5000. Concrete Structures and Construction

- 5100 — Reinforced Concrete
- 5200 — Prestressed Concrete
- 5300 — Reinforcing Bars, Reinforcing Details & Tolerances
- 5400 — Concrete Containments, Modular Construction & Mass Concrete
- 5500 — Durability, NDE & Masonry

5500. Durability, NDE & Masonry

- Objective and Scope
  - Provide introductory level review of concrete durability, NDE methods and masonry basics
  - Present and discuss
    - Durability of Nuclear Power Plant Concrete Structures
    - Non Destructive Evaluation Methods for Concrete
    - Masonry Basics

5500. Durability, NDE & Masonry

- 5510 — 5510 - Durability of NPP Concrete Structures
- 5520 — 5520 – NDE Methods for Concrete
- 5530 — 5530 - Masonry Basics

5500. Durability, NDE & Masonry

- 5510 — 5510 - Durability of NPP Concrete Structures
- 5520 — 5520 – NDE Methods for Concrete
- 5530 — 5530 - Masonry Basics

5510 - Durability of NPP Concrete Structures

- Portland cement concrete durability is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process or deterioration
- Durable concrete is one that retains its original form, quality, and serviceability in the working environment during its anticipated service life

Durability of Nuclear Power Plant Reinforced Concrete Structures

- The materials and mix proportions specified and used should be such as to maintain concrete's integrity and, if applicable, to protect embedded metal from corrosion
- The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship, and design should be considered

Durability of Nuclear Power Plant Reinforced Concrete Structures

- Guidelines for production of durable concrete are available in national consensus codes and standards such as ACI 318
- Serviceability of concrete has been incorporated into the codes through strength requirements and limitations on service load conditions in the structure

Durability of Nuclear Power Plant Reinforced Concrete Structures

- Durability of concrete has been incorporated into the codes through, e.g.,
  - allowable crack widths
  - limitations on midspan deflections of beams
  - maximum service level stresses in prestressed members

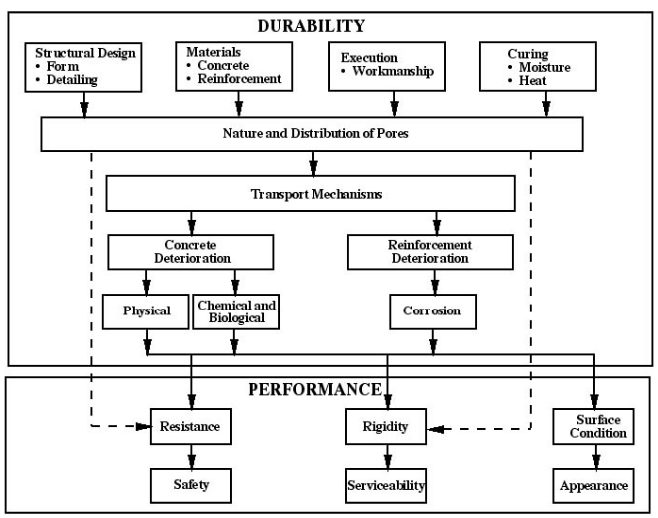
Durability of Nuclear Power Plant Reinforced Concrete Structures

- Durability generally has been included through items such as
  - specifications for maximum water-cement ratios
  - minimum cementitious materials contents
  - type of cementitious material
  - requirements for entrained air
  - minimum concrete cover over reinforcement
- Requirements are frequently specified in terms of environmental exposure classes (e.g., chloride and aggressive ground environments)

Durability of Nuclear Power Plant Reinforced Concrete Structures

- Controlling the degradation processes of concrete
  - Water is the single most important factor
    - fluid transport is dependent on the concrete pore structure (i.e., size and distribution), presence of cracks, and microclimate at the concrete surface
  - Mechanical deterioration
- Concrete compressive strength has traditionally been utilized as an acceptance test for concrete, but it typically is not a good indicator of durability

Relationship between the concepts of concrete durability and performance



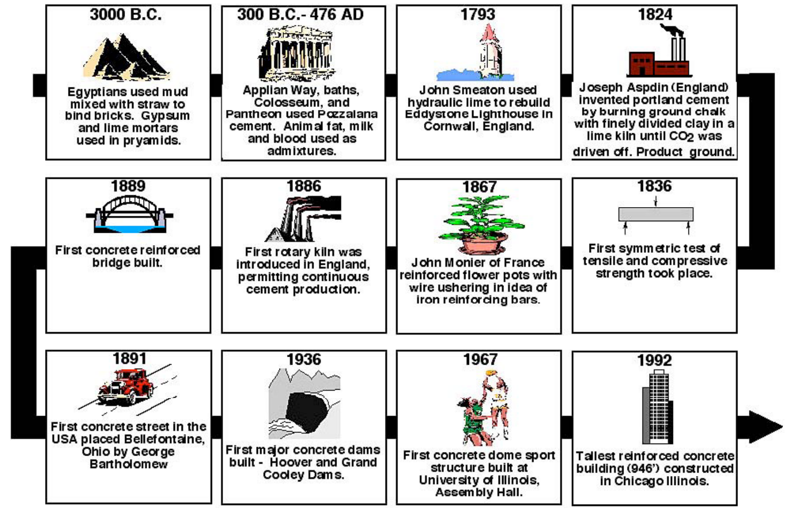
Safety-related Concrete Structures in Nuclear Power Plants

- Designed to withstand loadings from a number of low-probability external and internal events, such as earthquake, tornado, and loss-of coolant accident
- Consequently they are robust and not subjected to high stresses during normal operations
- Degradation usually attributed to construction or design deficiencies and improper material selection; or aging

Durability of Ancient Concrete Structures

Pantheon (built 119-128 A.D.); Colosseum (construction finished A.D. 80)

Concrete Historical Timeline



Relationship between Mechanical Properties and Section Dimensions

Mechanical Property	Concrete Thickness	Steel Reinforcement	Post-Tensioning System	Liner
Concrete				
Compressive strength	X	X	A	
Inital modulus		X	X	X
Delayed modulus			X	X
Shrinkage, creep			X	X
Steel Reinforcement				
Yield stress		X		
Post-Tensioning System				
Ultimate tensile stress			X	
Yield stress			X	
Relaxation value			X	
Friction factors			X	
Liner				
Yield stress			X	

A = anchorage zone.

Primary Degradation Factors that can Impact Safety-related Concrete Structures

Material System	Degradation Factor	Primary Manifestation
Concrete	*Physical processes*	
	Cracking	Reduced durability
	Salt crystallization	Cracking/loss material
	Freezing and thawing	Cracking/scaling/disintegration
	Abrasion/erosion/cavitation	Section loss
	Thermal exposure/thermal cycling	Cracking/spalling/strength loss
	Irradiation	Volume change/cracking
	Fatigue/vibration	Cracking
	Settlement	Cracking/spalling/misalignment

Primary Degradation Factors that can Impact Safety-related Concrete Structures (Cont'd)

Degradation Factor	Primary Manifestation
Chemical processes	
Efflorescence/leaching	Increased porosity
Sulfate attack	Volume change/cracking
Delayed ettringite formation	Volume change/cracking
Acids/bases	Disintegration/spalling/leaching
Alkali-aggregate reactions	Disintegration/cracking
Aggressive water	Disintegration/loss material
Phosphate	Surface deposits
Biological attack	Increased porosity/erosion

Primary Degradation Factors that can Impact Safety-related Concrete Structures (Cont'd)

	Degradation Factor	Primary Manifestation
Mild steel reinforcement	Corrosion	Concrete spalling/cracking/loss section
	Elevated temperature	Decreased strength
	Irradiation	Reduced ductility
	Fatigue	Bond loss
Post-tensioning	Corrosion	Strength loss/reduced ductility
	Elevated temperature	Reduced strength
	Irradiation	Reduced ductility
	Fatigue	Concrete cracking
	Stress relaxation/end effects	Prestress force loss
Liner/structural steel	Corrosion	Section loss
	Elevated temperature	Reduced strength
	Irradiation	Reduced ductility
	Fatigue	Cracking

Transport Mechanisms Important in the Consideration of Durability of Concrete

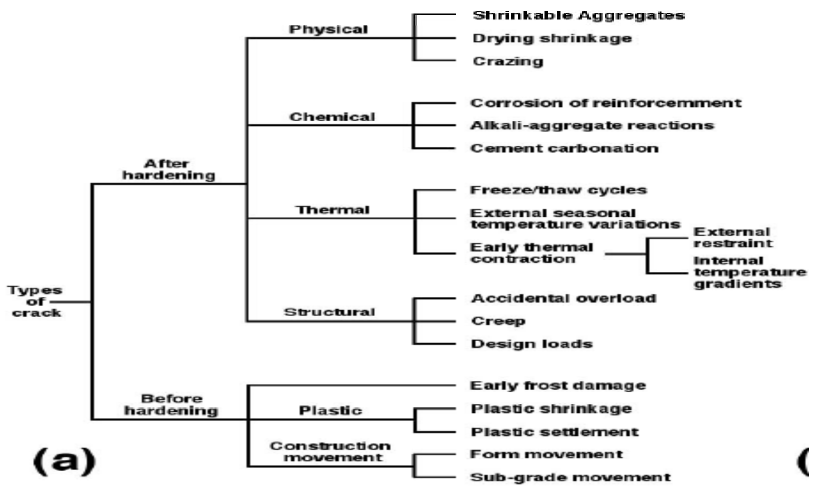
- Transport mechanisms include,
  - Diffusion of gases, CO_2, O_2, and water vapor through empty pockets, microcracks and the interfaces between components
  - Diffusion of ions (e.g., chlorides and sulfates) in the concrete pore solution and dissolved gases
  - Permeation of water or aqueous solutions under hydraulic head (submerged concrete or water-control structures)
  - Capillary suction of water (water absorption) or aqueous solutions in empty or unsaturated capillaries

Influence of Moisture State on Selected Durability Processes

Ambient relative humidity	Relative severity of deterioration process*				
	Carbonation of concrete	Frost attack on concrete	Chemical attack on concrete	Risk of steel corrosion: In carbonated concrete	Risk of steel corrosion: In chloride-rich concrete
Very low (<40%)	1	0	0	0	0†
Low (40-60%)	3ˆ	0	0	1	1
Medium (60-80%)	2©	0	0	3	3
High (80-90%)	1	2	1	2	3
Saturated (>98%)	0	3	3	1	1

*0 = insignificant, 1 = slight risk, 2 = medium risk, 3 = high risk.
†Corrosion risk in chloride-rich environments high if significant humidity variations.
ˆFor 40-50% relative humidity, carbonation is medium.
©For 60-70 % relative humidity, carbonation is high.

Relationship between Primary Causes and Types of Cracks in Concrete



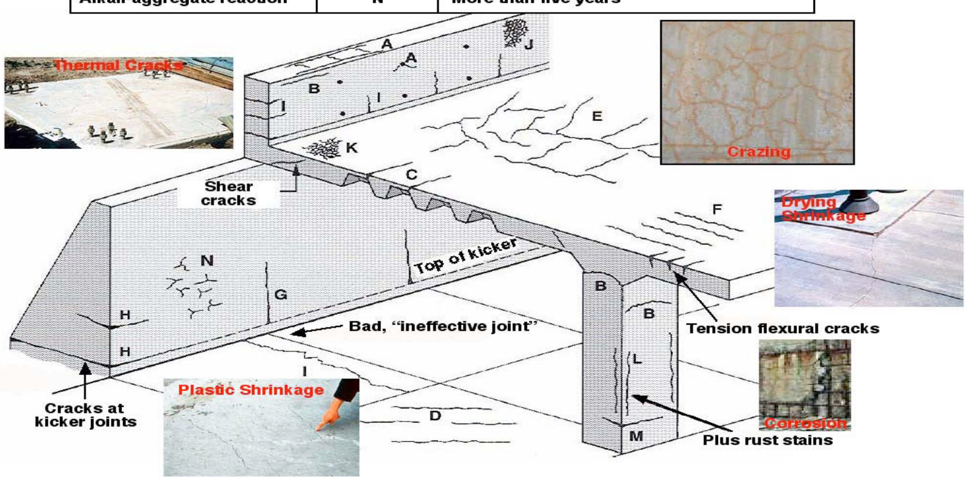
Relationship between Primary Causes and Types of Cracks in Concrete (Cont'd)

(b)

