CONCRETE

A preparatory course assembled for the
Architectural Record Examinations

Data accumulated from Kent Ballast's "Architecture Exam Review," and various sources of the Internet

(This is only for educational purposes)

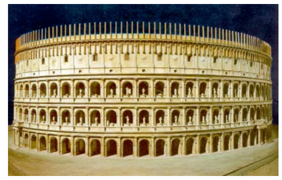
AVANT-GARDE ENGINEERING LLC
CONSULTING ARCHITECTS/ENGINEERS

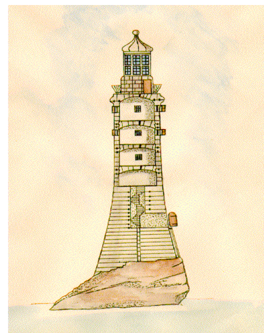
WHAT IS CONCRETE

- A basic material for construction that is very versatile, durable, strong, and it can take any shape defined by the designer.
- Although it has the above mentioned advantages, a proper process needs to be followed for concrete to set properly, and that includes the steps of formwork, reinforcing, casting, curing, testing and finishing.

HISTORY OF CONCRETE

- As early as the 3rd century BC, Romans used mortar of lime and sand.
- The use of pozzolana, a sandy volcanic ash (found in the area of Pozzuoli) with lime and water proved more effective. They used this new mixture with stone and brick rubble to build walls, or cast it in wooden forms to produce vaults, arches and domes.
- Concrete was forgotten until the 18th cent. When John Smeaton found that quicklime containing clay would harden underwater. He used this early form of mortar for a the Eddystone lighthouse.





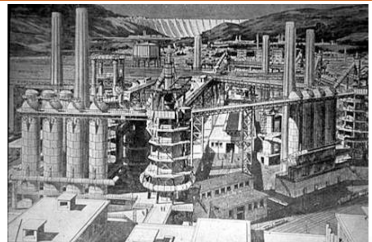
HISTORY OF CONCRETE

- In 1824, Joseph Aspdin from Leeds UK developed portland cement, the first manufactured "hydraulic" building material
- In 1867, reinforced concrete was patented by F. Joseph Monier, a gardner in Paris, to reinforce garden tubs, beams and posts. The French inventor had found that the tensile weakness of plain concrete could be overcome if steel rods were embedded in a concrete member.
- Concrete as a construction material was already established in the 19th cent. with examples like the concrete built portions of the main building of the 1867 Paris exhibition. Yet it was in the early 20th cent. that architects and engineers began to fully exploit the possibilities of this new material.

Hydraulic building material signifying the capability to set underwater.

HISTORY OF CONCRETE

- Auguste Perret, one of the early innovators of concrete, used the material for simple rectangular forms. The area between the concrete frame was usually filled with blocks.
- Tony Garnier, a contemporary of Perret envisioned the use of ferroconcrete for his Cite Industrielle designs of 1901-08.
- Robert Maillart designed extensively with concrete for bridges and industrial buildings. His Cement Hall was a thin shell that exhibited the strength and qualities of the new material.



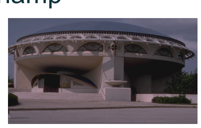
Cement Hall, Zurich, 1939.

Notre_Dame_du_Raincy 1922.

Salginatobel Bridge,1930. Grisons, Switzerland

HISTORY OF CONCRETE

- Luigi Nervi used concrete in some of the most innovative forms. His most famous include the Exhibition building in Turin (1948) and the Palazzetto dello Sport in Rome (1957).
- Le Corbusier used concrete extensively in many of his projects like the Villa Savoye (1923), the Notre Dame du Haut at Ronchamp (1954), and the Palace of Justice in Chandigarh (1953)
- F. L. Wright used concrete in many of his buildings like Fallingwater, the Johnson Wax Co, The Guggenheim museum. Wright also experimented with with Concrete masonry units in his California concrete block houses.



Annunciation Chappell, Milwaukee, 1956

Palazzetto dello Sport, Rome, 1957.

Interior of the Villa Savoye, Poissy, 1923

FORMWORK

- Formwork refers to the system of boards, ties and bracing that is applied to produce the molds in which concrete will be cast. It needs to be robust to withstand the pressure of a very heavy form of semi-liquid material that will be set in, and it needs to be easy to remove.

FORMWORK

- Types of forms:
  - There is a number of materials that can be used for the forms in which this very sculptural material will be cast. Like bronze sculpture, or like film developing, all that is dictated by the negative will come out in the final form; Wood grain, knots, joints etc are part of what we see in the end.
  - Plywood is the most common material. It is usually 3/4” thick and one side is coated with oil, a water resistant glue or plastic to prevent the transition of the water into the wood. Oil also prevents adhesion of the concrete to the wood and acts as a lubricant when the forms will need to be removed.

