The construction of the Suez Canal

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Abstract

The paper briefly describes the history of the great Canal at Suez, the engineering and construction challenges and the enormous obstacles that had to be overcome. The paper reviews the geology, topography and morphology of the Isthmus and provides a detailed review of the soil investigation campaign and the soil classification of the canal. The engineering aspects of the canal are also reviewed which include geotechnical, marine and port, material, hydraulic and irrigation engineering. The paper also reviews the construction techniques and utilization of dredgers. Although the projects to connect the two seas dates back to 1800 B.C., the beginning of present day construction of the Suez Canal started in 1859, with expansion of the canal still ongoing. The paper reviews today's continuing transportation and irrigation projects for development of the Suez Canal. Figure 1 presents the layout of the Suez Canal.

1 The history of the canal

1.1 Antecedent canals

The first canal linking the Nile River and the Red Sea has been estimated as being built in the reign of the Egyptian Pharaoh Sestostris I who died in 1926 BC. This canal was still in use during the reign of Seti I in 1290 BC. According to Herodotus and Diodorus, the Pharaoh Nacho of the XXVIth dynasty, who ruled Egypt between 609 and 593 B.C. started to build a new canal from the Pelusiac branch of the Nile through the way of Wadi Tumulat, a natural depression running east and west between the Nile delta and the Isthmus of Suez. Herodotus said that 100,000 Egyptians perished in the course of digging this canal.

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The Canal was continued after the Persian conquest by Darius Hystapsis (521–486 B.C.) who again discontinued it, fearing that if the Isthmus was cut through Egypt would be flooded by seawater, as the Red Sea was believed to be higher than mainland Egypt. At that time, the canal reached as far as the Bitter Lakes. The canal was finally completed by Ptolemy II and named Philadelphus (285–246 B.C.). A port called Arsinoe was created near the existing modern Suez. A lock was constructed with double gates between the Red Sea and the canal to prevent the influx of salt water to the Nile.

This canal does not seem to have remained navigable for long and had become disused by the beginning of the Christian era. After the Roman conquest it was restored to use in 98 A.D. under the Emperor Trajan, when the Nile terminal was moved to Babylon, a few miles upstream from modern Cairo, by extending the canal from the original terminal on the Pelusiac branch, to the mainstream of the Nile. Trajan's canal appears to have been used for navigation for about a century.

Amr Ibn El Aas, the Arab Governor of Egypt, re-opened Trajan's canal in 641–642 A.D., on the order of the Caliph Omar, for the purpose of transporting wheat from the Nile Valley to Mecca by water from Cairo to Jeddah via Suez. In 776 A.D., Abbasi Caliph Abu Jaafar Abdullah al Mansour ordered the canal to be blocked at the junction between the canal and the Bitter Lakes to hinder the transport of supplies between Egypt and the inhabitants of Medina, who were at that time in revolt against the Caliphate.

It seems likely that these earlier canals were only navigable during the seasons of high Nile water and for the rest of the year dependent on the level of water in the Nile, sometimes it was too low for the passage of ships of any size. Traces of these early canals were found both by Bonaparte's surveyors, during the French expedition at the end of the eighteenth century, and fifty-five years later by De Lesseps' engineers during their preliminary surveys.

1.2 The development of plans for the Suez Canal

The serious contemporary efforts that resulted in the evolution of the Suez Canal date back to the days of the French expedition. In 1798, Bonaparte accompanied by an impressive body of French scientists, engineers, physicians, zoologists, agronomists, archaeologists and many others, formed themselves into an "Institut d'Egypte" for the purpose of studying, and making recommendations about various aspects of Egyptian life and culture. Among the schemes for the modernization of Egypt was the Suez Canal. Bonaparte made a personal reconnaissance in the Isthmus, accompanied by members of the "Institut d' Egypte" and of the "Commission des Sciences et des Arts". He inspected the Suez, explored the country between Suez and the Bitter Lakes, and claimed to have discovered traces of the old Ptolemaic canal mentioned earlier. On his return to Cairo he appointed the engineer Le Père, to make a detailed preliminary survey.

