ACI 364.1R-19

Guide for Assessment of Concrete Structures before Rehabilitation

Reported by ACI Committee 364

American Concrete Institute
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SAMPLING AND TESTING OF CONCRETE AS PART OF AN ASSESSMENT

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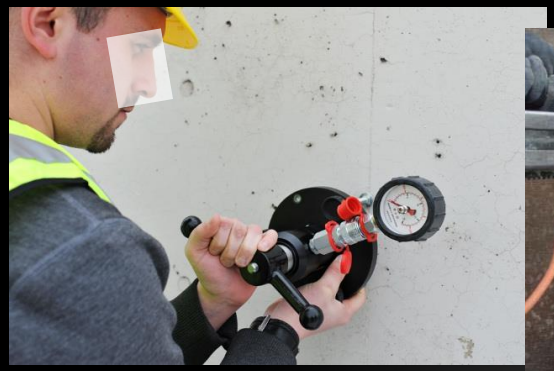
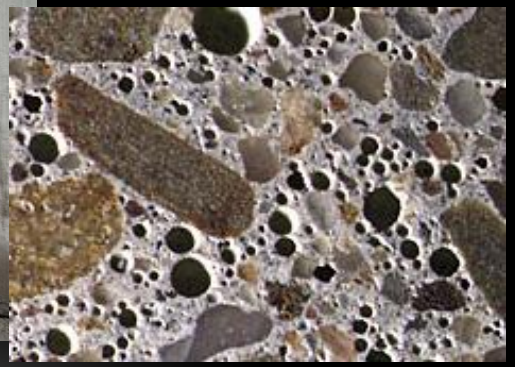
ACI 364.1R (Chapter 6) – Scope

- *What are the available methods & tools to supplement the basic information collected on site for the assessment of a concrete structure prior to rehabilitation?*
- *How to sample the structure?*

ACI 364.1R (Chapter 6) – Scope

- *Practices and methods for evaluating the condition and properties of materials that govern the behavior of a concrete structure*
  - *field-based nondestructive tests (NDT) and destructive tests*
  - *field sampling coupled with laboratory-based tests*





Sampling and Testing Requirements

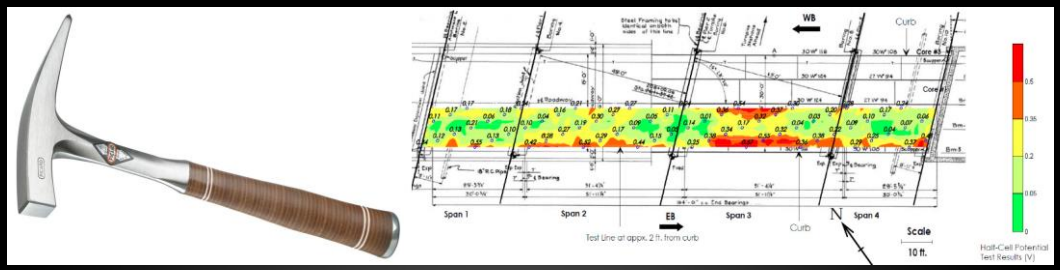
- Need for sampling and field/laboratory testing to be established, based upon :
  - review of available engineering documents related to the structure (Chapter 4)
  - findings of the field investigation (Chapter 5)
  - establishment of rehabilitation plans

Sampling and Testing Requirements

- Requirements for testing :
  - inadequate information about the materials in a structure
  - observed / suspected deterioration or defects (construction or materials)
  - uncertain load-carrying capacity or serviceability behavior
  - new requirements on the structure (ex. increased load demands, enhanced life safety goals, modified use)
  - performance of the structure altered by the planned rehabilitation

Sampling and Testing Requirements

- Many analytical and testing tools available
  - Selected test method(s) appropriate to yield reliably the required data
  - Supplemental testing needed as a result of the structure's exposure to aggressive environments or natural hazards
- The sampling and testing plan to be developed based on the LDP's judgement



