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

5400. Concrete Containments, Modular Construction & Mass Concrete

- Objective and Scope
  - Provide introductory level review of concrete containments, modular construction and mass concrete
  - Present and discuss
    - Code for Concrete Containments
    - Examples of Structural Modules
    - Mass Concrete

5400. Concrete Containments, Modular Construction & Mass Concrete

- 5410 • 5410 - Concrete Containments
- 5420 • 5420 - Modular Construction
- 5430 • 5430 - Mass Concrete

5400. Concrete Containments, Modular Construction & Mass Concrete

- 5410 • 5410 - Concrete Containments
- 5420 • 5420 - Modular Construction
- 5430 • 5430 - Mass Concrete

5410 - Concrete Containments
ACI 359 – Code for Concrete Containments

- 2007 ASME Boiler and Pressure Vessel Code

  III

  Division 2

  Code for Concrete Containments

- **Rules for Construction of Nuclear Facility Components**

- ASME Boiler and Pressure Vessel Committee
  - Subcommittee on nuclear power
  - ACI-ASME Joint Technical Committee

ACI 359 – Code for Concrete Containments

- General Design
  - Concrete Containment

a) These design criteria apply to concrete containments, with steel reinforcement, prestressed tendons or a combination thereof, and metallic liners

b) The requirements for radiation shielding, allowable leak rate, design life span of the structure, and qualitative values of the design loads shall be presented in the Design Specification

c) The metallic liner should be designed within limits of stress, strain, and deformation specified in this Article

d) The criteria for the containment as demonstrated by the design calculations shall consider factored as well as service load conditions. For factored load conditions, the following requirements shall be met

ACI 359 – Code for Concrete Containments

- General Design (cont'd)
  - Concrete Containment

- For factored load conditions, the following requirements shall be met:

1) Primary forces shall not bring the local section to a general yield state with respect to any component of section member strain or section flexural curvature
   - General yield state is the point beyond which additional section deformation occurs without increase in section forces

ACI 359 – Code for Concrete Containments

- General Design (cont'd)
  - Concrete Containment

- For factored load conditions, the following requirements shall be met:

2) Under combined primary and secondary forces on a section, the development of a general yield state with respect to those membrane strains and/or flexural curvatures which correspond to secondary stress components is acceptable, subject to rebar and concrete strain limits in *Allowable Stress for factored loads* (CC-3420)
   - The concept of a general yield state is not applicable to strains associated with radial shear stress

ACI 359 – Code for Concrete Containments

TABLE CC-3136.6-1
CLASSIFICATION OF FORCES IN CONCRETE CONTAINMENTS FOR STEEL REINFORCING AND CONCRETE ALLOWABLE STRESSES

Location	Origin of Loads	Type of Force	Classification
Regions away from discontinuities	External [Note (1)]	Membrane	Primary
		Bending	Primary
		Shear [Note (2)]	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions at and near gross changes in shell geometry	External [Note (1)]	Membrane	Primary
		Bending	Primary [Note (3)]
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions near large openings	External [Note (1)]	Membrane	Primary
		Bending	Primary
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary

GENERAL NOTE: Allowable stresses for concrete may be considered secondary in the region defined in CC-3422.1(c)(3).

NOTES:

(1) Includes prestressing.

(2) Includes both radial and tangential shear force.

(3) For allowable stresses, bending at discontinuities due to external loads is considered primary.

ACI 359 – Code for Concrete Containments

- Impulse Loads
  - Impulse loads are time dependent and include the following

a) The dynamic effects of accident pressure P_a where rate of loading affects the response of the structure

b) The effects of pipe rupture reactions R_{rr} and jet impingement loading R_{rj}

c) The dynamic effects of valve actuation G such as steam relief valve or other high energy device actuation effects where rate of loading affects the response of the structure

ACI 359 – Code for Concrete Containments

- Impact Effects

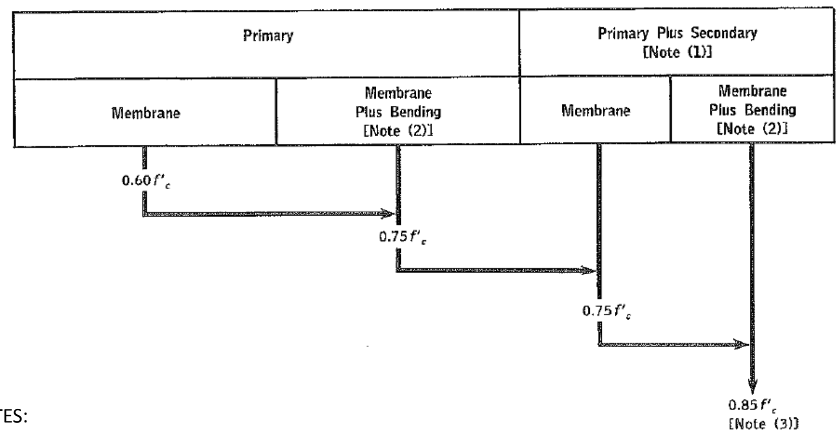
— Impact effects are those that can be specified in terms of kinetic energy at impact. These include the impact energies resulting from tornado missiles W_{tm}, pipe rupture generated missiles R_{rm}, and any other specific site dependent missiles, including the case where a gap exists between the pipe and it’s structural restraint

ACI 359 – Code for Concrete Containments

- Concrete Containment Structure Design Allowables
  - General
- In order to keep the containment basically elastic under service load conditions and below the range of general yield under factored primary loads, the allowable stresses and strains specified in this Subarticle shall be used
  - The allowable stresses given in Concrete: CC-3421, Reinforcing Steel: CC-3422, Tendon System Stresses: CC-3423, Concrete Stresses: CC-3431, Reinforcing Steel Stresses and Strains: CC-3432, Tendon System Stresses: CC-3433, shall not be exceeded when the containment is subjected to the loads given in the Load Combinations and Load Factors Table: CC-3230-1

ACI 359 – Code for Concrete Containments

TABLE CC-3421-1
ALLOWABLE COMPRESSION STRESSES FOR FACTORED LOADS



NOTES:

(1) The primary portion of this calculated stress shall not exceed the allowable stress applicable when primary stress acts alone

(2) The membrane portion of this calculated stress shall not exceed the allowable stress applicable when membrane stress acts alone

(3) The maximum allowable primary-plus secondary membrane and bending compressive stress of 0.85 f'_c corresponds to a limiting strain of 0.002 in./in. (0.051 mm/mm)

ACI 359 – Code for Concrete Containments

- Concrete Temperatures

a) The following temperature limitations are for normal operation or any other long-term period. The temperatures shall not exceed 150°F (65°C) except for local areas, such as around a penetration, which are allowed to have increased temperatures not to exceed 200°F (95°C)

b) The following temperatures limitations are for accident or any other short-term period. The temperatures shall not exceed 350°F (175°C) for the interior surface. However, local areas are allowed to reach 650°F (345°C) from steam or water jets in the event of a pipe failure

c) Higher temperatures than given in (a) and (b) above may be allowed in the concrete if tests are provided to evaluate the reduction in strength and this reduction is applied to the design allowables. Also, evidence shall be provided which verifies that the increased temperatures do not cause deterioration of the concrete either with or without load

ACI 359 – Code for Concrete Containments

- Concrete Crack Control

a) When an expected crack formation is so located that critical elements of the containment, such as anchor zone concrete, buttresses, ring girders, and large opening edges, may be weakened, bonded nonprestressed reinforcement shall be provided to carry the total tensile force in the concrete

