ANCIENT AND MODERN ENGINEERING

AND

THE ISTHMIAN CANAL

WILLIAM H. BURR

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BY

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INTRODUCTION.

THIS book is the outcome of a course of six lectures delivered at the Cooper Union in the city of New York in February and March, 1902, under the auspices of Columbia University. It seemed desirable by the President of the University that the subject-matter of the lectures should be prepared for ultimate publication. The six Parts of the book, therefore, comprise the substance of the six lectures, suitably expanded for the purposes of publication.

It may be interesting to state that the half-tone illustrations have, with scarcely an exception, been prepared from photographs of the actual subjects illustrated. All such illustrations in Parts V and VI devoted to the Nicaragua and Panama Canal routes are made from photographs at the various locations by members of the force of the Isthmian Canal Commission; they are, therefore, absolutely true representations of the actual localities to which they apply.

For other illustrations the author wishes to express his indebtedness to Messrs. G. P. Putnam's Sons, Messrs. Turneaure and Russell, John Wiley & Sons, The Morrison-Jewell Filtration Company, Mr. H. M. Sperry, Signal Engineer, *The Engineering News*, *The Railroad Gazette*, The American Society of Civil Engineers, The Standard Switch and Signal Company, The

Baldwin Locomotive Works, The American Locomotive Works, and the International Pump Company, and to others from whom the author has received courtesies which he deeply appreciates.

The classification or division of the matter of the text, and the table of contents, have been made so complete, with a view to convenience even of the desultory reader in seeking any particular subject or paragraph, that no index has been prepared, as it is believed that the table of contents, as arranged, practically supplies the information ordinarily given by a comprehensive index.

Complete and detailed treatments of the purely technical matters covered by Part II will be found in the author's "Elasticity and Resistance of Materials" and in his "Stresses in Bridge and Roof Trusses, Arched Ribs and Suspension Bridges."

W. H. B.

COLUMBIA UNIVERSITY,
October 24, 1902.

CONTENTS.

PART I.

ANCIENT CIVIL-ENGINEERING WORKS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

PART II.

BRIDGES.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

PART III.

WATER-WORKS FOR CITIES AND TOWNS.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

PART IV.

SOME FEATURES OF RAILROAD ENGINEERING.

CHAPTER XXI.

CHAPTER XXII.

CHAPTER XXIII.

PART V.

THE NICARAGUA ROUTE FOR A SHIP-CANAL.

PART VI.

THE PANAMA ROUTE FOR A SHIP CANAL.

PART I.

ANCIENT CIVIL-ENGINEERING WORKS.

CHAPTER I.

1. Introductory.—It is a common impression even among civil engineers that their profession is of modern origin, and it is frequently called the youngest of the professions. That impression is erroneous from every point of view. Many engineering works of magnitude and of great importance to the people whom they served were executed in the very dawn of history, and they have been followed by many other works of at least equal magnitude and under circumstances scarcely less noteworthy, of which we have either remains or records. During the lapse of the arts and of almost every process of civilization throughout the darkness of the Middle Ages there was little if any progress made in the art of the engineer, and what little was done was executed almost entirely under the name of architecture. With the revival of intellectual activity and with the development of science the value of its practical application to the growing nations of the civilized world caused the modern profession of civil engineering to take definite shape and to be known by the name which it now carries, but which was not known to ancient peoples. Unfortunately the beginnings of engineering cannot be traced; there is no historical record running back far enough to render account of the earliest engineering works whose ruins remain as enduring evidence of what was then accomplished.

It is probably correct to state that the material progress of any people has always been concurrent with the development of the art of civil engineering, and, hence, that the practice of civil engineering began among the people who made the earliest progress in civilization, to whom "the art of directing the Great Sources of Power in Nature for the use and convenience of man" became an early and imperative necessity. Indeed that conclusion is confirmed by the most ancient ruins of what may be termed public works that archæological investigations have revealed to us, among which are those to be found in the Chaldean region, in India, and in Egypt. Obviously, anything like a detailed account of the structural and other works of such ancient character must be lacking, as some of them were built before even the beginnings of history. Our only data, therefore, are the remains of such works, and unfortunately they have too frequently been subject to the destructive operations of both man and nature.

