The History of Concrete
Lessons Learned from the Past 9000 Years
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- As one of the key constituents of modern concrete, cement has been around for a long time. About 12 million years ago in what is now Israel, natural deposits of cement were formed by reactions between limestone and oil shale that were produced by spontaneous combustion.
- The earliest known use of limestone and quick lime cement in a structure has been dated back about 12,000 years. It was found in the Gobekli Tepe temple in modern-day Turkey.
- Nevali Cori is an ancient settlement in present-day Turkey. The Lime Kilns used to make concrete floors here are older than organized agriculture. In order to extract the Lime from the Limestone the kilns have to burn in excess of 1,500 degrees F.
- A slab from 7000 B.C. was unearthed in Galilee, Israel in 1985. The 9000-year-old slab varies in thickness from two to three inches, and rests on an even base of sandy clay. The concrete substance has been well consolidated and the surface is hard and smooth. There is evidence of this type of concrete construction in Eastern Europe and the Middle East for about 2000 years after this, but then it seems the technology was lost. From the evidence unearthed so far it seems that by 5000 BC the art of concrete had died out. We have to come down through the years to 2500 BC to see its re-emergence.
- Around 3000 BC, the northern Chinese used a form of cement in boat-building and in building the Great Wall. Some of these structures have withstood the test of time and have resisted even modern efforts at demolition.
- In the paper “An Experimental Study of Pig Blood–Lime Mortar Used on Ancient Architecture in China” we learn that the Chinese developed the use of PIGS BLOOD as a concrete admixture long before the Romans did. There are thousands of ancient Chinese structures which utilized pig’s blood in the Lime Cement component being preserved. When mixed with Quick Lime cement the blood would act as a Water Reducer and an Air-Entrainer, increasing durability
- Admixtures that either increase slump of freshly-mixed mortar or concrete without increasing water content OR maintain slump with a reduced amount of water, the effect being due to factors other than air entrainment. (ACI 116.R-2)
  - Lower Water to Cementitious Ratio – Improved strengths
  - Improved Workability, Finishability, Durability and Placeability
  - Controlled Time of Setting
- Water reducers allow for water entrapped within the cement clusters to be free. This results in improved workability of concrete mixture without any additional water being added. The Fluidity of a Water-cement System is a Function of Attractive and Repulsive Forces between Cement Particles.
• How Polycarboxylate-Based Admixtures Work- These products provide significantly improved cement dispersion due to inherent dual mechanism of electrostatic & steric repulsion. Polycarboxylate molecules work by attaching themselves to cement particles and impart a negative charge that causes cement particles to repel from one another (electrostatic repulsion). The long side chains on the molecules physically help to keep cement particles apart and totally surround the cement particles (steric hindrance). This dual mechanism results in improved dispersion, mix lubrication and performance.

• There are conflicting reports, but it would seem that a type of concrete was used in the construction of the Great Pyramid of Giza in ancient Egypt. The earliest known illustration of concrete work can be seen in a mural from Thebes in Egypt dating from about 1950 B.C. that shows various stages of concrete production. The production of concrete eventually spread from Egypt around the Mediterranean. Concrete in turn passed to ancient Greece.

• Pozzilans were used in the Eastern Mediterranean since 500–400 BC. Although pioneered by the ancient Greeks, it was the Romans that eventually fully developed the potential of lime-pozzolan pastes in Roman concrete used for buildings like the Pantheon. The Roman architect Vitruvius speaks of four types of pozzolana: black, white, grey, and red, all of which can be found in the volcanic areas of Italy. Typically it was very thoroughly mixed two-to-one with lime just prior to mixing with water. Today we find by utilizing Fly Ash, Slag, Silica Fume, Metakaolin, or other pozzilans / Supplementary Cementitious Materials we can increase the strength and durability of our concrete as well.

• The Pantheon in Rome has exterior foundation walls that are 26 feet wide and 15 feet deep and made of pozzolana cement tamped down over a layer of dense stone aggregate. That the dome still exists is something of a fluke. Settling and movement over almost 2,000 years, along with occasional earthquakes, have created cracks that would normally have weakened the structure enough that, by now, it should have fallen. The exterior walls that support the dome contain seven evenly spaced niches with chambers between them that extend to the outside. These niches and chambers, originally designed only to minimize the weight of the structure, are thinner than the main portions of the walls and act as control joints that control crack locations. Stresses caused by movement are relieved by cracking in the niches and chambers. This means that the dome is essentially supported by 16 thick, structurally sound concrete pillars formed by the portions of the exterior walls between the niches and chambers.