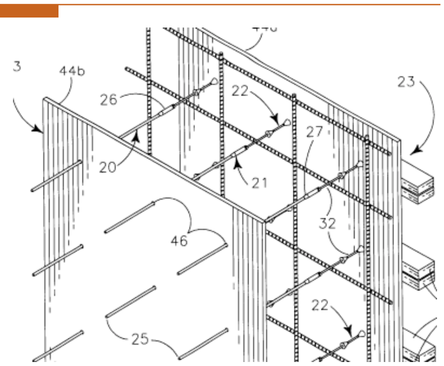
FORMWORK

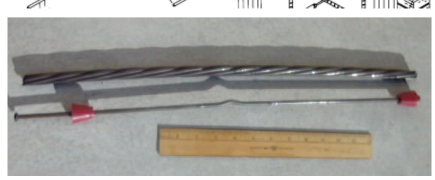
- Prefabricated Steel forms are often used for their strength, durability and the reusability. Waffle slabs, one way joint systems and round columns are most usually formed with steel forms.
- Other types…glass fiber reinforced plastic, hardboard…

The "Geotube", a reusable plastic type of form.

FORMWORK

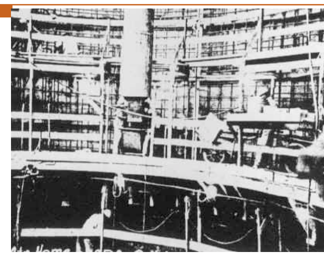
- For Architectural surfaces, a lot of care needs to be given for the choice of forms as all imperfections will be visible. Usually a certain pattern of joints and form ties that will tie well with the built composition will be determined by the architect.
- <u>Form ties</u> are metal wires or rods that hold opposite sides of the form together and also prevent their collapse. When forms are removed the excess is twisted off. The ends are made of cone shaped plastic heads that produce those round hole forms on the concrete surface.





FORMWORK

- Special forms:
  - Although in general, forms are constructed to stay in place until the concrete cures, a method called "slip forming" is applied for large surfaces like high-risers cores or tunnels. The form is constructed along with working platforms and supports for the jacking assembly. The form moves continuously at 6" to 1' per hour and it is supported by various types of jacking.
  - Flying forms are sections of framework that are removed after the curing process, and reused at a higher level to produce an identical form.



Slip forming of missile silo, Nov. 1960.

Modular prefabricated trusses supporting concrete flying forms.

FORMWORK

- Economy:
  - Reusability of forms is vital. Formwork is one of the most expensive aspects of cast in place concrete construction. Thus, it is advised that designers use modular forms, with constant slab thicknesses and minimize offsets unless if it structurally necessary. It is more prudent to overdesign and use more concrete than to produce forms that will only be used once.

FORMWORK

- Accuracy Standards:
  - The forming methods and the nature of the material suggest a process susceptible to imperfections. A tolerance level of 1/4” per 10’ is considered acceptable to both horizontal and vertical elements.
  - The max variation for a total height of structure is 1” if the structure is up to 100’ tall
  - Elevation control for slab on grade is a max of 1/2” in any 10’ bay, and max 3/4” for the total length of the structure.
  - For elevated, formed slabs, the tolerance is 3/4”. Finished concrete floors can accommodate a tolerance of 1/8” in 10’, to 1/2” for “bullfloated” slabs

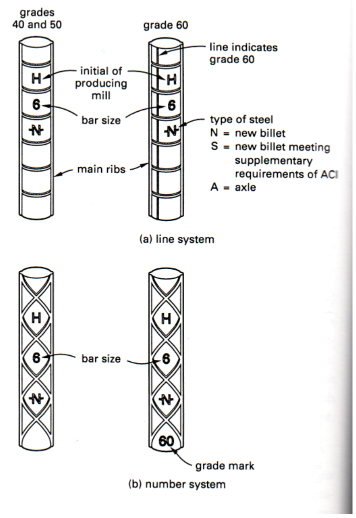
http://www.cement.org/basics/concretebasics_placing.asp

REINFORCEMENT

- Concrete is very strong in compression but…..not in tension
- Reinforcement bars are available at various sizes, designated in numbers that signify their diameter in increments of 1/8”, e.g. a #8 bar would be 8/8” or 1” in diameter. Larger sizes don’t precisely follow this rule but up to #10 this method is applicable.
- Although forces of adhesion are developed between the materials, those are not enough to secure the connection between steel and concrete. Thus a mechanical method of interlocking of steel and concrete needed to be applied. Rebars need to carry a specfic form patterns to lock within the concrete.
  - So how do we determine the diameter?

REINFORCEMENT

- Rebars come in various grades, but the most common are 60 and 40. 50 and 70 are also available but not as common.
- The most common grade used in everyday construction is 60, although for prestressing and the design of larger longer beams, grades of 250 or 270 are used.
- The significance of the grade is the strength of the steel used. Grade 60 signifies that the yield strength of the steel is 60 Ksi or 60000 psi.
- To easily identify the type of steel, coding is applied.



