The district which discharges into the eastern outlet comprehends an area of about 700 square miles, chiefly of high mountainous country, intersected by streams and lakes, which discharge themselves into Loch Oich, Loch Ness, and Loch Doughfour, and thence are conveyed into the Moray Firth by the River Ness. Loch Oich, the summit-level of the canal, has an area of about 2 square miles, and the present standard level of its surface is understood to be 102 feet above the level of mean high water of neap tides in Beauly Firth. It receives the drainage of Loch Quoich and Loch Garry. The waters of Loch Oich are discharged through the River Oich into Loch Ness, which is about 24 miles in length, and has an area of about 30 square miles. Loch Ness receives the waters of the Tarff, the Foyers, and Glenmoriston, and the drainage of numerous other streams and lakes of less note. It discharges its waters through a comparatively narrow neck, called Bona Passage, into the small loch of Doughfour, whence they find an exit to the Beauly and Moray Firths by the River Ness, on which the town and harbour of Inverness are situated.

The drainage of the western district of the country, including Loch Arkegg, finds its way into Loch Lochy, which is about 10 miles long, and thence by the River Lochy to the Western Sea at Loch Eil.

The two locks in Loch Beauly at the northern entrance to the canal are each 170 feet long, 40 feet wide, and have a lift of about 8 feet. At Muirtown, a little further on, are four locks of 170 feet in length and 40 feet in width, having a rise of 32 feet, raising the canal to the level of Loch Ness, which it enters at Bona. The works westward of Loch Ness are an artificial canal with seven locks communicating with Loch Oich. Between Lochs Oich and Lochy are two locks; at the south end of Loch Lochy is a regulating lock, and the canal is carried from this point on the level of Loch Lochy to Banavie, where it descends 64 feet by eight connected locks, forming what is called in the country "Neptune's Staircase;" finally at Corpach the canal descends by two locks to the level of Loch Eil.

Of the whole distance, about 37½ miles are natural lake navigation, and the remaining 23 are artificial or canal navigation. The canals were made 120 feet in width at top-water level, 50 feet at bottom, and 20 feet in depth. In the course of inquiries as to the state of the canal, under a remit from the Admiralty, the author found that the shallows at Loch Oich and the cutting at the summit level originally contemplated had not been carried to the full depth, and an additional depth had been gained at that place by raising the level of Loch Oich; but still he was led to the conclusion that the standard depth of the canal cannot be regarded as more than 18 feet, giving access to vessels of 160 feet in length. 38 feet beam, and 17 feet draught of water.[1]

In carrying out this remarkable work Telford had to deal with difficulties of no ordinary kind, in rendering available rugged Highland lakes, and surmounting the summit-level of the glen. The work, which cost about one million sterling, is a noble monument of his engineering skill.

The canals of Holland are specimens of the *second* class of works to which reference has been made, and of these a very remarkable one is the North Holland Canal, completed in 1825. It was designed by M. Blanken, who, instead of the high rugged Highland glens of Scotland, had to deal with the proverbial lowness of the country, and to protect his works not from the assaults of mountain torrents but from encroachments of the waves, for there vessels are locked *down* from the sea into the canal. It extends from Amsterdam to the Helder, is 50 miles in length, and is formed of the cross-section shown in fig. 4. It enables vessels trading from Amsterdam to avoid the islands and sand-banks of the dangerous Zuider Zee, the passage through which in former times often occupied as many weeks as the transit through the canal now occupies hours.

Fig. 4.—Cross-section of North Holland Canal.

But the North Holland Canal, which has long proved so useful to the commerce of the district, is destined soon to be superseded by the new Amsterdam Canal, a work of great magnitude, which it is proposed to describe as an illustration of ship-canals of the *second* class, from details furnished by Mr J. C. Hawkshaw, C.E.

The rapid increase in the trade of the ports to the southward and eastward of the Helder, effected by the construction of railways throughout Europe, rendered it imperative for the merchants of Amsterdam to provide better communication with the North Sea than that afforded by the North Holland ship canal already noticed, or suffer its trade to pass to other ports more favourably situated for over-sea traffic.

