - Shear strength calculated per ACI 318-08 as referenced by original building code
- Shear strength provided by concrete alone insufficient to carry the design shear forces
- Shear reinforcement necessary per ACI 318-08

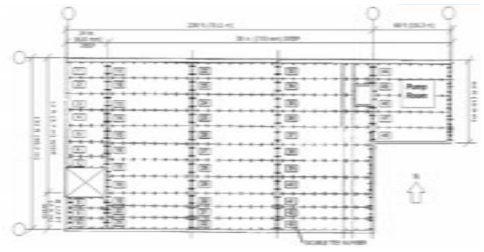
Structural Evaluation

- Mislocated or missing vertical reinforcement most likely resulted in the observed distress
- Complete failure of the double tee stems mitigated by reinforcement immediately adjacent to the daps
- The LDP prepared a basis of design report per ACI 562-16 1.5.3.1 which included:
  - Documentation of unsafe structural conditions
  - Identification of members requiring strengthening

Repair/Replacement Concepts

- Complete replacement of precast members
- Strengthening by concrete jacketing
- Strengthening with bonded steel plates
- Strengthening with carbon-fiber reinforced polymer (CFRP)

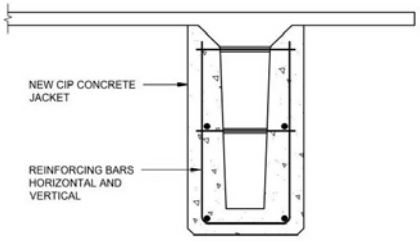
Complete Replacement



Complete Replacement

- Includes roof system replacement
- Disruptive to WTP operations
  - Temporary weatherproofing above existing equipment
  - Temporary relocation of suspended utilities
  - Extensive construction staging on facility grounds
- More rigorous quality assurance of precast fabrication necessary

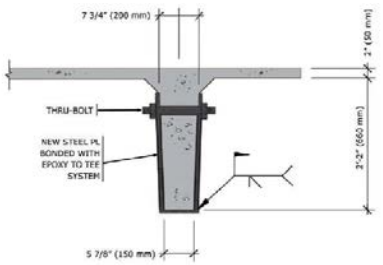
Concrete Jacketing



Concrete Jacketing

- Significant field labor requirements
  - Bond surface preparation
  - Reinforcement installation
  - Forming and concrete placement
- Significant access and protection requirements
  - Enclosed temporary work platforms
  - Permanent catwalk installation
- Design must consider additional dead-weight

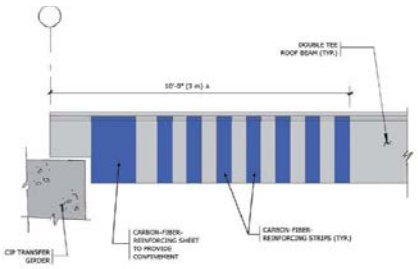
Bonded Steel Plates



Bonded Steel Plates

- Significant field labor requirements
  - Bond surface preparation
  - Plate installation and welding
- Significant access and protection requirements
- Quality assurance of field welding necessary
- Pertinent design considerations
  - Field handling of plate assemblies
  - Long-term corrosion in high humidity environment

Carbon-Fiber Reinforced Polymer



Carbon-Fiber Reinforced Polymer

- Lightest, least invasive repair option
- Significant access and protection requirements
- Pertinent quality considerations
  - CFRP bond to substrate concrete
  - Track record of CFRP repair system
  - Experience of installation contractor
  - Onsite quality assurance including testing
- Design must consider potential damage by fire

Repair/Replacement Concepts

- CFRP selected
  - More economical than concrete or steel repairs
  - Similar cost to full replacement due to access and protection requirements
  - Less disruptive to WTP operations

CFRP Repair Design

- Repairs designed in accordance with:
  - ACI 562-16 Chapter 7
  - ACI 440.2R-08
  - ACI 318-08
- Existing strength evaluated per:
  - ACI 562-16 7.8.2
  - ACI 562-16 5.5

Existing Strength - ACI 562-16 7.8.2 C

- Structural members repaired or modified with externally-applied FRP composites shall have adequate unrepaired strength…
- *… to prevent sudden failure of the member in case the FRP system is damaged or becomes ineffective… the structural member should have adequate strength without the FPR reinforcement…*

Existing Strength – ACI 562-16 5.5.2

…the required strength of the structure without external reinforcement shall satisfy [both of the following load combinations]…

$$\varphi R_n \geq 1.1D + 0.5L + 0.2S$$

$$\varphi R_n \geq 1.1D + 0.75L$$

Existing Strength

- Uncracked condition of double-tee stems to be restored through epoxy injection
- Nominal shear strength of unstrengthened concrete sections exceeded minimum strength requirements of ACI 562-16 5.5.2

Existing Strength – ACI 562-16 5.5.3

To account for potential performance issues during a fire event, the required strength of the structure without external reinforcement shall satisfy…

$$\varphi_{ex} R_n \geq (0.9 \text{ or } 1.2)D + 0.5L + 0.2S$$

where $\varphi_{ex} = 1.0$…

Existing Strength

- Fire evaluation per ACI 562-16 5.5.3 unnecessary
  - Lack of flammable material housed/used in WTP
  - Possibility of fire in WTP appeared quite low

Repair Design and Installation

- Designed in conformance with ACI 440.2R-08
- CFRP material conformed to ACI 440.6-08 or ACI 440.8-13 per ACI 562-16
- Pertinent installation considerations
  - Removal of surface protrusions/undulations
  - Proper corner radii per manufacturer guidance
  - Removal of surface contaminants and laitance
  - Bond verification per ASTM D7522

Repair Installation - Epoxy Injection

Repair Installation - CFRP Layup

Repair Installation - Completed

Repair Installation - Bond Testing

Repair Installation - Acrylic Coating

Thank you

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