Looking Back to See Ahead

Using Historical Knowledge of Durability to Provide Clues for Concrete Repair

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Errata and Clarifications included after references (May 3, 2025)

Fig. 1: Structures from the: top row: 1910s-30s; middle row: 1950s-70s; and bottom row: 1980s-2000s.

INTRODUCTION

Concrete buildings were constructed in the United States as early as 1835, but it wasn't until around 1870 that manufactured portland cement became available, 1875 until the first reinforced concrete house was believed constructed in the United States, and 1902 until the first "skyscraper" (the 210 ft tall Ingalls Building) was constructed in Cincinnati.[1] These developments started a new era of vast use of reinforced concrete as a durable and versatile construction material, but also brought the need for standardization, new materials, and research to promote safe construction. They additionally brought the need for more than 100 years of research to identify deterioration mechanisms and address them for making more durable construction. Indeed, research and advancement to these ends is still being conducted today, with new materials and methods being introduced perpetually as industry guides and codes are updated. Advancement forms the cornerstone of improvement and is described through the evolution of guides and codes.

While this evolution is healthy and productive, it can also make evaluation of older reinforced concrete structures, such as the ones shown in Figure 1, challenging, even for the most experienced professional. Often, information on the structure is limited and construction or maintenance records may be unavailable or incomplete. This places an engineer at a significant disadvantage for developing an effective evaluation plan. Given the year or approximate era of construction, how can one know:

- what should be expected,
- what was known in the industry at the time about degradation mechanisms,
- how best to understand the mindset of those responsible for construction,
- how to approach evaluation for developing appropriate maintenance and repair strategies, and
- what observed and evaluated distress and deterioration might be explained by the characteristic knowledgebase and state of practice when it was constructed?

Structural repair is governed by jurisdictional existing building codes, as well as industry standards they may reference. Repair often requires that engineers research structural requirements of the jurisdictional codes at the time of construction. Industry standards, such as ACI 562, *Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures*[2], provide direction regarding expected concrete and steel properties for historical concrete structures and provide direction regarding assessing existing buildings and designing repairs. However, it is beneficial to understand associated provisions of codes and guides contemporary to the time of construction as well as the mindset of the industry at the time of construction with respect to durability as this may impact how one views a structure and associated repair. For instance, for a particular structure, it may be helpful to know what the industry knew about freezing and thawing damage at the time of construction and how to mitigate it through durable design, when the industry became aware of alkali-aggregate reactivity, how the code addressed corrosion, or when certain types of materials were permitted in the code or in general use in the industry.

JURISDICTIONAL CODES AND INDUSTRY STANDARDS WITH DURABILITY PROVISIONS

The American Concrete Institute is generally considered the authority in the United States on concrete design and construction. Various guide documents and industry standard codes are developed by ACI. While ACI 318 and predecessors are sometimes referred to as "the Code" in this article, industry standard codes developed by ACI only become jurisdictionally enforceable or part of a national or local jurisdictional adopted building code if incorporated, in part or in whole, by reference. Codes are generally updated to reflect new information either determined within the code writing committee, or from incorporation of information from committees that prepare guide documents. Provisions in industry standard codes, such as the ACI 318 Building Code, generally lag information in industry guides, where the information is generally developed. National or jurisdictional codes generally lag industry standard codes, reflected by the time it takes for evaluation and incorporation by reference. For instance, for a building built in the year 1971 in Charleston, South Carolina, the 1955 National Building Code[3] was in effect. This code referenced ACI 318-51.[4a] This represents a 20-year lag between the time of construction and the state of the practice, as estimated through prevalent code provisions. It should be noted that synchronization of industry standards with jurisdictional codes has improved as it has become more consistent across jurisdictions. Also, the diligence of an engineer who may choose to use a more recent code with more restrictive provisions is possible, such that the overall lag may not be as pronounced as is possible. Thus, a historical look at the state of the industry is only an indicator of what may be expected on an existing building. Construction drawings may indicate more recent codes or design basis and are better indicators if available.

Durability is defined by the American Concrete Institute[5] as *"the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service."* American Concrete Institute Committee 201, Durability of Concrete, has developed updated guides on durable concrete since 1962.[6a] Manifestations of some common deterioration mechanisms are shown in Figure 2. The reader is referred to ACI 201.2R-16[6] for discussion of these mechanisms, as it is beyond the scope of this article.

Fig. 2: Examples of materials-related distress top left to right: alkali-silica reactivity (ASR) and freezing and thawing damage (F-T); bottom left to right: corrosion, and chemical attack / corrosion

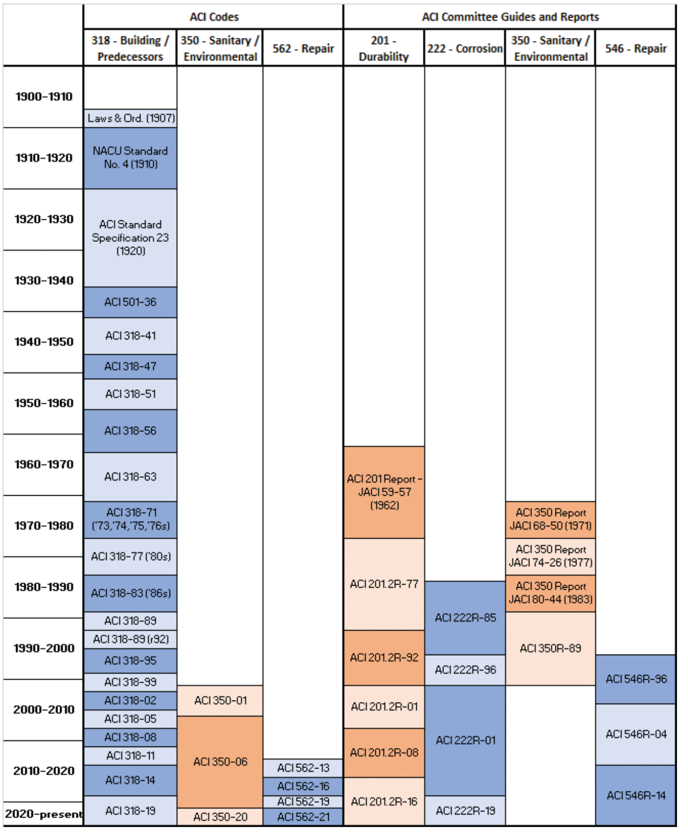


Fig. 3: Progression of industry standard ACI Codes and some durability-based guide documents (Refs 2, 4, 6-16). Documents prior included for additional reference

