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Construction of the Suez Canal

Mamdouh Hamza – Professor of Soil Mechanics and Foundations, Suez Canal University, Port-Said, Egypt & Chairman of Hamza Associates, Cairo, Egypt

ABSTRACT: This paper briefly describes the history of the great Canal at Suez, the engineering and construction challenges and the enormous obstacles which had to be overcome. The paper also highlights the principal role of De Lesseps, the fight between the French and English over ruling the world’s most important highway, the many sacrifices made by Egyptians and the evolution of the art of dredging.


1 INTRODUCTION

The construction of the Suez Canal created the most important highway in the world, connecting the Mediterranean Sea and the Red Sea. The construction of the Canal created three cities, Port-Said, Ismailia and Suez, and created two main ports, Port-Said and Suez. The Suez Canal project resulted in Egypt becoming bankrupt in 1876 and being occupied in 1882. The canal was nationalized in 1956, which led to the 1956 war between France, England and Israel from one side and Egypt on the other side.

2 THE HISTORY OF THE CANAL

2.1 Antecedent Canals

According to Herodatus and Diodorus, the Pharaoh Nacho of the XXVIth dynasty, who ruled Egypt between 609 and 593 B.C. started to build a canal from the Pelusic 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.

The Canal was continued after the Persian conquest by Darius Hystapsis (521-486 B.C.) who again discontinued it fearing that if he cut through the Isthmus, Egypt would be flooded by sea water 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 Pelusic branch, to the mainstream of the Nile. Trajan’s canal appears to have been used for navigation for about a century, Figure (1).

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., Abbas 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 and that, for the rest of the year, the level of water, which depended on the level of water in the Nile, 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 occupation at the end of the eighteenth century and fifty-five years later, by De Lesseps’ engineers during their preliminary surveys.

Although these canals were not built for the purpose of marine communication between the Mediterranean Sea and the Red Sea, the knowledge that they had been built served as an inspiration and example, one thousand and more years later, to those who began thinking and planning in terms of a canal for this purpose.

2.2 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, agriculturists, archaeologists and many others, formed themselves into an “Institut d’Egypte” for the purpose of studying, documenting, 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 anchorage at 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.

A serious 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
Figure 1: Isthmus of Suez and Delta with the Ancient Canal of Trajan, The Sweet Water Canal and the Maritime Canal.
objections to this scheme; danger of the banks bursting, or the opportunity came in September 1854 when Abbas, the Viceroy was unrealistic due to the known British opposition. De Lesseps realized that financial backing from the great European banks practical. From the political point of view, he seems to have accommodate and as a result a direct cut across the Isthmus was to have become convinced that the Talabot scheme for a canal of the ocean-going steamships which the canal would have to prevent flooding He therefore suggested the direct route as a possible alternative to the classical route 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 form 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”. They believed that De Lesseps would put his negotiating ability at the disposal of the “Societe d’Etudes”. De Lesseps was in disagreement with the “Societe d’Etudes” on two fundamental points. From the technical point of view he appears to have become convinced that the Talabot scheme for a canal via the Nile would be impracticable owing to the increasing size of the ocean-going steamships which the canal would have to accommodate and as a result a direct cut across the Isthmus was practical. From the political point of view, he seems to have realized that financial backing from the great European banks was unrealistic due to the known British opposition. 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.

During that time Mr. Maclean, a well known English engineer on the British Commission, submitted a proposal which was seriously considered, debated and finally rejected. This was to construct high banks all along the course of the Canal and raise the waterline almost to the level of these banks, confining the water between locks at both ends. But there were obvious objections to this scheme; danger of the banks bursting, or the 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 Nile.

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Table (1): The Different Projects of the Maritime Canal

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<thead>
<tr>
<th>Description</th>
<th>Date</th>
<th>Width (m)</th>
<th>Depth (m)</th>
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<th>Locks</th>
<th>Interior port</th>
<th>Estimated volume of excavation (m³)</th>
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<td>Alignment followed by the natural configuration of the places, avoiding as much as possible curvatures.</td>
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<td>100 m at water level, 65 m at bed level</td>
<td>7.50 to 8.00</td>
<td>2:1</td>
<td>With two locks</td>
<td>At Timsah lake</td>
<td>74,679,132</td>
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2.3 Concessions by the Egyptian Government

The main features of the first concession (1854) were:
- The period of the concession is 99 years from the day of the opening of the Canal between the two seas.
- All necessary land, will be granted free and exempted from taxes.
- The net profit will be divided as follows: 15% the Egyptian Government, 10% Founders shares, 75% the Company
- The Company is granted to work all mines and quarries belonging to the public lands without paying.
- The Company is to enjoy free importation of all machines and materials from abroad for the works of the Concession.

The main features of the second concession (1856) were:
- The Canal should be a direct cut between the Red Sea and the Mediterranean Sea;
- There should be a navigable freshwater canal connecting the Nile with Lake Timsh and running parallel to the whole length of the Maritime Canal;
- De Lesseps should be President of the Company for the first ten years after the Canal’s completion;
- At least four-fifths of the workers employed in the construction of the Canal shall be Egyptians;
- The Egyptian Government should give the Company free and free of tax the use of all public lands necessary for the construction of the Canal and its dependencies;
- The Company will get free of tax for the first ten years, the use of all public land brought into cultivation as a result of the Company’s operations.

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</tbody>
</table>
Figure 2: Comparative Different Plans For Several Project of The Maritime Canal
Figure 3: The Canal of Sweet Water (Ismailia Canal)
The difference between the two concessions can be summarized as follows:

- The first concession had been for a period of 99 years without provision for renewal. The second concession was also for 99 years but with a provision for renewal up to 500 years subject to an increased take by the Egyptian Government, 5% increase every 100 years.

- The second concession provided that De Lesseps should be President for ten years from the time that the Canal was opened, while the first concession provided that the President should be nominated by the Egyptian Government.

- The first concession made a provision for fortification for the canal to be erected by the Egyptian Government at their own charge. The second concession made no mention of fortification.

The supply of labor was done through corvee and courbash. A 'corvee' is a draft of forced labor, pressed into service by the village headmen under the orders of the Government to perform public work. A 'courbash' is a rawhide whip wielded by the overseers on the backs of the wretched laborers. It was certain that the only way of recruiting labor on the scale required would be by means of a corvee. Such a corvee would have to be raised by the Egyptian Government by an agreement between the Company and the Egyptian Government. The Decree appeared to commit the Government to supply on demand all the labor which the Company, in its own estimation, might require. Workers should be paid at a rate of from 2.5 to 3 piastres a day plus rations to the value of one piastre a day. A piastre is 1/100 of the Egyptian Pound.