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A surveying error was made over the relative levels of the Red Sea and the Mediterranean Sea, which seemed to confirm existing tradition and which affected future thinking about the Canal for the next fifty years. Le Père and his assistants found, erroneously, that the level of the Red Sea at high tide was thirty feet above that of the Mediterranean Sea. They deduced from this that a direct cut between the Mediterranean Sea and the Red Sea was impracticable, and concluded that a new canal must follow, more or less, the route of the old Ptolemaic canal and join the Red Sea to the Mediterranean Sea via the Nile.

In 1840, based on Mohamed Ali's instructions, Linant published a report on his canal studies. This report assumed the correctness of Le Père's findings about the relative levels of the Red Sea and the Mediterranean Sea. He suggested that the difference in head would provide a current running from south to north. He proposed a canal with locks and with strong banks to prevent flooding He therefore suggested the direct route as a possible alternative to the classical route via the Nile. In the spring of 1847 three teams of engineers from the "Societe d'Etudes" arrived in Egypt, led by Talabot, Stephenson and Negrelli. Stephenson's team was to investigate the Gulf of Suez, Negrelli's the Bay of Pelusium and Talabot's the interior of the Isthmus. They recommended the route from Alexandria to Suez via the Nile. As early as 1851 De Lesseps had got in touch with Talabot who supplied him with information about the work of the "Societe d'Etudes"and the "avon project" design of Linant. De Lesseps opportunity came in September 1854 when Abbas, the Viceroy of Egypt died and was succeeded by his uncle Mohamed Said, an old friend of De Lesseps.

2 Profile of the Isthmus

2.1 Morphology and topography

The Nile runs south north through Egypt. It is surrounded at parallels by two chains of mountains, which separate it from the Libyan Desert and the Red Sea. Near Cairo, the Nile bifurcates into two branches, which embrace the Delta plain. The eastern mountain chain becomes much lower after crossing the line connecting Suez and Cairo and extends as calcareous hills in a northeast direction to the other side of Lake Timsah.

Between the Red Sea and the Gulf of Pelusium, there is a depression, which is evident by the Bitter Lakes and Lake Timsah. The depression has indeed some undulations between the bitter lakes and Lake Timsah and further between Lake Timsah and Lake Manzala. With the exception of the two ridges, which rise from 12 to 15 meters and are very short, there is a sort of almost horizontal valley along the whole length of the isthmus. At the middle of this longitudinal valley there is a perpendicular depression, which extends from the center of the isthmus to the alluvial lands of the Delta. It results from this natural morphology of the isthmus that the direction of the canal is marked by nature, with the second depression, which connects Lake Timsah to Belbeis, representing the proper connection between the interior navigation of Egypt with the maritime navigation.

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All along the course of the Canal, there is a natural depression. The lowest portion of which is the basin of the lakes, which had long been dry. The ground level rises well above the level of the sea at three locations, Serapeum (35 feet), El Guisr (59 feet), and Chaluf (36 feet).

The first part of the canal is "Lake Manzala"; a shallow lake from four to five feet in depth, and in which for 29 miles the Canal was to be excavated. The mainland is then reached at "Kantara" where for about 3 miles it proceeds as a small tongue of land which separates the great lake from a smaller one, called "Lake Ballah", a distance of about five miles. Following this there is a tract extending for nearly ten miles and consisting of a gradually ascending series of hills in "El Guisr". This plateau was about ten miles in length and rose about fifty-five feet above the waterline.