Figure 3 shows the general progression of ACI industry standard codes and some guide documents from the beginning of the 20th Century to today.[2,4,6-16] This can be a useful tool for understanding what was available to practitioners at the time an older building was constructed. The National Association of Cement Users (NACU) was organized late 1904 and early 1905[17-19] and developed regulations that served as predecessors to the ACI 318 Building Code (NACU became ACI in 1913[17]). Prior to NACU Standard Building Regulations for the Use of Reinforced Concrete in 1910[10], proposed ordinances had been developed and proposed in or before 1907[7], and then updated 1908[8] and 1909.[9] As has been pointed out by others, it is interesting that the NACU Regulations in 1910 were just 14 small pages.[17] The current ACI 318-19[4], after about 20 revisions, is 623 full-sized pages, though it does include commentary.

Durability guides were developed and maintained over the last half of the 20th Century. Of note is that the industry standard code for design of environmental structures was first published in 2001[13a], approximately 30 years after the first associated guide documents.[15a] Devoted initiatives with respect to concrete repair only became prevalent in the last part of the 20th Century. Information associated with concrete repairs or restoration were included in the ACI 201 guide from 1962 through 2001 but were not included in the 2008 version.[6a] The Association of Concrete Repair Specialists, later renamed the International Concrete Repair Institute (ICRI), was established in 1988[20], and the first ACI 546 repair guide was developed in 1996[16a], approximately 17 years prior to the first published version of ACI 562 Repair Code.[2a]

ADVANCEMENTS IN MATERIALS, UNDERSTANDING OF DETERIORATION MECHANISMS, AND DURABILITY PROVISIONS

A timeline of some of the major advancements in codes and industry knowledge is provided in Figure 4 and Figure 5. Figure 4 shows general provisional changes focused primarily on materials and standards incorporated into the ACI 318 Building Code and its predecessors. Figure 5 is separated into five major durability categories: alkali-aggregate reactivity (represented by green), sulfate attack (represented by red), freezing and thawing distress (represented by blue), corrosion (represented by orange) and other/general (represented by purple). Some of the more major advancements on understanding of mechanisms, as well as provisions for mitigations, are included. Figure 6 includes the primary abbreviations used in the timelines.

The timelines include consolidated information and are intentionally provided as such to represent a range of information within a small area. They are meant to be used as a reference tool for experienced practitioners, and to aid in the instruction of younger professionals when reviewing older existing structures. Where possible, relevant information was included in the tables. Because the change in cover requirements from ACI 318-71[19] was extensive, Figure 7 was prepared for illustration of the changes, as well as primary subsequent changes as noted.

A few notes regarding the timelines and their use:

- The tables are based on ACI documents that represent industry standards in the United States and do not account for local jurisdictional code adoptions that historically can be highly variable from location to location. Additionally, as described in the previous section, jurisdictional codes can lag industry standard codes and industry guidance by long periods, especially for older structures. Original construction drawings, research on jurisdictional code adoption dates and locations, and other available information should always be consulted for more specific context for the particular location and structure.

- The tables are primarily related to structures with design governed by ACI 318 (or predecessors). Thus, transportation structures and some environmental structures would not be directly applicable, though state of the practice contemporary to the time of construction is reflected and could be used in context for these structures in some cases, as determined by a licensed design professional.

- Some overlap exists in the figures, as is necessary to provide context, but Figure 4 and Figure 5 should be used in conjunction, as there was an effort to avoid duplication of information.

- While important provisions in the author's opinion have been included, the tables do not include all code provisions. Also, emphasis was placed on information when it first was discovered or first included in the Code. Thus, previous knowledge and provisions are sometimes, if not often, a precursor for subsequent information.

- Information should be interpreted by licensed professionals and verified for context within the referenced codes when used.

- The tables do not include developments and advancements with respect to structural design. They are focused on materials-related distress mechanisms and materials with primary concentration of the mechanism and materials referenced in the ACI 318 Building Code lineage. While abrasion, chemical attack, sulfides in aggregates, microbial-induced corrosion, freshwater attack, physical salt attack (other than scaling provisions in codes), and other mechanisms can lead to deterioration, they have not been emphasized. With respect to corrosion, some broad information associated with mitigation measures for existing structures (cathodic protection, corrosion inhibitors) has been included because it can be useful to understand when these technologies came into use for possible presence on a structure; however, their treatment in the figures is not comprehensive. The most current version of ACI 201 and other referenced documents should be reviewed by the reader for descriptions of mechanisms and current knowledgebase. Historical versions can be used as appropriate for investigating an existing structure.

- The reader is encouraged to review ACI 562-21.[2] This document includes provisions for estimating historical properties based on period of construction for use in structural evaluation.

SUMMARY OF MAJOR ADVANCEMENTS

The following sections summarize major durability requirements in ACI codes throughout the 19th and into the 20th Century for each focus category. Figure 8 illustrates a small selection of historical materials, documents, and advancements.

MATERIALS AND GENERAL

Considerable early changes focused on enhancing material provisions within the code (for instance aggregates), until ASTM Standard Test Methods were developed and adopted. Prestressed concrete was developed in the industry in the 1920s, but did not appear in Codes until the 1950s and 1960s. Early research on supplementary cementitious materials was conducted in the first half of the 20th Century and incorporated into codes in the last half. ACI Committee 201 was formed in 1957 and prepared the first report on durability in 1962.[6a] This report included discussion on alkali-aggregate attack, corrosion, freezing and thawing, chemical attack, abrasion, deicing salts, and repair. Though these materials had been commercially available for some time prior, epoxy coated reinforcing steel and galvanized steel were included in the code in the latter part of the 20th Century. Considerable advancements were made with respect to corrosion protection of post-tensioned steel late in the 20th Century.

