Lecture 2

CM 510
Advanced Construction Techniques

- Dimensional Stability of Concrete
- Progress in Concrete Technology

1. Discuss Term Projects
2. Sign up for Presentations
3. Information on Field Trip
4. Success and Failures
5. Lecture 2
TERM PROJECT
GUIDELINES

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• Introduction
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• Conclusion
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Rancocas Bridge, NJ
BEFORE

900 ton double track bridge
On April 5, 2001, the steel portion of the light rail bridge over the Rancocas Creek, which was floating on a barge near its final position, rested at an angle as the barge supporting it capsized.

- The steel span, 200 feet in length, struck a crane, damaging it.
- There were no serious injuries reported.
CONSTRUCTION FAILURES
2nd Thai-Lao Friendship Bridge (2005)
CONSTRUCTION FAILURES
2nd Thai-Lao Friendship Bridge

- A large crane being used in the construction of the second Thai-Lao Friendship Bridge collapsed.
- The accident took place at about 4:45pm on Friday, July 22, 2005, when a crane being used to airlift concrete girders for installation suddenly snapped.
- The falling pieces of equipment hit about 30 engineers and workers at the construction site.
CONSTRUCTION FAILURES
2nd Thai-Lao Friendship Bridge
I-35W Mississippi River Bridge
An Engineering Failure
About

- Opened 1967
- Most recent river crossing on a new site in Minneapolis
- I-35W
- Minnesota’s 5th busiest: 140,000 vehicles daily

Aerial view of the I-35W Mississippi River Bridge. Just to its right is the older 10th Avenue Bridge, and at the far right is the Northern Pacific Bridge Number 9. At the left is the Lower Saint Anthony Falls Dam.
Design

- Eight lane, 1,907 ft
- Steel truss arch bridge
- 3 parts: deck superstructure and substructure
- Unique features
  - no piers in water
  - Anti-ice system

Inspections and the Road to Failure

- Bridge inspections must occur at least every two years by federal law
- I-35W bridge rated “structurally deficient” since 1990
- Annual inspections since 1993
- 2005 Bridge sufficiency rating: 50%
  - Only 4% similar bridges scored below 50%
- “Structurally deficient” due to corrosion in bearings
- Found signs of cracking and fatigue
- Only patch-up repairs conducted
- Scheduled for reconstruction in 2020-2025
Setting for Collapse

- Minor construction on bridge during few weeks prior
- Four of the eight lanes were closed for resurfacing
- 575,000 lbs. of construction supplies and equipment on bridge
- Rush hour traffic, about 100 vehicles on bridge

Collapse

- August 1, 2007 at 6:05 pm
- Central span collapsed, then the adjoining
- South part toppled eastward 81 feet

Collapse of the I-35W Bridge, looking southward
Recovery

- 93 people rescued from the collapsed bridge within three hours
- US Army Corps of Engineers lowered river level 2 feet downriver at Fort Dam to allow easier access to vehicles

Timeline

- 1967: Built
- August 1, 2007: Collapsed
- August 18: 80 of 88 stranded cars and trucks removed to impound lot
- August 21: last person’s remains pulled from wreckage
- End of October: completed demolition of bridge remnants
Expense

- 13 deaths, about 100 more injured
- Traffic congestion, rerouting
- Cost of emergency response: +$8 million
- Cost of collapse to state: $400,000 – 1 million/day
- Cost of rebuilding

Tools and Techniques Used to Analyze the Bridge Collapse

- Helicopters use lasers to produce a detailed map of the debris
- Then the images are uploaded to a computer where software can recreate the bridge
- The software recreates different scenarios that could have made the bridge collapse, then determines where it failed
- Results are then analyzed in case the computer assumptions are incorrect
Possible Reasons it Collapsed

- In past inspections fatigue cracks were found and part of the truss gave way the bridge would collapse
- The bridge was under larger amounts of pressure with the construction work being done
- Some say a design flaw - steel plates connected to girders (large support beams) were under larger amounts of stress with the construction equipment which caused the plates to separate and collapse
- Classified in inspections as a non redundant structure meaning if one part failed the whole thing would collapse and wasn’t due for replacement until 2020
- There was corrosion where the paint systems had deteriorated
State of the Nation’s Bridges