2. Hydraulic Works of Chaldea and Egypt.—It is absolutely certain that the populous centres of prehistoric times could not have existed nor have been served with those means of communication imperatively necessary to their welfare without the practice of the art of engineering, under whatever name they may have applied to it. It is known beyond any doubt that the anciently populous and prosperous country at the head of the Persian Gulf and watered by the Euphrates and the Tigris was irrigated and served by a most complete system of canals, and the same observation can be made in reference to the valley of the Nile. It is not possible at this period of that country's history to determine to what extent irrigation was practised or how extensively the former country was served by water transportation conducted along artificial channels; but hydraulic works, including dams and sluices with other regulating appliances designed to bring waters from the rivers on to the land, were certainly among the earliest executed for the benefit of the communities inhabiting those regions. The remains of those works, spread over a large territory in the vicinity of ancient Babylon, Nippur, and other centres of population, show beyond the slightest doubt that there existed a network of water communication

throughout what was in those days a country rich in agricultural products and which supported the operations of a most pros-

perous commerce. These canals were of ample dimensions to float boats of no mean size, although much smaller than those occupied in our larger systems of canal transportation. They

were many miles in length, frequently interlacing among themselves and intersecting both the Tigris and the Euphrates. The remains of these canals, some of them still containing water, show that they must originally have been filled to depths varying from five or six to fifteen or twenty feet, and that their widths may have been twenty-five or thirty feet or more. Another curious feature is their occasional arrangement in twos and threes alongside of each other with embankments only between. The entire Euphrates-Tigris valley from the head of the Persian Gulf at least to modern Baghdad (i.e., Babylonia) and possibly to ancient Nineveh was served by these artificial waterways. Later, when Alexander the Great made one of his victorious expeditions through the Assyrian country, he found in the Tigris obstructions to the passage of his ships down-stream in the shape of masonry dams. This was between 356 and 322 B.C. These substantial dams were built across the river for the purpose of intakes to irrigating-canals for the benefit of the adjacent country. These canals, like those of Egypt, were fitted with all the necessary regulating-devices of sluices or gates, both of a crude character, but evidently sufficiently effective for their purpose.

It is known that there were in those early days interchanges of large amounts and varieties of commodities, and it is almost if not quite certain that the countries tributary to the Persian Gulf not only produced sufficient grain for their own needs, but also carried on considerable commerce with the Asiatic coast. We have no means of ascertaining either the volume or the precise character of the traffic, but there is little or no doubt of its existence. It is established also that the waters of the Red Sea and the Nile were connected by a canal about 1450 B.C. Recent investigations about Nippur and other sites of ancient cities in that region confirm other indications that the practice of some branches of hydraulic engineering had received material development from possibly two to four thousand years before the Christian era.

3. Structural Works in Chaldea and Egypt.—The ruins of ancient buildings which have been unearthed by excavations in the same vicinity show with the same degree of certainty that the art of constructing buildings of considerable dimensions had

also made material progress at the same time, and in many cases must have involved engineering considerations of a decided character both as to structural materials and to foundations. Bricks were manufactured and used. Stones were quarried and dressed for building purposes and applied so as to produce structural results of considerable excellence. Even the arch was probably used to some extent in that locality in those early days, but stone and timber beams were constantly employed. In the prehistoric masonry constructions of both the Egyptians and Chaldeans and probably other prehistoric peoples, lime or cement mortar was not employed, but came into use at a subsequent period when the properties of lime and cement as cementing materials began to be recognized. The first cementing material probably used in Egypt was a sticky clay, or possibly a calcareous clay or earth. The same material was also used in the valley of the Euphrates, but in the latter country there are springs of bitumen, where that material exudes from the earth in large quantities. The use of this asphaltic cement at times possibly involved that of sand or gravel in some of the early constructions. Later, lime mortar and possibly a weak hydraulic cement came to be employed, although there is little if any evidence of the latter material.

