ENGINEERING AMONG THE ANCIENTS.

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In looking for a suitable subject for a presidential address, which would be of a sufficiently general character to interest all members of the Society, whether Civil, Mechanical or Mining, it struck me that very scant recognition is given nowadays to the works of the pioneers of Engineering, some of which works even now excite the wonder of all who have the good fortune to see them.

The oldest engineerng feats of which we have any record belong to the Department of Architecture rather than to that of Engineering proper, but the difficulties overcome by the engineers of two and three thousand years ago should make us as proud of the early members of our profession as we are of the man who could design a Forth Bridge or a Great Eastern.

ROADS.

Probably the most familiar works of olden times are the Roman roads. Roman roads are remarkable for preserving a straight course from point to point, regardless of obstacles which might easily have been avoided. The usual method of construction was as follows:—First two parallel trenches were cut to mark the width of the road; next the loose earth was removed until a solid foundation was reached, the earth being then replaced by suitable material thoroughly consolidated by ramming. This material appears to have been usually in four layers, generally of local material, but sometimes brought a great distance. The lowest layer consisted of two or three courses of stones—flat where these were procurable—laid in mortar, next came rubble masonry of smaller stones, or course concrete: next finer concrete, and lastly a pavement of polygonal blocks of hard stone, jointed with the greatest nicety. The whole was often three feet or more in thickness, but where the foundation was rock sometimes only the two upper layers are found. The paved surface was usually about 16 feet wide, and separated from it by raised stone causeways were unpaved footpaths, each about 8 feet wide. Where the surface was not paved, it was made of hard concrete, or pebbles and flint set in mortar. Sometimes clay and marl were used instead of mortar, but these inferior roads were made higher and given a rounder section.

Perhaps the best of these roads existing at the present day is the Via Appia, built in 312 B.C. by Appius Claudius. The French Chausées are similar in pattern to the Roman roads, though inferior in workmanship, but up to the end of the 18th century the only good roads in England were the old Roman roads—Watling Street, from London to Liverpool, with many branches; Via Julia, Ickneild Street, The Maiden Way, The Devil's Causeway, Ermine Street, and others.

Before leaving the subject of these roads, a word or two about the mortar used will not be out of place. This mortar was made from "pozzolana," a volcanic earth of a red, sandy appearance, which when mixed with lime made an excellent hydraulic cement. No particular stone was used for concrete, except in vaulting, where lava and pumice were used for the sake of lightness. Old Roman walls made of pozzolana concrete have proved more durable than those made of stone and cement mortar.

Another country whose roads are worthy of mention is Peru. These roads are of later date (possibly about 600 A.D.), but are products of a totally different civilisation to that of Rome. The best is that from Quito to Cuzco, 1500 miles long, and 40 feet wide, paved with earth and stones, but in marshy places formed of solid masonry. The gradients are good; small fissures are crossed by bridges of horizontal beams, and deep ravines by suspension bridges formed of half a dozen cables of twisted oziers passed over wooden supports and stretched from bank to bank; these are bound together with smaller ropes and covered with bamboos. The spans were sometimes as great as 225 feet, and loaded animals might travel over them. Both the Peruvians and the Chinese constructed roads for pedestrians, and these roads were maintained by the Government. In both countries wheeled transport was practically unknown.

CANALS.

Canals were among the earliest engineering works. In Egypt, Chaldaea, and Peru these were mainly for irrigation purposes, and do not call for comment, the methods being much the same as at the present day. Rameses II. also made a ship canal from the Nile to the Red Sea. The Chinese made many ship canals, one being over 1000 miles long. These were divided into lengths at different levels by sluices, over which the vessels were hauled by machinery. Of the more Western nations the Phoenicians were the greatest canal makers, and the improvements to Tyre, carried out by King Hiram about 1000 B.C., bear a strong resemblance to the works carried out on a larger scale in the south of England. He first enlarged the city by joining the two largest of the islands on which it was built and filling in to the east of them with rubbish, broken stone, etc. The area thus reclaimed was laid out in streets and squares. He then formed a breakwater about 700 feet long, connecting the N.E. point of the island with a reef which lay a little to the east. This breakwater consisted of two parallel piers, the inner of which was used as a landing stage. The opening to the harbour thus formed was about 100 feet wide, and the space enclosed about 300 yards by 235 yards, or about 70,000 square yards, sufficient for several hundreds of the ships of those days. His next work was a similar breakwater on the southern side of the city, about 600 feet long, and enclosing an area of about 80,000 square yards. This was further protected by an outer breakwater about 35 feet wide, and two miles long. Finally he joined the two harbours by a canal about half a mile long. We are also told that when Xerxes ordered a canal of a width sufficient to take two triremes abreast to be cut through Mount Athos, most of the workmen started to cut their portions with the required width at the top and with vertical sides, in consequence of which they rapidly fell in when acted on by the waves; but that the Phoenicians (from previous experience) made theirs twice the required width at the top and sloped the sides.

