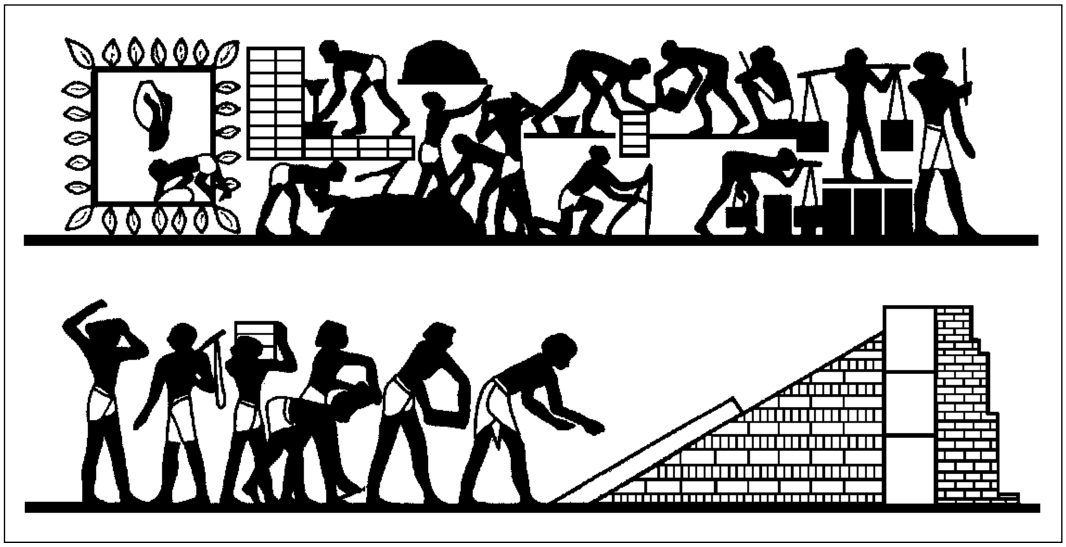

Figure 1. Concrete mortar work in ancient Egypt in 1950 B.C. as seen on a mural at Thebes. At the top, workmen fill earthenware jars with water, which is then mixed with lime to create mortar. Below, a masonry-faced concrete wall is under construction.

The history of concrete

Part 1: From prehistoric rubble mixes to Roman cement

By Richard W. Steiger

Although the Romans are generally credited as being the first concrete engineers, a form of concrete dating to 6500 B.C. has been discovered by archaeologists in Syria. From the Middle East, concrete technology spread and evolved, primarily in Europe. In 1871, the first portland cement was produced in the United States at Coplay, Penn.

Stone Age Syrians built permanent fire pits for heating and cooking. This led to a primitive calcining of surrounding rock and the accidental discovery of lime as a building material. There is evidence that the newly discovered technology gained widespread use. Central lime-burning kilns were constructed to supply mortar for rubble-wall house construction, concrete floors, and waterproofing cisterns. The evolution of concrete technology had begun.

Yugoslavia and China

Another form of early concrete was discovered along the banks of the Danube River in Yugoslavia. Stone Age hunters/fishermen used it to make floors in huts about 5600 B.C. The floors consisted of 10 inches of concrete over a chalk base. Analysis indicates that a red lime was brought to the site from 200 miles upstream and mixed with sand, gravel, and water to form the earliest concrete yet discovered in Europe.

Archaeologists have also discovered concrete in Gansu Province in northwest China that dates to about 3000 B.C. Greenish-black in color, it was used for floors and contained a cement mixed with sand, broken pottery, bones, and water.

There is no further proof of the art of making rudimentary concrete until about 2500 B.C. in Egypt. Sources are in some disagreement, but it has been reported that a cementing material produced from either a lime concrete or burnt gypsum was used in the Great Pyramid at Giza. The earliest known illustration (dating to about 1950 B.C.) of concrete being used in Egypt is shown in a mural on a wall in Thebes (Figure 1).

The use of lime-based mortars and concretes continued in the lands around the eastern Mediterranean Sea. About 600 B.C. the Greeks discovered a natural pozzolan on Santorini Island that developed hydraulic properties when mixed with lime. This made it possible to produce concrete that would harden under water, as well as in the air. The chemical reaction between the lime and the silica-alumina in the pozzolan made this possible. The Greeks used these lime-based compositions as protective coverings for walls of unburned bricks.

The Greeks also mixed a pseudo-concrete that preceded real concrete and consisted of roughly broken stone held together with a mortar of lime and sand. This mixture, however, was too weak to bind the whole together into a compact mass for serious building purposes.