Iron was manufactured and used at least in small quantities, and for some structural purposes, even though in a crude manner. Bituminous or other asphaltic material was found as a natural product at various points, and its value for certain structural purposes was well known; it was used both for waterproofing and for cement. It is practically certain that the construction of engineering works whose interesting ruins still remain involved a considerable number of affiliated engineering operations of which no evidence has yet been found, and of the employment of tools and appliances of which we have no record. So far as these works were of a public character they were constructed by the aid of a very different labor system from that now existing. The kings or ruling potentates of those early times were clothed with the most arbitrary authority, sometimes exercised wisely in the best interests of their people, but at other times the ruling motive was selfishness actuated by the most intense egotism

and brutal tyranny. Hence all public works were executed practically as royal enterprises and chiefly by forced labor, perhaps generally without compensation except mere sustenance. Under such conditions it was possible to construct works on a scale out of all proportion to national usefulness and without structural economy. When it is remembered that these conditions existed without even the shadow of engineering science, it is obvious that structural economy or the adaptation of well-considered means to an end will not be found to characterize engineering operations of prehistoric times. Nevertheless there are evidences of good judgment and reasonable engineering design found in connection with some of these works, particularly with those of an hydraulic character. Water was lifted or pumped by spiral or screw machines and by water-wheels, and it is not improbable that other appliances of power served the purposes of many industrial and crude manufacturing operations which it is now impossible for us to determine.

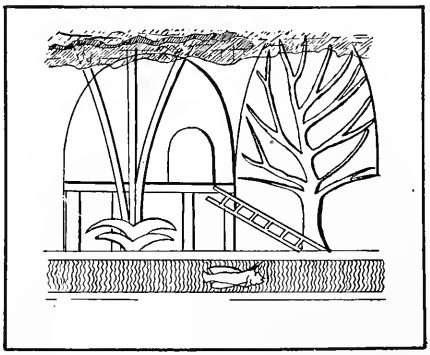


FIG. 1.—Home Built on Piles in the Land of Punt.

It is an interesting fact that while many ancient works were exceedingly massive, like the pyramids, the largest of those of which the ruins have been preserved seldom seem to show little or any evidence of serious settlement. Whether the ancients had unusually sound ideas as to the design of foundation works, or whether those only have come down to us that were founded directly upon rock, we have scarcely any means of deciding. Nor can we determine at this time what special recourses were available for foundation work on soft ground. Probably one

of the earliest recognized instances, if not the earliest, of the building of structures on piles is that given by Sir George Rawlinson, when he states that a fleet of merchant vessels sent down the northeast African coast by the Egyptian queen Hatasu, probably 1700 B.C. or 1600 B.C., found a people whose huts were supported on piles in order to raise them above the marshy ground and possibly for additional safety. A representation (Fig. 1) of one of these native homes on piles is found among Egyptian hieroglyphics of the period of Queen Hatasu.

4. Ancient Maritime Commerce.—It is well known that both the Chaldean region and the Nile valley and delta, at least from Ethiopia to the Mediterranean Sea, were densely populated during the period of two to four or five thousand years before the Christian era. By means of the irrigation works to which reference has already been made both lands became highly productive, and it is also well known that those peoples carried on a considerable commerce with other countries, as did the Phœnicians also, at least between the innumerable wars which seemed to be the main business of states in those days. These commercial operations required not only the construction of fleets of what seem to us small vessels for such purposes, but also harbor works at least suitable to the vessels then in use. The marine activity of the Phœnicians is undoubted, and there is strong reason to believe that there was also similar activity between Babylonian ports and those east of them along the shores of the Indian Ocean, perhaps even as far as ancient Cathay, and possibly also to the eastern coast of Africa.

