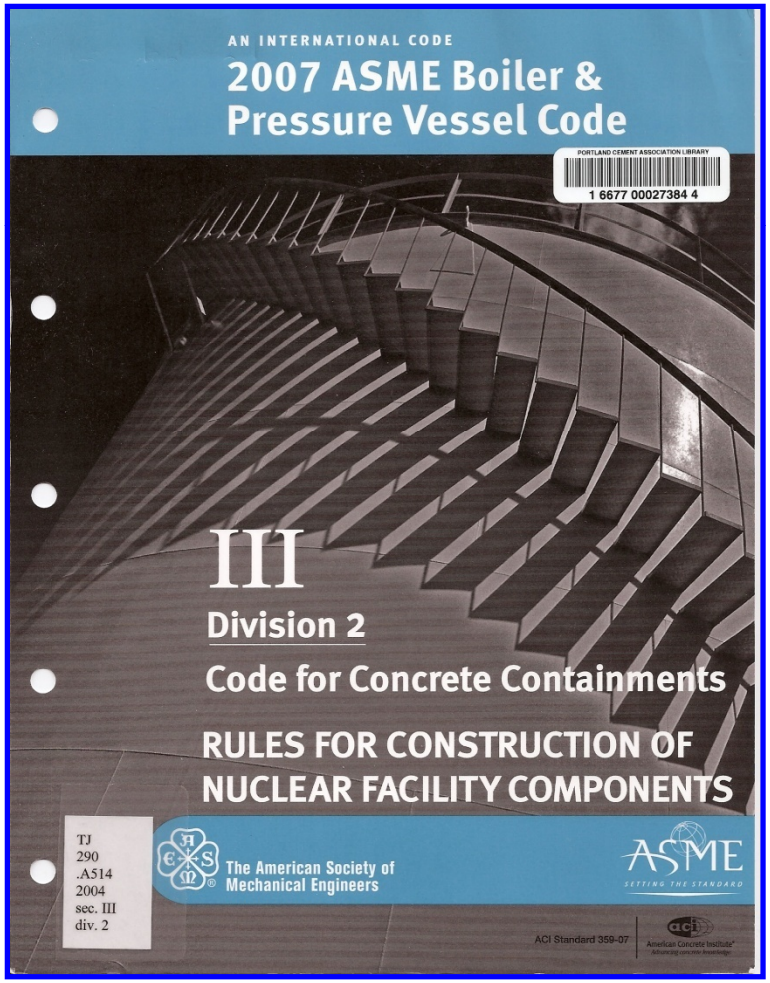
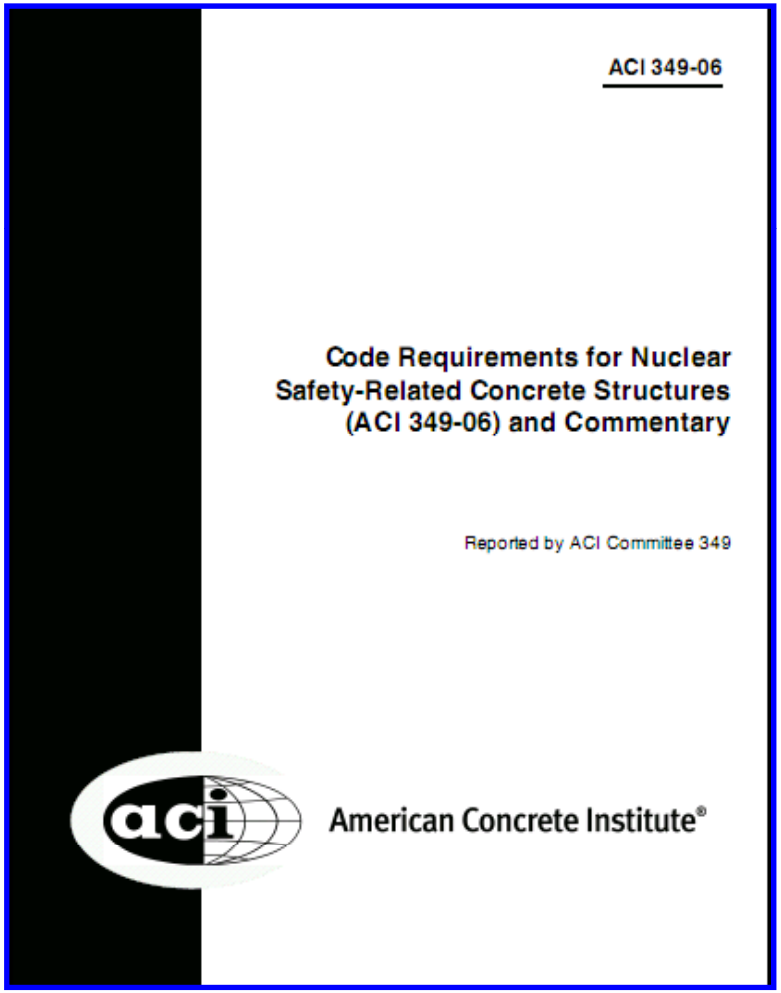
PCA

Concrete Technology and Codes

Nuclear Codes





Related ACI Documents for Concrete Components in Nuclear Structures

- ACI 349.1R-07 Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures
- ACI 349-2R-07 Guide to the Concrete Capacity Design (CCD) Method—Embedment Design Examples
- ACI 349.3R-02 Evaluation of Existing Nuclear Safety-Related Concrete Structures

PCA

Concrete Technology and Codes

Section III Division 2 Code for Concrete Containments (ACI 359-07)

- Joint ACI and ASME Standard
  - ACI (American Concrete Institute)
  - ASME (American Society of Mechanical Engineers)
- ACI Committee 359 – Concrete Components for Nuclear Reactors
- ASME Boiler and Pressure Vessel Code Committee, Section III, Division 2, Subgroup on Concrete Components
- Subsection CC – Concrete Containments (Prestressed or Reinforced)

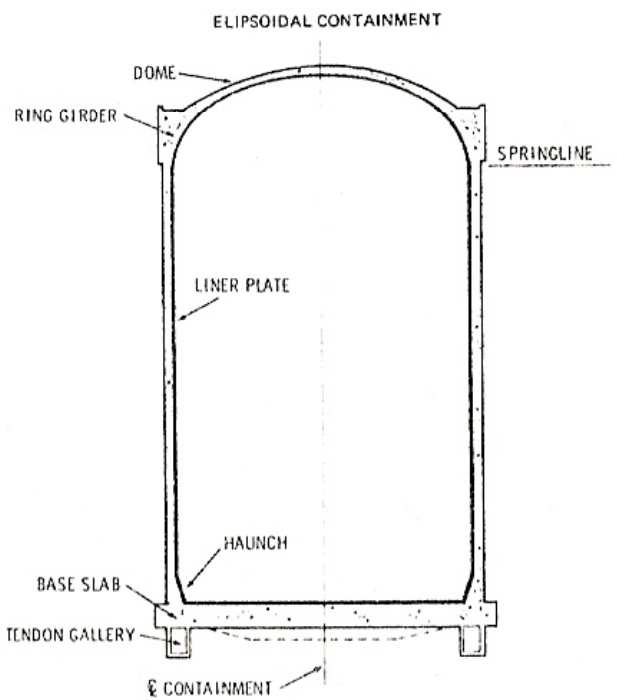
Scope of Subsection CC

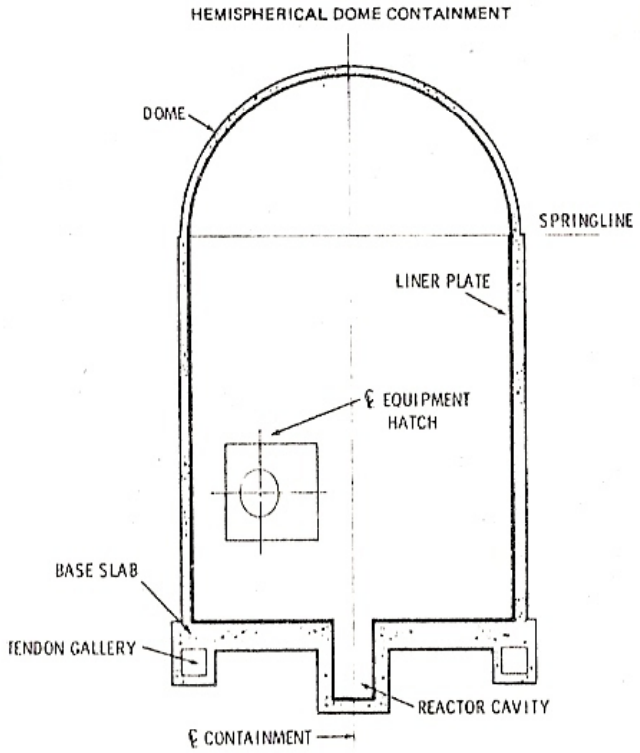
- The containments covered by this Subsection shall include the following:
  - (a) structural concrete pressure resisting shells and shell components
  - (b) shell metallic liners
  - (c) penetration liners extending the containment liner through the surrounding shell concrete

Types of Containments

- Conventionally reinforced
- Post-tensioned
- Partially post-tensioned

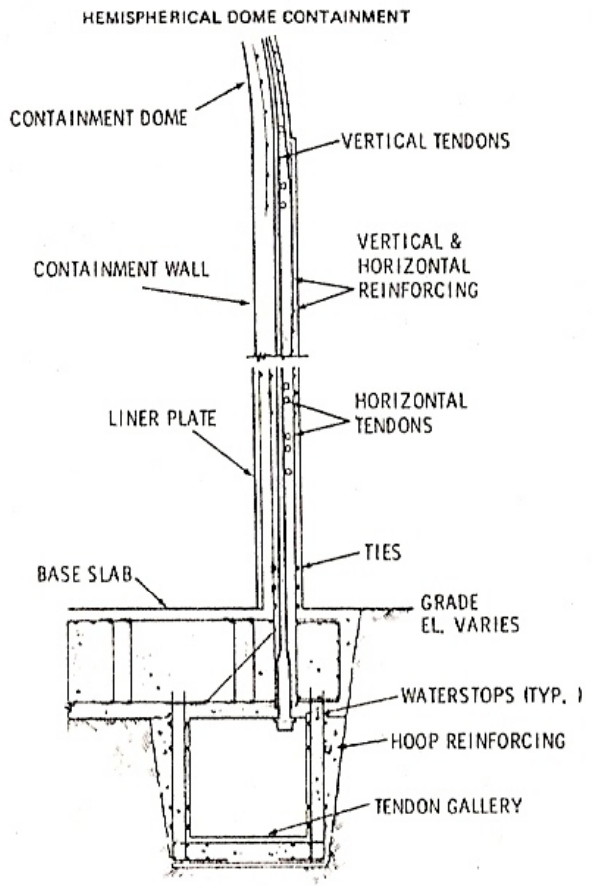
Post-Tensioned Concrete Containments - Elevation

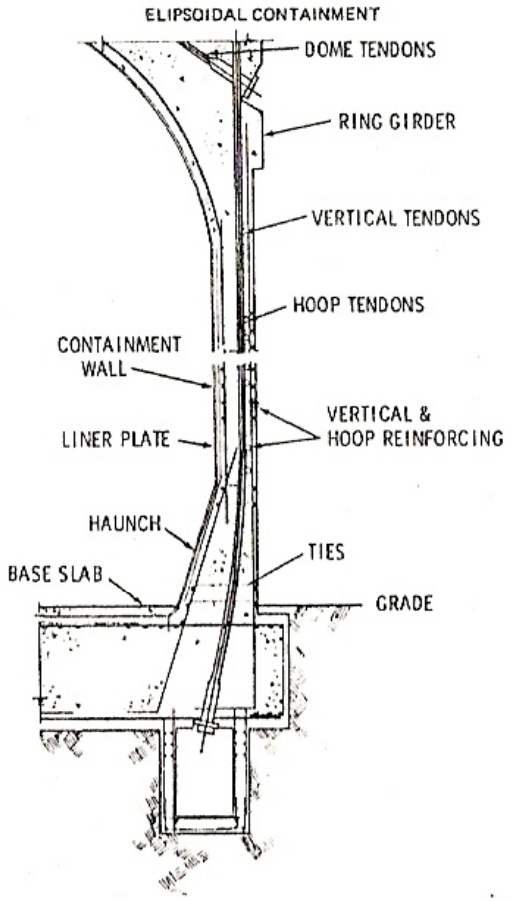




Common Dimensions –
Height: 125-260 ft. Dia.: 105-140 ft. Wall Thick: 2.5-4.5 ft.

Post-Tensioned Concrete Containment Walls





PCA

Concrete Technology and Codes

Subsection CC – Concrete Containments (Prestressed or Reinforced)

- CC-1000 Introduction
- CC-2000 Material
- CC-3000 Design
- CC-4000 Fabrication and Construction
- CC-5000 Construction Testing and Examination
- CC-6000 Structural Integrity Test
- CC-7000 Overpressure Protection
- CC-8000 Nameplates, Stamping and Reports
- Mandatory Appendices
- Nonmandatory Appendices

PCA

Concrete Technology and Codes

ACI 349-06 – Code Requirements for Nuclear Safety-Related Concrete Structures

- ACI Committee 349 – Concrete Nuclear Structures
- Minimum requirements for design and construction of nuclear safety-related concrete structures and structural members for nuclear power generating stations.
- Safety-related structures and structural members subject to this standard are concrete structures that support, house, or protect nuclear safety class systems or component parts of nuclear safety class systems.
- Specifically excluded from this Code are those structures covered by ASME Boiler and Pressure Vessel Code Section III, Division 2 (ACI 359).

