

SECT. II.—OTHER SELECTED PAPERS.

*(Paper No. 2711.)***"The Removal of the 'Iron Gates' of the River Danube."**

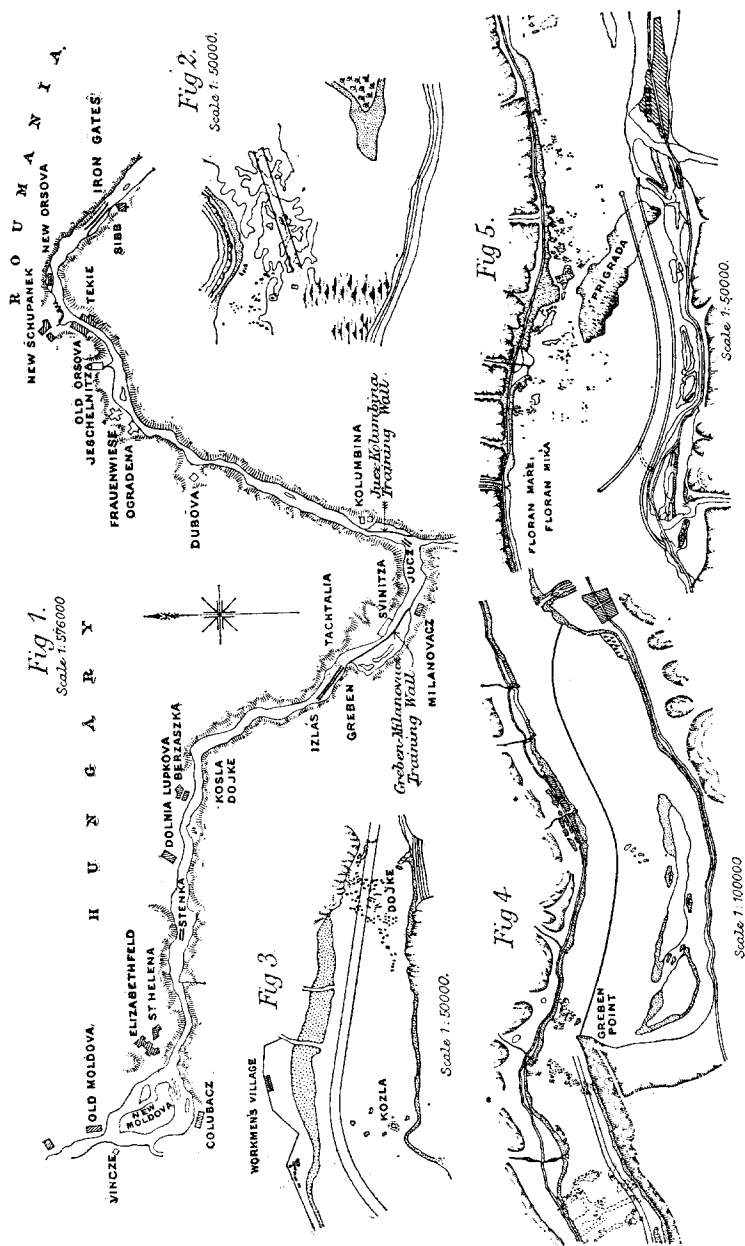
By OSCAR GUTTMANN, ASSOC. M. INST. C.E.

THE term "Iron Gates" is often applied, by those who are only superficially acquainted with the Danube, to denote all the obstructions to navigation on the lower Hungarian portion of the river. The part of the Danube that has to be regulated and improved, so as to make navigation practicable and safe under all conditions of water-level, is that between Bazias and Sibb, a length of about 82 miles, *Fig. 1*. Strictly speaking, it is only the lowest group of obstructions that are called the Iron Gates. Although these are most dangerous to navigation, they present by no means the greatest engineering difficulty to be overcome. How serious an impediment this particular section of the river is to the use of the Danube as a navigable waterway may be judged from the fact, that for about only one-half of the time it is not blocked by ice can vessels pass along this part, on account of the lowness of the water-level, due to the configuration of the river-bed; and for the greater part of this time special vessels of not more than 6 feet draught have to be used. Whenever the river falls below 11 feet 6 inches above datum, even these special vessels have to be lightened by discharging part of their cargo, and at 3 feet above datum navigation becomes impossible, even with rafts. At this state of the river, the cargoes have to be transferred by carts to the railway, and are taken as far as Turn-Severin, where the river is again navigable, and there transferred to boats. This re-handling, of course, largely increases the cost of transport—to nearly £2 per ton. With many classes of goods, it cannot be effected, and such consequently have to wait for a more favourable condition of the water-level before they can be forwarded.