After this, comes "Lake Timsah", where it was proposed to construct a halfway port. Across this hollow it was now to proceed for four miles. Next the Serapeum plateau was encountered, stretching for about seven miles. Its highest point being about 35 feet above the sea level. The distance through the Bitter Lakes was about twenty miles. After this bend the straight course was resumed, down to Suez, where another plateau, that of El Chalouf, was intersected. The basin of the Bitter Lakes provided a depth of twenty feet of water without cutting for a distance of about eight miles. The proposed scheme of the canal was sixty miles of passage through lakes and forty miles cut in the land.

2.2 Geology and soil

The Mediterranean Sea or the Red Sea has covered the Isthmus region during different geological ages. It is concluded (Ball, 1939) that between the commencement of the Pleistocene period and now, the lands bordering the Red Sea and Gulf of Suez have undergone elevation or the sea level has fallen by something like a hundred meters. The entire soil of the Isthmus of Suez belongs to the Tertiary formation like Lower and Middle Egypt and the great plateau of the Libyan Desert.

The initial soil investigation made by M. Le Père, as part of the work done by the Egyptian Commissioners, were two boreholes at stations 16 and 21 respectively. De Lesseps' engineers followed and made a further 19 boreholes along the 160 kilometers length of the canal. These 19 boreholes were executed between 1854 and 1855. During the actual construction additional and confirmation boreholes were drilled at average intervals of 150 meters. Sir J. Hawkshaw, President of the Institution of Civil Engineers, upon reviewing the soil investigation campaign declared that 150-meter apart boreholes are not a guarantee. The soils of the isthmus are mainly sand from Port Said to the Bitter Lakes and clays thereafter from the Lakes to Suez. Exceptions to the that are the soft clay in Lake Manzala, the gypsum found in Lake Balah, a layer of rock found near Serapeum, and crystallized salts found at the bottom of the Bitter Lakes.

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3 Engineering

3.1 Geotechnical engineering

3.1.1 Soft clay engineering

The portion from Port Said to Lake Manzala, a 20 miles distance, represented the first engineering challenge. This part was about 5 feet deep with the lake bottom consisting of very soft clay resulting from the rich Nile deposits. The problems were: (1) the excavation of the mud (2) the construction and foundation of the canal banks on very weak soil, and (3) the use of the excavated material for bank construction.

The solution was as simple as utilizing local labor to scoop up large masses and squeezed the water out by pressing it against their chests, then laid it in lumps one over the other. By doing this a small channel 12 feet wide was formed. This channel allowed dredgers to work, and the operation soon reached below the mud to the stiff clay. The soft clay was allowed to dry in the sun before another layer was added. This provided for cohesion to increase. When finished, the banks stood six feet high above water. The sun cooperated and baked the whole into a firm solid mass, so firm that the banks were used as roads where heavy loads were transported.

3.1.2 Rock engineering

In 1865, De Lesseps concluded that during the eight years they had been exploring and working the line, almost foot by foot, they had never come upon a single layer of rock, unless it might be a friable marl in the El Guisr cutting. He was also inclined to confess that close to Suez, in the Chalouf cutting, they had encountered a regular ledge of rock, but that the engineers had made a short curve and avoided it. During his visit to the project in 1863, Sir J. Hawkshaw had before warned of the danger of encountering rock layers. In fact, he predicted the possibility to encounter rock in this particular area. He declared that boring at such intervals were not a guarantee.

At the last moment, on the very eve of opening the Canal, a mass of rock was discovered which had escaped notice at the Chalouf cutting, exactly as Sir J. Hawkshaw had predicted. At a depth of 17 feet below the water line, a thin stratum of rock suddenly increased from a few inches to the thickness of 7 feet for about 80 yards. Lying between two trial borings, this layer was not detected until after the water had been let in. The rock was to be removed by blasting and dredging. The same problem was encountered at Serapeum, but here the rock excavation could not be finished before the opening date and was only finished 7 months later.