2.4 **Milestone Events of the Suez Canal**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1854</td>
<td>By a French initiative, the Viceroy of Egypt, Said Pasha, decided to build a canal connecting the Mediterranean Sea to the Red Sea.</td>
</tr>
<tr>
<td>1858</td>
<td>&quot;La Compagnie Universelle du Canal Maritime de Suez&quot; is formed to construct the canal. The company, which was owned by both French and Egyptian interests, agrees to build the canal and administer it for the following 99 years. After this time, the ownership would pass to the Egyptian government.</td>
</tr>
<tr>
<td>25/4/1859</td>
<td>Construction began.</td>
</tr>
<tr>
<td>17/11/1869</td>
<td>With great splendor, the canal is opened for navigation. Average dimensions were 22 meters in bottom width, 58 meters in surface width, and depth of 8 meters.</td>
</tr>
<tr>
<td>1875</td>
<td>The British government buys the Egyptian stocks.</td>
</tr>
<tr>
<td>1888</td>
<td>By an international convention, the canal was opened for ships of all nations.</td>
</tr>
<tr>
<td>1936</td>
<td>Through a treaty, the British received rights to keep military forces in the Canal Zone.</td>
</tr>
<tr>
<td>1948</td>
<td>Egyptian authorities introduced regulations against the use of the canal by vessels serving Israelsi ports.</td>
</tr>
<tr>
<td>1954</td>
<td>Agreement between Egypt and Britain provided for British withdrawal within the following 7 years.</td>
</tr>
<tr>
<td>1956 June</td>
<td>British troops left and Egyptian forces moved into British installations.</td>
</tr>
<tr>
<td>1956 July</td>
<td>Egypt nationalized the Suez Canal.</td>
</tr>
<tr>
<td>31/10/1956</td>
<td>France, Britain and Israel attacked Egypt, declaring their intention to open up the canal for all vessels. They were forced to withdraw under US pressure.</td>
</tr>
<tr>
<td>1957 March</td>
<td>Reopening of the canal, following UN action.</td>
</tr>
<tr>
<td>1962</td>
<td>All original shareholders were paid off.</td>
</tr>
<tr>
<td>5/6/1967</td>
<td>Due to the Six-Day War, the canal was closed.</td>
</tr>
</tbody>
</table>

The canal was damaged extensively and was out of operation for several years. 1975 June: The canal was again opened, and since then has been maintained and enlarged.

### 3 CONSTRUCTION COST AND EGYPT’S SHARE

According to the Company's books the total cost of the Canal construction at the end of 1869, was 453,645,000 Francs. Of this sum, 200,000,000 was funded from the original capital. All of which, including the Egyptian Government share holding, had been fully paid up by the end of 1869. The balance of 253,645,000 was paid as follows:

1. 100,000,000 Francs obtained from two bonds issued in 1867–1868.
2. 84,000,000 Francs indemnity.
3. 10,000,000 Francs received from the resale of the Wadi Lands to the Egyptian Government (the Company bought it earlier for 2,000,000 Francs from the Egyptian Government).
4. 30,000,000 Francs paid by the Egyptian Government to the Company for various physical assets, customer and fishing rights, etc., purchased by the Egyptian Government from the Company in accordance with the terms of a convention signed on 23 April 1869.
5. 30,000,000 Francs obtained from interest paid by the Egyptian Government under the terms of the March 1863 and January 1866 conventions, on amount due on the Egyptian Government’s ordinary shareholding and on the indemnity.

Apart from the sum of 453,645,000 Francs appearing in the Company's books, there were numerous expenses incurred by the Egyptian Government in connection with the Canal as follows: (1) Cost of construction of sweet water canal from Cairo to Ras El Wadi 21,500,000 Francs. (2) Cost of construction of Raddoub Basin at Suez 9,000,000 Francs. (3) Cost of construction of port works at Suez 23,395,000 Francs, and (4) Construction of lighthouses at northern terminal of Canal 1,250,000 Francs. The total comes to 55,145,000 Francs.

The money spent by the Egyptian Government on the Canal was in the form of share capital, indemnities, public works connected with the Canal, the expenses of Nubar’s missions to Paris and Constantinople, and the lavish entertainment which accompanied the formal opening of the Canal in 1869. Most of this money had to be raised by foreign loans. It has been estimated that the total amount of debt incurred by the Egyptian Government in the course of raising the money spent on the canal amounted to some 400,000,000 Francs. The 400,000,000 Francs in 1869, mostly loans, continued to grow and represented most of the Egyptian Government’s total debt of 2,225 million francs at the time of Egypt’s bankruptcy in 1876.

In return, the Egyptian Government received (1) ordinary share at a par value of some 87 million Francs. They had surrendered all interest and dividends until 1894, and in 1875, sold the shares to the British Government for 100 million Francs, and (2) 15% of the net profits of the Company, which was sold in 1880 to the Credit Fancier for a sum of 22 million Francs.

**Table (2): Annual Company Expenses in French Francs**

<table>
<thead>
<tr>
<th>Year</th>
<th>Construction Expenses</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860</td>
<td>3,624,678</td>
<td>5,575,934</td>
<td>9,200,612</td>
</tr>
<tr>
<td>1861</td>
<td>10,830,671</td>
<td>2,535,971</td>
<td>13,366,643</td>
</tr>
<tr>
<td>1862</td>
<td>9,177,026</td>
<td>7,950,420</td>
<td>17,127,447</td>
</tr>
<tr>
<td>1863</td>
<td>18,348,535</td>
<td>8,988,194</td>
<td>27,336,729</td>
</tr>
</tbody>
</table>
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. At only two locations does the ground rise much above the level of the sea: Chaluf (36 feet) and El Guisr (59 feet). Between these two wells, this rim an opening was to be made for the canal; further a port and a town would have to be formed, with docks to shelter and land. Within ten years this strip of very soft clay slob has been converted into a thriving town, laid out in regular streets and squares, having 10,000 inhabitants; a fine port had been created. It results from this natural morphology of the isthmus that the proper connection between the interior navigation of Egypt with the maritime navigation. Based on the above morphology and confirmed by finding from the soil investigation, the study revealed two main geological facts:

1. During great inundation, the Nile water reach the isthmus in three locations: (a) in the north at Lake Manzalah through Damietta Branch, (b) the central part at Lake Temsah through the valley of Wady Toumilat which is usually flooded during high Nile levels and filled parts of Lake Temsah and (c) Bitter Lakes by going around the Serapeum ridges during exceptionally high Nile floods.

2. The intrusion of the Red Sea to at least the Bitter Lakes as evidenced by the presence of salt bands and the marine shells.

The Nile runs south north through Egypt. It is surrounded almost parallelly 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 embraced 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 Temsah.

Between the Red Sea and the Gulf of Pelusium, there is a depression, which is evident by the presence of salt bands and the marine shells.
Figure 4: Egypt in the past geological times. (Adapted from Agas & Ball, 1939)
Figure 5: Isthmus of Suez Geological Map
The initial soil investigation was two boreholes by M. Lepere as part of the work done by the Egyptian Commissioners, at stations 16 and 21, respectively. This was followed by 19 boreholes by De Lesseps Engineers along the same 160 kilometers length of the canal. These 19 boreholes were executed between 1854 and 1855. During the actual construction additional confirmatory boreholes were drilled at an average intervals of 150 meters. Sir 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 19 boreholes were executed in the following locations:

Roadstead of Suez,
The ridge separates Suez from the Bitter Lakes,
The basin of the Bitter Lakes,
The ridge of Serapeum,
The ridge of El Guisr, the highest point of the Isthmus, and Lake Manzalah.

