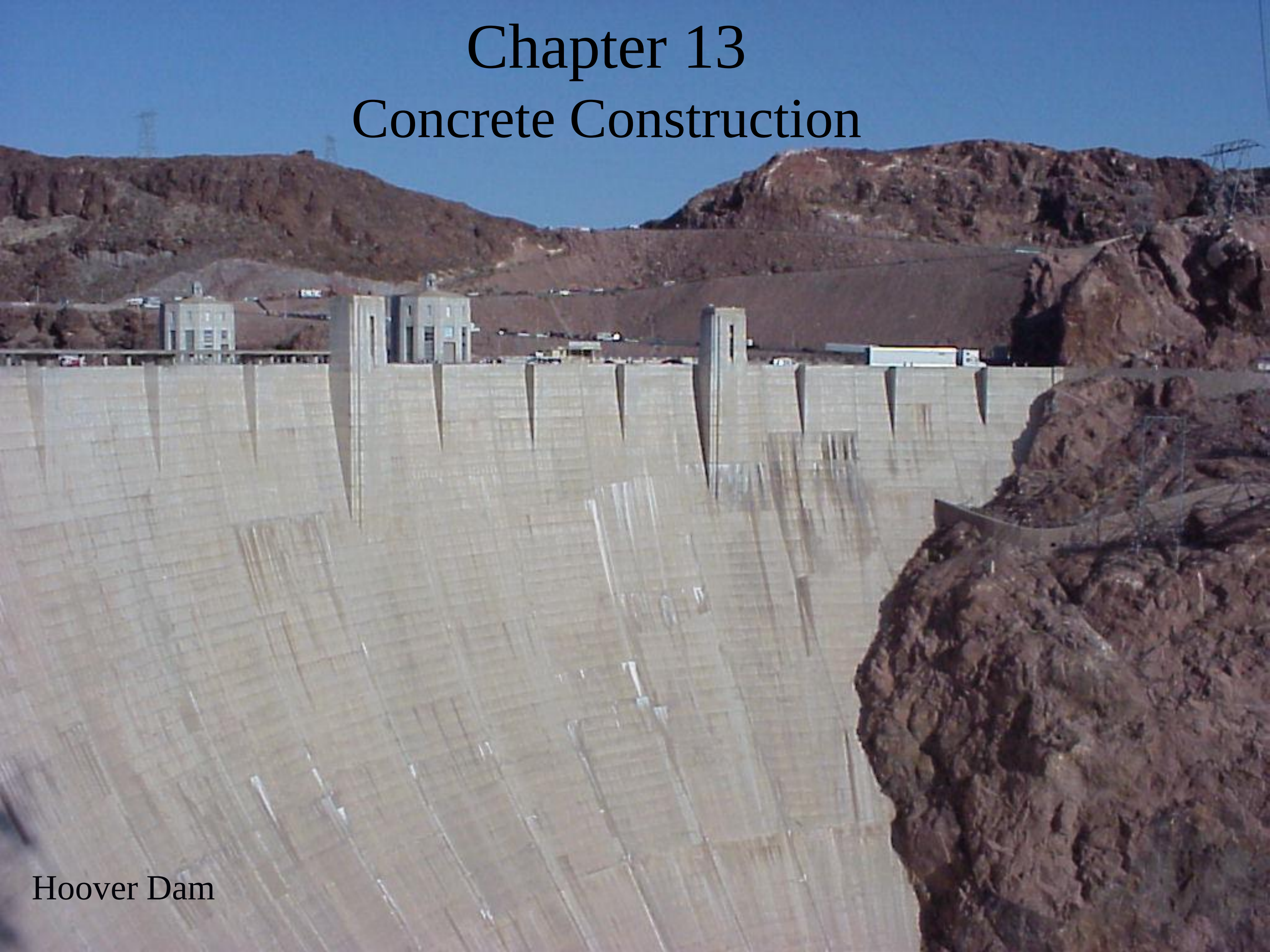
3. CONCRETE AND CONCRETE STRUCTURES

Chapter 13
Concrete Construction



Hoover Dam

3. CONCRETE AND CONCRETE STRUCTURES - OVERVIEW

3.1 Constituents: Cement, aggregates, water and admixtures

3.1.1 Purpose and function of constituents

3.1.1 History and manufacture cement - Development of cement-based products

3.1.1.1 Components, types and properties

3.1.1.1.1 Component materials required for cement making

3.1.1.1.2 Manufacturing process

3.1.1.1.3 Constituents of cement

3.1.1.1.4 Types of cement (CSA)

3.1.2 Setting, hydration and hardening of cement/concrete

3.1.3 Properties of aggregates, water and admixtures

3.1.3.1 Properties of aggregates

3.1.3.2 Properties of water

3.1.3.3 Admixtures: Need and type

3.1.3.3.1 Chemical admixtures

3.1.3.3.2 Mineral admixtures

3. CONCRETE AND CONCRETE STRUCTURES

(Cont'd)

3.2 Making and testing of concrete

3.2.1 Mixing, placing, finishing and curing of concrete

3.2.2 Properties of fresh concrete: Consistency and workability

3.2.3 Properties of hardened concrete

- **3.2.3.1 Strength: Compressive, tensile and flexure**
- **3.2.3.2 Modulus of elasticity**
- **3.2.3.3 Durability of concrete**
- **3.2.3.4 Creep and shrinkage**

3.3. Concrete Mix Design: Objectives

3.3.1 Principles of mix design

3.3.2 CSA Mix design - Based on absolute volume method

3.4 Concept of reinforcing concrete with steel - Properties and characteristics

3.5. Types of concrete: Mass concrete, reinforced concrete, pre-stressed concrete

- **Casting of slabs in grade**
- **Casting of a concrete wall**
- **Casting of a floor and roof framing system**

3.1 CONSTITUENT MATERIALS AND PROPERTIES

3.1.1 Constituents

3.1.1.1 Purpose and function of constituents

3.1.2 History and Manufacture of Cement

General - Development of cement-based products

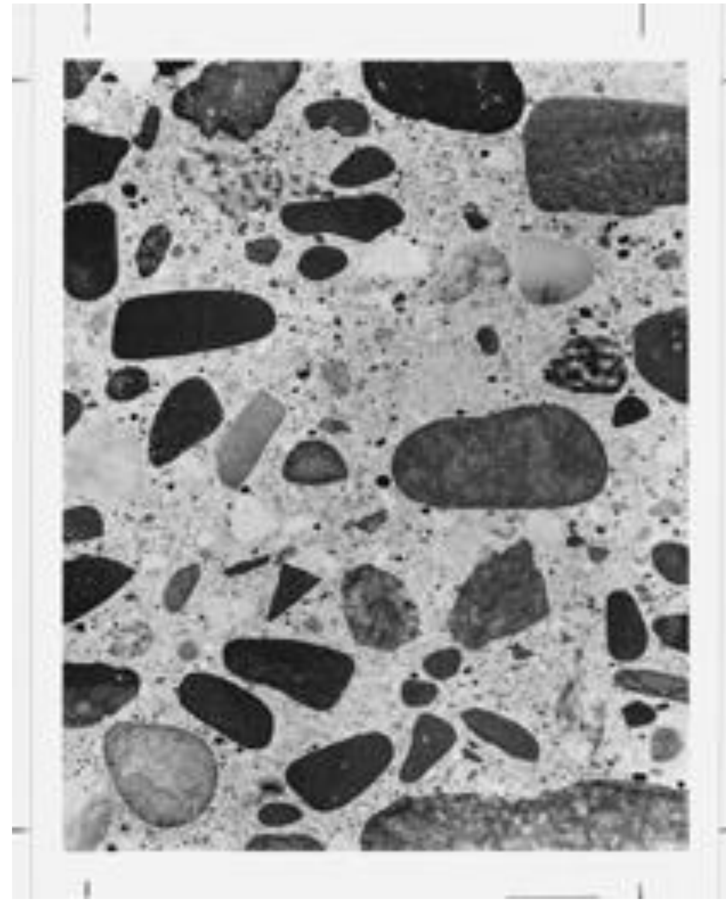
3.1.2.1 Components, types and properties