AQUEDUCTS.

Some of the finest engineering works of Europe are the aqueducts of the Greeks and Romans. The earliest of which we have any definite knowledge was constructed by Polycrates, tyrant of Samus, and was designed by Eupalinus, about 625 B.C. This was a tunnel 4200 feet long by 8 feet square, from the source of supply through an intervening hill to the city. In the tunnel a channel was cut, three feet wide, down which the water flowed in an accurately graded slope, and was received at the town end in a masonry conduit, whence it was distributed to fountains, baths, pipes, etc., and ultimately reached the harbour.

About 65 years later Pisistratus had a somewhat similar scheme carried out at Athens. From Mt. Hymettus two conduits passed under the bed of the Ilissus, most of the cutting being in rock, and from Mt. Pentelicus was a similar conduit, with air shafts reaching a few feet above the ground about every 50 yards. These shafts are about 4ft. to 5ft. in diameter, and about 60 of them are still preserved. Just outside Athens was a large reservoir, and water was distributed through the city by a ramification of underground channels of a round or square section, and walled with stone. The largest of these channels is about 5ft. 6in. by 3ft., and many have pipes of baked clay laid in them. Perhaps the most remarkable of these conduits is a submarine one connecting Syrocuse with the island of Ortygeia.

In Italy the conduits were somewhat similar, but the pipes were made of lead or baked clay; both cut and cover and tunnelling were resorted to, and shafts were erected about every 240 feet. The inside of the walls was coated with a mixture of chalk and broken tiles, which was impervious to water. These conduits were paid for publicly, and a tax levied for the use of the water.

Where it was necessary to take a conduit across a valley it was carried on a stone wall, the top courses of the wall forming the conduit, and being coated with an impervious stucco. To avoid blocking the traffic down the valley the wall had to be broken up into arches, from which the aqueduct bridges developed. The following are some of the best examples of these:—Aqua Claudia (45 miles long) and Anio Novo (62 miles long), both begun by Caligula, 38 A.D., and finished by Claudius ten years later. Of the former 35 miles are under and 10 miles above ground, while the latter is mostly on a chain of arches, reaching in one place a span of 109 feet. For the last six miles these follow the same course, one above the other.

An aqueduct now called the Pont du Gard was built by Augustus at Nismes, and reaches in one place 180 feet in height. At this place the lower course consists of six arches—one of 75 feet span and five of 60 feet—the next course is 12 arches of 60 feet span, and the next is 36 semi-circular arches, on which the aqueduct is carried.

The earliest Roman aqueduct was built by Appius Claudius 311 B.C., and was about two miles long.

At intervals along these aqueducts "castella" were erected to supply the surrounding districts and to effect repairs, the material and cost of repairs being supplied by the private owner of the property nearest to the damaged section.

The total length of the aqueducts supplying Rome was about 285 miles. Several of these are still in use, and it has been estimated that the daily supply was over 300 million gallons, or, estimating the population at one million, over 300 gallons per head per day, as against 24 to 50 nowadays.

At Spoleto there is an aqueduct of pointed arches 66 feet spans and 300ft. high, but this is of considerably later date.

In Turkey "Souterasi" are sometimes found. These are masses of masonry usually in the form of a truncated obelisk, the top being slightly above the level of the source, and open to the atmosphere, forming a basin, to which the water is led by a pipe. Another pipe leads it to the bottom of the obelisk, and thence to a subterranean pipe or channel across the valley to another of the souterasi. This method is said to have cost about 1-5th as much as an aqueduct bridge, but except that it discharges any air which may have collected in the pipe, its advantage over a simple underground conduit is hard to discover since the frictional resistance would be greater and the lead pipes would have to be very large to discharge as much water as the conduits, owing to the small head.

The ancient Assyrians made many dams across their canals for purposes both of irrigation and water conservation, but these were destroyed by Alexander because they impeded the traffic on the canals.