Two borings were first made near Suez in the course of the future Canal. The first borehole is eleven meters in depth. Soil formation is as follows from the surface to the bottom, yellow agglutinated sand, coarse and muddy sand, very fine sand, and yellow argillaceous sand. The second borehole is twelve meters in depth, produced shells, gravel, and coarse agglutinated sand, which forms a hard rock of 3½ meters in thickness; fine yellow sand slightly agglutinated, coarse red sand, and firm sand and gravel. Except for 3½ meters of thickness, where the agglutinated sand has almost attained the hardness of stone, the nature of soil is good for the dredgers to excavate to form the canal channel. To the north and west of Suez extends a plain mostly covered by sand that appears to consist of the deposit left by high tides. It is impregnated with a damp salt which makes it compact.

The third borehole was undertaken at 8½ kilometers from Suez, on the first traces of the canal of the Pharaohs, on the track of the caravans from Egypt to Mecca. The borehole showed ten meters of clay, more or less sandy. The two banks of the ancient canal can be recognized and were in some places fifty meters apart with height of five to six meters. The borehole also indicated some crystallized sulfate of lime and some pebbles in the sand mass. The fourth borehole is about twenty kilometers from Suez. The top 2 to 3 meters are sand followed by nothing but clay all the way to depth 16.0 meters. Borings 3 and 4 therefore, showed plainly that the ridge, which separates the Red Sea from the Bitter Lakes, consists almost entirely of clay, more or less compact.

The Bitter Lakes, forty kilometers are divided into two basins, a small and a larger basin. Four borings (5th 6th 7th and 8th) made in the small basin of bitter lakes, the superficial soil were besides sulphate of lime, sand and shells, and light brown clay, more or less sandy. This clay has occasionally the appearance of the slime of the Nile. The greater basin is about twenty-five kilometers long. The bottom is covered with sand, shells, and crystallized sulphate of lime. A thick bed of sea salt was found in the deepest part of the lake. Two borings have been made in the large basin of Bitter Lakes; these are the 9th and 10th. The 9th boring of depth of 26.20 meters, presents only agglutinations of shell, more than 20 centimeters in thickness, and after this, sulphate of lime and salt. The 10th boring, which is 3.5 meters deep, shows nothing but sea salt. At these two borings, the surface of the soil is 6.69 meters and 7.35 meters below the lowest level of the Mediterranean. These masses of salt are sometimes placed on deposits of mud from the Nile.

From the middle of the isthmus at the ridge of Serapeum to the Mediterranean nothing was found but sand, except at Boring 19, where there is marl.

Boring No. 11 made at the boundary between Bitter Lakes and Serapeum, produced only sand and fine gravel for 8 meters. A second, boring No. 12, made at the other end of Serapeum, and on the slope which leads to Lake Timsah, also produced sand mixed with fine gravel.

At Lake Timsah, the southern part was dry. There was a little water only in the northern part because the inundation of the Nile was not very great that year and the river did not then reach the lake. But the signs of the Nile presence could be seen everywhere by the slime which been previously left there, similar to that of the plains of Upper Egypt. It is probable that the Red Sea stretched even as far as Lake Timsah as under the slime, borings showed shells that belong to the Red Sea which do not exist in the Mediterranean Sea. Two boreholes No. 15 and 16 made in Lake Timsah, and yielded only sand of different color somewhat argillaceous.

To the north of Lake Timsah the ridge of El Guisr is the highest point of the Isthmus at 16 meters above the lower level of the Mediterranean Sea. It consists of a great deposit of sand. Borehole No. 18 was the deepest executed borehole at depth of 23.35 meters. The soil formation is, from the surface to the bottom, sand alternating with little beds of clay and of sulphate of lime; small gravel; fine sand. The last four meters are sand hardened almost into stone.

From the ridge of El Guisr to Pelusium, the gravel, has been getting finer and finer, and entirely disappears. Two borings were made in Lake Manzalah. Borehole (20) yielded Nile slime, sandy clay, and sea sand. Borehole (21) yielded sea sand, muddy sand, and, sandy mud. Figure (6) shows borehole locations and soil classification.

4.5 Soil Profile

For summary, along the Maritime Canal of Suez, in its whole course of 157,956 meters, the subsoil conditions are two principal kinds: (1) clays, from Suez to the Bitter Lakes; and (2) firm sand, from the Bitter Lakes to its termination in the Bay of Pelusium. It may be generally stated that the soil profile along the canal consists of two portions. The higher portion from "Lake Menezalah" to about the middle, was formed mainly of sand easy to work with. The second portion, the lower half, was mainly gravelly, with clay. The soil profile along the Canal is shown in Figure (7). Detailed soil profile is presented in Figures (B.1) through (B.4).

Near Serapeum a layer of rock was found, which in one place and for a length of eighty yards, increased suddenly form a few inches to a thickness of seven feet. Figure (B.5) provides a longitudinal profile along the rock layer found near Serapeum.

At the bottom of the Bitter Lakes a six feet deep deposit of crystallized salts was found. This proves that the Red Sea had formerly flowed over this basin. Figure (B.6) provides a longitudinal profile along the salt band and presents its disintegration with time.

5 HISTORICAL DEVELOPMENT OF THE CANAL CROSS SECTION AND ITS ALIGNMENT

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
Figure 6) Soil Investigation, Boreholes 1 Through 21
Figure 7: Longitudinal Geological Cross Section of the Maritime Canal
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.

The work was carried out with reference to these two sections in the following manner:

According to Section (1) (smaller section):

<table>
<thead>
<tr>
<th>From near El Ferdan to Lake Timsah</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Lake Timsah to the Bitter Lakes</td>
<td>9.5</td>
</tr>
<tr>
<td>Through the deep part of El Chalouf cutting</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
</tr>
</tbody>
</table>

According to Section (2) (larger section):