PCA

Concrete Technology and Codes

ACI 349-06 – Code Requirements for Nuclear Safety-Related Concrete Structures

1. General Requirements
2. Notation and Definitions
3. Materials
4. Durability Requirements
5. Concrete Quality, Mixing, and Placing
6. Formwork, Embedded Pipes, and Construction Joints
7. Details of Reinforcement
8. Analysis and Design – General Considerations
9. Strength and Serviceability Requirements
10. Flexure and Axial Loads
11. Shear and Torsion
12. Development and Splices of Reinforcement
13. Two-way Slab Systems
14. Walls

PCA

Concrete Technology and Codes

ACI 349-06 – Code Requirements for Nuclear Safety-Related Concrete Structures (con't)

15. Footings
16. Precast Concrete
17. Composite Concrete Flexural Members
18. Prestressed Concrete
19. Shells
20. Strength Evaluation of Existing Structures
21. Provisions for Seismic Design

Appendixes

- A. Strut-and-tie models
- B. BLANK
- C. Alternative load and strength-reduction factors
- D. Anchoring to concrete
- E. Thermal considerations
- F. Special provisions for impulsive and impactive effects
- G. SI metric equivalents of U.S. customary units

Materials and Construction Provisions in ACI 359-07 (ASME Section III Div. 2) and ACI 349-06

- Similar, but different provisions for materials and construction
- Proposals are being made to harmonize
- We will highlight significant differences in this module
- CAUTION: you need to verify which standards apply for specific project
- Pay particular attention to dates of referenced standards

PCA

Concrete Technology and Codes

CC-2000 Material

- CC-2100 General Requirements for Material
- CC-2200 Concrete and Concrete Constituents
- CC-2300 Material for Reinforcing Systems
- CC-2400 Material for Prestressing Systems
- CC-2500 Material for Liners
- CC-2600 Welding Material
- CC-2700 Material for Embedment Anchors
- CC-2800 Material Manufacturer's Quality System Programs

CC-2111(d) – "Pressure Retaining" and "Load Bearing Materials"

- Concrete
- Reinforcing material
- Prestressing material
- Liners
- Attachments to liners
- Embedment anchors

CC-2122.3 Material Tests

- Reports of all required examinations, tests, and treatments must be made available to Authorized Inspector of the Applicable Fabricator or Constructor.
- Provisions must be made for inspection as required by the Authorized Inspector

CC-2130 Certification of Concrete Materials

- Certified Material Test Report (CMTR)
  - Provide for concrete constituents, plastic concrete, reinforcing and prestressing material
  - Must include:
    - Certified reports of actual test results
    - Statement of any tests, examinations, or treatments not performed
    - Means for material identification
    - For plastic concrete, a batch ticket that includes weight or volume of constituents for each batch of concrete
- Certification by Fabricator or Constructor (CC-2132)

PCA

Concrete Technology and Codes

CC-2130 Certification of Concrete Materials

- Laboratory accreditation (comply with ASTM C1077)
- Certified Material Test Reports
  - Aggregate
  - Cement
  - Air-entraining admixtures
  - Fly ash and pozzolans
  - Chemical admixtures
  - ~~Water and ice~~ **Not required**

PCA

Concrete Technology and Codes

ACI 349-06
3.1 – Tests of Materials

1. Owner has right to order testing to verify quality meets specifications
2. Tests of materials and concrete to be made in accordance with referenced standards
3. Complete record of tests shall be available for inspection (see general requirements for owner inspection in 1.3)

ASTM Test Methods

- A definitive procedure that produces a test result
- A concise description of an orderly procedure for determining a property or constituent of a material, an assembly of materials, or a product
- The directions for performing the test include all of the essential details as to apparatus, test specimen, procedure, and calculations needed to achieve satisfactory precision and bias

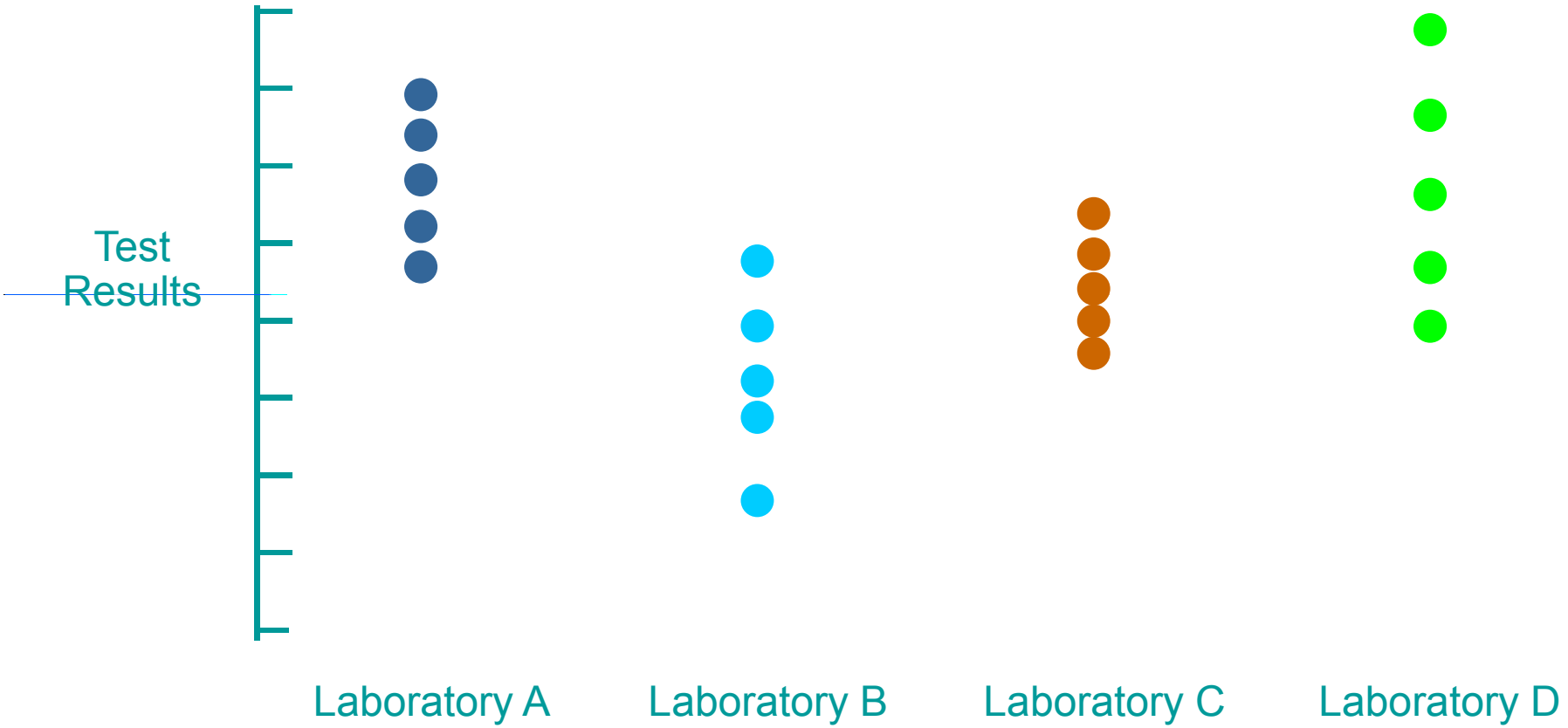
PCA

Concrete Technology and Codes

Precision and Bias

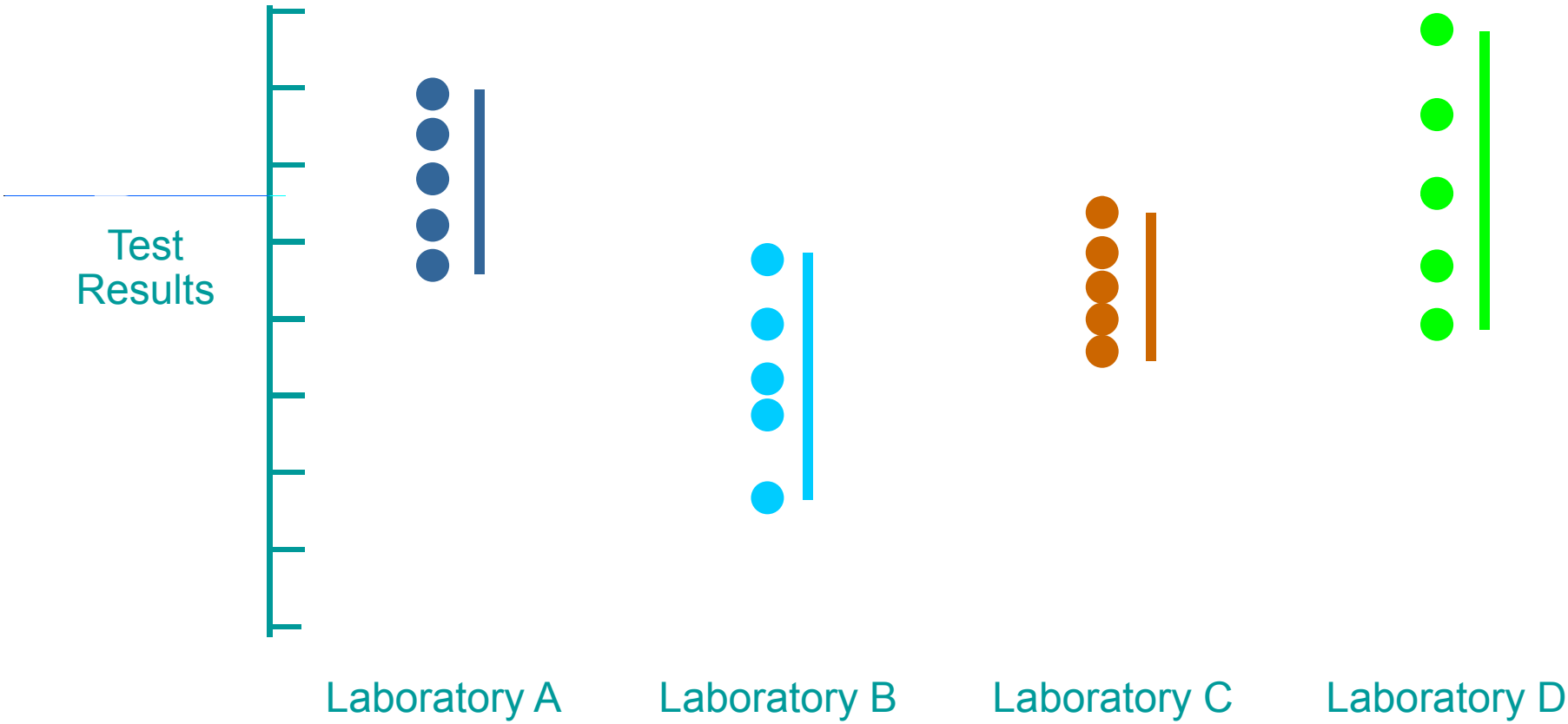
- Precision is the closeness of agreement between test results obtained under prescribed conditions. A precision statement provides guidelines as to the kind of variability that can be expected between test results when the test method is used in one or more reasonably competent laboratories.
- Bias is a systematic error that contributes to the difference between the mean of a large number of test results and an accepted reference value.

Precision



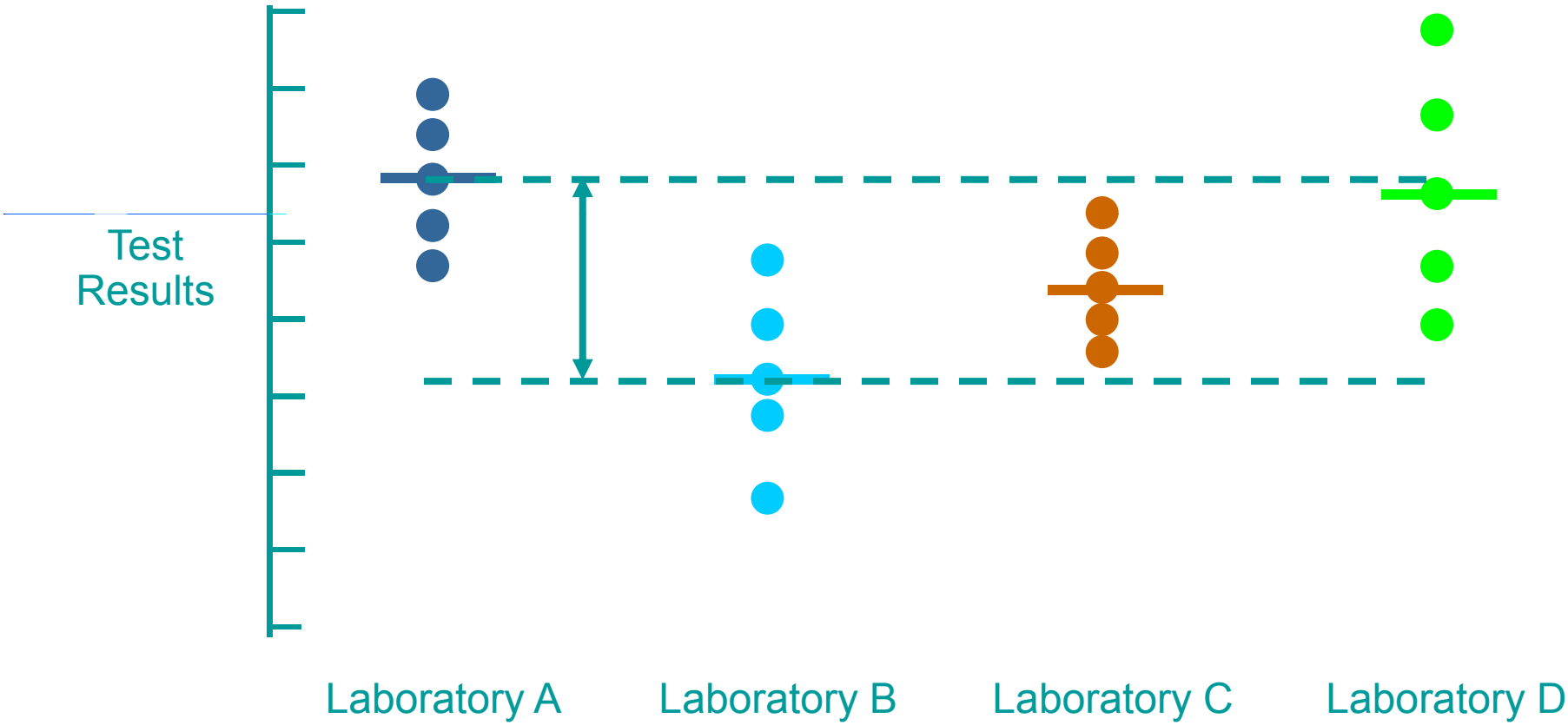
From Carino

Precision Within-Laboratory



From Carino

Precision Between-Laboratory



From Carino

Precision

- Repeatability—precision where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time.

Example – Repeatability

- The single-operator coefficient of variation has been found to be 2.5 %. Therefore, results of two properly conducted tests by the same operator on the same sample using the same equipment are not expected to differ from each other by more than 7.0 % of their average.