• The Domus Aurea was a vast landscaped palace built by the Roman Emperor Nero in the heart of Ancient Rome, it is thought to have covered 300 acres though most of it is still yet to be excavated. This structure was larger than the Colosseum of Rome, and its ruins are right next to it. The concrete walls were covered with frescos so stunning that the name of the artist is still used to describe things that are over the top - Fabulous was perhaps Rome’s most skilled artist working with cement and paint.

• Firmitas Utilitas Venustas - The Roman architect Vitruvius states in his 10 part book “De Architectura” that structures must be Durable, Useful, and Beautiful. This holds true in our days as well. In book 2 of Vitruvius’ “On Architecture” is stressed the importance of using clean aggregate. He proposes a simple test for determining the fitness of a sand for use in concrete, “Try this: throw some sand upon a white cloth and then shake it out, if the cloth is not soiled and no dirt adheres to it, the sand is suitable”. We today have ASTM C33 guidelines to follow. The effects of dirty aggregate on concrete strength have been written down for over 2000 years.
The Vitruvian Man is a drawing by Leonardo da Vinci. It is accompanied by notes based on the work of the Roman architect Vitruvius. The drawing is based on the correlations of ideal human body proportions with geometry described by the ancient Roman architect in Book III of his treatise De Architectura. Vitruvius described the human figure as being the principal source of proportion in architecture. That same chapter gives the mix design for water proof concrete.

Durability
  - Alkali Silica Reaction (ASR)
    - A type of concrete deterioration that occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete.
    - Needed in order for ASR to occur:
      - Cement alkali (>0.60)
      - Aggregate containing reactive silica minerals (ASTM- C295 / C1260)
      - Presence of moisture in the concrete
    - Prevention:
      - Total cementitious alkalis below 0.60
      - The addition of supplementary cementitious materials
      - Non-reactive aggregates
  - Delayed Ettringite Formation (DEF)
    - Sulfate compounds react with calcium aluminate in cement to form ettringite within the first few hours after mixing with water. If concrete is exposed to high temperatures during curing the ettringite can dissolve and when exposed to moisture later reform, creating expansive forces within concrete.
    - Expansion and cracking can occur in concretes of particular chemical makeup when they have achieved high temperatures soon after placement (~160 to 210 F)
    - Prevention:
      - Use sound (proven) materials
      - Cure below 158° F, after initial set
      - Use SCM’s to mitigate the re-formation of ettringite
  - Freeze / Thaw
    - The freezing of concrete results in the formation of ice inside the concrete. When frozen water expands by 9%, this volume expansion generates significant tensile stress in the concrete. Cycles of freezing and thawing leads to distress.
    - If the freezing water does not have microscopic air bubbles to expand within, then cracking and scaling can occur.
    - Prevention:
      - Air Content – 5%-8% for ¾” agg, Spacing factor <0.008 in, Specific surface area of 600in²/in³
      - W/C R <0.45
      - Min. 4500 psi
      - Fly ash, slag, silica fume not to exceed 25%, 50%, 10% respectively
      - Proper finishing after bleed water has evaporated
  - Permeability
- The amount of water migration through concrete when the water is under pressure or to the ability of concrete to resist penetration by water or other substances.
- Decreased permeability improves concrete’s resistance to freezing and thawing, sulfate, chloride-ion penetration, and other chemical attack.
- Decrease permeability by:
  - Lowering the water cement ratio
  - Using an aggregate with a more uniform gradation
  - Use a SCM (i.e. Slag, Fly Ash, Silica Fume...)
- Tests:
  - AASHTO T 259 – ponding chloride solution
  - ASTM C 1202 – rapid chloride permeability test (Coulomb)