Table (3): Alignment of the Suez Canal

<table>
<thead>
<tr>
<th>No.</th>
<th>Alignment</th>
<th>Angle</th>
<th>Length between angles (Km)</th>
<th>Tangents length (Km)</th>
<th>Strait line length (Km)</th>
<th>Curvatures length (Km)</th>
<th>Radius (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Between south extremity &amp; the first curvature</td>
<td>138° 30’ 00”</td>
<td>2.941</td>
<td>1.212</td>
<td>1.728</td>
<td>2.317</td>
<td>3.200</td>
</tr>
<tr>
<td>2</td>
<td>Of the Quarantine</td>
<td>167° 32’ 40”</td>
<td>2.905</td>
<td>0.328</td>
<td>1.364</td>
<td>0.654</td>
<td>3.011</td>
</tr>
<tr>
<td>3</td>
<td>Of Suez</td>
<td>172° 12’ 40”</td>
<td>9.483</td>
<td>0.204</td>
<td>8.950</td>
<td>0.408</td>
<td>3.000</td>
</tr>
<tr>
<td>4</td>
<td>South Small Bitter Lakes</td>
<td>152° 05’ 00”</td>
<td>15.122</td>
<td>0.497</td>
<td>14.621</td>
<td>0.949</td>
<td>2.000</td>
</tr>
<tr>
<td>5</td>
<td>The Small Bitter Lakes</td>
<td>137° 39’ 00”</td>
<td>6.910</td>
<td>1.162</td>
<td>5.251</td>
<td>2.217</td>
<td>3.000</td>
</tr>
<tr>
<td>6</td>
<td>South the Great Bitter Lakes</td>
<td>142° 36’ 30”</td>
<td>8.578</td>
<td>7.416</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>The Great Bitter Lakes</td>
<td>142° 36’ 30”</td>
<td>14.797</td>
<td>14.797</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Serapeum</td>
<td>155° 10’ 00”</td>
<td>14.422</td>
<td>0.477</td>
<td>13.945</td>
<td>0.936</td>
<td>2.000</td>
</tr>
<tr>
<td>9</td>
<td>Toussoum</td>
<td>160° 20’ 20”</td>
<td>7.178</td>
<td>0.706</td>
<td>0.210</td>
<td>0.496</td>
<td>0.364</td>
</tr>
<tr>
<td>10</td>
<td>Garage</td>
<td>109° 00’ 00”</td>
<td>0.706</td>
<td>0.210</td>
<td>0.496</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Timshah lake</td>
<td>144° 30’ 00”</td>
<td>2.138</td>
<td>0.565</td>
<td>1.363</td>
<td>1.093</td>
<td>1.765</td>
</tr>
<tr>
<td>12</td>
<td>Site no. VI</td>
<td>151° 00’ 00”</td>
<td>1.848</td>
<td>0.556</td>
<td>0.727</td>
<td>1.088</td>
<td>2.151</td>
</tr>
<tr>
<td>13</td>
<td>Two curvature at El Guisr</td>
<td>141° 20’ 00”</td>
<td>1.048</td>
<td>0.354</td>
<td>0.137</td>
<td>0.682</td>
<td>1.011</td>
</tr>
<tr>
<td>14</td>
<td>El Guisr</td>
<td>136° 55’ 00”</td>
<td>11.919</td>
<td>0.828</td>
<td>10.735</td>
<td>1.579</td>
<td>2.100</td>
</tr>
<tr>
<td>15</td>
<td>Ballah Lake</td>
<td>158° 00’ 00”</td>
<td>4.116</td>
<td>0.388</td>
<td>2.899</td>
<td>0.767</td>
<td>2.000</td>
</tr>
<tr>
<td>16</td>
<td>Ballah Lake</td>
<td>5.083</td>
<td>0.292</td>
<td>4.402</td>
<td>0.581</td>
<td>2.000</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Ballah Lake</td>
<td>171° 20’ 00”</td>
<td>2.167</td>
<td>0.151</td>
<td>1.723</td>
<td>0.302</td>
<td>2.000</td>
</tr>
<tr>
<td>18</td>
<td>El Menzalah Lake</td>
<td>145° 34’ 00”</td>
<td>48.105</td>
<td>0.924</td>
<td>47.026</td>
<td>1.797</td>
<td>2.991</td>
</tr>
<tr>
<td>19</td>
<td>Port Said</td>
<td>158° 00’ 00”</td>
<td>1.790</td>
<td>0.866</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4): Different Cross Sections of the Maritime Canal

<table>
<thead>
<tr>
<th>Place</th>
<th>From</th>
<th>To</th>
<th>Length (km)</th>
<th>Section ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port-Said lighthouse to the entrance of the canal</td>
<td>0.00</td>
<td>1.428</td>
<td>1.428</td>
<td>Part of the access channel and the Port basin</td>
</tr>
<tr>
<td>Crossing of El Manzalah lake and El Ballah Lakes</td>
<td>1.428</td>
<td>61.125</td>
<td>62.711</td>
<td>1.586</td>
</tr>
<tr>
<td>El Guisr</td>
<td>62.711</td>
<td>76.229</td>
<td>13.518</td>
<td>Profile (2) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Timshah lake</td>
<td>76.229</td>
<td>84.009</td>
<td>7.780</td>
<td>Profile (1) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Serapeum</td>
<td>84.109</td>
<td>94.013</td>
<td>9.904</td>
<td>Profile (2) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Entrance of Amers lakes</td>
<td>95.663</td>
<td>95.963</td>
<td>0.300</td>
<td>Profile (4) with two submerged dikes</td>
</tr>
<tr>
<td>The large Bitter lake</td>
<td>98.443</td>
<td>114.393</td>
<td>15.950</td>
<td>Profile (4) with one submerged dike (Africa side)</td>
</tr>
<tr>
<td>The small Bitter lake</td>
<td>114.524</td>
<td>132.300</td>
<td>17.776</td>
<td>Profile (5) with immere dikes</td>
</tr>
</tbody>
</table>

Table (5): Different Cross Sections of the Maritime Canal

<table>
<thead>
<tr>
<th>Place</th>
<th>From</th>
<th>To</th>
<th>Length (km)</th>
<th>Section ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port-Said lighthouse to the entrance of the canal</td>
<td>0.00</td>
<td>1.428</td>
<td>1.428</td>
<td>Part of the access channel and the Port basin</td>
</tr>
<tr>
<td>Crossing of El Manzalah lake and El Ballah Lakes</td>
<td>1.428</td>
<td>61.125</td>
<td>62.711</td>
<td>1.586</td>
</tr>
<tr>
<td>El Guisr</td>
<td>62.711</td>
<td>76.229</td>
<td>13.518</td>
<td>Profile (2) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Timshah lake</td>
<td>76.229</td>
<td>84.009</td>
<td>7.780</td>
<td>Profile (1) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Serapeum</td>
<td>84.109</td>
<td>94.013</td>
<td>9.904</td>
<td>Profile (2) + Profile modification (3A – 3B)</td>
</tr>
<tr>
<td>Entrance of Amers lakes</td>
<td>95.663</td>
<td>95.963</td>
<td>0.300</td>
<td>Profile (4) with two submerged dikes</td>
</tr>
<tr>
<td>The large Bitter lake</td>
<td>98.443</td>
<td>114.393</td>
<td>15.950</td>
<td>Profile (4) with one submerged dike (Africa side)</td>
</tr>
<tr>
<td>The small Bitter lake</td>
<td>114.524</td>
<td>132.300</td>
<td>17.776</td>
<td>Profile (5) with immere dikes</td>
</tr>
<tr>
<td>The small Bitter lake</td>
<td>132.300</td>
<td>133.500</td>
<td>1.200</td>
<td>Profile (4) with two submerged dikes</td>
</tr>
<tr>
<td>The small Bitter lake</td>
<td>133.500</td>
<td>134.303</td>
<td>0.803</td>
<td>Profile (4) with two submerged dikes</td>
</tr>
</tbody>
</table>
Figure 8: Vertical Cross Section Along The Maritime Suez Canal (1)
Figure 9: Vertical Cross Sections along the Maritime Suez Canal (2)
Figure 10: Vertical Cross Sections along the Maritime Suez Canal (3)
<table>
<thead>
<tr>
<th>Year</th>
<th>Cross Section (m$^2$)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1869</td>
<td>304</td>
<td>7.80</td>
</tr>
<tr>
<td>Before 1980</td>
<td>1800</td>
<td>16.00</td>
</tr>
<tr>
<td>1980</td>
<td>3600</td>
<td>19.50</td>
</tr>
<tr>
<td>1994</td>
<td>4000</td>
<td>20.50</td>
</tr>
<tr>
<td>Second stage (currently)</td>
<td>5000</td>
<td>25.00</td>
</tr>
</tbody>
</table>

Figure (11): Progress of Suez Canal Cross Section Since Opening in 1869 till Now 2000
The progress of the canal cross section since inauguration in 1869 is presented in Table (5). Figures (8) through (10) present the cross section along the canal at opening. Figure (11) shows the progress of the Canal cross section since opening in 1869.