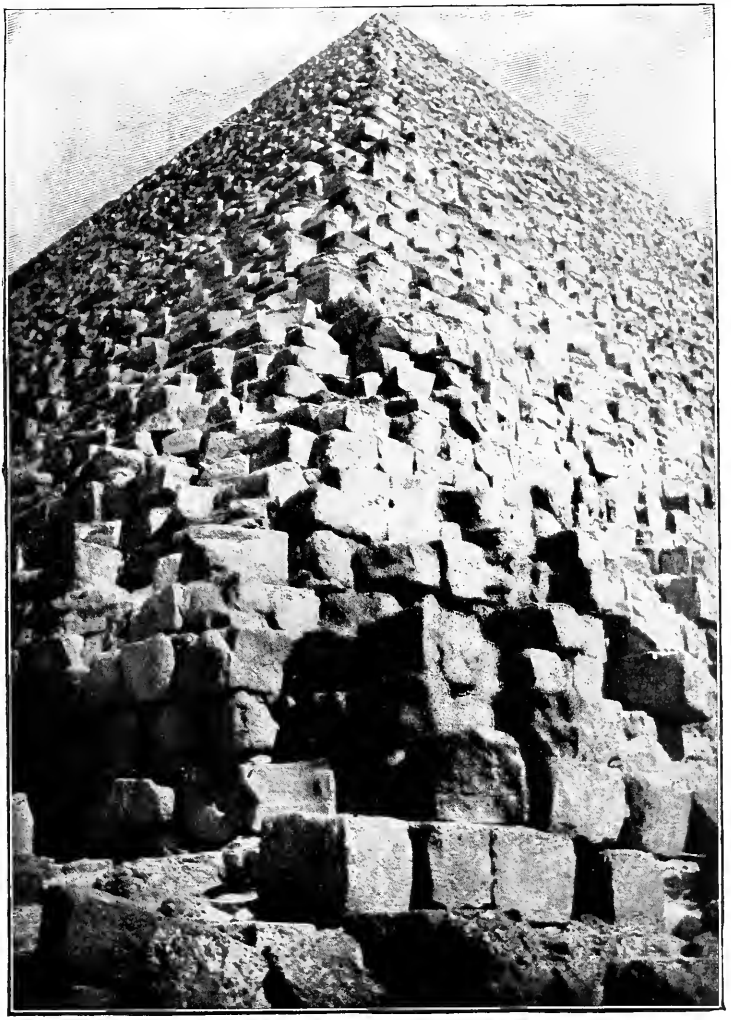
Investigations in the early history of Egypt have shown that a Phœnician fleet, constructed at some Egyptian port on the Red Sea, undoubtedly made the complete circuit of Africa and returned to Egypt through the Mediterranean Sea the third year after setting out, over 2100 years (about 600 B.C.) before the historic fleet of the Portuguese explorer Vasco da Gama sailed the same circuit in the opposite direction. It is therefore probable, in view of these facts, that at least simple harbor works of sufficient efficiency for those early days found place in the public works of the ancient kingdoms bordering upon the Mediterranean and Red seas and the Persian Gulf.

5. The Change of the Nile Channel at Memphis.—Although such obscure accounts as can be gathered in connection with the founding of the city of Memphis are so shadowy as to be largely legendary, it has been established beyond much if any doubt that prior to its building the reigning Egyptian monarch determined to change the course of the Nile so as to make it flow on the easterly side of the valley instead of the westerly. This was for the purpose of securing ample space for his city on the west of the river, and, also, that the latter might furnish a defence towards the east, from which direction invading enemies usually approached. He accordingly formed an immense dam or dike across the Nile as it then existed, and compelled it to change its course near the foot of the Libyan Hills on the west and seek a new channel nearer the easterly side of the valley. This must have been an engineering work of almost appalling magnitude in those early times, yet even with the crude means and limited resources of that early period, possibly, if not probably, at least 5000 B.C., the work was successfully accomplished.

6. The Pyramids.—Among the most prominent ancient structural works are the pyramids of Egypt, those royal tombs of which so much has been written. These are found chiefly in the immediate vicinity of Memphis on the Nile. There are sixty or seventy of them in all, the first of which was built by the Egyptian king Khufu and is known as the "Great Pyramid" or the "First Pyramid of Ghizeh." They have been called "the most prodigious of all human constructions." Their ages are uncertain, but they probably date from about 4000 B.C. to about 2500 B.C. These are antedated, however, by two Egyptian pyramidal constructions of still more ancient character whose ages cannot be determined, one at Meydoum and the other at Saccarah.

The pyramids at Memphis are constructed of limestone and granite, the latter being the prominent material and used entirely for certain portions of the pyramids where the stone would be subjected to severe duty. The great mass of most of the pyramids consists of roughly hewn or squared blocks with little of any material properly considered mortar. The interior portions, especially of the later pyramids, were sometimes partially com-

posed of chips, rough stones, mud bricks, or even mud, cellular retaining-walls being used in the latter cases for the main struc-



A Corner of the Great Pyramid.

tural features. In all pyramids, however, the outer or exposed surfaces and the walls and roofs of all interior chambers were finished with finely jointed large stones, perhaps usually polished.