3.1.2.1.1 Component materials required for cement making - Limestone, shale, slate, clay, chalk - Lime (~ 60%), silica (~ 20%), alumina (~ 10%) - Others : Iron oxide, magnesium oxide, sulphur trioxide, alkalies, carbon-di-oxide

3.1.2.1.2 Manufacturing process - Wet and dry methods - In both methods raw materials are homogenized by casting, grinding and blending - Approximately 80% of the ground materials pass through #200 sieve - Primary and Secondary crushers; wet and dry grinding mills

Concrete

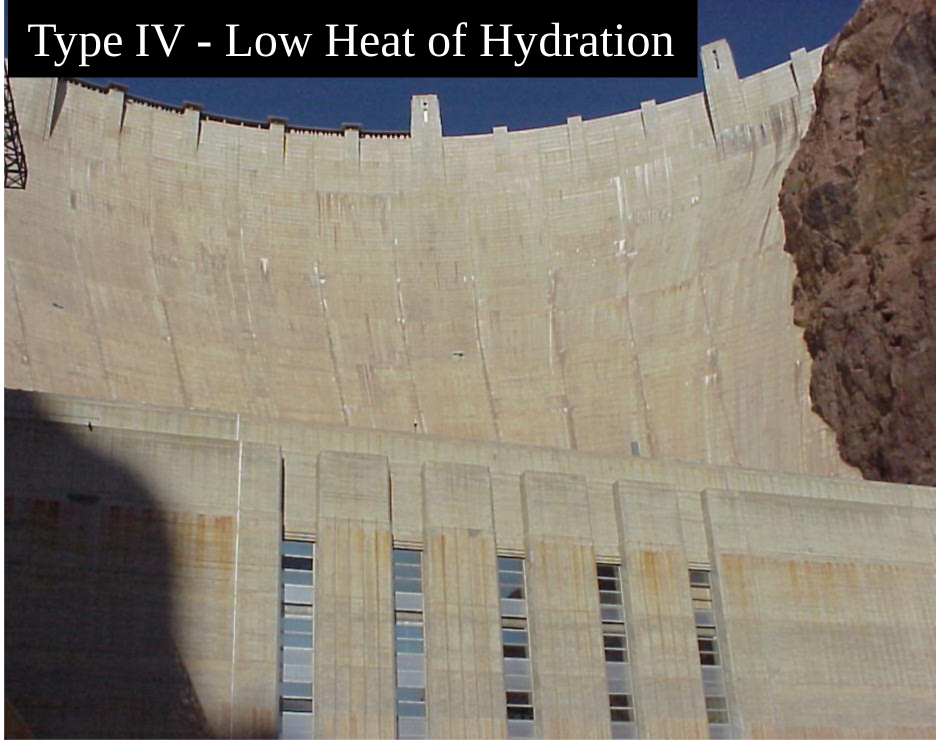
- Rocklike Material
- Ingredients
  - Portland Cement
  - Course Aggregate
  - Fine Aggregate
  - Water
  - Admixtures (optional)



Concrete Properties

- Versatile
- Pliable when mixed
- Strong & Durable
- Does not Rust or Rot
- Does Not Need a Coating
- Resists Fire

Type III - High Early


Type IV - Low Heat of Hydration


Type I - Normal


Type I - Normal

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

- **Wet process:** Mix containing homogenized constituents and 30 - 40 % of water is heated to 1510^o C in a revolving (slightly) inclined kiln - Oxide of silica, calcium and aluminum combine to form cement clinkers - Mixed with calcium sulphate (gypsum) to reduce the rate of setting and crushed into powder in ball mills before storing in silos or bags

- **Dry process:** The homogenized mix is fed into the kiln and burned in a dry state - Other steps are the same as for the wet process - Considerable savings in fuel consumption, but workplace is dustier

3.1.2.1.3 Constituents of cement: 75% is composed of calcium silicates; rest is made up of Al_2O_3, Fe_2O_3 and $CaSO_4$

Di-calcium silicate (C_2S) - $2CaO.SiO_2$ (15-40%)

Tri-calcium silicate (C_3S) - $3CaO.SiO_2$ (35-65%)

Tri-calcium aluminate (C_3A) - $3CaO.Al_2O_3$ (0-15%)

Tetra-calcium alumino-ferrite (C_4AF) - $4CaO.Al_2O_3.Fe_2O_3$ (6 -20%)

Calcium sulphate ($CaSO_4$) - (2%)

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

3.1.2.1.4 Types of cement (CSA)

Type 10 - Standard Portland cement - Used for general purposes; air entrained (50% C_3S; 24% C_2S; 11%C_3A; 8% C_4AF; 72% passing 45 μm sieve)

Type 20 - Modified Portland cement - Used when sulphate resistance and/or generation of moderate heat of hydration are required; air entrained (42% C_3S; 33% C_2S; 5% C_3A; 13% C_4AF; 72% passing 45 μm sieve)

Type 30 - High early strength Portland cement - Used for early strength and cold weather operations; air entrained (60% C_3S; 13% C_2S; 9% C_3A; 8% C_4AF; ….)

Type 40 - Low heat Portland cement - Used where low heat of hydration is required; air entrained (26% C_3S; 50% C_2S; 5% C_3A; 12% C_4AF; …….)

Type 50 - High sulphate-resistant concrete - Used where sulphate concentration is very high; also used for marine and sewer structures; air entrained (40% C_3S; 40 % C_2S; 3.5 % C_3A; 9% C_4AF; 72% passing 45 μm sieve)

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont’d)

3.1.2.2 Setting, Hydration and Hardening

- When cement is mixed with sufficient water, it loses its plasticity and slowly forms into a hard rock-type material; this whole process is called setting.
- Initial set: Initially the paste loses its fluidity and within a few hours a noticeable hardening occurs - Measured by Vicat’s apparatus
- Final set: Further to building up of hydration products is the commencement of hardening process that is responsible for strength of concrete - Measured by Vicat’s apparatus
- Gypsum retards the setting process
- Hot water used in mixing will accelerate the setting process
- During hydration process the following actions occur:

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

$2(3CaO.SiO_2) + 6H_2O = 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$

(Tricalcium silicate) (Tobermerite gel)

$2(2CaO.SiO_2) + 4H_2O = 3CaO.2SiO_2.3H_2O+Ca(OH)_2$

(Dicalcium silicate) (Tobermerite gel)

$3CaO.Al_2O_3 + 12H_2O + Ca(OH)_2 = 3CaO.\ Al_2O_3.\ Ca(OH)_2.12H2O$

(Tricalcium aluminate) (Tetra-calcium aluminate hydrate)

$4CaO.Al_2O_{3.}.Fe_2O_3 + 10H_2O + 2Ca(OH)_2 = 6CaO.\ Al_2O_3.\ Fe_2O_3.12H2O$

(Tetra-calcium alumino-ferrite) (Calcium alumino-ferrite hydrate)

$3CaO.Al_2O_3+10H_2O+ CaSO_4.2H_2O = 3CaO.Al_2O_3.CaSO_4.12H_2O$

(Tricalcium aluminate) (Calcium sulphoaluminate hydrate)

- C_3S hardens rapidly: responsible for early strength
- C_2S hardens slowly and responsible for strength gain beyond one week
- Heat of hydration: Hydration is always accompanied by release of heat
- C_3A liberates the most heat - C_2S liberates the least

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

3.1.3 Properties of Aggregates, Water and Admixtures

- Aggregates make up up 59-75% of concrete volume; paste constitutes 25-40% of concrete volume. Volume of cement occupies 25-45% of the paste and water makes up to 55-75%. It also contains air, which varies from 2-8% by volume

- Strength of concrete is dependent on the strength of aggregate particles and the strength of hardened paste

3.1.3.1 Properties of Aggregates

3.1.3.1.1 Compressive strength: Should be higher than concrete strength of 40-120 MPa

3.1.3.1.2 Voids: Represent the amount of air space between the aggregate particles - Course aggregates contain 30-50% of voids and fine aggregate 35-40%

3.1.3.1.3 Moisture content represents the amount of water in aggregates: absorbed and surface moisture - Course aggregates contain very little absorbed water while fine aggregates contain 3-5% of absorbed water and 4-5% surface moisture

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

3.1.3.1.4 Gradation: Grading refers to a process that determines the particle size distribution of a representative sample of an aggregate - Measured in term of fineness modulus - Sieve sizes for course aggregates are: 3/4", 1/2", 3/8", #4 and #8 - Sieve sizes for fine aggregates are #4, #8 , #16, #30, #50 and #100

3.1.3.1.5 Durability of concrete: Determined by abrasion resistance and toughness

3.1.3.1.6 Chemical reactivity: determined by the alkali-aggregate reaction

3.1.3.2 Properties of Water

Any drinkable water can be used for concrete making - Water containing more than 2000 ppm of dissolved salts should be tested for its effect on concrete

- Chloride ions not more than 1000 ppm - Sulphate ions not more than 3000 ppm
- Bicarbonate ions not more than 400 ppm

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

3.1.3.3 Need and types

Admixture are materials that are added to plastic concrete to change one or more properties of fresh or hardened concrete.

