Five Day Residential Training Programme on “Traditional and New construction methodologies of Buildings and Bridges”

AP HRDI
Concrete Mixture Design and Materials Testing

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Objectives of the Course

• Materials required for making concrete
• Mix design as per 10262:2009 and Draft Code
• Testing of materials and their acceptable limits
• Quality Assurance and Quality Control
Historical Information!!

**Hammurabi code (1686 BC)**

- If a builder build a house for someone and complete it, he shall give him a fee of two shekels in money for each sar of surface.

- If a builder build a house for someone, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death.

- If it kills the son of the owner the son of that builder shall be put to death.

- If it kills a slave of the owner, then he shall pay slave for slave to the owner of the house.

- If it ruin goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.
Concrete Components

CONCRETE

COARSE AGG. = SKELETON
FINE AGG. = FAT
CEMENT. MATERIAL = MUSCLE
WATER = BLOOD

HUMAN BODY

CONCRETE IS MADE BY MIXING...

Cement

SAND CRUSHED ROCK AGGREGATES
Concrete?
## Composition of concrete

### Materials (volume %)

<table>
<thead>
<tr>
<th>Material</th>
<th>Gravel</th>
<th>Sand</th>
<th>Air</th>
<th>Water</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34</td>
<td>30</td>
<td>3</td>
<td>18</td>
<td>15</td>
</tr>
</tbody>
</table>

### Cost (%)

<table>
<thead>
<tr>
<th>Material</th>
<th>Gravel</th>
<th>Sand</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>21</td>
<td>59</td>
</tr>
</tbody>
</table>
## Global Annual Consumption of Structural Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Weight (kg/m³)</th>
<th>Million Tonnes</th>
<th>Tonnes/Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural steel</td>
<td>7850</td>
<td>1244</td>
<td>0.18</td>
</tr>
<tr>
<td>Cement</td>
<td>1440</td>
<td>3400</td>
<td>0.48</td>
</tr>
<tr>
<td>Concrete</td>
<td>2400</td>
<td>~18,000</td>
<td>2.4 (990 litres)</td>
</tr>
<tr>
<td>Timber</td>
<td>700</td>
<td>277</td>
<td>0.04</td>
</tr>
<tr>
<td>Drinking water</td>
<td>1000</td>
<td>5132</td>
<td>0.73 (730 litres)</td>
</tr>
</tbody>
</table>
Advantages of Concrete

1. Moulded to any shape
2. Easy availability of materials (for manufacturing concrete)
3. Low maintenance
4. Water and fire resistant*
5. Good rigidity
6. High compressive strength
7. Economical*
8. Low-skilled labour required for handling concrete
Disadvantages of Concrete

1. Low tensile strength (one-tenth of its compressive strength)

2. Requires forms and shoring (Process of Supporting a Building).

3. Relatively low strength (the compressive strength of normal concrete is about 5–10% steel)

4. Time-dependent, volume changes with variation.

5. CO₂ emission*****
Concrete States

**Plastic State:** When the concrete is first mixed it is like 'bread dough'.
- It is soft and can be worked or moulded into different shapes. In this state concrete is called PLASTIC. Concrete is plastic during placing and compaction.
- The most important properties of plastic concrete are workability and cohesiveness.
- A worker will sink into plastic concrete.

**Setting State** Concrete then begins to stiffen.
- The stiffening of concrete, when it is no longer soft, is called SETTING.
- Setting takes place after compaction and during finishing.
- Concrete that is sloppy or wet may be easy to place but will be more difficult to finish.
- A worker leaves footprints in setting concrete.
Concrete States

Hardening State

- After concrete has set it begins to gain strength and harden.
- The properties of hardened concrete are strength and durability.
- Hardened concrete will have no footprints on it if walked on.
# Component Oxides of Cement

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbreviation</th>
<th>Chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>C</td>
<td>CaO</td>
</tr>
<tr>
<td>Silica</td>
<td>S</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Alumina</td>
<td>A</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>Iron</td>
<td>F</td>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>Water</td>
<td>H</td>
<td>H₂O</td>
</tr>
<tr>
<td>Sulphuric Anhydride</td>
<td>S —</td>
<td>SO₃</td>
</tr>
<tr>
<td>Magnesia</td>
<td>M</td>
<td>MgO</td>
</tr>
<tr>
<td>Soda</td>
<td>N</td>
<td>Na₂O</td>
</tr>
<tr>
<td>Potassa</td>
<td>K</td>
<td>K₂O</td>
</tr>
</tbody>
</table>