Table (5): Development of the Suez Canal Cross Section since Inauguration in 1869

<table>
<thead>
<tr>
<th>Year</th>
<th>Maximum Draft (m)</th>
<th>Maximum Tonnage (ton)</th>
<th>Depth (m)</th>
<th>Cross Sectional Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1869</td>
<td>6.76</td>
<td>5,000</td>
<td>6.76</td>
<td>304</td>
</tr>
<tr>
<td>1900</td>
<td>7.80</td>
<td></td>
<td>460</td>
<td></td>
</tr>
<tr>
<td>1908</td>
<td>8.35</td>
<td></td>
<td>680</td>
<td></td>
</tr>
<tr>
<td>1912</td>
<td>8.35</td>
<td></td>
<td>720</td>
<td></td>
</tr>
<tr>
<td>1914</td>
<td>8.84</td>
<td></td>
<td>870</td>
<td></td>
</tr>
<tr>
<td>1935</td>
<td>10.06</td>
<td></td>
<td>1,050</td>
<td></td>
</tr>
<tr>
<td>1954</td>
<td>10.67</td>
<td>30,000</td>
<td>14.00</td>
<td>1,200</td>
</tr>
<tr>
<td>1960</td>
<td>11.28</td>
<td>80,000</td>
<td>15.50</td>
<td>1,800</td>
</tr>
<tr>
<td>1980</td>
<td>16.15</td>
<td>150,000</td>
<td>19.50</td>
<td>3,600</td>
</tr>
</tbody>
</table>

6 ENGINEERING

6.1 Hydraulic Engineering

The final filling of the Canal took place on 15th August, 1869. The barrage at the Suez end was cut and the restless waters of the Red Sea stormed through the gap with torrential violence into the 22-mile dry cutting through the Suez Plain, the Chalouf cutting to the Bitter Lakes. The water release caused 40,000 English Pound worth of damage, the suspension of dredging for fifteen days and a consequent delay in the completion of the works.

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. Thus the Bitter Lakes were filled faster and Lake Timsah slower than had been calculated.

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. The creation of large surfaces of water increased the rainfall in the Isthmus but did neither produce any local extension of the area of cultivation nor significantly influence its climate.

The calculation indicated that the total quantity of water that flow through Serapeum Weir, from 18 March to 15 August 1869 (127 days), was 421.1 million m³. The average rate of flow per day was 3.32 million m³/day. This accounted for a loss of 60.4 million m³ by evaporation and infiltration. On 15 August 1869, the measured total quantity of water was found to be 499.2 million m³. On 26 August, the salt band of thickness 2.12 m had dissolved to 0.5 m over a total area of 65.9 km². The volume of dissolved strata was 106.9 million m³. Subtracting from the total quantity of water (499.2–106.9=392.3 million m³) then the total volume of water was 392.3 million m³. The volume difference between calculated and measured quantities of water was 31.6 million m³.

Figures (E.1) through (E.3) present schematic plans and sections of the barrages and weirs at Lake Timsah, Suez and Serapeum. Table (6) presents an engineering comparison between the three weirs. Table (7) presents the progress of the filling of Lake Timsah.

Table (6): Comparison between the Three Weirs, El Timsah, Serapeum and Suez Weir

<table>
<thead>
<tr>
<th>Construction period</th>
<th>El Timsah Weir</th>
<th>Serapeum Weir</th>
<th>El Suez Weir</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 1866 to November 1866</td>
<td>December 1868 to February 1869</td>
<td>16 August 1869</td>
<td></td>
</tr>
<tr>
<td>The filling begin on</td>
<td>12 December 1866</td>
<td>18 Mars 1869</td>
<td>16 August 1869</td>
</tr>
<tr>
<td>Name of the lake to be filled</td>
<td>El Timsah</td>
<td>Bitter Lakes</td>
<td>Bitter Lakes</td>
</tr>
<tr>
<td>From</td>
<td>Mediterranean Sea</td>
<td>Mediterranean Sea</td>
<td>Red Sea</td>
</tr>
<tr>
<td>Duration of filling</td>
<td>8 month</td>
<td>5 month before activation of El Suez Weir and 70 days after the entrance of the water of the Red Sea through El Suez Weir</td>
<td></td>
</tr>
</tbody>
</table>

Table (7): Filling of Lake Timsah

<table>
<thead>
<tr>
<th>Dates</th>
<th>Elevation of water in the lake (m)</th>
<th>The monthly water rise (m)</th>
<th>Average water rise per day (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 December 1866</td>
<td>13.80</td>
<td>1.28</td>
<td>6.4</td>
</tr>
<tr>
<td>End of December 1866</td>
<td>15.08</td>
<td>0.86</td>
<td>2.9</td>
</tr>
<tr>
<td>End of January 1867</td>
<td>15.94</td>
<td>0.76</td>
<td>2.7</td>
</tr>
<tr>
<td>End of February 1867</td>
<td>16.70</td>
<td>0.59</td>
<td>2.0</td>
</tr>
<tr>
<td>End of March 1867</td>
<td>17.29</td>
<td>0.32</td>
<td>1.1</td>
</tr>
<tr>
<td>End of April 1867</td>
<td>17.61</td>
<td>0.32</td>
<td>1.0</td>
</tr>
<tr>
<td>End of May 1867</td>
<td>17.93</td>
<td>0.06</td>
<td>0.2</td>
</tr>
<tr>
<td>End of June 1867</td>
<td>17.99</td>
<td>0.10</td>
<td>0.3</td>
</tr>
<tr>
<td>End of July 1867</td>
<td>18.09</td>
<td>0.11</td>
<td>0.6</td>
</tr>
<tr>
<td>15 August 1867</td>
<td>18.20</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

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6.2 Geotechnical Engineering

6.2.1 Soft Clay Engineering

The portion from Port-Said to Lake Menezaleh, a 20 miles distance, represented the first engineering challenge. This part was about 5 feet deep with the lake bottom consisting of slob 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. Slob and clay were 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.

6.2.2 Reliability of Soil Investigation

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 soundings at such intervals were not a guarantee.