In the time since the end of the 20th Century, a number of advancements have been made. Stainless steel was included in the Industry Standard Code in 2008. Provisions generally changed from using w/c as the basis for general quality to w/cm in ACI 318-02. A major organization of durability exposure classes in the code occurred in 2008. Corrosion inhibitors were included in the code in 2014, approximately 35 years after they became available commercially. Shotcrete and limestone cements have been some of the more recent materials addressed in ACI 318. ACI Committee 321, Concrete Durability Code, was formed in 2020 with the mission, per the committee webpage[51] to *"develop and maintain code requirements for the durability of concrete structures."* This represents a significant step toward the future of specifying and achieving durable structures. Indeed, ACI 440.11R-22[52], *"Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary"* has just been published and provides an avenue for design professionals to design with FRP in certain situations as it becomes adopted jurisdictionally.

ALKALI-AGGREGATE REACTIVITY

Alkali-silica reactivity (ASR) was identified in the late 1930s, first reported in 1940, and initially researched through the 1950s.[6,38,39] Alkali-carbonate reactivity was identified in 1957 and researched initially in the 1950s to 1970s.[6,38] Original ACI 318 provisions in the 1960s for ASR relied on limiting the alkali content in the cement by reference to ASTM C150 cements. Considerable effort has been made in the industry to identify test methods to evaluate ASR. In the early part of the 21st century, it has become increasingly realized that limiting alkali content in the cement does not adequately address the risk of ASR in all situations. ACI 318-19 is the first code that included provisions for mitigation per ASTM C1778, which is considered an improvement over the previous approach.

SULFATE ATTACK

Although the action of sulfate attack was known before the 20th century, early modern research for general identification of mechanisms was conducted between the 1910s and 1930.[6] The first code provisions for sulfate resistant cement were included in the 1941 Code[4a] via reference to ASTM C150. Codes in the 1970s evolved to include exposure classes and provisions for ensuring a low permeability concrete and sulfate resistant cement where needed. This continued into and beyond the 1980s. Use of ASTM C101[2] to evaluate concrete for sulfate resistance was introduced through the commentary and then into the Code late 20th Century and early 21st Century. Delayed ettringite formation (DEF) was identified as an issue in the 1990s[6], with provisions for specific maximum curing temperatures included in ACI 301 in 2010.[50]

FREEZING AND THAWING

The need for air-entrainment was accidentally discovered in the late 1930s.[29,30] Early research on the mechanisms and use of air-entraining additives occurred in the 1940s and 1950s. Early code provisions in the late 1940s and early 1950s addressed freezing and thawing durability by limiting the water-cement ratio (gallons of water per sack). The first ACI 318 requirement for reducing the water-cement ratio for non-air-entrained concrete was in 1956.[4a] ACI 318-63[4a] required use of air-entrainment, but did not specify amount or required air content. ACI 318-71[4a] provided requirements for total air content based on the aggregate size, and included provisions for w/c (normal weight concrete) and strength (lightweight aggregate concrete). These provisions were altered throughout the latter half of the 20th Century, but generally, it can be said that ACI 318 primarily addressed freezing and thawing transitionally to today's general approach between the 1950s and

FIGURE 4A: General material advancements up to the 1950s.

Blue and the suffix "C" after the year indicate Code provisions included in the indicated revision[4,7-12]. Green indicates industry advancement with references as appropriate. See Figure 6 for abbreviations.