The greatest water conservation works in the Euphrates Valley were carried out by Nebuchadrezzar at Sippar, on the left bank of the river, where he made a reservoir 35 miles in circumference, and 35 feet deep, with an elaborate set of hydraulic works. It was by means of these that he diverted the river to found the piers for his bridge. (See below).

BRIDGES.

The earliest bridge of which we have any definite knowledge was the Pons Sublicius, built by Ancus Martius, about 650 B.C., and famous on account of its defence by Horatius. It was made of timber. Each pier consisted of 12 piles in two rows, each pair being connected by a short timber about 12in. x 12in. Two cross beams, also about 12in. x 12in., were laid over these, with six stringers resting on each, the spans being about 40 feet. On top of the stringers were cross beams about 12in. x 8in., carrying the handrails and the flooring, which was laid longitudinally. Each set of six piles had a diagonal brace, to which each pile was fastened. The piles were probably driven in much the same way as that in use at present, and since the Tiber is a rapid river, and liable to floods, they must have been driven deep. The military bridge which Julius Caesar made across the Rhine in ten days was very similar to the modern military trestle bridge, but had no diagonal bracing or sill. There was a breakwater opposite each pier on the upstream face, and a single strut on the down-stream face.

About 100 B.C. Aelius Scaurus built the Pons Milvius over the Tiber, about 1½ miles from Rome. This was a stone bridge 413 feet long, 29 feet wide, and with arches of from 51 to 80 feet span.

Trajan's bridge over the Danube at the rapids below the Iron Gate was perhaps the greatest achievement in bridge building in the early days of the Roman Empire. It was built in 104 A.D., and had 20 piers of hewn stone 150ft. high, with spans of 170ft.; its total length was 4000ft., and it is of interest as being the first record we have of piers being founded by sinking caissons, the depth of the water in this case being 15ft. Unfortunately we know little about the superstructure, except that it was of wood, and that the spans were probably arches. There is a representation of it on Trajan's column, which shows a design which could not possibly have been used for spans of 170ft., and is probably conventional. There can be no doubt about the length of the spans, as the majority of the piers are still standing. The bridge was designed by Apollodorus of Damascus.

The suspension bridges of Peru have already been mentioned.

The bridge of Nebuchadrezzar over the Euphrates had buttressed piers of masonry, clamped with iron, and soldered with molten lead. The banks were lined with brick throughout the length of the river within the city. The river was diverted in order to found the piers and line the banks with brick. The superstructure was of wood, and consisted of planks laid from pier to pier, which were removed at night.

SHIPS.

Ships naturally appeared early on the scene, the oldest record being about 3000 B.C. This was an Egyptian ship with 24 rowers on each side, and capable of carrying merchandise and cattle. The bireme was invented by the Phoenicians about 900 B.C. The greatest warship of early days was built by Ptolemy Philopator, about 220 B.C. It had 40 rows of oars, and was 420 feet long, 76 feet beam, and 20 feet draught, with a displacement of about 11,320 tons, which gives a block coefficient of about .63—rather lower than a ship of the same displacement would have at the present day. The crew numbered 7500, of whom 4054 were rowers, giving a horsepower of about 490. This was the largest ship built until 1858 (when the Great Eastern was launched), but according to the historians was far too unwieldy to be of any fighting value. Compared with modern warships, it would come very close to our King Edward VII. class, which have a length of 425ft. and 78ft. beam; but the draught and displacement are 26ft. 9in. and 16,500 tons respectively, while the complement is only 776 all told, against 3450 (excluding the rowers) in Ptolemy's ship. It is interesting to note that at the Battle of Actium the light Liburnian biremes defeated the heavier galleys of Anthony, causing an abandonment of large warships for several centuries, and initiating a controversy between the advocates of the "Dreadnoughts" and of lighter ships, which has lasted to the present day.

BUILDINGS.

But the feats which most excite our admiration and wonder are without doubt the buildings, both walls and dwellings. The walls of Nineveh were 7 miles long, 100ft. high, and 25ft. wide at the top; the lowest 25ft. were of stone, the remainder brick. This was however, eclipsed by the great outer wall of Babylon, called Nimitti-Bel, which was 50 miles long, 75ft. wide, and probably not less than 130ft. high, with twin towers at intervals along the wall, rising to a height of 360ft. It was surrounded by a deep moat, the earth from which was made into bricks; these bricks were used to line the borders of the moat and build the wall. The cement used was hot bitumen, and a layer of wattled reeds was interposed at every 30th course. There were a hundred gates of brass in the wall, with brass lintels and side posts. This wall was built by Nebuchadrezzar.