In his notes De Lesseps wrote "fifteen days before the inauguration of the Canal, the engineers came to tell me that, between two soundings taken at distance of 1.50 meters, a hard rock layer had been discovered, which broke the buckets of our dredgers. We have been blamed for not perceiving it sooner. Was it possible to take soundings at shorter distances in a length of some 102 miles?"

De Lesseps rushed to the site where the rock layer was 15 feet below the proposed bottom of the canal and leaving only nine feet of water. As every one began by declaring that there was nothing to be done, De Lesseps shouted "Go and get powder at Cairo. He cried "powder in masses and then, if we cannot blow up the rock, we will blow ourselves up".

The original design total excavation works at Serapeum was 5,677,235 m³. On 15 October 1869 the total excavation work stood at 5,903,574 m³. The remainder to be excavated was 673,661 m³. After the adaptation of the minimum profile tolerance by reducing the amount of excavation by 200,000 m³, the remainder to be excavated was 473,661 m³. At the end of October 1869, two rock layers were discovered at Serapeum, at kilometer 87 and 93, respectively.

Table (8) summarizes the rock type, length of layer and the situation of excavation at inauguration date. At kilometer 87 explosives were utilized using bottles containing 5 kg of powder each, placed on the rock layer at a distance of 3.50 m to 4.00 m. At explosion, the rock layer was dislocated and broken. This method had produced satisfactory results at kilometer 87 and the band had been broken to small pieces and then elevated by dredgers. At kilometer 93 boring was utilized by digging open pits with variable depth 1.20m to 1.50m on the rock layer and fill it with cartridges containing variable amount of powder. The depth of the open pits varies between 2/3 to 3/4 of the layer thickness to be dislocated.

| Depth of water at (Inauguration day) | 8 m | 5.80 to 6.00 m |
| Remainder to be excavated | 241 m³ | 20000 m³ |
| End of extraction work | March 1870 | March 1870 |

6.2.3 Slope Stability of Sand

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 has 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 lines of tramway, 6 large engines and 250 wagons by the contractor M. Couvreux. Side slopes of 2:1 proved to be safe and stable.

6.2.4 Salt Band of Bitter Lakes

At the bottom of Bitter Lakes, an extraordinary band of salt, seven miles long by five miles wide was found. It was feared that it would be dealt with like rock. It turned out that it was easily dissolved. The progress of the salt dissolution is presented in Figure (B.6).

6.2.5 Effect of Sand Drifting by Tornadoes and Whirlwinds

It was believed that such storms could bury an object in an incredibly short period of time, filling up the cuttings. The contradiction to this assumption was the existence of large natural depressions such as Ballah Lake and Timsh Lake. It was found that certain banks formed by these whirlwinds protected these natural depressions from being buried. This suggested that artificial banks all along the canal would be needed to operate as a protecting measure against filling the canal.

However, a study by Sir J. Hawkshaw using records from the nearby Sweet Water Canal and soil type around the Maritime Canal concluded that the sand lying adjacent to the canal was generally compacted and, being often covered with small gravel preventing its shifting. Only the portion from Lake Timsh to Lake Ballah (22% km) and a portion near Serapeum (14 km) would be subject to drifting sand. Engineer M. Villers estimated that 30,000 cubic meters of sand found its way to the Sweet Water Canal. By proportion, Sir J. Hawkshaw estimated that the Suez Canal would be subject to 118,000 cubic meters, which was insignificant.

6.2.6 Rock Engineering

During excavation for 9 miles in Lake Ballah, an irregular almost dry swamp, the excavated soil was found to be gypsum which when used for the banks cracked and decomposed. Other material, a combination of slob and plaster, had to be carried from some distance to be used for bank construction.

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 very 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. However, Sir J. Hawkshaw predicted in 1862 the presence of a rocky formation in that area. 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 depth of 17 feet below 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 removed by blasting and dredging. Three dredgers were at work with huge blocks of stones being brought up by the buckets, which were split and broken by the rock. The rock

Table (8) Rock excavation at Serapeum

<table>
<thead>
<tr>
<th>Type of rock</th>
<th>Kilometer 87</th>
<th>Kilometer 93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>17m</td>
<td>150m</td>
</tr>
<tr>
<td>Gypsum</td>
<td>5.30 m</td>
<td>4.50 m</td>
</tr>
<tr>
<td>Agglomerate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
layers extraction at El Chalouf section, from kilo point 132 to 142, are summarized in Table (9):

Table (9): Rock layer extraction at El Chalouf

<table>
<thead>
<tr>
<th>From</th>
<th>138.230</th>
<th>138.145</th>
<th>134.800</th>
<th>134.150</th>
</tr>
</thead>
<tbody>
<tr>
<td>To</td>
<td>138.530</td>
<td>138.230</td>
<td>134.930</td>
<td>134.220</td>
</tr>
<tr>
<td>Length (m)</td>
<td>300</td>
<td>85</td>
<td>130</td>
<td>70</td>
</tr>
<tr>
<td>Type of rock</td>
<td>Hard rock</td>
<td>Sandstone</td>
<td>Hard sandstone &amp; Gypsum</td>
<td>Sandstone encounter ed by marl</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>0.5 to 2.60</td>
<td>0.30 to 0.40</td>
<td>0.20 to 0.60</td>
<td>0.40 to 1.40</td>
</tr>
<tr>
<td>Excavation method</td>
<td>Dry excavation</td>
<td>Dry excavation</td>
<td>Dry excavation</td>
<td>Dry excavation</td>
</tr>
<tr>
<td>Excavated Soil (m3)</td>
<td>90,800</td>
<td>20,800</td>
<td>39,490</td>
<td>11,730</td>
</tr>
<tr>
<td>Excavated Rock (m3)</td>
<td>19,980</td>
<td>120</td>
<td>1,920</td>
<td>1,250</td>
</tr>
</tbody>
</table>

6.3 Marine and Port Engineering

6.3.1 Port-Said Entrance

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 expected and the formation of an inner submarine beach. On the onshore half, and forces it to deflect from the pier at a considerable angle and to flow back to meet the offshore half at the north of the west pier. This resulted in the finer particles falling to the bottom and a submarine beach is formed, which increases every summer. During winter the north west winds level it down and produce general shallowing of the mouth of the harbor.

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 shoal had crept along the entire length of the 2100 m west pier. 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.

Different plans for the design of Port-Said Port are presented in Figures (D.1) through (D.4). Figure (D.5) presents the design of Suez Port. Figure (D.6) presents the design of jetties in both Suez and Port-Said ports.

6.3.2 Chemical Disintegration of the Piers

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

7. CANAL CONSTRUCTION

7.1 Construction of the Sweet Water Canal

The digging of the Sweet Water Canal, from the end of the Zagazig Canal at the head of Wadi Tumulate 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. A map and cross sections of the Sweet Water Canal are presented in Figure (3). It was later determined to draw water from the Nile directly instead of a branch at Zagazig to maintain the flow during most of the year. 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.

7.2 Construction Equipment

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.