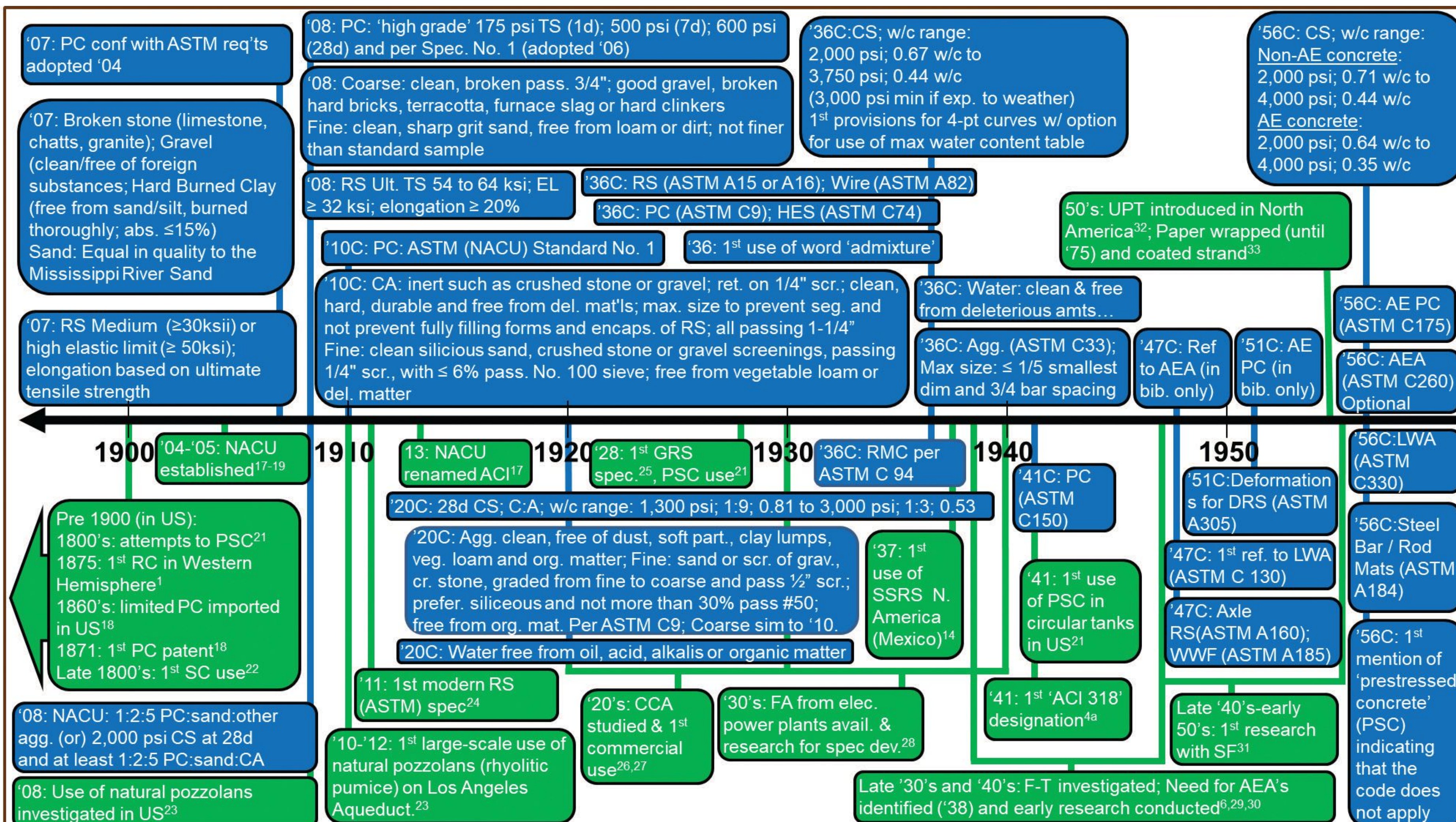


FIGURE. 4B: General material advancements from the 1950s to today.

Blue and the suffix "C" after the year indicate Code provisions included in the indicated revision.[4,7-12] Green indicates industry advancement with references as appropriate. See Figure 6 for abbreviations.

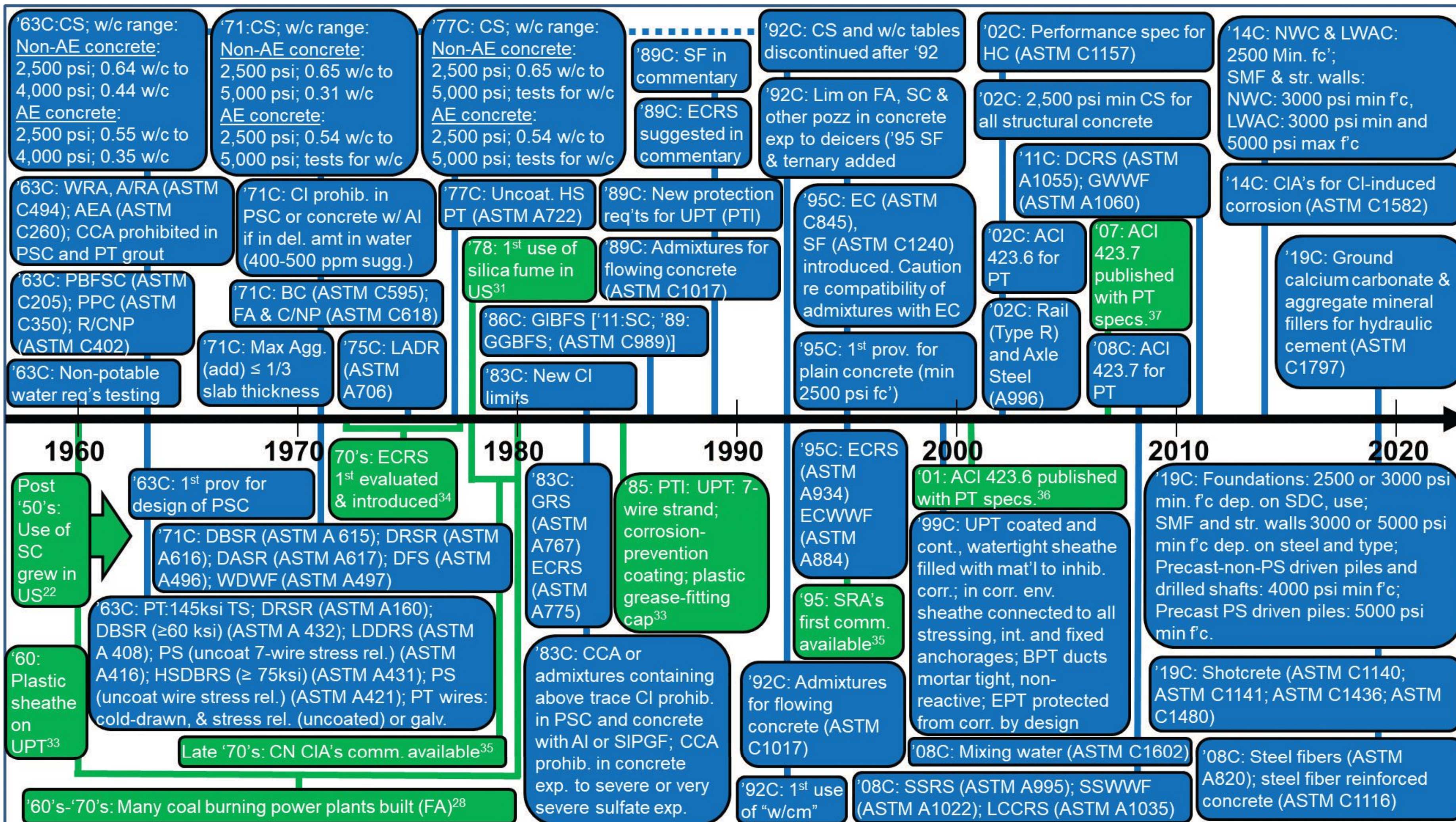


FIGURE 5A: Advancements in the knowledge and provisions for major durability categories addressed in the building code up to the 1950s.

Darker shaded boxes and the suffix "C" after the year indicate code provisions. Lighter shaded boxes indicate industry advancement. See Figure 6 for abbreviations. References in figure.