The Great Pyramid has a square base, which was originally 764 feet on a side, with a height of apex above the surface of the ground of over 480 feet. This great mass of masonry contains about 3,500,000 cubic yards and weighs nearly 7,000,000 tons. The area of its base is 13.4 acres. The Greek historian Herodotus states that its construction required the labor of 100,000 men for twenty years. An enormous quantity of granite was required to be transported about 500 miles down the Nile from the quarries at Syene. Some of the blocks at the base are 30 feet long with a cross-section of 5 feet by 4 or 5 feet. The bulk of the entire mass is of comparatively small stones, although so squared and dressed as to fit closely together. Familiar descriptions of this work have told us that the small passages leading from the exterior to the sepulchral chambers are placed nearly in a vertical plane through the apex. The highest or king's chamber, as it is called, measures 34 feet by 17 feet and is 19 feet high, and in it is placed the sarcophagus of King Khufu. It is composed entirely of granite most exactly cut and fitted and beautifully polished. The construction of the roof is remarkable, as it is composed of nine great blocks "each nearly 19 feet long and 4 feet wide, which are laid side by side upon the walls so as to form a complete ceiling." There is a singular feature

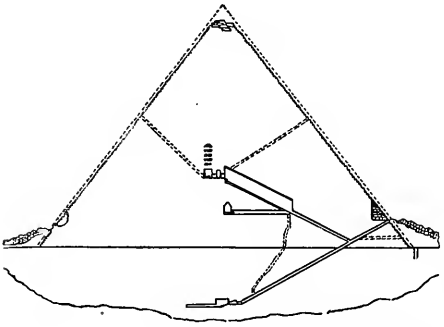
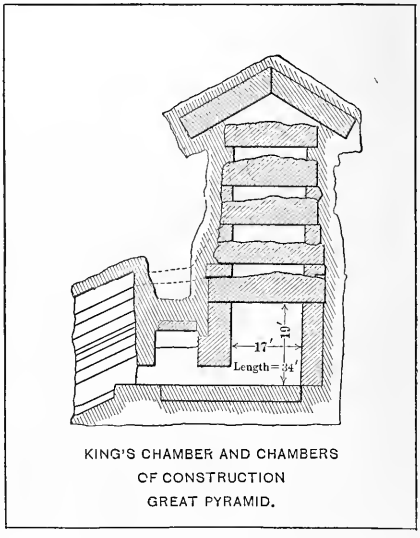


FIG. 2.—Section of the Great Pyramid.



KING'S CHAMBER AND CHAMBERS OF CONSTRUCTION GREAT PYRAMID.

FIG. 3.

of construction of this ceiling designed to remove all pressure from it and consisting of five alternate open spaces and blocks of granite placed in vertical series, the highest open space being

only the inclined highest set of granite blocks or slabs carry any load besides their own weight. There are two small ventilating- or air-shafts running in about equally inclined directions upward from the king's chamber to the north and south faces of the pyramid. These air-shafts are square and vary between 6 and 9 inches on a side. The age of this pyramid is probably not far from 5000 years.