The smaller dredgers were 15-horse power. There were also intermediate size dredgers, then followed the largest machines of 75-horse power. The largest dredgers were 110 feet in length, with 27 feet beam, and having their drums 48 feet above the water-line. The cost of each was £20,000.

De Lesseps, said “our dredging machine carried from two to three thousand cubic meters a day, and as we had sixty of them, we succeeded in extracting monthly as much as two million cubic meters (about 2,763,000 cubic yards)”. The consumption of coal came to a total of £40,000 each month. The cost of these dredgers was nearly £2,500,000. The disposal of dredged material took one of the following forms:

1. If the dredged material was required for reclaiming land, or for making concrete blocks, the spoil was made to fall.

2. If not, it was returned to the bottom at the head of the canal.
into large boxes, having a capacity of four cubic yards. Seven of these fit into a barge, which was moored under the spout of the dredger. When all were filled, the barge was floated under a steam crane, by which the boxes were lifted out and placed on trucks, running on tramways. On arriving at their destination, one end of these boxes opened on hinges, and the contents were thus readily deposited.

2. The greater portion of the Port-Said dredged material was, however, conveyed in large barges (twelve screws of 30-horsepower) some four or five miles out to sea, and dropped into deep water. These barges were 140 feet long, with a beam of 23 feet. The dredged material was discharged by means of twelve trapdoors, at the bottom of the barge, the opening and closing of these being regulated by chains.

3. Large proportion of the dredged material was discharged from dredgers into an apparatus which had been named the long couloir (long duct), one of the most important machines. These couloirs varied in length, the longest being about 75 yards. Their shape was that of a semi-ellipse, five feet wide and two feet deep. They were supported by a tall iron framework resting on the deck of a barge, ninety-six feet long by twenty-eight feet beam, and drawing six feet of water. The dredgings, when dropped into the elevated end of the long duct, were assisted in their downward progress by a strong current of water, which was supplied by a rotary pump driven by a separate engine. In addition to this, when the dredged material were found to be of tenacious nature, scrapers or sweepers were employed. This apparatus consisted of an endless chain, which was made to pass along the center of the couloir. On this, scrapers were fixed at intervals, fitting the shape of the couloir. With the assistance of waterpower, the long couloirs could deliver their dredged material almost on a horizontal line. The longest couloirs were used with the largest class of dredging machines. The upper end was about twelve yards and the lower about six yards above the water-line, thus easily clearing the low banks previously formed by smaller dredgers. The shorter couloirs were placed on the dredging machine itself, and were balanced by a counterweight on the opposite side.

4. The elevator was introduced in situations where dredges were far below the level of embankments. This machine resembled in principle the couloir, but the inclination of the plane was in the opposite direction, i.e. upwards instead of downwards. This duct consisted of an inclined plane, about fifty-two yards long, and carrying two lines of tram rail. The inclination was one in four, and it was supported in the middle by an iron frame. When this machine was at work, the lower extremity of the duct was three yards above the water, whereas the upper end is about fifty-two yards distant, with an elevation of twelve yards, thus reaching over the embankments. Seven boxes of dredged material were floated under the lower extremity of the elevator. Each box was raised in succession by an endless steel wire rope, and it then travels to the upper end of the incline. On reaching this point the box swings vertically, then the door opened, and the contents were thus completely emptied.

Figures (12) and (13) present a schematic for the basic excavation system. Figure (14) shows a plan and elevation of a large dredger with a 70m couloir. Figure (15) shows elevation for the Couvreux Excavator. In addition, Figures (C.1) through (C.7) show schematic plans and elevations of different dredgers and equipment used for excavation of the Canal.

7.3 Construction Techniques

7.3.1 Cutting through Serapeum Plateau

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 Bitter Lakes,
- 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.

- The dredged materials were conveyed by lighters into large artificial lakes, which have been formed for this special purpose in close proximity to the Maritime Canal. These lakes were made in November 1866, the level of the Nile then being at its highest point at that season. They contain 5,000,000 cubic yards of water and were capable of receiving 2,800,000 cubic yards of dredgings.

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 Suez Canal was 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.

7.3.2 Extending to Suez

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.

7.4 Construction Sequence

The withdrawal of the forced labour during May 1864 compelled the Company to increase its European employees and to mechanize its operations as much as possible. At that time, the excavation was limited to 18,500,000 cubic yards, or 15% of the reduced cube of excavation. The Company divided the work of excavation into four large contracts, (1) with Alphonse Couvreux on 1 October 1863 for the El-Guisir cutting, (2) with Dussaud Brothers on 20 October 1863 for the harbour moles of Port-Said, (3) with William Aiton on 13 January 1864 for the thirty-seven miles from Port-Said to El Guisir and (4) with Borel & Lavalley on 26 March 1864 for the whole of the fifty-four miles from El Guisir to the Red Sea.

The main contract was that of Aiton since all the others were dependent on its execution. Aiton had successfully dredged most of the Clyde but was almost ruined by the high cost of dredging of Lake Menzaleh and surrendered his contract to Borel & Lavalley. Thus the Company entrusted ninety miles to a single great contractor, Borel & Lavalley.

Borel and Lavalley, were both graduates of the Ecole Polytechnique. They got involved in 1864 but had successfully adapted their techniques to the conditions of the Isthmus and perfected the construction of the most powerful bucket-dredgers ever built. Their share of the work was increased from one-third to three-quarters. They gave employment to 20,000 men and excavated 74,000,000 cubic yards along ninety miles of the
1st STAGE OF EXCAVATION
REMOVAL OF SOIL BY THE HANGING WHEELBARROW

2nd STAGE OF EXCAVATION
REMOVAL OF SOIL BY THE WHEELBARROW

Figure 12: Stages and Methods of Excavation (1)
3\textsuperscript{rd} STAGE OF EXCAVATION
REMOVAL OF SOIL BY THE INCLINED PLAN

4\textsuperscript{th} STAGE OF EXCAVATION
REMOVAL OF SOIL BY THE DREDGER AND THE INCLINED PLAN

Figure 13: Stages and Methods of Excavation (2)
Figure 14: Large Dredger (Couloir of 70 Meter)
Couvreux Excavator: Bucket type dredge but operated from the shore. The dredger is moved on the banks of the channel on a rail system. Dredged spoil is discharged through the chute into land based carriages.
Figure 16: The Opening Ceremony
Canal, the greatest task ever commissioned to a single contractor. Unfortunately Paul Borel died on 17 October 1869 under the pressure of the work.

Work was temporarily interrupted in 1866 by the epidemic of cholera which broke out at Suez on 21 May and at Alexandria on 2 June. The disease was carried from the Delta by refugees fleeing to the disease-free Isthmus and broke out at Ismailia on 24 June and at Port-Said on 29 June. The epidemic caused a panic flight of workers led by the Greeks, reducing the labour force from 6,000 to 3,000. The disease affected Ismailia more severely than Port-Said or Suez, killing 6% of the population of 4,000, including the only grandson of De Lesseps and the wife of Voisin, before its ravages ceased in August.