Sampling and Testing Requirements

- Selection of suitable test methods and determination of the number and locations of tests typically depending on :
  - variation in material properties within the structure
  - extent of the member or structure over which a specific property is measured or extrapolated
  - access to critical locations (ex. connections, lateral load transfer areas)
  - variations in exposure, loading, and use
  - availability of sampling/testing equipment and qualified test personnel

Sampling and Testing Requirements

- Selection of test method(s) to diagnose the nature and extent of distress/deterioration should notably consider :
  - likely cause(s) or source(s) (ex. corrosion, ASR)
  - accessibility
  - structure configuration/geometry
- Special attention required in case of distress caused by prior loading events (ex. seismic, wind, gravity overload)

Sampling and Testing Requirements

- Sampling and laboratory studies
  - Sampling location(s) representative of the structure
  - Primary reinforcing steel prevented from damage
  - Samples protected during recovery

Sampling and Testing Requirements

- Special considerations for architectural or historic structures*
  - Testing required / possible
    - sampling in less visible location
    - adapted repair procedure for restoring the structure's appearance
  - Testing not possible
    - based upon the date of construction, conservative use of historical values for concrete compressive strength and yield strength of reinforcing steel (ASCE/SEI 41; ACI 562)

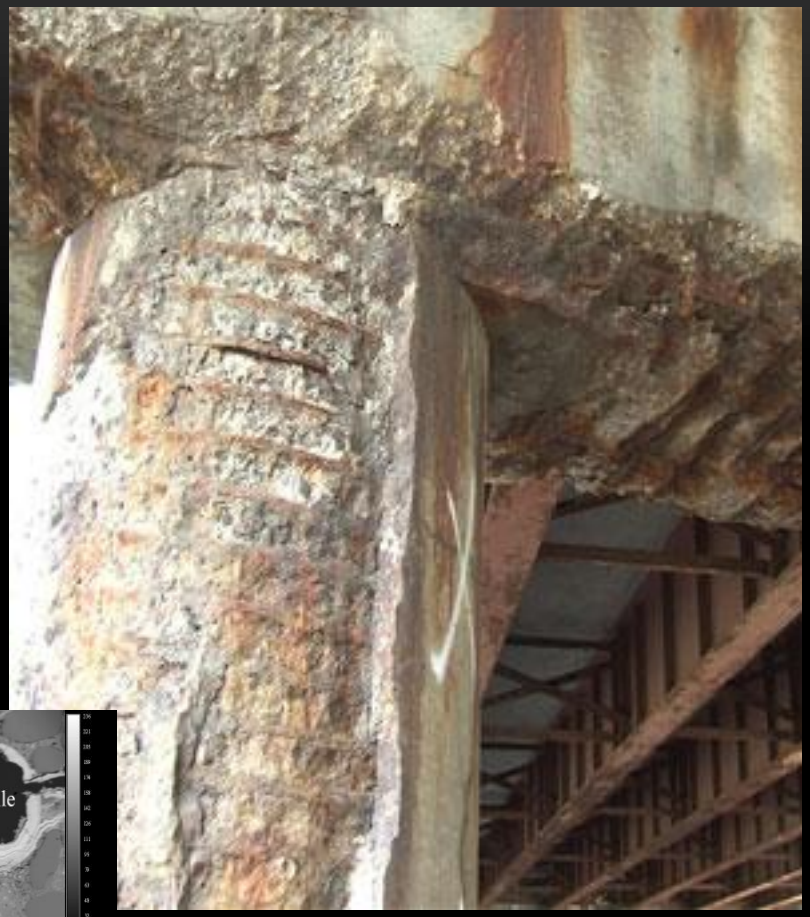
*(ACI 364.2R in development)