3.1.3 Slope stability of sand

It was expected that the El Guisr excavation would represent a major challenge and one of the serious difficulties of the work. El Guisr plateau is a series of hills of sand. The delusion at that time was that cutting through sand the rest will fall and fill up the space and the workmen would be buried alive. The excavation had

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to be made to a depth of nearly 70 feet with a total volume of 50 million cubic yards. The work was done using 3 tramway lines, 6 large engines and 250 wagons by the contractor M. Couvreuxo. Side slopes of 2:1 proved to be safe and stable. Sample of the excavation equipment used for dredging is presented in Figure 2.

3.1.4 Salt banks in bitter lakes

At the bottom of the Bitter Lakes, an extraordinary band of salt, seven miles long by five miles wide was found. It was feared that it would have to be dealt with like rock. It turned out that it was easily dissolved.

3.2 Marine and port engineering

The Mediterranean Sea is separated from Lake Manzala by a long strip of very soft clay that appears on the map like the rim of a tea-cup. Within ten years this strip of very soft clay had been converted into a thriving town, laid out in regular streets and squares, having 10,000 inhabitants; a fine port had been created. The shoreline was very shallow and large ships could not approach to within four or five miles. However, a point was discovered in the rim of sand where a full 30 feet of water could be found, little more than a mile from the shore.

Work began in April 1859 on the construction of the artificial port. A temporary jetty 300 feet long was constructed to receive material by sea, particularly stone from the Mex quarries. Stone was also made on the spot with a mixture of one-third hydraulic lime and two-thirds sand, machine mixed with salt water and made into blocks 12 cubic yards in size and weighing 22 tons each. Nearly 30,000 of these blocks were used in the construction of piers, jetties and breakwaters.

At Port Said the west mole was completed on 10 September 1868 to a length of 1.75 miles, which was exceeded only by that of the breakwaters of Holyhead, Cherbourg and Marseilles. That mole provided the protection essential for the new harbor but destroyed the equilibrium of the coastline and led to the accumulation of a sandbank fifty times as fast as had been expected and the formation of an inner submarine beach. On 31st January 1869 the less important east mole was completed, having required only 40% as much concrete as the longer west mole. Together those moles created a harbor where few experts had thought it possible and where no materials existed for its construction.

Comparing the survey of 1870 to that of 1873, it was found that during three years more than 5,000,000 cubic yards of sand and silt had accumulated between the 18 and 30 feet contour lines. The 30 foot contour line was receded seaward 1200 yards and became 1450 meters from pier head in May 1873. The coastline of solid dry sand had advanced 780 feet. The Company decided to extend the west pier 600 m into the sea at £150,000 expense with plans to extend it further 1500 m in the subsequent years. Developments of different plans for the design of Port-Said Port are presented in Figure 3.

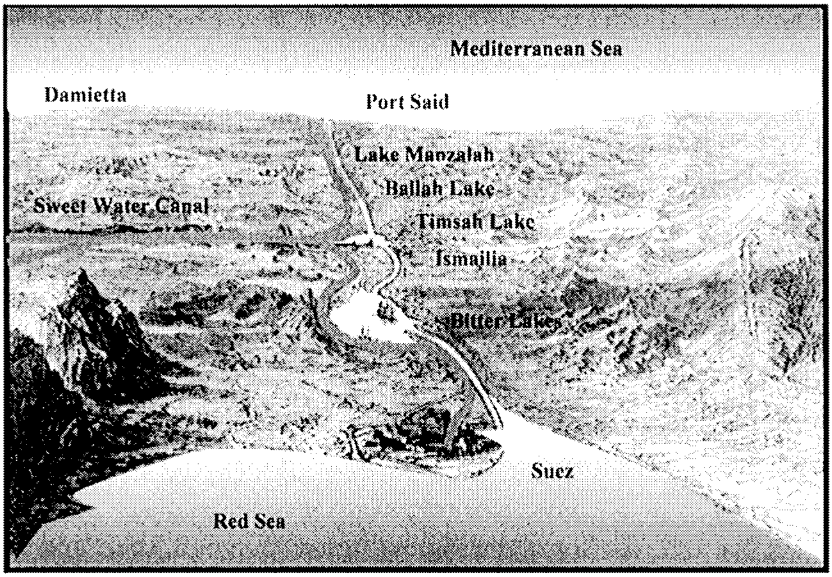

Figure 1. Lakes, ports and cities of the Suez Canal.