- 24.93% of all bridges rated “deficient” in 2005
- 147,913 deficient bridges total
- 756 bridges built with the same design as the I-35W bridge

**Deficient Bridges (by percentage)**

1. Nevada 3.89
2. Arizona 5.50
3. Wyoming 12.37
4. Colorado 12.96
5. Minnesota 13.16
6. Wisconsin 15.03
7. Delaware 16.55
8. Utah 17.55
9. Illinois 17.56
10. California 17.59
11. Florida 18.33
12. New Mexico 18.43
13. Idaho 18.91
14. Tennessee 19.26
15. Georgia 20.35
16. Texas 20.56
17. Kansas 21.05
18. Montana 21.20
19. Indiana 21.83
20. Arkansas 22.24
21. Virginia 22.46
22. Alaska 22.84
23. Ohio 23.61
24. South Carolina 23.63
25. North Dakota 24.24
26. Nebraska 24.55
27. Washington 24.55
28. Alabama 24.94
29. Oregon 25.34
30. South Dakota 25.62
31. Mississippi 26.42
32. Maryland 26.93
33. Iowa 27.06
34. Michigan 27.60
35. New Jersey 27.91
36. Maine 29.87
37. New Hampshire 30.54
38. Louisiana 30.67
39. North Carolina 30.91
40. Kentucky 31.45
41. Missouri 31.47
42. Oklahoma 33.04
43. Connecticut 34.18
44. Vermont 34.80
45. Massachusetts 36.38
46. Hawaii 36.85
47. New York 37.08
48. West Virginia 37.10
49. Pennsylvania 39.00
50. Rhode Island 53.01

Mean 24.52
**Action!**

- The I-35W bridge crisis prompted governors of several states to call for extra inspections on bridge conditions
- Federal Highway Administration issued special advisories
- The issue has in general made the nation more aware of the poor state of US bridges

**Problems for the Future**

- Spending on bridge repair is increasing, but so are construction costs
- 25% of bridges are now deficient, down from 29% in 1998
- At the current construction rate, it will take 50 years to bring all bridges up to safety standards
- This incident shows what we will face if more action is not taken to make our bridges structurally sound and safe for the use of the public for years to come.
The Millau Viaduct is a cable-stayed road-bridge that spans the valley of the river Tarn near Millau in southern France.

It is the tallest bridge in the world with one mast's summit at 343.0 metres (1,125 ft) above the base of the structure.

It is the 12th highest bridge deck in the world, being 270 metres (890 ft) between the road deck and the ground below.
CONSTRUCTION SUCCESS
Millau Bridge
CONSTRUCTION SUCCESS
Confederation Bridge, Canada

- The Confederation Bridge is a bridge spanning the Abegweit Passage of Northumberland Strait, linking Prince Edward Island with mainland New Brunswick, Canada.
  - Total length: 42,323' (12,900 m)
  - Longest span: 820' (250 m)
  - Construction started: October 7, 1993
  - Opened: May 31, 1997
  - Height: 197' (60 m)
CONSTRUCTION SUCCESS
Confederation Bridge, Canada
CONSTRUCTION SUCCESS
Confederation Bridge, Canada

SWING BRIDGE
Field Trip Information
Seattle Spokane Street Swing Bridge
Seattle Spokane Street Swing Bridge

- Owner: Seattle Transportation
- Engineer: Andersen Bjornstad Kane Jacobs, Inc.
- Contractor: Kiewit-Global Joint Venture
- Structure Type: Concrete Double Leaf Swing Bridge
- Overall Length: 827 feet
- Overall Width: 51 feet
- Total Cost: $33.5 million

Seattle Spokane Street Swing Bridge

- The Spokane Street Bridge is a concrete double-leaf swing bridge that crosses the Duwamish River, connecting Harbor Island to West Seattle.
- It has a 480-foot (150 m) span. Its construction was finished in 1991.
Seattle Spokane Street Swing Bridge

- Each 7,500 ton leaf of the bridge floats on a 100-inch (2.5 m) steel barrel in hydraulic oil.
- It is claimed to be the only bridge of its type in the world and it has received several awards for its innovation, including the Outstanding Engineering Achievement Award of the American Society of Civil Engineers in 1992.