J S Kalyana Rama
The Four Major Cement Compounds

✓ These compounds present in the raw materials when subjected to high clinkering temperature combine with each other to form compounds called Bogue’s compound -

- **Tricalcium silicate** \(3 \text{CaO} \cdot \text{SiO}_2\) \(C_3S\)
- **Dicalcium silicate** \(2 \text{CaO} \cdot \text{SiO}_2\) \(C_2S\)
- **Tricalcium Aluminate** \(3 \text{CaO} \cdot \text{Al}_2\text{O}_3\) \(C_3A\)
- **Tetracalcium** \(4 \text{CaO} \cdot \text{Al}_2\text{O}_3\) \(C_4AF\)
- **Aluminoferrite** \(\text{Fe}_2\text{O}_3\)
The Bogue Equations

\[ C_3S = 4.07C - 7.6S - 6.72A - 1.43F - 2.85S \]
\[ C_2S = 2.87S - 0.754(C_3S) \]
\[ C_3A = 2.65A - 1.69F \]
\[ C_4AF = 3.04F \]
Properties of the Compounds

$C_3S$: Rapid strength gain gives early strength (e.g. 7 days)

$C_2S$: Slow strength gain. This gives long term strength.

$C_3A$: Quick setting. The gypsum (calcium sulphate) is added to control this otherwise flash set would occur. $C_3A$ reacts with sulphate resulting in sulphate attack on the concrete. It also reacts with chlorides to form chloro-aluminates and "bind" them and thereby protect the steel.

$C_4AF$: Little contribution to setting or strength. Responsible for the grey colour of cement.
### Chemical Composition of Cementitious Materials

<table>
<thead>
<tr>
<th>Oxides</th>
<th>Cement</th>
<th>Fly Ash</th>
<th>Microsilica</th>
<th>GGBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>63-68%</td>
<td>1-2%</td>
<td>0</td>
<td>30-40%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>19-24%</td>
<td>55-65%</td>
<td>95%</td>
<td>30-40%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>4-7%</td>
<td>10-16%</td>
<td>0</td>
<td>11-16%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1-4%</td>
<td>10%</td>
<td>0</td>
<td>--</td>
</tr>
</tbody>
</table>
Types of Cement

1) Ordinary Portland Cement
   a) O.P.C 43 Grade - IS:8112:1989
   b) O.P.C 53 Grade - IS:12269:1987
2) Rapid Hardening Cement - IS:8041:1990
3) Sulphate Resisting Cement - IS:12330:1988
6) Portland Pozzolana Cement - IS:1489 (Part I)
Storage of Cement

Cement should be stored off the ground in a well- aired, clean, dry place. Wrapping the cement bags in plastic sheets gives extra protection, Bulk cement will normally be stored in silos.
Basis for Selection of Concrete Mix Proportions

The characteristics that form basis for proportioning concrete mixture involves:

- Economy
- Strength
- Durability
- Placeability
Data for Mix Proportioning

a) Grade designation;

b) Type of cement, and grade of cement (if applicable);

c) Maximum nominal size of aggregate;

d) Minimum cement/cementitious materials content and maximum water-cement/cementitious materials ratio to be adopted; or Exposure conditions as per Table 3 and Table 5 of IS 456;

e) Workability required at the time of placement;

f) Transportation time;

g) Method of placing;

k) Degree of site control (good/fair) or value of established standard deviation, if any;
Data for Mix Proportioning

l) Type of coarse aggregate (angular/sub angular/gravel with some crushed particles/rounded gravel/manufactured coarse aggregate;
m) Type of fine aggregate (natural sand/ crushed stone or gravel sand/manufactured sand/ mixed sand);
n) Maximum cement content;
o) Whether a chemical admixture shall or shall not be used and the type of chemical admixture and the extent of use; and
p) Whether a mineral admixture shall or shall not be used and the type of mineral admixture and the extent of use;
q) Any other specific requirement like early age strength requirements.
Mix Design as per Draft code of 10262