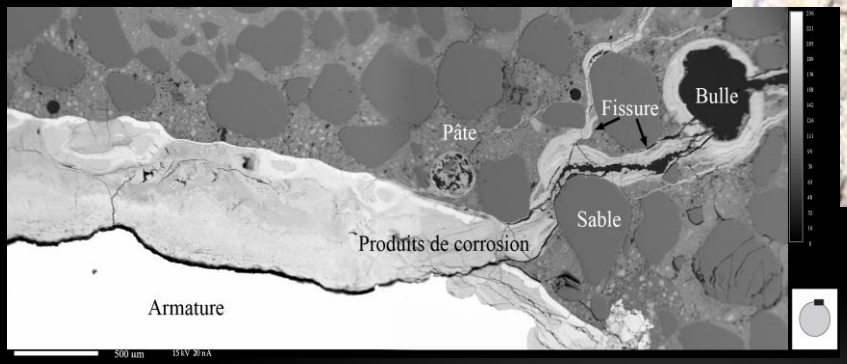
Testing and Evaluation

- Evaluation of existing concrete based upon:
  - existing conditions, strength, and serviceability
  - properties of the concrete as derived from field tests or laboratory studies on samples removed from the concrete structure
- Data collection and subsequent evaluation to provide an understanding of the ability of the structure to sustain the loads and environmental conditions to which it is subjected

Test Methods

- Test procedures
  - Hardened concrete
  - Steel reinforcement





Tests Methods – Hardened concrete

- Mechanical properties

Property/ condition	Possible test methods	
	Primary	Secondary
Compressive strength	Cores for compression testing (ASTM C42/ C42M; ASTM C39/C39M; ACI 214R)	Penetration resistance (ASTM C803/ C803M); drilled in pullout testing (ASTM C900)
Relative compressive strength	Rebound number (ASTM C805/C805M); ultrasonic pulse velocity (UPV) (ASTM C597)	—
Tensile strength	Splitting tensile strength of cores (ASTM C496/ C496M)	—
Flexural strength	Sampling and testing of sawed beams (ASTM C42/C42M)	Break-off test (Carino and Malhotra 2004)
Static modulus of elasticity	Compression test of cores (ASTM C469/C469M)	—
Dynamic modulus of elasticity	Resonant frequency testing of sawed specimens (ASTM C215)	Ultrasonic pulse velocity (ASTM C597); impact-echo; spectral analysis of surface waves (SASW)

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Tests Methods – Hardened concrete

- Durability characteristics & properties

Property/ condition	Possible test methods	
	Primary	Secondary
Air permeability	SHRP surface airflow method Figg Technique (SHRP S-329)	
Electrical resistance of concrete	AC resistance using four-probe resistance meter	SHRP surface resistance test (SHRP S-327)
Density	Specific gravity of samples (ASTM C642)	—
Resistance to chloride penetration	Coefficient of chloride diffusion of cementitious materials (ASTM C1556)	Electrical indication of concrete's ability to resist chloride-ion penetration (ASTM C1202; AASHTO T 259)

Tests Methods – Hardened concrete

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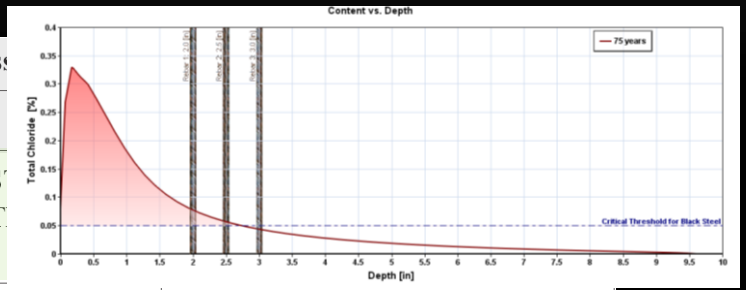
Tests Methods – Hardened concrete

- Condition

Property/ condition	Possible test methods	
	Primary	Secondary
Moisture content	Moisture meters (ASTM D6938; ASTM D4263; ASTM F1869; ASTM F2170; ASTM F2420; ASTM F2659)	—
Chloride ion content	Acid-soluble (ASTM C1152/C1152M) and water-soluble (ASTM C1218/C1218M)	Specific ion probe (SHRP S-328)
Carbonation, pH	Phenolphthalein (qualitative indication); pH meter	Petrographic examination, pH indicators (for example, litmus paper)
Shrinkage/ expansion	Length change of drilled or sawed specimens (ASTM C157/C157M; ASTM C341/C341M)	—