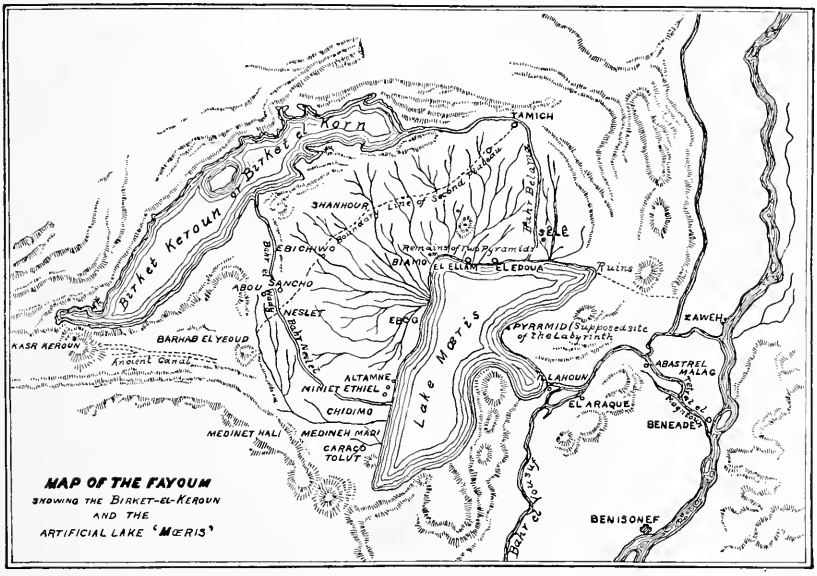
The second pyramid is not much inferior in size to the Great Pyramid, its base being a square of about 707 feet on a side, and its height about 454 feet. The remaining pyramids are much inferior in size, diminishing to comparatively small dimensions, and of materials much inferior to those used in the earlier and larger pyramids.

7. Obelisks, Labyrinths, and Temples.—Among other constructions of the Egyptians which may be called engineering in character, as well as architectural, are the obelisks, the "Labyrinth" so called, on the shore of Lake Mœris, and the magnificent temples at the ancient capital Thebes, which are the most remarkable architectural creations probably that the world has ever known. These latter were not completed by one king, as was each of the pyramids. They were sometimes despoiled and largely wrecked by invading hosts from Assyria, and then reconstructed in following periods by successive Egyptian kings and again added to by still subsequent monarchs, whose reigns were characterized by statesmanship, success in war, and prosperity in the country. Their construction conclusively indicates laborious operations and transportation of great blocks of stone characteristic of engineering development of the highest order for the days in which they took place. The dates of these constructions are by no means well defined, but they extend over the period running from probably about 2500 B.C. to about 400 B.C., with the summit of excellence about midway between.

Another class of ancient structures which can receive but a passing notice, although it deserves more, is the elaborate rock tombs of some of the old Egyptian monarchs in the rocks of the Libyan Hills. They were very extensive constructions and contained numerous successions of "passages, chambers, corridors, staircases, and pillared halls, each further removed from

the entrance than the last, and all covered with an infinite number of brilliant paintings." These tombs really constituted rock tunnels with complicated ramifications which must have added much to the difficulty of the work and required the exercise of engineering skill and resources of a high order.

8. Nile Irrigation.—The value of the waters of the Nile for irrigation and fertilization were fully appreciated by the ancient Egyptians. They also apparently realized the national value of some means of equalizing the overflow, although the annual régimen of the Nile was unusually uniform. There were, however,



periods of great depression throughout the whole Nile valley consequent upon the phenomenal failure of overflow to the normal extent. One of the earliest monarchs who was actuated by a fine public spirit undertook to solve the problem of providing against such depressions by diverting a portion of the flood-waters of the Nile into an enormous reservoir, so that during seasons of insufficient inundation the reservoir-waters could be drawn upon for the purpose of irrigation. This monarch is known as the good Amenemhat, although the Greeks call him Mœris. In

the Nile valley, less than a hundred miles above Memphis, on the left side or to the west of the river, there is a gap in the Libyan Hills leading to an immense depression, the lower parts of which are much below the level of the water in the Nile. This topographical depression, perhaps 50 miles in length by 30 in breadth, with an area between 600 and 700 square miles, now contains two bodies of water or lakes, one known as the Birket Keroun and the other as Lake Mœris. The vicinity of this depression is called the Fayoum. A narrow rocky gorge connects it with the west branch of the Nile, known as Bahr el Yousuf, and it is probable that during extreme high water in the Nile there was a natural overflow into the Fayoum. The good Amenemhat, with the judgment of an engineer, or guided by advisers who possessed that judgment, appreciated the potential value of this natural depression as a possible reservoir for the surplus Nile waters and excavated a channel, possibly a natural channel enlarged, of suitable depth from it to the Bahr el Yousuf. As a consequence he secured a storage-reservoir of enormous capacity and which proved of inestimable value to the lowlands along the Nile in times of shortage in the river-floods.