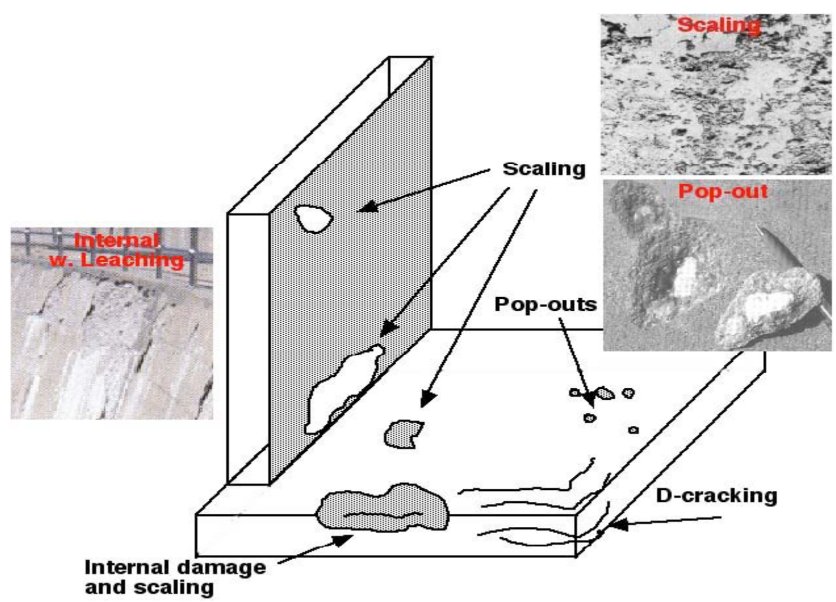
	Primary cause	Appearance	Description
Cracks due to rheological concrete properties	Rapid early drying		Surface of slabs and similar structural elements; low depth of cracks
	Plastic shrinkage		Cracks cross the full cross-section; no defined direction
	Plastic settlement of fresh concrete		Cracks follow reinforcing bars; voids underneath the bars
Cracks caused by load/imposed deformation	Pure flexure	M	Direction of cracks transverse to tensile reinforcement
	Shear		Cracks develop from those due to flexure
	Pure tension		Cracks cross the full cross-section
	Bond failure		Cracks may form in the anchorage zones; they are parallel th the reinforcing bars

Examples of Cracks in a Hypothetical Structure

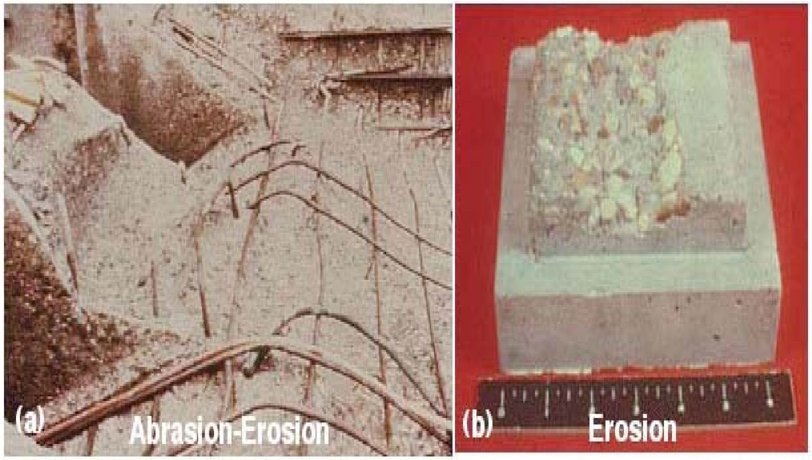
Type of Cracking	Designation	Time of Occurrence
Plastic settlement	A, B, C	Ten minutes to three hours
Plastic shrinkage	D, E, F	Thirty minutes to six hours
Early thermal contraction	G. H	One day to two to three weeks
Long-term drying shrinkage	I	Several weeks or months
Crazing	J, K	One to seven days - sometimes much later
Corrosion of reinforcement	L, M	Several years, but my be sooner
Alkali-aggregate reaction	N	More than five years



Types of freeze-thaw damage



Abrasion-erosion of Concrete

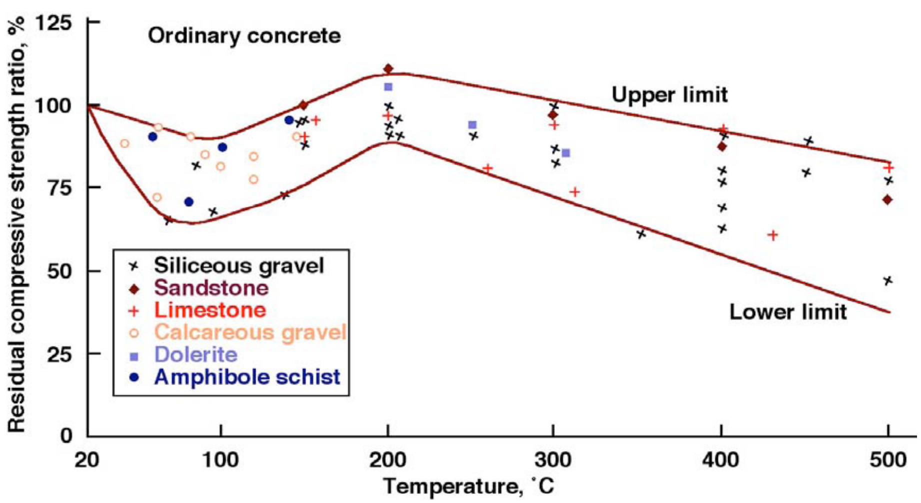


Influence of Environmental Factors on Heated Concrete

Factor	Influence	Comment
Temperature level	*** **	• Chemical-physical structure and most properties • Properties (e.g., comp. strength and modulus) of some concretes when heated under 20-30% load can vary less with temperature – up to about 500°C – than if heated without load
Heating rate	** ***	• <2°C/min: second order influence • >about 5°C/min: becomes significant tending toward explosive spalling
Cooling rate	* ** ***	• <2°C/min: negligible influence • >2°C/min: cracking could occur • Quenching: very significant influence
Thermal cycling	** **	• Unsealed concrete: significant influence mainly during first cycle to given temperature • Sealed concrete: influence in that it allows longer duration at temperature for hydrothermal transformations to develop
Duration at Temperature	** ***	• Unsealed concrete: only significant at early stages while transformations decay • Sealed concrete; Duration at temperatures above 100°C lead to continuing hydrothermal transformations
Load-Temp. sequence	***	• Very important
Load level	*** ***	• <30%: linear influence on transient creep at least in range up to 30% cold strength • >50%: failure could occur during heating at high load levels
Moisture level	** ***	• Unsealed: small influence on thermal strain and transient creep particularly above 100°C • Sealed: very significant influence on structure of cement paste and properties of concrete above 100°C

***first order influence, **second order influence, *negligible influence

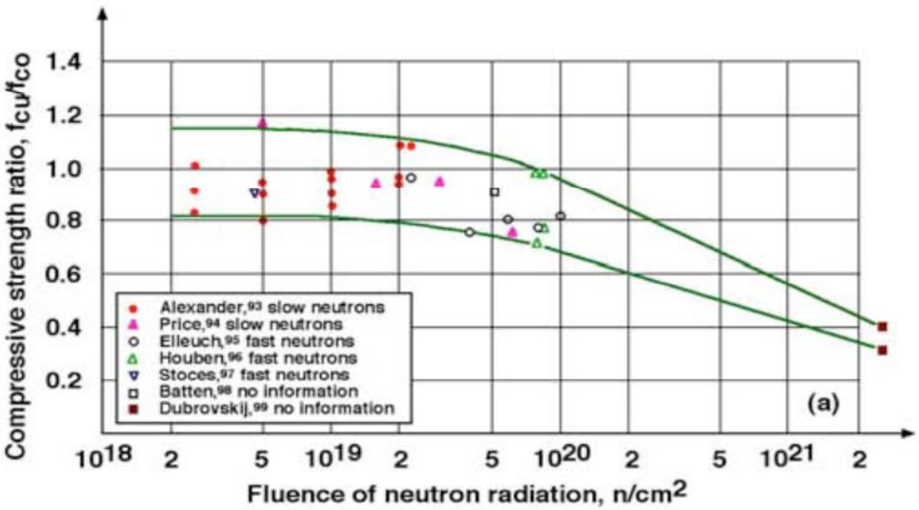
Effect of Temperature on Residual Compressive Strength: Unsealed Specimens



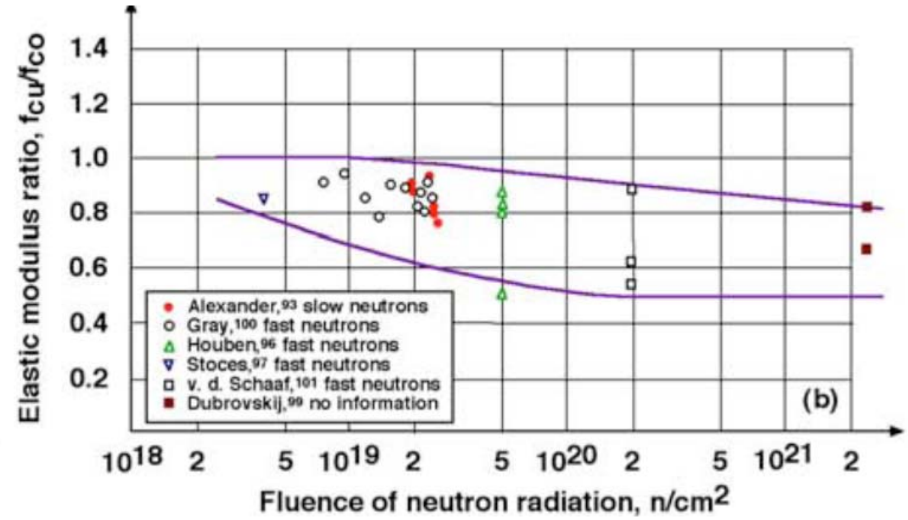
Residual Ratios for Ordinary Concrete at Elevated Temperature: Unsealed Specimens

Temp-erature (°C)	Residual ratio (%)*								
	Compressive strength			Tensile strength			Elastic modulus		
	Lower limit	Upper limit	Average	Lower limit	Upper limit	Average	Lower limit	Upper limit	Average
20	100	100	100	100	100	100	100	100	100
50	70	95	85	65	75	70	70	95	85
90	65	90	80	65	80	75	70	85	80
100	65	90	80	70	80	75	65	90	75
200	85	110	100	60	85	70	50	70	60
300	70	100	85	50	70	60	40	60	50
400	55	95	75	35	55	45	30	55	40

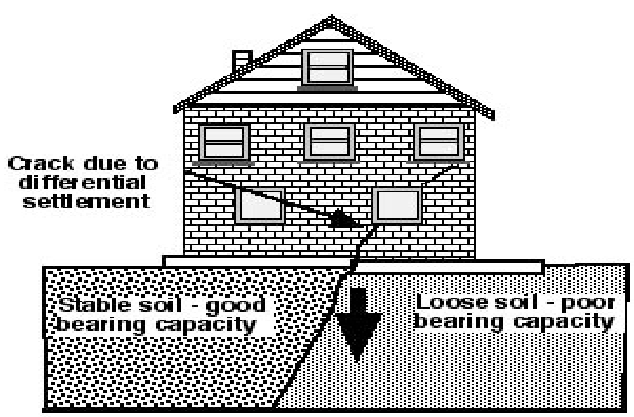
Effect of Neutron Radiation on Compressive Strength Relative to Unirradiated and Unheated Control Specimens



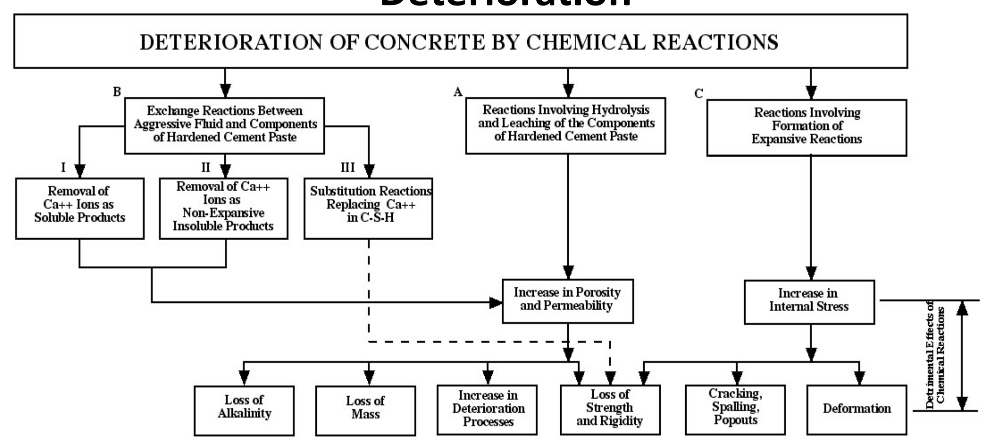
Effect of Neutron Radiation on Modulus of Elasticity Relative to Unirradiated and Unheated Control Specimens