To fresh concrete: Added to influence its workability, setting times and heat of hydration

To hardened concrete : Added to influence the concrete's durability and strength

Types: Chemical admixtures and mineral admixtures

- Chemical: Accelerators, retarders, water-reducing and air-entraining
- Mineral : Strength and durability

3.1.CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

3.1.3.3.1 Chemical admixtures

- Accelerating admixtures: Compounds added to cement to decrease its setting time and to improve the early strength developments - Used in cold-weather concreting - A 25% of strength gain observed at the end of three days - $CaCl_2$ (less than 2% by weight of cement); Not recommended for cold weather concreting; Triethanolamine; Sodium thiocyanate; Acetyl alcohol; Esters of carbonic and boric acids; Silicones - Problems: Increased heat of hydration, also leads to corrosion of steel

- Retarding admixtures: Added to concrete to increase its setting times - Used in hot weather applications - Sodium/calcium triethanolamine salts of hydrogenated adipic or gluconic acid - Problem: early strength of concrete reduced

- Water-reducing admixtures and super plasticizers

water used in concrete mixes - High range water reducers reduce the water required for mixing by 12% or greater - Added to improve the consistency/workability of concrete and increase the strength - Water reducers: Lignosulphates, hydroxylated carboxylic acids, carbohydrates - Superplasticizers: Suphonated melamine/naphtalene formaldehyde condensates

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

- Air-entraining admixtures: Allows dispersal of microscopic air bubbles (diameters ranging from 20 to 2000 μm) throughout the concrete - Decreases the freeze-thaw degradation

- Foaming agents: Vinsol resin; Sulphonated lignin compounds; Petroleum acid compounds; Alkyd benzene compounds

3.1.3.3.2 Mineral Admixtures:

- Used in concrete to replace part of cement or sand - When used to replace sand called as supplementary cementing materials - Added in large quantities compared to chemical admixtures.

- Pozzolans: Raw and calcined natural materials such as cherts, shale, tuff and pumice - Siliceous or siliceous and aluminous materials which by themselves possess no cementing property, but in fine pulverized form and in the presence of water can react with lime in cement to form concrete

3.1 CONSTITUENT MATERIALS AND PROPERTIES (Cont'd)

- Fly ash: By-product of coal from electrical power plants - Finer than cement - Consists of complex compounds of silica, ferric oxide and alumina - Increases the strength of concrete and decreases the heat of hydration - Reduces alkali aggregate reaction.

- Silica fume: By-product of electric arc furnaces - Size less than 0.1μm -

Consists of non-crystalline silica - Increases the compressive strength by 40-60%

3.2 MAKING AND TESTING OF CONCRETE

3.2.1 Mixing, placing, finishing and curing of concrete

3.2.1.1 Mixing: Involves weighing out all the ingredients for a batch of concrete and mixing them together - A six-bag batch contains six bags of cement per batch - Hand-mixing (tools used) - Mixing with stationary or paving mixer - Mixing with truck mixers - Rated capacities of mixers vary

3.2.1.2 Pumping and placing: Concrete is conveyed to the construction site in wheel barrows, carts, belt conveyors, cranes or chutes or pumped (high-rise building) - Pumps have capacities to pump concrete up to 1400 feet and at 170 cu.yds. per hour - Concrete should be placed as near as possible to its final position - Placed in horizontal layers of uniform thickness (6” to 20”) and consolidated before placing the next layer

3.2.1.3 Finishing: The concrete must be leveled and surface made smooth/flat - Smooth finish; Float/trowel finish; Broom finish; Exposed aggregate finish

Transit Mix Truck (Ready-Mix Truck)


Placement Today - Direct From
the Transit Mixer, or

Improperly consolidated Concrete

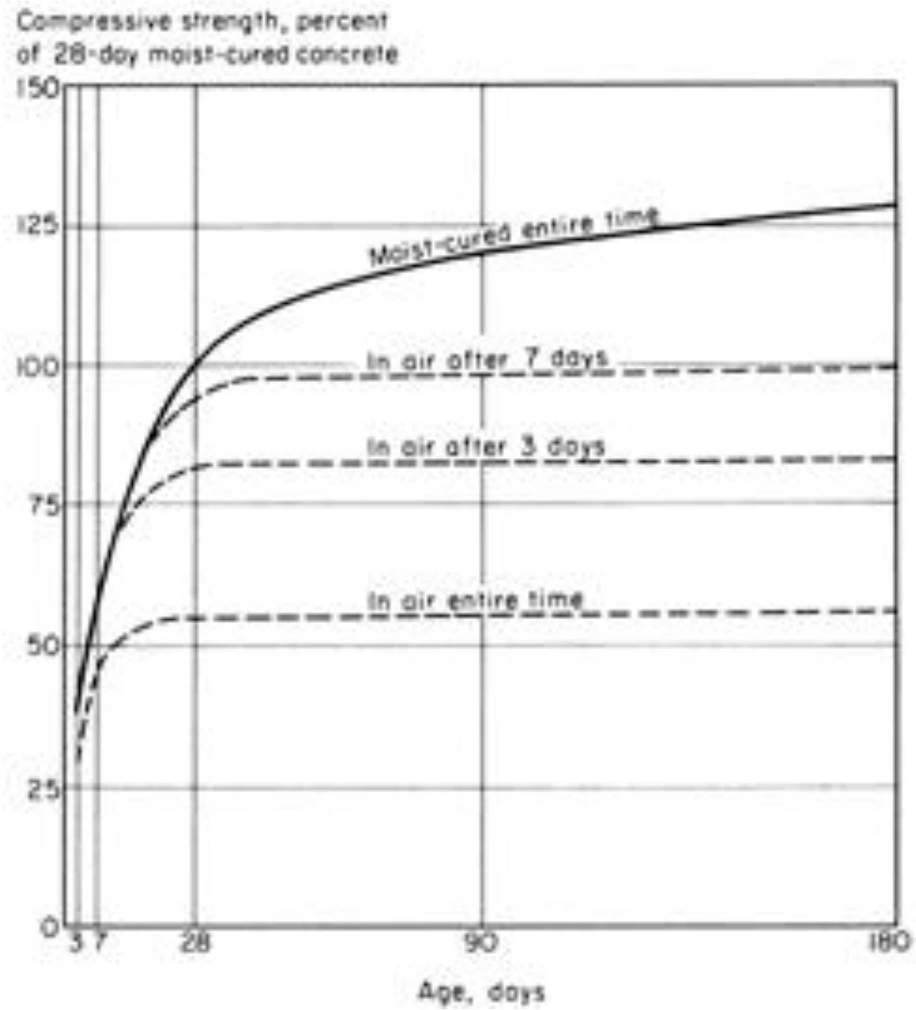
3.2 MAKING AND TESTING OF CONCRETE (Cont'd)