The following major modifications have been made

a) The standard has been divided into five sections, as follows:
   1) Section 1: General
   2) Section 2: Ordinary and Standard Grades of Concrete
   3) Section 3: High Strength grades of Concrete
   4) Section 4: Self Compacting Concrete
   5) Section 5: Mass Concrete

b) Mix design procedure for high strength concrete for M65 or above (up to target strength of M100)

c) The initial data to be provided for mix proportioning has been made more encompassing, covering the provisions of revised IS 383 : 2015 'Coarse and Fine Aggregates for Concrete', admixtures, etc.
Mix Design as per Draft code of 10262

d) The target strength for mix proportioning formula has been refined to include a new factor based on the grade of concrete. This has been done to ensure a minimum margin between the characteristic compressive strength and the target mean compressive strength.

e) The calculations for standard deviation have been detailed.

f) A graph of water-cement ratio versus 28 day strength of concrete has been introduced for different grades and types of cement, as an alternate method for assuming the initial water-cement ratio.

j) Illustrative annexes for concrete mix proportioning using high strength concrete, self compacting concrete and for mass concreting have been added.

k) Guidelines on using/selecting water reducing admixtures have been introduced as an informatory Annex (see Annex F).

l) The consideration of air content in design of normal (non- air entrained) concrete mix proportion, has been reintroduced.
Mix Design as per Draft code of 10262

Guidelines as per Draft version of IS 10262
## Different Types of Concrete and Their Applications

1. Normal Strength Concrete
2. Plain or Ordinary Concrete
3. Reinforced Concrete
4. Prestressed Concrete
5. Precast Concrete
6. Light – Weight Concrete
7. High-Density Concrete
8. Air Entrained Concrete
9. Ready Mix Concrete
10. Polymer Concrete
    - i. Polymer concrete
    - ii. Polymer cement concrete
    - iii. Polymer impregnated concrete
11. High-Strength Concrete
12. High-Performance Concrete
13. Self – Consolidated Concrete
14. Shotcrete Concrete
15. Pervious Concrete
16. Vacuum Concrete
17. Pumped Concrete
18. Stamped Concrete
19. Limecrete
20. Asphalt Concrete
21. Roller Compacted Concrete
22. Rapid Strength Concrete
23. Glass Concrete
Different Types of Concrete and Their Applications

1. Normal Strength Concrete
The concrete that is obtained by mixing the basic ingredients cement, water and aggregate will give us normal strength concrete. The strength of these type of concrete will vary from 10 MPa to 40MPa. The normal strength concrete has an initial setting time of 30 to 90 minutes that is dependent on the cement properties and the weather conditions of the construction site.

2. Plain Concrete
The plain concrete will have no reinforcement in it. The main constituents are the cement, aggregates, and water. Most commonly used mix design is 1:2:4 which is the normal mix design.
The density of the plain concrete will vary between 2200 and 2500 Kg/meter cube. The compressive strength is 200 to 500 kg/cm².
These types of concrete are mainly used in the construction of the pavements and the buildings, especially in areas where there is less demand of high tensile strength. The durability given by these type of concrete is satisfactory to high extent.
Different Types of Concrete and Their Applications

3. Reinforced Concrete

The reinforced cement concrete is defined as the concrete to which reinforcement is introduced to bear the tensile strength. Plain concrete is weak in tension and good in compression. Hence the placement of reinforcement will take up the responsibility of bearing the tensile stresses. R.C.C works with the combined action of the plain concrete and the reinforcement.

The steel reinforcement used in the concrete can be in the form of rods, bars or in the form of meshes. Now fibers are also developed as reinforcement. Fiber reinforced concrete are concrete that use fibers (steel fibers) as reinforcement for the concrete. Use of meshes in concrete will give Ferrocement.

Whatever be the type of reinforcement used in concrete, it is very necessary to ensure proper bond between the concrete and the reinforcement. This bond will control the strength and the durability factors of the concrete.
Different Types of Concrete and Their Applications
4. Prestressed Concrete

Most of the mega concrete projects are carried out through prestressed concrete units. This is a special technique in which the bars or the tendons used in the concrete is stressed before the actual service load application. During the mixing and the placing of the concrete, these tensioned bars placed firmly and held from each end of the structural unit. Once the concrete sets and harden, the structural unit will be put in compression. This phenomenon of prestressing will make the lower section of the concrete member to be stronger against the tension.

The process of prestressing will require heavy equipment and labor skill (jacks and equipment for tensioning). Hence the prestressing units are made at site and assembled at site. These are used in the application of bridges, heavy loaded structures, and roof with longer spans.
Different Types of Concrete and Their Applications
Different Types of Concrete and Their Applications

5. Precast Concrete
Various structural elements can be made and cast in the factory as per the specifications and bought to the site at the time of assembly. Such concrete units are called as the precast concrete.

