A BACKSIGHT

PRESIDENTIAL ADDRESS BY LESLIE J. HOOPER

(Presented at Annual Meeting of Boston Society of Civil Engineers, March 23, 1966)

A young engineer fresh from school frequently feels that engineering has only started to develop at his graduation; that the boundaries of scientific and engineering knowledge only extend back for 100 years or so. Reference to an article of that vintage, however, shows that there already existed a very good foundation for that particular development and references are made to a previous century. This process cannot be continued indefinitely since, unfortunately, history of an engineering sort is usually fragmentary. There are no glorious military leaders nor victories to be remembered. The developments and improvements have been unspectacular. However, it might be interesting to take a glimpse into the past to get some idea of the basis of our present achievements.

If much that is referred to in the following discussion is of a hydraulic nature, it is a fact that water is a prime essential of life. It might be added that the author's mind at a very early date turned to water.

One engineer, when pressed to establish the ancient antecedents of his profession quoted Genesis 1:3-31 to support his claim. There it states that the heavens, the earth and all that is therein were created in a six-day working week. This, the engineer contended, was an engineering work of the first magnitude.

The development of New England depended in large part on water power. Many of our large towns are located at suitable sites for the development of power that was adequate in those days for the operation of grist mills, saw mills, and later cotton and woolen mills. Mr. Arthur Safford, a past president of this Society, wrote an excellent paper in 1922 on the development of the Francis turbine in New England. He carried this history back to approximately 1840 in a very detailed manner. Before that, as he pointed out, there existed tub wheels, flutter wheels, undershot wheels, overshot wheels and many other types that have since passed from the scene.

The most efficient of these early designs was the overshot wheel. It was brought to this country by the settlers from Europe. There is a record that a tidal mill was established in 1630 at Neponset. There was such a mill at Riverdale in Gloucester that was operating as a grist mill in 1910. The development of these overshot wheels is not easy to trace.

One excellent source is Mr. and Mrs. Herbert Hoover's translation of Agricola's "De Re Metallica." This is a description of mining techniques as of 1550 in Southern Germany. Here we find the overshot wheel frequently used for pumping and for hoisting. In the latter case, two overshot wheels were used side by side but operating in opposite directions so that the load could be lifted or dropped as necessary.

The only notice of an overshot wheel previous to this is by Friederich Klemm where he shows a cut of 16 wheels in series at Barbigal near Arles in France, with a date of approximately 250 A.D. From the cut, it is obvious that these were overshot wheels. Vitruvius, writing at the time of Augustus Caesar, speaks only of undershot wheels with flat blades, so far as can be determined from the translation. The undershot wheels were used from time immemorial in places where the current of the river was sufficiently rapid to drive the wheel of pots or similar devices.

It is well established that ancient civilizations started in arid areas. Apparently in such a place it was possible for a small number of people to kill off the wild animals and get the protection that they needed from other tribes and their surroundings. Naturally, in such a location they needed drinking water first for themselves and their flocks and later for irrigation. It is natural to suppose that methods of lifting water took a high priority in the development of the hydraulic art. The power required to lift water was largely supplied by animals and slaves until the end of the Roman Empire. For this reason, pumps probably have an older history that water wheels.

Our ubiquitous centrifugal pump is truly a recent development. Merriman indicated they were of very little utility before 1840. Ewbank indicated that Demour in France developed the first pump utilizing centrifugal action. This was a very crude device essentially to show only the fact that water could be lifted by such a means. Naturally the requirement of high speed of operation did not lend itself to the older forms of power available. Oddly enough, Hero's reaction turbine never seems to have been driven as a centrifugal pump.

Practically all of the older forms of lifting water depended on some manner of direct lifting. Agricola shows the chain of pots frequently used in deep mines and the Archimedean screw for low lifts. He also shows the piston force pump used occasionally. Inasmuch as the latter could only be placed at a limited distance above the water level, it was not largely used in mines where the water power of the time would be on the surface and the water to be pumped would be at a depth.

Vitruvius refers to the same two "engines" for lifting water in his Ten Books of Architecture. Inasmuch as he would be reporting on the commonly used methods of raising water at the time, this indicated that the two designs were commonly used at that time, one for high lifts and the other for low lifts.

The chain of pots is not specifically mentioned in Herodotus at the time of the Hanging Gardens of Babylon, but all references to that particular wonder of the ancient world speak of an engine located at the top of the gardens which lifted the water directly in a single lift. Since this lift was of the order of 300 feet, it is felt that a chain of pots was undoubtedly used in the Hanging Gardens for irrigation purposes. It is not known how much before that time (600 B.C.), that they might have been used.

