Concrete understanding

10 July 2019

This article on historic concrete structures looks at how the material came to be so widely used

---

While it is unclear when concrete originated, it is likely that attempts to make it occurred at several locations during the Neolithic period. Some of the oldest known examples include lime concrete floors at Yiftahel, southern Galilee, from around 7000 BCE, and Lepenski Vir, Serbia, around 5600 BCE.

By 500 BCE, concrete was being used in Greece with a degree of skill, and some of this contained highly siliceous, volcanic Santorin earth. Roman builders, often incorrectly thought to be the inventors of concrete, were the first to appreciate its full potential and used it in some notable structures, including the Colosseum and the Pantheon. They also mastered the use of pozzolana, volcanic ash from Pozzuoli containing silica and alumina, which allowed them to create hydraulic cements. While engineers carried this knowledge with them throughout the empire, the use of hydraulic limes and concrete died out with the fall of Rome, and was not rediscovered until the 18th century.

In 1756, John Smeaton received a commission to build the 3rd Eddystone Lighthouse in the English Channel. Due to the failure of the previous timber lighthouses, Smeaton concluded that it must be made of stone blocks cemented together, and that this could only be done by using an hydraulic mortar. After experimenting, he selected one comprising equal parts Blue Lias lime from south Wales and Italian pozzolana from Civitavecchia.

> *The London Building Act 1774 prompted great experimentation and resulted in many different types of hydraulic cement*

By the end of the 18th century, there was a demand for reliable hydraulic cement as civil engineers sought to build canals, harbours and bridges. Furthermore, the *London Building Act* 1774, which effectively prohibited the use of exposed timber details on buildings, prompted great experimentation and resulted in many different types of hydraulic cement. The most famous was James Parker?s so-called Roman cement, and although it set too quickly to be used in foundations, it became popular for structures in contact with water as it rendered them watertight.

Prominent figures who made use of Roman cement were Thomas Telford, who employed it in constructing the Chirk Aqueduct and Aberdeen Harbour, for instance, and Scottish civil engineer Robert Stevenson, in building Bell Rock lighthouse.

There followed several notable attempts to produce higher-quality cements, by Louis Vicat, James Frost and Charles Pasley for example, though none gained the popularity of Roman cement. When Parker?s patent lapsed in 1810, many manufacturers began to produce their own Roman cement, the most successful manufactured by Francis and White. This cement was famously used by Brunel on the Wapping?Rotherhithe tunnel under the Thames, and by other renowned figures, such as English railway engineer Robert Stephenson and, then president of the Institution of Civil Engineers, James Walker.

In 1824, Joseph Aspdin patented Portland cement; however, this was merely an hydraulic lime and did not contain the necessary clinker phases that modern Portland cement does. The first cement to do so was produced by Aspdin?s son William, who discovered that clinkered or overburnt material substantially increased its strength. Isaac Charles Johnson, works manager for White, then produced the first reliable Portland cement, as his understanding of chemistry allowed him to appreciate the importance of vitrification in burning raw materials.

The first known major use of concrete in 19th century Britain was by Sir Robert Smirke at Millbank Penitentiary, which was built between 1817 and 1822; he underset the walls with lime concrete to a depth of 3.7?5.5m. The rescue of the London Customs House from 1825 to 1827 then involved undersetting sinking walls with a new system of lime concrete and brickwork laid in cement. The use of lime concrete for foundations soon became standard practice, though further attempts to make structural concrete with natural cements, lime and Roman cement were of limited success. This changed, however, with the invention of Medina cement by Francis.

After the dissolution of the partnership of Francis and White, he had relocated to the Isle of Wight where he produced a number of cements, including Medina, which was then used in several notable construction projects, including some on the island. One such was on Queen Victoria?s Osborne House estate, where it was used for the walls and arches of 2 houses. However, Medina cement?s success would be short-lived as, by 1848, it had to compete with reliable sources of Portland, which provided a more practical alternative. Yet, in the first major use of Portland cement for concrete at the breakwater at Cherbourg harbour, Medina also had to be used as Portland set too quickly. Around 2,000 concrete blocks were supplied for the project, each of which was 20m3 and required 4 tonnes of Portland cement and 1.75 tonnes of Medina.

In 1850, in an attempt to promote the use of his Portland cement for house construction, William Aspdin began work on a large mansion near Gravesend, Kent, called Portland Hall. It was to be completely cased in Portland cement stucco, to feature Portland cement statues and ornaments in its grounds, and to be surrounded by a high concrete wall, thought to be some of the earliest commercially produced precast concrete units.

Although improvements in Portland cement chemistry in the 1800s led to a stronger material with a wider range of applications, the use of concrete in construction was hindered by its tensile capacity. It was therefore confined to large, mass concrete structures that carried loads in compression. Examples of the ingenuity with which the compressive strength of mass concrete was put to use can be found in the viaducts on the West Highland Railway, particularly the Glenfinnan Viaduct, which was constructed by Sir Robert McAlpine in 1897.