3.2.1.4 Curing of concrete : Process of maintaining enough moisture in concrete to maintain the rate of hydration during its early stages - The most important single step in developing concrete strength, after proper mix design - If not properly carried out, affects its strength, water tightness and durability - **Methods of curing:** Ponding or immersion; spraying or fogging ; wet coverings (with burlap, cotton mats or tugs); Impervious paper (two sheets of Kraft paper cemented together by bituminous adhesive with fiber reinforcements); Plastic sheets (Polyethyelene films 0.10 mm thick); membrane-forming curing compound; Steam curing

3.2.2 Properties of Fresh Concrete: Concrete should be such that it can be transported, placed, compacted and finished without harmful segregation - The mix should maintain its uniformity and not bleed excessively; these two are collectively called as workability - Bleeding is movement and appearance of water at the surface of freshly-placed concrete, due to settlement of heavier particles

Concrete Curing

- Must be kept Moist
- Moisture Needed for:
  Hydration
  (Development of Strength)



Top of Slab being protected during cold weather


Sample collected


Slump Cone Filled


Cone Removed and Concrete Allowed to 'Slump'


Slump Measured

3.2 MAKING AND TESTING OF CONCRETE (Cont'd)

3.2.2.1 Consistency and Workability: Consistency is a measure of its wetness and fluidity - Measured by the slump test - Workability dependent on water content, fineness of cement, and surface area of aggregates

3.2.3 Properties of Hardened Concrete:

Dependent on strength (compressive, tension and flexure), Modulus of elasticity, Durability, Creep and shrinkage

3.2.3.1 Strength: Compressive strength: Determined using 3", 4" or 6" diameter cylinders having twice the diameter in height; can be as high as 100 MPa - Dependent on amount of cement, curing, days after casting, fineness modulus of mixed aggregate, water-cement ratio and temperature - **Tensile strength:** Obtained using split cylinder tests - **Flexural strength:** Determined by third point loading - Modulus of rupture

Specified by 28 Day Compressive Strength

Measured in pounds of compressive strength per square inch (psi) or Newtons/square metre

Primarily Determined By:

- Amount of Cement
- Water-Cement Ratio
- Other influencing factors:
  - Admixture(s)
  - Aggregate Selection & Gradation

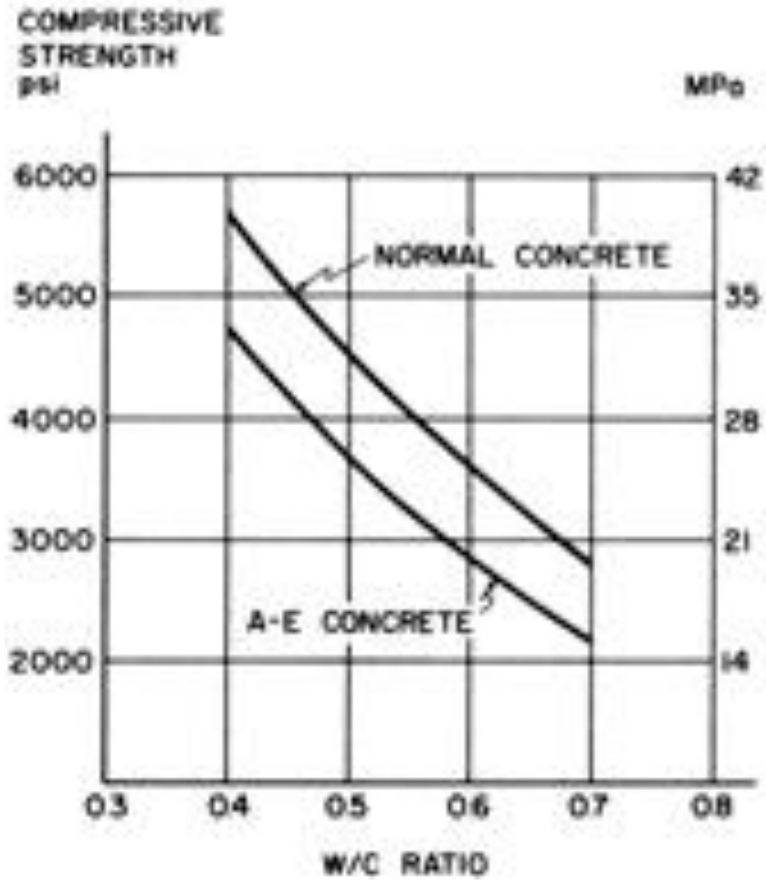
Strength Ranges: 2000 - 22,000+ psi

If a low water cement ratio is desirable for quality concrete, why would one ever want to add excess water?

Concrete with high W/C ratio is easier to place.

Workability, with desired qualities, often accomplished with admixtures

EFFECT OF WATER-CEMENT RATIO



3.2 MAKING AND TESTING OF CONCRETE (Cont'd)

2.3.2 Modulus of Elasticity

As per ASTM

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.00005}$$

S_2 = stress at 40% of ultimate load with a strain of ε_2

S_1 = stress at ε_1 equal to 0.00005

3.2 MAKING AND TESTING OF CONCRETE (Cont'd)

- It is also dependent on compressive strength, and density of concrete

$$\mathbf{E = 33\, w^{1.5}\, [f'_c]^{0.5}}$$

where,

w = density of concrete

f'_c = compressive strength of concrete

3.2.3.3 Durability of Concrete: Dependent on alkali aggregate reaction, freeze-thaw degradation and sulphate attack

- Alkali-aggregate reaction - Certain aggregates react with the alkali of Portland cement (released during hydration), in the presence of water, producing swelling - Form map-like cracks - Use low alkali cement to prevent this effect - Use of fly ash minimizes

3.2 MAKING AND TESTING OF CONCRETE (Cont'd)

- Freeze-thaw process: Water stored in voids of concrete expands as a result of freezing - Generates stresses that tend to crack the concrete after a number of cycles - Air entrainment improves resistance to freezing-thaw cracking

- Sulphate attack: Sulphates in soil and seawater react with aluminates in cement to produce compounds that increase in volume - Leads to cracking - Use low alumina cement - Fly ash reduces sulphate attack

- Carbonation of concrete: Carbon-di-oxide from the air penetrates the concrete and reacts with $Ca(OH)_2$ to form carbonates; this increases shrinkage during drying (thus promoting crack development) and lowers the alkalinity of concrete, which leads to corrosion of steel reinforcement.

- Creep and Shrinkage: **Creep** is the time dependent increase in strain and deformation due to an applied constant load - Reversible creep and irreversible

creep - **Shrinkage** is made up of plastic shrinkage and drying shrinkage - Plastic shrinkage occurs when the concrete is plastic and is dependent on type of cement, w/c ratio, quantity and size of aggregates, mix consistency etc. - Drying shrinkage occurs when water is lost from cement gel - Smaller than 1500×10^{-06} (strain)

3.3 CONCRETE MIX DESIGN

Objective : To determine the **proportion of ingredients** that would produce a **workable concrete mix** that is **durable**, and of **required strength**, and at a **minimum cost**

3.3.1 Principles of Mix Design

- Workable mix
- Use as little cement as possible
- Use as little water as possible
- Gravel and sand to be proportioned to achieve a dense mix
- Maximum size of aggregates should be as large as possible, to minimize surface area of aggregates

3.3. CONCRETE MIX DESIGN (Cont'd)

3.3.1.1 Methods of Mix Design

- Volumetric method (arbitrary)
- Proportioning from field data method
- Proportioning by trial mixtures method
- Mass proportioning method
- Absolute volume method (CSA approved method)

3.3.2 CSA Design based on Absolute Volume

3.3.2.1 Using the given data, select the maximum slump as per the task

3.3.2.2 Select the maximum size of aggregates

3.3.2.3 Estimate the mixing water and air content

3.3.2.4 Select the w/c ratio

3. Concrete Mix Design (cont.)

3.3.2.5 Calculate the cement content

3.3.2.6 Estimate the weight of dry rodded coarse aggregates

3.3.2.7 Estimate the fine aggregate content

3.3.2.8 Find the weights of field mix (containing moisture) per unit volume

3.3.2.9 Compute the field mix proportions

3.4 CONCEPT OF REINFORCING CONCRETE WITH STEEL REINFORCEMENT

- Why do you need steel reinforcement?
- Properties of steel reinforcing bars
- Size, grade, identification marks, ribbed
- Bars, welded wire mesh
- Standard hooks, ties and stirrups
- Chairs and bolsters for supporting reinforcing bars in beams and slabs
- Continuity in beams and slabs
- One-way or two-way reinforced beams and slabs