- In Mesoamerica, during the time of Roman Emperors, the Mayans developed mortar and stucco using Quick Lime, and they produced some Concrete. It was mostly used to create cast in place beams in post and lintel structures, roads, cisterns, and plazas. Mayan cement was a hydrologic cement like Portland Cement. When the Mayans made cement rituals accompanied the kiln burning. Women were not permitted near the kiln during the burning, since the kiln, considered to be feminine, would become jealous and refuse to operate properly. In these hot climates concrete would perform differently as the temperature changed.
- Temperature
  - “Rules of Thumb” 10°F Change in Concrete  
    - Temperature =
  - Changes slump by 1”
  - Requires 1 gallon of water per yard to maintain slump
  - Changes set time
    - 150 to 200 psi average strength change
- The leaning tower of Pisa was built with limestone and lime mortar beginning in 1173, though the exterior of the tower is covered in marble. Ironically, the limestone is probably why the tower has not cracked and broken- the rock and lime cement mortar is flexible enough that it can withstand the pressures placed on it by the lean.
- During the 1700’s, in the race to develop better building materials the English had an advantage, they had John Smeaton. Smeaton is known as the father of civil engineering. More than a thousand years after the fall of Rome and the loss of concrete’s secrets, Smeaton rediscovered how to make cement. He was commissioned to build a lighthouse on a dangerous perch on the Eddystone Rocks, just off the southern coast of England. These rocks had sunk hundreds of ships and resulted in thousands of deaths. Three lighthouses on the site had all failed. The first was taken by waves. The second collapsed during a hurricane. The third burnt down. Smeaton was determined to build the strongest lighthouse in the world. The lighthouse was constructed between 1756 and 1759 using a hydraulic cement-filled mortar that Smeaton developed by mixing lime with high clay content with fly ash. It stood on the Eddystone Rocks for more than a century before the rocks themselves began to erode. In 1882, the lighthouse was disassembled and rebuilt in Plymouth, England where it still stands today. The new lighthouse was built out of concrete of course.
- Joseph Aspdin 1824 - first Portland cement patent. Most of us know that it was Joseph Aspdin who patented the first Portland Cement. But it was his son William Aspdin who perfected that to
be the first modern Portland Cement (containing Alite). He was a scandalous character who had little to no chemistry training. He was a master of trial and error. When each newly loaded kiln was ready for firing he would step out of his office and scatter handfuls of brightly colored crystals over the raw mix, to give the impression that the special properties of his product were the result of an unidentified "magic ingredient".

- In 1836 the first systematic testing of compressive and flexural strength of concrete was conducted in Germany. In 1877 the German Cement Manufacturers Association released the first Standard for Portland Cement. Today it’s important to watch cement mill certifications over time. Be aware of what’s happening with your cement. Also, ask your cement supplier for his ASTM C917 report, to monitor strength variation closely.

- The Stoney-Baynard Plantation House was constructed in 1840 from a type of concrete known as “Tabby”. Tabby was made by burning oyster shells to drive off the carbon, leaving a powder of calcium oxide. This was mixed with beach sand and whole oyster shells, then packed into wooden forms. This ruins is on Hilton Head Island, but there are fine examples of tabby structures all over the coastal Southeastern US that have withstood warfare, natural disasters, and the ravages of time.

- During the American Civil War, almost all roads were dirt that became quagmires of mud after it rained. Only a few hard-surface all-weather roads existed. These were called “macadamized” roads after their inventer, Scottish civil engineer John Loudon McAdam, who in turn was indebted to the road builders of the ancient Roman empire. The pavement (from Latin pavinentum) was made of compressed layers of gravel set on a cement bed with limestone shoulders. Ditches at the sides of the road provided necessary drainage. Stonewall Jackson’s early success in his 1862 campaign was due to the fact that he could move his troops very quickly along the Shenandoah Valley Turnpike which was paved with this type of concrete, his opposition was moving along dirt roads.

- The Ward House in Rye Brook, NY is the oldest surviving reinforced concrete building in the U.S. The structure was erected in 1873-1876 by William E. Ward. The 17-room mansion was constructed entirely of concrete, utilizing 4,000 barrels of Portland cement, 8,000 barrels of sand, and 24,000 barrels of stone. The concrete was reinforced with small, lightweight iron I-beams and 3/8-inch round iron rods. In preparing the concrete, Ward followed the technique of French industrialist François Coignet, making the mixture very dry and tamping it into place. The roof is solid concrete and hollow spaces in the floors and walls were connected to the furnace to provide a central heating system. When it was first built neighbors called it "Ward's Folly" because of their lack of confidence in the new building material. Its been in service 142 years, its now called "Ward's Castle".