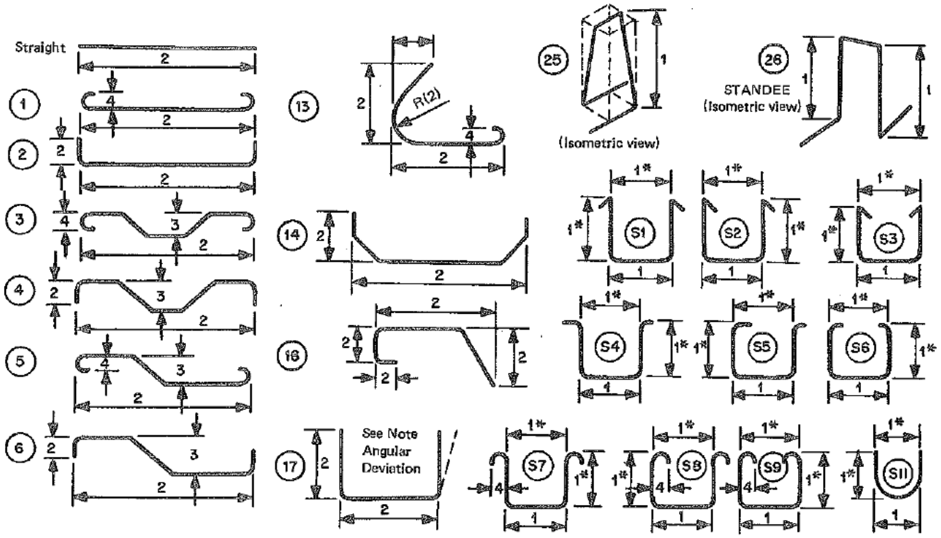
b) Nonprestressed reinforcement shall be provided in the containment shell to control surface and membrane cracking from the effects of shrinkage, temperature, and membrane tension. The area of such reinforcement in each direction at each face of the concrete shall be a minimum of 0.0020 times the gross cross-sectional area of the section

ACI 359 – Code for Concrete Containments

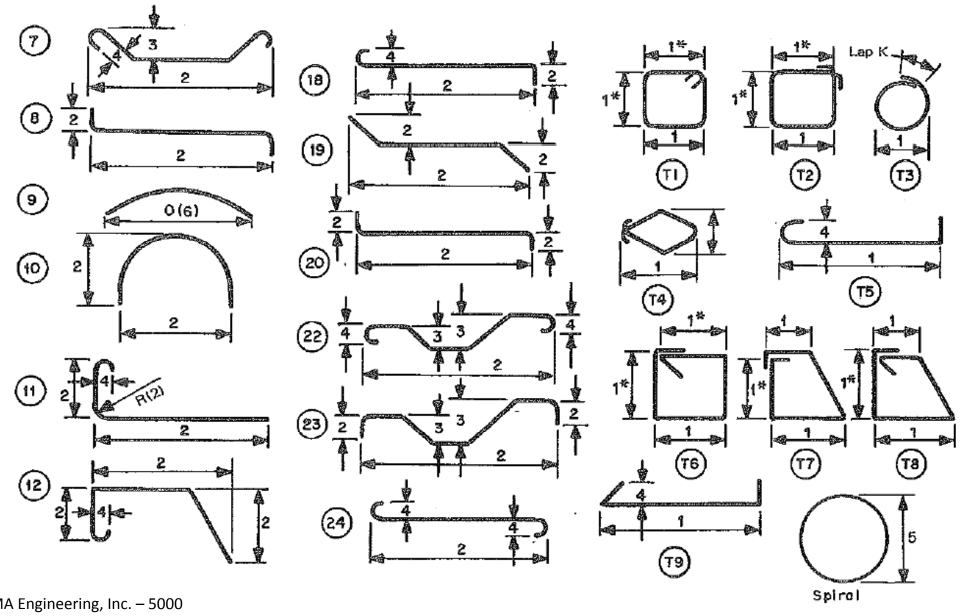
- Concrete Crack Control (cont'd)

(cont'd) b) This requirement may be met in whole or in part by reinforcement otherwise required to resist calculated loads. An integral steel liner, if provided, may be included to satisfy the requirement for inside face reinforcement. Reinforcing bars considered as face reinforcement shall not be more than one-fifth of the total section thickness from the concrete face.

ACI 359 – Code for Concrete Containments



ACI 359 – Code for Concrete Containments



ACI 359 – Code for Concrete Containments

FIG. F-1220-1 STANDARD FABRICATING TOLERANCES FOR BAR SIZES #3 (10 mm) THROUGH #11 (35 mm) (CONT'D)

GENERAL NOTES:

(a) Entire shearing and bending tolerances are customarily absorbed in the extension past the last bend in a bent bar.

(b) Angular Deviation: maximum ±2½ deg or ±1½ in./ft (±38 mm/305 mm) on all 90 deg hooks and bends. Saw cut both ends: overall length ±½ in. (±13 mm). All tolerances single plane and as shown.

(c) Tolerances for Types S1–S9, T1–T9 apply to bar sizes #3–#5 inclusive only.

(d) Tolerance Symbols

1 = bar sizes # 3 (10 mm), 4 (13 mm), 5 (16 mm): ±½ in. (±13 mm) [gross length < 12 ft-0 in. (< 3.66 m)]
= bar sizes # 3 (10 mm), 4 (13 mm), 5 (16 mm): ±½ in. (±13 mm) [gross length < 12 ft-0 in. (≥ 3.66 m)]
= bar sizes # 6 (19 mm), 7 (22 mm), 8 (25 mm): ±1 in.

2 = ±1 in. (±25 mm)

3 = ±0 in. (±0 mm), –½ in. (–13 mm)

4 = ±½ in. (± 13 mm)

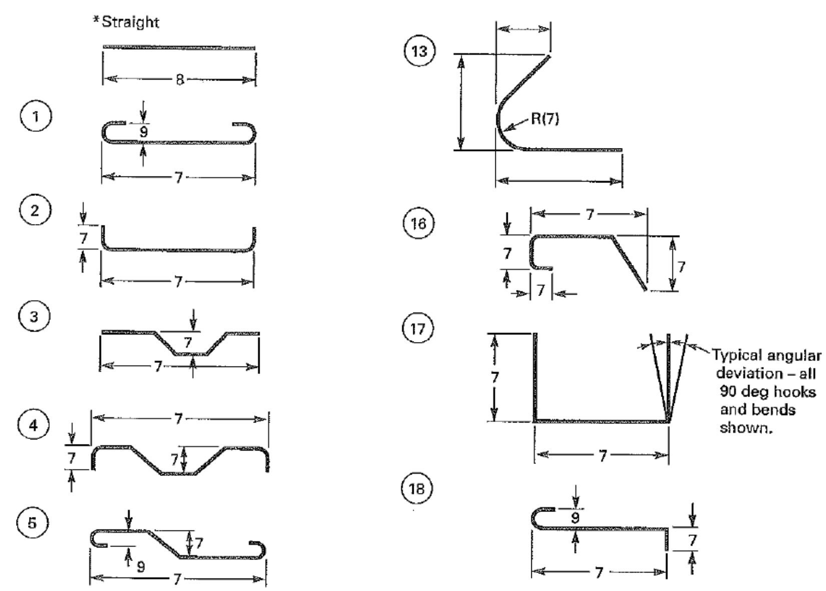
5 = diameter ≤ 30 in. (< 750 mm) ±½ in. (±13 mm)
= diameter < 30 in. (< 750 mm) ±½ in. (±13 mm)

6 = ±1.5% × 0 dimension, ±2 in. (±50 mm) min.**

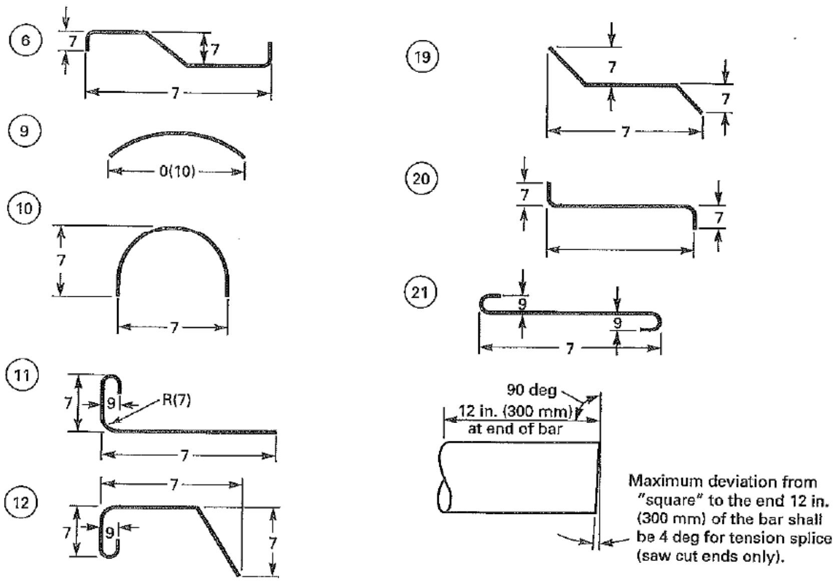
* Dimensions on this line are to be within tolerance shown but are not to differ from the opposite parallel dimension by more than ½ in. (13 mm).