Concrete Reinforcing

- **Concrete - No Useful Tensile Strength**
- **Reinforcing Steel - Tensile Strength**
  - Similar Coefficient of thermal expansion
  - Chemical Compatibility
  - Adhesion Of Concrete To Steel

- **Theory of Steel Location**

  "Place reinforcing steel where the concrete is in tension"

Reinforcing Steel

- **Sizes**

  Eleven Standard Diameters

  3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 18

  Number refers to 1/8ths of an inch

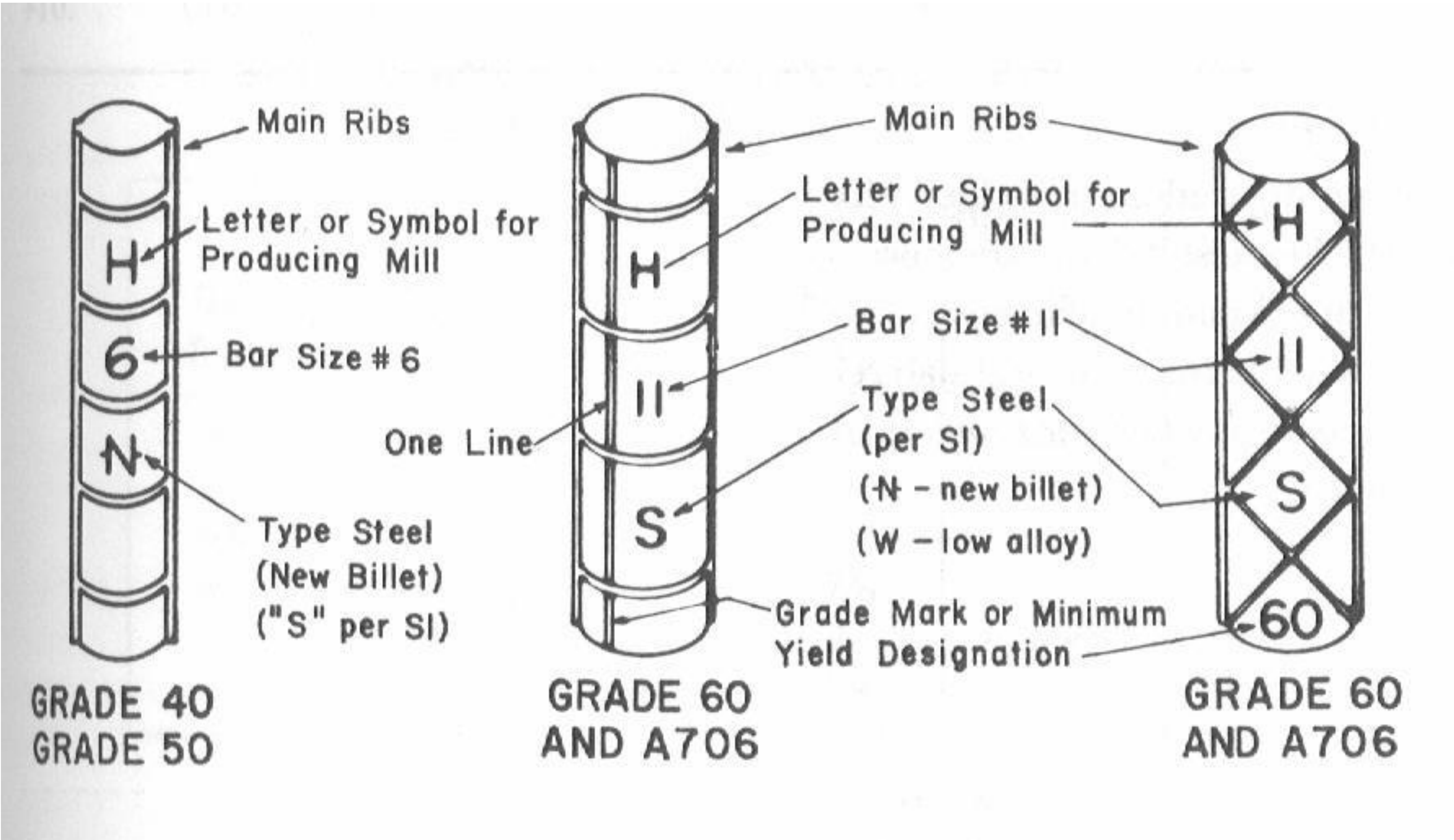
- **Grades**

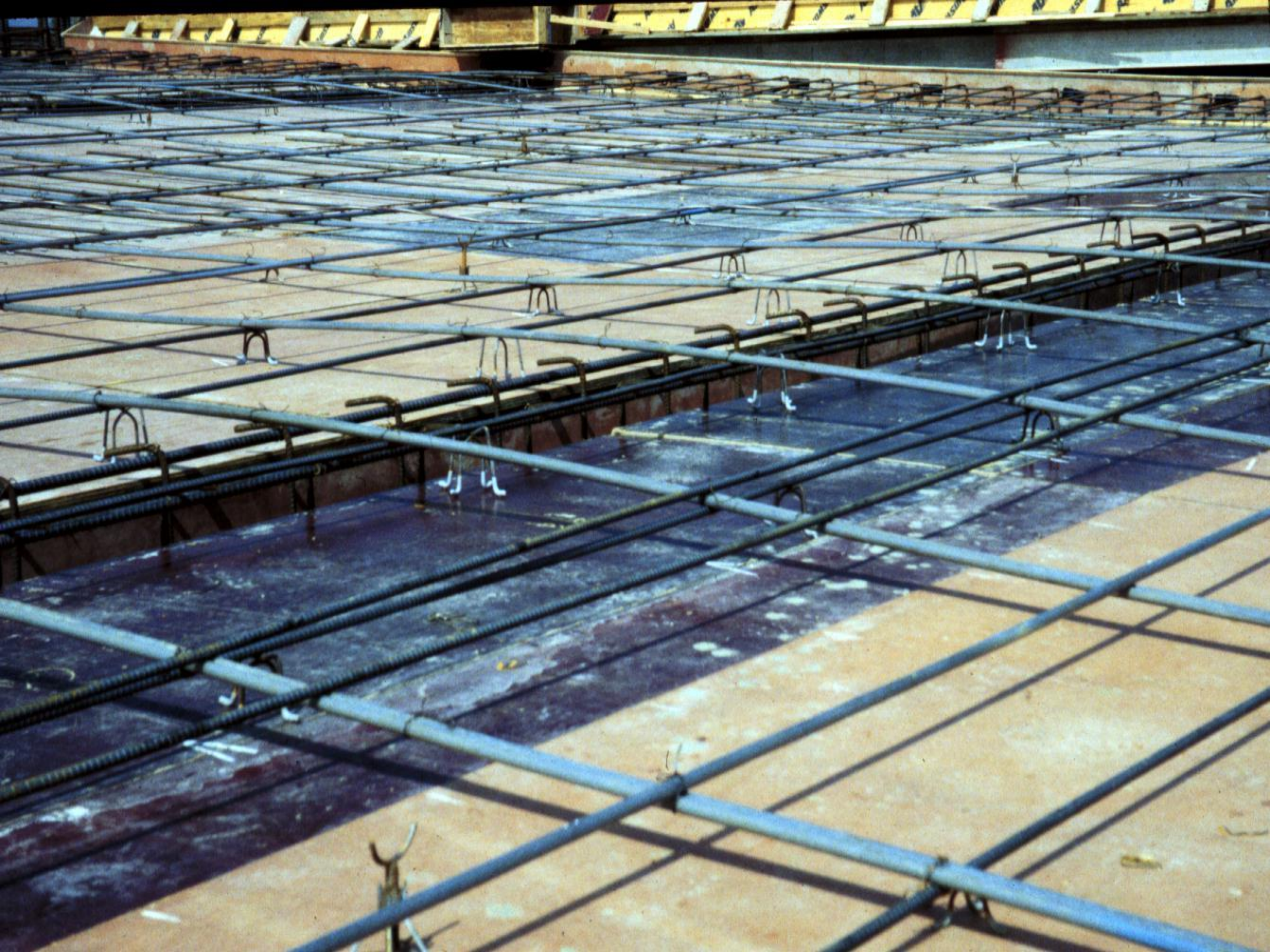
  40, 50, 60

  Steel Yield Strength

  (in thousands of psi)