Following the Industrial Revolution, it became apparent that there was a need for a strong, economical and fire-resistant building materials

Following the Industrial Revolution, it became apparent that there was a need for strong, economical and fire-resistant building materials in structures such as mills and warehouses, which were often destroyed in fires. This need could be met by concrete, reinforced with steel to increase tensile capacity. The invention is generally credited to William Wilkinson, who was granted a patent in 1854 and was the first to use reinforced concrete as a composite structure, embedding a network of flat iron bars or wire rope in floors or beams of flat or arched concrete. While his design was never adopted by the building industry, Wilkinson applied it himself in constructing an entirely reinforced concrete cottage around 1865.

Numerous other reinforcing systems were patented and implemented in construction with varying levels of success. In 1855, Fran?ois Coignet filed a patent describing a design for c
ncrete flooring that contained iron rods; while the patent itself failed to take off in the U
, Coignet established himself as a contractor in France, and the ideas he put forward w
re further developed on this side of the channel by other contractors such as Joseph T
ll and Charles Drake. As well as constructing some of the earliest reinforced concrete b
ildings in the UK, Tall is also noteworthy for his invention of standardised, re-useable t
mber shuttering, which significantly reduced the cost of concreting works. This system w
s improved by Drake, who also constructed a number of stately homes from concrete.

Further progress in reinforced concrete design can be attributed to US and European inventors. In 1871, American William E. Ward began to experiment with reinforced concrete and concluded that placing the reinforcement at the bottom of concrete beams was the most effective use of the iron?s strength. Another American, Thaddeus Hyatt, came to the UK in the early 1870s and investigated the most economical way of making reinforced concrete that was still fire-resistant.

The most successful figure in the history of reinforced concrete is undoubtedly Fran?ois Hennebique, whose system was the first to be widely used in the UK

The most successful figure in the history of reinforced concrete is undoubtedly Fran?ois Hennebique, whose system was the first to be widely used in the UK. H
nnebique?s success can be attributed to his design, which incorporated cheap, r
adily available reinforcement, and also the way he affiliated himself with established c
ntractors, granting them access to operate his patents on the understanding that t
ey followed his strict specifications on methods and supervision of work. Originally, a
l calculations were carried out by Hennebique?s engineers in Paris, but were later d
ne by his agents in their own offices before being sent to the capital to be checked. I
 1902, 10 years after starting his company, Hennebique was handling more than 1
500 contracts a year and directing a company with licensed contractors in almost e
ery country in Europe. By 1909, his system had been used in almost 20,000 s
ructures, and the company had 62 offices across 4 continents.

The first decade of the 20th century saw the continued international development of many different reinforced concrete systems, with varying degrees of commercial success. At this time, there were no regulations for concrete and specialists had their own requirements for designs. It was not until 1904 that the first British textbook on reinforced concrete appeared; written by Charles Fleming Marsh, it described various proprietary systems developed in Europe and the USA, as well as structural theory and calculations. Despite this publication, and the formation of the Concrete Institute in 1908, the design of reinforced concrete structures remained in the hands of a few specialist consultants. However, this all changed in 1915, when reinforced concrete regulations were introduced and technical information finally became widely available to designers and contractors.

This was not only an era of experimentation with reinforcement systems but also the concrete?s physical composition. Concrete is a mixture of cement, sand, coarse aggregate and water, and while the basic mix design for reinforced concrete at this time was 1:2:4 of cement, sand and coarse aggregate, respectively, with proportions of 1:1:2 and 1:1.5:3 also common, many specialist contractors had their own mixes that they would specify for use with their reinforcement systems.

There was also a great deal of variation in the amount of water added to each mix. For example, Hennebique?s only specification for water content was that it resulted in a plastic mix that could be rammed ? a requirement that would itself vary with the mix proportions, and the type and grading of aggregate used. The water-to-cement ratio is a key factor determining concrete?s durability, as it affects how porous the hardened material is and therefore how easily harmful agents can ingress and cause deterioration. This was not understood by engineers at that time.

The composition and size grading of aggregates were also extremely variable, primarily due to variations in local geology, the technology available to crush rock and a lack of scientific understanding. These factors not only affect the strength of hardened concrete but also the workability of the fresh mix and its tendency to segregate. It was not until 1907 that Fuller and Thompson published the first major work on the selection of aggregate grading, and not until much later, in the second half of the 20th century, that the effects of an aggregate?s chemical composition were properly considered.

While 20th-century building codes and design standards gradually evolved to take all these issues into account, there remain a vast number of structures around the world that have been built with various binders, aggregates, mix designs and reinforcing systems very different from those with which we are familiar today.

Simeon Wilkie is assistant scientist at the Getty Conservation Institute

Further information

- This feature has come from the RICS Built Environment Journal (June/July 2019)
- Related categories: Concrete , Building elements