- The first patent for a chemical admixture for concrete dates back to 1873 in Germany. It was for Calcium Chloride accelerator. ASTM first published its C494 standard in 1962, titled “Standard Specification for Chemical Admixtures for Concrete,” which set performance criteria for five types of admixtures: A, B, C, D and E. Types F and G, high-range water-reducing admixtures, were not added until 1980. In 1962, only 36 state DOTs allowed the use of admixtures in concrete. Recently we’ve seen the addition of Type S admixtures (Special).
  - Dosages depend on a number of variables that are specific to each mix design and production facility.
  - Can specify in oz / 100wt or oz per yard.
Admixture effectiveness varies depending on its concentration in the concrete and the effect of the various other materials.

Adequate testing should be performed to determine the effects of an admixture on the plastic and hardened properties of concrete.

A rule of thumb is for all admixtures to be added separately.

ACI Education Bulletin E4-12 “Chemical Admixtures For Concrete” – Free Resource

- At 218 feet Britain’s Sway Tower is the tallest unreinforced concrete structure. It was built 1879. It’s been a restaurant, B&B, and family home since it was constructed. It was 4 bedrooms and an indoor swimming pool. It’s still a desirable property, recently selling for over £2million. Concrete homes stand the test of time.

- Plymouth Rock is the storied rock of the pilgrims’ first step on the new world. In 1776 there was so much excitement about the formation of the new country that the rock was broken free from its base of granite and carted around New England so that people could touch it. At one point it fell from the cart and broke in half. You can still see the scar. In the 1880’s while the country was stitching itself back together after its bloodiest conflict there was a desire for a symbolic effort to stitch Plymouth Rock back to gather as well. How was this accomplished? Concrete! Concrete was used to put the Rock back together, “cementing” its place in an iconic origin story and national identity of this country.

- In 1887 Henri deChatalier established oxide ratios to produce cement. He named them Alite (tricalcium silicate), Belite (dicalcium silicate), and Celite (tetracalcium aluminoferrite). He proposed that concrete hardening is caused by the formation of crystalline products of the reaction between cement and water. Part of Le Chatelier’s work was devoted to industry. He was a consulting engineer for a cement company, the Société des chaux et ciments Pavin de Lafarge, today known as Lafarge Cement.

- Portland Cements are hydraulic since they set and harden by reacting with water. The raw materials used in manufacturing cement consist of combinations of limestone, marl, or oyster shells, shale, clay and iron ore. The raw materials must contain appropriate proportions of lime, silica, alumina, and iron components.

- C3S hydrates and hardens rapidly and is largely responsible for initial set and early strength.

- C2S hydrates and hardens slowly and contributes to strength increases at ages beyond one week.

- C3A causes the concrete to liberate heat during the first few days of hardening and contributes slightly to early strength.

- C4AF reduces the clinkering temperature in the manufacture of cement. It hydrates rapidly but contributes very little to strength.

- Amount of material remaining on a 325 mesh (325 openings per 1 in²).

- The coarse particles that remain play a small role in hydration and strength development.

- In conjunction with the blaine this value can give you a better indication of the particle size distribution.

- If blaine is very high (ie 4800) and 325 mesh is low (ie 82) it means that there is a large amount of “super” fines, (which have a tendency to a function of clinker that has
already hydrated….since they have already reacted their presents is detrimental to concrete).