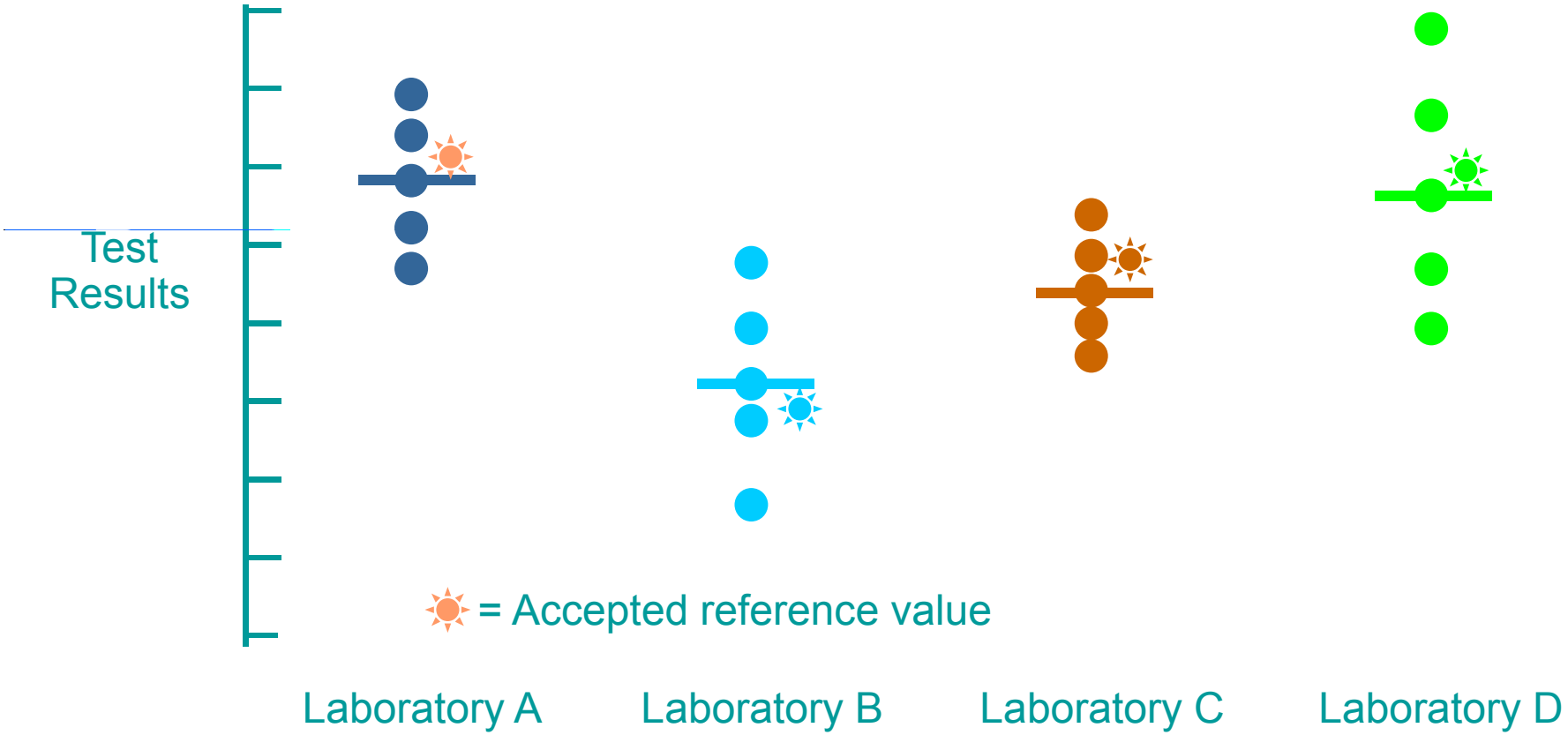
Precision

- Reproducibility—precision where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

Example – Reproducibility

- The multilaboratory coefficient of variation has been found to be 5.0 %. Therefore, results of two different laboratories on identical samples of a material are not expected to differ from each other by more than 14 % of their average.

Bias



From Carino

PCA

Concrete Technology and Codes

Laboratory Inspection and Accreditation Options

- Lab Inspections – Cement and Concrete Reference Laboratory (CCRL)
- Lab Accreditation
  - National Voluntary Laboratory Accreditation Program (NVLAP)
  - American Association for Laboratory Accreditation (AALA)
  - American Materials Engineering Council (CEMC)

ASTM C 1077

Designation: C 1077 – 07

Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[1]

This standard is issued under the fixed designation C 1077; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice identifies and defines the duties, responsibilities, and minimum technical requirements of testing laboratory personnel and the minimum technical requirements for laboratory equipment utilized in testing concrete and concrete aggregates for use in construction.

C 40 Test Method for Organic Impurities in Fine Aggregates for Concrete
C 117 Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
C 125 Terminology Relating to Concrete and Concrete Aggregates

ASTM C1077 Scope

- This practice identifies and defines the duties, responsibilities, and minimum technical requirements of testing laboratory personnel and the minimum technical requirements for laboratory equipment utilized in testing concrete and concrete aggregates for use in construction.

ASTM C1077 Scope (con't)

- This practice provides criteria for the evaluation of the capability of a testing laboratory to perform designated ASTM test methods on concrete and concrete aggregates. It can be used by an evaluation authority in the inspection or accreditation of a laboratory or by other parties to determine if the laboratory is qualified to conduct the specified tests.

ASTM C1077 Personnel Requirements

- Technical director (licensed professional engineer)
- Supervising laboratory technicians
- Supervising field technicians
- Concrete laboratory technicians
- Aggregate laboratory technicians
- Concrete field technicians

PCA

Concrete Technology and Codes

ASTM C1077 Laboratory Capabilities

- Required test methods and practices
  - Laboratories testing concrete
  - Laboratories testing concrete aggregates
- Optional test methods or practices

7.2 *Required Test Methods and Practices*:

7.2.1 *For Laboratories Testing Concrete*:

7.2.1.1 *Sampling*, Practice C 172,

7.2.1.2 *Slump*, Test Method C 143/C 143M,

7.2.1.3 *Unit Weight, Yield, and Air Content*, Test Method C 138/C 138M,

7.2.1.4 *Air Content*, Test Method C 173/C 173M (volumetric method), or Test Method C 231 (pressure method), or both.

7.2.1.5 *Temperature*, Test Method C 1064/C 1064M,

7.2.1.6 *Making and Curing Test Specimens*, Practice C 31/C 31M,

7.2.1.7 *Compressive Strength*, Test Method C 39/C 39M,

7.2.2 *For Laboratories Testing Concrete Aggregates*:

7.2.2.1 *Sieve Analysis*, Test Method C 136,

7.2.2.2 *Material Finer Than 75-μm (No. 200) Sieve*, Test Method C 117,

7.2.2.3 *Specific Gravity and Absorption*, Test Method C 127 (Coarse Aggregate) and Test Method C 128 (Fine Aggregate), and

7.2.2.4 *Organic Impurities in Fine Aggregate*, Test Method C 40.

PCA

Concrete Technology and Codes

ASTM C1077 Laboratory Quality Manual

- Record of personnel evaluation
- Equipment calibration and maintenance records
- Inventory and description of test equipment
- Current library including all relevant test methods
- Record of participation in proficiency sample programs
- Procedures for handling technical complaints
- Procedures for ensuring quality of external technical services

PCA

Concrete Technology and Codes

ASTM C1077 Laboratory Evaluation

- Facilities and personnel to be inspected approximately every 24 months
  - Personnel and equipment during the evaluation shall be representative of the personnel and equipment available during the period between evaluations
  - Temporary acquisition of personnel or equipment to enhance the results of the evaluation shall not be permitted
- Correction of deficiencies within 30 day of report

PCA

Concrete Technology and Codes

CCRL—Laboratory Inspection Program

- "…provides a laboratory with a comprehensive account of how its procedures, practices, equipment and facilities compare with ASTM standards requirements."
  - Verification of apparatus
  - Observation of testing procedures
  - Review of quality system

PCA

Concrete Technology and Codes

CCRL—Laboratory Inspection Program

- CCRL not a “referee” in disputes
- Services rendered on “advisory” basis
- Laboratories not rated, certified or accredited
- Inspection used by others in providing accreditation

PCA

Concrete Technology and Codes

CCRL Equipment

- Load cells
- Balance and reference masses
- Thermometers and psychrometers
- Length measuring devices
- Reference literature

PCA

Concrete Technology and Codes

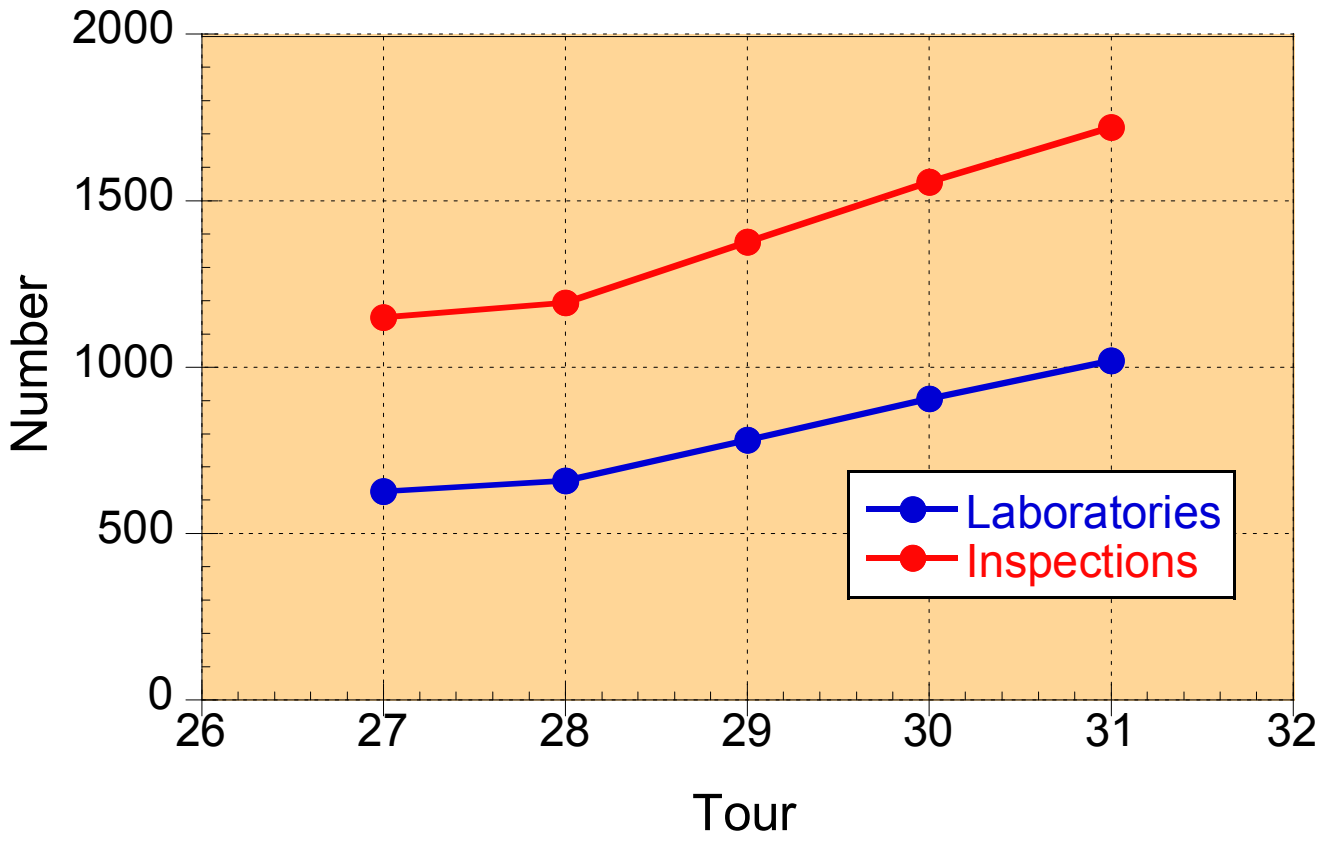
CCRL "Hands On" Laboratory Inspection

- Evaluates actual performance of the tests by laboratory technicians
- Assists technicians in understanding the tests
- Provides guidance on how to improve laboratory performance

PCA

Concrete Technology and Codes

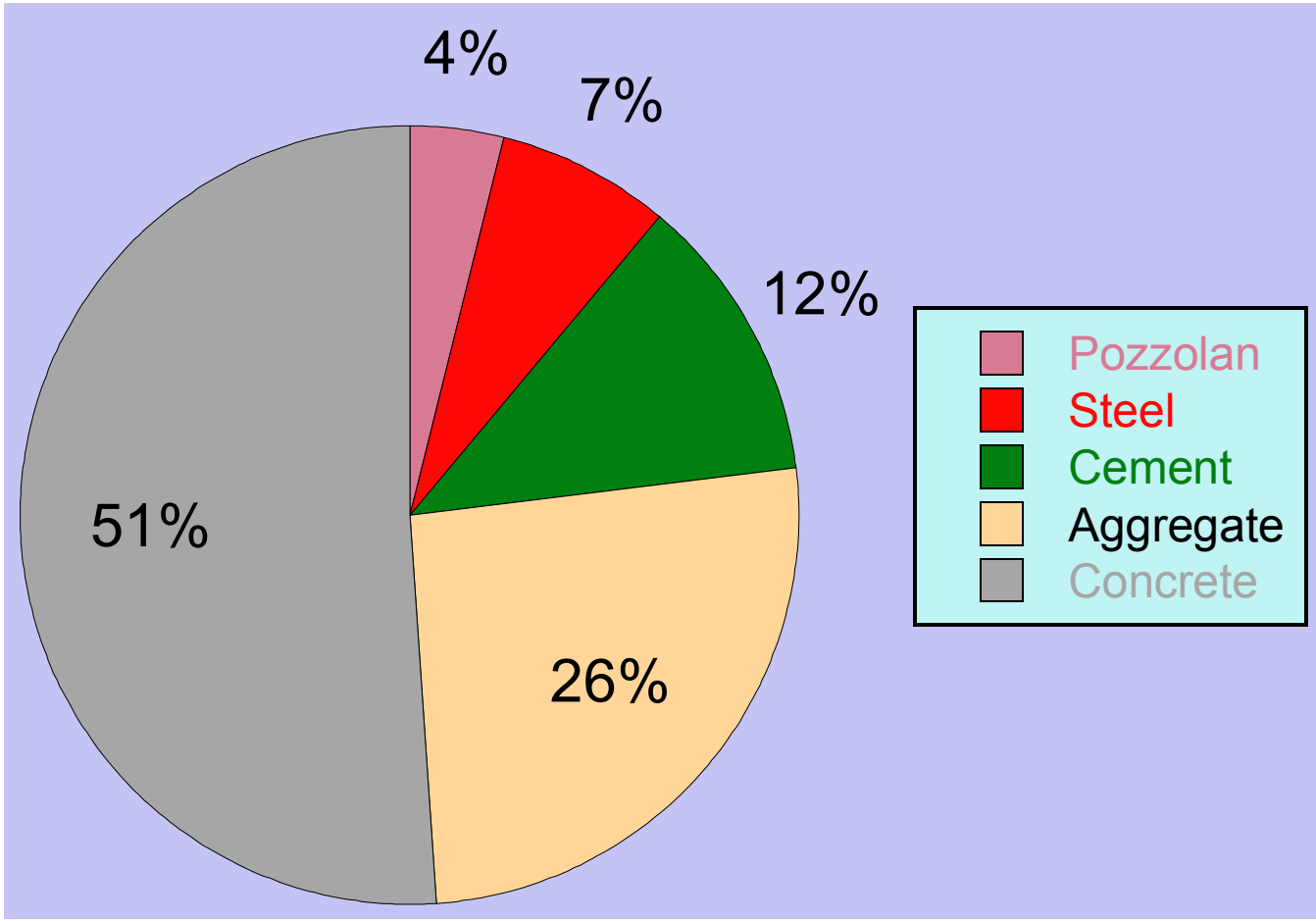
Numbers of Laboratories and Inspections per CCRL Tour