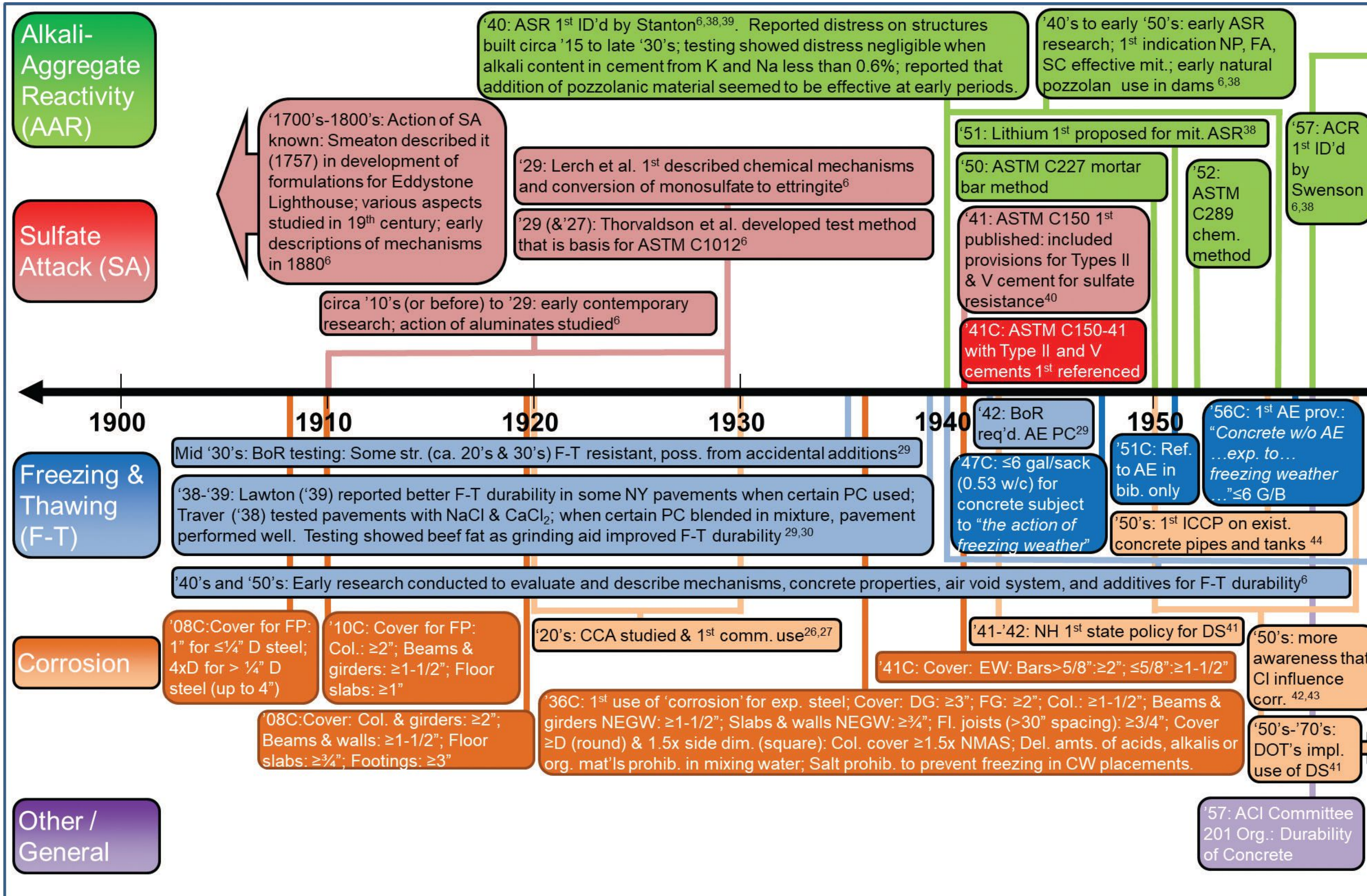
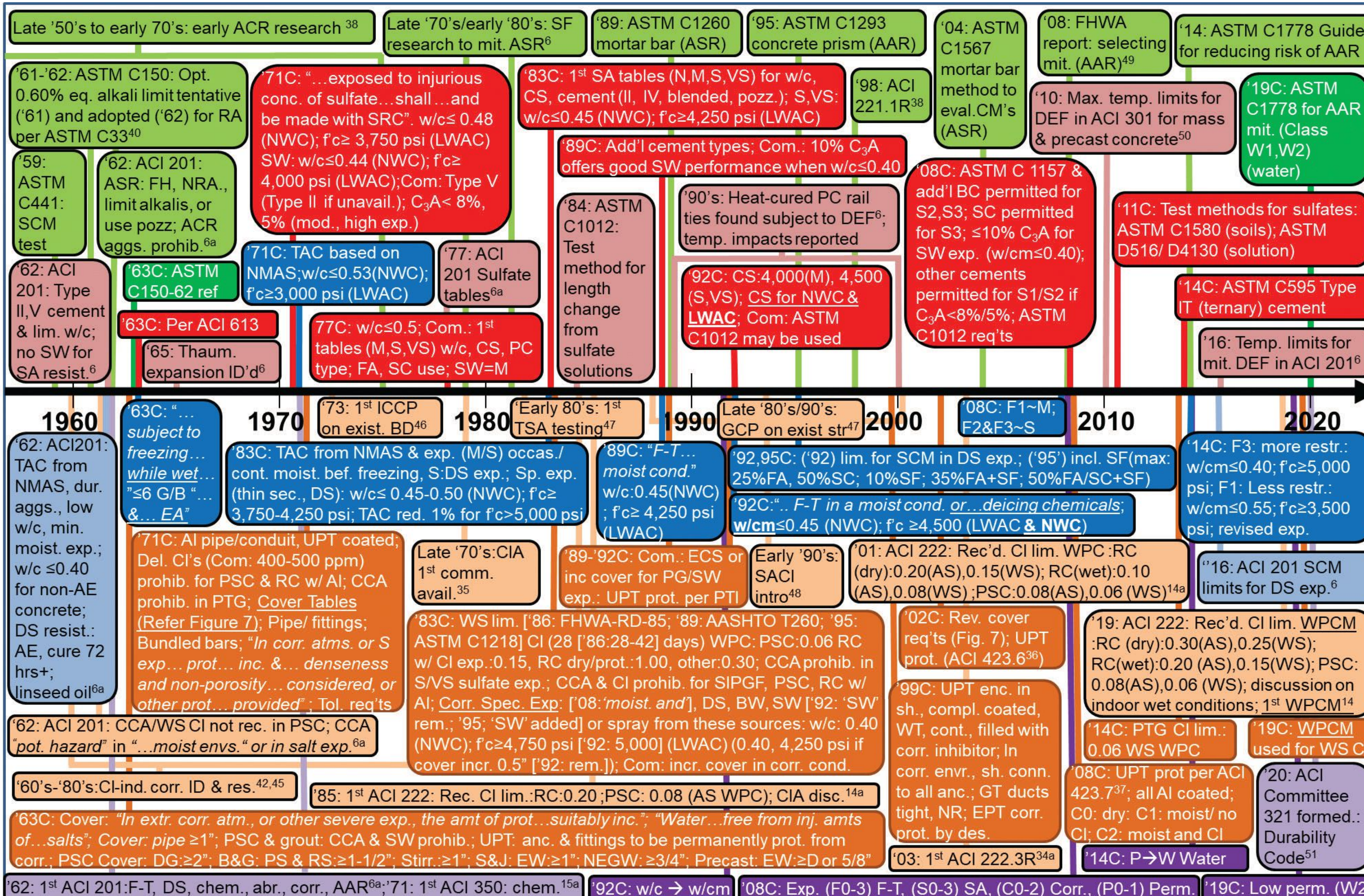