REINFORCEMENT

- Rebars take a major amount of stress within the concrete structural members. Therefore they need to be Integrated and Protected.
- They need to be integrated because the tension that they are subjected to should not allow them to slide or… to crack the concrete. If they are exposed they are useless.*
- They need to be protected because if steel is subjected to the elements it will want to return to its natural state, so it will rust. If it rusts, it will not serve its role in reinforcement, but also it will make the concrete chip out.
- If the concrete will be exposed to corrosive elements, specifically chlorides, in seawater or deicing salts, the rebars are coated with an epoxy compound or are galvanized.

Location	Distance
	inches
surfaces not exposed directly to the weather or ground:	
slabs and walls	3/4
beams and columns	1 1/2
surfaces exposed to the weather or in contact with the ground:	
no. 5 bars and smaller	1 1/2
larger than no. 5 bars	2
concrete poured directly on the ground	3

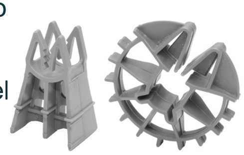

* Development length is the necessary length for a rebar to fully integrate with concrete.

REINFORCEMENT

- Welded Wire Fabric is used for temperature reinforcement in slabs and consists of cold-drawn steel wires welded at right angles to create a mesh of 4" – 6" squares.
- The designation system for the wire fabric determines the size first and then the gage.
  - e.g. 4"x4" - W1.4 x 1.4 signifies 4" squares and 0.014 in^2 wire.

REINFORCEMENT

- Accessories: Before concrete is cast into the forms, a series of accessories need to be placed inside the forms besides the reinforcement. Those can be:
  - Welding plates for attachment of steel and other structural members,
  - Electrical boxes and conduit,
  - Pipes that need to pass through the concrete,
  - Other anchoring devices for suspended components and finish walls.
  - Embedded items must be accurately placed and affixed by wiring to the rebars or by nails.
- Other accessories needed are the elements that hold the rebars. Those are "spacers" in walls and "chairs" in slabs.



CONCRETE MATERIALS

- Basic components:
  - Concrete is a mixture of cement and aggregates of different sizes, mixed in water and left to cure. Admixtures are used to impart specific qualities of the mix.
  - Portland cement is the agent that generates the bonds among the constituents. It is made of silica, lime, iron oxide, and alumina under strictly controlled conditions. It reacts with water to generate a paste like substance that binds the aggregates and solidifies in a durable form.

CONCRETE MATERIALS

- Basic components cont.:
  - There are 5 main types of cement:
    - Type I: Standard or normal, used for general construction
    - Type II: Modified, used for places where modest sulfate resistance is needed.
    - Type III: High early strength, is used when quick set is needed.
    - Type IV: Low heat, used for high massive structures to minimize cracking.
    - Type V: Sulfate resisting, is used for structures exposed to water or soil with high alkaline content.
      - Additionally we have:
      - Type IA Normal w/Air Entraining Additive
      - Type IIA Moderate Sulfate Resistance w/Air Entraining Additive
      - Type IIIA High Early Strength w/Air Entraining Additive

CONCRETE MATERIALS

- Basic components cont.
  - Although water is necessary to mix, place into forms and for the hydration process – that is the chemical hardening – too much water will actually decrease the strength of concrete.
  - Generally for complete hydration to take place, water equal to a 25% of the weight of the cement is required. An extra 10-15% is required to make a workable mix.
  - The water must be potable, ensuring no foreign agents will react with the cement or interfere with the adhesion of aggregates to the cement.

CONCRETE MATERIALS

- Basic components cont.
  - For most concrete mixes, the minimum water-cement ratio is about 35 – 40% by weight. Based on the standards, this turns 4 – 4.5 gallons of water per 94 lb sack.
  - Water content is the most critical factor for the strength outcome of concrete. Water should be used just to give workable mix. If too much water is used, “laitance” will be developed. That is the effect of water rich cement rising to the top surface, generating a chalky layer that is very weak. If additional concrete is to be placed, laitance needs to be removed in order to allow concrete to bond.

CONCRETE MATERIALS

- Basic components cont.
  - There are fine and coarse elements in concrete aggregates (fine being those that pass a #4 sieve). Since cement is the most expensive element in concrete, the objective during the mixing is to have such a combination of aggregate sizes that will fill most of the volume with a minimum amount of cement while keeping the strength to the desired standards. Typically, aggregates occupy 70-75% of the volume of concrete.
  - Generally, aggregates are sand and gravel although clays, slags and shales are used for lightweight concrete. Pumice or cinders are used for insulating concrete.
  - The standard weight of concrete is 150lb/ft^3 but lightweight mixes may weigh 50lb/ft^3 for insulating concrete to 120lb/ft^3 for lightweight structural concrete.
  - The size of coarse aggregates is determined by the size of the forms and the spacing between the reinforcing. In many cases it should be not larger than 3/4 of the smallest distance between reinforcing bars or larger than 1/5 of the smallest dimension of the form, or more than 1/3 of the depth of the slabs