The force pump consisting of two single acting pistons delivering into a common air chamber to eliminate pulsations of flow was mentioned by Agricola, and again it is mentioned by Ctesibius in Egypt at approximately 300 B.C. This particular development presents a very interesting puzzle. The design is essentially the same as we see in the 1850's as used in our fire engines. Yet it was shown completely developed in this form by Ctesibius as stated. The question as to how they would use a pump of this sort is puzzling.

One might think that the strength of available pipes might limit their use. Vitrified clay pipes were available for low pressure use and lead pipes for high pressure. Vitruvius and Frontinus give us the standards of lead pipe at approximately the time of Christ. It was quite customary to build such pipe with a wall thickness of 5/16″ and interior diameters ranging from 1″ up to 27″. The larger size would only handle about 40 ft. head before bursting. However, the 1″ pipe would carry something of the order of 760 ft. head which was quite adequate for most of the applications that might be considered in that age.

The force pump and the bellows are completely similar in construction and in operation. The primary requirement in this design is related to the valves which must be of simple construction but pressure tight. As to the construction of bellows, we find that Jeremiah refers to them. Further, Homer, in the Iliad describing the forge of Vulcan, indicated that a double action bellows with valves was being used at a very early date. Professor Smith at Massachusetts Institute of Technology, who is interested in the history of metallurgy, feels that all of the common metals were being reduced from their common ores possibly as early as 5000 B.C. He bases his supposition on the fact that when the necessary heat can be raised in a fire by blowing, to reduce the ores of tin and copper, that an adequate technology exists to reduce many of the common ores or iron also. This particular problem probably lies with the prehistory of the Hittites who seem to have first made iron available. But in any case, our oldest description of the force pump comes from Ctesibius who was known to be a barber's son. It is interesting to contemplate in this case whether he was the developer of the force pump in one stroke of genius or whether he was reporting developments of an even earlier age by others.

The one type of lifting device that has not been mentioned is the wheel of pots which in Asia Minor is called the Persian wheel, in Egypt, the Egyptian wheel and in China the noria. The noria was probably developed to its highest degree by the Chinese. With them, it was constructed of bamboo throughout and with no iron whatsoever, which is an indication of its ancient origin. The axle and the pedestal were made of solid wood, this being the only concession to heavier loading. It consisted of a wheel with a number of pots tied to the circumference at an angle so that they would fill at the bottom of the travel when immersed in the river. They would not lose any substantial amount of water until they had reached the top of their travel. In some designs the pots were pivoted and were tipped by a suitable bar at the top of the travel so as to reduce spillage to a minimum. Ewbank, in describing this construction indicated that the Chinese excelled in construction of large wheels which were necessary to achieve the highest lifts in a single stage. In his second edition (1842) he indicated that the Chinese frequently built these wheels to a diameter of 90 feet which "was far in excess of the highest building in New York at the present time." Times have certainly changed rapidly in the last century with us.

Sometimes these norias were propelled by the treading of men or beasts but when the current was swift, a number of flat paddles would be mounted on the periphery of the wheel and the kinetic energy of the river would be used to lift the water to the required height. This was particularly true of the Persian wheels, found in the vicinity of Hamath, which apparently had a swift flowing stream adapted to such construction.

In China, at some ancient date, they also constructed windmills that operated in a horizontal plane instead of the vertical plane that we associate with the Dutch construction. These windmills were used to drive the equivalent of a screw or noria for lifting water. It is regrettable that very little evidence is available in our American libraries to indicate the high stages of development of the hydraulic and engineering arts in China and, for that matter, in India. Civilization in both of these countries is old and there must be a wealth of information that is still awaiting revelation.

Turning to other civil engineering works, a hydraulic engineer naturally thinks of dams. Hathaway presented an interesting article on several ancient dams. He pointed out that so far as we know the most ancient dam of any size was constructed by the Egyptians about 18 miles south of Cairo and called the Sadd el-Kafara. This particular dam was probably constructed about 2800 B.C. It was 348 feet long at the top and had a crest height of 40 feet above the stream bed. The structure was made up of two separate rubble masonry dams each around 80 feet thick at the base with a space of 120 feet along the stream bed between them. This space was filled with random material from the stream bed and the adjacent hillsides. It appears that the dam was constructed to provide drinking water for the workmen at a nearby quarry. Although the Nile valley is subject to cloudbursts, no spillway was provided in the construction of this dam. Since there is no sign of sediment deposit in the reservoir area, it is felt that the dam was overtopped and failed soon after completion. In any case, there is no further evidence of any such dam being built in Egypt for more than 1000 years.