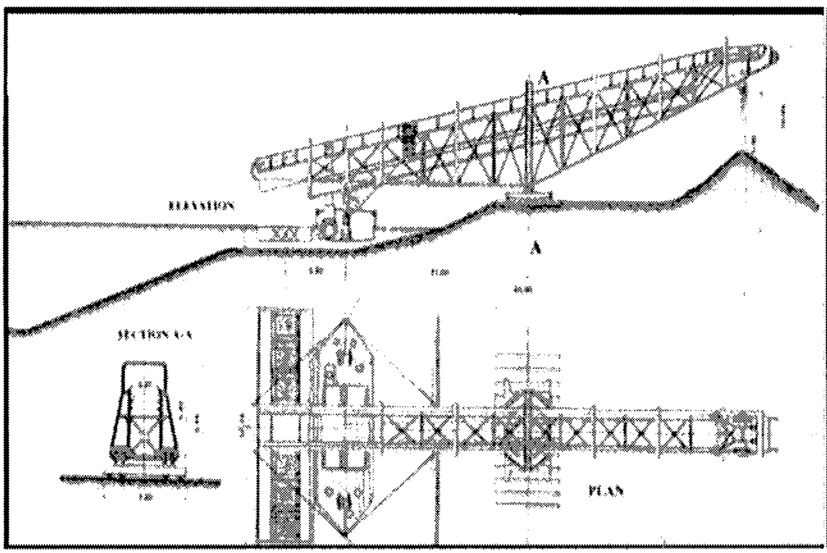

Figure 2. Elevator equipment.

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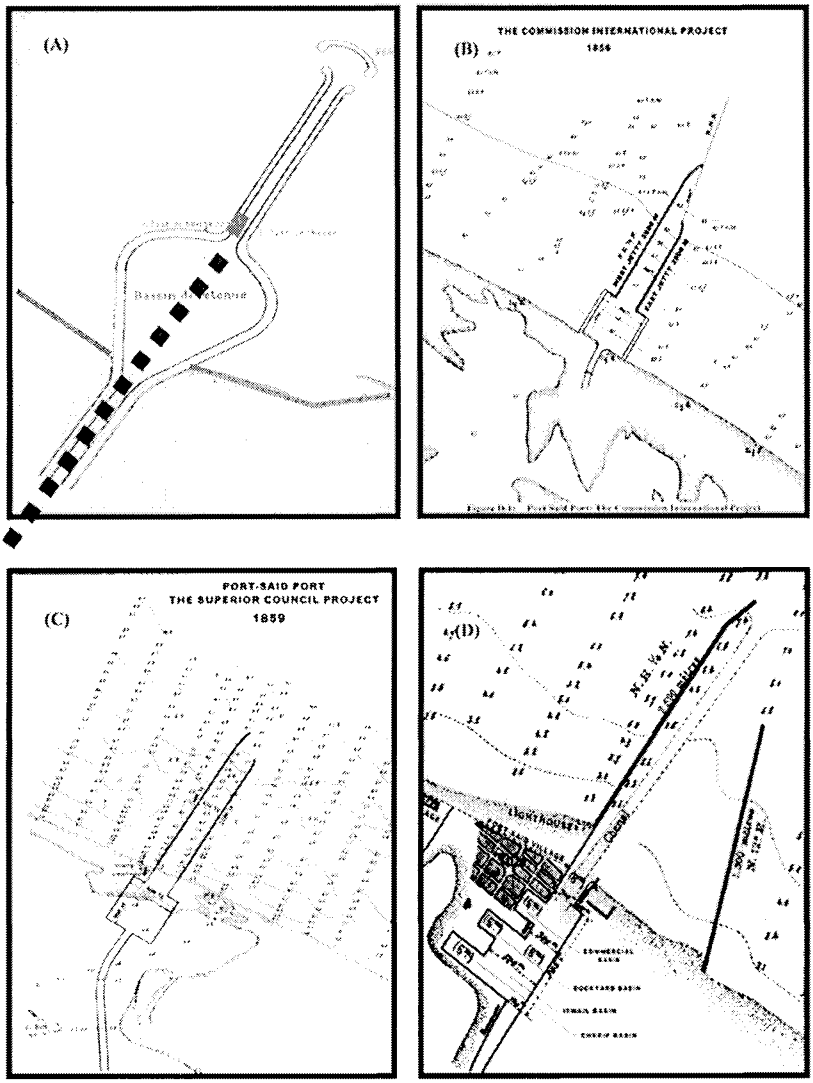