CONCRETE MATERIALS

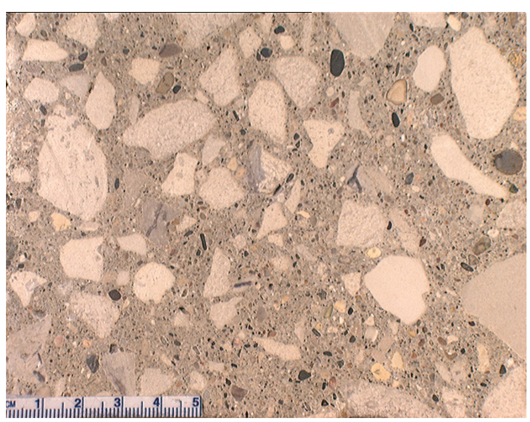
- Proportions:
  - There are several methods of proportioning concrete mix.
  - One is by defining the ratio of cement to sand to gravel by weight like 1:2:4. In addition to that, the amount of water needs to be specified.
  - Another is to specify the weight of the materials, including water, per 94lb bag of cement.
  - Yet another method applicable for large quantities is to define the weight of the materials needed to form a cubic yard of concrete.

CONCRETE MATERIALS

- Proportions cont.:
  - The strength of the final mixture is specified by the compressive strength of the concrete after 28 days of curing, and that is known as the "design strength".
  - The symbol used is f'c and it is anticipated – according to specifications to be 2 ksi 3 ksi or 4 ksi. Higher strengths reaching 12 ksi are achievable but they are used only for special applications and they are more expensive than standard mixtures. The most common strength specified is 3 ksi.

CONCRETE MATERIALS

- Admixtures:
  - They are used to speed hydration, retard hardening, improve workability and durability or even add color.
  - "Air-entraining" agents form tiny bubbles in the concrete improve durability and resistance to freezing and thawing.
  - "Accelerators" speed up the hydration of the cement to strengthen faster



CONCRETE MATERIALS

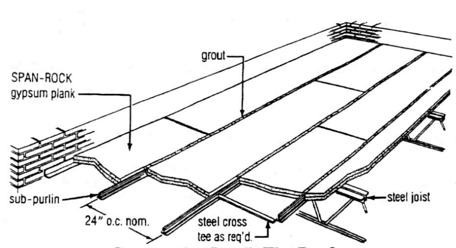
- Admixtures cont.:
  - Plasticizers reduce the amount of water needed, allowing the mixture of higher strength concrete, while maintaining consistency for correct placement.
  - Retarders slow down the setting time to reduce the heat of hydration.
  - Waterproofing agents decrease the permeability of concrete.

Performing Slump test for verification

CONCRETE MATERIALS

- Poured Gypsum Decks:
  - They are used for roofs and are similar to concrete in terms of being liquid mixtures poured on reinforcing material.
  - In typical gypsum deck construction, purlins support fiber plank or rigid insulation. Wire mesh reinforcing is placed over this and gypsum is poured to the assembly to a depth of 2.5” min, forming a highly fire resistant roof deck.
  - Precast gypsum planks with tongue and groove edges are also available in 2” and 4” thicknesses, reinforced with wire fabric and spanning to 10’.

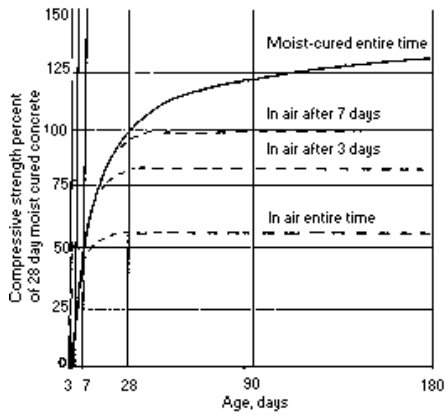
FIGURE 1 - GYPSUM PLANK DECKING SYSTEM



Construction Details/Flat Roofs

CURING AND TESTING

- Curing:
  - Concrete's drying is not a hardening method similar to that of clay drying. There is a chemical reaction that takes place between cement and water and that process needs a certain amount of time to optimize the hardening.
  - It is critical for the first 7 days to have proper temperature and moisture conditions, and up to 2 weeks it is very important.
  - 30% of concrete's strength, or even more, can be lost if concrete dries fast



CURING AND TESTING

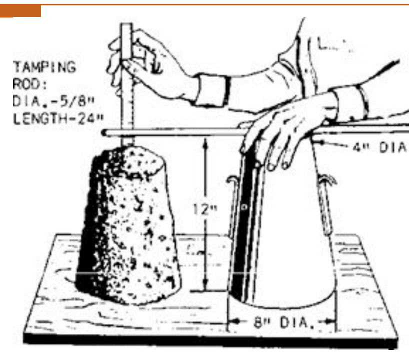
- Curing:
  - Naturally, with high-early-strength concrete time can be reduced as it already gains 70% of it's strength in the first week.
  - There are many techniques to maintain correct moisture in concrete, like the use of sealing compounds, covering with plastic, or sometimes by continually sprinkling the surface, although without any doubt, the best option is to chose a time of the year with the best weather!

