Roman Hydraulic Concrete

by C. Mundigler

Hydraulic concrete: not exactly the stuff of dreams to modern engineers, but to the ancient Romans, 2000 years ago, it was a dream come true. Literally out of the rubble around them, they produced an innovative building material that was both economical and unbelievably strong.

Compared to the building materials they had at hand previously - basically stone, baked brick and mortar - the Romans, from the second century B.C. onward, knew that their invention of concrete was, by far, superior to these. Lime and gypsum mortar were used in many parts of the Mediterranean from Greece to Phoenicia and Egypt, but none were as versatile and durable as the new concrete. Not only were walls, partitions, roadwork, domes and arches built of concrete, but it was found that hydraulic concrete even set underwater! This process is documented for us by the first century B.C. architect Marcus Vitruvius Pollio. In his "Ten Books on Architecture", Book 2.VI.1, he tells us that when a volcanic ash - known as tufa or pozzolana from the region around Mount Vesuvius - is mixed with conventional lime mortar, it "not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set hard underwater."

Vitruvius goes on to give a wonderful account, in Book 5.XII, of how hydraulic concrete can be used to build harbours and breakwaters where no natural protection exists. He describes the process by which a wooden form is built, sunk into the sea at a predetermined location, and filled with hydraulic concrete - mixed at a ratio of two to one - to form blocks, walls and piers in the open sea. In this case, we have not only a literary description of the technique, but archaeological evidence to back it up as well. What is, perhaps, the greatest example found to date of the use of hydraulic concrete is at Caesarea Maritima on the Mediterranean coast of Israel. Built by the Romans between 22 and 10 B.C., in the reign of King Herod, the harbour stood as a marvelous triumph of Roman innovative engineering. Massive concrete blocks, some measuring 45 feet in width, have been found by the Caesarea Ancient Harbour Excavation Project. These blocks were built in the same way described by Vitruvius - double-walled wooden forms were sunk in place on the sea bottom, filled with hydraulic concrete and, once hardened, were finished off with paving stones. These massive blocks formed two incredible breakwaters - one of which was 200 feet wide by 1800 feet long, the other 200 feet wide by 900 feet long - and would have easily rivalled anything built by modern engineers. Not only were the concrete blocks themselves found underwater, but even portions of the wooden forms used to contain the concrete were discovered, intact, just where the Romans had sunk them. A beautiful artist's reconstruction of these wooden forms being positioned in the harbour of Caesarea can be found in the February 1987 issue of National Geographic Magazine. The painting brings to life the grandeur - and back-breaking work - which must have gone into the laying of monumental hydraulic concrete blocks. The archaeological evidence by itself stands as a tribute to Herod's engineers, but we have evidence beyond even this. Joseph ben Matthias, more commonly known as Flavius Josephus, a first century A.D. historian, actually documented the splendour of Herod's harbour complex for us in Chapter 3 of his work, the Jewish War. What he describes as massive "stone blocks" lowered into the sea were actually the concrete blocks built in the manner outlined by Vitruvius for pouring blocks underwater.

Hydraulic concrete is one of those marvelous inventions for which we have not only literary evidence - such as Vitruvius - but also archaeological evidence - such as at Caesarea - to back up what could otherwise be considered as fanciful writing. In any case, hydraulic concrete, made possible by the same volcanic ash which would inundate Pompeii and Herculaneum in A.D. 79, was a remarkable invention with which the ancient Romans were able to tame rugged coastal ports. Piers and harbours could be built to withstand the forces of nature not only close to Rome, but even at the outskirts of the Roman frontiers. Thus, hydraulic concrete helped make possible the extension of the Roman Empire and cemented alliances with subordinate states.