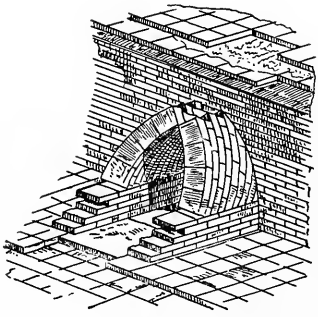
Investigators have differed much in their conclusions as to the extent of this reservoir. Some have maintained that only the lower depressions of the Fayoum were filled for reservoir purposes, while others, like Mr. Cope Whitehouse, believe that the entire depression of the Fayoum was utilized with the exception of a few very high points, and that the depth of water might have been as much as 300 feet in some places. In the latter case the circuit of the lake would have been from 300 to 500 miles. Whatever may have been the size of the lake, however, its construction and use with its regulating-works was a piece of hydraulic engineering of the highest type, and it indicates an extraordinary development of that class of operations for the period in which it was executed. The exact date of this construction cannot be determined, but it may have been as early as 2000 B.C., or perhaps earlier.

9. Prehistoric Bridge-building. — The development of the art of bridge-building seems to have lagged somewhat in the prehistoric period. The use of rafts and boats prevented the

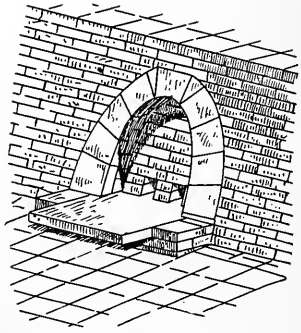
need of bridges for crossing streams from being pressing. It is not improbable that some small and crude pile or other timber structures of short spans were employed, but no remains of this class of construction have been found. Large quantities of timber and much of an excellent quality were used in the construction of buildings. That much is known, but there is practically no evidence leading to the belief that timber bridges of any magnitude were used by prehistoric people. It is highly probable that single-timber-beam crossings of small streams were used, but that must be considered the limit of ancient bridging until other evidence than that now available is found.

10. Ancient Brick-making.—It has already been seen that stone as a building material has been used since the most ancient periods, and the use of brick goes back almost as far. Fortunately it was frequently a custom of the ancient brick-makers to stamp proprietary marks upon their bricks, and we know by these marks that bricks were made in the Chaldean regions certainly from 3000 to 4000 years before the Christian era. In Egypt also the manufacture of brick dates back nearly or quite as far. Some of these Chaldean bricks, as well as those in other parts of the ancient world, were of poor quality, readily destroyed by water or even a heavy storm of rain when driving upon them. Other bricks, however, were manufactured of good quality of material and by such methods as to produce results which compare favorably with our modern building-bricks. The ruins of cities, at least in Assyria and Chaldea, show that enormous buildings, many of them palaces of kings, were constructed largely of these bricks, although they were elaborately decorated with other material. The walls were heavy, indeed so massive that many of the ruin-mounds are frequently formed almost entirely of the disintegrated brick of poorer quality. These old builders not only executed their work on a large scale, but did not hesitate to pile up practically an artificial mountain of earth, or other suitable material, on which to construct a palace or temple. The danger of water to these native bricks was so well known and recognized that elaborate and very excellent systems of subsurface drains or sewers were frequently constructed to carry off the storm-water as fast as it fell.

11. Ancient Arches. — In the practice of these building operations it became necessary to form many openings and to construct roofs for the sewers or drains, and the arch, both true and false, came to be used in the Euphrates valley, in that of the Nile, and in other portions of the ancient world. Pointed sewer-arches of brick have been found in what is supposed to be the palace of Nimrod on the Tigris River, possibly of the date about 1300 B.C. Excavations at Nippur have revealed a mud-brick pointed arch supposed to date back to possibly 4000 B.C. Also semicircular voussoir arches have been discovered at the ruins of Khorsabad near Nineveh with spans of 12 to 15 feet. These arches are supposed to belong to the reign of Sargon, an Assyrian king who flourished about 705 to 722 B.C. Again, the ancient so-called treasury of Atreus at Mycenæ in Greece, although a dome, exhibits an excellent example of the method of forming the false arch, the date of the construction being probably about 1000 B.C. The main portion of this structure consists of a pointed dome, the diameter of the base being



VAULTED DRAIN, KHORSABAD
FIG. 4



VAULTED DRAINS, KHO SABAD.
FIG. 5.