- Rebar, 1889 - Alvord Lake Bridge, San Francisco
- By 1897, Sears Roebuck was selling 50-gallon drums of imported Portland cement for $3.40 each. Although in 1898 cement manufacturers were using more than 90 different formulas, by 1900, basic testing and manufacturing methods had become standardized.
- In the early days of Portland cement production, kilns were vertical and stationary. In 1885, an English engineer developed a more efficient kiln that was horizontal, slightly tilted, and could rotate. The rotary kiln provided better temperature control and did a better job of mixing materials. By 1890, rotary kilns dominated the market. In 1909, Thomas Edison received a patent for the first long kiln. This kiln, installed at the Edison Portland Cement Works in New Village, New Jersey, was 150 feet long.
- Edison wanted to create a piano that was cheap enough that every American home could have one. A piano made of concrete would still house a wooden soundboard, where most of the sound is produced. A mold allowed the concrete to be cast with embellishments only achieved in wood through expensive hand carving. The Lauter Piano Company briefly produced concrete pianos in 1931.
- Thomas Edison pioneered the concept of Steel Forms for concrete construction. In 1913, U.S. Steel thought Edison’s concrete homes built in Montclair NJ would be a solution to the housing shortage in Gary Indiana, a fast-growing company town. Contractors used Edison’s patented steel molds to build row houses for the company’s employees. Now, over 100 years later, Gary’s Edison Concept Houses have entered the National Historic Register. (over 70 remain of the 86 buildings that employed Edison’s steel molds)
  - Bugholes can be decreased by providing a sufficient quantity of fine aggregate with high surface area (minus No.8 sieve). Larger amounts of sand are not as effective as finer sand.
  - Changing the cement content of a mixture by 94lbs. Generally has the same effect on workability as changing the minus No.8 fraction of the combined aggregate by 2.5%
- In 1891, George Bartholomew poured the first modern concrete street in the U.S., and it still exists today. The concrete used for this street tested at about 8,000 psi. You are welcome to drive over Court Street in Bellefontaine, Ohio.
- Harmon S. Palmer invented the first commercially successful concrete block machine in 1900.
- Duff A. Abrams was an American researcher in the field of composition and properties of concrete. He was a researcher, professor, and director of the research laboratory of the Portland Cement Association. Some of the results of his research were: The definition of the concept of fineness modulus. The definition of the water-cement ratio (1918). A test method for the workability of a concrete mix by using what is called 'Abrams cone', (concrete slump test.) According to Engineering News Record the Big Four Railway Bridge in Ohio was the first large-scale project where the concrete mix design method proposed by Professor Duff A. Abrams was used. Now almost a century later this absolute volume method is still used, and so is the bridge.
  - Water Cement Ratio is the most significant factor to both early and late compressive strength, as well as long term durability
  - Weight (in pounds) of water per pound of cementitious material
  - 26 gal x 8.33 = 217 lbs  
  - 217 / 720 lbs. = 0.30 w/c ratio
- The amount of water needed to fully hydrate a pound of cement is about 0.25lb water.
- A typical w/c ratio for prestressed members is 0.38 to 0.43 (driven by release).
- In 1902, August Perret designed and built an apartment building in Paris using steel-reinforced concrete for the columns, beams and floor slabs. The building had no bearing walls, but it did have an elegant concrete façade, which helped make concrete more socially acceptable. The building was widely admired and concrete became more widely used as an architectural material as well as a building material. It was influential in the design of reinforced-concrete buildings in the years that followed, and so Architectural Concrete was born.
- The Ingalls Building was the world’s first concrete skyscraper, constructed in 1903. Ever since concrete has been climbing to new heights.
- Writer Franz Kafka is credited with developing the first civilian "hard hat" in 1912 while employed at the Worker's Accident Insurance Institute for the Kingdom of Bohemia. In 1919 Edward Bullard patented a "hard-boiled hat" made of steamed canvas, glue and black paint. That same year, the U.S. Navy commissioned Bullard to create a shipyard protective cap, that began the widespread use of hard hats. Shortly after, Bullard developed an internal suspension to provide a more effective hat. These early designs bore a resemblance to the military helmets of WWI that served as their inspiration. Six Companies, Inc became the first to mandate the use of hard hats by its employees in 1931, during the construction of the Hoover Dam. In 1933 the Golden Gate Bridge became the first construction site to require the use of hard hats by everyone on site, by order of Joseph Strauss, project chief engineer. Aluminum became a standard for hard hats around 1938. The plastic helmet was introduced in 1930. Fiberglass came into use in the 1940's. Today, most hard hats are made from high-density polyethylene or advanced engineering resins. Remember your PPE today, be safe out there!
- In 1913 the concrete industry was revolutionized when the Kuhlman Company started the first Ready-Mixed Concrete Company in Baltimore Maryland.
- The use of fly ash from coal burning power plants as a pozzolanic ingredient in concrete was recognized as early as 1914, although the earliest noteworthy study of its use was in 1937.
- In 1915 Lynn Mason Scofield founded the first company to produce color for concrete. It is still producing color today.
- In Australia, the New South Wales Government Railways made early use of precast concrete construction for its stations and other buildings. Between 1917 and 1932, they erected 145 precast buildings.
- The SS Atlantis was one of the first self-propelled concrete ships, built in 1918. It was over 200 feet long and could carry 1150 tons of cargo. Concrete ships were used at the end of WWI through WWII because of steel shortages and because a Ship's Hull could be poured in weeks compared to months to construct steel hulls.
- In the 1920s, the U.S. Post Office began experimenting with cross-country delivery of mail by air. Before the advent of radio guidance, mail pilots made their way by following visible landmarks, a system that worked where there were recognizable geological or man-made features to be guided by, but it was problematic in areas such as vast stretches of empty desert. In 1924 the Post Office began erecting combinations of large concrete arrows and lighted beacons every 10 miles along its established airmail routes. These days, while very few of the lighting towers are left, a lot of those painted concrete arrows still dot the American landscape.
• In 1927 the German engineers Max Giese and Fritz Hull came upon the idea of pumping concrete through pipes. They pumped concrete to a height of 125 feet and a distance of 130 yards. Shortly after, a concrete pump was patented in Holland in 1932 by Jacob Cornelius Kweimn. This patent incorporated the developer’s previous German patent.