** If application of positive tolerance to Type 9 results in a chord length equal to or greater than the arc or bar length, the bar may be shipped straight.

ACI 359 – Code for Concrete Containments



ACI 359 – Code for Concrete Containments



ACI 359 – Code for Concrete Containments

FIG. F-1230-1 STANDARD FABRICATING TOLERANCES FOR BAR SIZES #14 (43 mm) AND #18 (57 mm) (CONT'D)

GENERAL NOTES:

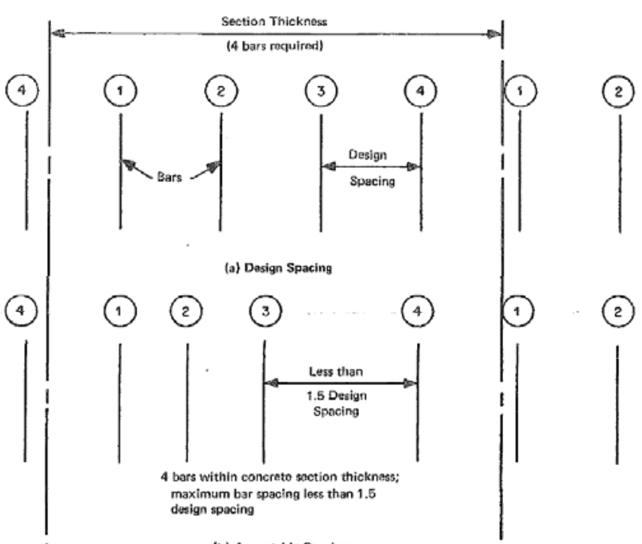
(a) Tolerance Symbols

Tolerance Symbols	#14 (43 mm)	#18 (57 mm)
7 = plus or minus	2½ in. (60 mm)	3½ in. (90 mm)
8 = plus or minus	2 in. (50 mm)	2 in. (50 mm)
9 = plus or minus	1½ in. (40 mm)	2 in. (50 mm)
10 = ± 2% × 0 dimensions ≥	± 2½ in. (± 60 mm) min.*	± 3½ in. min.* (± 90 mm)

(b) Angular Deviation: maximum ±2½ deg or 0±½ in./ft (0 ±13 mm / 300 mm) on all 90 deg hooks and bends.

* Saw cut bends: overall length ±½ in. (±13 mm)

ACI 359 – Code for Concrete Containments
Location of Reinforcement



(a) Design Spacing

(b) Acceptable Spacing

ACI 359 – Code for Concrete Containments
Location of Reinforcement (cont'd)

(c) Unacceptable Spacing

NUREG – 0800 (3.8.1)– Concrete Containment

- Review of Design & Analysis Procedures will Include

A. Assumptions on boundary conditions
B. Treatment of axisymmetric and nonaxisymmetric loads
C. Treatment of transient and localized loads
D. Treatment of the effects of creep, shrinkage, and cracking of the concrete

NUREG – 0800 (3.8.1)– Concrete Containment

- Review of Design & Analysis Procedures will Include (Cont'd)

E. A description of the computer programs used in the design and analyses
F. The treatment of the effects of seismically induced tangential (membrane) shears
G. The evaluation of the effects of variations in specified physical properties of materials on analytical results

NUREG – 0800 (3.8.1)– Concrete Containment

- Review of Design & Analysis Procedures will Include (Cont'd)

H. The treatment of the large, thickened penetration regions
I. The treatment of the steel liner plate and its anchors
J. Ultimate capacity of the concrete containment
K. Structural audit
L. Design report submitted for review

NUREG – 0800 (3.8.1)– Concrete Containment

- Structural Acceptance Criteria. For each load combination specified, the reviewer compares the proposed allowable limits with the acceptable limits delineated in the USNRC SRP. These allowable limits include the following major parameters:

A. Compressive stresses in concrete, including membrane, membrane plus bending, and localized stresses
B. Shear stresses in concrete, particularly those tangential (membrane) stresses induced by lateral loads
C. Tensile stresses in reinforcement

NUREG – 0800 (3.8.1)– Concrete Containment

- Structural Acceptance Criteria (Cont'd)

  D. Tensile stresses in prestressing tendons

  E. Tensile or compressive strain limits in the liner plate, including membrane and membrane plus bending

  F. Force/displacement limits in the liner plate anchors, including those induced by strains in the adjacent concrete

NUREG – 0800 (3.8.1)– Concrete Containment

- Materials, Quality Control, and Special Construction Techniques. Review will include:

  A. The concrete ingredients

  B. The reinforcing bars and splices

  C. The prestressing system

  D. The liner plate

NUREG – 0800 (3.8.1)– Concrete Containment

- Materials, Quality Control, and Special Construction Techniques. Review will include (Cont'd):

  E. The liner plate anchors and associated hardware

  F. The structural steel used for embedments such as beam seats and crane brackets

  G. The corrosion-retarding compounds used for the prestressing tendons

NUREG – 0800 (3.8.1)– Concrete Containment

- Materials, Quality Control, and Special Construction Techniques. Review will include (Cont'd):

  – The staff reviews the quality control program that is proposed for the fabrication and construction of the containment with emphasis on the extent of compliance with Articles CC-4000 and CC-5000 of the ASME Code and RG 1.136. This includes examination of the materials, as well as tests to determine the physical properties of concrete, reinforcing steel, mechanical splices, the liner plate and its anchors, and the prestressing system, if any; placement of concrete; and erection tolerances of the liner plate, reinforcement, and prestressing systems.

NUREG – 0800 (3.8.1)– Concrete Containment

- Materials, Quality Control, and Special Construction Techniques. Review will include (Cont'd):
  - The review covers any proposed special, new, or unique construction techniques, such as slip forming, on a case-by-case basis to determine their effects on the structural integrity of the completed containment.

NUREG – 0800 (3.8.1)– Concrete Containment

- Testing and In-service Surveillance Requirements
  - For concrete containments, it is important to accommodate in-service inspection of critical areas. The review includes any special design provisions (e.g., providing sufficient physical access, providing alternative means for identification of conditions in inaccessible areas that can lead to degradation, or providing remote visual monitoring of high-radiation areas) to accommodate in-service inspection of concrete containments.

NUREG – 0800 (3.8.1)– Concrete Containment

- Testing and In-service Surveillance Requirements (Cont'd)
  - The review covers the preoperational structural testing program for the completed containment and for individual components
  - The review also includes inservice surveillance programs, such as the periodic surveillance and inspection of the containment and prestressing tendons, if any, and examines the applicable technical specifications, at the operating license stage.

NUREG – 0800 (3.8.1)– Concrete Containment

- Testing and In-service Surveillance Requirements (Cont'd)
  - The review of programs for the examination of inaccessible areas, and monitoring of settlements and differential displacements proceeds on a case-by-case basis
  - The staff also reviews special testing and in-service surveillance requirements proposed for new or previously untried design approaches on a case-by-case basis.

NUREG – 0800 (3.8.1)– Concrete Containment

- Requirements for acceptance include:
  1. 10 CFR 50.55a and GDC 1, as they relate to concrete containment being designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function to be performed
  2. GDC 2, as it relates to the design of the concrete containment being able to withstand the most severe natural phenomena such as winds, tornadoes, floods, and earthquakes and the appropriate combination of all loads.