Figure 3. Port Said layout (A) Mohamed Ali project, (B) the commission international project, (C) the superior council project and (D) the executed project.

3.3 Material engineering

Examining the pier blocks in 1873, the submerged blocks were very satisfactory as they were covered with shells and weeds and away from air. The upper blocks however, were exposed to the action of air and spray, which had disintegrated several of them. Of the 1459 blocks that were visible, 1059 were broken. Two thirds of the broken ones show signs of chemical disintegration. It was

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recommended to use rubble masonry laid in mortar of stronger composition to resist the chemical reaction.

3.4 Hydraulic engineering

The filling of the canal and its lakes was regulated through El Timsah, Serapeum, and El Suez Weirs. The final filling of the Canal took place on 15th August, 1869. The union of the two seas caused the rapid dissolution of the salt crust of the Bitter Lakes whose 100,000 acres were filled by 24th October, in seven months rather than the anticipated ten months. The absence of current between the two ends of the canal proved the accuracy of Bourdaloue's survey of 1847. The tidal influence of the Red Sea extended only as far as the Bitter Lakes, which worked as a great reservoir of the waterway and regulator of the sea level at either ends.

3.5 Irrigation engineering

The digging of the Sweet Water Canal, from the end of the Zagazig Canal at the head of Wadi Tumulat to Lake Timsah and then southward to Suez, was quite straightforward and was done mainly with forced labour and by hand. The cross-section of Sweet Water Canal was sixty feet in width by eight feet in depth. It was completed from Ras-El-Wadi to Timsah (twenty miles) in February 1862. The extension to Suez (fifty miles) was completed in December 1863. The stretch from Timsah to Port Said was at first supplied with fresh water by pipeline, after the completion of the Sweet Water Canal to Timsah, but the extension of the Sweet Water Canal to Port Said was completed in 1869. The elevation of the fresh water canal at Lake Timsah was some fourteen feet above the sea as well as the future Suez Canal. The Sweet Water Canal was connected to the lake by two locks. The difference in elevation was used to excavate the south part of the Suez Canal by dredging and to eliminate the effect of Red Sea high tide while dredging to the final depth. The Sweet Water Canal now irrigates some 500,000 acres about 10% of Egypt's agriculture land.

4 Canal construction

The Suez Canal presents an excellent instance where the difficulties prompted the discovery of means to overcome them. The work was fortunate in having as chief contractors two men of extraordinary energy and resources, Borel and Lavalley, who took over the work in 1865. They recognized that the contract could only be achieved by the aid of machinery. They accordingly devised those extraordinary dredgers to suit such difficulties. The dredgers varied in size according to the work for which they were required, and the disposal of the dredged materials. Dredgers came in different sizes, the smaller dredgers were 15-horse power, next came intermediate size dredgers, then followed the largest machines of 75-horse power. The largest dredgers were 110 feet in length, with a 27 feet beam, and had drums 48 feet above the water-line. The cost of each was £20,000.