Exclusive of a number of isolated rocks, the obstructions to navigation between Bazias and Sibb may be divided into four sections: the Stenka rapids, the Kozla-Dojke rapids, the Greben section, and the Iron Gates. At the Stenka rapids, *Fig. 2*, there

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is a bank of rocks, some of which are dry at low water, extending almost across the river, which here is about 985 yards wide. The fall of the river-bed is small. The length of these rapids is about 1,100 yards. The Kozla-Dojke rapids, *Fig. 3*, extend about $1\frac{1}{2}$ mile along the river, and are situated some $9\frac{1}{4}$ miles below the Stenka rapids. The river here is from 169 to 330 yards wide, and the fall is about 1 in 1,000. These rapids are caused by two banks of rock, which cause very sudden alteration in the direction of the current. At a distance of $5\frac{2}{3}$ miles further down the river is the Greben section, *Fig. 4*, where there are a number of formidable obstacles. The regulation of the river here is certainly the most difficult part of the whole work of improvement. First, there is the Izlás bank, and close to it the Tachtalia mare and mica (large and small Tachtalia) banks. A spur of the Greben mountain running out into the river just below suddenly reduces its width from 2,300 feet to 1,400 feet at high water; whilst at low water, on account of adjacent rocks, the width is only half this. Immediately below these narrows the river widens out to about $1\frac{1}{2}$ mile, forming the Milanovac bay. This group of obstructions ends about 7 miles further down stream with the Jucz rapids, where there is a multitude of small reefs. At the lowest river level there is only a few inches depth of water here, and the river-bed has a fall of 1 in 433. The Iron Gates, *Fig. 5*, properly so called, are situated about 34 miles below the Greben point. The chief obstacle here is the Prigrada bank, which, with the innumerable small banks on the left, nearly blocks the river, and behind it there is a sudden fall of 3 in 1,000 in the river-bed.

The advantage of having a continuous waterway up the Danube has long been recognised. The Romans, under Trajan, were the first to attempt its construction. Traces are still visible of the canal they cut, and afford evidence of the great labour expended upon the undertaking. No further attempt seems to have been made until the present century, during which local removal of rocks by blasting has from time to time been effected. The first person who took up the matter seriously was the Hungarian patriot, Count Stephen Széchenyi, who, with his engineer, Paul Vásárhelyi, worked indefatigably to prepare all the necessary plans, and endeavoured to inaugurate this great undertaking. Political and financial difficulties prevented the execution of their scheme, although every detail of it was carefully worked out. It was left for Gabriel Baross, Under Secretary, and afterwards Chief Secretary of State for Commerce, to give, in 1883, a practical start to the affair. The preparation of the plans and deciding upon the

method of working was entrusted to Mr. Ernst Wallandt; and whilst the broad outlines upon which the regulation could best be carried out had been shown previously by experts of various nationalities, Messrs. Vásárhelyi and Wallandt—both Hungarians—are alone responsible for the engineering details of the work. Before tenders were invited, the whole of the river-bed was surveyed, bench-marks were placed in position, and the quantity of rock to be removed and that required for building the training-walls was calculated. In the meantime a public competition was instituted, with a view to determine the best method of removing the subaqueous rocks, especially those at Jucz, and the most suitable explosive to use. The result of the competition not being satisfactory, the Government decided to leave the details of the execution to the contractors. Only two tenders were received, and the work was finally entrusted to a company consisting of Mr. Hajdu, a Hungarian engineer, Mr. Luther, of Brunswick, and the Berlin Discount Company.