NUREG – 0800 (3.8.1)– Concrete Containment

- Requirements for acceptance include (Cont'd):
  3. GDC 4, as it relates to the concrete containment being appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit
  4. GDC 16, as it relates to the capability of the concrete containment to act as a leak-tight membrane to prevent the uncontrolled release of radioactive effluents to the environment

NUREG – 0800 (3.8.1)– Concrete Containment

- Requirements for acceptance include (Cont'd):
  5. GDC 50, as it relates to the concrete containment being designed with sufficient margin of safety to accommodate appropriate design loads
  6. 10 CFR Part 50, Appendix B as it relates to the quality assurance criteria for nuclear power plants

NUREG – 0800 (3.8.1)– Concrete Containment

- Requirements for acceptance include (Cont'd):
  7. 10 CFR 50.34(f), as it relates to demonstrating containment integrity of applicable plants for loads associated with an accidental release of hydrogen generated from metal-water reaction of the fuel cladding, accompanied by hydrogen burning or added post accident pressure
  8. 10 CFR 50.44, as it relates to demonstrating the structural integrity of all containments for loads associated with combustible gas generation

5400. Concrete Containments, Modular Construction & Mass Concrete

5410
- 5410 - Concrete Containments

5420
- 5420 - Modular Construction

5430
- 5430 - Mass Concrete

5420 - Modular Construction

Modular Construction for Safety-Related Structures at NPP's

- Modular construction techniques have been successfully used in a number of industries, both domestically and internationally
- Recently, the use of structural modules has been proposed for advanced nuclear power plants
- The objective in utilizing modular construction is to reduce the construction schedule, reduce construction costs, and improve the quality of construction

Modular Construction for Safety-Related Structures at Advanced NPP's

- Several advanced reactor designs utilize modular construction to shorten construction schedule, reduce costs and improve construction quality
- Structural modules are fabricated in off-site facilities in parallel with other fabrication and construction related activities
- Engineering should be substantially complete prior to start of construction, in order to maximize the use of standardized element

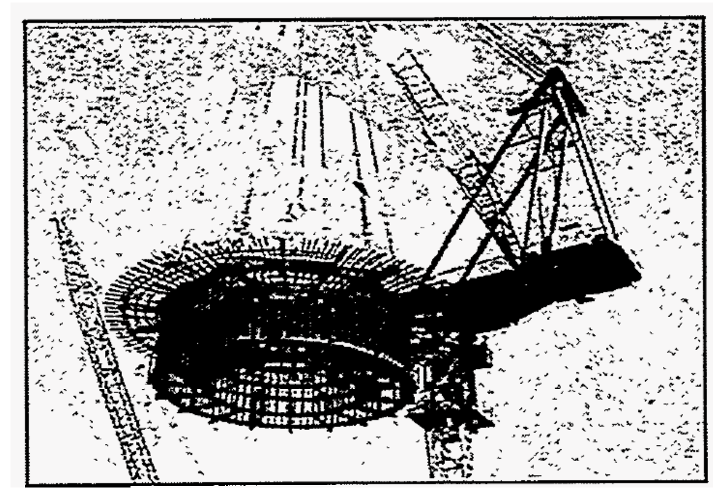
Modular Construction for Safety-Related Structures at Advanced NPP's

- The US DOE has sponsored a number of studies on the use of modularization in NPP's
- Japan and others have utilized prefabrication and modular construction techniques in NPP's
- Numerous tests and studies have been performed in Japan to understand the behavior of concrete-filled steel type structural module
- Westinghouse has used modularization concepts in the design of the AP600 & more recently in the design of the AP1000

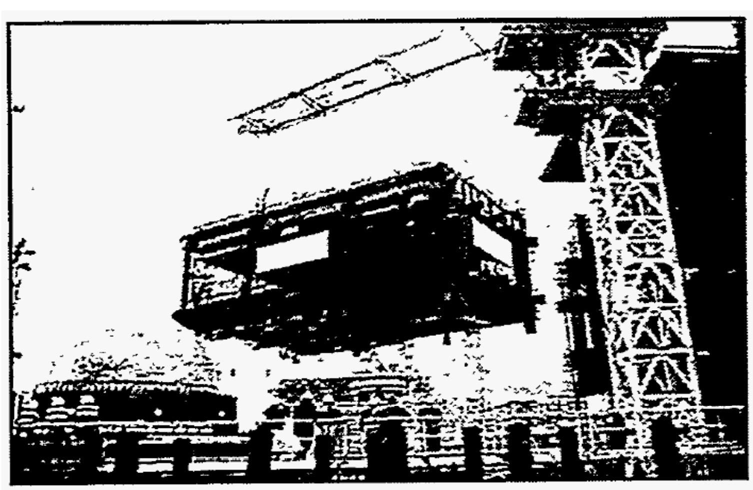
Modular Construction for Safety-Related Structures at Advanced NPP's

- The term "**module**" is defined to be "a major system or structural subassembly which can be assembled and tested in an offsite location and installed by field forces as a single piece**"**
- Some of the issues that have been cited regarding modularization include:
  - Assurance of composite action between steel elements and concrete in wall and floor elements
  - Assurance of the ductility of connections and joints between modules
  - The judicious application of codes and standards
  - the establishment of an impeccable quality assurance and quality control program.

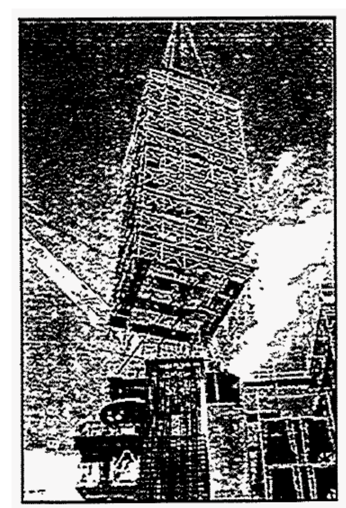
Large Block Prefabrication for Base Mat Central Part (wt. 100 ton)



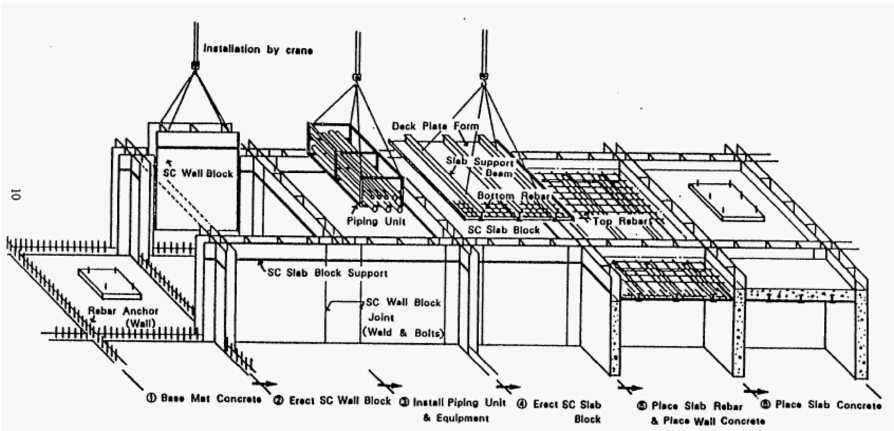
Room Module Method for Main Control Room (wt. 440 ton)



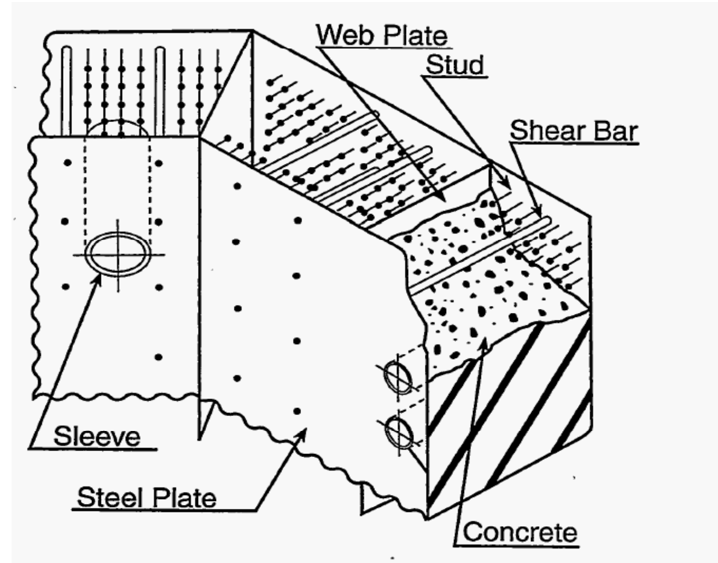
Scaffold Prefabrication for T/G Pedestal