In 1865 a company was formed for the purpose of constructing a canal from Amsterdam, in nearly a direct line, to the North Sea, through Lake Y and Wyker Meer, a distance of 16½ miles. Sir John Hawkshaw and Mr Dirks were appointed the engineers to carry out the work, a plan and section of which are given in Plate XXXVI.

The harbour in which the canal terminates in the North Sea is formed by two piers built of concrete blocks founded on a deposit of rough basalt. The piers are each 5069 feet in length, and enclose an area of about 260 acres. About 140 acres of this area are to be dredged to a depth of 26¼ feet, the remainder is to be left at the present depth for the accommodation of small craft and fishing-boats.

From its commencement at the harbour the canal passes by a deep cutting through a broad belt of sand-hills which protect the whole of this part of the coast of Holland from the inroads of the sea. The cross-section of the canal at this place is shown in fig. 5. This cutting is about 3 miles

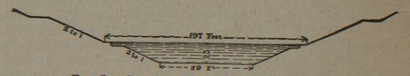

Fig. 5.—Cross-section of Amsterdam Canal.

in length; the greatest depth of cutting from the surface to the bottom of the canal is 78 feet, and the amount of earthwork excavated is 6,213,000 cubic yards. On emerging from the sand-hills the canal passes by the village of Velsen, in the neighbourhood of which it is crossed by the railway from Haarlem to the Helder, and there enters the Wyker Meer, a large tract of tide-covered land. After traversing the Wyker Meer it passes by a cutting of 327,000 cubic yards through the promontory called Buitenhuizen, which separates that Meer from Lake Y, another large tide-covered area. The rest of its course lies through Lake Y as far as Amsterdam.

There are two sets of locks, one set at each end. The North Sea locks are at a distance of about three-quarters of a mile from the North Sea harbour. These locks, as shown in fig. 6, have three passages. The central or main one is 60 feet wide and 390 feet long, and will be furnished with two pairs of gates at each end, pointing in opposite direc-

[1] *Report on the Caledonian Canal to the Admiralty*, 1849, by James Veitch, R.E., and David Stevenson, C.E.

tions, and one pair in the centre. The northernmost side passage for barges is 30 feet long and 34 feet wide, with three pairs of gates; that to the south is 227 feet in length and 40 feet wide, with five pairs of gates.

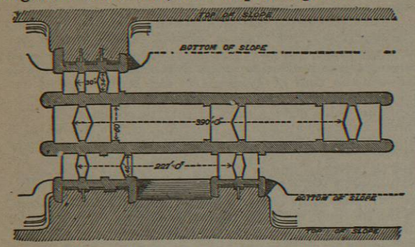

Fig. 6.—Plan of Locks on Amsterdam Canal.

In constructing the canal, which is (1876) now far advanced towards completion, the cuttings were first begun. The material proceeding from these cuttings was deposited so as to form two banks 443 feet apart, through the lakes on each side of the main canal, as shown by the hard lines on the plan, and also to form the banks of the branch canals on either side. The total length of these banks is 38¾ miles. The nucleus of the bank is formed of sand with a coating of clay, and protected during its progress with fascines; and when the banks are far enough advanced, the deep channel for the canal is excavated by dredging. The cross-section of the canal and banks through these meers or lakes is shown in fig. 7.

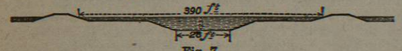

Fig. 7.

The formation of the banks through the Wyker Meer and Lake Y will enable about 12,000 acres of the area, as shown on the plan, which is now occupied by these lakes, to be reclaimed. For the purpose of this reclamation, and also to provide for the drainage of the land on the margin of the lakes, including a large portion of what was formerly Haarlem Meer, pumps are provided by the company at various points on the main and branch canals. The Canal Company are bound to keep the surface-water of the canal about 1 foot 7 inches *below* average high-water level. In order to insure this level being maintained, three large pumps have been erected in connection with the locks hereafter to be described, on the dam between Amsterdam and the Zuider Zee. They consist of three Appold pumps, the largest of the kind yet made, the fans being 8 feet in diameter. Each pump is worked by a separate engine of 90 nominal horse-power. The maximum lift is 9 feet 9 inches, at which the three pumps are capable of discharging 1950 tons a minute; with the ordinary working lift of 3½ feet they will discharge 2700 tons a minute.