FIGURE 5B: Advancements in the knowledge and provisions for major durability categories addressed in the building code from the 1950s to today.

Darker shaded boxes and the suffix "C" after the year indicate code provisions. Lighter shaded boxes indicate industry advancement. See Figure 6 for abbreviations. References in figure



early 1970s. In 1992, the first provisions were included to limit the amount of SCM's in concrete exposed to deicing salts for scaling resistance.

CORROSION OF REINFORCING STEEL

Corrosion was not generally considered a major issue in concrete until it was better studied in the 1960s through 1980s.[42, 43, 45] Cover, originally included for fire protection in the code, was modified in early revisions regularly. The 1971 code[4a] organized cover requirements into the general form of the current ACI 318 (Figure 7). Focus has been on improving protection for post-tensioned steel, inclusion of alternative types of steel, and verbiage for increased protection of steel over standard cover requirements. Although calcium chloride admixture, first commercially available in the 1920s[26,27], and other chlorides had progressively been limited for use in prestressed concrete members and members with aluminum, the 1983 Code[4a] was the first to impose direct limits for chlorides in concrete on this basis. These limits were recognized in the commentary at the time as being *"more liberal"* than recommended by Committees 201 (durability) and 222 (corrosion), and per the commentary[4a] were *"…developed after consultation with Committees 201 on durability and 222 on corrosion, and are considered to represent the best information available at the time of adoption."*

Test methods for determining the chloride levels were refined in versions after the 1983 revision. Chloride limits in new construction have been the subject of recent debate in ACI Committee 222 meetings. The study of measuring and reporting chloride thresholds, as well as chloride limits for new construction, have been facilitated through the formation of a task group in ACI Committee 222. Recommended chloride limits have been modified in the ACI 222R-19 Guide[14], and along with ACI 201 recommendations remain more conservative than ACI 318 limits. ACI 318 requirements have largely been unchanged since 1983, except for permitting evaluation based on cementitious materials content instead of cement, as was adopted in ACI 318-19.[4] Required strength and w/cm has changed over the years, as have descriptions of exposure.

A/RA = Accelerating and retarding admixtures
AAR = Alkali-aggregate reactivity
Abr. = abrasion
ACI = American Concrete Institute
ACR = Alkali-carbonate reactivity
AE = Air-entrained
AEA = Air-entraining admixture
Agg(s). = Aggregate(s)
Al = Aluminum
Anc. = anchorage or anchor (in context)
AS = Acid soluble
ASR = Alkali-silica reactivity
Atm. = atmosphere
B&G = Beams and girders
BC = Blended cements
BD = Bridge deck
BoR = Bureau of Reclamation
BPT = Ponded Post-Tensioned Steel
BW = Brackish water
C/NP = Calcined or natural pozzolans
CA = Coarse aggregate
C:A = Cement:aggregate
CCA = Calcium chloride (accelerating) admixture
Chem. = chemical attack
Cl = Chloride(s)
CIA = Corrosion inhibiting admixture
CM = Cementitious materials
CN = Calcium nitrite
Col. = Column
Com. = Commentary
Compl. = Complete or completely (in context)
Conc. = Concentration
Cond. = Conditions
Conn. = Connected
Cont. = Continuous
Const. = Construction
Corr. = Corrosion or corrosive (in context)
CS = Compressive strength
CW = Cold weather
D = Diameter
DASR = Deformed axle steel reinforcing
DBSR = Deformed billet steel reinforcing
DCRS = Dual coated (zinc and epoxy) reinforcing steel
DEF = Delayed ettringite formation
Del. = Deleterious
Des. = Design
Dev. = Developed / Develop (in context)
DFS = Deformed steel wire
DG = Deposited against ground
DOT = Department of Transportation
DRS = Deformed reinforcing steel
DRSR = Deformed rail steel reinforcing
DS = Deicing salts (or deicing chemicals)
EA = Entrained air
EC = Expansive cement
ECRS = Epoxy-coated reinforcing steel
ECWWF = Epoxy-coated welded wire fabric
EGW = Exposed to ground or weather
EL = Elastic limit
Enc. = Encased
Env. = Environment
EPT = External post-tensioning
EW = Exposed to weather
Exp. = exposure or exposed (in context)
Ext = External
Extr. = Extreme or extremely (in context)
FA = Fly ash
FG = Formed against ground
FH = Field history
FP = Fireproofing
F-T = Freezing and Thawing
G/B = Gallon per 94 lb bag (or sack)
GCP = Galvanic cathodic protection
GRS = Galvanized reinforcing steel
GT = Grouted tendons
GWWF = Galvanized welded wire fabric
HC = Hydraulic cement
HES = High early strength
HSDBRS = High strength deformed billet-steel reinforcing steel
ICCP = Impressed current cathodic protection
Inc. = Increased
Ind. = induced
Inj. = Injurious
Int. = Intermediate
LADR = Low alloy deformed reinforcing
LCCRS = Low chromium carbon reinforcing steel
LDDRS = Large deformation deformed reinforcing steel
Lim. = limit
LWAC = Lightweight aggregate concrete
M = Moderate
Mit. = Mitigate or mitigation (in context)
Moist. = Moisture
N = Negligible
NACU = National Association of Cement Users
NEGW = Not exposed to ground or weather
NMA = Nominal maximum aggregate size
NP = Natural pozzolans
NR = Non-reactive
NRA = Non-reactive aggregates
NW = Normal weight concrete
PBFSC = Portland blast-furnace slag cement
PC = Portland cement
PCC = Precast concrete
Perm. = Permeability
PG = Parking garage (parking deck)
Pot. = Potential
Pozz. = pozzolans
PPC = Portland-pozzolan cement
Prohib. = Prohibit(ed)
Prot. = protect or protection (in context)
PS = Prestressing steel
PSC = Prestressed concrete
PT = Post-tensioned steel or post-tensioning (in context)
PTG = Post-tensioning grout
PTI = Post-Tensioning Institute
R/CNP = Raw and calcined natural pozzolans
RA = Reactive aggregates
RC = Reinforced Concrete
Rec. = Recommended
Rem. = Removed
Res. = Research
RMC = Ready-mix concrete
Rpt. = report
RS = Reinforcing steel
S = Severe
S&J: Slabs and joists
SA = Sulfate attack
SACI = surface-applied corrosion inhibitors
SC = Slag cement (also referred to as ground iron blast furnace slag (GIBFS) and ground-granulated blast-furnace slag) (GGBFS)
SCM = Supplementary cementitious materials
SDC = Seismic Design Category
Sec. = Section(s)
Sh. = Sheathing or sheathe (in context)
SIPGF = Stay-in-place galvanized forms
SMF = Special moment frames
Sp. = Special
SRA = Shrinkage-reducing admixture
SRC = Sulfate resisting cement
SSRS = Stainless steel reinforcing steel
SSWWF = Stainless steel welded wire fabric
Stirr. = stirrups
Str. = Structures
SW = seawater
TAC = Total air content
Thaum. = Thaumasite
Tol. = Tolerance
TS = Tensile strength
TSA = Thermal spray galvanic anode
UPT = Unbonded post-tensioning steel or unbonded post-tension (in context)
VS = Very severe
w/c = water-cement ratio by weight (mass)
w/cm = water-cementitious materials ratio by weight (mass)
WDWF = Welded deformed wire fabric
WPC = percent by weight (mass) of portland cement
WPCM = percent by weight (mass) of cementitious materials with SCM content not exceeding PC content
WRA = Water-reducing admixture
WS = Water soluble
WT = Watertight
WWF = Welded wire fabric