The work to be done may be thus summarized :—

At Stenka, Kozla-Dojke, Izlás and Tachtalia, channels 66 yards wide have to be cut to a depth of about 6 feet 6 inches below low water. The point of the Greben mountain has to be entirely removed for a distance of 167 yards back from its original face, and to a depth of about 6 feet 6 inches below the low-water level. This is to prevent the swelling of the river above the Greben point, on account of the sudden narrowing of the river-bed at this spot. Below the Greben Point, where the river widens out rapidly, a training-wall nearly 4 miles long has to be built along the Servian shore, in order to obtain sufficient depth of water, by confining the river in a narrow channel. This training-wall is between 7 and 9 feet high, 10 feet wide at the top, battered at 1 to 1½. To connect it with the shore, and to equalize the water-level behind the training-walls, there are two dams, 6 feet 6 inches wide at the top. At Jucz, a channel of similar dimensions to those just mentioned has to be cut, and a training-wall built between the Porecska brook and the Golubinji island. At the Iron Gates, a channel 89 yards wide and about 3,000 yards long has to be cut to a depth of 6 feet 6 inches below low-water level along the Servian side of the river, passing through the Prigrada bank, and terminating at the village of Sibb. The depth mentioned not giving sufficient water for purposes of navigation during a great part of the year, training-walls on each side of the channel are being built to confine the water so as to raise its level. The right-hand wall is to have a width at the top of 19 feet

6 inches, and will serve as a tow-path; the left wall will be 13 feet wide at the top, the batter of both being 1 to 1½. After the greater part of this channel had been blasted to a depth of 6 feet 6 inches, it was decided to increase the depth to 13 feet below low water, in order to allow small war-vessels to get up as far as Orsova, and at the end of 1891 powers were obtained to carry out this alteration. It will, of course, give at the same time much greater facility for trade, and will probably make Orsova a large trading centre. All the training-walls are being built of stone, and have flat revetments to protect them against ice. For those at Greben, the stone from the Point is utilized.

The quantities of work to be executed are, according to official details, as follows:—

Place.	Removal of Rock in the River.	Removal of Rock on Shore or in Shallow Water.	Stone-depositing on Dams.	Various Dam work.	Stone Revetment.	Depositing Stone.
	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.
Stenka . . .	7,400					
Kozla-Dojke .	65,800					
Izlás Tachtalia .	46,800	..	505,600	..	..	106,300
Juez	3,200	..	70,000	..	..	29,000
Iron Gates . .	..	227,000	294,000	270,000	68,400	
Between rapids	10,000					
Totals . .	133,200	227,000	869,600	270,000	68,400	135,300

The rock at the Stenka rapids is granite and crystalline slate, at Izlás and Tachtalia are porphyritic tufa. The Tachtalia mica and the Greben mountain consist of quartzite and limestone. At the Iron Gates, the rock is a hard arenaceous limestone. The total cost of the work is estimated at £725,000 sterling, and the contractors have undertaken to complete the work before the end of 1895. Work was commenced on the 18th of September, 1890.

The most striking feature of the operations, as they are now being carried out, is their extreme simplicity. Colonel Lauer's method of subaqueous blasting, which was originally thought to be the only one available, and on which the first estimates were based, has been found unsuitable for these works; although it gave most satisfactory results in the preparation of the bridge foundations at Peterwardein on the Danube. This system is carried out by mooring in the usual manner a barge, having over

the front a wrought-iron framework with a number of apertures, through which a rod made of gas-tubing can be slipped down to the river-bed from a fixed point overhead. A number of equidistant points can thus be touched. On the end of the rod a charge of 2.2 lbs. of dynamite, in a tin case, fixed to a short wooden rod, is attached by a suitable holder. The charges are fired electrically, and usually only the wooden lengthening-piece is broken. The rocky bed of the river is removed in steps, with the free side down stream, so that all the small *débris* is carried away by the current. The difficulty experienced in working by this system at the Iron Gates was that when a depth of rock of 6 feet had to be removed, it had to be taken off in three or four layers; on attempting to start the second layer, the shots had very little effect when the rock was soft, and it seemed as if the rock had been compressed by the first set of explosions. In addition, there was also the danger of permanently leaving needle-like points projecting, which would have been most dangerous to passing vessels. Finally, there was the minor difficulty that the wooden lengthening-pieces became so tightly jammed into the iron rod that nothing short of burning them out sufficed to remove them. Whilst for small obstacles Lauer's method was effective and cheap, other methods had to be resorted to for attacking the heavier work.