PCA

Concrete Technology and Codes

31st CCRL Tour: Material Types



CC-2131.4 Personnel Qualification

- Tests required by CC-2000 Material
  - Laboratory testing personnel may be qualified using industry or laboratory standards
- Tests required by CC-2200 Material
  - Qualification and certification rules of Appendix V (nonmandatory)

PCA

Concrete Technology and Codes

CC-2200 Concrete and Concrete Constituents

- Introduction
- Concrete constituents
  - Cement
  - Aggregates
  - Mixing water
  - Admixtures
- Concrete mix design
- Cement grout
- Marking and identification of concrete constituents

CC-2212 Substitutions (Concrete Constituents)

- Alternate shall meet requirements of qualification tests
- Prior to use, Designer:
  - Confirms similarity and compatibility
  - Establishes need for and extent of testing by CC-2230

PCA

Concrete Technology and Codes

ACI 349-06
Chapter 3 – Materials

1. Tests of materials
2. Cements
3. Aggregates
4. Water
5. Steel reinforcement
6. Admixtures
7. Storage and identification of materials
8. Referenced standards

PCA

Concrete Technology and Codes

CC-2221 Cement

- ASTM C150-89 Standard Specification for Portland Cement
- ASTM C595-87 Standard Specification for Blended Hydraulic Cements

CC-2221 – Types of ASTM C150 Portland Cement Permitted

Type	Characteristics
I	When special characteristics not required
II	Moderate heat of hydration or sulfate resistance
IV	Low heat of hydration
V	High sulfate resistance

CC-2221 – Types of ASTM C595 Blended Cement Permitted

- Type IP: Portland-pozzolan cement
- Type IP(MS): Portland-pozzolan cement (moderate sulfate resistance)
- Type IP(MH): Portland-pozzolan cement (moderate heat of hydration)

ACI 349-06 Cements

- ASTM C150-04a Standard Specification for Portland Cement
- ASTM C595-03 Standard Specification for Blended Hydraulic Cements
  - Excluding Types S and SA
- ASTM C845-04 Standard Specification for Expansive Hydraulic Cement
- ASTM C1157-03 Standard Performance Specification for Hydraulic Cement

CC-2222 Aggregates

- ASTM C33 Standard Specification for Concrete Aggregates
- Additional requirements
  - Gradation adjustments permitted
  - Preplaced aggregate method (ACI 304)
  - Flat and elongated particles < 15% (CRD-C119)
  - Petrographic examination (ASTM C295)
  - ASR tests (ASTM C227, C289, C342, C586)
  - Chloride content (ASTM D1411)
  - Abrasion loss <40% (C131)

Maximum Aggregate Size

- **maximum size of aggregate** —the smallest sieve opening through which the entire amount of aggregate is required to pass.
- **nominal maximum size of aggregate** —the smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

CC-2222.1(h) Maximum Size of Coarse Aggregates

- Max. size shall not be larger than:
  - 1/5 narrowest dimension of finished wall or slab
  - 3/4 of min. clear spacing between individual bars or wires
  - 3/4 of min. clear spacing between bundled bars, ducts, or embedments

ACI 349-06 Maximum Size of Coarse Aggregates (3.3.2)

- Max. size shall not be larger than:
  - 1/5 narrowest dimension between sides of forms
  - 1/3 the depth of slabs
  - 3/4 of min. clear spacing between individual bars, wires, or tendons
  - 3/4 of min. clear spacing between bundled bars, bundled tendons, or ducts
- Limitations may be waived if engineer judges concrete can be placed without honeycombs or voids.

PCA

Concrete Technology and Codes

CC-2222.2 Heavy Weight Aggregates

- ASTM C637 Standard Specification for Aggregates for Radiation Shielding Concrete
- Construction specification requirements
  - Steel punchings
  - Sheared reinforcing steel
  - Iron shot
  - Boron materials

CC-2223 Mixing Water

- Applies to mixing water and water used for making ice
- Clean – total solids ≤ 2000 ppm (ASTM D1888)
- Test for chlorides (ASTM D512)
- Comparative tests (ASTM C109)
  - Strengths ≥ 90% of cubes made with distilled water

CC-2224 Admixtures

- General requirements
  - Specify type, quantity, additional limitations
  - ≤ 1% chloride ion (prestressed containments)
- Air-entraining admixtures (ASTM C260)
- Chemical admixtures (ASTM C494)
- Mineral admixtures (ASTM C618)
  - Maximum available alkaki
  - Maximum chloride ion

CC-2224 Admixtures (con't)

- Special grouting admixtures
  - Construction Specification defines limits
  - Gelling agents permitted if specified
- Grout fluidifier (ASTM C937)
- Chemical admixtures for flowing concrete (ASTM C1017)

ACI 349-06 Admixtures

- Admixtures subject to approval by engineer
- Admixture must be same as that used to establish concrete properties
- Calcium chloride or other chloride-containing admixtures not permitted in prestressed concrete, with embedded aluminum, or in galvanized steel forms
- Admixtures used with expansive cements must be compatible
- Tests for compliance of admixtures required prior to initial shipment and acceptance on site; then periodically

ACI 349-06 Admixtures (con't)

- Air-entraining admixtures (ASTM C260)
- Water-reducing, retarding, accelerating, water-reducing and retarding, and water-reducing and accelerating admixtures (ASTM C494)
- Chemical admixtures for flowing concrete (ASTM C1017)
- Infrared spectrum trace required for conformance of air-entraining and water-reducing chemical admixtures

ACI 349-06 Admixtures (con't)

- Fly ash and other pozzolans (ASTM C618)
- Ground granulated blast furnace slag (ASTM C989)
- Silica fume (ASTM C1240)

PCA

Concrete Technology and Codes

CC-2230 Concrete Mix Design

- CC-2231 Concrete Properties
- CC-2232 Selection of Concrete Proportions
- CC-2233 Proportioning on the Basis of Field Experience and/or Trial Mixtures

PCA

Concrete Technology and Codes

CC-2231 Concrete Properties

1. General requirements
2. Chloride content
3. Alkali content
4. Specified properties
5. Physical properties
6. Thermal properties
7. Durability

CC-2231.1 General Requirements

- Properties established in the Construction Specification
- Concrete mixtures designed for:
  - Strength
  - Workability limits
  - Heat rise
  - *Durability*

PCA

Concrete Technology and Codes

CC-2231.4 Specified Properties

- Table CC-2231-1 Concrete Properties
  - Perform prior to construction except creep
  - Creep data prior to prestressing (special provisions for exceeding design value)
  - For changes in mixture test when change initiated
- Construction Specification shall include:
  - Age, strength, and temperature for properties
  - Applicable environmental or design conditions
  - Properties other than those listed in CC-2231-1

TABLE CC-2231-1
CONCRETE PROPERTIES

Property	Test Method
Slump	ASTM C 143
Compressive strength	ASTM C 39
Flexural strength	ASTM C 78
Splitting tensile strength	ASTM C 496
Static modulus of elasticity	ASTM C 469
Poisson's ratio	ASTM C 469
Coefficient of thermal conductivity	CRD-C 44
Coefficient of thermal expansion	CRD-C 39
Creep of concrete in compression	ASTM C 512
Shrinkage coefficient (length change of cement-mortar and concrete)	ASTM C 157
Density (specific gravity)	ASTM C 642
Maximum temperature rise in concrete	CRD-C 36

CC02231.5 Physical Properties

- For max. allowable creep limit (rate and total),
  - Test for limiting combination of stress-strength ratios, ages of loading, temp levels, and cycles in Construction Specification
  - Use ASTM C512 with modifications for specimen curing, sealing, and test temps in Construction Specification
- For allowable range of E_c, Poisson's Ratio, and load rate
  - Test at specified load rates
  - Use ASTM C469 with modifications as needed

PCA

Concrete Technology and Codes

CC02231.6 Thermal Properties

- Test in accordance with Construction Specification requirements

PCA

Concrete Technology and Codes

Durability Provisions

- Freezing and Thawing Exposures
- Watertight Concrete
- Sulfate Resisting Concrete
- Corrosion Protection
- Alkali Content (Resistance to Alkali-Aggregate Reactivity)

Freezing and Thawing Exposures*

Nom. maximum size aggregate, mm (in.)	Total air content, percent[1]		
	Severe exposure (ACI 349)	Moderate exposure (ACI 349/359)	Tolerance as delivered
10 (3/8)	7.5	6	+/- 1.5
13 (½)	7	5.5	+/- 1.5
19 (¾)	6	5	+/- 1.5
25 (1)	6	4.5	+/- 1.5
40 (1½)	5.5	4.5	+/- 1.5
50 (2)[2]	5	4	+/- 1.5
75 (3)[2]	4.5	3.5	+/- 1.5

Freezing and Thawing Exposures – Special Considerations

1. Allowance for higher strength concretes
   - ACI 359: Can reduce air volume by 1% for f'c ≥ 5000 psi (35 MPa)
   - ACI 349: Can reduce air volume by 1.0% for f'c > 5000 psi
2. Testing concrete with Nominal Max. Aggregate Size > 1.5 in. (40 mm)
   - Hand pick or sieve sample to remove aggregate > 1.5 in.
   - Test minus 1.5 in. fraction for total air

Freezing and Thawing Exposures – Water-Cement Ratio Limits

- ACI 359-07 CC-2231.7.1
  - Water-Cement Ratio ≤ 0.50 by weight
  - Definition of Water-Cement Ratio?
- ACI 349-06 Section 4.2
  - Water-to-Cementitious Materials Ratio ≤ 0.45 by weight
  - Min, f'c = 4500 psi (31 MPa)
  - See Table 4.2.3 for exposure to deicing chemicals

Deicer Exposure (ACI 349-06)

Cementitious materials	Max. % of total cementitious, by mass
Fly ash or other pozz. (ASTM C618)	25
Slag (ASTM C989)	50
Silica fume (ASTM C1240)	10
Fly ash (pozz.) + slag + silica fume	50*
Fly ash (pozz.) + silica fume	35*

* With total weight containing no more than 25% fly ash or other pozzolan and 10% silica fume

Watertight Concrete

Exposure Condition	**Max. W/C, by mass**	**Min. f'_c, (ACI 349)**
Low perm. when exposed to water (ACI 359-07/ACI 349-06)	0.50	4000 psi (28 MPa)
Low perm. when exposed to brackish or seawater (ACI 359) Freeze-thaw in moist condition (ACI 349)	0.45	4500 psi (31 MPa)
Cl^- exposure, seawater, brackish, etc. (ACI 349)	0.40	5000 psi (35 MPa)

Sulfate Exposure Classes

Sulfate exposure	Water-soluble sulfate (SO_4) in soil, % by mass	Sulfate (SO_4) in water, ppm
Negligible	< 0.10	< 150
Moderate (seawater)	0.10 to 0.20	150 to 1500
Severe	0.20 to 2.00	1500 to 10,000
Very severe	> 2.00	>10,000

Sulfate exposure	Water-soluble sulfate (SO_4) in soil, % by mass	Sulfate (SO_4) in water, ppm	Cement type	Maximum w/c, by mass
Negligible	< 0.10	< 150	No special type	—
Moderate (seawater)	0.10 to 0.20	150 to 1500	II, IP(MS), V	0.50
Severe	0.20 to 2.00	1500 to 10,000	V	0.45
Very severe	> 2.00	>10,000	V + pozz	0.45

Sulfate exposure	Water-soluble SO_4 in soil, % by mass	Sulfate (SO_4) in water, ppm	Cement type	Maximum w/cm (Normal wt.), by mass	Minimum design compressive strength, f'_c, MPa (psi)
Negligible	< 0.10	< 150	No special type	—	—
Moderate (seawater)	0.10 to 0.20	150 to 1500	II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	28 (4000)
Severe	0.20 to 2.00	1500 to 10,000	V	0.45	31 (4500)
Very severe	> 2.00	>10,000	V + pozz	0.45	31 (4500)

PCA

Concrete Technology and Codes

Limits for Corrosion Protection of Reinforcement

- Concrete Chloride Levels
- Water-Cement Ratio
- Compressive Strength
- Concrete Cover

Chloride Content of Concrete (ACI 359-07)

Type of Member	Max. Water Soluble Chloride Ion (Cl^-) in Concrete, % by weight
Prestressed Concrete (steel and concrete in direct contact)	0.06
Reinforced Concrete or Prestressed Concrete (ducts with grout or permanent coating)	0.15

Chloride Content of Concrete (ACI 359-07)

- Determine chloride content of:
  - Water and ice
  - Aggregate
  - Liquid admixtures
- Combine to determine total water soluble chloride content of concrete

Corrosion Protection of Reinforcement (ACI 349)

Type of Member	Max. Water Soluble Chloride Ion (Cl^-) in Concrete, % by mass
Prestressed Concrete	0.06
Reinforced Concrete	0.15

Chloride Content of Concrete (ACI 349-06)

- Chloride limits apply to hardened concrete at ages from 28 to 42 days contributed from:
  - Water
  - Aggregates
  - Cementitious materials
  - Admixtures
- Test in accordance with ASTM C1218

Concrete Requirements for Corrosion Protection

Exposure Condition	Max. W/C, by weight	Min. f'_c
Chloride exposure, seawater, brackish, etc. (ACI 359-07)	0.40 or 0.45 if cover increased by 0.5 in. (13 mm)	N/A
Chloride exposure, seawater, brackish, etc. (ACI 349-06)	0.40	5000 psi (35 MPa)