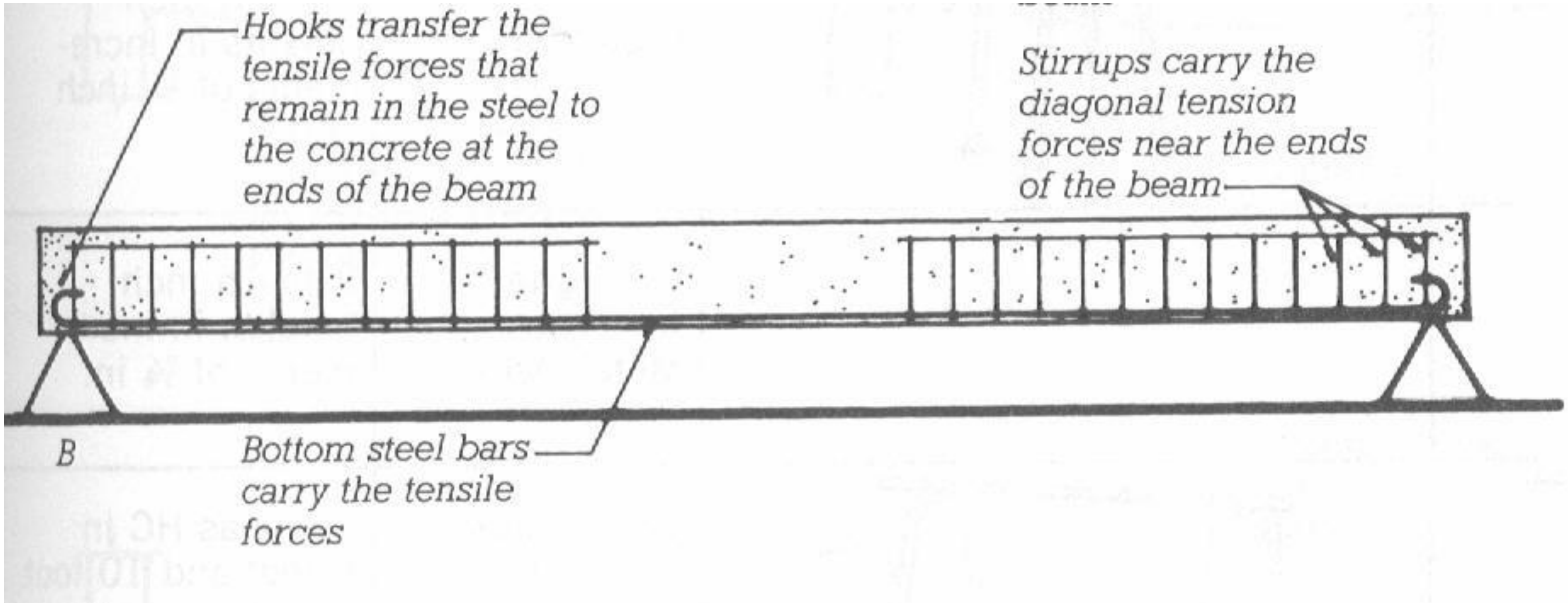
Details of Markings in Reinforcement





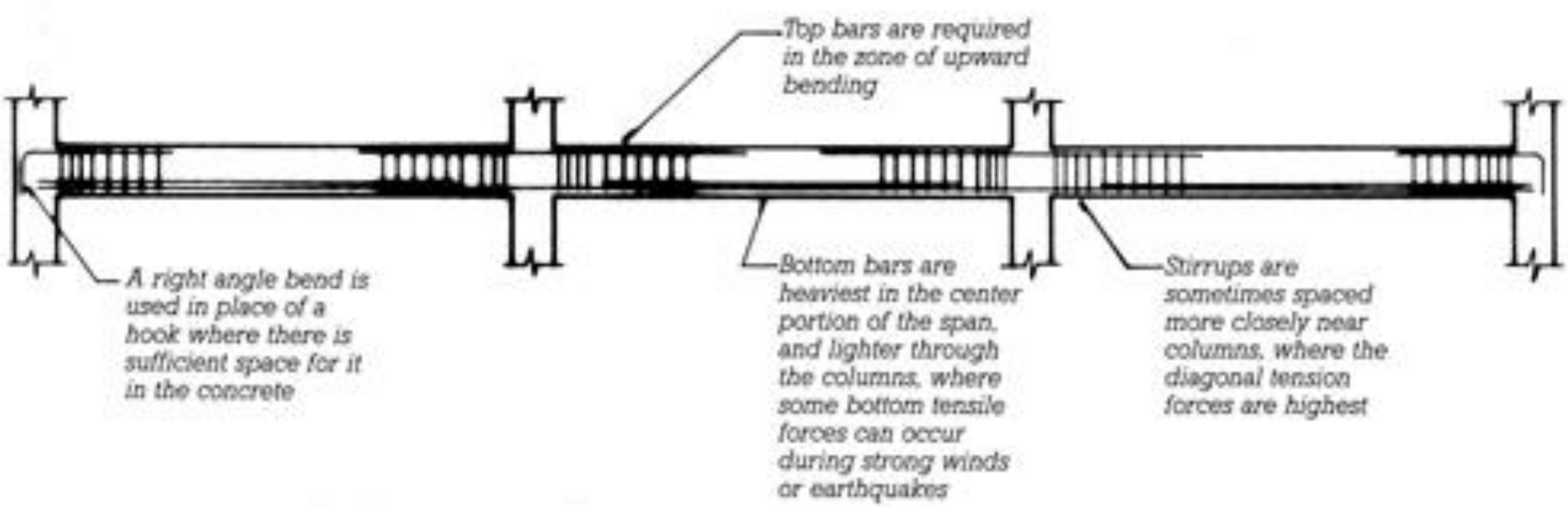
Reinforcing Stirrups

- **Position Beam Reinforcing**
- **Resist Diagonal Forces / Resist Cracking**



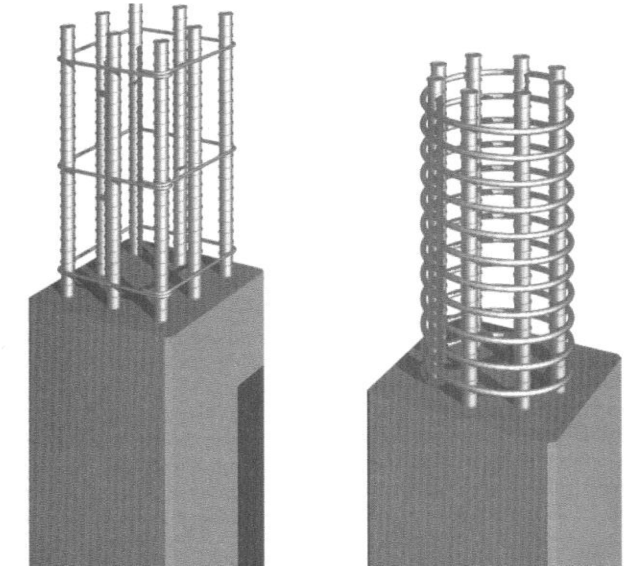
Reinforcing a Continuous Concrete Beam

- **Most Beams are not simple span beams**
- **Location of Tension Forces Changes**
- **Midspan - Bottom in Tension**
- **At Beam Supports - Top in Tension**



Reinforcing Concrete Columns

- **Vertical Bars**
  - **Carry Compressive &**
    Tension Loads
  - **Bar Configuration -**
    Multi-story
- **Ties - Small bars**
  - **- Wrapped around the vertical bars**
  - **- Help prevent buckling**
  - **- Circular or Rectangular**
  - **- Column Ties or**
  - **- Column Spirals**
- **Installation**