The first important piece of work is that on the Greben section. The removal of the Greben Point is now finished. As the spur of the mountain had an almost vertical face towards the river, work was commenced on it at two different levels simultaneously, and a tunnel was driven to carry away the spoil. The first material removed was pumped into the river, and sufficient ground made to build locomotive-sheds and workshops, and to form a connection with the little village of workmen's houses. As soon as the rock was cut back sufficiently far from the shore, chamber-mining was resorted to. The chambers were very simple in shape. A heading 3 feet wide by 4 feet high was driven about 80 feet, quite straight; and then a chamber, 6 feet 6 inches cube was blasted out at right angles to it. This was charged in the usual way, and the heading was closed first with brickwork set in cement and then with dry stone-work. The ignition was accomplished electrically. Such a mine would have a charge of 5 tons of second grade new dynamite containing about 45 per cent. of blasting gelatine. At first, carboazotine,¹ a low explosive of the

¹ Carboazotine consists of 74 per cent. of potassium nitrate, 12 per cent. of sulphur, 8 per cent. of soot and 6 per cent. of bran, and is prepared by a wet process.

nature of blasting-powder, was used. One of these chamber-mines fired last year had a breast of 20 yards and a height of 33 yards. According to calculations 3·885 tons of carboazotine was the charge required, so a charge of about 4 tons was used. The result was that about 700,000 cubic feet of rock were thrown down. The largest blast hitherto made was fired in May 1894, when 2,100,000 cubic feet of rock were thrown down by a charge of 12 tons of second grade dynamite. In both cases, about 80 cubic feet of rock were removed per lb. of explosive.

The formula used for charging the chamber-mines was

$$L = 3 (v^3 + 5h) q,$$

where L is the weight of the charge in kilograms, v the line of least resistance in metres, h the height in metres of the rock above, and q a coefficient depending on the explosive used; for carboazotine, this was found to be between 0·18 and 0·23, but was usually taken as 0·22.

The height of the rock seems to be of little importance, as the omission of the term $5h$ from the calculation only makes a difference of 100 kilograms in a charge of 4,000 kilograms. Thus the formula practically resolves itself into the cube of the line of least resistance multiplied by a coefficient. This is almost identical with the formula obtained by considering the explosive to act in spherical waves in an unlimited homogeneous solid, namely, $L = 4 \cdot 1888 r^3 c$. This is the formula used in the harbour works at Fiume, where the ratio of height to line of least resistance was kept constant at 3 : 2. Both these formulas give the quantity of charge too high, since they can only be true in a perfectly confined space,—a condition which never occurs in practice, for there is always at least one free surface,—and consequently the formula based on the formation of a conical crater must be more accurate. This formula is—

$$L = k (w + r)^3,$$

where L is the weight of the charge in kilograms, w is the longest line of resistance at right angles to and towards the free face in metres, and r is the radius of the crater in metres, which should not be more than $\frac{3}{2} w$. As an additional quantity of charge is desirable to ensure success, the spherical-wave formula may be used, though at some extra expense. As previously stated, the stone thrown down from the Greben Point is utilised in building the training-wall along the Milanovacz shore. The measurement of the quantity of material put into the training-wall is attained