The palaces in Assyria and Media were mostly built on platforms, which were raised above the level of the surrounding country. These platforms were mostly of stone, and were of enormous extent, reaching 100 acres in area, by 100ft. high—an undertaking that would employ 120,000 men for a year. The palace of Darius at Persepolis is built of Cyclopean masonry, with joints so accurately fitted that though the stones were clamped together with iron, the iron has rusted away, leaving the joints so perfect that they are often hard to discover. The blocks are 30ft. to 50ft. long, 8ft. high, and from 4ft. 6in. thick. The stairs are of marble, 4 inches rise, and from 18 to 24 inches tread, several stairs being hewn out of one block. One flight of 30 stairs is hewn out of a single block! The roofs were probably of timber, except in very small buildings and tombs, where they were of stone. The excellence of the Babylonian bricks, which are about 12in. square and 3in. thick, is shown by the fact that the inhabitants still dig them up from the ruins to build their houses.

The Phoenicians were famous for their substructures, of which an excellent example may be seen in the foundations for the Temple of Jerusalem, built about 1000 B.C. This is now in some parts 50ft. to 60ft. above ground, with about 80ft. below the surface. The whole is made of gigantic stones laid in regular courses without cement, and of very different lengths. Some of these stones are nearly 40ft. long, 7ft. high, and weigh over 100 tons, while the average size of the blocks is from 30 to 40 tons. The Temple itself was mostly of timber, and was probably of Phoenician design, as well as workmanship.

The Pyramids of Gizeh in all probability have had more labour expended on them than any other work of man.

The Great Pyramid is 756ft. square, by 481ft. high, and contains over 90 million cubic feet of masonry; and the statement of Herodotus, that it required the continuous labour of 100,000 men for 20 years can hardly be an exaggeration.

Professor Flinders Petrie has ascertained, by examining the stones, that the tools used by the ancient Egyptians in stone dressing were bronze cutting tools with corundum points, straight and circular saws, and tubular drills.

That the labour question was not very acute in early times can be seen from the fact that the palace of Nebuchadrezzar was built in 15 days.

Another noteworthy engineering feat in Egypt was the erection of the Great Obelisks of Thothmes III., one of which is now in Rome. This is 105ft. high, 9ft. 6in. square at the base. tapering to 8ft. 7in., and weighs over 450 tons. It is formed of a single stone, covered with well-cut hieroglyphics, and was erected outside the Temple of Ammon at Thebes.

MINING.

The methods of mining were much the same as at present, the ore being heated, then crushed by water power, and afterwards washed and sifted until the pure metal was obtained. There was no way of separating one metal from another, so that the gold was often alloyed with silver, and the silver with lead. Archimedean screws were used for pumping.

METAL WORKING.

As an example of foundry work, the great bowl or laver in the Temple of Jerusalem may be mentioned. This was the work of the Phoenicians, and had a circumference of 47 feet, and a capacity of 17,000 gallons. It was made of brass, 4 inches thick, and was cast in one piece—a feat which would tax the ingenuity of modern metallurgists.

Of course steam and machine tools have made easy many things which were formerly hardly possible, and have enabled us to carry out works of which the cost would have been otherwise prohibitive, but we should not lose sight of the fact that the ancients in many cases did as good work as we can do nowadays with all our advantages. One difficulty is to understand how, in the big works where much of the labour must have been unskilled, the work could be fitted as accurately as it is. This accuracy is evident in the work of the Phoenicians, Egyptians, Babylonians, and Romans; the two former used no mortar, the Babylonians used both mortar and iron clamps, but the joints have outlasted both, while the Romans used such good mortar that walls 2000 years old are still like a single solid block of stone.

I have said nothing about the means by which the enormous stones used were put in place, as it is still more or less guess work, but from drawings and carvings found in Assyria it appears that one method was to drag them up a ramp, which was afterwards dug away.

One survival of old times is seen in the treatment of the engineers; if anything went wrong the engineer in charge had to take the blame. The best evidence we have of this is that when Xerxes' bridge of boats over the Hellespont was destroyed by a storm, he promptly ordered the execution of the engineers. The next bridge was storm-proof.

I think the few examples I have given should impress on us that engineering of to-day is not a modern growth, but the result of a gradual evolution which has been going on for thousands of years. This result has been reached by retaining the good points of previous work, and gradually eliminating the faults, and it is just as important for us to try to improve the old methods where these have been successful, as it is to devise new ones.