Fig. 6: Abbreviations used in Figure 4 and Figure 5, and throughout this article

Cast-in-place concrete (not prestressed)

Exposure	Member Type	Reinforcing Size	Min. Cover (in)
Earth or weather	Cast against/perm exposed to earth	All	3
	All others	#6 through #18	2
		#5, 5/8" wire and smaller	1-1/2
No weather or contact with ground	Slabs, walls, joists	#14 and #18	1-1/2
		#11 and smaller	3/4
	Beams, girders, columns (all)	All	1-1/2
	Shells and folded plate members	#6 and larger	3/4
		#5, 5/8" wire and smaller	1/2

Other Provisions:

Pipe and fittings:
1-1/2" for concrete exposed to weather
3/4" for concrete not exposed to weather or ground
Bundled bars:
Min cover: Equivalent diameter for the bundled bars, not to exceed 2"
['77: 3" minimum for concrete cast against ground]

Prestressed concrete members

Exposure	Member Type	Reinforcing Size	Min. Cover (in)
Earth or weather	Cast against/perm exposed to earth	All	3
	Wall panels, slabs and joists	All	1
	Other members	All	1-1/2
No weather or contact with ground	Slabs, walls, joists	All	3/4
	Beams, girders, columns	Principal reinforcement	1-1/2
		Ties, stirrups, spirals	1
	Shells and folded plate members	5/8" and smaller	3/8
		Other	3/4 ≤ D

Other Provisions:

Prestressed concrete
Non-prestressed reinforcement under plant control may be that for precast members
Cover increase of 50% for higher tensile stresses with exposure to weather, earth or corrosive environments

Precast concrete manufactured under plant conditions

Exposure	Member Type	Reinforcing Size	Min. Cover (in)
Earth or weather	Wall panels	#14 and #18; ['02: PS > 1-1/2"]	1-1/2
		#11 and smaller; ['02: PS ≤ 1-1/2", 5/8" wire and smaller]	3/4
	Other members	#14 and #18; ['02: PS > 1-1/2"]	2
		#6 through #11; ['02: PS 5/8" to 1-1/2"]	1-1/2
		#5, 5/8" wire and smaller; ['02: PS ≤ 5/8"]	1-1/4
No weather or contact with ground	Slabs, walls, joists	#14 and #18; ['02: PS > 1-1/2"]	1-1/4
		['02: PS ≤ 1-1/2"]	['02: 3/4]
		#11 and smaller; ['02: 5/8" wire and smaller]	5/8
	Beams, girders, columns	Principal reinforcement	5/8 ≤ D ≤ 1-1/2
		Ties, stirrups, spirals	3/8
	Shells and folded plate members	['02: PS]	['02: 3/4]
		#6 and larger	5/8
		#5, 5/8" wire and smaller	3/8

Other Provisions:

Tolerances included for cover for flexural, wall and compression members based on depth, d:
± 1/4" for d ≤ 8"; ± 3/8" for 8" < d < 24";
± 1/2" for d ≥ 24"; - 1/3 of min specified cover

['74 revised tolerances: - 3/8" for d ≤ 8"; - 1/2" for d > 8"; - 1/4" for formed soffits; - 1/3 of min specified cover]

Fig. 7: Cover requirements from ACI 318-714a as referenced in Figure 5. Primary modifications through revisions in 1974, 1977 and 2002[4a] noted and indicated in red.