The examples of precast concrete units are concrete blocks, the staircase units, precast walls and poles, concrete lintels and many other elements. These units have the advantage of acquiring speedy construction as only assemblage is necessary. As the manufacturing is done at site, quality is assured. The only precaution taken is for their transportation.
Different Types of Concrete and Their Applications

6. Lightweight Concrete
Concrete that have a density lesser than 1920kg/m3 will be categorized as lightweight concrete. The use of lightweight aggregates in concrete design will give us lightweight aggregates.

Aggregates are the important element that contributes to the density of the concrete. The examples of light weight aggregates are the pumice, perlites, and scoria.

The light weight concrete is applied for the protection of the steel structures and are also used for the construction of the long span bridge decks. These are also used for the construction of the building blocks.
Different Types of Concrete and Their Applications

7. High-Density Concrete
The concretes that have densities ranging between 3000 to 4000 kg/m$^3$ can be called as the heavyweight concrete. Here heavy weight aggregates are used.

The crushed rocks are used as the coarse aggregates. The most commonly used heavy weight aggregates is Barytes.

These types of aggregates are most commonly used in the construction of atomic power plants and for similar projects. The heavy weight aggregate will help the structure to resist all possible type of radiations.

8. Air Entrained Concrete
These are concrete types into which air is intentionally entrained for an amount of 3 to 6% of the concrete. The air entrainment in the concrete is achieved by the addition of foams or gas – foaming agents. Some examples of air entraining agents are resins, alcohols, and fatty acids.
Different Types of Concrete and Their Applications

9. Ready Mix Concrete
The concrete that mix and bathed in a central mixing plant is called as ready-mix concrete. The mixed concrete is brought to the site with the help of a truck-mounted transit mixer. This once reached in the site can be used directly without any further treatment.

The ready-mix concrete is very precise and specialty concrete can be developed based on the specification with utmost quality.

The manufacture of these concrete will require a centralized mixing plant. These plants will be located at an adjustable distance from the construction site. If the transportation is too long then it will result in setting of concrete. Such issues of time delay are cope up with the use retarding agents that delays the setting.
Different Types of Concrete and Their Applications
10. Polymer Concrete
When compared with the conventional concrete, in polymer concrete the aggregates will be bound with the polymer instead of cement. The production of polymer concrete will help in the reduction of volume of voids in the aggregate. This will hence reduce the amount of polymer that is necessary to bind the aggregates used. Hence the aggregates are graded and mixed accordingly to achieve minimum voids hence maximum density.

This type of concrete has different categories:
• Polymer Impregnated Concrete
• Polymer cement concrete
• Partially Impregnated
11. High-Strength Concrete
The concretes that have strength greater than 40MPa can be termed as high strength concrete. This increased strength is achieved by decreasing the water-cement ratio even lower than 0.35.

The calcium hydroxide crystals that are the major concern product during hydration for the strength properties is reduced by the incorporation of silica fume. In terms of performance, the high strength concrete ought to be less performing in terms of workability which is an issue.
12. High-Performance Concrete
These concretes conform to a particular standard but in no case, will be limited to strength. It has to be noted that all the high strength concrete can be high-performance type. But not all high-performance concrete (HPC) are high strength concrete. Standards that conform to the high-performance concrete are enlisted below:

- Strength gain in early age
- Easy placement of the concrete
- Permeability and density factors
- Heat of hydration
- Long life and durability
- Toughness and life term mechanical properties
- Environmental concerns
13. Self – Consolidated Concrete
The concrete mix when placed will compact by its own weight is regarded as self-consolidated concrete. No vibration must be provided for the same separately. This mix has a higher workability. The slump value will be between 650 and 750. This concrete due to its higher workability is also called as flowing concrete. The areas where there is thick reinforcement, self – consolidating concrete works best.

14. Shotcrete Concrete
Here the concrete type differs in the way it is applied on the area to be cast. The concrete is shot into the frame or the prepared structural formwork with the help of a nozzle. As the shooting is carried out in a higher air pressure, the placing and the compaction process will be occurring at the same time.
Pervious or permeable concrete are concrete that are designed such a way that it allows the water to pass through it. These types of concrete will have 15 to 20% voids of the volume of the concrete when they are designed. The pervious concrete is created by unique mixing process, performance, application methods etc. These are used in the construction of pavements and driveways where storm water issues persist. The storm water will pass through these pervious concrete pavements and reach the groundwater. Hence most of the drainage issues is solved.
Different Types of Concrete and Their Applications

16. Vacuum Concrete
Concrete with water content more than required quantity is poured into the formwork. The excess water is then removed out with the help of a vacuum pump without waiting for the concrete to undergo setting.