The most outstanding dam of antiquity was located approximately 40 miles from the ancient city of Marib in the kingdom of Yemen. This may well have been the kingdom over which the Queen of Sheba ruled around 950 B.C. as mentioned in the Old Testament. This dam, along with many other smaller dams, was the basis of the agricultural prosperity of this part of the country. This dam was constructed of large stone walls of huge stones very well fitted together. They also used headers to provide ties between the two layers of the stone. No mortar was used in filling the joints of the dam, but it was used as a covering on top of the dam to prevent damage from rain water. There is no evidence that the dam was provided with a spillway. However, because of the heavy type of construction, it is very possible that this dam would withstand overtopping in modest amounts and only in the case of a severe flood would it be breached. History indicates that while it was constructed approximately 1000 B.C. it had to be rebuilt in 449 A.D. In 450 A.D. it was breached again and a complete renovation was required. In 542 A.D. another breach of the dam occurred. Apparently the dam was not repaired and the prosperity of the kingdom of Sheba or as it is more recently called, Saba, disappeared and the region reverted to desert. Naturally, it is referred to in the Encyclopedia of Islam as a punishment of God since the people turned away from Him.

Returning to Egyptian accomplishments, their greatest hydraulic work was the construction of Lake Moeris at approximately 2300 B.C. This reservoir was located in the province of Fayoum where there is a natural depression below the level of the Nile. It became a reservoir by being connected to the Nile by a canal through a low lying ridge of rock. This canal was constructed 300 feet wide and 10 miles long. The intake to this canal was at a point opposite the island of Nome where the Nile divided into two channels. Sir William Willcocks testifies that there is no indication that the Egyptians had any conception of control gates but rather used as a barrage of earth to fill the entrance of the canal when it was desired to close off the Nile from the lake. This was a work of considerable magnitude and expense and it is obvious from the records that have come down to us that even a Pharoah of Egypt was reluctant to undertake this work unless there was good reason for doing so. It is quite probable, according to Willcocks, that the use of Lake Moeris diminished and finally had to be abandoned when the channel on the western side of the island of Nome became silted up and therefore the lake was no longer effective in controlling the flood flows of the Nile.

The only other hydraulic work of note among the Egyptians was the construction of the canal from the Nile to the Red Sea. Herodotus tells us that this canal left the Nile near Memphis and was connected to the Red Sea at the point where the Suez Canal now joins the Red Sea. Herodotus states that he saw the remains of the Red Sea Canal during his own visit to Egypt (circa 450 B.C.). However, in our day, there is no trace of the existence of this canal, undoubtedly due to the fact that the desert quickly reclaims anything which is not continually maintained.

In Mesopotamia, however, canal building was an ancient art and they produced works of the first magnitude. The people of Mesopotamia said the original canals were constructed by the gods themselves which is only an indication that canal construction went back beyond the mists of oral tradition. An outstanding canal in Mesopotamia was the Nahrwan Canal, which diverted the waters of the Tigris near Opis, forcing that river to irrigate a large area eighteen to twenty-five miles wide between the old bed of the Tigris and the Eastern hills. Another of the old and tremendous canals was the Pallocopas or Hindia, to use the older name. Both of these canals were of the order of 400 feet wide and 15 feet deep. Alexander sailed his seagoing fleet from the Persian Gulf into the Pallocopas after he had broken down some barrages to allow their passage. These canals went out of use and were lost after Tamerlane devastated the country of Mesopotamia so that there was no one to provide maintenance. Before that time, the country maintained agriculturally a population of over 12 million people, and at the present time, the population is about 5 million.

In the matter of aqueduct building, the Romans have left the most enduring monuments which are well known and well described in many references such as the Pont du Gard and the Claudian aqueduct; the former because of its beauty and size and the Claudian because of its length, which altogether was 62 miles. The reason for the building of aqueducts across the valleys was to shorten the path that the water had to follow to the city so as to make the water available at a higher elevation.

Frontinus indicates that the normal flow of the Claudian was about 11,700 GPM or 26 cfs. The total flow of all 9 aqueducts supplying Rome was estimated to be 58,000 GPM or 130 cfs. The water carrying cross-section of the Claudian was 3.3 ft. wide and 6.6 ft. high.