Inadequate Foundation Design



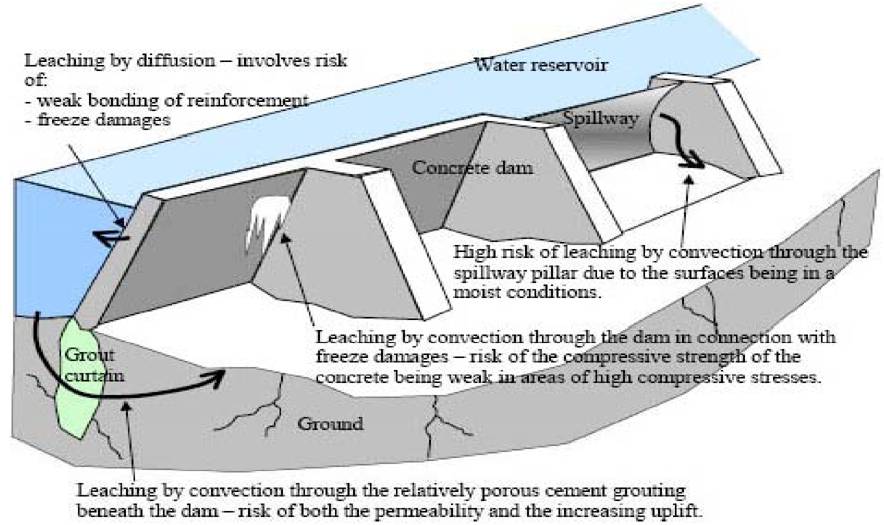
Chemical Reactions Responsible for Concrete Deterioration



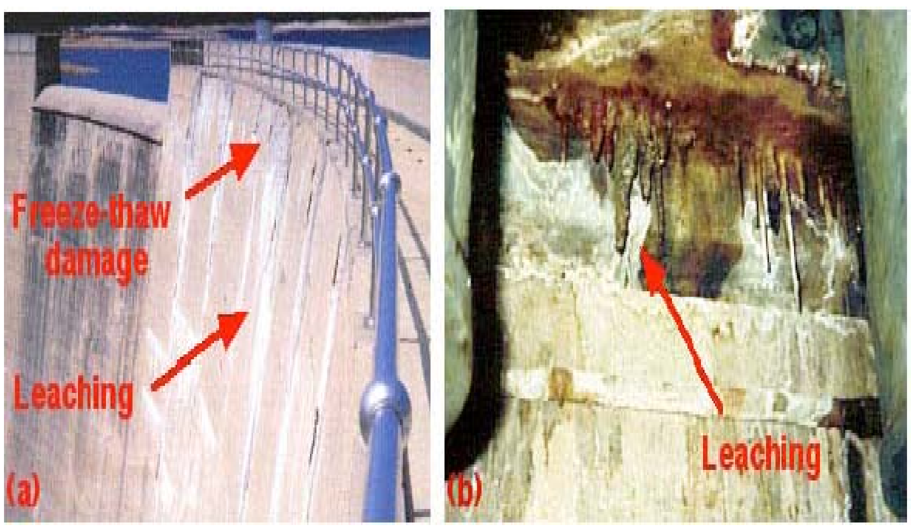
A: Softwater attack on calcium hydroxide and C-S-H present in hydrated portland cements;
B(I): acidic solution forming soluble calcium compounds such as calcium sulfate, calcium acetate, or calcium bicarbonate;
B(II): solutions of oxalic acid and its salts, forming calcium oxalate;
B(III): long-term seawater attack weakening the C-S-H by substitution of Mg^{++} for Ca^{++};
C(1): sulfate attack forming ettringite and gypsum;
C(2): alkali-aggregate attack;
C(3): corrosion of steel in concrete; and
C(4): hydration of crystalline MgO and CaO.

Efflorescence in Water Structure

Leaching Types in Concrete Hydraulic Structures

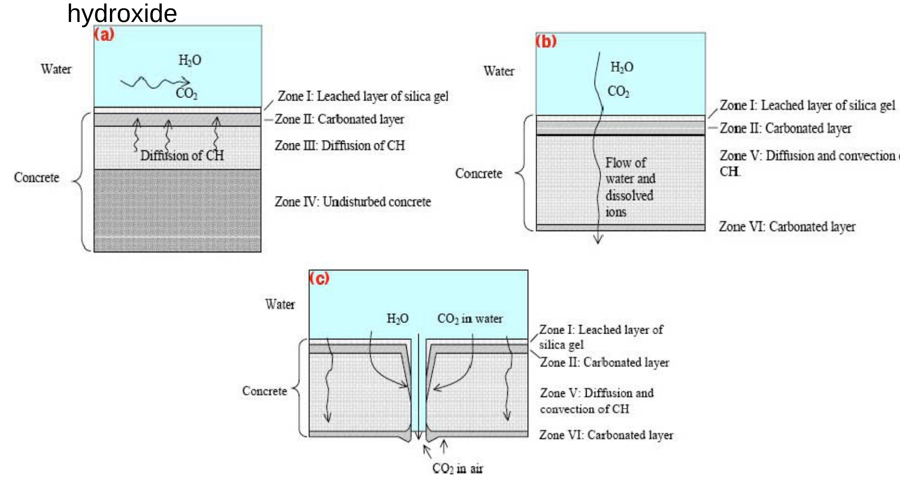


Leaching: (a) Dam with Freeze-thaw Damage and Leaching, (b) Nuclear Power Plant Tendon Gallery Leaching



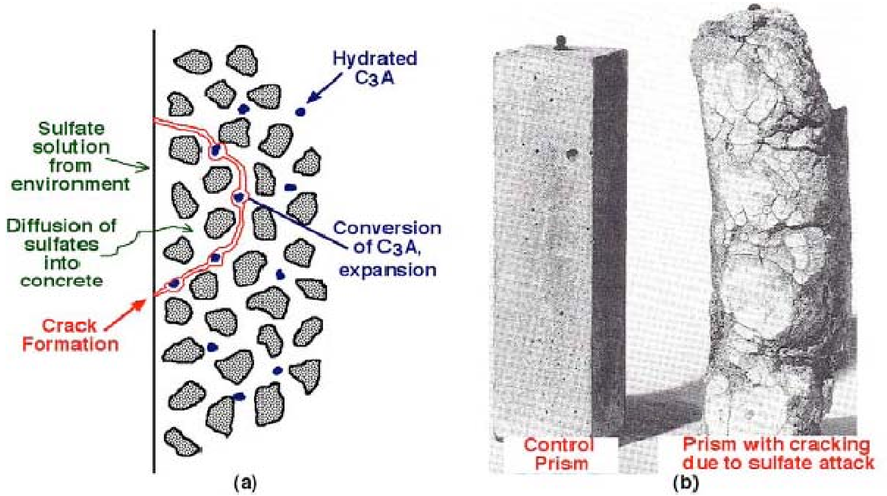
Conceptual Models for Concrete Leaching Mechanisms

(a) leaching from free surfaces, (b) homogeneous percolation through porous concrete, and(c) leaching from surfaces of cracks. CH = calcium hydroxide



Concrete Cracking due to Sulfate Attack

(a) mechanism, (b) example of concrete cracking due to sulfate attack



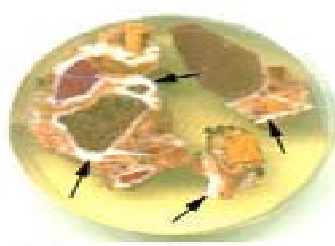
Building Code Requirements for Concrete Exposed to Sulfate-containing Solutions

Sulfate exposure	Water soluble sulfate (SO_4) in soil, % by weight	Sulfate (SO_4) in water, ppm	Cement type^	Maximum water-cementitious materials ratio, by wt., normal weight aggregate concrete**	Minimum f_c', normal weight aggregate concrete, psi (MPa)
Negligible	0.00-0.10	0-150	-	-	-
Moderate*	0.10-0.20	150-1500	II, IP(MS), P(MS), I(PM)(MS),I(SM)(MS)	0.50	4000 (27.6)
Severe	0.20-2.00	1500-10,000	V	0.45	4500 (31.0)
Very severe	>2.00	>10,000	V plus pozzolan***	0.45	4500 (31.0)

^See Reference 31; *Sea water; **A lower water-cementitious materials ratio or higher strength may be required for low permeability or for protection against corrosion of embedded items or freezing and thawing; ***Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

Thaumasite Sulfate Attack

(a) Subsurface concrete pier affected by thaumasite sulfate attack

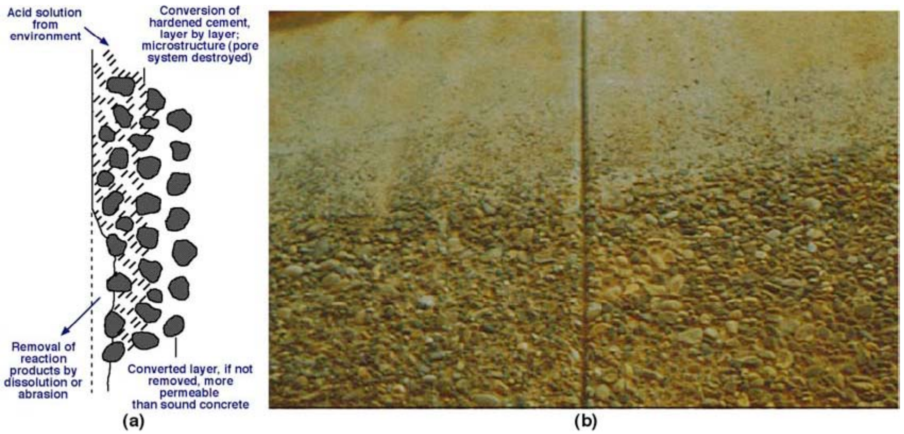


(b) Scanning electron micrograph showing thaumasite formation

Cracking damage in a concrete structure due to Delayed Ettringite Formation

Surface Loss due to Acid Attack

(a) mechanism, (b) example of acid attack on concrete wall

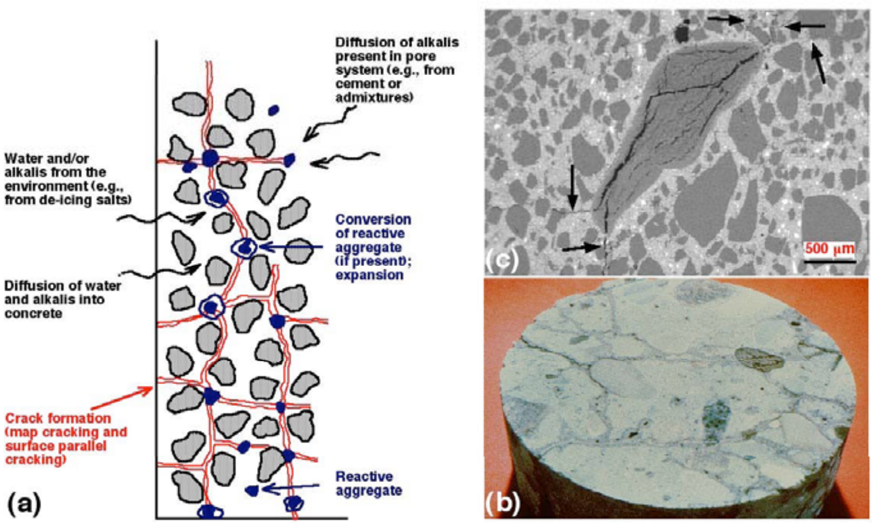


Reactivity of Various Materials with Concrete and Steel

Material	Effect on concrete	Effect on steel
Acetone	Liquid loss by penetration (may contain acetic acid and cause slow disintegration)	None
Acidic water (pH<6.5)	Disintegrates concrete slowly	May attack rebar and embedments
Boric acid	Negligible effect unless immersed	Severely corrosive to liner and reinforcing steel
Borated water (and boron)	Negligible effect unless immersed	Very corrosive at high concentration
Chlorine gas	Concrete (moist) slowly disintegrates	Highly corrosive
Demineralized water	Leaches	Slight
Deicing salt	Scaling of non-air entrained concrete	Highly corrosive
Diesel exhaust gas	May disintegrate moist concrete by action of carbonic, nitric, or sulfurous acid; minimal effect on hardened dry concrete	Minimal
Hydrochloric acid	Disintegrates concrete rapidly	Highly corrosive
Hydroxides	At low concentrations, slow disintegration; at high concentrations, greater disintegration	Unknown
Nitric acid	Disintegrates rapidly	Highly corrosive
Lubricating oil	Fatty oils, if present, slowly disintegrate concrete	Minimal
Sea water	Disintegrates concrete with inadequate sulfate resistance	Highly corrosive
Sodium hydroxide	Not harmful below 10% concentration; disintegrates at concentrations >20%	Minimal
Sodium pentaborate	Disintegrates at varying rates depending on concentration	Dependent on concentration
Sulfates	Disintegrates at varying rates with concentration (concretes with low sulfate resistance such as Type I)	Harmful at certain concentrations
Sulfuric acid	Disintegrates rapidly in concentrations between 10 and 80%	Very corrosive