ACI 359-07 Alkali-Aggregate Reactivity Provisions

- CC-2231.3 Alkali Content
  - Test aggregate (ASTM C295, C227, C289, C342, and/or C586.
  - If potentially reactive, establish appropriate test program in Construction Specification
  - Any additional limits are established in Construction Specification

ACI 349-06 Alkali-Aggregate Reactivity Provisions

- Section 3.3.3.1
  - Test aggregate for potential reactivity (ASTM C289) unless specifically exempted.
  - Provisions of ASTM C33 apply

CC-2232 Selection of Concrete Proportions

- Design mixture to meet requirements for:
  - Workability and consistency
  - Resistance to special exposures (durability)
  - Strength
- Evaluate materials to be used for proposed work (each combination of materials for different portions of the proposed work must be evaluated)
- Establish proportions based on field experience or trial mixtures

ACI 349-06 Selection of Concrete Proportions (5.1)

- Design mixture to meet requirements for:
  - Specified compressive strength, f'c
  - Durability criteria
- f'c ≥ 2500 psi (17 MPa)
- Requirements are based on cylinder tests
- f'c based on 28 days unless otherwise specified and indicated on drawings or specs
- Splitting tensile strength test not for acceptance
- Show f'c for each part of structure on design drawings

Concrete Mixture Design

- Determine standard deviation
- Determine required average strength ($\mathbf{f'_{cr}}$ = required average compressive strength used as basis for selection of concrete proportions)
- Select mixture proportions to produce $\mathbf{f'_{cr}}$

CC-2240 Cement Grout

- Grout for general purposes
  - Under base plates
  - Around large penetrations
- Grout for prestressed tendons
- Grout for preplaced aggregate concrete

CC-2241 Constituents for Cement Grout

- Cement (ASTM C150 Types I or II)
- Aggregates
- Water
- Admixtures

} Same as for concrete

- Other material
  - For ex. Aluminum powder
  - Test for suitability

ACI 349-06 Grout for Bonded Tendons (18.18)

- Cement
- Water
- Admixtures

} **Same as for concrete**

- Sand (ASTM C144)
- Calcium chloride prohibited

PCA

Concrete Technology and Codes

CC-2242 Cement Grout for General Grouting Purposes

1. General requirements
2. Compressive strength
3. Fly ash and pozzolans
4. Water
5. Prepackaged cement grout
6. Epoxy grouts and bonding agents

PCA

Concrete Technology and Codes

CC-2242.5 Prepackaged Cement Grout

1. Permitted uses
2. Modification of product
3. Approval of designer
4. Construction procedures
5. Aggregate
6. Water
7. Quality assurance program requirements
8. Certified Material Test Reports
9. In-process testing

PCA

Concrete Technology and Codes

CC-2242.6 Epoxy Grouts and Bonding Agents

1. Permitted uses
2. Modification of product
3. Approval of designer
4. Construction procedures
5. Aggregate
6. Quality assurance program requirements
7. Certified Material Test Reports
8. In-process testing

PCA

Concrete Technology and Codes

CC-2243 Cement Grout for Grouted Tendon Systems

1. General requirements
2. Physical properties of the grout
   - Water-Cement ratio
   - Fluidity (except thixotropic)
   - Viscosity (thixotropic)
   - Bleeding
   - Compressive strength
3. Chemical requirements
   - Chloride and nitrate ion limits

CC-2250 Marking and Identification of Concrete Constituents

- Cement
  - Sealed and tagged at plant
  - Maintained at site
  - Lot no., controlling specification, date of manufacture, type
- Aggregates
  - Size, source, controlling specification
  - During transit and at batch plant
- Admixtures
  - Mark containers/identify bulk tanks
  - Storage requirements, controlling specification, name of admixture

ACI 349-06 Storage and Identification of Materials (3.7)

- Prevent damage or deterioration (special protective environments if necessary)
- Tag or label all stored materials
- For cementitious materials and aggregates, prevent deterioration or intrusion of foreign matter (discard deteriorated or contaminated material)
- Store reinforcement to permit inventory control and preclude damage or deterioration
- Document, tag, or control reinforcing steel by heat until review of CMTR
- Store prestressing system materials to permit traceability to CMTR while in transit and storage

PCA

Concrete Technology and Codes

CC-2300 Material for Reinforcing Systems

- Introduction
  - Reinforcing bars (ASTM A615 or A706)
  - Bar splice sleeves (ASTM A513, A519, or A576)
  - Splice sleeves to liner plates/structural steel (ASTM A513, A519, or A576 Grades 1008 – 1030)
  - Limits for welding to liner plates/structural steel
- Material identification
  - Tagged – traceable to CMTR
  - During production, in transit, in storage
- Special material testing

CC-2330 Special Material Testing

- Tensile tests
  - Full-size reinforcing bar for each 50 tons of each heat (SA-370)
  - Acceptance by ASTM A615 or A706
  - Retest of two additional specimens permitted (both must pass)
- Chemical analysis
  - Ladle analysis of each heat
  - Acceptance by ASTM A615 or A706
  - Special provisions for bars to be welded (CC-2333.1)

ACI 349-06 Steel Reinforcement (Section 3.5)

- Reinforcing bars (ASTM A615 or A706)
  - For fy > 60,000 psi (420 MPa), take yield at stress corresponding to strain of 0.35%
  - One tensile test for each 50 tons of each bar size produced from each heat (ASTM A370)
- Bar mats (ASTM A184 with A615 or A706 bars)
- Deformed wire (ASTM A496, but ≥ D4)
- Welded wire (ASTM A185, but ≤ 12 in. spacing)
- Epoxy coated bars or wire (ASTM A775, A934, A884)
- Plain bars for spirals (ASTM A615, A706)
- Plain wire for spirals (ASTM A82)

Reinforcing Steel Grades

Minimum Yield Strength

Specification	Inch-pound (ksi)	SI (MPa)
A615/A615M	40, 60, 75	280, 420, 520
A706/A706M	60	420

Designation: A 615/A 615M – 06a

American Association State Highway and Transportation Officials Standard
AASHTO No.: M 31

Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation A 615/A 615M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers deformed and plain carbon steel bars for concrete reinforcement in cut lengths and coils. Steel bars containing alloy additions, such as with the AISI and SAE series of alloy steels, are permitted if the resulting product meets all the other requirements of this specification. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1. The text of this

1.5 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

ASTM A615/A615M

TABLE 2 Tensile Requirements

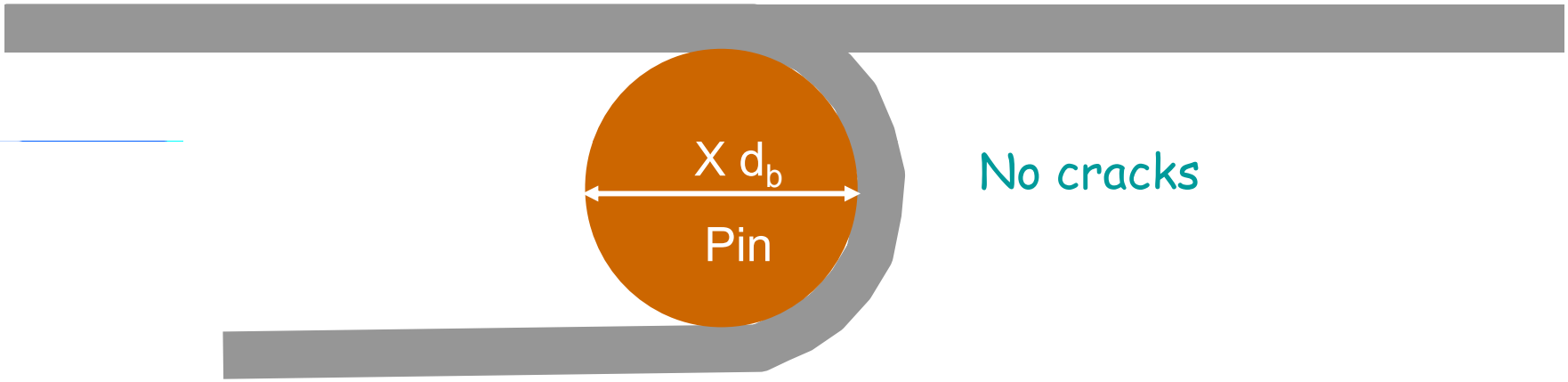
	Grade 40 [280][A]	Grade 60 [420]	Grade 75 [520][B]
Tensile strength, min, psi [MPa]	60 000 [420]	90 000 [620]	100 000 [690]
Yield strength, min, psi [MPa]	40 000 [280]	60 000 [420]	75 000 [520]
Elongation in 8 in. [203.2 mm], min, %:			
Bar Designation No.			
3 [10]	11	9	. . .
4, 5 [13, 16]	12	9	. . .
6 [19]	12	9	7
7, 8 [22, 25]	. . .	8	7
9, 10, 11 [29, 32, 36]	. . .	7	6
14, 18 [43, 57]	. . .	7	6

Standard Bar Sizes
inch-pound [metric]

TABLE 1 Deformed Bar Designation Numbers

Bar Designation No.[A]	Nominal Weight, lb/ft [Nominal Mass, kg/m]	Diameter, in. [mm]
3 [10]	0.376 [0.560]	0.375 [9.5]
4 [13]	0.668 [0.994]	0.500 [12.7]
5 [16]	1.043 [1.552]	0.625 [15.9]
6 [19]	1.502 [2.235]	0.750 [19.1]
7 [22]	2.044 [3.042]	0.875 [22.2]
8 [25]	2.670 [3.973]	1.000 [25.4]
9 [29]	3.400 [5.060]	1.128 [28.7]
10 [32]	4.303 [6.404]	1.270 [32.3]
11 [36]	5.313 [7.907]	1.410 [35.8]
14 [43]	7.65 [11.38]	1.693 [43.0]
18 [57]	13.60 [20.24]	2.257 [57.3]

180º Bend Test



No cracks

d_b = bar diameter
X = specified value ranging from 3 to 9;
depends on bar diameter and type of steel

From Carino

ASTM A615/A615M

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for Bend Tests[A]		
	Grade 40 [280]	Grade 60 [420]	Grade 75 [520]
3, 4, 5 [10, 13, 16]	3½ *d*[B]	3½ *d*	. . .
6 [19]	5*d*	5*d*	5*d*
7, 8 [22, 25]	. . .	5*d*	5*d*
9, 10, 11 [29, 32, 36]	. . .	7*d*	7*d*
14, 18 [43, 57] (90°)	. . .	9*d*	9*d*

[A]Test bends 180° unless noted otherwise.

[B]*d* = nominal diameter of specimen.

ACI 359-07 Limits on Bar Bends

TABLE CC-4322-1
MINIMUM DIAMETER OF BEND

Bar Size	Minimum Diameter, bars
No. 3–No. 8	6
No. 9–No. 11	8
No. 14, No. 18	10

Designation: A 706/A 706M – 06a

Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation A 706/A 706M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 *General*—This specification covers deformed and plain low-alloy steel bars in cut lengths or coils for concrete reinforcement intended for applications where restrictive mechanical properties and chemical composition are required for compatibility with controlled tensile property applications or to enhance weldability. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1. The text of this specification references notes and

1.7 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

ASTM A706/A706M

TABLE 2 Tensile Requirements

Tensile strength, min, psi [MPa]	80 000 [550][A]
Yield strength, min, psi [MPa]	60 000 [420]
Yield strength, max, psi [MPa]	78 000 [540]
Elongation in 8 in. [203.2 mm], min, %	
Bar Designation Nos.	
3, 4, 5, 6 [10, 13, 16, 19]	14
7, 8, 9, 10, 11 [22, 25, 29, 32, 36]	12
14, 18 [43, 57]	10

[A] Tensile strength shall not be less than 1.25 times the actual yield strength.

ASTM A706/A706M

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for 180° Bend Tests
3, 4, 5 [10, 13, 16]	3*d*[A]
6, 7, 8 [19, 22, 25]	4*d*
9, 10, 11 [29, 32, 36]	6*d*
14, 18 [43, 57]	8*d*

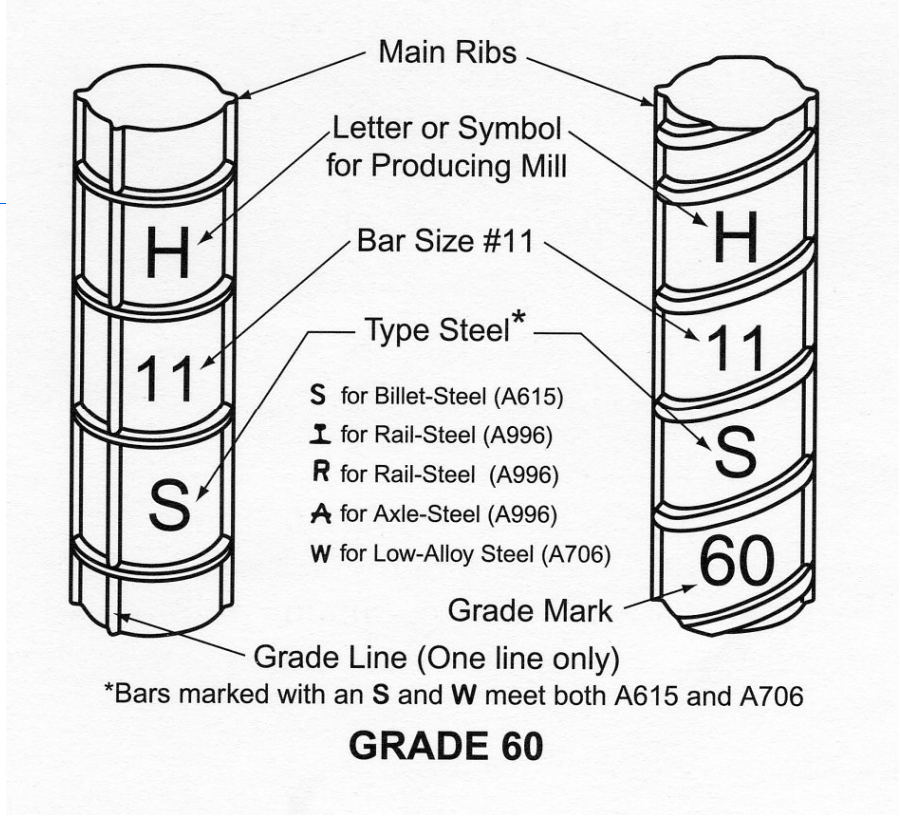
[A] *d* = nominal diameter of specimen.