Figure 2. Completed in A.D. 128, the Pantheon of Rome had unreinforced concrete lower walls that were 20-feet-thick. Brick rubble and volcanic stone were used as aggregate. The cement was made from pozzolanic powder which was produced from volcanic ash. The lightest of this pumice was used in the dome which is 142 feet in diameter. The Pantheon is 1,867 years old, and still in fine condition.

Roman concrete

The first examples of Roman concrete date to 300 B.C. The Romans not only improved concrete technically, they also gave it a name. The word "concrete" comes from the Latin *concretus,* meaning grown together or compounded. A concrete made with pozzolanic, hydraulic cement, developed by the Romans in 75 B.C. was used in building the theater at Pompeii and the Roman baths. The cement was a ground mix of lime and volcanic ash containing silica and aluminum, found near Pozzuoli, Italy, hence the name, pozzolanic cement.

Roman concrete, although unreinforced, still stands today and was used on a large scale. Both the Colosseum (completed in A.D. 82) and the Pantheon (completed in A.D. 128, Figure 2) contain large amounts of concrete. The Basilica of Constantine and the foundations of the Forum buildings also were constructed of concrete.

In the Pantheon, aggregate in the concrete ranged from heavy basalt in the foundations and 20-foot-thick lower walls, through brick and tuff (a stone formed from volcanic dust) in the upper walls, to the lightest of pumice toward the top of the 142-foot diameter dome. The entire structure is in good condition and stands today in its original form. It is an amazing feat considering that the builders did not understand the chemistry of hydraulic lime.

There was an attempt by Roman engineers to use bronze strips and rods to reinforce concrete in their quest for lighter weight and thinner wall sections. However, it did not prove successful because the bronze had a higher rate of thermal expansion than the concrete and caused spalling and cracking.

Unfortunately, although the Romans used concrete in many structures built across their far-flung empire, it was impractical to transport volcanic ash from Italy. Therefore, the pozzolan technology used so successfully in Rome, did not survive the fall of the Roman Empire in A.D. 476. All concrete construction for the next 1,300 years used lime mortars and concretes.

British concrete technology

Originally it was thought the Normans had reintroduced the art of making concrete into Britain, but recent excavations in Northampton have brought to light three Saxon concrete mixers dating from A.D. 700 (Figure 3). They were in the form of shallow bowls cut into bedrock, with a central post hole. A beam rotated around a central axis with paddles attached to it and did the mixing. Labor was supplied by either humans or animals.

Saxon concrete work was relatively limited and it really was the Normans who brought more sophisticated concrete technology to Britain when they landed in 1066. Reading Abbey in Berkshire (dating to 1130) has been stripped of its stone facade revealing a concrete core which still stands today.

Concrete was widely used in castles, including the White Tower in the Tower of London. Salisbury Cathedral (completed in 1265), with the tallest spire in Britain, has a concrete foundation that is still in excellent condition. Some cathedrals founded on less durable materials have recently required major underpinning operations to save them from collapse.

John Smeaton's breakthrough

In 1756, engineer John Smeaton was commissioned to build a new lighthouse on the Eddystone rocks in the English Channel 14 miles southwest of Plymouth. Two previous lighthouses on the site had been destroyed. The first, made of wood, burned down, and the second, also of timber, blew away in a gale. Smeaton determined that blocks of stone were the only practical building material. The problem