Welded Wire Fabric (WWF)

- **Type of Reinforcing**
- **Grid of “wires” spaced 2-12 inches apart**
- **Specified by wire gauge and spacing**
- **Typical Use - Horizontal Surfaces**
- **Comes in Mats or Rolls**
- **Advantage - Labor Savings**

3.5. TYPE OF CONCRETE FOR STRUCTURAL USE

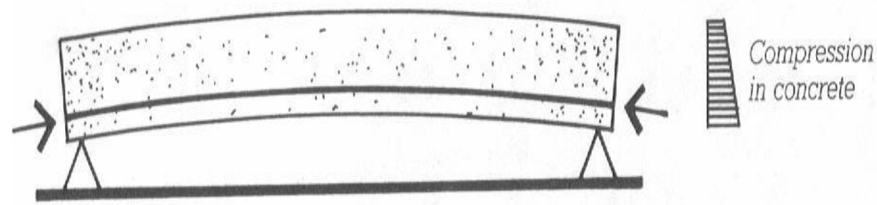
- Mass concrete
- Normal reinforced concrete - Beam behavior and cracking
- Pre-stressed concrete
- Mechanics of pre-stressing
- Pre-tensioned and post-tensioned profile of pre-stressing bars
- Casting of a concrete wall
- Casting of a floor and roof framing system

Prestressing

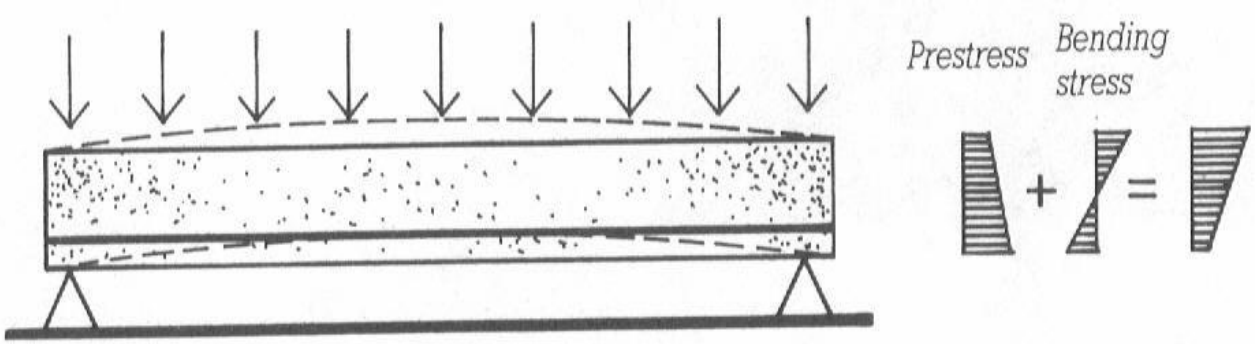
Theory: **"Place all the concrete of the member in compression" (take advantage of concrete's compressive strength of the entire member)**

Advantages:

- **Increase the load carrying capacity**
- **Increase span length, or**
- **Reduce the member's size**



When a concrete beam is prestressed, all the concrete acts in compression. The off-center location of the prestressing steel causes a camber in the beam



Under loading, the prestressed beam becomes flatter, but all the concrete still acts in compression, and no cracks appear

Prestressing - Pretensioning

- **Pretensioning**
  - **Prior to concrete placement**
  - **Generally performed**
  - **at a plant - WHY???**

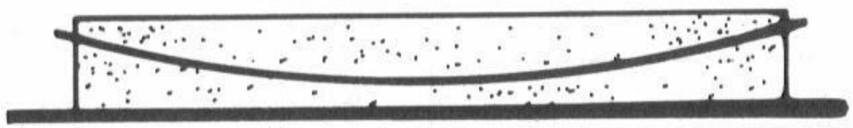
1. The first step in pretensioning is to stretch the steel prestressing strands tightly across the casting bed

2. Concrete is cast around the stretched strands and cured. The concrete bonds to the strands

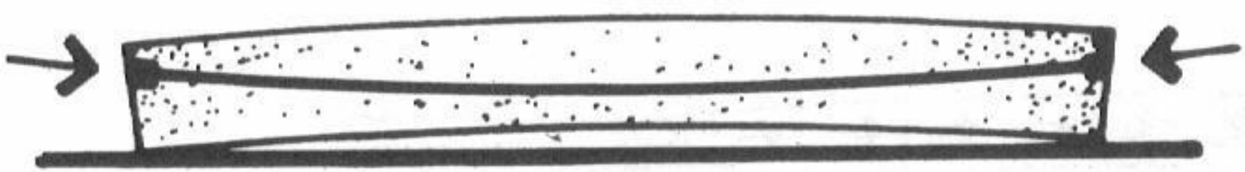
3. When the strands are cut the concrete goes into compression and the beam takes on a camber

Prestressing - Posttensioning

- Cables positioned prior to concrete placement
- Stressed after concrete placement (& curing)
- Generally performed
  at the jobsite



1. In posttensioning, the concrete is not allowed to bond to the steel strands during curing

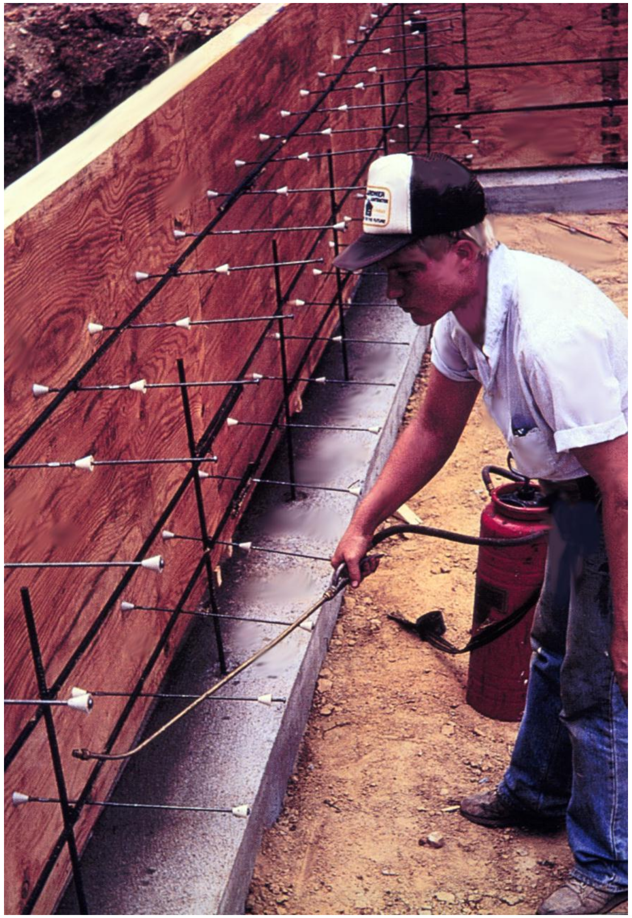


2. After the concrete has cured, the strands are tensioned with a hydraulic jack and anchored to the ends of the beam. If the strands are draped, as shown here, higher structural efficiency is possible than with straight strands

Large Conduits for Placement of Post Tensioning Cables on a Bridge

Casting A Concrete Wall (cont)