• Air entraining agents, used to improve concrete’s resistance to freeze/thaw damage, were introduced in 1930. The 1930’s saw the construction of the Hoover Dam, the first structure to exceed the masonry mass of the Great Pyramid of Giza. Approximately 3,250,000 cubic yards were placed in the dam itself, and another million plus yards around the site. The Hoover Dam marks a milestone in Concrete history for many reasons, and sure it’s still curing. But my favorite thing about the Hoover Dam is the monument atop the structure for the 100 who died building it. The monument’s base is a star map cast into terrazzo that places the cosmos in the position of the moment that FDR dedicated the Dam. The designers and builders were so confident that the concrete structure would outlast today’s civilization that they put a mathematical time stamp on it for future discoverers.

• The Concrete Fleet, also known as the Kiptopeke Breakwater, consists of several concrete ships lined end to end just west of the former Chesapeake Bay ferry terminal. The fleet consists of 9 of the 24 concrete ships contracted by the U.S. Maritime Commission during World War II. In 1948 the ships were brought to Kiptopeke Beach in order to bring protection to the terminal during severe weather. This concrete served faithfully during WWII and is still serving as a protection to the beautiful Virginia Environment.

• A series of “Flak Towers” were constructed across Germany during WWII containing anti-aircraft guns and fortifications for thousands. This one in Berlin was shot at by the Russians and then the French for weeks after the war. Then the French tried to demolish it with an extreme amount of explosives. Giving up on ever destroying the concrete structure the US buried it in the rubble of the city. Well mostly, the top two stories of this 7 story concrete fortress are still exposed to tourists.

• The Schwerbelastungskörper(German: "heavy load-bearing body") is a hefty concrete cylinder in Berlin. It was erected in 1941–1942 by Hitler’s chief architect Albert Speer to determine the feasibility of constructing a large triumphal arch on the area's marshy, sandy ground. at a cost of 400,000 Reichsmark, the Schwerbelastungskörper consists of a foundation with a diameter of 36 ft that reaches 60 ft into the ground and contains rooms which once housed instruments to measure ground subsidence caused by the weight of the cylinder, which was estimated as equivalent to the load calculated for one pillar of the intended arch. It was deemed too large and strong to demolish.

• Between the World Wars, before the invention of radar, Concrete parabolic sound mirrors were used as early-warning devices by military air defense forces to detect incoming enemy aircraft by listening for the sound of their engines. During World War 2 on the coast of southern England, a network of large concrete acoustic mirrors were built, later the project was cancelled owing to the development of the Chain Home radar system. Many of these mirrors are still standing today. This concept was later used to develop the modern Sound Wall.