As compared to this, the first aqueduct of which any remains have been found was constructed by Sennacherib in 691 B.C. to bring drinking water from the mountains to his capitol city of Nineveh. At one spot he had to cross over a river valley and he built the Jehrwan Aqueduct for this purpose. The remains indicate that this aqueduct carried a channel 50 feet wide and 5 feet deep over a length of 920 feet across the valley. This was certainly a stupendous work as compared to the Roman aqueducts.

The Romans, Greeks and Persians are known to have done a great deal of tunnel work and mining. Before the advent of metal which could be hardened sufficiently to penetrate rock, there were only two methods of cutting into rock. In mining where the rock face was not to be preserved, it was customary to build a fire against the working face and then dash water or vinegar onto the heated rock in order to crack or spall the surface rock. Pliny states that vinegar was more effective in cracking the rock than water, and its use is indicated by Vitruvius as being the most desirable. With the poor ventilation that existed in mines of those days, the use of fires and vinegar in the mines must have resulted in conditions that were hardly conducive to long life of miners.

When rock was being quarried, on the other hand, it was necessary to maintain a good working face and the Egyptians were among the foremost in this type of work. Their approach for cutting out a block of stone, a lintel or an obelisk for instance, consisted of digging a trench all around the block that was to be freed from the matrix. This was done by slaves pounding with balls of diorite, which was the hardest stone available at the time. This could smash or powder the limestone or granite that was being quarried. It was estimated by one archeologist, who has tried the process, that a large block of stone such as an obelisk, could be quarried in about eight or nine months by a suitable number of operators disposed all the way around the rock that was being freed.

Probably one of the outstanding examples of rock excavation that was performed by the Egyptians was the construction of Joseph's well near Cairo. In this case, the water bearing layer is 295 feet below grade. This was reached by two shafts with a small reservoir or basin excavated in the rock at the junction point between the two. The upper shaft was 24 × 18 feet in plan and 165 feet deep. Below the basin, the lower shaft was 15 × 9 feet in plan and continued another 130 feet deeper. Inasmuch as the water was lifted by two chains of pots, it was necessary to get oxen or donkeys down to the level of the basin to operate the lower chain of pots. Access was provided by a passageway 6′4″ wide and 7′2″ high, that was excavated in solid rock on the outside of the 24 × 18 foot shaft. This passageway was laid on a uniform grade all the way to the intermediate basin. In order to provide light to the passageway, openings were cut through the wall into the shaft itself. An examination of these openings shows that the original builders maintained a uniform thickness of wall of only 6 inches between the passage and the shaft. Although this well is ascribed to Joseph who lived approximately 1700 B.C., it could be more ancient than this due to the habit of people of that time ascribing memorable works to an outstanding public figure.

All through antiquity it is evident that the mining experts did not hesitate to sink wells, or construct tunnels as necessary. Dean Finch has indicated the example of the tunnel on the island of Samos, which is 3300 feet long, cut on a grade of fairly uniform slope, but also along a curved center line in plan. Due to the imperfect civil engineering techniques available in those days, it was customary to sink vertical shafts to the location of the tunnel and then tunnel between these shafts. This allowed frequent checks of the alignment of the tunnel and kept the errors of alignment from getting too large. There are evidences in the ancient descriptions of tunnels that started from two ends that missed each other by very considerable amounts (Lanciani's "Ancient Rome") so that this precaution was deemed very necessary.

This method of tunnelling has been used for centuries in Islamic countries for intercepting water at a distance in the mountains and bringing it to the cities for a water supply. Butler, speaking of the water supply for the city of Teheran in 1933, comments that the entire water supply for the city at that time, which had a population of 275,000 was obtained from 36 tunnels which were from 8 to 16 miles in length and in places over 500 feet below the surface of the ground.

The space in such a paper is much too short to go into many areas of ancient accomplishments in engineering but there are several little vistas or anecdotes that are intriguing.

In the first place, our medical friends refer to a tradition of Hippocrates, but the most ancient authentic manuscript referring to his works that can be found is dated approximately 900 A.D. In engineering, we are most fortunate in having an engineering handbook of Vitruvius, a Roman architect-engineer, who wrote at the time of Caesar Augustus at approximately the time of Christ. In his Ten Books of Architecture, he speaks on city planning, the construction of walls, foundations, temples and buildings in general, the finding of water, the construction of engines of war and he even finds time to give advice or warning concerning the use of models. In regard to models, he remarks that "not all things are practicable on identical principles," or to the general effect that a model is a most unsafe thing to believe if you do not know the principles of its operation.

Similarly, we are fortunate in having the English translation of the report of "Frontinus on the Water Supply of Rome," when he became the water commissioner. As you all know, this work was essentially done by Clemens Herschel, who provided the translation into engineering English after others had provided the translation into French, German or English from the original Latin. Both of these experts have been quoted previously in this presentation.