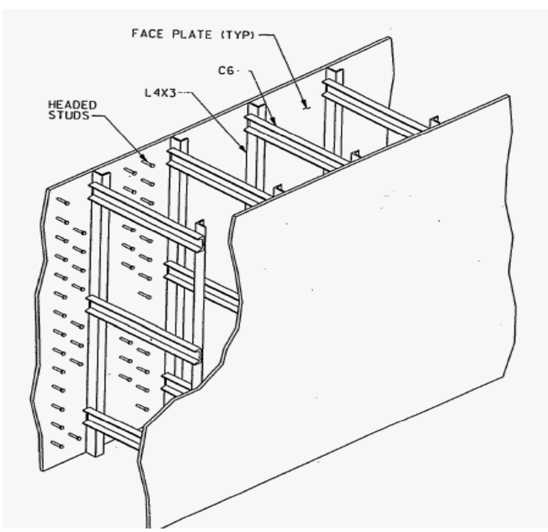
Construction Method that Utilizes Concrete Filled Steel Structures



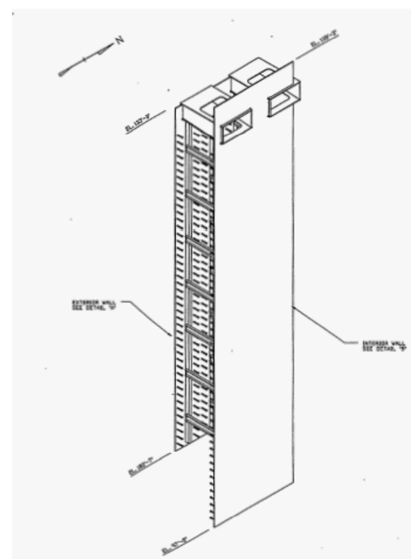
Concrete Filled Steel Structure



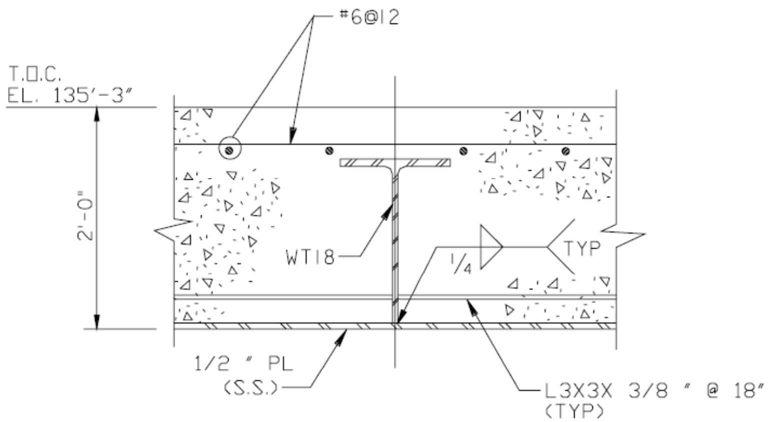
AP600 & AP1000 Concrete-Filled Steel Module



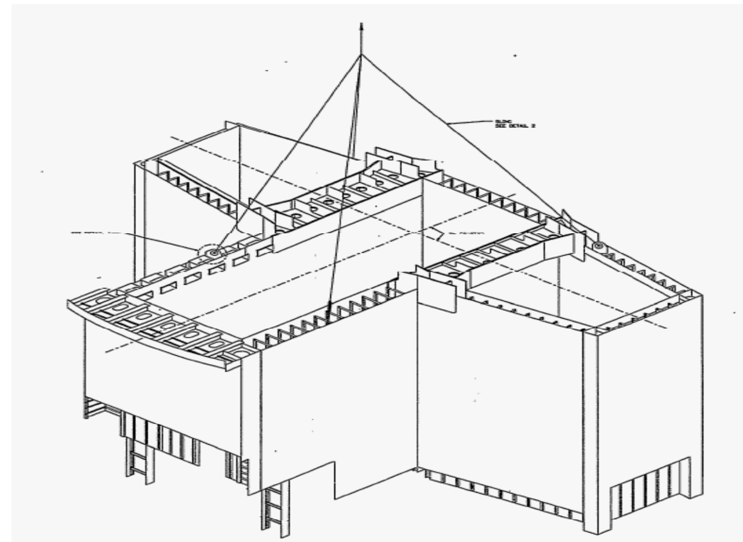
AP600 & AP1000 Typical M-1 Modular Subunit



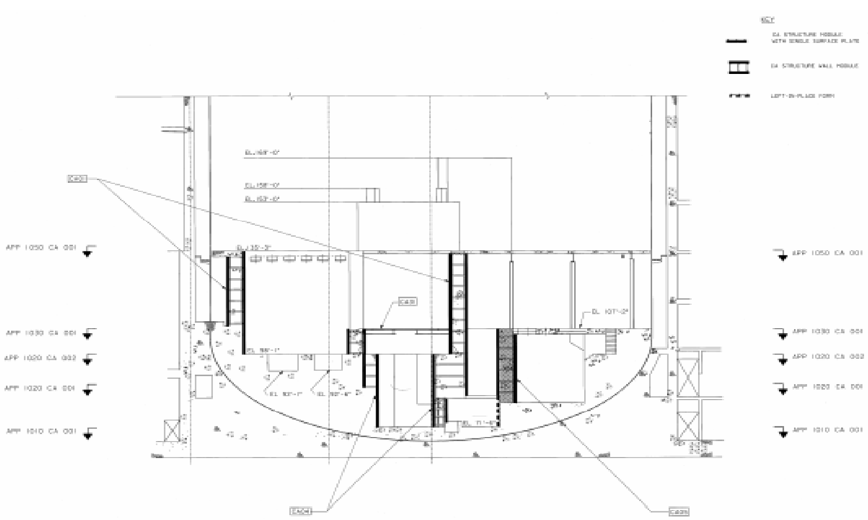
AP1000 - Typical Structural Floor Module



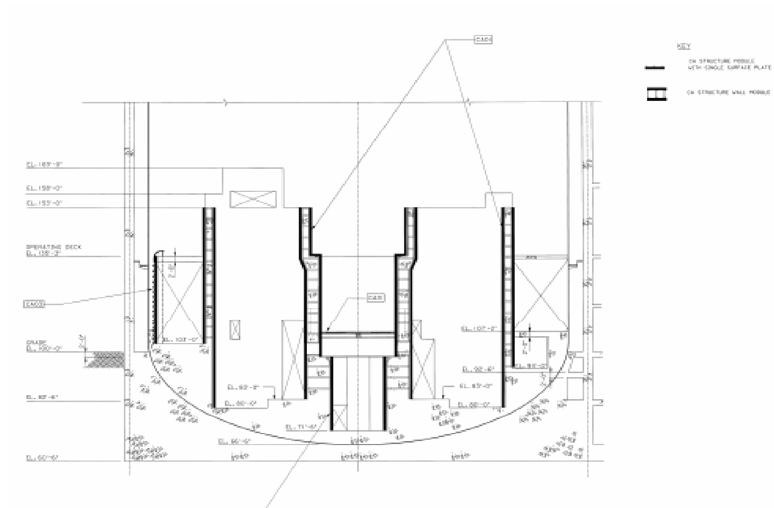
AP600 Unit Handling of M-1 Module



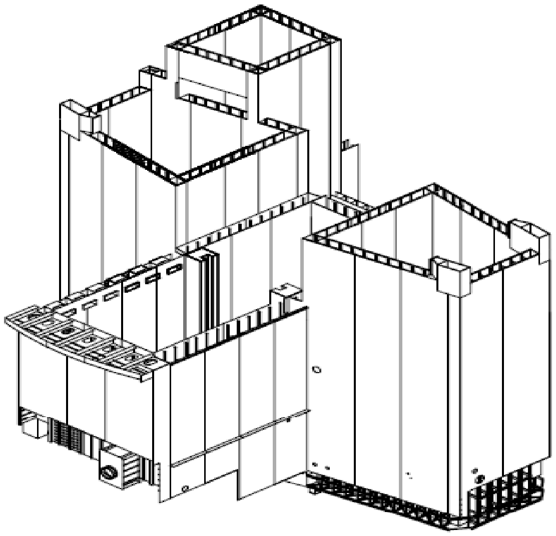
AP1000 - Structural Modules in Containment Internal Structures



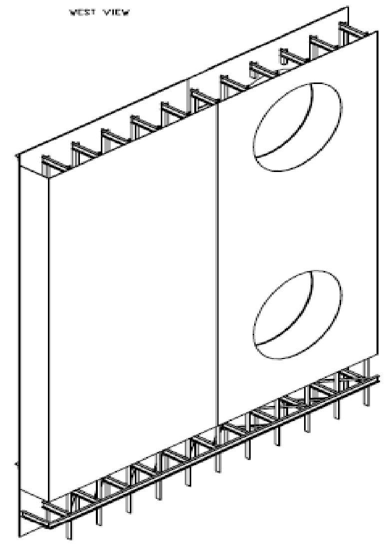
AP1000 - Structural Modules in Containment Internal Structures (Cont'd)



