Post-tensioning was one of the great advances in concrete technology in the 20th century. Here, modern-day precast concrete segments are post-tensioned together to create long span box-girder viaducts.

The history of concrete

Part 2: From portland cement to structural concrete

By Richard W. Steiger

In 1756, British engineer John Smeaton was commissioned to build a lighthouse on the Eddystone rocks in the English Channel. To develop a mortar that could withstand the constant soaking of seawater, Smeaton undertook a program where he combined numerous materials from various parts of England and the Continent. He achieved success when he combined a limestone from South Wales and an Italian pozzolan. This combination produced the first high-quality cement since the fall of the Roman Empire.

Smeaton outlined his research in a book titled *A Narrative of the Eddystone Lighthouse*. Joseph Aspdin, a young Leeds bricklayer, purchased a copy of the book and it apparently made a distinct impression on him. In 1824, Joseph Aspdin took out a patent for the manufacture of the world's first portland cement. This was the culmination of research by Aspdin and numerous others who preceded him.

James Parker's Roman cement and other natural cements which preceded Aspdin's formula were used extensively during and after that period. However, portland cement was definitely superior and was the forerunner of the cement used for concrete today.

The name portland cement came not from the fact that it was made in Portland, but rather from the color of the material which resembled stone from the Isle of Portland. This cement was undoubtedly the best cement of its day. However, present-day portland cement has been improved so much that it resembles Aspdin's cement in name only.

Aspdin's patent read in part, "My method of making a cement or artificial stone is as follows: I take a specific quantity of limestone, such as that generally used for making or repairing of roads, and I take it from the roads after it has been reduced to a puddle or a powder; but if I cannot procure a sufficient quantity of the above from the roads I obtain the limestone itself, and cause it to be calcined. I then take a specific quantity of argillaceous earth or clay and mix them with water to a state approaching impalpability. After this I put the mixture in a slip pan for evaporation until the water is entirely evaporated. Then I break the mixture into suitable lumps and calcine them in a furnace similar to a lime kiln until the carbonic acid is entirely expelled. The mixture so calcined is ground, beat, or rolled to a fine powder and is then in a fit state for making cement or artificial stone."

Joseph Aspdin went into the business of manufacturing portland cement and was quite successful in his endeavors. In 1852, William Aspdin, Joseph's younger son, carried on the family tradition and eventually set up at Gateshead-on-Tyne what was probably the largest cement works in the world, with a manufacturing capacity of 3,000 barrels or 648 tons of cement a week.

One of the drawbacks of portland cement at that time was that it cost roughly 10 times the relative cost of cement today. The high cost of manufacture prevented its wide-scale use. This would not be remedied until the installation in the 1880s of the continuous process rotary kiln, designed by Ernest Ransome.

The next milestone was the improvement of portland cement. Isaac Johnson, who owned a cement works near Northfleet, superseded the Aspdins as the leading manufacturer of portland cement in Britain. In 1845, he made a simple adjustment that propelled cement technology into the modern age: He raised the temperature at which the cement was fired. As a result, Johnson is considered the father of modern portland cement.

Reinforced concrete

Although the Romans had attempted to use bronze—unsuccessfully—to reinforce concrete, it was not until 1830 that the idea of reinforced concrete was mentioned in the *Encyclopedia of Cottage, Farm and Village Architecture,* which suggested that a lattice of iron tie rods could be imbedded in concrete to form a roof.

In 1848, French lawyer Jean-Louis Lambot constructed two reinforced concrete rowboats by forming a network of fine iron rods and plastering the matrix with mortar.

This was followed in 1849 by Joseph Monier, a French engineer and gardener, who constructed some large plant tubs using the same technique. Monier patented his process and went on to build reinforced concrete pipes, reservoirs, floors, bridges, and straight and arched beams.

Next came Francois Coignet, another Frenchman, who developed a different technique for encasing an iron skeleton framework in walls and floors.

However, the man generally credited in Britain with inventing reinforced concrete was a Newcastle builder named William Wilkinson who took out a patent in 1854. In his patent Wilkinson states that a number of strips of hoop iron were to be laid on edge 2 feet apart. Wilkinson also suggested the use of secondhand wire colliery ropes to be embedded in the fresh concrete and the ends formed into loops or splayed by opening out the strands and twirling them in different directions so that the wires could not be drawn out when the concrete was under load. His drawings show the wire ropes following the lines of tension, illustrating Wilkinson's basic understanding of structural principles.