Fig. 8: Top row from left: 1910 NACU (predecessor to ACI 318), early cloth cement bag, reinforcing steel bars from buildings constructed in the 1910s-20s, 1962 ACI Committee 201 Durability Report, ACI 318-19 (current Industry Standard Code); Bottom row from left: examples of SCMs incorporated into codes in the 20th century, galvanized reinforcing steel and epoxy coated reinforcing steel, thermal spray on existing concrete structures, galvanic anodes in patch repairs; and stainless steel

This article is not focused on technologies for existing structures, but the presence of corrosion mitigation technologies can impact how one might approach a repair project. Impressed current cathodic protection was used on concrete pipes and tanks in the 1950s[44] and was first installed on a bridge deck in 1973.[46] The development and use of galvanic cathodic protection occurred in the late 1980s and early 1990s[47] with a number of patents being issued thereafter for patch repair anodes and different surface-applied and embedded systems. Surface applied corrosion inhibitors were introduced in the early 1990s and a large amount of research has been conducted on them in the decades that followed.[48]

SUMMARY AND CLOSING

This article provides general discussion on the use of information in historical codes and industry standards to aid condition assessments for evaluating and repairing structures. Major changes and advancements in codes with respect to durability and deterioration mechanisms, as well as industry practice, were provided. It is hoped that the information may be of use to practitioners as they evaluate existing structures and train new professionals.

ACKNOWLEDGMENTS

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REFERENCES

References have been consolidated to accommodate article space requirements. Refer years referenced in text and figures for applicable years of Codes. Current versions of ACI Codes and Guides are indicated as primary reference with previous versions (of varying titles) noted. Where previous versions of guides or codes are relevant, superscript "a" is used in reference, corresponding to the indicated year.

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2. ACI 562-21, *Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary*, American Concrete Institute, Farmington Hills, MI, 2021, 88 pp.
    a. Previous versions in 2013, 2016, and 2019.
3. 1955 National Building Code, National Board of Fire Underwriters, 1955, 395 pp.
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Errata and Clarifications (May 3, 2025):

Figure 3: Note that new versions of ACI PRC 201.2-23, ACI PRC546-23, ACI 318-25 and ACI 562-25 have been published since this original publication. Information has not been incorporated into the errata. ACI recognizes an additional standard published in 1927: Reinforced Concrete Building Design and Specifications. Some items indicated first included in 1936 may have been included in that 2027 version.

Figure 7: Items associated with shells were removed from ACI 318 in 2014 and moved to ACI 318.2.

Page 13 (Sulfate Attack - 10th line): C101^{2} should be C1012.

Page 13: Sulfate Attack clarification: DEF had been identified by the 1980's. In the 1990's, there were widespread reports associated with railroad ties (per ref 6). Additional reference:

Heinz, D., and Ludwig, U., 1987, “Mechanism of Secondary Ettringite Formation in Mortars and Concretes Subjected to Heat Treatment,” Concrete Durability: Katherine and Bryant Mather International Conference, J. M. Scanlon, ed., SP-100, V. 2, American Concrete Institute, Farmington Hills, MI, pp. 2059-2071.

Page 13: Freezing and Thawing clarification: ACI 318-63 indicated that concrete exposed to freezing temperature while wet shall have entrained air. As indicated in the original article, no specific air content requirements were provided in ACI 318-63. Both ACI 318-56 and ACI 318-63 referenced ACI 613-54 (1954), "Recommended Practice for Selecting Proportions for Concrete". This recommended practice included recommendations for average total air contents ranging between 3 and 8 percent depending on the size of coarse aggregate. ACI 613-54 provided recommendations (not mandatory language) that included, in part, " "Because of its greatly improved resistance to deterioration, air-entrained concrete should be used wherever concrete is to be exposed to freezing and thawing, to action of salts used for de-icing, or to other destructive weathering agencies". Thus, it can be said that the ACI recommended practice, and thus good practice, was to produce air-entrained concrete with air contents as recommended ACI 318-54. ACI 318 recommended use of ACI 613, but ACI 318 did not have specific requirements for air content until the 1971 version (as stated in the original version of this article).

Page 18: First sentence requires clarification. Corrosion of reinforcing steel in concrete was know before 1910 with advancing knowledge from the 1940's-1960's. Research increased drastically from the 1960's on. Other portions remain the same. Additional references:

Thompson SE, "Report of Committee on Reinforced Concrete," ACI Journal Proceedings, V. 5. 1909, pp. 21 pp.

Davis C, "Concrete for Maritime Structures," ACI Journal Proceedings, V. 6, No. 2. 1910, pp. 120-57.

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January/February 2023
Vol. 36, No. 1

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2023 ICRI PRESIDENT PIERRE HÉBERT

CONCRETE REPAIR MATERIAL AND METHODS SELECTION

ICRI CONCRETE REPAIR
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ON THE COVER: 2023 ICRI President Pierre Hébert. See the President's Message on page 2.

CRB CONCRETE REPAIR BULLETIN

January/February 2023
Vol. 36, No. 1

FEATURES

DEPARTMENTS

NOTE FROM THE EDITOR

The new year starts off with a bang as ICRI celebrates its 35th anniversary in 2023. ICRI starts this anniversary year with its annual Kick-Off Party in conjunction with World of Concrete in Las Vegas. This year's event is hosted at the 1928 Prohibition Bar at Mandalay Bay. ICRI will host several certification programs thoughout the year, starting with the Concrete Slab Moisture Testing Certification Program at World of Concrete. Please check the event calendar on the ICRI website for the certification locations and dates in 2023.

The 2023 ICRI Spring Convention will be held at the JW Marriott Parq Vancouver in Vancouver, BC, April 17-19. ICRI Chapters will also be holding many events during 2023. Check the Chapter News section in the *Concrete Repair Bulletin* and the website for more information.

This issue of the *CRB* is themed "Concrete Repair Material and Methods Selection" and features articles on technology to increase the durability and lifespan of bridges with performance concrete repair solutions, using historical knowledge of durability to help design new concrete repairs, and a case study on the Hamilton House Condominium restoration. We will also meet 2023 ICRI President Pierre Hébert.

Please make sure you send Dale Regnier your upcoming chapter events and remember to check the ICRI website for the schedule of upcoming events.

I hope you all have a successful, safe, and healthy 2023!

Jerry Phenney
Editor, *Concrete Repair Bulletin*
RAM Construction Services

PRINT CORRECTION: NOVEMBER/DECEMBER 2022 *CRB*
The titles in the table of contents on page 1 of the printed version incorrectly stated "2021 ICRI Awards". It shoud have stated "2022 ICRI Awards." Also, the "On the Cover" message mistakenly identified the cover image. It shoud have read "2022 ICRI Project of the Year Award Winner: Mount Umunhum Radar Tower, Page 14." ICRI apologizes for the errors.