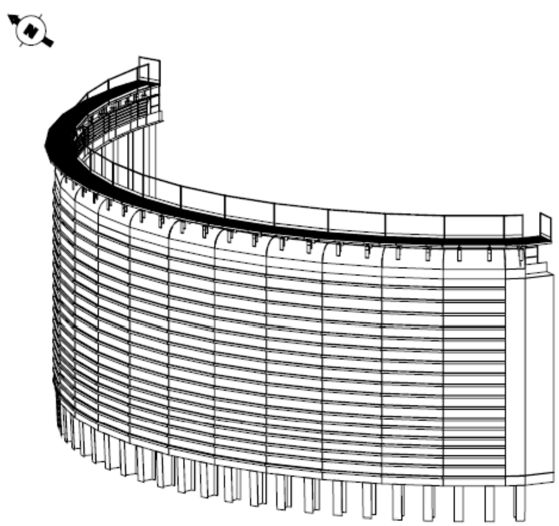
AP1000 - CA-01 Module



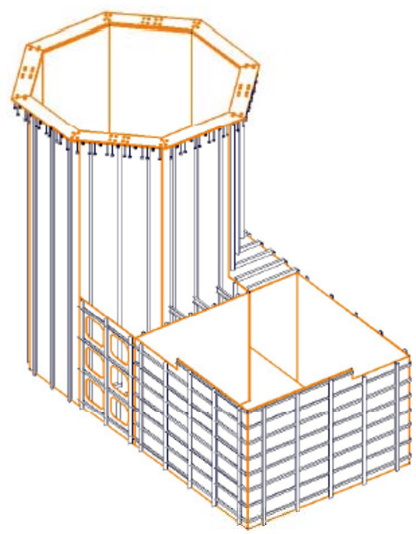
AP1000 - CA-02 Module



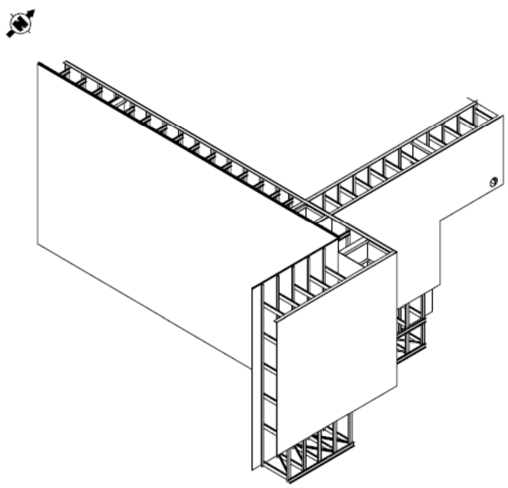
AP1000 - CA-03 Module



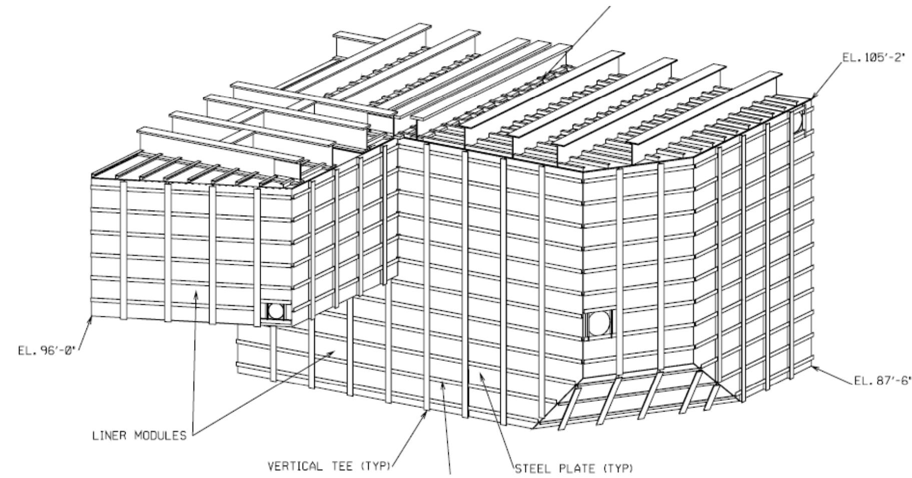
AP1000 - CA-04 Module



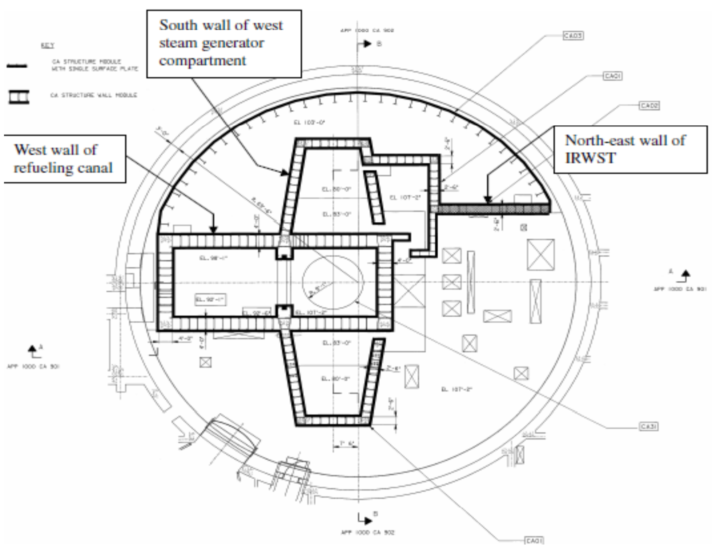
AP1000 - CA-05 Module



AP1000 - Typical Liner Modules



AP1000 - Location of Structural Wall Modules



5400. Concrete Containments, Modular Construction & Mass Concrete

5410
- 5410 - Concrete Containments

5420
- 5420 - Modular Construction

5430
- 5430 - Mass Concrete

5430 - Mass Concrete

- **Definition:**
  According to ACI 207, "**mass concrete** is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change to minimize cracking."

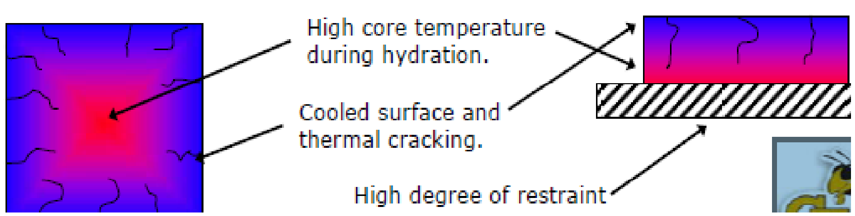
- The design of mass concrete structures is generally based on durability, economy, and thermal action, with strength often being a secondary concern

Thermal Cracking

- Cement hydration produces a rise in internal Temperature
- The outer surface cools faster than the core of the Section
- By thermal expansion/contraction, the temperature differential induces thermal (tensile) stresses at the surface

Thermal Cracking

- Stresses **>** Tensile Strength => Thermal Cracking!