Seattle Spokane Street Swing Bridge

- Two 413-foot-long concrete leaves, each weighing 7,500 tons, pivot on a single pier on each bank of the Duwamish.
- At least six times a day, seven days a week, using a 9-foot-diameter hydraulic cylinder, operators lift the leaves just one inch and swing them open to allow ships to pass.
- The bridge was built simultaneously on both sides of the river in the open position.
Seattle Spokane Street Swing Bridge

- The concrete box girders were cast in place segmentally, starting at the piers and moving outward.
- Extra transverse, longitudinal, and vertical post-tensioning was used to prevent long-term deformations and allow field adjustments.
- When the bridge leaves were closed for the first time, they fit together perfectly.
- After nearly twenty three years of operation, the stiff concrete leaves still open and close with precision.

Seattle Spokane Street Swing Bridge

- Concrete’s reduced capital and life cycle costs made it the obvious choice over steel. Over time, the city would save by eliminating the need for costly bridge painting, steel inspection, and deck grating replacement.
- In addition, the concrete swing provides a wider channel opening and greater vertical clearance from the water, reducing the number of openings by 30 percent.
Concrete is aesthetically compatible with the adjacent concrete high bridge.

As the city began to operate the new bridge, additional advantages became apparent.

The absence of a slippery steel deck grating dramatically reduced the number of bridge accidents.
Concrete as a Composite Material

- Both cement paste and aggregates show linear elastic properties.
- The non-linear portion of the stress-strain curve for concrete is due to cracking of the cement paste.

![Graph showing typical stress-strain behavior of cement paste, aggregate, and concrete.](image-url)
**Schematic Diagram of Concrete Behavior**

- Figure below is the Diagrammatic representation of the stress-strain behavior of concrete under uniaxial compression*. 
- The progress of internal microcracking in concrete goes through various stages, which depend on the level of applied stress.

![Stress-Strain Diagram](image)


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**Dimensional Stability**

Figure in the previous slide reflects four stages of concrete behavior:

1. **Stage 1**: Even before the application of external loads, microcracks already exist in the transition zone between the matrix mortar and coarse aggregate.
2. **Stage 2**: The number and width of these cracks depend on:
   - Bleeding characteristics
   - Strength of TZ
   - Curing history of concrete
3. **Stage 3**: Below 30% of the ultimate load, the transition zone cracks remain stable.
Dimensional Stability

- Above 30% of $f'_c$ as the stress increases, the TZ microcracks begin to increase in length, width and numbers.
- Until about 59% of the ultimate stress, a stable system of microcracks may be assumed in TZ.
- At 50 to 60% of $f'_c$ cracks begin to form in the matrix.

- Increase the stress up to 75% of $f'_c$
- The TZ cracks become unstable.
- The cracking in the matrix will increase.
- At 75 to 80% of $f'_c$ the rate of strain energy release reaches the critical level necessary for spontaneous crack growth.
- Above 75% of $f'_c$ bridging of cracks in matrix and TZ.
Elastic Modulus of Concrete

- Types of Elastic Modulus ($E$)

- $E$ is given by the shape of $\sigma - \varepsilon$ curve for concrete under uniaxial loading (since the curve for concrete is nonlinear, three methods for computing moduli are used).

  - **Tangent Modulus** (slope of a line drawn tangent to the $\sigma - \varepsilon$ curve at any point on the curve)
  
  - **Secant Modulus** (slope of the line drawn from the origin to a point on the curve corresponding to a 40% $f'_c$)
  
  - **Chord Modulus** (slope of a line drawn between two points on the $\sigma - \varepsilon$ curve)

### Calculating the Elastic Moduli

- **Initial Tangent Modulus**
  
  \[ \sigma_{\text{ULT}} = 3600 \text{ psi} \]
  
  \[ 40\% \sigma_{\text{ULT}} = 1440 \text{ psi} \]

- **Secant Modulus**
  
  Slope of the line corresponding to stress $50% = \frac{1440}{400} \times 10^{-6} = 3.6 \times 10^6$ psi

- **Chord Modulus**
  
  Slope of the line corresponding to stress $50% = \frac{(1440-200)/(400-50)}{10^{-6}} = 3.5 \times 10^6$ psi

- **Tangent Modulus**
  
  Slope of the line $T'T'$ drawn tangent to any point on the $\sigma - \varepsilon$ curve $= 2.5 \times 10^6$ psi