48 feet and the interior central height 49 feet. A central section shows a beehive shape, as in Fig. 6.

The exterior approach is between two walls 20 feet apart, the intermediate entrance to the dome or main chamber being a passage 9 feet 6 inches wide at the bottom and 7 feet 10 inches at the top and about 19 feet high. At right angles to the entrance there is a chamber 27 feet by 20 feet cut into the adjacent

rock, entered through a doorway about 4 feet 6 inches wide and 9 feet 6 inches high. Both the main entrance to the dome and the doorway to the adjacent chamber are covered or roofed with large flat lintel-stones, over which are the triangular relieving (false) arches, so common in ancient construction, by which the lintels are relieved of load, the triangular openings being closed by single, great upright flat stones. There are a considerable number of these in Greece. The stone used is a "hard

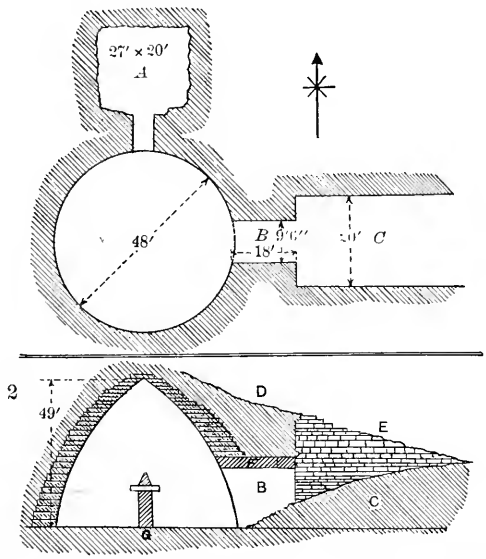


FIG. 6.—Plan and Section of the Treasury of Atreus at Mycenæ.

1. Plan of the Treasury of Atreus: *A*, rock-cut chamber, probably a tomb; *B*, doorway; *C*, approach.

2. Section of the above: *B*, doorway; *C*, approach filled up with earth; *D*, slope of the ground; *E*, wall on north side of approach; *F*, lintel stone, weight 133 tons; *G*, door to rock-cut chamber.

and beautiful breccia" from the neighboring hills and Mount Eubora near by. The courses of stone are about two feet thick and closely fitted without cement.

The great majority, or perhaps all, of the Assyrian true arches, so far discovered, are formed of wedge-shaped bricks, most of them

being semicircular, although some are pointed, the span being not over about 15 feet. The most of the arches found at Nineveh and Babylon belong to a period reaching possibly from 1300 to 800 B.C., but some of the Egyptian arches are still older. Egyptians, Assyrians, Greeks, and other ancient people used false arches formed by projecting each horizontal course of stones or bricks over that below it on either side of an opening. The repetition of this procedure at last brings both sides of the opening together at the top of the arch, and they are surmounted at that point with a single flat stone, brick, or tile. It has been supposed by some that these false arches, whose sides may be formed either straight or curved, exhibit the oldest form of the arch, and that the true arch with its ring or rings of wedge-shaped voussoirs was a subsequent development. It is possible that this is true, but the complete proof certainly is lacking. In Egypt and Chaldea both styles of arches were used concurrently, and it is probably impossible to determine which preceded the other. Again, some engineers have contended that two flat slabs of stone leaning against each other, each inclined like the rafters of a roof, was the original form of the arch, as found in the pyramids of Egypt; but it is probable that the true arch was used in Chaldea prior to the time of the pyramids. Indeed crude arches of brick have been found at Thebes in Egypt dating back possibly to 2500 B.C., or still earlier. Aside from that, however, such an arrangement of two stones is not an arch at all, either true or false. The arrangement is simply a combination of two beams. A condition of stress characteristic of that in the true arch is lacking.

The ancient character of the engineering works whose ruins are found in Chaldea and Assyria is shown by the simple facts that Babylon was destroyed about the year 690 B.C. and Nineveh about the year 606 B.C.