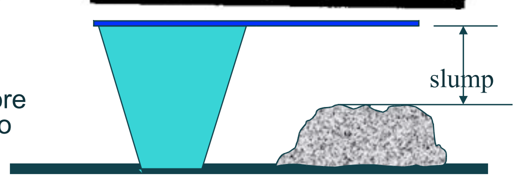
CURING AND TESTING

- Curing:
  - Frost may be an even worse threat to concrete. Concrete exposed to frost during the period of curing may lose up to half its strength.
  - The heat produced by the concrete during the curing period (heat of hydration) may be used to prevent frost. By applying insulation around curing concrete, the produced heat can be trapped instead of dispersed in the cold atmosphere. In case of very cold temperatures, type III cement may be used and external heat supplied. Also, the water and the aggregates may be heated prior to mixing.

CURING AND TESTING

- Testing:
  - Concrete's curing process has such a high number of variables that it is easy for something to go wrong. Thus a continuous set of tests need to be performed to secure the fact that the structure will not fail. Three tests are the most important to keep in mind.
  - The Slump Test verifies the consistency of the concrete before it is cast. It is performed on site right before the concrete will be cast into the forms.





CURING AND TESTING

- Testing cont.:
  - The slump test is a very simple test where concrete is placed in a 1' cone of 8" opening and 4" top diameter. It is compacted manually and the excess concrete is wiped off with a rod. Then the cone is removed. Depending on how the concrete will be used, the desired slump drop should be between 2" and 6". More drop indicates excessive water content while a drop less than 2" indicates that the mixture is stiff and will likely not be placed correctly within the forms.

CURING AND TESTING

- Testing cont.:
  - The second most important test is the <u>Cylinder test</u> that measures the compressive strength of the concrete f'c. As the concrete is about to be cast, samples are placed in cylinder molds of 6" dia. And 1' length. The test takes place on the 7th and the 28th day. Usually the strength measured on the 7th day is about 60-70% of the strength anticipated on the 28th day.
  - The sample is placed in a machine that applies compression and measures the f'c of the curing concrete.
  - The cylinder test can be applied also on the 1st, 3rd, and 14th day.

CURING AND TESTING

- Testing cont.:
  - The Core Cylinder test is the third one. It is applied when a portion of the structure as it is in place needs to be tested for its strength. A cylindrical form of the concrete is drilled out and tested in a laboratory for its f'c value.

CURING AND TESTING

- Testing cont.:
  - Another test is the Kelly ball test, also known as the ball penetration test. In this test, a hemispheric mass (30 lb) of steel with a calibrated stem is dropped onto a slab of freshly laid concrete. The amount of penetration of the ball is measured and compared to half the value of the slump test.

CURING AND TESTING

- Testing cont.:
  - The Impact hammer test is a non destructive method to verify the strength of concrete after it cured. A spring loaded plunger is snapped against a concrete surface, and the amount of rebound is measured. The rebound distance provides an approximate value of the concrete strength. If the accuracy of this test is not enough or if valid doubts are raised, it is suggested to apply the core cylinder test.

CURING AND TESTING

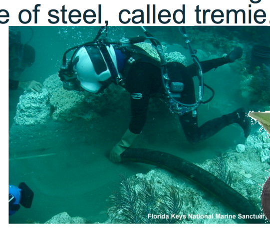
- Testing cont.:
  - Finally, the K-slump test uses a 3/4" tube that contains a floating scale. The tube is placed on wet concrete and the scale is pushed into the mixture and released. The distance of the scale floats out and it is read directly. This test provides a measurement of the consistency of the fresh concrete, similar to the slump test.

PLACING AND FINISHING

- Concrete placement:
  - That involves a series of steps, from transportation of the mixed material to pumping it to the forms, and vibrating.
  - The transportation is responsibility of the providers, to bring the mixture at a certain consistency and at the specified temperature range.

PLACING AND FINISHING

- Concrete placement:
  - Transportation can take place in either through pumping, small buggies or wheel-barrows, or with bottom dump buckets. The choice of these methods depends on volume, accessibility and logistics.
  - Underwater placement of concrete takes place with the use of a long chute made of steel, called tremie.



PLACING AND FINISHING

- Concrete placement:
  - Concrete needs to be placed in such a way that no segregation will occur within the mixture. Long distance dropping of concrete may cause segregation. Typically, 5' should be considered as the maximum distance for concrete to be dropped.
  - Excessive lateral movement of concrete inside the forms should also be avoided.

The effect of segregation in the shown case is also known as honeycombing.

PLACING AND FINISHING

- Concrete placement:
  - After placement, the concrete needs to be compacted and verify the mixture has filled the forms completely, with no air pockets. If rebars are out of contact with the mixture, the design is bound to fail.
  - For small jobs, manual compaction may take place but typically vibrators are used to secure an even distribution of the mixture within the forms.