Concrete Cracking due to Alkali-silica Reaction

(a) mechanism, (b) resulting gel that causes expansion and cracking, (c) polished section showing extensive internal cracks



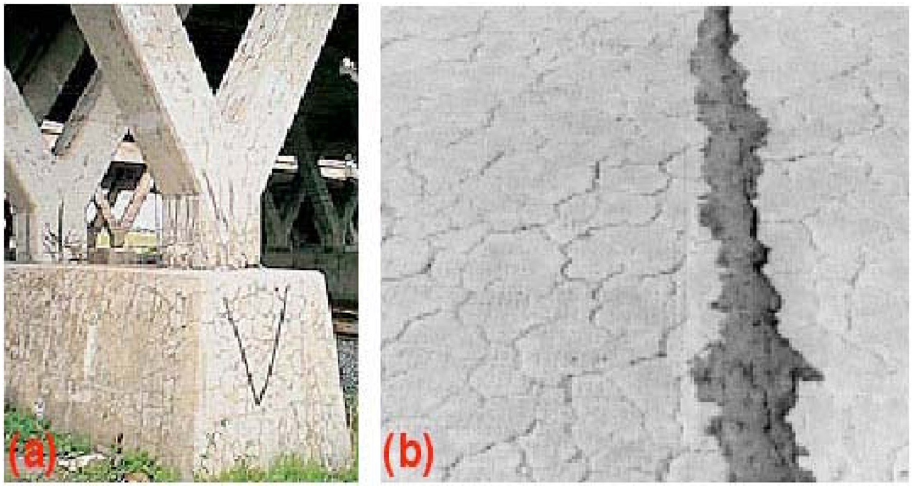
Some Potentially Harmful Reactive Minerals, Rock, and Synthetic Materials

Alkali-silica reactive substances*		Alkali-carbonate reactive substances**
Andesites	Opal	Calcitic dolomites
Argillites	Opaline shales	Dolomitic limestones
Certain siliceous limestones and dolomites	Phylites	Fine-grained dolomites
Chalcedonic cherts	Quartzites	
Chalcedony	Quartzoses	
Cherts	Rhyolitic	
Cristobalite	Schists	
Dacitic	Siliceous shales	
Glassy or cryptocrystalline volcanics	Strained quartz and certain other forms of quartz	
Granite gneiss	Synthetic and natural siliceous glass	
Graywackes	Tridymite	
Metagraywackes		

*Several of rocks listed (e.g., granite, gneiss, and certain quartz formations) react very slowly and may not show evidence of any harmful degree of reactivity until concrete age is >20 years.
**Only certain sources of these materials have shown reactivity.

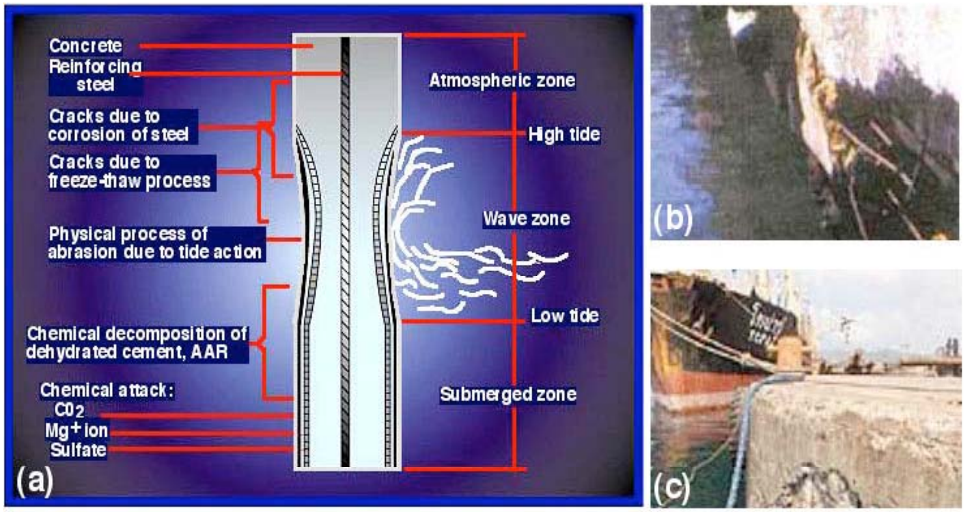
Examples of Concrete Cracking

(a) alkali-silica reaction in bridge pier, (b) alkali-carbonate reaction in sidewalk with exudation of joint material



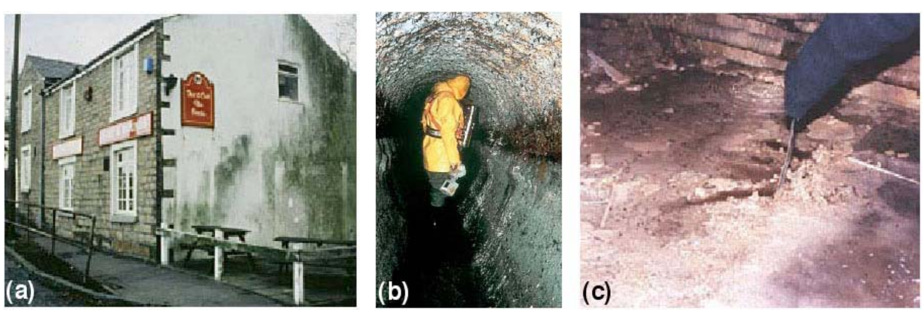
Sea Water Attack of Concrete

(a) mechanism, (b) and (c) examples of attack



Concrete Biological Attack

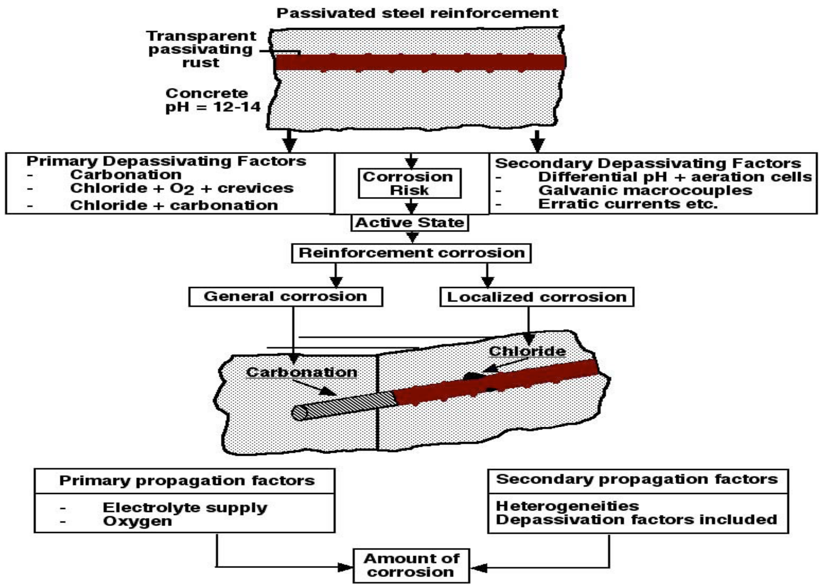
(a) algae growth on outside wall of house, (b) biogenic sulfuric acid attack in sewer system, (c) decaying concrete floor in flooded cellar



Corrosion in Reinforced Concrete

(a) sea water structure, (b) bridge structure

Factors Leading to Depassivation of Steel in Concrete



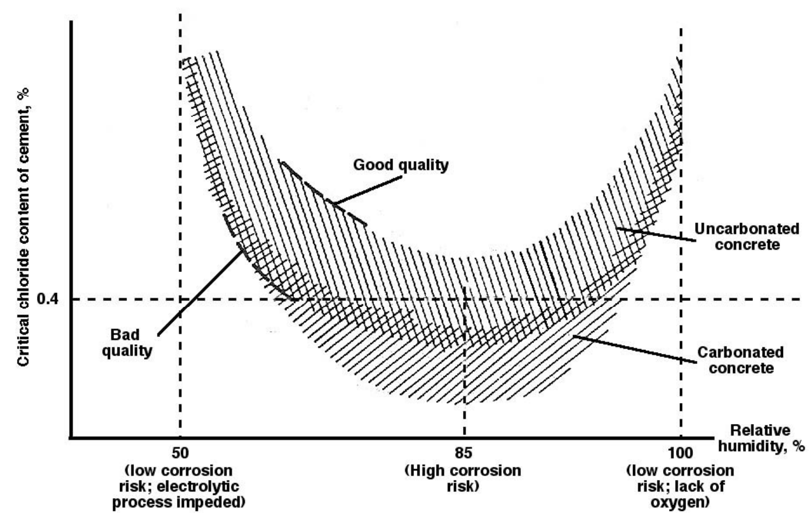
Expected Carbonation Depths for Different Strength Concretes and Storage Conditions

Concrete strength	Storage conditions	Carbonation depth (mm) at time t				
		t = 1 year	t = 2 years	t = 5 years	t = 10 years	t = 25 years
Low	Outdoors (moist)	6	9	13	19	30
	Indoors	10	14	22	32	50
Medium	Outdoors(moist)	2	3	4	6	10
	Indoors	5	7	11	16	25
High	Outdoors(moist)	1	1.5	2	3	5
	Indoors	2	3	4	6	10

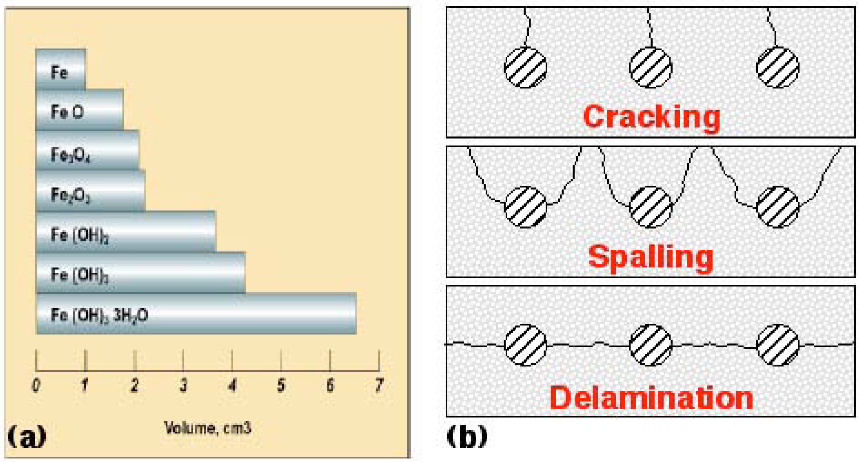
Expected times to Corrosion (in years) as a Function of w/c Ratio and Concrete Cover

Water/cement ratio	Concrete cover (mm)					
	5	10	15	20	25	30
0.45	19	75	100^+	100^+	100^+	100^+
0.50	6	25	50	99	100^+	100^+
0.55	3	12	27	49	76	100^+
0.60	1.8	7	16	29	45	65
0.65	1.5	6	13	23	36	52
0.70	1.2	5	11	19	30	43

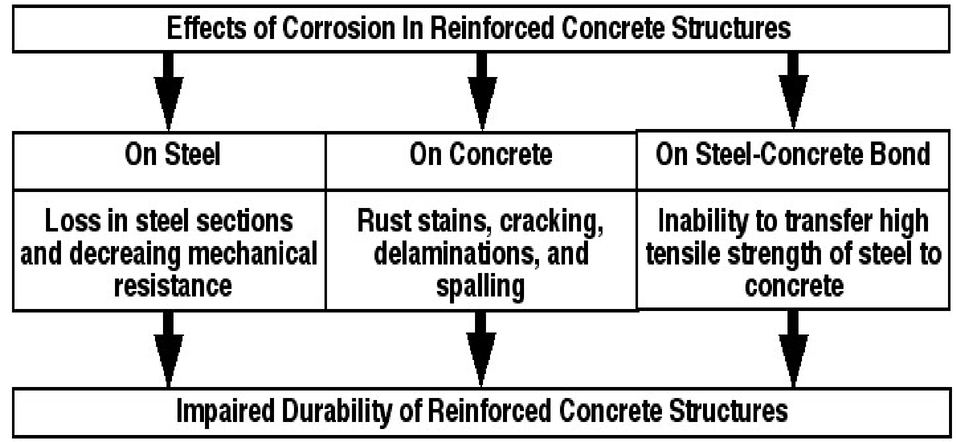
Variation of Critical Chloride Content with Environment