- **Dynamic Modulus**
  
  (Initial Tangent Modulus): Slope of the OD from the origin $= \frac{1000}{200 \times 10^{-4}} = 5 \times 10^6$ psi
Elastic Modulus of Concrete

- According to ACI Building Code 318, with a concrete unit weight between 90 and 155 lb/ft$^3$, the modulus of elasticity can be determined from:

$$E_c = W_c^{1.5} \times 33 f'_c^{1/2}$$

Where:
- $E_c$ = elastic modulus
- $W_c$ = unit weight of concrete (lb/ft$^3$)
- $f'_c$ = the 28-day compressive strength of standard cylinders

Factors Controlling Elastic Modulus

- In single phase solids (homogeneous materials) a direct relationship exists between density and modulus of elasticity.
- In heterogeneous, multi-phase materials, i.e., concrete, the volume fraction, density, and modulus of elasticity of each phase, and the characteristics of TZ determine the elastic behavior of the composite.
Factors Controlling Elastic Modulus

- **Aggregate:**
  - Porosity of aggregate (determines stiffness) is the most important factor that affects $E$ of concrete. Dense aggregates have a high $E$.
  - In general, the larger the amount of coarse aggregate with a high elastic modulus in a concrete mixture, the greater would be the modulus of elasticity of concrete.

- **Elastic Mismatch:**

<table>
<thead>
<tr>
<th>Material</th>
<th>$E_{a}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>$20 \times 10^6$</td>
</tr>
<tr>
<td>Sandstone (porous)</td>
<td>$3-7 \times 10^6$</td>
</tr>
<tr>
<td>Lightweight expanded shale</td>
<td>$1-3 \times 10^6$</td>
</tr>
</tbody>
</table>

Factors Controlling Elastic Modulus

- **Hydrated Cement Paste (HCP):**
  - The elastic modulus of the cement paste matrix ($E_p$) is determined by its porosity.
  - The factors controlling the porosity of the cement paste are: $w/c$, air content, mineral admixtures, and degree of cement hydration.

  \[
  E_c = E_a g + E_p \left(1 - g\right)
  \]

  - Volume fraction of aggregate
  - Volume of cement paste

- **Transition zone (TZ):**
  - Void space, microcracks, and orientation of CH crystals are more common in TZ than in bulk cement paste; therefore they play a very important role in determining the stress-strain relationship in concrete.
Poisson’s Ratio

For a material subjected to simple axial load, the ratio of the lateral strain to axial strain **within the elastic range** is called **Poisson’s ratio**.

\[ \text{Poisson's Ratio} = \frac{\text{Lateral Strain}}{\text{Axial Strain}} = \nu \]

With concrete the values of Poisson’s ratio generally vary between 0.15 and 0.20.

Drying Shrinkage and Creep

Causes

- **Drying Shrinkage:**
  - Loss of surface adsorbed water from C-S-H + loss of hydrostatic tension in small capillaries (<50 nm).
    (low RH)
- **Creep:**
  - (1) Loss of adsorbed water under mechanical pressure
  - (2) Delayed elastic response of aggregate
  - (3) Transition zone crack propagation.
  (cement paste deforms first, then aggregate particles become more stressed, then aggregate will have elastic deformation - that’s why its delayed) - (Elastic deformation of aggregate particles)
Drying Shrinkage of Concrete

\[ \varepsilon_{ds} \approx 400 - 1200 \times 10^{-6} \text{ in/in} \]

(depending on aggregate type and cement)

- Factors affecting drying shrinkage:
  - material and mix proportions
  - Aggregate type and content
  - Cement type and content

\[ S_c = f(S_p, V_p, n) \]

\[ S_c = S_p \left(1 - g\right)^n \]

Creep of Concrete

- Creep: deformation with time under certain load.
- Creep in concrete is a post-elastic phenomena.