Reinforcing Bar Markings

- Point of origin – mark established by producer
- Bar size
- Type of steel (S, W, R, A)
- Grade (number or extra longitudinal rib)

Examples

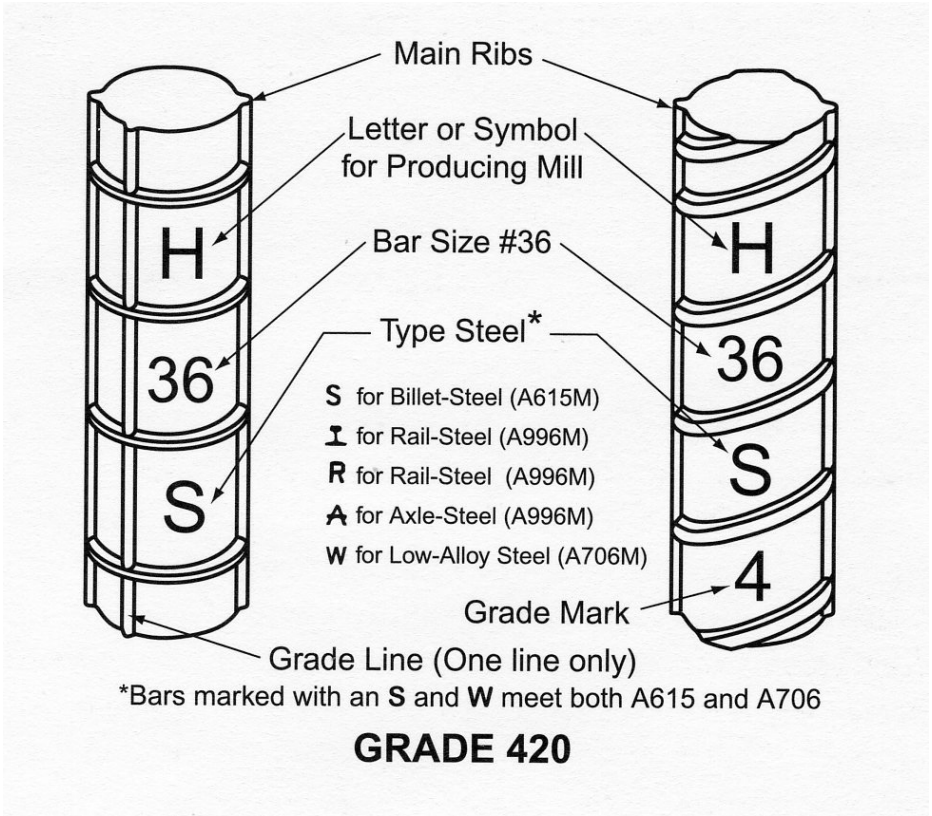
Inch-Pound



*Bars marked with an **S** and **W** meet both A615 and A706

GRADE 60

Metric

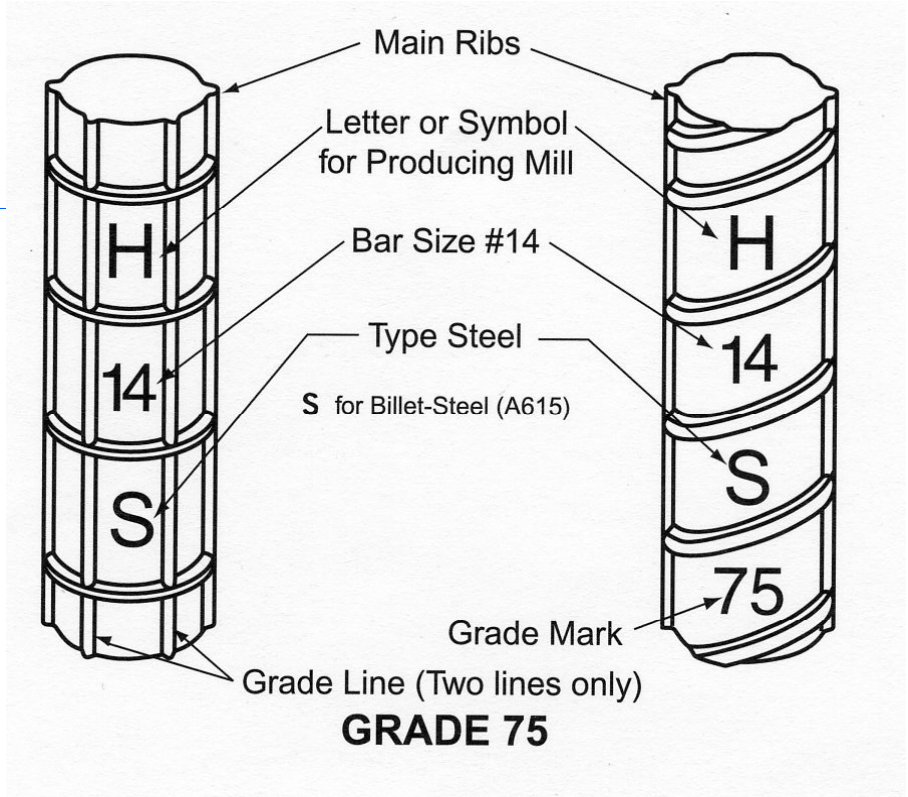


*Bars marked with an **S** and **W** meet both A615 and A706

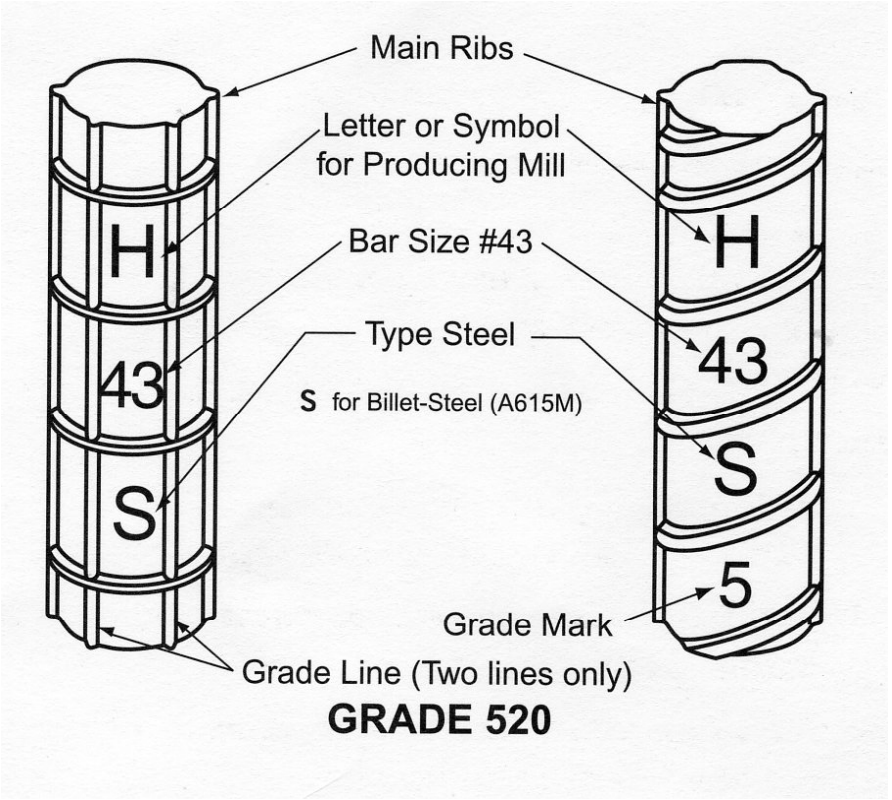
GRADE 420

Examples

Inch-Pound



Metric



PCA

Concrete Technology and Codes

CC-2400 Material for Prestressing Systems

- Introduction
- Prestressing steel
- Anchorage components
- Nonload-carrying and accessory materials
- Performance requirements
- Performance tests
- Marking and identification of prestressing material

CC-2420 Prestressing Steel

- Permitted material
- Test specimen sizes
  - All mechanical tests on full-size specimens
- Tensile tests
  - Follow ASTM specification
  - CMTR to include tensile strength, yield, elongation, other pertinent data
- Stress relaxation properties

Types of Prestressing Steel

- Seven-wire uncoated strand—ASTM A416/A416M
- Stress-relieved uncoated wire—ASTM A421/A421M
- High-strength uncoated bars—ASTM A722/A722M
- Seven-wire uncoated, compacted, stress relieved strand—ASTM A779/A779M

Permitted Prestressing Steel

ASTM	Grade/Type	Form
A416	250	Strand
A416	270	Strand
A421	BA	Wire
A722	150	Bar
A722	160*	Bar
A779	270	Strand
A779	260	Strand
A779	245	Strand

* Special - must conform to all other requirements of ASTM A722

Designation: A 416/A416M – 06

Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete[1]

This standard is issued under the fixed designation A 416/A416M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers two types and two grades of seven-wire, uncoated steel strand for use in pretensioned and post-tensioned prestressed concrete construction. The two types of strand are low-relaxation and stress-relieved (normal-relaxation). Low-relaxation strand shall be regarded as the standard type. Stress-relieved (normal-relaxation) strand will not be furnished unless specifically ordered, or by arrangement

MIL-STD-129 Marking for Shipment and Storage[3]
MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[3]

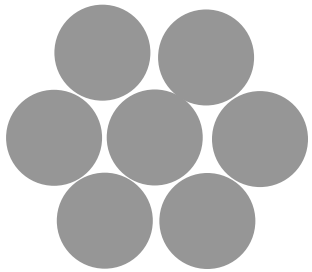
2.3 *U.S. Federal Standard:*
Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

ASTM A416/A416M

- strand—a group of wires having a center wire enclosed tightly by six helically placed outer wires with uniform pitch of not less than 12 and not more than 16 times the nominal diameter of the strand.



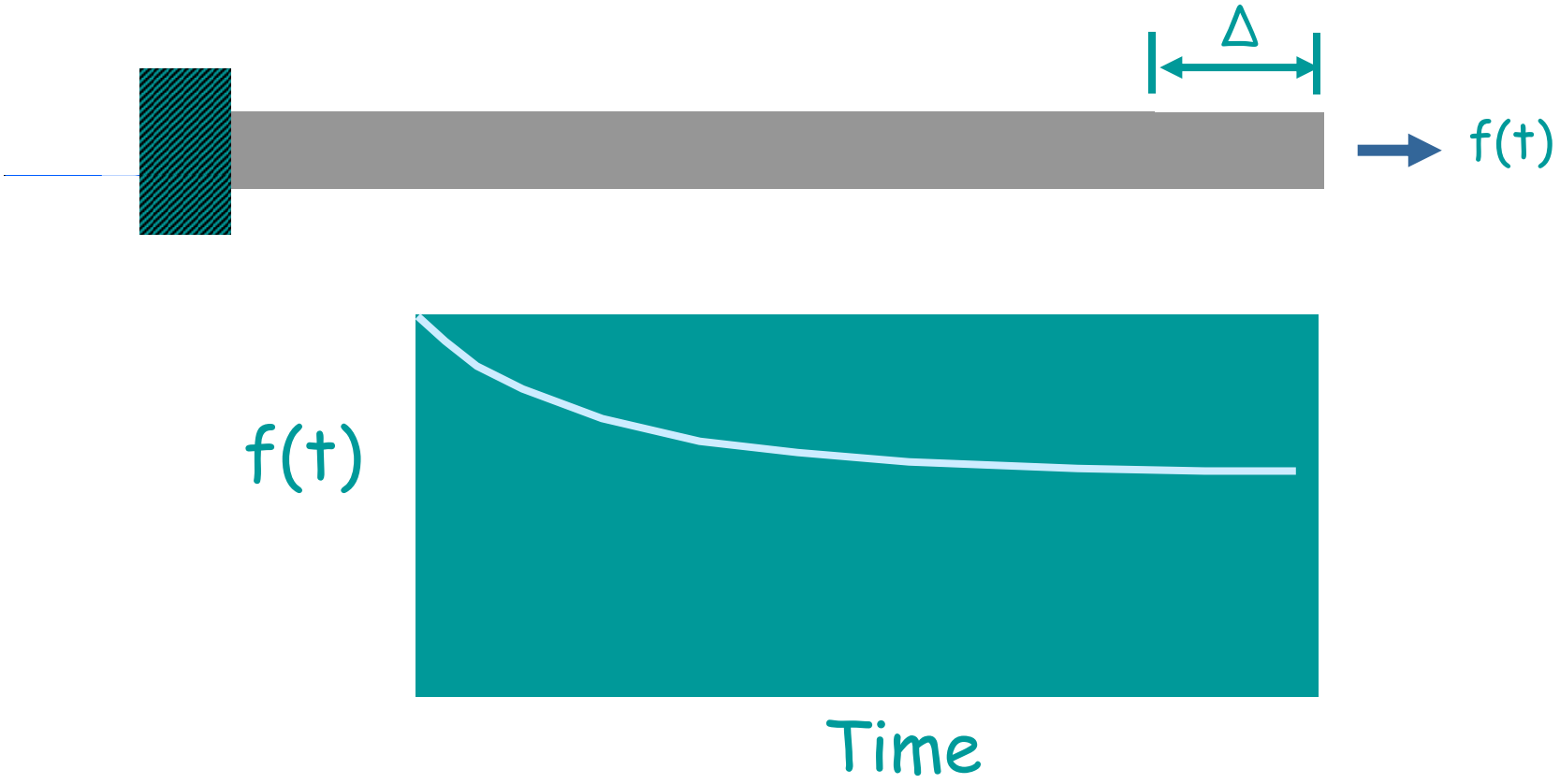
From Carino

ASTM A416/A416M

- Types
  - Low relaxation — < 2.5 % loss at 70 % f_u or < 3.5 % loss at 80 % f_u over 1000 h
  - Normal relaxation
- Tensile Strength
  - Grade 1725 [250] = 1725 MPa [250 ksi]
  - Grade 1860 [270] = 1860 MPa [270 ksi]

Stress Relaxation

Time dependent reduction in stress at constant strain



From Carino

ASTM A416/A416M

- Yield strength
  - At least 90 % f_u for low-relaxation
  - At least 85 % f_u for normal-relaxation
- Elongation
  - At least 3.5 % for gage length of at least 600 mm

Designation: A 421/A 421M – 05

American Association State
Highway and Transportation Officials Standard
AASHTO No.: M 204

Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete[1]

This standard is issued under the fixed designation A 421/A 421M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers two types of uncoated stress-relieved round high-carbon steel wire commonly used in prestressed linear concrete construction, as follows:

1.1.1 *Type BA* wire is used for applications in which cold-end deformation is used for anchoring purposes (Button Anchorage), and

1.1.2 *Type WA* wire is used for application in which the ends are anchored by wedges, and no cold-end deformation of

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[4]

2.3 *Federal Standard:*

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[4]

3. Ordering Information

3.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Such requirements shall include, but are not

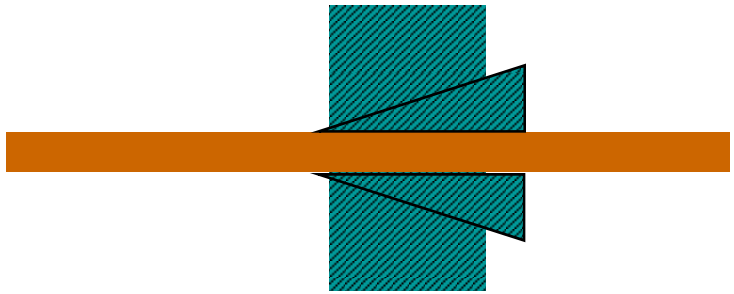
Stress-Relieved Wire

- Wire is formed by drawing through successively smaller dies
- The large strains that occur introduce residual stresses within the microstructure
- These stresses make the steel more brittle
- Residual stresses are removed by heat treatment

ASTM A421/A421M

- Type BA—button end

- Type WA—wedge anchors



From Carino

ASTM A421/A421M

TABLE 1 Tensile Strength Requirements

Nominal Diameter, mm (in.)	Tensile Strength, min, MPa (psi)	
	Type BA	Type WA
4.88 (0.192)	[A]	1725 (250 000)
4.98 (0.196)	1655 (240 000)	1725 (250 000)
6.35 (0.250)	1655 (240 000)	1655 (240 000)
7.01 (0.276)	1620 (235 000)	1620 (235 000)

[A]This size is not commonly furnished in Type BA wire.