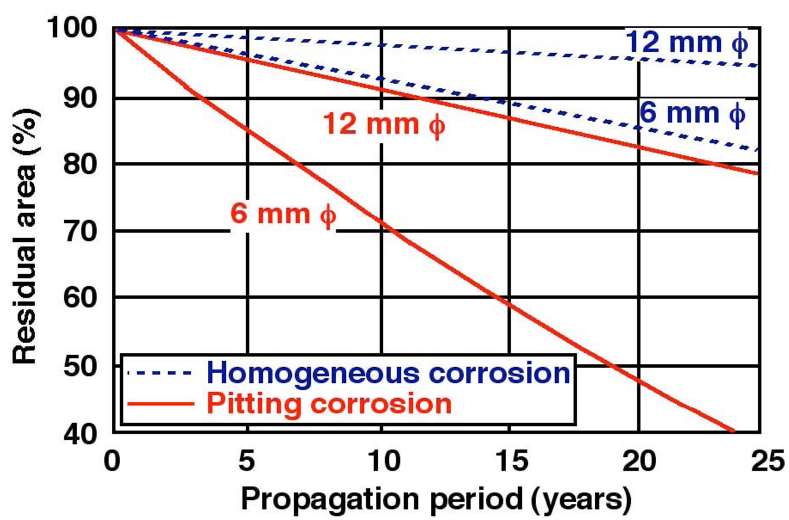
Oxidation States of Iron and Representations of Visible Forms of Corrosion



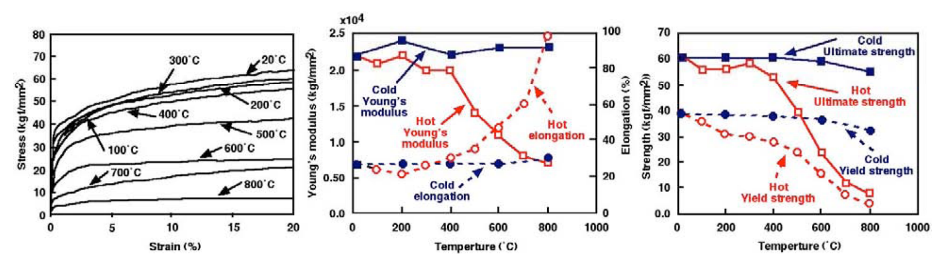
Effects of Corrosion on Reinforced Concrete Structures



Residual Steel Reinforcement Area as a Function of Type and Longevity of Corrosion



Effect of Temperature on a 3,500 kgf/cm² Minimum Specified Yield Strength Steel Bar



Irradiation

- Neutron irradiation produces changes in the mechanical properties of carbon steels (e.g., increased yield strength and rise in the ductile-to-brittle transition temperature)
- The changes result from the displacement of atoms from their normal sites by high-energy neutrons, causing the formation of interstitials and vacancies

Irradiation (Cont'd)

- A threshold level of neutron fluence of 1×10^{18} neutrons per square centimeter has been cited for alteration of reinforcing steel mechanical properties
- Fluence levels of this magnitude are not likely to be experienced by the safety-related concrete structures in nuclear power plants
- Except possibly in the concrete primary biological shield wall over an extended operating period

Durability of Post-Tensioning Systems in NPP's

- Potential causes of degradation of the post-tensioning systems include corrosion, elevated temperature, irradiation, fatigue, and stress relaxation/end effects
- Of these, corrosion and loss of prestressing force are the most pertinent consequences
- The post-tensioning systems used in nuclear power plants are designed to have the ability to be retensioned and replaced (nongrouted systems)

Post-Tensioning Systems in NPP's - Elevated Temperature

- Thermal exposures up to ~200°C do not significantly reduce (< 10%) the tensile strength of prestressing wires or strands
- Elevated-temperature exposures also affect the relaxation and creep properties of prestressing tendons
- Creep (length change under constant stress) of stress-relieved wire is negligible up to 50% its tensile strength

Post-Tensioning Systems in NPP's - Elevated Temperature (Cont'd)

- Creep effect in steel varies with its chemical composition as well as with mechanical and thermal treatment applied during the manufacturing process
- Temperature levels experienced by prestressing tendons for example in light-water reactor facilities are below 200°C, the possibility for thermal damage to the prestressing tendons under normal operating conditions is low
- Elevated temperature may increase the creep of concrete in the vicinity of tendon anchorage zones which can lead to loss of prestressing force

Post-Tensioning Systems in NPP's - Irradiation

- Irradiation of post-tensioning system steel affects its mechanical properties because atoms are displaced from their normal sites by high-energy neutrons to form interstitials and vacancies
- These defects can propagate or combine and effectively both strengthen the steel and reduce its ductility; or, at higher temperatures, they can recombine and annihilate each other and, for a given neutron dose, reduce the irradiation damage

Post-Tensioning Systems in NPP's – Irradiation (Cont'd)

- 2.5-mm-diam prestressing wires were stressed to 70% of their tensile strength and irradiated to a total dose of 4 x 1016 neutrons per square centimeter (flux of 2 x 1010 neutrons·cm2·per s) showed that for exposures up to this level, the relaxation behavior of irradiated and unirradiated materials was similar
- These flux levels are higher than the level likely to be experienced in a light-water reactor containment vessel

Degradation Factors for Safety-related NPP Structures: Concrete

Concrete				
Aging Stressors/Service Conditions	Aging Mechanism	Aging Effect	Potential Degradation Sites	Remarks (e.g., Significance)
Percolation of fluid through concrete due to moisture gradient	Leaching and efflorescence	Increased porosity and permeability; lowers strength	Near cracks; areas of high moisture percolation	Makes concrete more vulnerable to hostile environments; may indicate other changes to cement paste; unlikely to be an issue for high quality, low permeability concretes
Exposure to alkali and magnesium sulfates present in soils, sea water, or ground water	Sulfate attack	Expansion and irregular cracking	Subgrade structures and foundations	Sulfate-resisting cements or partial replacement of cements used to minimize occurrence
Exposure to aggressive acids and bases	Conversion of hardened cement to soluble material that can be leached	Increased porosity and permeability	Local areas subject to chemical spills; adjacent to pipework carrying aggressive fluids	Acid rain not an issue
Combination of reactive aggregate, high moisture levels, and alkalis	Alkali-aggregate reactions leading to swelling	Cracking; gel exudation; aggregate pop-out	Areas where moisture levels are high and improper materials utilized	Eliminate potentially reactive materials; use low alkali-content cements or partial cement replacement
Cyclic loads/vibration	Fatigue	Cracking; strength loss	Equipment/piping supports	Localized damage; fatigue failure of concrete structures unusual

Degradation Factors for Safety-related NPP Structures: Concrete (Cont'd)

Concrete (cont.)				
Aging Stressors/Service Conditions	Aging Mechanism	Aging Effect	Potential Degradation sites	Remarks (e.g., Significance)
Exposure to flowing gas or liquid carrying particulates and abrasive components	Abrasion; erosion; cavitation	Section loss; loss cover to expose rebar to corrosion	Cooling water intake and discharge structures	Unlikely to be an issue for containment structures; intake structures at most risk
Exposure to thermal cycles at relatively low temperatures	Freezing and thawing	Cracking; spalling	External surfaces where geometry supports moisture accumulation	Air-entrainment utilized to minimize potential occurrence
Thermal exposure/thermal cycling	Moisture content changes and material incompatibility due to different thermal expansion values	Cracking; spalling; reduced modulus of elasticity	Near hot process and steam piping	Generally an issue for hot spot locations; can increase concrete creep that can increase prestressing force loss
Irradiation	Aggregate expansion; hydrolysis	Cracking; loss of mechanical properties	Structures proximate to reactor vessel	Containment irradiation levels likely to be below threshold levels to cause degradation (e.g., $<10^{19}$ neutrons/cm^2 or $<10^{10}$ rads dose)
Consolidation or movement of soil on which structure founded	Differential settlement	Equipment alignment; cracking	Compacted structures on independent foundations	Allowance made in design; soil sites generally include settlement monitoring instrumentation
Exposure to water containing dissolved salts (e.g. sea water)	Salt crystallization	Cracking and scaling	Surfaces subject to salt spray; intake structures; foundations	Minimized through use of low permeability concretes, sealers, and barriers

Degradation Factors for Safety-related NPP Structures: Reinforcing Steel

Mild Steel Reinforcement				
Aging Stressors/Service Conditions	Aging Mechanism	Aging Effect	Potential Degradation sites	Remarks (e.g., Significance)
Depassivation of steel due to carbonation or presence of chlorides	Composition or corrosion cells leading to corrosion	Concrete cracking and spalling; loss of reinforcement crosss-section	Outer layer of steel reinforcement in all structures where cracks or local defects (e.g., joints) are present	Prominent potential form of degradation; leads to reduction of load-carrying capacity
Elevated temperature	Microcrystalline changes	Reduction of yield strength and modulus of elasticity	Near hot process and steam piping	Of significance only where temperatures exceed ~200°C
Irradiation	Microstructural transformation	Increased yield strength; reduced ductility	Structures proximate to reactor vessel	Irradiation levels likely to be below threshold levels to cause degradation
Cyclic loading	Fatigue	Loss of bond to concrete; failure of steel under extreme conditions	Equipment/piping supports	Localized damage; fatigue failure of concrete structures unusual

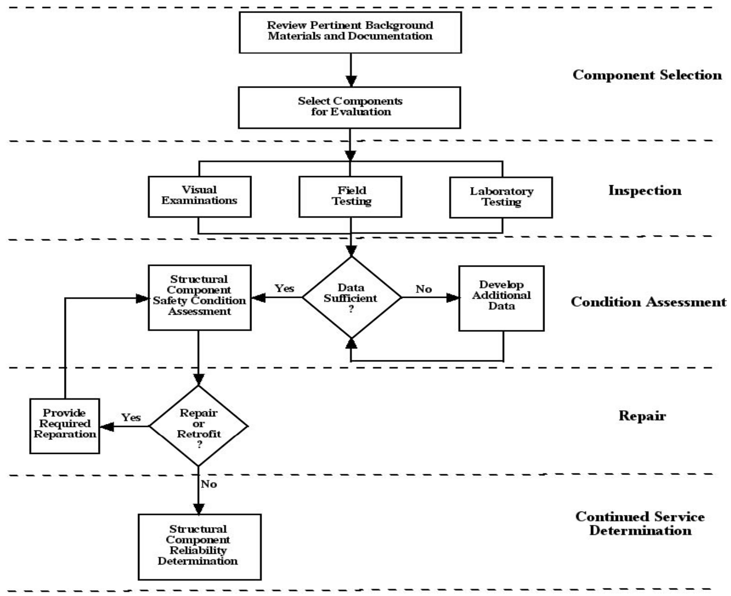
Degradation Factors for Safety-related NPP Structures: Prestressing Steel

Prestressing Systems				
Aging Stressors/Service Conditions	Aging Mechanism	Aging Effect	Potential Degradation sites	Remarks (e.g., Significance)
Localized pitting, general corrosion, stress corrosion, or hydrogen embrittlement	Corrosion due to specific environmental exposure (e.g., electrochemical, hydrogen, or microbiological)	Loss of cross-section and reduced ductility	Tendon and anchorage hardware of prestressed concrete containments	Potential degradation mechanism due to lower tolerance for corrosion than mild steel reinforcement
Elevated temperature	Microcrystalline changes	Reduction of strength; increased relaxation and creep	Near hot process and steam piping	Thermal exposure not likely to reach levels that can produce aging effects in prestressing
Irradiation	Microstructural transformation	Increased strength; reduced ductility	Structure proximate to reactor vessel	Containment irradiation levels likely to be below threshold levels to cause degradation
Cyclic loading due to diurnal or operating effects	Fatigue	Failure of prestressing under extreme conditions	Tendon and anchorage hardware of prestressed concrete containments	Not likely as cyclic loadings are generally small in number and magnitude
Long-term loading	Stress relaxation; creep and shrinkage of concrete	Loss of prestressing force	Prestressed concrete containments	Larger than anticipated loss of prestressing forces