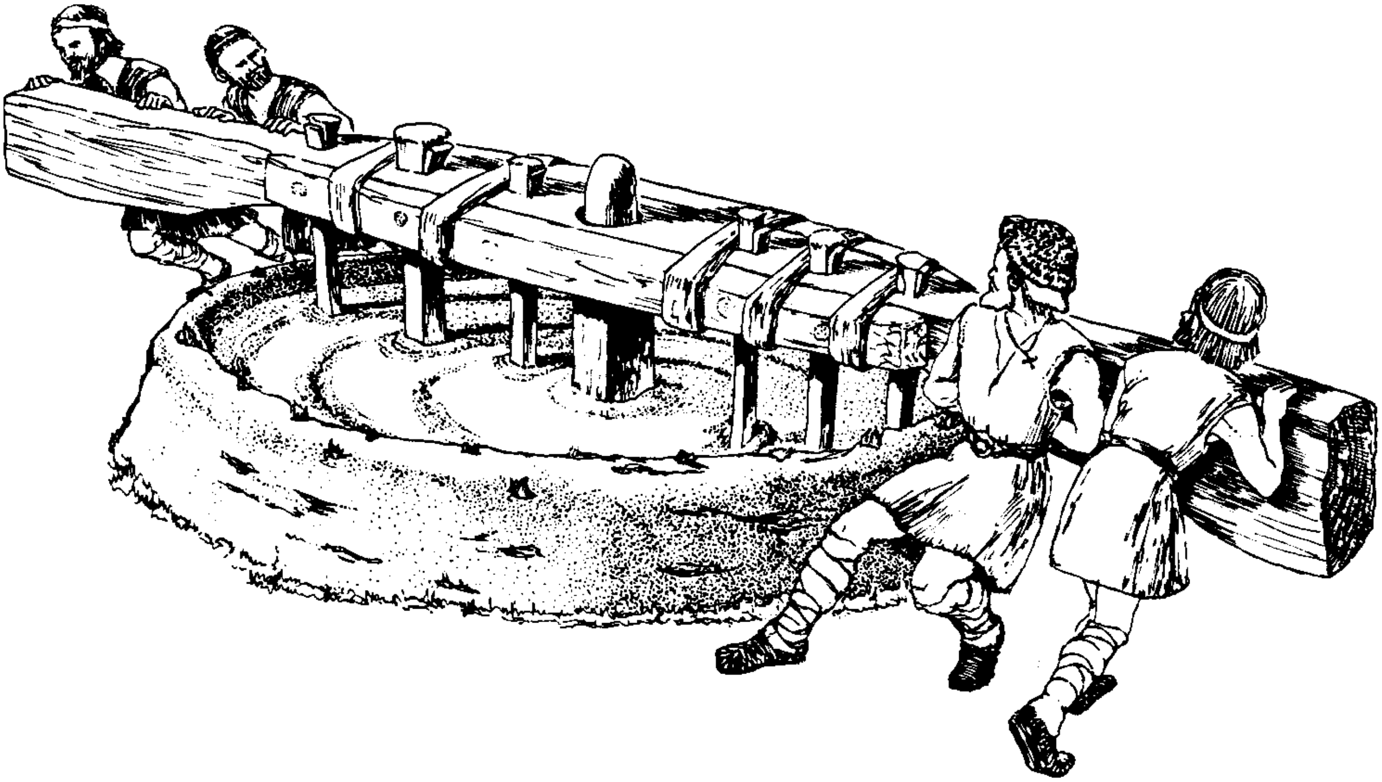

Figure 3. Remains of a Saxon concrete mixer discovered in Britain show that shallow bowls were cut into bedrock, with a central post of timber. A wooden beam with paddles rotated about the central axis to mix the concrete. Labor was supplied by humans, as shown here, or by animals such as oxen or horses.

was how to bind them together to create a solid monolithic structure that could withstand the constant soaking of seawater. The only cements available in 1756 were weak and slow-setting. He undertook a program of trial and error, combining all of the known materials used to produce mortar from various parts of England and the Continent. Finally he made a real breakthrough when he combined burnt Aberthaw blue lias, a limestone from South Wales, and an Italian pozzolan from Civitavecchia. With this combination Smeaton produced the first high-quality cement since the fall of the Roman Empire.

Smeaton used this hydraulic cement in the mortar to key and cement stone blocks together to create the first Eddystone Lighthouse in 1759. Smeaton's lighthouse endured for more than a century. By 1876 the structure began to weaken and was replaced by a new, much larger concrete lighthouse. At the request of the people of Plymouth, Smeaton's original lighthouse was dismantled and re-erected as a monument on Plymouth Hoe where it stands to this day. The original stump of Smeaton's tower is still in evidence, resisting the elements on the same rock on which Smeaton built it over 200 years ago.

Roman cement patented

Rev. James Parker of Northfleet patented what he called Roman cement in 1796. Attracted to some beach stones on the Isle of Sheppey, Parker collected some of the stones and when he got home threw one into the fireplace. It rolled out later thoroughly calcined. Undertaking some experiments, he was able to develop a natural cement he believed to be the reincarnation of the Roman cement of ancient times. Large quantities of the stones, which were actually nodules of septaria from the London clay, were collected from the Thames Estuary to make a cement which remained popular until the middle of the 19th century.

The first major use of Parker's cement was in mortar for the first tunnel under a navigable river, the 1,200-foot-long brick tunnel under the Thames River. During construction from 1825 to 1845 there were some breaks in the tunnel roof. Tons of portland cement, which was available after 1828, were reportedly dumped into the river to seal the roof. Eventually the tunnel was completed and is still in use today, carrying trains between Whitechapel and New Cross. ✥

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Next month in Concrete Journal, read "The history of concrete, Part 2: From portland cement to structural concrete."

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