Tests Methods – Hardened concrete

- Condition



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Tests Methods – Hardened concrete

- Condition (…)

Property/ condition	Possible test methods	
	Primary	Secondary
Internal voids, delaminations	Acoustic impact (ASTM D4580/D4580M), impulse response impact-echo, infrared thermography, UPV, radar	Gamma radiography
Air content; cement content and degree of hydration; aggregate characteristics (alkali-aggregate reactivity; freezing-and-thawing susceptibility); cement paste microstructure characteristics and condition	Petrographic examination of concrete samples removed from structure (ASTM C856 and C457/ C457M); cement content	—
Alkali-silica reactivity (ASR)	Petrographic examination of concrete samples removed from structure (ASTM C856 and C457/ C457M)	Cornell/SHRP rapid test (SHRP C-315)
Fire damage	Petrographic examination of cores (ASTM C856), compressive strength tests (ASTM C39/C39M), splitting tensile strength tests (ASTM C496/ C496M), rebound number (ASTM C805/C805M)	SASW; UPV; impact-echo; impulse-response
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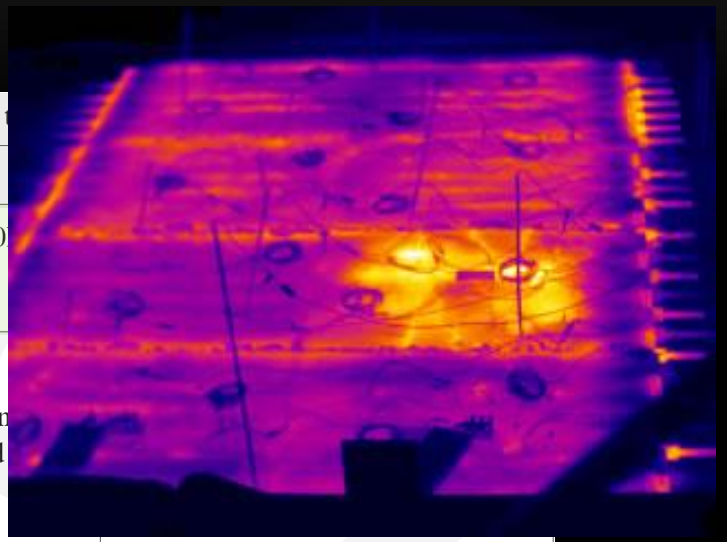

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Tests Methods – Hardened concrete

- Condition (…)

Property/ condition	Possible Primary	
Internal voids, delaminations	Acoustic impact (ASTM D4580/D458 impulse response impact-echo, infrared thermography, UPV, radar	
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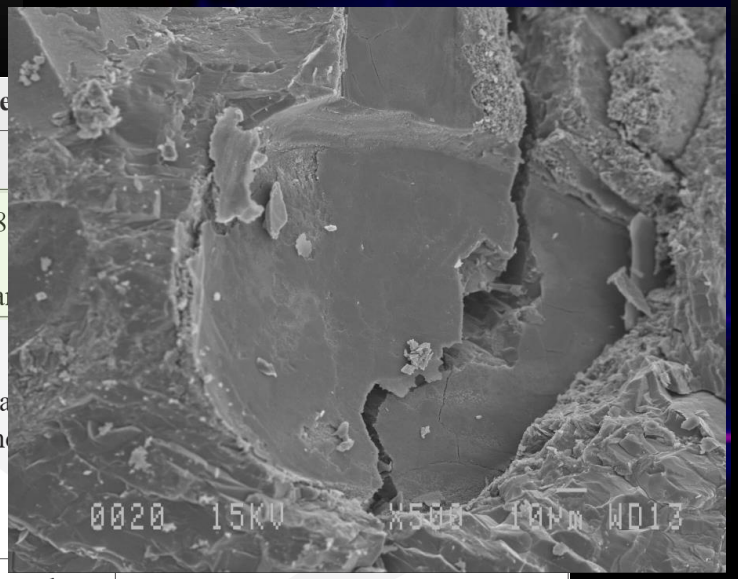