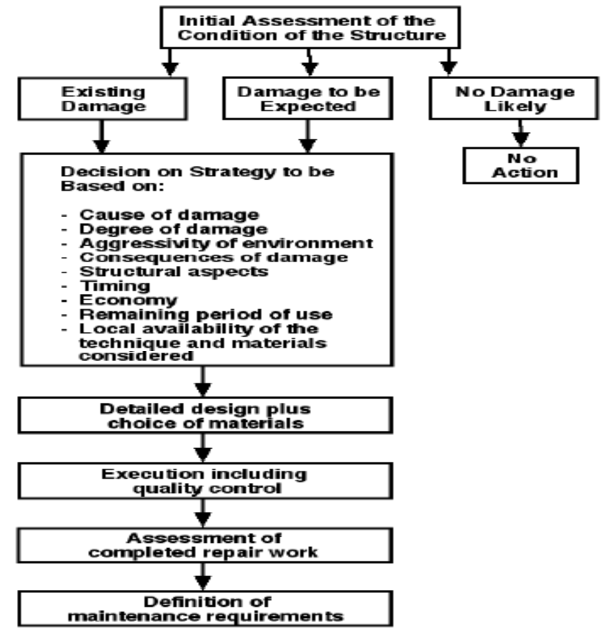
Degradation Factors for Safety-related NPP Structures: Liner Steel

Containment Liners				
Aging Stressors/Service Conditions	Aging Mechanism	Aging Effect	Potential Degradation sites	Remarks (e.g., Significance)
Electrochemical reaction with environment (metallic liners)	Composition or concentration cells leading to general or pitting corrosion	Loss of cross-section; reduced leaktightness	Areas of moisture storage/accumulation, exposure to chemical spills, or borated water	Corrosion has been noted in several containments near where the liner becomes embedded in the concrete
Elevated temperature (metallic liners)	Microcrystalline changes	Reduction of strength; increased ductility	Near hot process and steam piping	Thermal exposure not likely to reach levels that can produce aging effects in metal liners
Irradiation (metallic and nonmetallic liners)	Microstructural transformation (metallic); increased cross-linking (nonmetallic)	Increased strength; reduced ductility	Structures proximate to reactor vessel	Containment irradiation levels likely to be below threshold levels to cause degradation
Cyclic loading due to diurnal or operating effects (metallic and nonmetallic liners)	Fatigue	Cracking; reduced leaktightness	Inside surfaces of concrete containment building	Not likely as cyclic loadings are generally small in number and magnitude
Localized effects (nonmetallic liners)	Impact loadings; stress concentrations; physical and chemical changes of concrete	Cracking; reduced leaktightness	Inside surfaces of concrete containment building	Potential problem in high traffic areas

Evaluation Methodology for Nuclear Power Plant Concrete Structures



Steps to be taken in a Repair Process



Condition Survey Results for Various NPP Concrete Structures

Local Degradation Mechanisms	Plant									
	A	B	C	D	E	F	G	H	I	J
Concrete										
Chemical Attack	b,c	c	b	c	c	c	c	c		
Efflorescence and Leaching		b,c,d	b,c		b,d	b,d	d	b,d,f	a,b, c,d	b,f
Alkali-Aggregate Reaction										a
Freeze/Thaw Cycling	d			a,d			d	f		
Thermal Exposure			c	c	c			c		
Abrasion/Erosion			c				c,d			
Fatigue/Vibration		c								
Cracking	c,d, f,g	a,b, c,d	c,d,g	c,d	a,b, c,d,g	b,e, d,f,g	b,f	b,c, d,f	b,c, d,f	b,f,g
Conventional Reinforcing										
Corrosion	b,d	b,d	b		b,d	b		b,d	b	b,f
Prestressing System										
Corrosion	n/a	e[1]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Block Walls										
Excessive Cracking		c			d		c	a		
Structural Steel and Liners										
Corrosion	d	e	c,d				c,e		e	g
Soil/Structure Issues										
Differential Settlement	c									
Soil Erosion (Scour)	d									

Key:

a – External Structure (Power Block)
b – Subgrade Structure (Power Block)
c – Internal Structure (Power Block)
d – Water Control Structure (Intake, Discharge, Etc.)
e – Containment Vessel
f – Other Site Structure
g – Equipment Supports

Notes:

Sampling of Concrete Problems in NPP's

Plant	Problem Area	Remedial Measure Implemented
Wolf Creek	Voids up to 1.8-m wide and through the wall thickness occurred under equipment and personnel hatches in reactor containment building.	Voids and quality assurance program updated
Callaway 1	Nineteen randomly located areas of honeycomb extending to bottom layers of rebar of reactor building basemat in annular area of tendon access area, cause was use of low-slump concrete in congested area.	Defective material removed from 33 of 172 tendon trumplates and voids repaired
South Texas 1,2	Crack in fuel handling wall due to shrinkage.	No structural significance.
	Rebars improperly located in buttress region of Unit 1 containment.	Detailed analysis of as-built condition determined that no safety hazard to public occurred.
	Voids occurred behind liner plate of Unit 1 reactor containment building exterior wall because of planning deficiencies, long pour times, and several pump breakdowns.	Sounding and fiber optic exam through holes drilled in liner plate were used to determine extent, areas were repaired by grout injection.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Palo Verde 2/3	Honeycombing around vertical tendon sheaths blockouts with most voids at buttress/shell interface above last dome hoop tendon.	Condition was localized so area was repaired with grout.
Farley 1	Cracks detected in six containment tendon anchors during refueling outage.	Anchorheads replaced.
Farley 2	Three anchorheads on bottom ends of vertical tendons failed and 18 cracked with several tendon wires fractured, occurred about 8 years after tensioning, cause was attributed to hydrogen stress cracking.	All tendons and anchorheads from same heat were inspected with no further problems noted, 20 tendons replaced.
La Salle 1,2	Low concrete strength at 90 days.	In-place strength determined acceptable from cores, cement contents for future pours increased, strength low in only a small percent of pours so did not threaten structural integrity.
Brunswick 1,2	Voids occurred behind liner during construction of suppression chamber.	Grout injected into voids through holes drilled in liner, some grout in Unit 1 did not harden but was left in place to provide limited resistance.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Summer 1	Voids located behind liner plate of reactor containment building wall, windows cut in liner revealed voids up to 22-cm deep, cause was use of low-slump concrete with insufficient compaction. Excessive heat from welding caused liner attached to concrete on inside face of concrete primary shield wall cavity to buckle and fail stud anchors.	Voids chipped, cleaned to sound concrete, and filled with nonshrink grout, liner repaired and all welds leak tested. Liner and concrete to depth of 15 cm removed, new liner plate welded in place and void filled with high-strength grout.
Sequoyah 2	Concrete in outer 2.5 to 5 cm of Unit 2 shield building was under strength because of exposure to freezing temperatures at early concrete age	Determined not to affect shield building capability.
Beaver Valley 1	Void ~0.9-m long and 0.9-m deep in outer containment wall in concrete ring around equipment hatch.	No threat to structural integrity, void repaired with dry pack.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
North Anna	Cracks >1.6-mm wide in containment floor slab occurred around neutron shield tank anchor bolts following pressure testing of seal chambers due to inadvertent pressurization, cores showed cracks extended into concrete vertically. Cracked basemat	Cracks no structural threat, routed and sealed to prevent fluid penetration.
San Onofre 3	Tendon liftoff forces in excess of maximum value listed in plant technical specifications, cause was lower relaxation rate than expected.	No threat to structural integrity.
Zion 1	Excessive pitting in some tendon wires in Unit 2 during installation, cause was outdoor storage in conjunction with high precipitation and inadequate protection.	Defective tendons replaced.
Crystal River 3	28-day concrete strength was low due to failure of cement to meet specifications. Dome delaminated over ~32-m diameter area due to low concrete properties and no radial reinforcement to accommodate radial tension due to post-tensioning.	Design review revealed strength attained to be adequate, cement inspection increased. Upper delaminated section removed, additional rebars provided, concrete replaced, dome retensioned, and structural integrity test conducted.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Three Mile Is. 1	Cracking <0.02-cm-wide in containment building ring girder and around tendon bearing plates.	Cracks repaired and monitored during subsequent surveillance.
Salem 2	Incomplete concrete pour near equipment hatch due to wrong concrete mix.	Voids repaired with high-strength nonshrink grout.
Calvert Cliffs 1,2	11 of top bearing plates at Units 1 & 2 depressed into concrete because of voids, 190 plates of each containment exhibited voids upon further inspection. Broken tendon wires.	Tendons detensioned, plates grouted and tendons retensioned. Several tendons replaced
Ginna	Excessive loss of prestressing force.	Tendons retensioned with no recurrence noted in subsequent inspections.
Indian Point 2	Concrete temperature local to hot penetrtion >66°C but <93°C.	No safety problem due to relatively short periods of exposure.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Grand Gulf 1,2	7 of 19 cylinders for control building base slab concrete did not meet 28-day design strength.	90-day values were acceptable.
Turkey Point 3	Voids below containment wall and near reactor pit.	Repaired with high-strength grout.
	Dome delamination.	Delaminated concrete removed, additional rebars provided, concrete replaced.
	Grease leakage from 110 of 832 tendons at casing.	Tendon casing repaired.
	Concrete spalling of horizontal joint at containment ring girder with cavities 3 to 5-cm wide by 7 to 10 – cm deep.	No threat to structural integrity, repaired by drypacking.
	Small void under equipment hatch barrel.	No threat to structural integrity, repaired by grouting.
Oconee	Spalled concrete beneath anchor bearing plate.	Repair concrete spall.
	Tendon grease leakage.	Monitor grease quantity.
	Water infiltrtion.	Tendon galleries purged periodically to remove excess water.

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Millstone 3	Cement erosion of porous concrete subfoundation.	Surveillance of sumps for cement erosion, settlement monitoring.
Brunswick 1,2	Corrosion of drywell liner at junction of base floor and liner.	Cleaned joints, repaired pitted liner plate, resealed gap.
Waterford	Cracked basemat.	N.A.*
Diablo Canyon	Rebar corrosion and concrete cracking	N.A.
San Onofre 1	Exterior concrete walls of intake structure and concrete beams supporting service water pumps were cracked extensively.	N.A.
Pilgrim	Rebar corrosion and concrete cracking.	N.A.
Trojan	Concrete cracking and leaching in bioshield wall, auxiliary building, control building, fuel building, and service water pump room.	N.A.
Point Beach	General concrete cracking in pumphouse walls, auxiliary building, and emergency diesel generator building.	N.A.
	Ground water seepage in undrground portions of safety-related structures.	

Sampling of Concrete Problems in NPP' (Cont'd)

Plant	Problem Area	Remedial Measure Implemented
Robinson 2	Cracking and spalling of concrete (in limited areas) in walls and ceilings of the reactor auxiliary building, emergency diesel generator room, and intake structure.	N.A.
	Liner corrosion	
Beaver Valley 1	Cracks, water infiltration, and calcium deposits in the ceilings and walls of the service building, safeguard structure, and steam generator drain tank.	N.A.
	Liner corrosion.	
Cooper	Cracking and spalling of concrete in service water booster pump room and in exterior walls of the diesel generator building and reactor building	N.A.
Fort Saint Vrain	Tendon wire failures due to corrosion caused by microbiological attack of corrosion inhibitor.	Analysis revealed sufficient tendons intact to provide structural integrity, surveillance increased and tendons inerted by nitrogen blanket.

* N.A.