Mass Concrete
Suitable Types of Hydraulic Cement

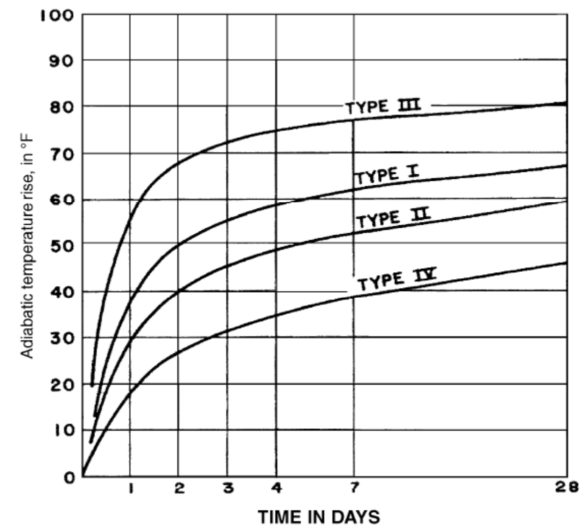
The following types of hydraulic cement are suitable for use in mass concrete construction:

- *Portland* cement—Types I, II, IV, and V, as covered by ASTM C 150;
- *Blended* cement—Types P, IP, S, IS, I(PM), and I(SM), as covered by ASTM C 595; and
- *Hydraulic* cement—Types GU, MS, HS, MH, and LH, as covered by ASTM C 1157

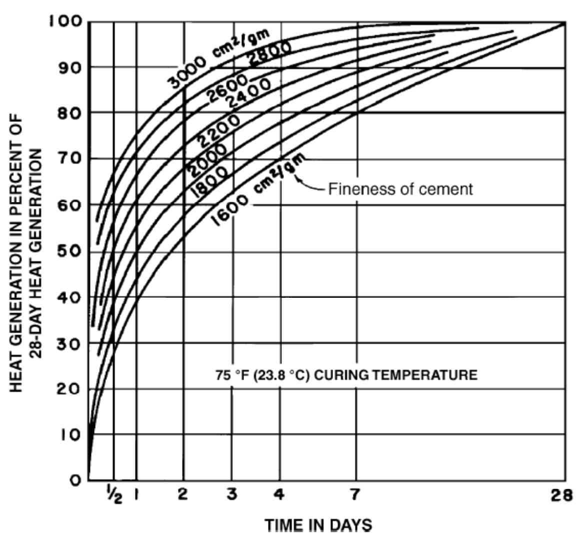
Type II (moderate heat) and MH Cements

- The US Type II (moderate heat) and MH cements are suitable for mass concrete construction because they have a moderate heat of hydration, which is important to the control of cracking. Type II must be specified with the moderate heat option as most Type II and MS cements are designed for moderate sulfate resistance and do not have moderate heat properties. Specifications for Type II Portland cement require that it contain no more than 8% tricalcium aluminate (C3A), the compound that contributes substantially to early heat development in concrete

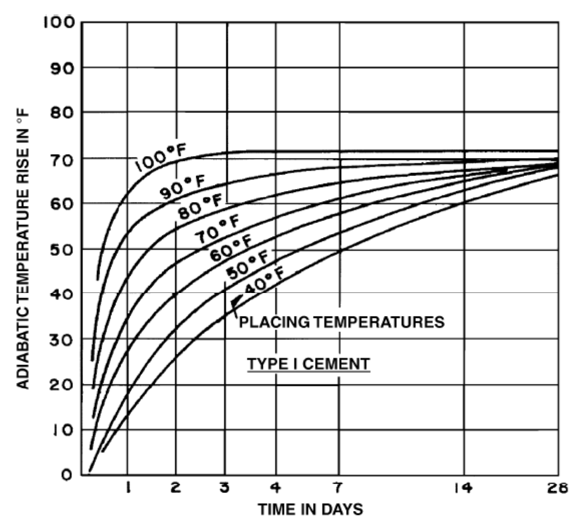
Temperature Rise of Mass Concrete Containing 376 lb/yd^3 of Various Types of Cement



Rate of Heat Generation as Affected by Fineness for Cement Paste Cured at 75 °F



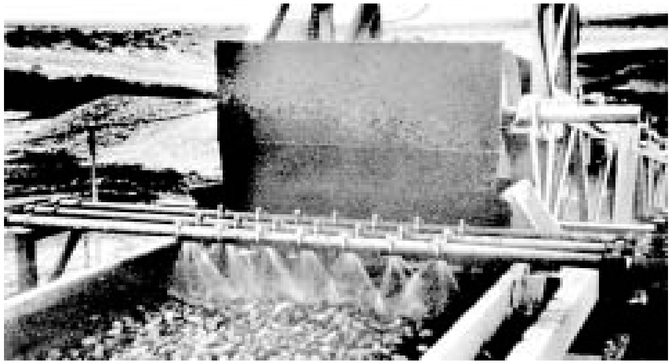
Curing Temperature and Time vs Temperature Rise of Mass Concrete Containing 376 lb/yd3 of Type I Cement



Mass Concrete
Coarse Aggregate

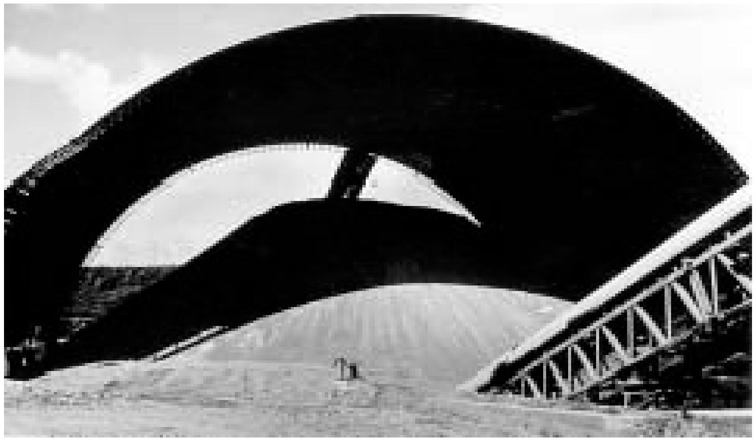
- The rule for mass concrete should be to use the largest practical size of coarse aggregate;
- To ensure aggregate cleanliness coarse-aggregate rewashing screen at the batch plant may be used to remove dust and coatings accumulated from stockpiling and handling

Mass Concrete
Coarse Aggregate Rewashing



Cooling Coarse Aggregate by Chilled Water Spray and Inundation

Metal Cover over Drained Fine Aggregate Stockpile to Reduce Heat Absorption



Pozzolans in Mass Concrete

- Pozzolans in mass concrete may be used to reduce portland cement factors for better economy, lower internal heat generation, improve workability, and lessen the potential for damage from alkali-aggregate reactivity and sulfate attack

- Properties of different pozzolans may vary widely. Before a pozzolan is used, it should be tested in combination with the project cement and aggregates to establish that the pozzolan will beneficially contribute to the quality and economy of the concrete

Mass Concrete
Chemical admixtures

- The chemical admixtures that are important to mass concrete are classified as air entraining, water-reducing, or set-controlling

- Water-reducing and set-controlling admixtures generally consist of one or more of the following: lignosulfonic acid, hydroxylated carboxylic acid, polymeric carbohydrates, and naphthalene or melamine types of high-range water reducers

Mass Concrete
Concrete Strength

- Mass concrete containing pozzolan is usually designed on the basis of 90-day to 1-year strengths

- While mass concrete does not require strength at early ages to perform its design function, the construction method used may require high early strength

Mass Concrete
Concrete Strength (Cont'd)

The geometry of massive reinforced concrete sections are often set by criteria totally unrelated to the strength of concrete. Such criteria are often based on:

- Stability requirements where self-weight rather than strength is of primary importance;
- Arbitrary requirements for water tightness per unit of water pressure;

Mass Concrete
Concrete Strength (Cont'd)

- Stiffness requirements for the support of large pieces of vibrating machinery where the self-weight itself is of primary importance; or

- Shielding requirements, as found in nuclear power plants.

Mass Concrete
Temperature Control Program

- Cementitious material content control, where the choice of type and amount of cementitious materials can lessen the heat-generating potential of the concrete;

- Precooling, where cooling of ingredients achieves a lower concrete temperature as placed in the structure;

Mass Concrete
Temperature Control Program (Cont'd)

- Post cooling, where removing heat from the concrete with embedded cooling coils limits the temperature rise in the structure; and

- Construction management, where efforts are made to protect the structure from excessive temperature differentials by knowledge of concrete handling, construction scheduling, and construction procedures.