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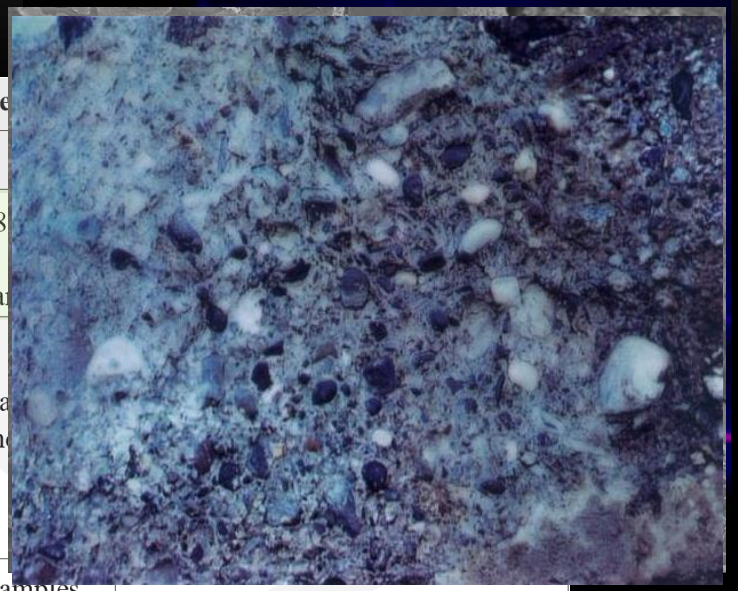

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Tests methods – Steel reinforcement

- Reinforcement characteristics and condition

Property/condition	Possible test method	
	Primary	Secondary
Reinforcement location	Expose reinforcement for measurement, pachometer; ground-penetrating radar (GPR) (ASTM D4748, D6432)	X-ray and γ-ray radiography
Reinforcement cross-sectional area reduction	Expose reinforcement and measure diameter; using calipers, ultrasonic thickness gauge (requires direct contact with steel)	Intrusive probing; radiography
Corrosion potentials	Half-cell potential (ASTM C876)	—
Corrosion rate	Linear polarization (SHRP S-324 and S-330)	Electrochemical impedance
Tensile testing	Tension testing of metallic materials (ASTM A370 and ASTM E8/E8M)	—
Chemical analysis	Laboratory test on sample (ASTM A751)	—
Protective coating thickness	Remaining coating thickness on exposed surfaces (ASTM E376; ASTM D7091; ASTM G14; ASTM G20)	—

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Test Methods

- General considerations
  - NDT methods* generally preferred to measure material properties where applicable, to minimize sampling and repair needs
  - Based on findings of the field investigation, sampling and laboratory studies used to determine the causes of existing distress or deterioration (ex. petrographic analysis)
  - Field load test involving components or the full-scale structure for supplemental information regarding in-place structural behavior or extent of distress
    - feasibility limited by various technical and economical constraints

*(ACI 228.1R, ACI 228.2R)

Sampling Techniques – Concrete

- Concrete samples can be retrieved in the field and tested in the laboratory to determine strength as well as many other physical and chemical properties
- Representativeness
  - appropriate care in all phases (obtaining, identifying, handling, and storing)
  - number & location(s) of samples – sampling plan

Sampling Techniques – Concrete

- Development of a sampling plan (ASTM C823)
  - Scope
    - statistical information about the properties of concrete in the structure

      and / or
    - characterization of unusual or extreme conditions in specific components
  - Random distribution desirable in the area of interest of a structure / member
    - whole area
    - sub-areas (varying conditions, special structural considerations)

Sampling Techniques – Concrete

- Development of a sampling plan (…)
  - Sample size for average values of properties (ex. f_c, E_c, air %)
    - ASTM E122, ASTM C42, ACI 214.4R
    - function of the size of the structure, condition / deficiencies, extent of problems, available information
  - Concrete not an isotropic material, with properties that may vary depending on the location or direction of sampling
    - special attention to be paid to vertical concrete components or members, such as columns, walls, and deep beams