It is fortunate indeed, for English speaking engineers that there are some competent people who can not only translate from the original language of a manuscript but also translate into engineering English of our day. By way of example, Breasted gave a literal translation into English of the story of Creation according to the Babylonian epic. It was a description of a combat between gods which carried no particular implications to an American engineer. Sir William Willcocks was an English irrigation engineer who was brought up and spent his engineering life in Arabic speaking countries, understanding the idiom as well as the language. He translated this same epic into engineering English; he pointed out that in the combat, the god of the river was ensnared in a net which was created by the hero god Marduk. The magic net which was used to ensnare the river was the canal system of Mesopotamia, which made civilization in the lower reaches of the Tigris-Euphrates basin possible.

Similarly, in Exodus 15:25, Moses made the bitter waters of Marah sweet by laying a reed therein. Willcocks points out that this is an Oriental method of referring to the common manner of building low dams in water. A base of brush was covered with reeds and then overlaid with mud to make a watertight and safe dam. Moses, operating as an engineer, constructed a low dam to keep out the brackish backwater and allow the sweet water from the spring to be used for drinking purposes. So a miracle becomes an everyday engineering work and loses its glamor to the ordinary man.

Thus, it is also seen how necessary it is for an English speaking engineer to try to find a description of ancient works that have been translated not only into English but also engineering terms so that the comprehension of what was originally intended can be conveyed.

In review it is interesting to contemplate the position of the engineer-architect through the ages. In Egypt, inscriptions and monuments have been found that show that the engineer-architect was frequently of the nobility, highly educated, close to the king and greatly honored for his ability. However, in Mesopotamia, the works of creation were always ascribed to the gods. This may indicate that the priest-kings of that era may have also had a considerable engineering knowledge. No record exists that bears on this point. Later, in Persia and in Greece, we find that the engineer as such was a craftsman and almost always a slave. The Greeks greatly admired philosophy and the arts that did not soil the hands, and even Archimedes, who was a Greek of Syracuse, writing at approximately 300 B.C., disdained to mention any of the applications of the various works with which he is credited.

During the Middle Ages, our written history seldom records the names of engineers even though they were no longer slaves.

Thus, we see that today the lot of the engineer is gradually improving. He does receive more public recognition than was the case in the past. However, it has been the tradition of the engineer to serve, and it still continues. Few of us chose this profession with the idea of great worldly acclaim or gain. The most we can hope for is the recognition of our peers and the satisfaction of a work soundly conceived and well executed.

REFERENCES

1. SAFFORD, ARTHUR T. AND HAMILTON, EDWARD PIERCE. "The American Mixed Flow Turbine and Its Setting," trans. A.S.C.E. Vol. LXXXV 1922, pp. 1237-1356.
2. HOOVER, HERBERT CLARK AND LOU HENRY. "De Re Metallica," Dover Publications, 1950, New York City.
3. RAWLINSON, GEORGE. "History of Herodotus" translation, edited by Manual Komroff 1939, Tudor Publishing Co., New York City.
4. HERSCHEL, CLEMENS. "Frontinus and the Water Supply of the City of Rome, A.D. 97," Dana Estes and Co., 1899, Boston.
5. EWBANK, THOMAS. "Hydraulic and Other Machines for Raising Water," D. Appleton and Co., 1842, New York City.
6. MORGAN, MORRIS HICKY. Translation of Vitruvius, "The Ten Books on Architecture," 1926 Harvard University Press, Cambridge, Mass.
7. WILLCOCKS, SIR WILLIAM. "From the Garden of Eden to the Crossing of the Jordan," E. and F. N. Spon, 1920, London.
8. SINGEN, DOROTHEA WALEY. Translation of Klemm, Friederich, "A History of Western Technology," Charles Schribner's Sons, 1959, New York City.
9. FINCH, G. K. "The Engineer Through the Ages," Civil Engineering, February 1957-March 1958.
10. HATHAWAY, GAIL. "Dams—Their Effect on Some Ancient Civilizations" Civil Engineering, January 1958, p. 58.
11. BUTLER, MILLARD A. "Irrigation in Persia by Kanats," Civil Engineering, February 1933, p. 69.
12. GANDOLFO, J. H. "Tracing the Engineer in Early Egypt and Assyria," Civil Engineering, April 1931, p. 632.
13. LANE, E. W. "Ingenuity of the Ancient Chinese," Civil Engineering, October 1930, p. 17.