Hence the concrete structure or the platform will be ready to use earlier when compared with normal construction technique.

These concretes will attain their 28 days compressive strength within a period of 10 days and the crushing strength of these structure is 25% greater compared with the conventional concrete types.
17. Pumped Concrete
One of the main property of the concrete used in large mega construction especially for the high-rise construction is the conveyance of the concrete to heights. Hence one such property of concrete to easily pump will result in the design of pumpable concrete.

The concrete that is used for pumping must be of adequate workability so that it is easily conveyed through the pipe. The pipe used will be rigid or a flexible hose that will discharge the concrete to the desired area.

The concrete used must be fluid in nature with enough fine material as well as water to fill up the voids. The more the finer material used, greater will be control achieved on the mix. The grading of the coarse aggregate used must be continuous in nature.
18. Stamped Concrete
Stamped concrete is an architectural concrete where realistic patterns similar to natural stones, granites, and tiles can be obtained by placing impression of professional stamping pads. These stamping is carried out on the concrete when it is in its plastic condition. Different coloring stains and texture work will finally give a finish that is very similar to costlier natural stones. A high aesthetic look can be obtained from a stamped finish economically. This is used in the construction of driveways, interior floors, and patios.
19. Limecrete
This is a concrete type in which the cement is replaced by lime. The main application of this product is in floors, domes as well as vaults. These unlike cements have many environmental and health benefits. These products are renewable and easily cleaned.

20. Asphalt Concrete
Asphalt concrete is a composite material, mixture of aggregates and asphalts commonly used to surface roads, parking lots, airports, as well as the core of embankment dams. Asphalt concrete is also called as asphalt, blacktop or pavement in North America, and tarmac or bitumen macadam or rolled asphalt in the United Kingdom and the Republic of Ireland.
Different Types of Concrete and Their Applications

21. Roller Compacted Concrete
These are concrete that is placed and compacted with the help of earth moving equipment like heavy rollers. This concrete is mainly employed in excavation and filling needs. These concretes have cement content in lesser amount and filled for the area necessary. After compaction, these concretes provide high density and finally cures into a strong monolithic block.

22. Rapid Strength Concrete
As the name implies these concretes will acquire strength with few hours after its manufacture. Hence the formwork removal is made easy and hence the building construction is covered fastly. These have a wide spread application in the road repairs as they can be reused after few hours.

23. Glass Concrete
The recycled glass can be used as aggregates in concrete. Thus, we get a concrete of modern times, the glass concrete. This concrete will increase the aesthetic appeal of the concrete. They also provide long-term strength and better thermal insulation also.
Quality Concepts

Quality – Meeting requirements
Quality Management – The means we devise for Quality
QC – The means of knowing where we are relative to Quality
QA – the assurance we give ourselves and others (Customers, shareholders, regulators)
Audit – Independent enquiry to examine whether the management is appropriate and whether quality is being achieved.
Why Quality Control?

Even with the best mixture designs, failures occur in concrete structures, some of which are attributable to design and the others to the material itself. However, more often than not, the failure is a result of negligence and lack of attention to quality on the jobsite during construction.

Quality control (QC) is a check of the quality of the material and the finished product, while Quality Assurance (QA) is systematic implementation of QC as per laid down procedures.
Grade wise Cube Strength

Grade wise Cube Strength

<table>
<thead>
<tr>
<th>Grade of Concrete</th>
<th>No. of Samples</th>
<th>Avg. Strength</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 20</td>
<td>59</td>
<td>27.74</td>
<td>2.97</td>
</tr>
<tr>
<td>M 25</td>
<td>67</td>
<td>32.02</td>
<td>3.09</td>
</tr>
<tr>
<td>M 30</td>
<td>14</td>
<td>36.01</td>
<td>4.19</td>
</tr>
</tbody>
</table>
BIS acceptance criteria

As per the IS code (Clause 16 of IS 456:2000), for a given set of tests, the compressive strength is taken as the average of three tests, no one test differing from the average by more than 15%. The strength requirements are deemed to meet standards if the following conditions are satisfied.