Iron, and later steel, reinforcement of concrete was on its way, and would now be used for major buildings, bridges, and other structures built with concrete in the 19th and 20th centuries. An important reason for this success was that steel had the same coefficient of expansion as concrete.

Structural concrete

One of the most successful French engineers who devised a system of reinforcing concrete was Francois Hennebique. Building on the techniques devised by his predecessors, Hennebique began with reinforced floor slabs in 1879 and progressed to a complete building system, patented in 1892. He employed structural beams of concrete reinforced with stirrups and longitudinal bars designed to resist the tensile forces against which ordinary concrete was weak. Within a few years he had perfected a system for reinforcing columns, beams, and floors, which he demonstrated in the construction of an apartment building in Paris. Hennebique's system quickly gained acceptance in Britain and subsequently in the United States and is essentially the same basic system that is in use today.

In 1917, another Frenchman, Eugene Freyssinet, discovered the value of mechanical vibration for compacting concrete. Until that time, concrete had been compacted by hand with pieces of wood or metal tampers. Freyssinet, however, is better known for pioneering the system of prestressing concrete.

The French country home of Francois Hennebique. A completely reinforced concrete building system was designed by Hennebique and patented in 1892. This home used his system of reinforcement, which allowed the design and building of the two intersecting cantilevers that carry the main tower, which weighs about 200 tons.

American innovation and its contribution to concrete

Although the United States did not participate in the earliest development of concrete, much has been added to ongoing concrete technology in this country.

Although Ernest Ransome was born in England, he immigrated to America in 1870. He invented the first cylindrical-drum paddle-type concrete mixer in 1885. He followed this with the first continuously rotating cylindrical kiln that made the production of portland cement competitive. In 1900, Ransome produced the first continuously rotating drum concrete mixer.

Here are some other highlights:

1907: Robert Aiken is one of the first to use tilt-up wall construction, near Zion City, Ill.

1908: Thomas Edison patents a system of cast-iron molds for a monolithic concrete house that forms walls, floors, stairways, roof, bath and laundry tubs, and conduits for electric and water service in one single casting operation.

1909: The first moving concrete transit mixer is introduced in Sheridan, Wyo.

1918: Stephen Hayde of Kansas City, Mo., develops a lightweight aggregate from expanded shale. Its development sparks the use of lightweight structural concrete in ocean-going concrete vessels, higher buildings, and thin shell roofs.

1932: Concrete pumping, invented in 1909, becomes more feasible when 6-, 8-, and 10-inch-line concrete pumps are developed. Concrete can be pumped over distances up to 2,000 feet.

1938: Air entrainment is discovered and first used by the New York Highway Department.

1952: The first large structure to use fly ash is Hungry Horse Dam in Kalispell, Mont.

Prestressing concrete

Prestressing involves creating preliminary compressive stresses in concrete, with the primary objective of preventing cracking while under load. Prestress is applied by stretching steel wires, bars, or cables. The steel is said to be pretensioned (or prestressed) if it is stretched before the concrete is set, and post-tensioned if it is stretched after the concrete has hardened.

Freyssinet's research revealed that the success of prestressed concrete depended on both high-quality concrete and high-tensile steel. He collected data from three years of experiments, begun in 1926. In 1934, he was given an opportunity to save the harbor station at Le Havre which was slowly sinking into the mud. He was able to stop the settlement by using his prestressing technique, thereby demonstrating its merits to the French authorities.

During World War II, the Germans used prestressing to strengthen their fortifications and the roofs of their submarine pens. From 1949, with the construction of the Walnut Lane Bridge in Philadelphia, rapid advances in prestressing have taken place in the United States and throughout the world. Today the potential is fully realized. Prestressing permits the design of graceful, slender, yet strong structures, while saving time and materials.

Concrete's future

With the development of high-strength and rapid-setting concrete, new admixtures, and steel, plastic, and glass-fiber reinforcement, plus a developing world of materials that both lighten and strengthen concrete, today's architects, designers, and engineers have access to one of the strongest, most versatile, and pliable building materials known to man. This, coupled with the latest equipment for forming, handling, transporting, and placing concrete, ensures the ongoing evolution and future history of concrete. In the years ahead, it will be fascinating to witness concrete's progress. ✥

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