Lake Y extends about 4½ miles to the eastward of Amsterdam; and here it was necessary to form a dam with locks for the passage of vessels. The dam crosses Lake Y at a point about 2 miles to the eastward of Amsterdam, where it is contracted to 4265 feet in width. As it was necessary to construct these locks before completing the dam across Lake Y, a circular cofferdam 590 feet in diameter, consisting of two rows of piles 49 feet long, was constructed in the tideway, and within this dam the locks were built. These locks have three main passages, each with five pairs of gates, and one smaller passage with three pairs of gates, arranged much in the same manner as the North Sea locks in fig. 6. The whole of the masonry and brickwork for these locks and sluiceways was founded on bearing-piles, upwards of 10,000 in number. The bottom where the cofferdam was placed consisted of mud, and some difficulty was experienced in maintaining it till the work was completed. The dam across Lake Y, as shown in section, fig. 8, consists of clay and sand, placed on and

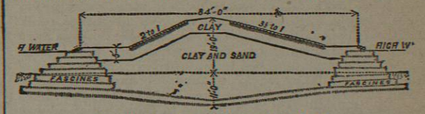

Fig. 8.—Section of Dam across Lake Y.

protected at the sides by large masses of wicker-work, which is afterwards covered with basalt in the manner usually adopted in Holland.

All the lock gates at both ends of the canal pointing seawards are of malleable iron; the gates pointing inwards towards the canal are of wood. The necessity, for drainage purposes, of maintaining the surface water of the canal at the prescribed low level calls for a sufficient barrier being provided against the sea at both ends, as the sea-level will not unfrequently, at high water, be several feet above the level of the canal. This necessity, as well as the difference of level and periods of high water in the Zuider Zee and the North Sea, required a totally different design from the Suez Canal, to be afterwards described. The contract sum for the execution of the Amsterdam Canal is £2,250,000, and it is expected that it will be ready for traffic in 1877.

Suez Canal

Of the *third* class of works there is, as yet, only a single example in the Suez Canal, one of the most remarkable engineering works of modern times; but though it is called a canal, it bears little resemblance to the works we have described under that name, for it has neither locks, gates, reservoirs, or pumping-engines, nor has it, indeed, anything in common with canals, except that it affords a short route for sea-borne ships. It is in fact, correctly speaking, an artificial strait or arm of the sea, connecting the Mediterranean and the Red Sea, from both of which it derives its water-supply; and the fact that the two seas are nearly on the same level, and the rise of tide very small, allowed this construction to be adopted.

The idea of forming this connecting link between sea and sea is of very ancient origin, and its author is unknown. It is understood, however, that a water communication for small vessels between the two seas was formed as early as 600 years before the Christian era, and existed for a period of about 1400 years, after which it was allowed to fall into disuse. Baron De Tott in his *Memoirs of the Turks and Tartars*,[1] written in 1785, after giving quotations from the historian Diodorus as to the existence of certain portions of the early work, and its having been abandoned in consequence of the supposed difference of level between the two seas, and threatened inundation of Egypt, says there still exist those early traces of work "qu'un léger travail rendrait navigable sans y employer d'écluses et sans menacer l'Égypte d'inondations." De Tott's opinion expressed in 1785 has certainly been carried out, but on a scale and at an expenditure of labour and money far beyond the conception of the French diplomatist.