Sampling Techniques – Concrete

- Core sampling
  - Procedures for properly removing concrete samples by core drilling (ASTM C42)
  - The number, size, and location of core samples to be selected depending on the laboratory tests requirements
  - Recommended use of separate core samples for each different test to avoid cross-contamination of test results

Sampling Techniques – Concrete

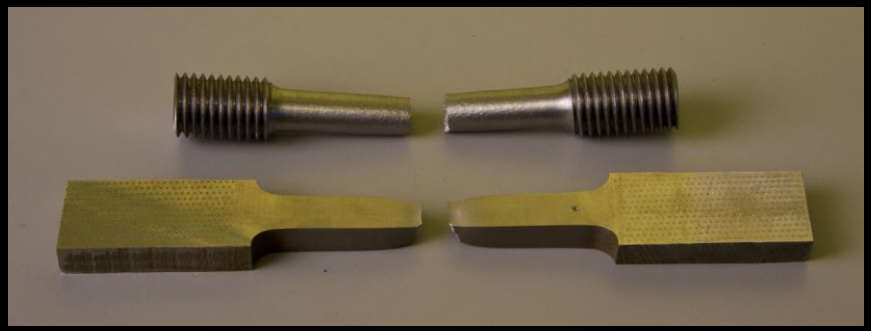
- Core sampling (…)
  - Average strength from core specimens
    - only to verify the in-place concrete strength
    - not to be used directly in calculating the existing load-carrying capacity
    - appropriate adjustment needed for use in calculations (in-place compressive strength)
    - 3 cores min. at each location in the structure, with the strength value taken as the average of the 3 cores (ACI 318; ACI 562)

Sampling Techniques – Concrete

- Sampling of concrete with sawed beams (ASTM C42)
  - Where appropriate, alternative sampling by sawing beam sections
  - Differences encountered between cores and sawed beam samples to assess the actual in-place concrete strength (ACI 214.4R; ASCE/SEI 11)
- Random sampling of broken concrete
  - Inappropriate for evaluating mechanical properties of concrete
  - Acceptable for assessing chemical / physical deterioration using laboratory analyses (*note: cause of the fracture to be evaluated*)

Sampling Techniques – Steel reinforcement

- Samples of reinforcement tested for determination of physical or chemical properties of the reinforcing steel
- Sampling: characteristics, selection, and preparation (ASTM A370)



(testlabs.ca)

Sampling Techniques – Steel reinforcement

- General considerations – conventional reinforcement
  - Specimens removed at locations of minimum stress
  - Only one specimen removed from the same cross section of a member
  - Specimen locations apart at least the development length (l_d)
  - For structural members investigated
    - span < 25 ft or loaded area < 625 ft^2: at least one specimen from the main longitudinal reinforcement (not stirrups or ties) (ACI 437R)
    - longer spans / larger areas: more specimens from locations well distributed to detect potential differences in steel grade

Sampling Techniques – Steel reinforcement

- General considerations – conventional reinforcement (…)
  - Information from grade / mill marks on rebars for guiding sample collection
    - Newer reinforcing steel: typically exhibits low variability and less sampling needed
    - Older structures with smooth/square/iron-based reinforcement: potentially more extensive
  - Minimum gauge length for mechanical properties in accordance with ASTM A370
    - Shorter samples (> 4 in) useful to yield information on physical and chemical properties

Sampling Techniques – Steel reinforcement

- Sampling of prestressed reinforcement for laboratory
  - Testing with care using appropriate safety procedures
  - Unbonded tendons with accessible anchorages
    - visual examination
    - lift-off tests to measure the prestress force
    - sampling generally not recommended unless structural capacity is threatened

Test Reporting

- Scope of sampling and testing completed
- Lab certification information
- Date of testing and personnel involved
- Equipment used and accuracy/calibration information
- Alignment of sampling/test performed with plan document
- Test execution observations and results
- Data recovered, sorted by specific tests completed and data type
- Assessment of test results and extrapolation of such relative to the concrete structure as a whole
- Recommendations for additional testing or other action

THANKS FOR YOUR ATTENTION!