Compressive strength:

Mean of 4 test results > \( f_{ck} + 0.825 \sigma \), or \( f_{ck} + 4 \text{ MPa} \) (whichever is greater)

Individual strength result > \( f_{ck} – 4 \text{ MPa} \)

Flexural strength (\( f_t \) is the characteristic flexural strength):

Mean of 4 test results > \( f_t + 0.3 \text{ MPa} \)

Individual strength result > \( f_t – 0.3 \text{ MPa} \)
Quality Control in Concrete Construction

**Stages of Quality Control**
Testing of materials for concrete

Tests on Cement at Construction Site To Check Quality of Cement
Testing of materials for concrete

Testing of Sand Quality at Construction Site for Concrete
Testing of materials for concrete

Properties of Aggregates and its Values for use in Construction
Types of Concrete Structures and Critical Technological Aspects

- Bridges
- Buildings
- Precast/prefab construction
- Offshore structures
- Shell structures
- Tunnels
- Dams
- Canals
- Airport runways and other pavements
- Nuclear containment structures
- Stadiums
Bridges

Benson Street Bridge, Ohio, 1910; renovated 1992
Concrete tied-through arch bridge

Multnomah Falls Footbridge, Oregon, 1914
14 m span arch

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Bridges

Crooked River Gorge Bridge, Oregon, 2000

Cast-in-place segmental arch bridge

Cable-stay technology made the construction possible

Steel cables suspended the segmental travelers from stay towers during casting

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Bridges

Jadukata Bridge, Meghalaya, 1997
140 m span was constructed by cantilever in-situ segmental method with traveling formwork

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Bridges

Bhima Aqueduct, Sholapur
Precast/prestressed concrete
Magdeburg water (canal) bridge across the Elbe river, Germany
Completed in 2003, 918 m long
Bridges

Pasco-Kennewick Bridge, Washington, 1978
Continuous girder assembled from precast elements

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Great Belt Link, Denmark/Sweden, 1998

Rail and road project consisting of a railway tunnel and two bridges 100-year service life was specified. 1.1 million m$^3$ of concrete was used in the project. The East Bridge has a main span of 1624 m, resting on two 250 m high concrete pylons and massive anchor blocks.
Bridges

Confederation Bridge, Canada, 1997
13 km long; 100 year design life
Main bridge has 43 spans of 250 m
Girders and piers were precast

Crane placing main girder onto pier

Pier shaft and ice shield

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Bridges

Confederation Bridge, Canada, 1997

Drop-in girder being placed to close span

Wintertime view

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Bridges

Millau Viaduct, France, 2004
World’s tallest piers (78 to 245 m)
2.5 km bridge has 8 spans

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Bridges

Millau Viaduct, France, 2004

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Bridges

Critical Technological Aspects

- In-situ construction often requires concrete plant on site and use of local aggregates
- High transportation times
- Lifting of concrete to casting location
- Special unique formwork
- Curing may be difficult
- Shrinkage and creep have to be limited
- Durability is important
- High strength concrete is often used in pylons and anchor blocks
- Marine structures need to resist sea water and ice

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311 South Wacker Drive, Chicago, 1990

All-concrete frame 295 m tall 10 different concrete mixes were used, mostly high strength concretes with strengths ranging to 83 MPa, incorporating silica fume and fly ash
Buildings

Shandong Hotel, Jinan, China, 2002

Structural frame and floor slabs are of cast-in-place reinforced concrete.

Exterior balcony and sun screens are precast concrete.

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Buildings

Calgary Airport, Alberta, Canada, 1977
Entire structure built with precast segments
Precast column segments were post-tensioned
Buildings

Critical Technological Aspects

• High strength concrete leads to more slender columns and beams
• Lightweight concrete sometimes used in the slabs
• Construction in cities imply problems for transportation and long transportation times
• Noise due to vibration (compaction) could be avoided by using self-compacting concrete
• Shrinkage could cause serviceability problems
• Reusable formwork makes construction economical
• Aesthetics is important
• Use of precast elements increases construction rate and quality
Buildings

Tilt-up construction
Buildings

Tilt-up construction

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Tilt-up construction

- Connections have to be designed and detailed properly.

- Improper handling could result in chipping/crushing of corners and edges.

- Early-age shrinkage cracking could be induced by bottom restraint and improper curing.

- Higher tensile strength and toughness could prevent cracking during erection.