• During WWII the soviets tried casting “Concrete Armor” onto their T-32 tanks to protect them from German anti-tank weaponry. Although this was successful in stopping AT rounds it made the Soviet tanks so heavy they were easily out maneuvered.
• Standardized precast components were developed in the USSR. During the 1960’s through the 1980’s the Soviet Union was undergoing rapid urban development. Entire cities were being designed in central offices and constructed in Soviet territories. To address the necessary speed of construction they developed standardized concrete panels that could be arranged to construct many different multi-story buildings. Examples can be spotted throughout Europe and Russia. The city of Tashkent is representative of the different types and possible arrangements of these concrete panels, including decorative, and stylistic patterns.

• In 1967 Israeli/Canadian architect Moshe Safdie first designed 3-D precast concrete modules. Habitat 67 is one of the most acclaimed works in architecture due to its grey aesthetics and chaotic arrangement. Safdie opened the door to concrete modular design.

• The precast concrete “sails” of the Sydney Opera House, one of the world’s most recognizable buildings, soar 200 feet above Sydney Harbor. Less well known is the fact that this building extends almost the same distance underground; beneath the structure is the deepest parking garage in the world. It extends 12 stories into the earth, where most only go down 5 stories. At 120 feet this is considered the deepest basement in the world. The garage contains a double-helix concrete ramp structure that has a capacity for 1,100 cars.

• **Prestress Addendum**

• Peter H. Jackson of New York, is the first person to propose prestressing concrete. In the three decades from 1858 to 1888, Peter H. Jackson obtained five patents by developing systems of applying prestress to building construction. Jackson is traditionally cited as the first engineer to patent prestressed concrete structures.

• Between 1886 and 1906, the idea of prestressing concrete was perfected by Eugène Freyssinet. Interrupted by World War I, Freyssinet used the depression years to develop essential prestressing equipment like jacks and forms. By embedding the tendon in the concrete, Freyssinet liberated the concrete from the necessity to form an arc, thereby defining the look of a prestressed bridge right from the start. The Boutiron Bridge is one of three similar bridges built by Freyssinet in France, in the mid 1920’s. A few months after construction, he was cycling over the bridge when he realized that it was no longer straight, but was dipping at the mid-span of each arch. He concluded that the arch must have shortened. This led him to realize that concrete creeps under load. He decided that to make prestressed concrete work, very high quality concrete was needed, with very high tensile steel strand. Creep would still occur, but the prestress that would be left after these losses would still be adequate. He set up a company to produce telegraph poles, using thin concrete tubes made with mortar, and prestressed with piano wire. This company was set up during the depression and was a financial failure.

• Eugène Freyssinet developed the prestress strand anchor, or “Chuck”, in 1926. It was made of a steel and concrete.

• Prestressed concrete found its way to Germany from France with the help of Dr. Karl Mautner, professor at the Technical University in Aachen. He was of Jewish descent, but despite holding the Iron Cross for his distinguished service in WWI, he was rounded up with other Jewish professionals and put in Buchenwald concentration camp in 1938. At that time it was possible to buy yourself out of the camps and with the help of the British Secret Services he went to England. He brought with him details of Freyssinet’s work. He formed the Prestressed Concrete Company at Southall in 1938 and set up a plant in Lincolnshire to produce prestressed concrete beams. In England, during the early part of WWII, a number of prestressed concrete bridge...
beams were made, to be stored for emergency use. These aided in the quick reconstruction of the British infrastructure after the war.

• In 1939 the German engineer Edwald Hoyer develops the first long-line prestress casting bed.
• In the early 1940’s, building on Eugéne Freyssinet’s work, Prof. Gustave Magnel performed extensive research programs on full scale prestressed concrete beams at Ghent University in Belgium. He gave many lectures around the world on the principles of prestressed concrete. He was instrumental in the design of the first prestressed concrete bridge in the USA, the Walnut Lane Bridge in Philadelphia in 1950, and he wrote the first English language textbook on prestressed concrete.
• The history and legacy of concrete is the story of quality workmanship… Poor Quality concrete will make the news, but it will never make the history books.