The idea of restoring this ancient communication or 9

[1] *Mémoires du Baron de Tott, sur les Turcs et les Tartares*, Amsterdam, 1785, vol. ii. p. 271.

scale suited to modern times is understood to be due to Napoleon I. who, about the close of the last century, obtained a report from M. Lepère, a French engineer, which however was followed by no result, and it remained for M. de Lesseps, in the present day, to realize what were thought the dreams of commercial speculators, by carrying out the long-desired passage between the two seas. But the postponement of the scheme unquestionably favoured the chances of its commercial success, for had the canal been completed even a few years earlier, comparatively few vessels would have been found to take advantage of it. Masters of sailing-vessels would not from choice have navigated the Mediterranean and encountered the passage through the canal and the tedious and difficult voyage of the Red Sea. They would undoubtedly have preferred to round the free seaway of the Cape of Good Hope, with all its ocean dangers and excitements, to threading their way through such an inland passage, involving risks of rocks and shoals, protracted calms and contrary winds. But the introduction of ocean-going screw-steamers was an entirely new feature in navigation. Being independent of wind for their propulsion, and being admirably fitted for navigating narrow straits and passages, their rapid and general adoption by all the leading shipping firms in the world afforded not only a plea, but a necessity for the short communication by the Mediterranean and Red Sea. It was indeed a great achievement to reduce the distance between Western Europe and India from 11,379 to 7628 miles, equal, according to Admiral Richards and Colonel Clarke, R.E., to a saving of thirty-six days on the voyage; and this is the great result effected by cutting the Suez Canal between the Mediterranean and the Red Sea.

Mr Bateman, C.E., who visited the canal as the representative of the Royal Society, communicated to that body a description of the works, in which he gives the following account of the early negotiations of M. Ferdinand Lesseps, who has the credit of having brought the work to a successful issue:[1]—

"The project" of M. Ferdinand Lesseps "was to cut a great canal on the level of the two seas, by the nearest and most practicable route, which lay along the valley or depression containing Lake Menzaleh, Lake Ballah, Lake Timsah, and the Bitter Lakes. The character of this route was described in 1830 by General Chesney, R.A., who examined and drew up a report on the country between the Mediterranean and the Red Sea. At that time a difference of 30 feet between the two seas was still assumed, and all proposals for canals were laid out on that assumption. General Chesney summed up his report by stating, —'As to the executive part there is but one opinion; there are no serious difficulties; not a single mountain intervenes, scarcely what deserves to be called a hillock; and in a country where labour can be had without limit, and at a rate infinitely below that of any other part of the world, the expense would be a moderate one for a single nation, and scarcely worth dividing among the great kingdoms of Europe, who would all be benefited by the measure.'

"M. Lesseps was well advised therefore in the route he selected, and (assuming the possibility of keeping open the canal) in the character of the project he proposed.

"From 1849 to 1854 he was occupied in maturing his project. In the latter year Mahomet Said Pasha became Viceroy of Egypt, and sent at once for M. Lesseps to consider with him the propriety of carrying out the work. The result of this interview was, that on the 30th of November a commission was signed at Cairo, charging M. Lesseps to constitute a company named 'The Universal Suez Canal Company.' In the following year, 1855, M. Lesseps, acting for the Viceroy, invited a number of gentlemen, eminent as directors of public works, as engineers, and distinguished in other ways, to form an International Commission for the purpose of considering and reporting on the practicability of the scheme.

"The Commission met in Egypt in December 1855 and January 1856, and made a careful examination of the harbours in the two seas, and of the intervening desert, and arrived at the conclusion that a ship canal was practicable between the Gulf of Pelusium in the Mediterranean and the Red Sea near Suez. They differed, however, as to the mode in which such a canal should be constructed. The three English engineering members of the Commission were of opinion that a ship canal, having its surface raised 25 feet *above* the sea-level, and communicating with the Bay of Pelusium at one end and the Red Sea at the other, by means of locks, and supplied with water from the Nile, was the best mode of construction. The foreign members, on the contrary, held that a canal having its bottom 27 feet *below* sea-level, from sea to sea, without any lock, and with harbours at each end, was the best system,—the harbours to be formed by piers and dredging out to deep water.

"The Commission met at Paris in June 1856, when the views of the English engineers were rejected, and the report to the Viceroy recommended the system which has since been carried out.

"Two years from the date of this report were spent in conferences and preliminary steps before M. Lesseps obtained the necessary funds for carrying out the works. About half the capital was subscribed on the Continent, by far the larger portion being taken in France, and the other half was found by the Viceroy. Further time was necessarily lost in preparation, and it was not till near the close of 1860 that the work was actually commenced.