5400. Concrete Containments, Modular Construction & Mass Concrete

5510
- 5510 - Durability of NPP Concrete Structures

5520
- 5520 – NDE Methods for Concrete

5530
- 5530 - Masonry Basics

5520 – NDE Methods for Concrete

- Various NDE methods for concrete structures have been developed ; they include
  - Pulse Velocity Method
  - Impact Echo Method
  - Rebound Hammer
  - Maturity Method
  - Radioactive Methods
  - Infrared Thermography
  - Ground Penetrating Radar

Nondestructive Evaluation of Concrete Structures

- Brief descriptions of the following methods follows
  - Pulse Velocity Method
  - Impact Echo Method
  - Rebound Hammer
  - Ground Penetrating Radar

Pulse Velocity Method

- The ultrasonic pulse velocity method is a stress wave propagation method that involves measuring the travel time over a known path length
- The pulses are introduced using a piezoelectric transducer
- A similar transducer acts as a receiver to monitor the surface vibration caused by the arrival of the pulse
- A timing circuit is used to measure the time it takes for the pulse to travel from the transmitting to the receiving transducer

Pulse Velocity Method (Cont'd)

- Lower density of the concrete or cracks increases the travel time and results in lower pulse velocity
- By conducting tests at various points on a structure, locations with lower quality concrete can be identified
- The method was approved as a tentative ASTM method in 1967 (ASTM C 597-67T)
- In Europe, the International Union of Testing and Research Laboratories for Material and Structures (RILEM) published a a draft recommendation in 1969

Ultrasonic Inspection

- Ultrasonic inspection of concrete has traditionally been conducted in the time domain
- The pulse velocity test (ASTM C597) has traditionally been used for the condition evaluation of concrete
- Signal processing needs to be in the frequency domain to incorporate the inhomogeneous nature of concrete

Ultrasonic Inspection (Cont'd)

- Many avenues of NDT have been explored
- Generally Ultrasonic methods hold the greatest potential
- To identify a practical, cost effective and reliable method, a set of four constraints were developed:
  - Non-destructive
  - Local
  - One sided
  - Inexpensive
- Currently no single test satisfies all criteria with acceptable reliability
- The Impact Echo method was identified as the best candidate

Ultrasonic Inspection (Cont'd)

- Pulse Velocity has been the most popular
- Governed by ASTM C 597
- Uses Linear Ultrasound to detect internal cracking
- Requires accessibility to 2 sides
- Many parametric studies have found this method unsatisfactory

Ultrasonic Inspection (Cont'd)
Spectral Analysis of Surface Waves (SASW)

- Based on the propagation of mechanically induced Rayleigh waves
- Provides layer thickness and stiffness determination
- Only one sided access required
- Primarily used for strength determination
- Rebar has significant influence on data

Ultrasonic Inspection (Cont'd)
Non-Linear Ultrasonic Testing (NLUT)

- Increased sensitivity
- Applicable to inhomogeneous materials
- Monitors P-wave velocity, amplitude attenuation and frequency shift
- Utilizes a pulser-receiver or a pitch-catch system

The Impact Echo Method

- Uses impact generated stress waves that propagate through concrete and are reflected by both the material's external surfaces and internal flaws
- The typical system consists of transducers, impactor set, transducer spacer, PC software and battery charger

The Impact Echo Method (Cont'd)
Portable IE System

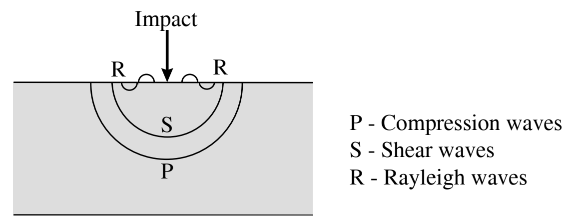
The Impact Echo Method (Cont'd)
Portable IE System

The Impact Echo Method (Cont'd)

- The Impact echo method uses impact-generated stress (sound) waves
- Waves are reflected by internal flaws and external surfaces
- Applications include determining thickness and flaws
- The method requires an experienced operator
- Artificial intelligence technique (neural network) may be used to train a computer program that may then be used to classify the results of tests on structures

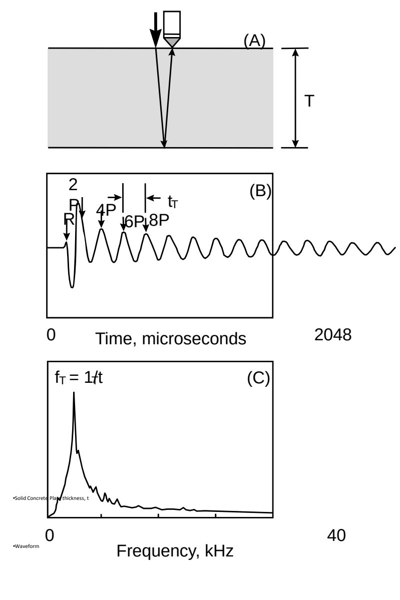
The Impact Echo Method (Cont'd)

- The impact-echo method is a technique for flaw detection in concrete based on stress wave propagation
- Compression (P), Shear (S) and surface/Rayleigh (R) waves are generated



- Reflected waves are received by a transducer
- Displacement waveform is dominated by P-wave arrival

The Impact Echo Method (Cont'd)



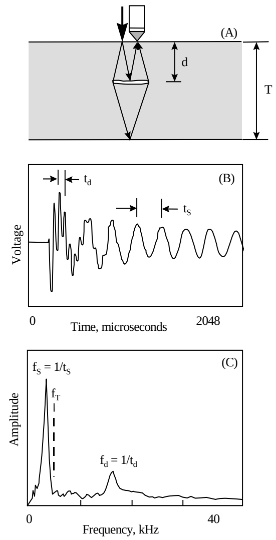
The Impact Echo Method (Cont'd)

- The waveform is clearly periodic
- The related set of equations are:

$t = 2T / C_p$ or $T = C_p / 2f_p$ or $f_p = C_p / 2T$

where: C_p is the P- wave speed
f_p is the frequency of reflected waves
t is the period of reflected waves
T is the thickness of the medium (concrete plate)

The Impact Echo Method (Cont'd)



•Flaw Detection

•Waveform

•Spectrum

The Impact Echo Method (Cont'd) Distributed Damage

- Distributed damage manifests as map cracking or micro-cracking
- Micro-cracks first develop during curing, due to shrinkage and the resulting stresses
- Initial micro-cracks form at boundaries of aggregate and paste, in what is called the interfacial transition zone (ITZ)
- The ITZ is weakest due to disparities between material properties such as elastic modulus, density and moisture content
- Micro-cracks can combine in the form of strain localization and coalesce to form a major crack

The Impact Echo Method (Cont'd) Attenuation of Stress Waves

- The result of scattering and absorption of wave energy
- In concrete – reflection, refraction, diffraction and mode conversion occurs at the ITZ
- Attenuation increases with damage

Rebound Hammer

- When concrete is struck by a hammer, the degree of rebound is an indicator of hardness
- Schmidt standardized the hammer blow by developing a spring-loaded hammer and devised a method to measure the rebound
- The essential parts include the outer body, the hammer, the plunger, the spring, and the slide indicator

Rebound Hammer (cont'd)
Manual Model

Rebound Hammer (cont'd)
Digital Model

Rebound Hammer (cont'd)

- The relationship between concrete strength and the rebound number is not unique
- For best accuracy a correlation should be developed using the same concrete and forming materials
- Without such a correlation the rebound hammer is useful only for detecting gross changes in concrete quality throughout a structure

Rebound Hammer (cont'd)

- Because of uncertainties, its incorporation into standards was delayed
  - –The British Standards Institution included the method in 1971
  - –A tentative method was adopted by ASTM in 1975 (ASTM C 805 75-T)
  - –A draft recommendation was published by REILEM in 1977
- The method is recognized as a useful too for performing quick surveys to assess uniformity of concrete, but is not generally recommended where accurate strength estimates are needed

Ground Penetrating Radar

- Radar (acronym for RAdio Detection And Ranging)
- In civil engineering applications, inspection depths are relatively shallow and only short pulses of electromagnetic waves (microwaves) are used
- For this reason, the technique is often called short-pulse radar, impulse radar, or ground penetrating radar (GPR)
- Can be used to locate reinforcing bars and post-tensioning tendons

Ground Penetrating Radar (Cont'd)

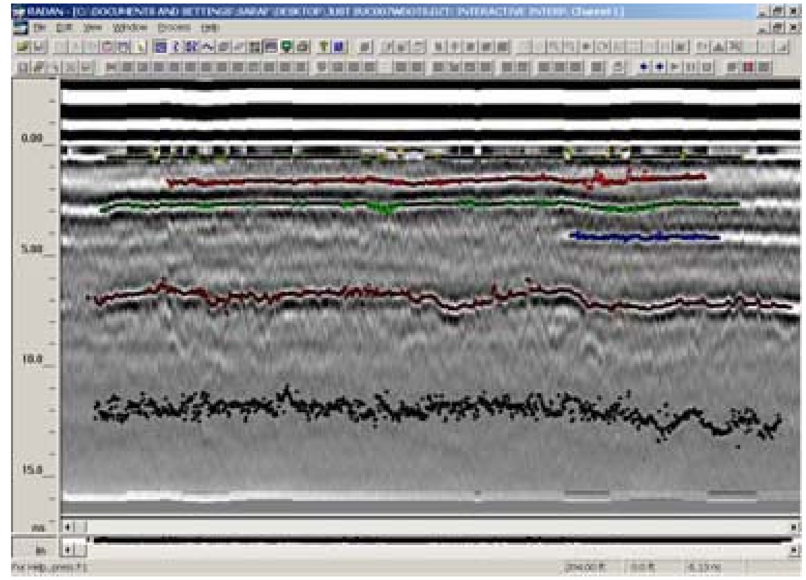
- Can be used to estimate the thickness of slab, wall or pavement
- Can be used to locate and identify concrete anomalies and deterioration (i.e. moisture variations, delamination, honeycombing or fractures)
- Highly sensitive to subsurface moisture and embedded metal
- Can detect both metallic and non-metallic objects

Ground Penetrating Radar (Cont'd)

Ground Penetrating Radar (Cont'd)

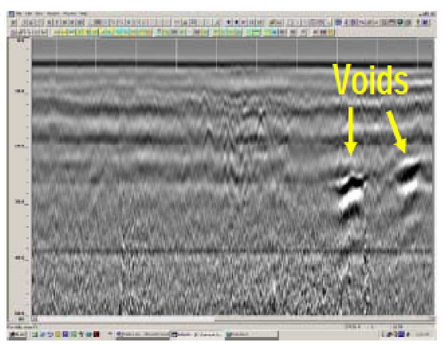
Ground Penetrating Radar (Cont'd)

Ground Penetrating Radar (Cont'd)



Ground Penetrating Radar (Cont'd)

- Determination of Pavement Layer Thickness
- Determination of Voids/Density in Asphaltic Mixtures
- 3D Imaging of Sub-structural Defects and Voids
- 3D Imaging of Joint Deterioration Under Pavement
- Determination of high moisture accumulation
- A Non-Destructive Tool



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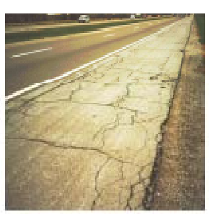
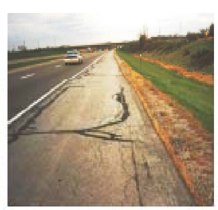
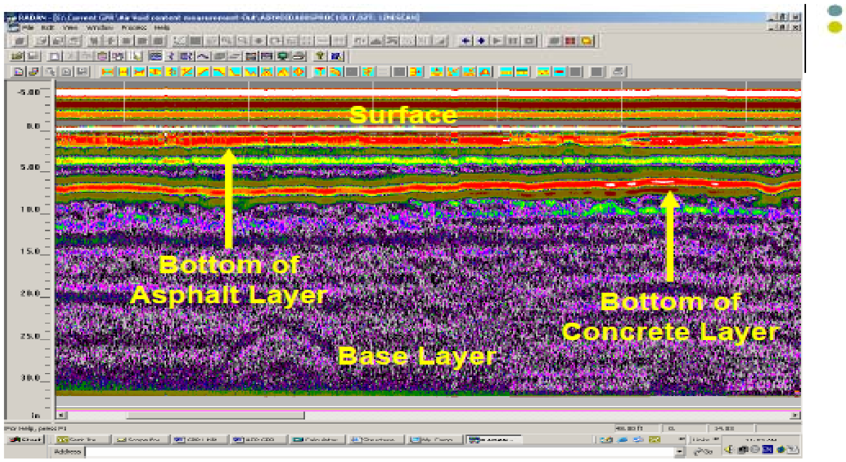




GPR - Advantages

- No Traffic Interruption
- Concrete & Asphaltic Pavements
- Determine Pavement Thickness
- Asphaltic Pavement Density & Void Determination
- Joint Conditions
- Subgrade Support Condition

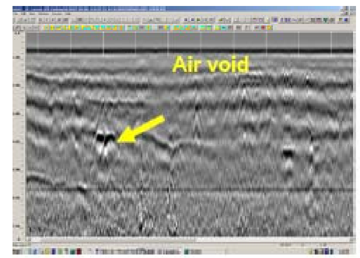
GPR – Typical Scan

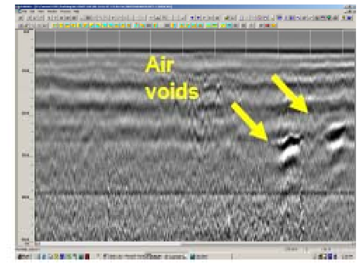


A typical GPR Scan showing layers of pavement and air voids between top layer of asphalt and the asphalt layer below it