PLACING AND FINISHING

- As-Cast finishes:
  - Concrete can be finished in several ways. The simplest is the rough form that shows the formwork pattern. Defects, holes, wood grain patterns may be left or treated. Untreated finish like this is used only in areas that are not visible.
  - A smooth form finish (otherwise known as fair-face) takes place when smooth forms of wood, metal, or board are used, joints and tie holes are set in a regular pattern and treated. Any "fins" left from concrete seeming into the joints are sanded to provide a smooth surface

PLACING AND FINISHING

- Architectural Finishes are used when concrete will be exposed and appearance is prime:
  - Form liner is formed with liners of plastic, wood, or metal. Parallel rib liners are one of the most common types. Joints and tie holes can be treated or left exposed for a rougher look. This applies well with the whole idea of "Beton Brut" as presented by Le Corbusier during the Modernist era.

PLACING AND FINISHING

- Architectural Finishes cont.:
  - Scrubbed: The surface is wetted and scrubbed with wire brush, removing part of the surface fine mortar and exposing the rougher aggregates.
  - Acid Wash : The surface is wetted with *muriatic* acid to expose and accentuate the aggregate and its color.
  - Water jet: A high pressure mixture of air and water jet hits the surface to expose the rougher aggregates.

PLACING AND FINISHING

- Tooled and Sandblasted Finishes: Tools are applied to mechanically modify the surface:
  - Bush hammering is a process that yields a very rough texture through the removal of portions of the surface.
  - Grinding is a process that removes the surface mortar, yielding a very smooth texture that accentuates the aggregate mixture and it looks like *Terazzo.*

PLACING AND FINISHING

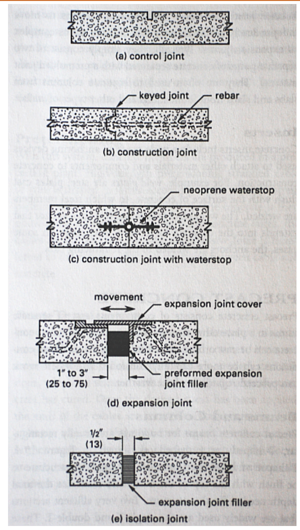
- Tooled and Sandblasted Finishes cont.:
  - Applied finish is the result of addition of layers of another material such as stucco.
  - Sandblasted finish is another method of removing the fine mortar from the surface. Depending on the power specified for the sandblasting (light, medium, or heavy) the surface is accordingly formed.

PLACING AND FINISHING

- Rubbed Finishes:
  - Smooth finish is produced by wetting the surface and rubbing it with carborundum brick, yielding a smooth texture and consistent color.
  - Grout Cleaned finish is the result of applying grout over concrete to produce a homogeneous surface and color.

JOINTS AND ACCESSORIES

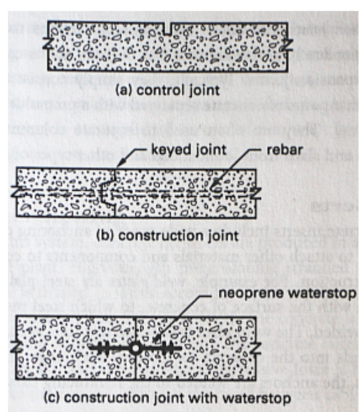
- Purposes and Types of Concrete Joints:
  - There are four main types of joints used for concrete. All four types are applied for different purposes and are designed differently.
  - The types of joints are the following:
    - Control
    - Construction
    - Expansion
    - Isolation.



Picture source: Ballast, D.K.: *Architectural Exam Review, Vol II*, pg.15-9, Professional Publications, Belmont, CA, 1998.

JOINTS AND ACCESSORIES

- Purposes and Types of Concrete Joints cont.:
  - Control joints form a weak section in the concrete, allowing cracks to occur along them. They are formed on a linear pattern by the use of tools whilst the concrete is wet.
  - Construction joints are created along the line where concrete is poured. That is after a section has cured, and another section needs to be added. Construction joints need to be strategically located where minimum shear forces are anticipated. Reinforcing should normally extend from one section to another.
  - Also, as water may leak through, waterstops may be applied in the first pour, extending into what will be the next section



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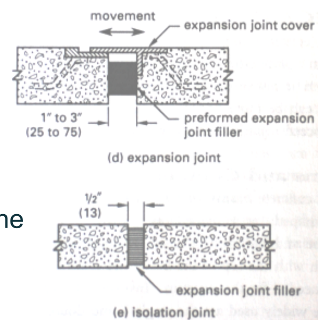
JOINTS AND ACCESSORIES