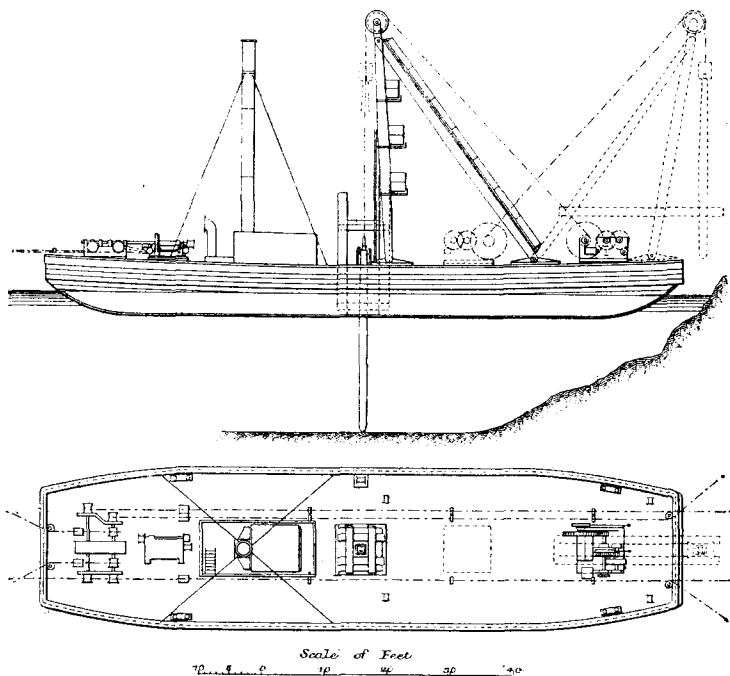
by weighing the loaded trucks, the weight per cubic metre of the piled stone having been previously determined, and being from time to time checked; and payments to the contractor are made according to the number of cubic metres of training-wall built, calculated from the weights of broken rock sent on to it. The training-walls are being built by tipping the rock from trucks running on a line of tramway laid along the top of the wall, and by barges at the more distant part, from which the rock is thrown out by hand. Some difficulty was experienced at Greben in mooring the barges; rings fixed in the ordinary way would not hold, on account of the very strong current and occasionally high water-level. By using a ring bolt with a split end, and driving it on to a steel wedge placed at the bottom of the bolt-hole, a perfectly secure mooring-ring was obtained.

The work that presents the greatest difficulty is the cutting of the channel through the Jucz rapids. This channel, which has a width of 197 feet, has to be accurately cut through a mass of submerged reefs, to a depth of 6 feet 6 inches below low water. A mixed system of rock removal has been decided upon for cutting this channel. In parts where the average depth is sufficient, with isolated rocks scattered about, Lobnitz cutters are used for levelling the bed of the channel. Where large reefs of considerable thickness have to be cut through, machine drilling and blasting is adopted. The rock-cutting machines employed are similar in principle to those described by Mr. Fred Lobnitz, Assoc. M. Inst. C.E., in his Paper on "The Removal of Rock under Water without Explosives."¹ This method consists of shattering the rock by the blow of a heavy bar allowed to fall freely from a height on to the face of the rock. The machines in use at the Iron Gates are somewhat different from those described in the Paper alluded to. They have only one cutter in place of ten. With the rapid current and other local conditions on the Danube, a machine with one cutter of great weight is more suitable than a larger machine with a battery of cutters of various weights. The general arrangement of one of the machines used is shown in *Figs. 6*. The barge is 100 feet in length, 25 feet broad, and 7 feet deep, with a draught of about 3 feet. The boiler is placed near the stern; abaft the boiler are the manœuvring winches, for moving the vessel along the main and the four side-chains. Near the centre of the vessel is the tripod, or sheer-legs, for manipulating the cutter, the hoisting-winch of which is placed in the fore part of the barge. The cutter is, as a rule, dropped through a well in

¹ Minutes of Proceedings Inst. C.E., vol. xevii., p. 369.

the centre of the barge, but arrangements are made for swinging over the tripod so as to allow the cutter to work over the fore end of the vessel. The action of the machine is that of a pile driver, the pointed cutter-bar replacing the "monkey" of the ordinary pile-driver. The cutters consist of wrought-iron or mild steel bars 30 feet long, square in section. They are 7 inches square at the top, increasing to a maximum of 13 inches square, 10 feet from the point, and diminishing again to 11 inches square at the lower end.

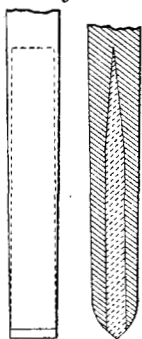
Figs. 6.



For a length of 4 feet at the lower end, a hard steel core 11 inches by 4 inches is welded in along the centre line of the bar. The point of the bar is chisel-shaped, the sides being shaped off to a 9-inch radius. The cutter is hardened by heating the point to a cherry red and dipping it into the water. Details of the cutter are given in *Figs. 7*. This steel blade, being protected on two sides by wrought-iron, can be used up to the last few inches, and always keeps sharp; its weight is about $8\frac{1}{2}$ tons. Sometimes a cutter 24 feet long is used. The cutters have a scale painted on

them so that the depth of the river can be measured. When the rock at one particular spot has been shattered the barge is moved sideways, and when a width of 20 inches has been broken away