Temperature Control Program
Control Measures May Include

- The use of pozzolans;

- The careful production control of aggregate gradings and the use of large-size aggregates in efficient mixtures with low cement contents;

- The precooling of aggregates and mixing water (or the batching of ice in place of mixing water) to make possible a low concrete temperature as placed;

Temperature Control Program
Control Measures May Include (Cont'd)

- The use of air-entraining and other chemical admixtures to improve both the fresh and hardened properties of the concrete;
- The coordination of construction schedules with seasonal changes to establish lift heights and placing frequencies;
- The use of special mixing and placing equipment to quickly place cooled concrete with minimum absorption of ambient heat;

Temperature Control Program
Control Measures May Include (Cont'd)

- The evaporative cooling of surfaces through water curing;
- The dissipation of heat from the hardened concrete by circulating cold water through embedded piping; and
- The insulation of surfaces to minimize thermal differentials between the interior and the exterior of the concrete;

Temperature Control Program
Control Measures May Include (Cont'd)

- Immersion in cool water or saturation of coarse aggregates, including wet belt cooling;
- Vacuum evaporation of moisture in coarse aggregate;
- Nitrogen injection into the mixture and at transfer points during delivery;

Temperature Control Program
Control Measures May Include (Cont'd)
Nitrogen Injection

- Cost ≈$75 to cool a truckload of concrete by 25°F

Temperature Control Program
Control Measures May Include (Cont'd)

- Using light-colored mixing and hauling equipment, and spraying the mixing, conveying, and delivery equipment with a water mist;
- Scheduling placements when ambient temperatures are lower, such as at night or during cooler times of the year; and
- Cooling aggregates with natural or manufactured chilled air.

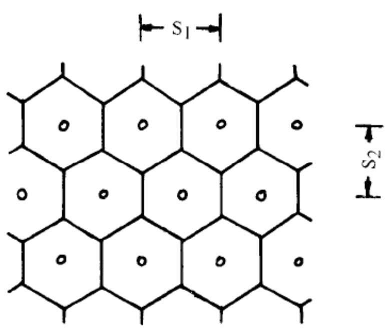
Temperature Control Program
Control Measures May Include (Cont'd)

Two schools of thought exist on post-placement techniques to reduce thermal cracking:

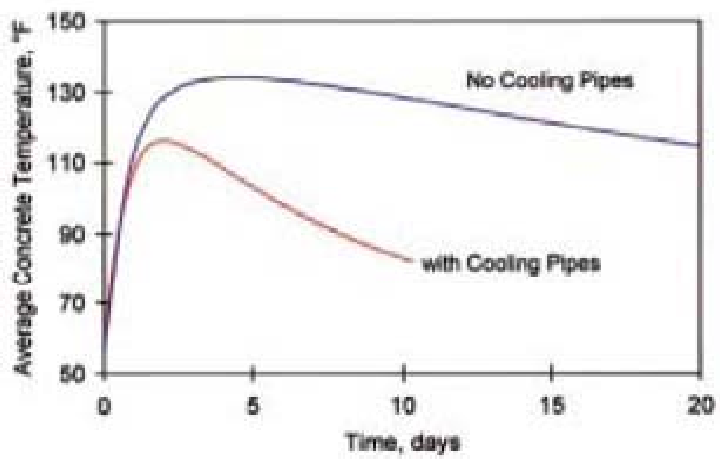
- Cool the core of the concrete to reduce the temperature differential
- Insulate the outer surface to reduce the temperature differential

Temperature Control Program
Post-Cooling

- Post-Cooling utilizes cold water flowing through pipes embedded into the concrete. This helps to transfer heat from the core, and reduce the temperature differential
- Pipes must be spaced in a manner which achieved the desired temperature differential



Temperature Control Program
Post-Cooling (Cont'd)



Temperature Control Program
Insulation After Placement

- By limiting the heat loss from the surface, the difference in temperature between the surface and the core is minimized. This is especially important in very cold conditions
- Removing formwork to soon can cause "thermal shock" to the surface, and extensive cracking will occur
- Metal formwork is very conductive to heat, so additional insulation may be needed to limit heat loss

Temperature Control Program
Expansion Reinforcement

- Expansion Reinforcement can be used to lessen thermal cracking
- Expansion reinforcement distributes thermal stresses to minimize crack widths
- Expansion reinforcement is impractical for very large pours

Temperature Control Program
Refrigeration Requirement per cubic yard

Ingredient	Initial temperature, °F	Degrees to 50 °F, °F	Water equivalent, lb	Btus to get to 50 °F, Btu
Moist coarse aggregate	75	25	535	13,375
Moist fine aggregate	73	23	205	4715
Cement	120	70	41	2870
Fly ash	73	23	17	391
Batched water	70	20	139	2780
Heat of mixing, estimated				1000
Totals			937	25,131

Temperature Control Program
Trial Heat Balance

Ingredient	Temperature as batched, °C	Temperature after mixing, °C	Water equivalent, kg	Heat exchanged, kJ
Coarse aggregate (moist)	24	16	300	10,032
Fine aggregate (moist)	23	16	121	3540
Cement	49	16	25	3448
Fly ash	23	16	10	293
Heat of mixing				1390
			Approximately	18,700
Batched water				
Ice	0	334*	47	–15,698
Ice (melted)	0	16	47	–3143
Water (chilled)	2	16	35	–2048
			Approximately	–20,900

*Units of heat required to change 1kg of ice at 0 °C to water at same temperature.

Compressive Strength and Elastic Properties of Mass Concrete

						Elasticity properties							
		Compressive strength, psi (MPa)				Modulus of elasticity, $E \times 10^6$, psi ($E \times 10^4$, MPa)				Poisson's ratio			
		Age, days				Age, days				Age, days			
No.	Dam	28	90	180	365	28	90	180	365	28	90	180	365
1	Hoover	3030 (20.9)	3300 (22.8)	—	4290 (29.6)	5.5 (3.8)	6.2 (4.3)	—	6.8 (4.7)	0.18	0.20	—	0.21
2	Grand Coulee	4780 (33.0)	5160 (35.6)	—	5990 (41.3)	4.7 (3.2)	6.1 (4.2)	—	6.0 (4.1)	0.17	0.20	—	0.23
3	Glen Canyon	2550 (17.6)	3810 (26.3)	3950 (27.2)	—	5.4 (3.7)	—	5.8 (4.0)	—	0.11	—	0.14	—
4	Glen Canyon*	3500 (24.1)	4900 (33.8)	6560 (45.2)	6820 (47.0)	5.3 (3.7)	6.3 (4.3)	6.7 (4.6)	—	0.15	0.15	0.19	—
5	Flaming Gorge	2950 (20.3)	3500 (24.1)	3870 (26.7)	4680 (32.3)	3.5 (2.4)	4.3 (3.0)	4.6 (3.2)	—	0.13	0.25	0.20	—
6	Yellowtail	—	4580 (31.6)	5420 (37.4)	5640 (38.9)	—	6.1 (4.2)	5.4 (3.7)	6.2 (4.3)	—	0.24	0.26	0.27
7	Morrow Point*	4770 (32.9)	5960 (41.1)	6430 (44.3)	6680 (46.1)	4.4 (3.0)	4.9 (3.4)	5.3 (3.7)	4.6 (3.2)	0.22	0.22	0.23	0.20
8	Lower Granite*	1270 (8.8)	2070 (14.3)	2420 (16.7)	2730 (18.8)	2.8 (1.9)	3.9 (2.7)	3.8 (2.6)	3.9 (2.7)	0.19	0.20	—	—
9	Libby	1450 (10.0)	2460 (17.0)	—	3190 (22.0)	3.2 (2.2)	4.0 (2.8)	—	5.5 (3.8)	0.14	0.18	—	—
10	Dworshak*	1200 (8.3)	2030 (14.0)	—	3110 (21.4)	—	3.7 (2.6)	—	3.8 (2.6)	—	—	—	—
11	Ilha Solteira	2320 (16.0)	2755 (19.0)	3045 (21.0)	3190 (22.0)	5.1 (3.5)	5.9 (4.1)	—	—	0.15	0.16	—	—
12	Itaipu	1885 (13.0)	2610 (18.0)	2610 (18.0)	2755 (19.0)	5.5 (3.8)	6.2 (4.3)	6.2 (4.3)	6.5 (4.5)	0.18	0.21	0.22	0.20
13	Peace site*	3060 (21.1)	3939 (27.2)	4506 (31.1)	4666 (32.2)	—	—	—	—	—	—	—	—
14	Theodore Roosevelt modification	2400 (16.5)	4500 (31.0)	5430 (37.4)	5800 (40.0)	4.5 (3.1)	5.4 (3.7)	—	6.2 (4.3)	0.20	0.21	—	0.21

*Water-reducing agent used.

5400. Concrete Containments, Modular Construction & Mass Concrete

- Objective and Scope Met
  - Provided introductory level review of concrete containments, modular construction and mass concrete
  - Presented and discussed
    - Code for Concrete Containments
    - Examples of Structural Modules
    - Mass Concrete and the Control Measures Needed in Construction