At least 4 % elongation over 250 mm gage length

ASTM A421/A421M

$f_y \geq 85\ \%\ f_u$

TABLE 2 Yield Strength Requirements

Nominal Diameter, mm (in.)	Initial Stress, MPa (psi)	Minimum Stress at 1 % Extension, MPa (psi)	
		Type BA	Type WA
4.88 (0.192)	200 (29 000)	[A]	1465 (212 500)
4.98 (0.196)	200 (29 000)	1407 (204 000)	1465 (212 500)
6.35 (0.250)	200 (29 000)	1407 (204 000)	1407 (204 000)
7.01 (0.276)	200 (29 000)	1377 (199 750)	1377 (199 750)

[A]This size is not commonly furnished in Type BA wire.

Initial stress: corresponds to 0.1 % strain when strain gage is attached

Designation: A 722/A 722M – 06

Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete[1]

This standard is issued under the fixed designation A 722/A 722M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers uncoated high-strength steel bars intended for use in pretensioned and post-tensioned prestressed concrete construction or in prestressed ground anchors. Bars are of a minimum ultimate tensile strength level of 1035 MPa (150 000 psi).

1.2 Two types of bars are provided: Type I bar has a plain surface and Type II bar has surface deformations.

3.1.1 Quantity,

3.1.2 Name of material (uncoated high-strength bars for prestressing concrete),

3.1.3 ASTM designation and year of issue,

3.1.4 Size and length,

3.1.5 Type,

3.1.6 Special inspection requirements, if desired (see Section 12),

ASTM A722/A722M

- Type I—plain surface
- Type II—deformed surface
- Minimum tensile strength—150 ksi [1035 MPa]
- Minimum yield strength
  - Type I – 85 % f_u
  - Type II – 80 % f_u
- Minimum elongation
  - 4.0 % for gage length of 20 d_b, or
  - 7.0 % for gage length of 10 d_b

CC-2430 Anchorage Components

- Permitted material
  - Performance requirement – test system (CC-2460)
- Bearing plates
  - Finish, alignment, tolerances in construction specification
- Anchorhead assemblies and wedge blocks
  - Mechanical tests requirements
  - Acceptance standards in construction spec
- Wedges and anchor nuts
  - Hardness tests
  - Acceptance standards in construction procedures

CC-2440 Nonload-Carrying and Accessory Materials

- Tendon ducts, channels, trumpets, and transition cones
- Corrosion preventative material
  - Temporary coatings
    - Bonded systems
    - Unbonded systems
  - Permanent coatings

PCA

Concrete Technology and Codes

CC-2450 Performance Requirements

- Anchorages and couplings
- Tendon assemblies
  - Anchorages
  - Couplings
  - Low temperature requirements

CC-2460 Performance Tests

- Material used in tests same as for production tendons
- Type and number of performance tests
  - Static tensile test (yield strength, ultimate strength, elongation, no. of failed wires or strands)
  - High cycle dynamic tensile test (500,000 cycles from 60 to 66% of min. specified ult. strength of the tendon)
  - Low cycle dynamic tensile test (50 cycles from 40 to 80%)
- Size of performance test specimens
  - Length > 100 in (2500 mm)
  - Number of prestressing elements (full anchorage capacity for static and dynamic in single element tendon and at least 10% area for dynamic in multiple element tendons)

CC-2460 Performance Tests (con't)

- Test results report form (Fig. CC-2462-1)
- Essential variables
  - General requirements for retest
  - Essential variables in prestressing element material (CC-2466.2 (a)-(e)
  - Essential variables in anchorage items (CC2466.3 (a)-(f)

CC-2470 Marking and Identification of Prestressing Material

- Marked and tagged in transit and storage
- Ensure traceability to CMTR

PCA

Concrete Technology and Codes

Article CC-4000 Fabrication and Construction

- CC-4100 General Requirements
- CC-4200 Concrete
- CC-4300 Fabrication of Reinforcing Systems
- CC-4400 Fabrication and Installation of Prestressing Systems
- CC-4500 Fabrication of Liners
- CC-4600 Fabrication of Embedment Anchors

Article CC-4100 General Requirements

- Introduction
- Certification of material and fabrication or construction by component fabricator or constructor
  - Means of certification
  - Material identification
    - Concrete
    - Reinforcing materials
    - Prestressing system material
    - Liner material
    - Control of material
  - Examinations

PCA

Concrete Technology and Codes

CC-4200 Concrete

- General
- Storing, batching, mixing, and placing
- Preplaced aggregate concrete
- Curing

CC-4200 Concrete (con't)

- Formwork and construction joints
- Cold and hot weather conditions
- Repairs to concrete
- Cement grout for grouted tendon systems
  - Equipment for grouting
  - Grouting

PCA

Concrete Technology and Codes

CC-4220 Storing, Batching, Mixing, and Placing

- Stockpiling and storing
  - Aggregates
  - Moisture control
- Batching
  - General
  - Measuring
- Mixing
  - General
  - Operation of mixers

CC-4220 Storing, Batching, Mixing, and Placing (con't)

- Conveying
  - General
  - Conveying equipment
- Depositing
  - General
  - Continuity
- Consolidation
  - General
  - Use of mortar
  - Placeability tests

CC-4240 Curing

- Protection against thermal and physical damage
- Special requirements for type and duration of curing in Construction Specifications
- Cold weather
  - Cold weather: avg. outdoor temp below 40F (5C) more than 3 consecutive days
  - Maintain surfaces > 40F (5C) for first 3 days
- Protection against freezing
  - Compressive strength at least 500 psi (3.5 MPa) and no early strength requirements

PCA

Concrete Technology and Codes

CC-4250 Formwork and Construction Joints

- Formwork design
- Construction joints
  - Locations shown on design drawings
  - Preparation method in Construction Specification
  - All debris, water, and ice removed
  - All laitance and unsound material removed
  - Roughen to expose aggregate
  - Wet prior to placement
- Precast concrete segments

PCA

Concrete Technology and Codes

CC-4260 Cold and Hot Weather Conditions

- In accordance with Construction Specifications
- Permissible range of as-placed temperatures
- Preheating and precooling requirements for constituent materials
- Temperature control methods (use of ice, etc.) including max. rate of cooling
- ACI 305R Hot Weather Concreting and ACI 306R Cold Weather Concreting

PCA

Concrete Technology and Codes

CC-4270 Repairs to Concrete

- Repair or replace honeycombed or defective concrete as directed by the Designer
- Prepare adjoining surfaces as specified for construction joints

PCA

Concrete Technology and Codes

ACI 349-06 Batching, Mixing, Placing, and Curing (Chapter 5)

- Preparation of equipment and place of deposit
- Mixing
- Conveying
- Depositing
- Curing
- Cold weather requirements
- Hot weather requirements

PCA

Concrete Technology and Codes

ACI 349-06 Formwork, Embedded Pipes, and Construction Joints (Chapter 6)

1. Design of formwork
2. Removal of forms, shores, and reshoring
3. Conduits and pipes embedded in concrete
4. Construction joints

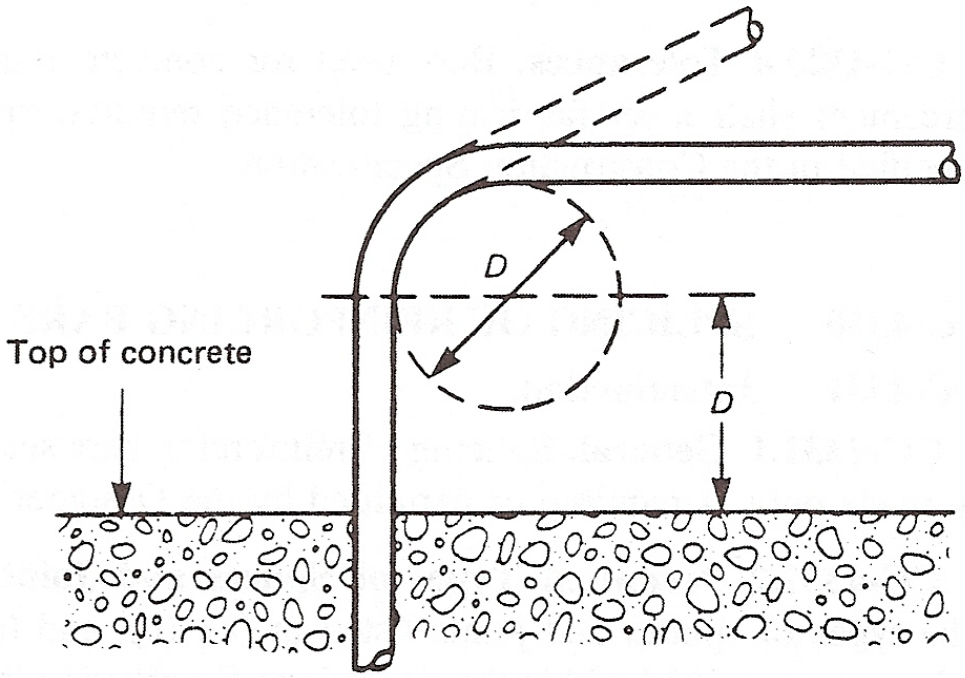
PCA

Concrete Technology and Codes

CC-4300 Fabrication of Reinforcing Systems

- General
- Bending of reinforcing bars
  - Standard Hooks
  - Stirrups, Tie Hooks, and Bends Other Than Standard Hooks
  - Bending
- Splicing of reinforcing bars
  - Introduction
  - Lap Splices
  - Mechanical Splices
  - Arc Welded Joints

CC-4323.2 Bending of Bars Partially Embedded in Set Concrete



D = minimum diameter of bend from Table CC-4322-1

TABLE CC-4333-1
TENSILE REQUIREMENTS FOR MECHANICAL REINFORCING BAR SPLICES AND WELDED JOINTS

	Reinforcing Bar Properties			Splice or Joint Strength Requirements	
Specification	Bar Grade	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)	Minimum Average Mechanical Splice or Welded Joint Tensile Strength, psi (MPa) [Note (1)]	Minimum Single Mechanical Splice or Welded Joint Tensile Strength, psi (MPa) [Note (2)]
ASTM A 615	Grade 40	40,000 (280)	70,000 (480)	70,000 (480)	50,000 (350)
ASTM A 615	Grade 60	60,000 (420)	90,000 (620)	90,000 (620)	75,000 (520)
ASTM A 706	. . .	60,000 (420)	80,000 (550)	80,000 (550)	75,000 (520)

NOTES:

(1) See CC-4333 and Appendix VIII.

(2) These values are equivalent to 125% of the yield strength of each bar grade.

PCA

Concrete Technology and Codes

CC-4300 Fabrication of Reinforcing Systems (con't)

- Placing reinforcement
  - General
  - Supports
  - Tolerances
- Spacing of reinforcement
  - Layers
  - Splices
- Surface condition

PCA

Concrete Technology and Codes

ACI 349-06 Details of Reinforcement (Chapter 7)

- Standard hooks
- Minimum bend diameters
- Bending
- Surface conditions of reinforcement
- Placing reinforcement
- Spacing limits for reinforcement

PCA

Concrete Technology and Codes

Cover and Spacing for Reinforcing Bars, Prestressing Tendons, Ducts, Bundled Bars

- ACI 359-07
  - CC-3534 Reinforcing Steel Cover and Spacing Requirements
- ACI 349-06
  - 7.6 – Spacing limits for reinforcement
  - 7.7 – Concrete protection for reinforcement

PCA

Concrete Technology and Codes

CC-4400 Fabrication and Installation of Prestressing Systems

- General
- Receiving, storing, and handling material
- Tendon fabrication
  - Anchorage Components
  - Tendon Assembly
- Tendon identification
- Tendon installation
  - Installation Procedure
  - Tendon Ducts and Channels

CC-4400 Fabrication and Installation of Prestressing Systems (con't)

- Post tensioning
  - Supervision
  - Stressing Sequence
  - Alignment
  - Load Extension and Measurement
  - Loss of Prestressing Force
- Permanent corrosion protection
  - General
  - Cement Grout for Grouted Tendon Systems

PCA

Concrete Technology and Codes

CC-5000 Construction Testing and Examination

- CC-5100 General Requirements for Examination
- CC-5200 Concrete Examination
- CC-5300 Examination of Reinforcing Systems
- CC-5400 Examination of Prestressing Systems
- CC-5500 Examination of Welds

PCA

Concrete Technology and Codes

CC-5100 General Requirements for Examination

- Procedures, qualifications, and evaluations
- Qualification and certification of nondestructive testing personnel
- Qualification of concrete inspection and testing personnel
  - General requirements
  - Personnel qualification
  - Verification by authorized inspectors
- Records

PCA

Concrete Technology and Codes

CC-5130 Qualification of Concrete Inspection and Testing Personnel

- CC-5131 General
  - Each organization shall insure all personnel are competent and knowledgeable
  - All inspection and testing shall be evaluated by qualified personnel
  - Assignment of responsibilities at discretion of responsible organization
- CC-5132 Personnel Qualification
  - Personnel shall be qualified in accordance with Appendix V – Qualifications of Concrete Inspection Personnel
- CC-5133 Verification by Authorized Inspectors
  - Authorized Inspector had duty to verify, audit, and require requalification