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Offshore Structures

Concrete gravity base structure

106 m Base Slab
Cast on shore and floated

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Hibernia Offshore Platform, 1997

Lightweight concrete was used to improve buoyancy

Caissons hold oil and ballast

Designed to withstand iceberg impact

**Slip forming**
- rapid-setting concrete
- long-lasting formwork
Offshore Structures

Critical Technological Aspects

• Durability is of main concern
• Freeze-thaw could also be important
• Damage due to impact (e.g., from ice) should be avoided
• High strength lightweight concrete may be used to increase buoyancy when structure is afloat
Shell Structures

CNIT, Paris, 1958
Double shell concrete building
Shell Structures

Storage silo, Jagdishpur
Economical industrial building

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Shell Structures

Storage domes, California, 1990
Cold storage hemi-spherical domes of 70 m diameter
Constructed with shotcrete over air supported forms

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Shell Structures

Critical Technological Aspects

• Formwork has to be properly designed
• Shotcrete is often used
• Fibre reinforcement eliminates need for cover concrete
• Uniformity of shell thickness should be ensured
Tunnels

Eurotunnel, English Channel, 1994

Initial wet-process shotcrete lining

Final lining constructed with precast segments

Lining with shotcrete

Lining with precast segments

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Tunnels

Underground Metro Rail Corridor, New Delhi, under construction
Partly with cut and cover method
Partly with tunnel boring machine resulting in a lining of precast segments

Cut and cover section

Lining with precast segments

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Tunnels

Critical Technological Aspects

• Compressive strength
• Water-tightness
• Shrinkage at early-ages could lead to cracking
• Local collapse due to non-uniform soil/rock pressure should be avoided
• When segments are used, they should withstand handling and tunnel boring machine reactions
• Fibre reinforcement is a good alternative to mesh reinforcement when shotcrete is used
Dams

Hoover Dam, Nevada/Arizona, 1936
Arch gravity structure
Raised by placing and cooling
concrete in 230 massive blocks
Dams

Three Gorges Dam, China, under construction
Largest concrete gravity dam
2309 m long, 185 m high

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Dams

Roller compacted concrete dams

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Dams

Critical Technological Aspects

• Heat development should be controlled
• Permeability should be low
• Aggregates may not always be of good quality

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Canals

Sai Ganga approach canal

Critical Technological Aspects

• Shrinkage cracking should be controlled
• Permeability should be low
• Aggregates may not always be of good quality

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Airport Runways

LaGuardia Airport Runway Extension, 1966
Cast-in-place post-tensioned concrete deck

Critical Technological Aspects

• Shrinkage cracking should be controlled
• Impact, abrasion and fatigue resistance

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Nuclear Structures

Narora Nuclear Power Plant, 1989
Concrete reactor containment structure

Critical Technological Aspects

• Safety, durability and strength
• Heavy weight concrete is used often to control radiation leakage

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Stadiums

Montreal Olympic Stadium, 1976
Precast ribs made with superplasticized concrete

Diamond Stadium, Richmond, 1985
Predominantly precast concrete
Constructed in 7 months

Critical Technological Aspects

• Durability and strength
• Aesthetics is important
Formwork

Rigid formwork

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Formwork

Flexible fabric formwork

Fabric moulded panel
Production, Transportation and Placing

Ready mixed concrete

• Ready mixed concrete (RMC) started being used in the USA in the 1920s. The volume of cement used there in RMC rose from 5% in 1933 to 72% in 1990. There are about 3700 RMC companies in the US who produce 370 million cubic metres of concrete (1990).

• Currently India produces about 25 million cubic metres of RMC from about 500 plants.

• Cement consumption by RMC in India is about 4% (against 60% in developed countries).
Production, Transportation and Placing

Trucks

Critical Aspects
• Truck should not be loaded to more than 80% of capacity
• Blades should be in good condition
• Rotation should be limited during transportation
• Drum should be rotated at high speed before discharging
• No addition of water during transportation should be allowed
• Exceptionally admixtures or fibres can be mixed in the drum on site

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Placing

Truck-screed placing
Transportation and Placing

Truck-screed placing
Placing

Pumping
• Uniformity should be controlled
• Excessive pumping speeds can lead to segregation and/or reduction in air content
• Free fall height should be limited to about 2m
Placing

Telescopic conveyor belt

Mast mounted pump boom

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Placing

Power screed

Needle/poker vibration

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THANK YOU!