"The original concession granted extraordinary privileges to the Company. It included or contemplated the formation of a 'sweet water' canal for the use of the workmen engaged, and the Company were to become proprietors of all the land which could be irrigated by means of this canal. One of the conditions of the concession also was that the Viceroy should procure forced labour for the execution of the work, and soon after the commencement of operations, and for some time, the number of workmen so engaged amounted to from 25,000 to 30,000. The work thus commenced steadily proceeded until 1862, when the late Viceroy, during his visit to this country at the time of the International Exhibition, requested Sir John Hawkshaw to visit the canal and report on the condition of the works and the practicability of its being successfully completed and maintained. His Highness's instructions were that Sir John Hawkshaw should make an examination of the works quite independently of the French company and their engineers, and report the results at which he arrived."

We quote these results as given in Sir John Hawkshaw's report, because they show the nature of the difficulties that had been raised and the soundness of the advice which Sir John gave—advice which undoubtedly greatly contributed to the successful completion of the work.

The following are given by Sir John as the objections to the work:—

"1. That the canal will become a stagnant ditch.

"2. That the canal will silt up, or that the moving sands of the Desert will fill it up.

"3. That the Bitter Lakes through which the canal is to pass will be filled up with salt.

"4. That the navigation of the Red Sea is dangerous and difficult.

"5. That shipping will not approach Port Said, because of the difficulties that will be met with, and the danger of that port on a lee shore.

"6. That it will be difficult, if not impracticable, to keep open the Mediterranean entrance to the canal."

[1] *Proceedings of the Royal Society*, 1870, p. 132.

Having analysed each of these objections, and fully weighed the arguments on which they were based, he came to the following conclusions as to the practicability of construction and maintenance:—

"*1st*, As regards the engineering construction, there are no works on the canal presenting on their face any unusual difficulty of execution, and there are no contingencies that I can conceive likely to arise that would introduce difficulties insurmountable by engineering skill.

"*2dly*, As regards the maintenance of the canal, I am of opinion that no obstacles would be met with that would prevent the work, when completed, being maintained with ease and efficiency, and without the necessity of incurring any extraordinary or unusual yearly expenditure."

"Said Pasha died between the period of Sir John Hawkshaw's examination of the country and the date of his report. He was succeeded by his brother, Ismail, the present Viceroy or Khedive, who, alarmed at the largeness and uncertainty of the grants to the Canal Company, of the proprietorship of land which could be irrigated by the sweet water canal, and anxious to retire from the obligation of finding forced labour for the construction of the works, refused to ratify or agree to the concessions granted by his brother. The whole question was then referred to the arbitration of the late Emperor of the French, who kindly undertook the task, and awarded the sum of £3,800,000 to be paid by the Viceroy to the Canal Company as indemnification for the loss they would sustain by the withdrawal of forced or native labour, for the retrocession of large grants of land, and for the abandonment of other privileges attached to the original act of concession. This money was applied to the prosecution of the works.

"The withdrawal of native labour involved very important changes in the mode of conducting the works, and occasioned at the time considerable delay. Mechanical appliances for the removal of the material, and European skilled labour, had to be substituted; these had to be recruited from different parts of Europe, and great difficulty was experienced in procuring them. The accessory canals had to be widened for the conveyance of larger dredging-machines, and additional dwellings had to be provided for the accommodation of European labourers. Ultimately all difficulties were overcome, and the work proceeded."