PCA

Concrete Technology and Codes

CC-5200 Concrete Examination

- General
- Concrete constituents
- Concrete
- Cement grout for grouted tendon systems

CC-5210 Concrete Examination – General

- Examinations used to qualify or disqualify the lot of concrete constituents represented
- Performed by the Constructor, Fabricator, or Manufacturer of Nonmetallic Materials
- Monitored by Authorized Inspector
- If performed by Manufacturer, Authorized Inspector of the Constructor or Fabricator shall be provided access for inspection
- Results of Manufacturer's examinations shall be verified by the Fabricator or Inspector

PCA

Concrete Technology and Codes

CC-5211 Concrete Examination – Laboratory Qualification

- Tests required shall be performed by an accredited laboratory that complies with ASTM C1077
- Testing personnel shall be qualified in accordance with CC-5132
- Laboratory Inspections and Accreditations can follow:
  - CCRL inspections
  - NVLAP, AALA, or CEMC accreditations

PCA

Concrete Technology and Codes

CC-5220 Concrete Constituents

- Cement
- Admixtures
- Aggregates
- Mixing water

TABLE CC-5200-1
MINIMUM TESTING FREQUENCIES FOR CONCRETE CONSTITUENTS AND CONCRETE

Material	Requirements	Test Method	Frequency [Note (1)]	
			Initial [Note (2)]	After Field Experience [Note (3)]
Cement	Standard chemical properties	ASTM C 114	Each 1,200 tons (1 100t)	Each 1,200 tons (1 100t)
	Fineness	ASTM C 204 or ASTM C 115	Each 1,200 tons (1 100t)	Each 1,200 tons (1 100t)
	Autoclave expansion	ASTM C 151	Each 1,200 tons (1 100t)	Each 1,200 tons (1 100t)
	Compressive strength	ASTM C 109	Each 1,200 tons (1 100t)	Each 1,200 tons (1 100t)
	Time of setting	ASTM C 266 or ASTM C 191	Each 1,200 tons (1 100t)	Each 1,200 tons (1 100t)
Air-Entraining Admixtures	Uniformity	Infrared spectrophotometry, pH, and solids content in accordance with ASTM C 260	Composite of each shipment or production lot	Composite of each shipment or production lot
Mineral Admixtures (Fly Ash and Pozzolans)	Loss on ignition	ASTM C 311	Each 400 tons (360t)	Each 400 tons (360t)
	Fineness (No. 325 sieve analysis)	ASTM C 311	Each 400 tons (360t)	Each 400 tons (360t)
	Specific gravity	ASTM C 311	Each 400 tons (360t)	Each 400 tons (360t)
	Reactivity with cement alkalies [Note (4)]	ASTM C 441	Each 2,000 tons (1 800t)	Each 2,000 tons (1 800t)
	Available alkalies [Note (4)]	ASTM C 311	Each 2,000 tons (1 800t)	Each 2,000 tons (1 800t)
Chemical Admixtures	Uniformity	Infrared analysis, specific gravity (liquids singly), and residue by oven drying in accordance with ASTM C 494	Composite of each shipment or production lot	Composite of each shipment or production lot
Grout Fluidifier	Physical properties	ASTM C 937	Composite of each shipment or production lot	Composite of each shipment or production lot
Aggregate	Gradation	ASTM C 136	Each 1,000 cu yd (760 m^3) concrete	Each 2,000 cu yd (1 500 m^3) concrete
	Moisture content	ASTM C 566	Twice daily during production	. . .
	Material finer than #200 sieve	ASTM C 117	Each 1,000 cu yd (760 m^3) concrete	Each 2,000 cu yd (1 500 m^3) concrete
	Organic impurities [Note (5)]	ASTM C 40	Each 1,000 cu yd (760 m^3) concrete	Each 2,000 cu yd (1 500 m^3) concrete
	Flat and elongated particles	CRD-C 119	Monthly	Every 6 months
	Friable particles [Note (5)]	ASTM C 142	Monthly	Every 6 months
	Lightweight particles [Note (5)]	ASTM C 123	Monthly	Every 6 months

PCA

Concrete Technology and Codes

CC-5230 Concrete

- Mixer Uniformity
- Concrete Properties
- Preplaced Aggregate Concrete
- General Purpose Grout

CC-5232.3 Concrete Physical Properties

- Test to establish compliance with Construction Specification
- Frequency in Table CC-5200-1
- Min. five randomly selected batches
- Each strength test result is avg. of two or more cylinders tested at 28 days or other age as specified

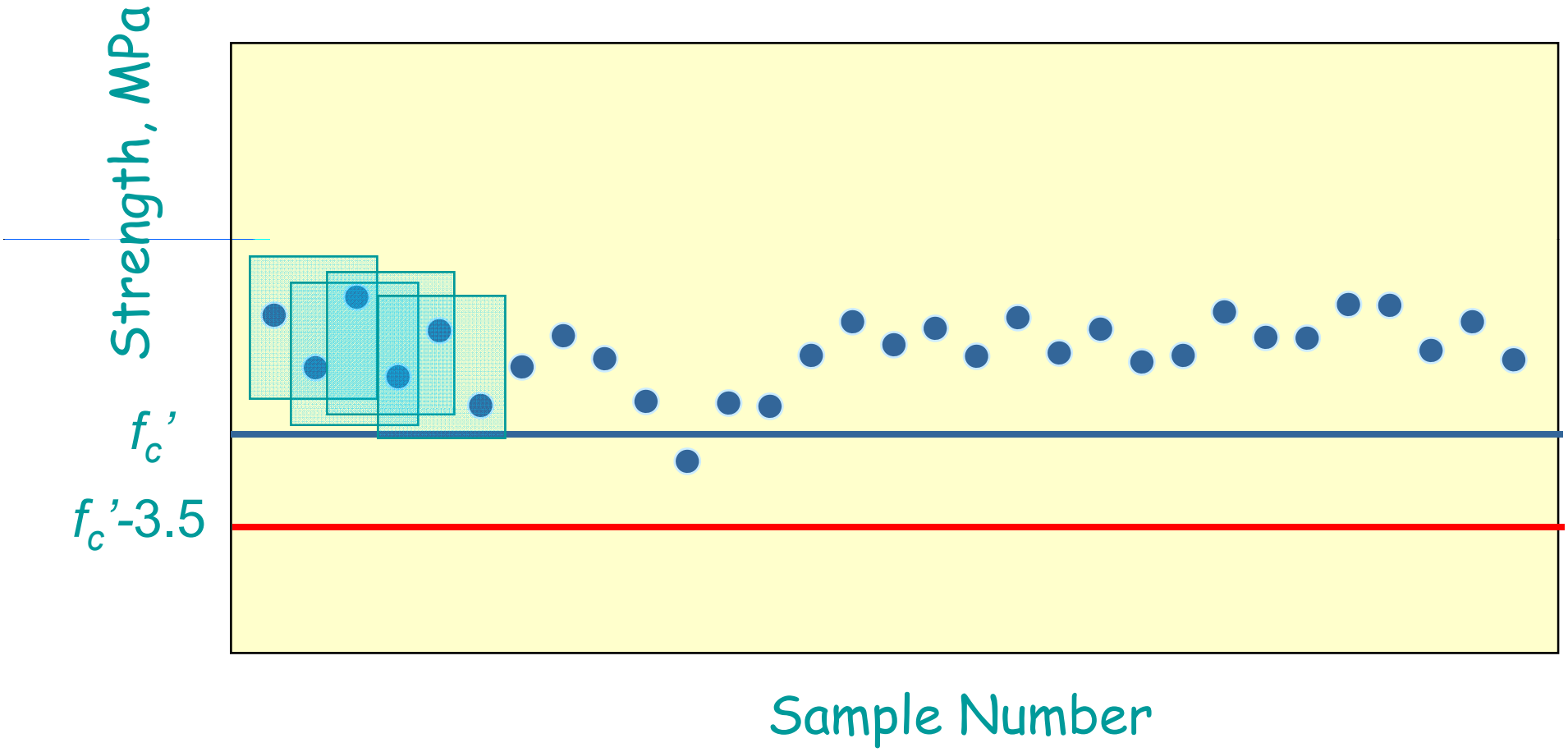
ACI 359-07 Concrete Acceptance Criteria (Based on Standard Cured Cylinders)

- Avg. of any three consecutive strength tests ≥ f'_c
- No individual strength test below f'_c by more than 500 psi (3.5 MPa)

ACI 349-06 Concrete Acceptance Criteria (Based on Standard Cured Cylinders)

- Avg. of any three consecutive strength tests ≥ f'_c
- No individual strength test below f'_c by more than:
  - 500 psi (3.5 MPa) when $f'_c \leq 5000$ psi (35 MPa)
  - 0.10 f'_c when $f'_c > 5000$ psi (35 MPa)

Testing Record



From Carino

PCA

Concrete Technology and Codes

CC-5232.3.2(d) Supplementary Compressive Strength Tests

- ASTM C 31/C 31M Field Curing
- Estimate the in-place strength
  - Apply service loads
  - Remove formwork
  - Apply post-tensioning
  - Terminate protection or curing
- Not used as basis for acceptance of concrete

ASTM C31/C31M Field-Cured Cylinders

10.2.1 *Cylinders*—Store cylinders in or on the structure as near to the point of deposit of the concrete represented as possible. Protect all surfaces of the cylinders from the elements in as near as possible the same way as the formed work. Provide the cylinders with the same temperature and moisture environment as the structural work. Test the specimens in the moisture condition resulting from the specified curing treatment. To meet these conditions, specimens made for the

CC-5232.3.2(d) — Supplementary Compressive Strength Tests

- Procedures for protecting and curing concrete shall be improved when strength of field-cured cylinders at test age designated for determination of $\mathbf{f'_c}$ is less than 85 percent of that of companion laboratory-cured cylinders.
- The 85 percent limitation shall not apply if field-cured strength exceeds $\mathbf{f'_c}$ by more than 500 psi (3.5MPa).

Investigation of Low-Strength Test Results

- If any strength test of laboratory-cured cylinders falls below f'_c by more than the values given in the acceptance criteria or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to assure that load-carrying capacity of the structure is not jeopardized.
- If the likelihood of low-strength concrete is confirmed and calculations indicate that load-carrying capacity is significantly reduced, tests of cores drilled from the area in question are permitted.

Investigation of Low-Strength Test Results

- Take three cores from area in question [ACI 359-07 requires three cores for each test result more than 500 psi (3.5 MPa) below the specified strength.]
- Test cores by ASTM C42 “Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete”
- Concrete adequate if average ≥ 85% f'_c and no single core < 75% f'_c

PCA

Concrete Technology and Codes

CC-5233 Preplaced Aggregate Concrete

- Aggregate
- Cement, Mineral Filler, and Fluidifier
- Intrusion grout
- Concrete

PCA

Concrete Technology and Codes

CC-5234 General Purpose Grout

- Constituents
  - Requirements
  - Test frequency (Table CC-5200-1)
- Physical properties
  - Requirements
  - Test frequency (Table CC-5200-1)

PCA

Concrete Technology and Codes

CC-5240 Cement Grout for Grouted Tendon Systems

- General
- In-Process Testing Frequencies
  - Temperatures
  - Fluidity/Viscosity
  - Compressive strength
  - Chemical requirements

PCA

Concrete Technology and Codes

CC-5300 Examination of Reinforcing Systems

- General
- Examination of mechanical splices
  - Sleeve with ferrous filler metal splices
  - Taper treaded splices
  - Swaged splices
  - Threaded splices in thread deformed reinforcing bars
- Examination of bends

CC-5400 Examination of Prestressing Systems

- General
- Required examination
  - General
  - Bearing plates
    - Preplacement
    - Post-Placement
  - Tendon ducts
    - Preplacement
    - Post-Placement
  - Prestressing steel
  - Anchorage components
  - Tensioning

PCA

Concrete Technology and Codes

CC-6000 Structural Integrity Tests of Concrete Containments

- CC-6100 General Requirements
- CC-6200 Test Procedure
- CC-6300 Structural Test Requirements
- CC-6400 Evaluation of Test Results
- CC-6500 Analysis of Data and Preparation of Report

PCA

Concrete Technology and Codes

Appendix V – Qualifications of Concrete Inspection Personnel (Mandatory)

- V-1000 Introduction
  - Scope
  - Responsibility
- V-2000 General Requirements
  - Planning
  - Certification
  - Training
  - Evaluation of performance
  - Certification of qualification

Appendix V – Qualifications of Concrete Inspection Personnel (Mandatory)

- V-3000 Qualifications
  - General requirements
  - Qualification of concrete inspection and testing personnel
    - Qualifications
      - Level I Concrete Inspection and Testing Technician
      - Level II Concrete Inspector
      - Level III Concrete Inspector
    - Physical capabilities
    - Technical
      - Level I
      - Level II
      - Level III

Appendix V – Qualifications of Concrete Inspection Personnel (Mandatory)

- V-4000 Performance
  - Concrete inspection and testing functions (Table V-4100-1)
  - Concrete inspection and testing functions
    - Level I
    - Level II
    - Level III
- V-5000 Review of Qualifications
  - Records of qualifications
  - Certification of concrete inspection personnel

TABLE V-4100-1
MINIMUM LEVELS OF CAPABILITY FOR FUNCTIONS

Function	Level		
	L-I	L-II	L-III
Recording inspection and testing data	X	X	X
Implementing inspection and testing procedures	X	X	X
Planning inspections and tests: setting up tests including preparation and setup of related equipment	...	X	X
Evaluating the validity and acceptability of inspection and testing results	...	X	X
Reporting inspection and testing results	...	X	X
Supervising equivalent or lower level personnel	...	X	X
Certifying lower level personnel	...	...	X
Evaluating the adequacy of specific programs used to train and test inspection and testing personnel	...	...	X
Approve inspection and test procedures	...	...	X

PCA

Concrete Technology and Codes

Case Studies

- Materials
  - Concrete
  - Reinforcing steel
  - Prestressing steel
- Construction
  - Formwork
  - Reinforcement and prestressing placement
  - Splicing systems
  - Concrete mixing, transporting, and placing
  - Post-tensioning operations
  - Curing
- Testing and Inspection

PCA

Concrete Technology and Codes

Summary

- 2007 ASME Boiler & Pressure Vessel Code; Section III, Division 2 Code for Concrete Containments

- ACI 349-06 Code Requirements for Nuclear Safety-Related Concrete Structures