Figs. 7.



the vessel is advanced that distance. The rock is removed 1 foot more than the specified depth, so that the possibility of leaving spurs of rocks that would be dangerous to boats is avoided. The varying hardness of the rock prevents an accurate account of the rate of work being given. The drop given to the cutters is 5 metres, and from fifty to one hundred blows per hour the average speed. The rate of working depends upon the necessary amount of shifting and manœuvring of the barge, which is larger when the rock has to be removed to a small depth than when it is thicker. The average amount removed per blow is 2 cubic feet of the hard rock at Jucz. One great advantage of

this system is that the broken stone is always small enough to be easily removed by ordinary dredgers. Up to the middle of August 1893, 22,315 cubic metres of rock had been broken down by Lobnitz cutters, by far the largest portion of this having been done in 1892, only 7 per cent. of the total work having been accomplished at the end of that year. There are two of these rock-cutting machines at work, and a third one, which has a platform supported on two barges for carrying the machinery instead of one large barge. They are working in a most satisfactory manner and are giving very good results.

The blasting operations and the drilling of the bore-holes are also conducted from specially-constructed barges. There are two systems at work, namely, that of the Ingersoll-Sergeant Drill Company at Jucz, and the Fontane system at Izlás and Tachtalia. The Ingersoll "scow," as the makers term it, is provided with spears, one at each corner, up which the scow can be raised by hydraulic jacks fed by a Worthington pump. This enables the scow to be lifted out of the water so as to rest on the four spears, thus giving a working platform independent of the movement of the water. The arrangements for manœuvring the scow are similar to those on the rock-cutters described. Along one side of the barge rails are set, carrying four $4\frac{1}{4}$ -inch Ingersoll drills worked by steam supplied by a boiler on the scow. As the current is strong in this part of the river and carries a good deal of detritus, a protecting tube, held by a special iron framework and pressed against the river-bed, surrounds the drilling-bar. When the

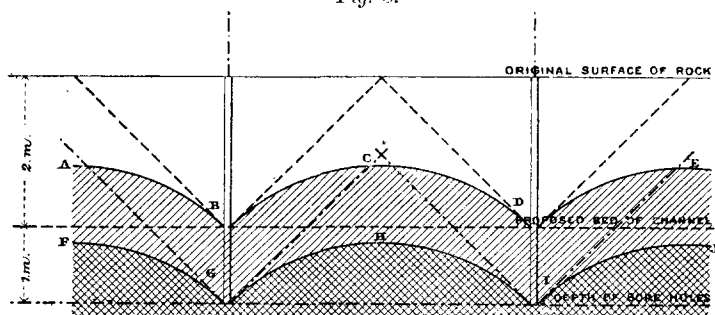
drilling of a hole is finished, it is washed out by a jet of water and the charge of dynamite is lowered into the bore-hole through the protecting tube, which is split along one side to allow the wires of the electric fuze to pass. The dynamite charges are enclosed in tin cases, having an iron weight attached to their lower ends to keep them in position. When all the bore-holes for one blast have been charged, the scow is lowered on to the water, and floated away to a distance of about 50 feet, the charges being fired simultaneously by electricity. The Ingersoll scow is said not to be perfectly steady, and the blows of the drill cause a rather excessive vibration. The protecting tube does not invariably fulfil its object, on account of its lower end failing to become truly bedded all round on the rock, and the bore-hole sometimes becomes choked with mud. Two of these scows have already been blown up, the charges having become jammed as they were being lowered through the protecting tube, and the workmen having thereupon attempted to force the charges down with a boring bar. On the whole, however, the two Ingersoll-Sergeant blasting and drilling scows at work at Jucz have given satisfaction.

In the Fontane system, two barges are coupled by a platform on which the drills are mounted. This system gives a much greater range of work than that previously described without moving the platform, which is of advantage in reducing the time lost in manœuvring the drilling-platform. The twin barges should also give much greater steadiness to the platform, but, unfortunately, the Fontane barge has been built too slightly, and there is consequently a great deal of vibration; so that the work which is being done by this system has not yet been satisfactory as regards quantity. A stronger barge is, however, to be built, as the system is thought highly of on these works.