Considering the various combination of loading, restaining, and humidity conditions, the following terms are defined: True or basic creep, specific creep, drying creep, and creep coefficient.
Creep of Concrete

- **True or Basic Creep:** Creep with no loss of water to the environment (under 100% RH)
  - When drying shrinkage and creep happen together, it is more than basic creep.
- **Specific Creep:** is defined as creep strain per unit of applied stress: \( \text{Specific Creep} = \frac{e_c}{\sigma} \)
- **Drying Creep:** is the additional creep that occurs when the specimen under load is also drying.
- **Creep Coefficient:** is defined as the ratio of creep strain to elastic coefficient. Creep Coefficient \( \frac{e_c}{E_c} \) (In well-cured concrete)

\[
C_c = \text{creep of concrete} \\
C_p = \text{creep of cement paste} \\
g = \text{aggregate content} \\
\mu = \text{unhydrated cement} \\
C_c = C_p \left(1 - g\right)^{\alpha}
\]

Factors Affecting Shrinkage & Creep

I. Material and mix proportions

II. Curing and testing conditions

- **Aggregate:**
  - a) Modulus of Elasticity
  - b) Aggregate content
    - Any increment of these two factors reduce the drying shrinkage & creep.
Factors Affecting Shrinkage & Creep

- Cement:
  - a) Water/cement ratio:
    - For a constant cement content an incremental increase in W/C ratio increases both drying shrinkage and creep.
  - b) Cement content:
    - For a constant W/C ratio an incremental increase in cement content reduces the creep but increases the drying shrinkage. This is the only case in which exists an opposite effect.

Factors Affecting Shrinkage & Creep

- Humidity:
  - One of the most important factors for both shrinkage and creep is the relative humidity of the medium surrounding the concrete. For a given concrete, creep is higher the lower the relative humidity.
  - An incremental increase on relative humidity of air decreases both the drying shrinkage and creep.
Factors Affecting Shrinkage & Creep

- **Temperature:**
  - Given the same curing history for two specimens, the one that is kept in a higher temperature will have more creep and drying shrinkage than the other one.

- **Age of loading:**
  - There is a direct proportionality between the magnitude of sustained stress and the creep of concrete. Because of the effect of strength on creep, at a given stress level, lower creep values were obtained for the longer period of curing before the application of the load. Shrinkage is not affected by this factor.
Progress in Concrete Technology

- Approximately 35 percent of the bridges in the United States are classified as deficient (The 1993 report of the secretary of transportation to the U.S. Congress)
  - structurally deficient (21 percent)
  - functionally obsolete (14 percent)
- The Federal Highway Administration (FHWA) estimates that the cost to eliminate the nation’s bridge deficient backlog by 2028, is $20.5 billion annually, while only $12.8 billion is being spent currently.
Progress in Concrete Technology

- Portland Cement Types:
  - Type I  General Use
  - Type II  Moderate sulfate resistance or moderate heat
  - Type III High early strength
  - Type IV Low heat of hydration
  - Type V  Sulfate resistant

Problem:

- Low Strength/Weight Ratio

  Steel: \( \frac{30,000 \text{ psi}}{500 \text{ pcf}} = 60 \)

  Concrete: \( \frac{3,000 \text{ psi}}{150 \text{ pcf}} = 20 \)

- To improve the ratio:
  - (a) Lower the density
  - (b) Increase the strength

High-Strength Concrete

  HSC: \( \frac{10,000 \text{ psi}}{150 \text{ pcf}} = 66 \)

Light-Weight Aggregate Conc.

  LWAC: \( \frac{10,000 \text{ psi}}{100 \text{ pcf}} = 100 \)
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Progress in Concrete Technology

- Lightweight Concrete
- High-Strength Concrete
- High Workability or Flowing Concrete
- Shrinkage Compensating Concrete
- Fiber-Reinforced Concrete
- Concrete Containing polymers
- Heavyweight Concrete
- Mass Concrete
- Roller-Compacted Concrete

Structural Lightweight Concrete

- Definition:
  - 28-day $f'_c \geq 2,500$ psi
  - Unit weight: Min: 90 pcf
    Max: 110 pcf
- Microstructural Properties:
  - Dense, strong transition Zone due to pozzolanic reaction.
  - Strength more influenced by aggregate characteristics than by transition zone.
Structural Lightweight Concrete

Durability
- Freeze-Thaw Resistance
- Permeability
- Creep / Drying Shrinkage
- Abrasion / Erosion Resistance
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Structural Lightweight Concrete

Applications

- Lower overall cost of the structure
- Bridge Decks
- Floor slabs
- Pre-cast concrete elements

Figure 11-3 Structural lightweight concrete wall panels, 16 ft wide and 27 ft high, are light enough to be handled by a small crane. (Photographs courtesy Expanded Shale, Clay, and Slate Institute, Bethesda, Md.)
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Structural Lightweight Concrete