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The practical breadth of the canal is its breadth at the bottom. At opening, the Suez Canal cross-section breadth measured 72 feet from end to end, though for seventy-seven miles (78% of the total length) it was double the width. The smaller dimensions were adopted for the heavy cuttings, to save expense. At the opening, the Canal had been excavated mainly according to one of the following sections:

1. 196 feet in width at the surface of water, 26 feet deep, and 72 feet at the bottom. The slopes are 2 horizontal to 1 vertical, with one or more horizontal benches of 10 feet in width, according to the depth of the cutting.
2. 327 feet in width at the surface of water, with the same depth of 26 feet for width of 72 feet at the bottom. The slopes of the lower part of the excavation are also 2 horizontal to 1 vertical, but those above and below the surface of the water are 5 horizontal to 1 vertical, connected by a horizontal bench of 58 feet.
3. Through Lake Timsah and the Bitter Lakes, only the lower portion was required to be excavated, in consequence of the low level of the ground.

The cutting in the Serapeum plateau offered the most extraordinary difficulties, which the contractor was unable to overcome. Manual labor failed to make the enormous cuttings. An intelligent idea was to excavate using dredgers as follows: the contractors banked up the Canal at the point to which the Mediterranean Sea water had been brought, Scooped out the remainder to a certain depth by manual labor, Banked this up at the end next to the Bitter Lakes and turned the Fresh Water Canal into the excavation. Then the dredgers were brought into play, dredgers, which were originally forwarded by means of the Maritime Canal from Port Said to Ismailia. There they passed through the locks into the Fresh Water Canal, which raised them seventeen feet above the sea level. A cross-cutting was then made from the Fresh Water Canal to the line of the works on the Maritime Canal, by which the machines were floated into their respective positions at this superior elevation. When these dredgers had dredged to the required depth, the connection with the Fresh Water Canal was closed and the dam in the line of the Suez Canal removed. By this means the level of the Fresh Water Lake fell to that of the sea level. The dredgers descending at the same time continued to dredge the canal to its final prescribed depth. The final stretch of 12 miles near the Red Sea towards Suez was also dredged using fresh water through a junction with the Fresh Water Canal. In doing so, the dredgers were independent of the high tide of the Red Sea.

5 Opening ceremony

Ismail, Egypt's Viceroy at the time of the Canal's construction, invited to the opening ceremony all the Moslem princes of Asia and Africa as well as all the Christian princes of Europe and America, but not the Turkish Sultan whose presence would have deprived Ismail of the opportunity to play host to his fellow monarchs. The greatest drama ever witnessed in Egypt began on 17 November at Port Said on the beach to the west of the mole and in front of the Eugenie Quay.

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The completion of the Suez Canal revived the dream of a Panama Canal and inspired many to think to imitate at Panama what De Lesseps had achieved at Suez. The Americans became eager to construct the Panama Canal. The successful completion of the Suez Canal produced a mania for cutting through Isthmuses and to provide vessels with a direct course. The success of De Lesseps thus encouraged proposals for a Cornith Canal, a Holstein Intermaritime Canal, a Bridgwater-Exeter Canal and a Manchester-Liverpool Ship Canal. Even a Calcutta-Calais Canal was proposed, in order to link India to Manchester.

6 The continuous project

Although the construction of the Suez Canal project started in 1859 the expansion of the canal has never stopped. The current Canal cross-section is 15 times larger than that of the original section on opening in 1869. Many transportation and irrigation projects have been conducted to further develop the Suez Canal and the Suez Canal region. Among them are expansions of the Canal Cross-Section and bypasses, Ahmed Hamdi Tunnel, El Sheikh Zaid Syphon, El Salam Canal Syphon, El Sukhna Port, El Ferdan Bridge, Mubarak Suspended Bridge, East Port Said Port, and the proposed Port Said Tunnel.

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