Special care has to be taken to leave no reefs in the proposed channel. If the bore-holes were only drilled to the intended depth of the canal, such reefs would inevitably be left, as will be seen from the diagram, *Fig. 8*, which shows the probable effect of two bore-holes fired simultaneously by electricity. If the bore-holes were only put down to the level of the bed of the proposed channel, the latter after blasting would have approximately the form shown by the line A, B, C, D, E, *i.e.*, a projecting piece would be left between each pair of bore-holes. To avoid this, the holes are always drilled 3 feet deeper than the proposed bed of the canal, so that the bed left after blasting may be approximately as shown by the line F, G, H, I, J. The highest water-level is 13 feet, and the highest reef is 6 feet 6 inches above

datum. This, with the additional 3 feet required for safety, gives a depth of 22 feet 6 inches to be drilled below high-water mark. The explosive used is new dynamite No. 1, which is similar in composition to gelignite in England. The rock broken away by the cutters and by blasting is removed by dredgers. That broken away by blasting was expected to give some trouble, as much of it consists of large lumps, and dredging it is by no means an easy or cheap undertaking. Some of the dredgers are of the Priestman type, others are ladder-dredgers with buckets. Messrs. Lobnitz and Co., of Renfrew, built one specially for dredging the larger rocks. This was a sea-going dredger, and made the voyage, remarkable for a vessel of this type, from Renfrew to Jucz *via* the Black Sea, in forty-five days, under her own steam. The dimensions of this vessel are:—length between perpendiculars, 130 feet; breadth, moulded, 33 feet;

Fig. 8.



and depth, moulded, 11 feet. Her draught when at work is 6 feet, which enables her to dredge in the shallowest part of the works. She is specially designed for rock excavation, and is fitted with strong steel buckets and elastic pitch chain drive, one element of which weighs $1\frac{1}{2}$ ton. The dredging-machinery and the propellers are actuated by a compound surface-condensing engine with direct-acting inverted cylinders. The high-pressure cylinder is 16 inches in diameter, the low-pressure cylinder 30 inches in diameter, and the stroke is 2 feet. This engine, which indicates about 250 HP., can be connected at will with either the dredging-machinery or the twin-propellers with which the vessel is fitted. Besides this engine, there are auxiliary ones for driving winches, &c. All the machinery in the dredger is controlled by levers placed forward, which are manipulated by the dredging-master, who has thus absolute control over the dredger.

The work at the "Iron Gates" proper is of an easy character compared with that in the Greben section, although it is perhaps of more general interest on account of its vast dimensions. As shown in *Fig. 5*, the channel to be made there will be bell-mouthed at both ends; so that under the most unfavourable conditions sufficient water will flow through to give the desired depth. The work was commenced by building a cross-dam, diverting the river, and leaving the route of the proposed channel dry. The two training-walls were then simultaneously built, and a small channel was cut to carry away water leaking in. The cutting of the permanent channel along this dried river-bed presents no difficulties. The whole of the blasting operations are performed by hand; the broken rock is carried away in trucks drawn by locomotives to a shunting station and then on to the two training-walls. The quantity of rock obtained in cutting the channel being insufficient, a quarry had to be opened about a mile up the river. On account of the bank and the bordering hills being covered to a considerable depth with loose gravel, this quarry had to be opened on the top of a hill some 500 feet high; the stone from it is shot down a steep slide on the hill-side. It is likely that the velocity of the current in this channel will be considerable; in fact, with the depth of 6 feet 6 inches as originally proposed, a velocity of 13 feet per second was expected, and means of towing boats through had to be considered. With the depth of 13 feet, the sudden drop in the bed at the lower end will largely disappear, and it may be possible so to arrange the fall that the velocity of the current in the channel will be reduced to such an extent as to obviate the necessity of towing.

According to official returns, the quantity of work executed up to the end of 1893 was as follows:—

	Cubic Metres.	Percentage of estimated Total.
Blasting under water (of which 67,536 cubic metres have been removed)	122,758	77·77
Blasting at the Iron Gate	307,223	90·60
Stone depositing	345,978	68·93
Various work on dams	133,065	20·05
Stone revetment	9,150	square metres.
Facing dams	56,340	„ „

The Paper is accompanied by eight tracings, from which the *Figs.* in the text have been prepared.