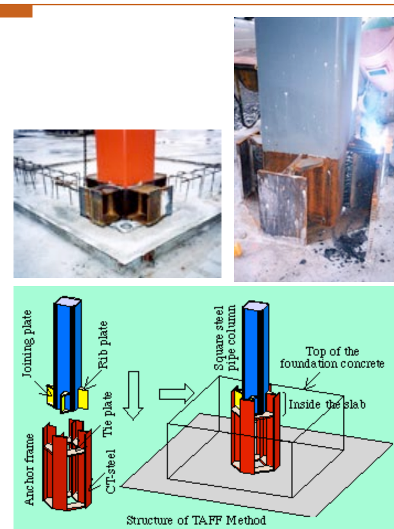
- Purposes and Types of Concrete Joints cont.:
  - Expansion joints are designed to allow entire sections of concrete structure to shrink and expand without generating axial compression to the adjacent slab. Since the movement is anticipated to be either due to shrinkage or expansion, both movements should be accommodated by the joint.
  - Expansion joints may be fairly complex designs since some parts need to be embedded within the concrete and some exposed. The joints extend throughout the building form (slab or wall) and thus no rigid connection between the adjacent sections of the building form exists.
  - Isolation joints also allow sections of the building to move independently but they do not carry the same complex mechanisms as expansion joints. They are usually applied to separate columns from slabs and slabs from foundations.



Picture source: Ballast, D.K.: *Architectural Exam Review, Vol II*, pg.15-9, Professional Publications, Belmont, CA, 1998.

JOINTS AND ACCESSORIES

- Inserts:
  - Concrete inserts are a series of anchoring devices used to attach other elements or material to the concrete, e.g. “weld plates” to which steel members are welded.

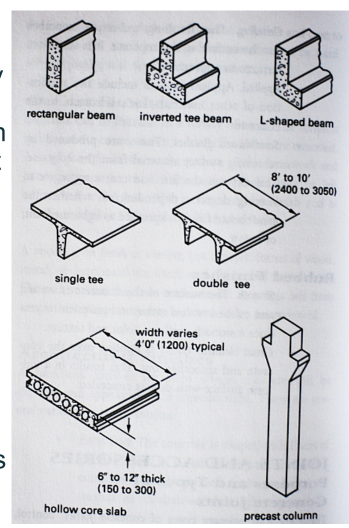


PRECAST CONCRETE

- Precast concrete consists of components cast in separate forms in a place other than their final location. It can be cast either on site or in a pre-fabrication plant where conditions can be better monitored and quality is better controlled regardless of weather conditions.

PRECAST CONCRETE

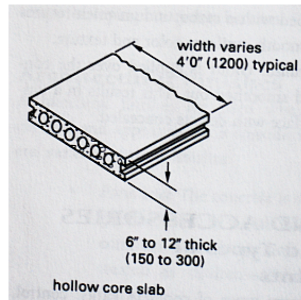
- Beams and columns:
  - Precast beams for buildings are usually set in T-shape or L-shape forms that allow the floor to be flush with the beam top. This minimizes the total depth that the beam will need to have.
  - Single-T and Double-T sections combine deep section to enhance the moment of inertia of the beam and a wide flange formation. With T-sections usually a topping slab is set to cover joints and make the floor more level.
  - Precast columns are usually set in rectangular form and cast with welding plates on top and bottom and haunches to support beams.



Picture source: Ballast, D.K.: *Architectural Exam Review, Vol II*,pg 15-10, Professional Publications, Belmont, CA, 1998.

PRECAST CONCRETE

- Floor and Roof Panels:
  - Besides the T-sections that can serve as floor and roof structures, simple reinforced concrete slabs can be precast. They can be solid or hollow according to the amount of stress that they are supposed to take. Hollow will be deeper and can carry more load and span longer.
  - Cored slabs are 6" to 1' thick and normally 4' wide and they span up to 36'



Picture source: Ballast, D.K.: *Architectural Exam Review, Vol II*,pg 15-10, Professional Publications, Belmont, CA, 1998.

PRECAST CONCRETE

- Floor and Roof Panels cont.:
  - Lift slab construction is a method of casting entire floors on the ground one on top of another around pre-erected columns.
  - A bond-breaker (liquid solution or sheet of plastic) is applied between slabs as concrete is poured. The slabs are then erected with jacks and connected to the columns with weld plates.
  - This is a very efficient method that minimizes the amount of formwork needed as well as the construction time.

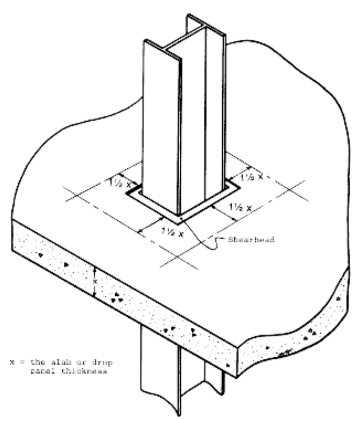
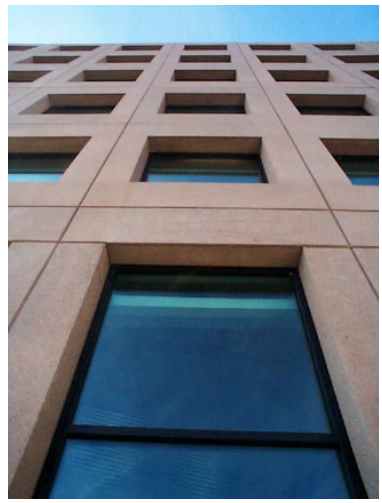


Figure 1--Column Head Area

PRECAST CONCRETE

- Wall Panels:
  - Wall panels can be cast in a variety of sizes and shapes. For economic reasons the number of panels and openings should be kept to a minimum.
  - The panels are usually set at 5” – 8” thickness (although they can be thicker) and long enough to span columns or beams.
  - If they are set to span beams, greater savings can be achieved by spanning two floors in multi-storey buildings.