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Structural Lightweight Concrete
High-Strength Concrete

- **Definition:**
  - 28-day $f'_c \geq 6,000$ psi (40 MPa)

- **Materials and mix proportions:**
- **Key:** POROSITY in 3 phases

<table>
<thead>
<tr>
<th>Water/Cement Ratio</th>
<th>$f'_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38</td>
<td>6,000 psi</td>
</tr>
<tr>
<td>0.36</td>
<td>7,500 psi</td>
</tr>
<tr>
<td>0.34</td>
<td>9,000 psi</td>
</tr>
</tbody>
</table>

- **Problem:** Mixing, placing, and consolidation
- **Use:** Water-Reducing Admixture.

High-Strength Concrete Mix Design

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>QUANTITY / TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Type III</td>
<td>600 pcy (356 Kg/m³)</td>
</tr>
<tr>
<td>Rice Husk Ash (RHA)</td>
<td>90 pcy (53 Kg/m³)</td>
</tr>
<tr>
<td>Crushed Limestone (3/8” MSA)</td>
<td>1,780 pcy (1,044 Kg/m³)</td>
</tr>
<tr>
<td>Top Sand (FM=3.0)</td>
<td>1,325 pcy (768 Kg/m³)</td>
</tr>
<tr>
<td>Water</td>
<td>215 pcy (128 Kg/m³)</td>
</tr>
<tr>
<td>Water</td>
<td>5.7 Liters/ m³</td>
</tr>
<tr>
<td>Superplasticizer Admixture</td>
<td></td>
</tr>
<tr>
<td>W/C</td>
<td>0.358</td>
</tr>
<tr>
<td>Slump</td>
<td>1 inch (25 mm)</td>
</tr>
<tr>
<td>Strength</td>
<td>11,000 psi (75.8 MPa)</td>
</tr>
</tbody>
</table>
High-Strength Concrete

- The Max Size of Aggregate (MSA): Limit to 3/4 inch or Lower
- Incorporate Pozzolanic Material into the Concrete Mixture
- In Portland Cement:
  \[ \text{C}_3\text{S} + \text{aq.} \xrightarrow{\text{Fast}} \text{C-S-H} + \text{CH} \]
- In Portland Pozzolan Cement:
  \[ \text{Pozzolan} + \text{CH} + \text{aq.} \xrightarrow{\text{Slow}} \text{C-S-H} \]
High-Strength Concrete

Applications

- High-Rise Projects
  Construction of RC frames of buildings 30 stories and higher/lower 1/3 conventional RC—reduction in size of the columns in the lower 2/3 of the building

- Bridges
  Reduces the risk of thermal cracking

- Stilling Basin of Dams
  Long-term durability to abrasion-erosion

- Floating Concrete Container Terminals
  (Valdez, AK; Tacoma, WA)
  High durability in seawater

New Tjorn bridge in Sweden was designed and built in less than 2 years
High-Strength Concrete

(a) No, these are not craters on the moon. This is the result of abrasion-erosion damage to the concrete stilling basin at the Kinzua Dam in Pennsylvania.

High-Strength Concrete

TWO PRUDENTIAL PLAZA
High-Strength Concrete

![Image of construction site with high-strength concrete use]

High-Strength Concrete

![Image of construction site with high-strength concrete use]
Lecture 2

High-Strength Concrete

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High-Strength Concrete

WASHINGT0N
Concrete Damage Due to Earthquake

Cypress Structure
Oakland, California
October 17, 1989

San Francisco Earthquake - 1989
San Francisco Earthquake - 1989
San Francisco Earthquake - 1989

[Image of damage from the San Francisco Earthquake - 1989]

San Francisco Earthquake - 1989

[Image of another scene from the San Francisco Earthquake - 1989]
San Francisco Earthquake - 1989

San Francisco Earthquake - 1989
Shrinkage-Compensating Concrete (SCC)

- Shrinkage-compensating concrete is concrete containing expansive cement or an expansive admixture, which produces expansion during hardening and thereby offsets the contraction occurring during drying (drying shrinkage).
- Shrinkage-compensating concrete is used in concrete slabs, pavements, structures, and repair work to minimize drying shrinkage cracks.
- Expansion of concrete made with shrinkage-compensating cement should be determined by the method specified in ASTM C 878.
Shrinkage-Compensating Concrete (SCC)

- Shrinkage-compensating concrete can be proportioned, batched, placed, and cured similarly to normal concrete with some precautions necessary to assure the expected expansion.
- Additional information can be found in ACI 223, Standard Practice for the Use of Shrinkage-Compensating Concrete.