The Mediterranean Sea water was first admitted to the Canal on 12 December 1866 through El Guis reach into Lake Timsah, which became a lake of salt rather than of fresh water. At the limestone plateau of Scrapeum, which was on the same level as the Sweet Water Canal to Suez, that canal was tapped during the successive high Niles of 1865, 1866 and 1867 in order to turn three large depressions into artificial lakes of fresh water. Within those lakes, dredgers worked from January 1867, dredging their way down from a height of 33 feet above sea level and so replacing dry excavation by dredgings. They disposed of their spoil with the help of side emptying lighters introduced from December 1866 and were reinforced by trough dredgers which arrived via the preliminary channel from April 1867.

Lake Timsah admitted its first dredger on 20 June 1867. By 15 August 1867 the lake had reached the level of the Mediterranean Sea, in 8 months rather than the anticipated 4.5 months. At El Guis, Couvreux made rapid progress during 1866 and 1867, and completed his contract by 31 January 1868, having perfected his mechanical excavator in the process. By the end of 1867, 44,000,000 cubic yards or 45% of the new cube of excavation had been removed at 71% of the total cost. By 15 February 1868, 49,000,000 cubic yards or 49.5% of the cube of excavation had been removed, leaving only half to be excavated at steeply falling unit-costs as the Company at last reaped the advantages of its large-scale overhead investment in mastering the techniques necessary to conquer the desert. By 15 July 1869, 90,000,000 cubic yards or 91% of excavation had been extracted.

Figures (F.1) through (F.11) demonstrate the main construction activities during the 11 year span between 1859 and 1869.

8 OPENING CEREMONY

The fixing of the opening date of the Suez Canal to 17 November 1869 raised the Company's shares 23 per cent above par value to 615 francs and created a sensation in England. It stopped owners of sailing ships from buying new vessels and created a marked recession to the business of steam shipping, especially in Marseilles, Trieste, Genoa, Odessa, Barcelona, Amsterdam and Liverpool. On 28th September 1886 De Lesseps made the first direct trip from the Mediterranean Sea to the Red Sea in fifteen hours.

Voisin Bey carried the works to their triumphant conclusion and earned the highest reputation in civil engineering by his nine years of service in the Isthmus. Colquhoun, British Consul-General in Egypt, wrote "It is clear that De Lesseps was a man of immense vitality, great persuasiveness, and supreme self-confidence".

Ismail, Egypt Viceroy at the time of Canal construction, invited 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 Viceroy made the necessary arrangements for receiving 6000 foreign guests. Sheds were constructed in a few days to hold 6000 persons, with tables constantly replenished and served. The Viceroy had brought over 500 cooks and 1000 servants from Trieste, Genoa, Leghorn, and Marseilles.

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. Three pavilions had been erected, with that of Ismail's guests overshadowing both those devoted to Islam and Christian guests, as shown in Figure (16).

The completion of the Suez Canal revived the dream of 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 Cornwall Canal, a Holsten Interimarian 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.

At the end, I would like to acknowledge the wealth of information found in the great documentary book "le Canal de Suez" by Voisin Bey published in 1904. I took the liberty to use excerpts, figures and illustrations from this book and reproduce them from their original for purpose of illustration in the paper and in the oral presentation. The figures have been modified slightly to restore their original quality, highlight the important information and translate the data from the French language to the English language.

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Figure B.3: Longitudinal Geological Cross Section of the Maritime Canal (3)
Figure B.4: Longitudinal Geological Cross Section of the Maritime Canal (4)
ROCK LAYER EXTRACTION AT SERAPEUM

PROFILES

PROFILE OF KILOPOINT 87 000

PROFILE OF KILOPOINT 92 900

PROFILE OF KILOPOINT 93 000

LONGITUDINAL PROFILE OF THE ROCK LAYER
KILO 138

NORTH

SOIL BEFORE EXCAVATION (20-48)

SOUTH

PLATFORM DETAILS OF THE RIGHT PLAN

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Figure C.2: Evrard Dredger
Burnichon Dredger: Spoil discharge is sideways over relative short distance using a flat conveyor belt

Figure C.3: Combe Dredger
Burnichon Dredger: Spoil discharge is sideways over relative short distance using a flat conveyor belt.

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Figure C.6: Elevator Equipment
Boats carrying fill: These barges are equipped with different type of discharge system: (1) bottom doors, i.e. the doors are moved by means of chains; (2) side doors, the spoil is discharged sideways through chain activated doors.

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THE COMMISSION INTERNATIONAL PROJECT

1856

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6. THE EXCAVATION OF THE SERVICE CHANNEL
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8. THE CONSTRUCTION OF EL GIISR ESTABLISHMENT
9. THE CONTINUATION OF EXCAVATION WORK IN PORT SAID BASIN & NAVAL DOCKYARD

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1. The west jetty length was 400m.
2. The continuation of excavation work in Port Said Basin.
3. The continuation of the island.
4. Reconstruction of the band in some parts.
5. The improvement of potable water canal from Gassassine to Ismailia.
6. The construction of potable water canal surrounding Ismailia city.
7. The excavation of the potable water canal to Suez.
8. Establishment at El Chalouf.
9. The construction of a spillway at Neficha (Suez).
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Figure F.5: Construction Sequence of the Maritime Suez Canal (1863)
1. Continuation of basin excavation at Port Said
2. Reconstruction of some parts of the band
3. Construction of the potable water duct from km 34 to Port Said
4. The construction of the railway from Ghebel Geneffe to the potable water (Suez Branche)
5. The construction of a water tank at Port Said
6. The beginning of the construction of two locks for the sweet water canal at Ismailia

Figure F.6: Construction Sequence of the Maritime Suez Canal (1864)
1. The extension of jetties by the artificial blocks
2. Basin excavation in Port Said
3. Construction of potable water to El Cap
4. The construction of the two locks at Ismailia & excavation of the canal in between
5. The construction of a lock at KM 16
6. The construction of a lock at KM 42
7. The construction of a lock at KM 68
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9. The improvement of the maritime canal at El Guisr
10. Excavation of 1st stage of Ismailia Canal from Cairo to Abasce to Gassassin
11. The removal of the rock layer at Chalouf

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1. West Jetty of length 2200 m (Artificial Blocks)

2. East Jetty of length 950 m (Artificial Blocks)

3. Basin Widening in Port Said

4. The Excavation of the Sweet Water Canal (Ismailia Canal) from Cairo to Abasce

5. The Excavation of the Sweet Water Canal from Abasce to Ismailia

6. Improvement of the Canal from Abasce to Gassassin

7. Site Preparation for Dredgers

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FINISHING OF THE JETTIES

THE IMPROVEMENT OF THE ACCESS CHANNEL AT PORT SAID PORT WITH DEPTH 8.50M

FINISHING OF THE 1ST STAGE OF THE CANAL FROM PORT SAID TO AMERS LAKES (100 KM)

RAILWAY FROM ZAGAZIG TO ISMAILIA

RAILWAY FROM ISMAILIA TO SUEZ

THE IMPROVEMENT OF THE 2ND STAGE OF THE CANAL

FINISHING OF SUEZ PORT

Figure F.10: Construction Sequence of the Maritime Suez Canal (1868)
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