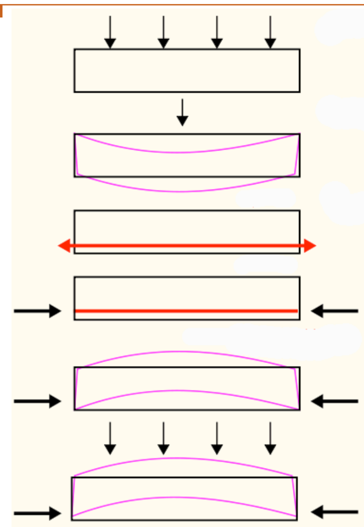


PRECAST CONCRETE

- Wall Panels:
  - Wall panels can be cast on site also. A very typical and efficient method is that of “tilt wall”. Panels are cast on site, essentially right next to where they will be set. Once the concrete cures, the panels are raised by crane.
  - The difficulty with these structural forms during the raising is to make sure that they are designed to take the stress while the rotational action takes place and they do not snap.

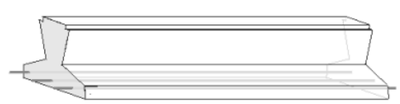
PRECAST PRESTRESSED CONCRETE

- Prestressed concrete members are designs where concrete and reinforcing steel are set in ways that stresses experienced by either of the two materials synergetically extend the capacity and the dimensions of a structural member, in a way that would have been impossible through conventional methods. Reinforcing steel is set in the structural member under high tension. Concrete assumes compressive forces caused by the stressed steel. The location is that where the concrete would have been in tension after normal loads would be applied. The steel, being in tension, transfers the stress in the opposite way to the concrete.



PRECAST PRESTRESSED CONCRETE

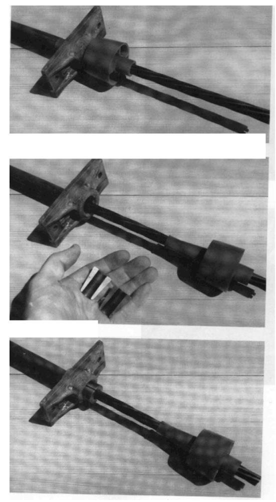
- Pretensioning:
  - Concrete members are fabricated in a plant for this type of prestressing. The high strength pre-tensioning cable is set and a tensile force is applied to them in the forms, according to the specifications. Then the concrete mixture is poured. Once the concrete cures, the cables are cut and the resulting force is balanced between the cables and the concrete through the bond that is created between the two materials.



Stage 1

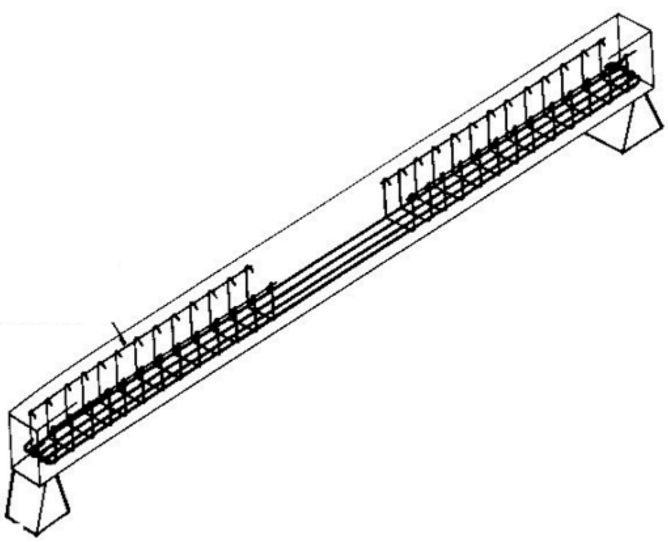
PRECAST PRESTRESSED CONCRETE

- Post-Tensioning:
  - Post-tensioned construction is similar to the pre-tensioning method with the difference that hollow sleeves or conduits are placed into the forms on site and concrete is poured around them. High strength steel tendons are set within the sleeves and stressed with hydraulic jacks after the concrete has cured.
  - Once the specified stress is applied, the ends of the cables are secured and jacks removed.
  - If the tendons are to be bonded, the sleeves are removed and grout is forced into the space between the concrete and the tendons.



Anchors for post-tensioning cables

Reinforcement Placement



Anchors for Post-tensioning Cables