- Layout, Install one side, anchor, & brace
- Coat w/ Form Release

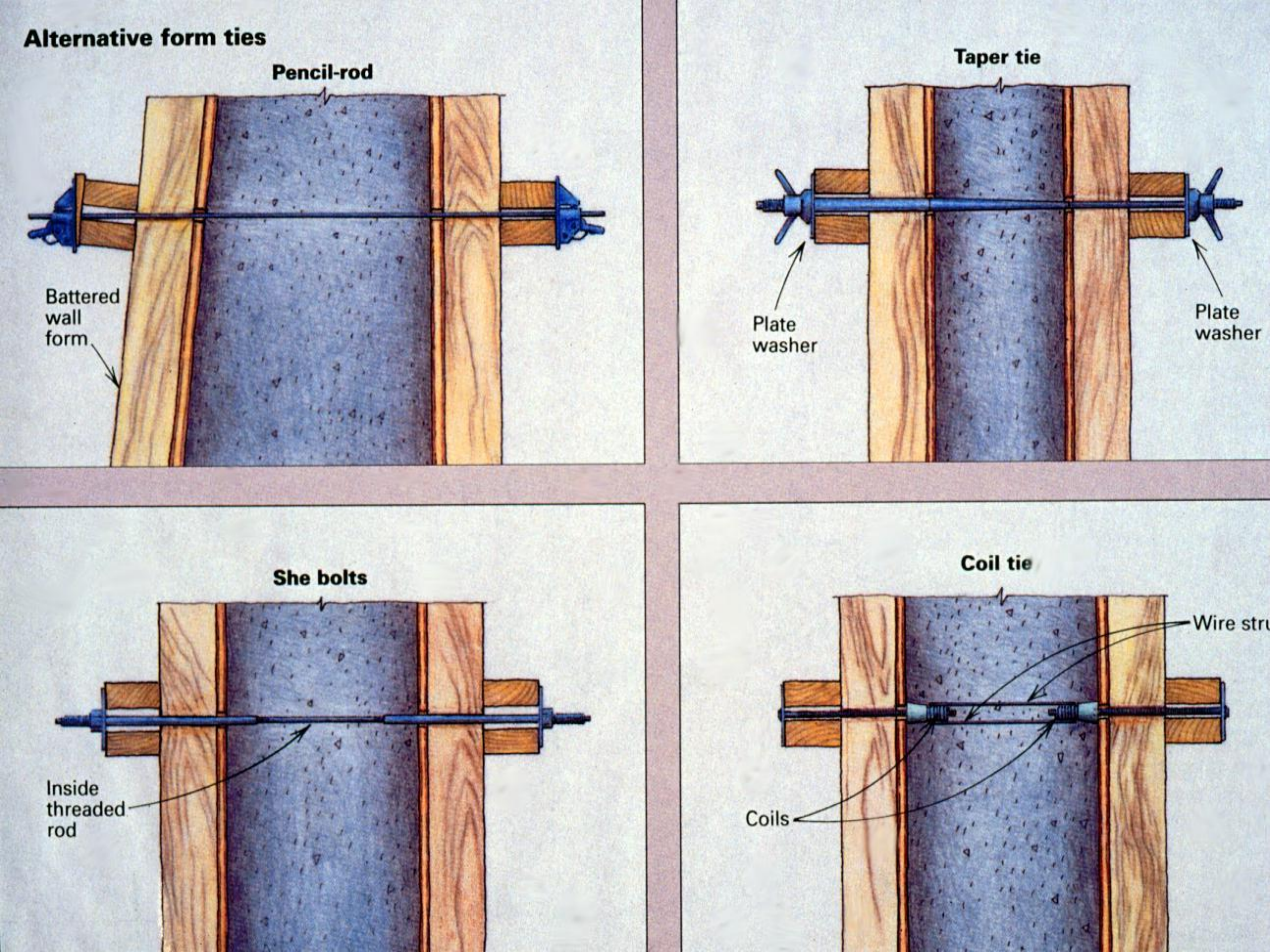



Wall Braced
Wall Braced

Casting A Concrete Wall (cont)

- **Install Form Ties**

  “Small diameter metal rods which hold the forms together (generally remain in the wall)



Alternative form ties
Pencil-rod
Battered wall form
Taper tie
Plate washer
Plate washer
She bolts
Inside threaded rod
Coil tie
Wire stru
Coils

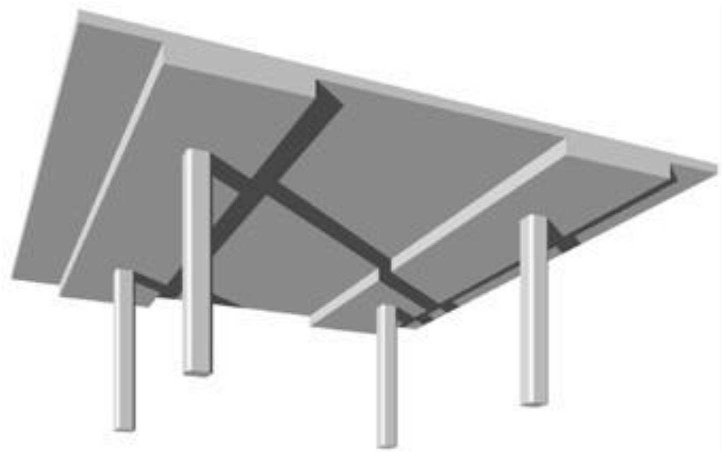
Casting A Concrete Wall (cont)

- **Install Embeds (if required)**
- **Install Bulkheads**
- **Inspect**
- **Erect second side**
- **Plumb& Brace**
- **Establish Pour Hgt.**

Elevated Framing Systems

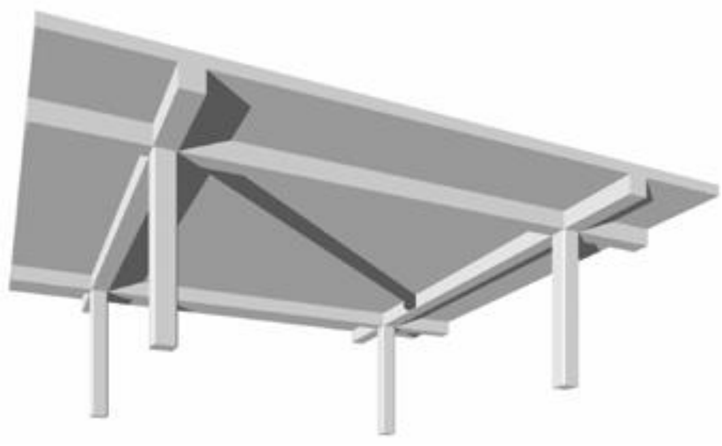
- **One-Way System**

  Spans across parallel lines of support furnished by walls and/or beams



- **Two-Way System**

  Spans supports running in both directions

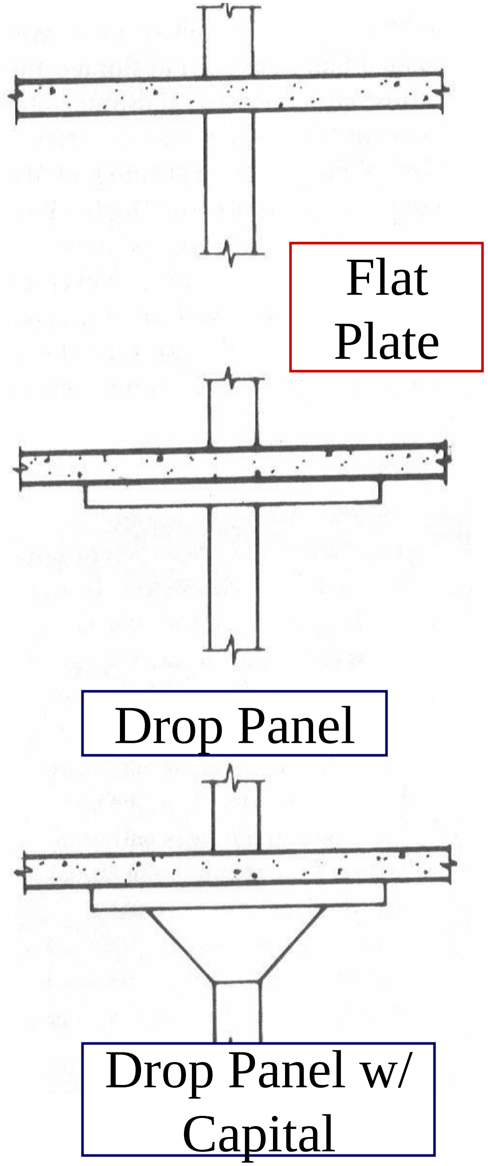


One-Way Slab & Beam

Two-Way Flat Slab

- **Flat slab w/ reinforcing beams**

- **With, or w/o Capitals or drop panels**



Two-Way Waffle Slab