After the works had been nearly completed, the Lords of the Admiralty instructed Admiral Richards, the hydrographer, and Lieutenant-Colonel Clarke, R.E., to visit Egypt, and report as to the condition of the canal. These officers accordingly made a most minute survey of the canal and its terminal harbours, and issued a most interesting report,[1] from the information contained in which the plan of the canal, Plate XXXVI., has been mainly constructed. From this plan it will be seen that the canal extends from Port Said on the Mediterranean to Suez on the Red Sea, and that, as shown by the section, it traverses a comparatively flat country. This route has been selected so as to take advantage of certain valleys or depressions which are called lakes, but were in fact, previous to the construction of the canal, low-lying tracts of country, at some places below the level of the Mediterranean and Red Seas. These valleys were found to be coated with a deep deposit of salt, and are described as having had all the appearance of being covered with snow, bearing evidence of their having been at one period overflowed by the sea. As will be seen from the plan, Lake Menzaleh is next to the Mediterranean, Lake Timsah about half-way across the isthmus, and the Bitter Lakes next to the Red Sea. Lake Timsah, which is about 5 miles long, and the Bitter Lakes, about 23, were quite dry before the cutting of the canal, and the water which has converted them into large inland lakes was supplied from the Red Sea and Mediterranean. The water began to flow from the Mediterranean in February 1869, and from the Red Sea in July, and by the beginning of October of the same year these vast tracts of country, which had formerly been parched and arid valleys, were converted into great lakes navigated by vessels of the largest class. It will be seen from the section that the surface of the ground is generally very low, the chief cuttings being at Serapeum and El Guisr, where the sandy dunes attain an elevation of about 50 to 60 feet. The channel through the lakes was excavated partly by hand labour and partly by dredging, and for a considerable portion the level of the valleys was so low as to afford sufficient depth without excavation. The material excavated appears to have been almost entirely alluvial, and easily removed; the only rock was met with at El Guisr, where soft gypsum occurred, removable to a considerable extent by dredging, so that the canal works presented no physical difficulty.

The whole length of the navigation is 88 geographical miles. Of this distance 66 miles are actual canal, formed by cuttings, 14 miles are made by dredging through the lakes, and 8 miles required no works, the natural depth being equal to that of the canal. Throughout its whole length the canal was intended to have a navigable depth of 26 feet for a width of 72 feet at the bottom, and to have a width at the top varying according to the character of the cuttings. At those places where the cuttings are deep, the slopes were designed to be 2 to 1, with a surface width at the water-line of about 197 feet, as shown in fig. 9, which

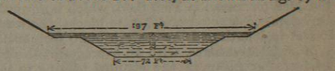

Fig. 9.—Cross-section of Suez Canal at El Guisr.

is a cross-section at El Guisr; in the less elevated portions of the land, where the stuff is softer, the slopes are increased, giving a surface width of 325 feet. It will be understood that in the lakes the canal consists of a navigable channel of sufficient depth and breadth to admit the traffic, the surface of the water extending on either side to the edge of the lake. Fig. 10 shows a cross-section at Lake

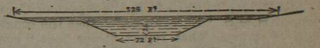

Fig. 10.—Cross-section at Menzaleh.

Menzaleh. The deep channel through the lakes is marked by iron beacons on either side, 250 feet apart, and the Admiralty reporters state that "in practice it is found more difficult to keep in the centre while passing through these beacons, than it is when between the embankments." At every 5 or 6 miles there is a passing-place, to enable large vessels to moor for the night, or to bring-up in order to allow others to pass, all these movements being regulated by telegraph from Port Said, Ismailia, or Suez. Perhaps the most interesting question to the engineer is the action of the tide in the narrow channel between the two seas, and the observations made on this subject are given in the following quotation from the Admiralty report:—

"The tidal observations which we were able to make were necessarily somewhat imperfect from want of time, but they were made at that period of the moon's age when their effect would be greatest; the results show that in the southern portion of the canal, between Suez and Great Bitter Lake, the tidal influence from the Red Sea is felt, there being a regular flow and ebb,—the flood running in for about seven hours, and the ebb running out for five hours; at the Suez entrance, the rise at springs, unless effected by strong winds, is between 5 and 6 feet; about half way from Suez to the Small Bitter Lake, a distance of 6 miles, it is under 2 feet; at the south end of the Small Bitter Lake, a few inches only; while at the south end of the Great Lake there is scarcely any perceptible tidal influence. We were informed by the authorities at Ismailia, that since the Great Lake has been filled, the level of Lake Timsah, which was

[1] *Report on the Maritime Canal connecting the Mediterranean at Port Said with the Red Sea at Suez*, February 1870.