GPR – Data Collection


400 MHz and 1500 MHz antennas in use during data collection from the parking lot area of ODOT District 6





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5400. Concrete Containments, Modular Construction & Mass Concrete

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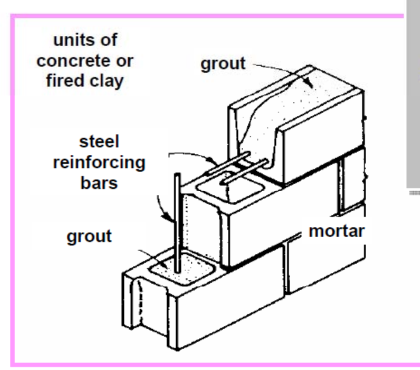
INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics

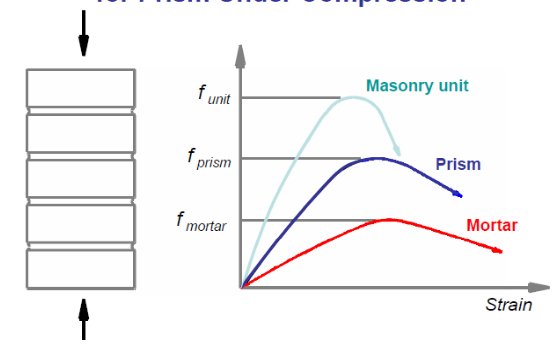


... typical materials in reinforced masonry

INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

Masonry Behavior Stress-Strain Curve for Prism Under Compression

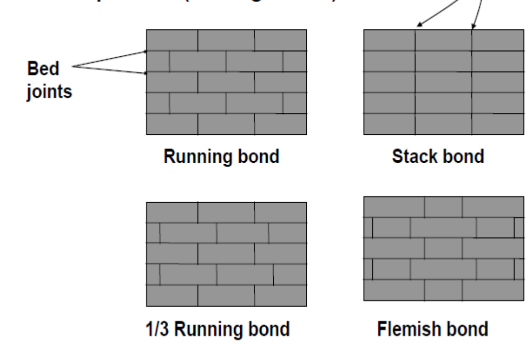


INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

Basic Terms

- **Bond patterns (looking at wall):**

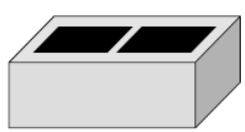


INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

Masonry Units

- **Concrete masonry units (CMU):**
  - **Specified by ASTM C 90**
  - **Minimum specified compressive strength (net area) of 1900 psi (average)**
  - **Net area is about 55% of gross area**
  - **Nominal versus specified versus actual dimensions**
  - **Type I and Type II designations no longer exist**

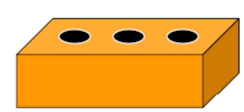


INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

Masonry Units

- **Clay masonry units:**
  - **Specified by ASTM C 62 or C 216**
  - **Usually solid, with small core holes for manufacturing purposes**
  - **If cores occupy ≤ 25% of net area, units can be considered 100% solid**



INTRODUCTION TO MASONRY STRUCTURES

Masonry Mortar

- Mortar for unit masonry is specified by ASTM C 270
- Three cementitious systems
  - Portland cement – lime mortar
  - Masonry cement mortar
  - Mortar cement mortar

INTRODUCTION TO MASONRY STRUCTURES

Masonry Mortar

- Within each cementitious system, mortar is specified by type (M a S o N w O r K):
  - Going from Type K to Type M, mortar has an increasing volume proportion of portland cement. It sets up faster and has higher compressive and tensile bond strengths.
  - As the volume proportion of portland cement increases, mortar is less able to deform when hardened.
  - Types N and S are specified for modern masonry construction

INTRODUCTION TO MASONRY STRUCTURES

Masonry Mortar

- Under ASTM C270, mortar can be specified by proportion or by property
- If mortar is specified by proportion, compliance is verified only by verifying proportions. For example:
  - Type S PCL mortar has volume proportions of 1 part cement to about 0.5 parts hydrated mason's lime to about 4.5 parts mason's sand.
  - Type N masonry cement mortar (single-bag) has one part Type N masonry cement and 3 parts mason's sand

INTRODUCTION TO MASONRY STRUCTURES

Masonry Mortar

- **The proportion specification is the default. Unless the property specification is used, no mortar testing is necessary.**
- **The proportion of water is not specified. It is determined by the mason to achieve good productivity and workmanship.**
- **Masonry units absorb water from the mortar decreasing its water-cement ratio and increasing its compressive strength. Mortar need not have high compressive strength.**

INTRODUCTION TO MASONRY STRUCTURES

Grout

- Grout for unit masonry is specified by ASTM C 476
- Two kinds of grout:
  - Fine grout (cement, sand, water)
  - Coarse grout (cement, sand, pea gravel, water)
- ASTM C 476 permits a small amount of hydrated lime, but does not require any. Lime is usually not used in plant – batched grout.

INTRODUCTION TO MASONRY STRUCTURES

Grout

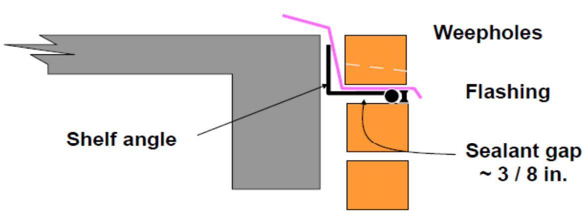
- Under ASTM C476, grout can be specified by proportion or by compressive strength:
  - Proportion specification is simpler. It requires only that volume proportions of ingredients be verified.
  - Specification by compressive strength is more complex. It requires compression testing of grout in a permeable mold (ASTM C 1019)

INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

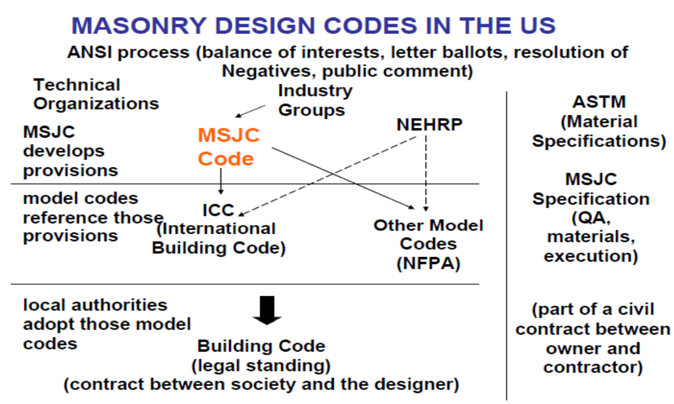
Accessory Materials

Horizontally oriented expansion joint under shelf angle:



INTRODUCTION TO MASONRY STRUCTURES

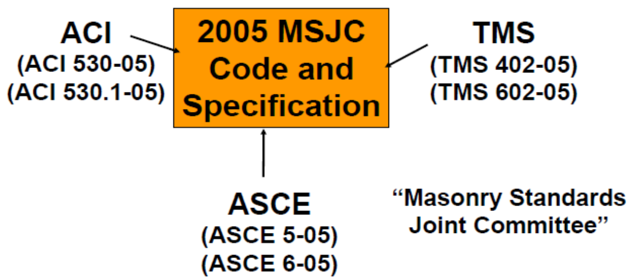
- Masonry Basics (Cont'd)



INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

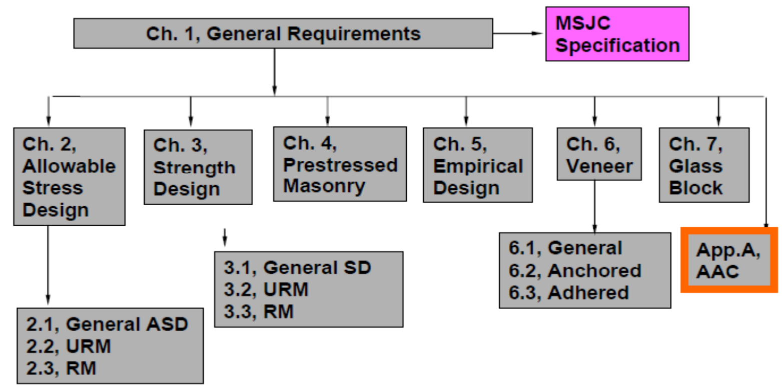
What is the MSJC Code and Specification... ?



INTRODUCTION TO MASONRY STRUCTURES

- Masonry Basics (Cont'd)

2005 MSJC Code



INTRODUCTION TO MASONRY STRUCTURES

Relation Between Code and Specification

- **Code:**
  - Design provisions are given in Chapters 1-7 and Appendix A
  - Sections 1.2.4 and 1.14 require a QA program in accordance with the specification
  - Section 1.4 invokes the specification by reference.
- **Specification:**
  - Verify compliance with specified f_m'
  - Comply with required level of quality assurance
  - Comply with specified products and execution

INTRODUCTION TO MASONRY STRUCTURES

- **Role of f_m'**
  - **Designer states assumed value of *fm'***
  - **Compliance is verified by "unit strength method" or by "prism test method"**

INTRODUCTION TO MASONRY STRUCTURES

Verify Compliance with Specified f_m'

- Unit strength method (Spec 1.4 B 2):
  - Compressive strengths from unit manufacturer
  - ASTM C 270 mortar
  - Grout meeting ASTM C 476 or 2,000 psi
- Prism test method (Spec 1.4 B 3):
  - Pro -- can permit optimization of materials
  - Con -- require testing, qualified testing lab, and procedures in case of non-complying results

INTRODUCTION TO MASONRY STRUCTURES

Code 1.8, Material Properties

- Chord modulus of elasticity, shear modulus, thermal expansion coefficients, and creep coefficients for clay, concrete, and AAC masonry
- Moisture expansion coefficient for clay masonry
- Shrinkage coefficients for concrete masonry

INTRODUCTION TO MASONRY STRUCTURES

Code 1.9, Section Properties

- Use minimum (critical) area for computing member stresses or capacities
  - Capacity is governed by the weakest section; for example, the bed joints of face-shell bedded hollow masonry

INTRODUCTION TO MASONRY STRUCTURES

Code 3.1.4, Strength-reduction Factors for SD

Action	Reinforced Masonry	Unreinforced Masonry
Combinations of flexure and axial load	0.90	0.60
Shear	0.80	0.80
Anchorage and splices of Reinforcement	0.80	---
Bearing	0.60	0.60

INTRODUCTION TO MASONRY STRUCTURES

Code 3.1.7.1.1, Compressive Strength of Masonry

- For concrete masonry, 1,500 psi ≤ f_m' ≤ *4,000 psi*
- For clay masonry, 1,500 psi ≤ f_m' ≤ *6,000 psi*

INTRODUCTION TO MASONRY STRUCTURES

Code 3.3, Reinforced Masonry

- Masonry in flexural tension is cracked
- Reinforcing steel is needed to resist tension
- Similar to strength design of reinforced concrete

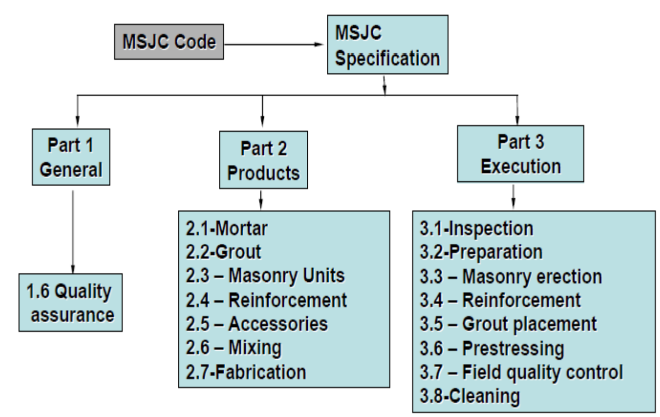
INTRODUCTION TO MASONRY STRUCTURES

Code 3.3.2, Design Assumptions

- Continuity between reinforcement and grout
- ε_{mu} *= 0.0035 for clay masonry, 0.0025 for concrete* masonry
- Plane sections remain plane
- Elasto-plastic stress-strain curve for reinforcement
- Tensile strength of masonry is neglected
- Equivalent rectangular compressive stress block in masonry, with a height of 0.80 *fm' and a depth of 0.80 c*

INTRODUCTION TO MASONRY STRUCTURES

Organization of MSJC Specification



5500. Durability, NDE & Masonry

- Objective and Scope Met
  - Provided introductory level review of concrete durability, NDE methods and masonry basics
  - Presented and discussed
    - Durability of Nuclear Power Plant Concrete Structures
    - Non Destructive Evaluation Methods for Concrete
    - Masonry Basics