Shrinkage-Compensating Concrete

- SCC is an expansive cement concrete which, when properly restrained by reinforcement, will expand an amount equal or slightly greater than the anticipated drying shrinkage.
- Because of the restraint, compressive stresses will be induced in the concrete during expansion. Subsequent drying shrinkage will reduce these stresses.
- Ideally, a residual compression will remain in the concrete, eliminating the risk of shrinkage cracking.

Comparison of length change characteristics between portland cement and Type K cement concrete.
Shrinkage-Compensating Concrete

- As the type K cement hydrates, large amounts of ettringite are formed.
- The concrete bonds to the reinforcement, at the same time start expanding.
- Concrete’s expansion under the restraining influence of the steel will induce tension in the steel while the concrete itself goes into compression.
- At the end of moist curing, it will shrink like a normal portland cement concrete.

Shrinkage will first relieve *precompression* before inducing tensile stresses in concrete (prevension of buildup of high tensile stresses).
Shrinkage-Compensating Concrete

Classification:
- Type K
- Type M
- Type S
- Type O

Applications
- Expansive cements have been used since 1960s.
  - Water and Sewage-handling structures
  - Water Storage tanks
  - Spillways
  - Cooling tower basins
  - Swimming pools
  - Floors without joints
Roller Compacted Concrete (RCC)

- RCC is based on the concept that no-slump concrete mixture transported, placed, and compacted with the same construction equipment that is used for earth and rockfill dams can meet the design specifications for conventional

Willow Creek Dam near Heppner, Oregon (1982), was the world's first all-roller compacted concrete dam.
Roller Compacted Concrete (RCC)

- The development of Roller Compacted Concrete (RCC) caused a major shift in the construction practice of mass concrete dams and locks.
- The traditional method of placing, compacting, and consolidating mass concrete is typically a slow process.
- Improvements in earth-moving equipment has made the construction of earth and rock-filled dams speedier and, therefore, more cost-effective.

Roller Compacted Concrete (RCC)

- Materials and Properties:
  - For effective consolidation, the concrete must be dry to prevent sinking of the vibratory roller equipment but wet enough to permit adequate distribution of the binder mortar throughout the material during the mixing and vibratory compaction operation.
  - The conventional concept of minimizing water/cement ratio to maximize strength does not hold.
Roller Compacted Concrete (RCC)

- Materials and Properties (cont’d):
  - The best compaction gives the best strength, and the best compaction occurs at the wettest mix that will support an operating vibratory roller.
  - From the standpoint of workability, fly ash is commonly included in RCC mixtures.
  - In Willow Creek Dam, the adiabatic temperature rise was only 11°C in 4 weeks.

Roller Compacted Concrete (RCC)

- Advantages of RCC:
  - Cement consumption is lower because much leaner concrete can be used.
  - Formwork costs are lower because of the layer placement method.
  - Pipe cooling is unnecessary because of the low temperature rise.
  - Cost of transporting concrete is lower than with cable crane method because concrete can be hauled by end dump trucks; it is spread by bulldozers and compacted by vibratory rollers.
  - Rates of equipment and labor utilization are high because of the higher speed of concrete placement.
  - The construction period can be shortened considerably.
Roller Compacted Concrete (RCC)

Transportation

Roller Compacted Concrete (RCC)

Transportation
Roller Compacted Concrete (RCC)

Placement

Compaction
Roller Compacted Concrete (RCC)

Compaction

Roller Compacted Concrete Pavements (RCCP)
- RCCP can be constructed with the same equipments as asphalt pavements, laid by the same pavers and compacted by rollers.
- The strength grows fast enough to permit opening for traffic in a short time.
- Since the drying shrinkage is small, the interval between joints can be maximized.
- Applications: Ordinary roads, Roads in factories, Temporary roads for construction works, Parking areas, Service areas, Container yards, and Material handling yards.
Roller Compacted Concrete Pavements (RCCP)

- The photograph on the right is a sample cut from RCCP pavement. It is seen that this sample is tightly compacted from top to bottom.