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“The Removal of Rock under Water without Explosives.”

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As the removal of subaqueous rock is one of the slowest and most difficult of the works undertaken for the improvement of harbours, rivers, and canals, it may be of interest to describe a method of shattering and then dredging subaqueous rock, by which the danger of blasting, and unforeseen delays and expenditure are avoided. The system consists in letting fall a heavy, suitably-shaped mass on the surface of the rock, which shatters it, like artillery fire demolishes the stone walls of a fortress.

Mr. Henry Lobnitz, shipbuilder of Renfrew, invented this system of rock-cutting rams in view of the rock excavation necessitated by the widening and deepening of the Suez Canal through the strata of rock between the Bitter Lakes and Suez, which has to be executed under water without intercepting or endangering the incessant traffic passing along the Canal.

A steel-pointed rock-cutter, weighing 2 tons, was experimented with at Craigmillar quarry, Edinburgh, being raised by a steam-winch on a frame, like a pile-engine, running on rails. With a fall of about 18 feet, over 4 cubic feet of the hard rock were dislodged, on the average, per blow. The first blow, delivered 3 feet from a face, made an almost imperceptible crack in the rock; a second and third blow on the same spot opened the crack, about 5 feet long by 3 to 4 feet deep; and at the next blow, the wedge-shaped point of the cutter generally entered the crack, and split off the piece of rock. Striking blows, out of sight, under water on an unknown surface, modified the conditions of the experiments on land; but nevertheless the “*Dérocheuse*,” the first rock-cutting machine built, fully confirmed the expectations of the inventor, and has been purchased by the Suez Canal Company for widening and deepening the rocky portions of the canal (Plate 9, Figs. 1, 2, and 3).

The s.s. “*Dérocheuse*” is a vessel capable of navigating independently; and in spite of the height of the framing, the metacentric height is over 5 feet, owing to her great beam, giving a good stability curve. She steamed out to Port Said from the Clyde

in twenty days' steaming time, encountering several severe gales. The hull of this rock-cutting dredger is 180 feet long by 40 feet broad and 12 feet deep; the mean draught is 9 feet, and there are eighteen water-tight compartments. Five steel-pointed rock-cutting rams, each weighing 4 tons, are arranged in line on each side of the central well, through which the buckets lift the crushed rock (Plate 9, Fig. 8). Hydraulic power raises them to a height of from 5 to 20 feet, and they are then let fall on the rock. These rams can work on each side of the lower tumbler, or they can be moved by steam-power either forward or aft, to suit the position of the dredging gear or the requirements of the work. With the set of hydraulic levers, placed below the steam-crane, between two hundred and three hundred blows per hour can be delivered with one set of five cutters. Combined with the rock-cutting apparatus, dredging machinery, specially adapted for lifting broken rock, is provided. A guide-wheel is fitted, which supports the bag of the bucket-chain when wear has taken place, and relieves the strain on the bearings and pins. With this guide-wheel, or relieving drum, the maximum dredging depth of the machine is 40 feet; without it, more than 30 feet would not be attained. Some old dredgers, to which such a guide-wheel has been added, have been able to dredge 15 feet deeper than before, and with greater speed, of which the Clyde Navigation dredger No. 8 is an instance. For driving the bucket-chain, there is a four-cylinder two-crank compound engine of 200 indicated HP., which by special friction-gear works two steel pitch-chains passing round pitch-wheels connected to the upper tumbler. If the buckets catch on solid rock, the friction-gear slips until the undue strain is relieved.

While at work, the vessel is moved over the surface in a series of arcs, by independent winch motion arranged for swinging the vessel from side to side, pivoting on a steel mooring pile, which goes down through the hull in the after part of the machine and rests on the rock (Plate 9, Figs. 1 and 4). There are two of these pivot-piles manœuvred by hydraulic power, which enable the vessel to advance an equal distance after each swing, and which prevent her from losing position. This double pivot system of working is useful for accurate rock-breaking, when the vessel is situated on a large surface of water, where a dry land base of operations cannot be had. There are two jib cranes; one 3-ton hand-crane on deck for repairing the bucket-chain, and the steam-crane of 6 tons, placed on the top of the framing which supports the hydraulic hoists for the rock-cutters, enables the latter to be easily removed and replaced. For navigating purposes, twin screw-engines of 300

indicated HP. are provided. There are two independent boilers, with a working pressure of 75 lbs. per square inch. Two sets of automatic hydraulic pumps are fitted, working independently with separate lines of piping to the hoists, so that repairs can be done while at work. A separate three-cylinder engine actuates the condenser pumps, which causes the vacuum to remain constantly efficient. The ladder-hoist engine is placed forward, and winds the chain round a large grooved barrel. An accumulator is used to regulate the hydraulic pressure, and to raise or lower the pivot-piles.

In designing this machinery, much care was taken to make it specially suitable for what it was expected the conditions of actual work would be; and few of the arrangements adopted were found to be unsuitable for the task which they had to perform.

The every-day work was carried out under the supervision of the Author; and the daily log of the first few months is a record of experiments with different systems of using the machine. The system, finally adopted as the best, may be accepted as an advantageous manner of using rock-cutting rams combined with dredging apparatus under similar circumstances.

At the Red Sea end of the Suez Canal, the mooring place for vessels has a variable conglomerate bottom containing gypsum, sand, and sometimes shells. On this bed of variable rock, the machine was first put to work. The mean depth of water, of about 27 feet, has been ample for the traffic up till recently; but as the variation of water-level in the Red Sea is from 6 to 10 feet, the depth of water at low-water is scarcely sufficient for the increased draft of the large liners. The surface of this rock has been attacked by powerful dredgers in past years, but this plan was expensive, owing to the great damage done to the dredgers, which could only scrape away the soft surface and soft places, and continually had serious break-downs. These dredgers, although of a good type, could only load one barge of 200 cubic yards of clay and rock, in from a week to a fortnight; and their daily advance was often not more than 2 or 3 feet, where the "Dérocheuse," later on, did from 20 to 30 feet with the same depth of cut. However, the Port Tewfik rock had been thus lowered a foot or two over a surface of about 10,000 square yards; and this method was only stopped because the rock got harder below the original rotten surface, making progress slow, especially as the dredgers required to be under repair very frequently. Thus where the rock-breaking machine started work, the surface was clean and of a genuine rocky nature, the thickness of the bed being so great as not to be

definitely known. It speedily became apparent that the conglomerate, having a large proportion of gypsum in its composition, was so elastic and tough that the blows of the sharp-pointed rams had no splitting effect on it whatever. Each blow of a cutter made a hole in the rock, varying from 6 inches to 2 feet in depth; and a second blow, delivered even quite close to the first, made a similar square cavity, leaving the wall of rock between the two holes intact to all appearance. The partition of conglomerate between two such holes was sometimes only from 4 to 6 inches in thickness, yet showed no cracks such as had been anticipated from the dry land experiments. This result, due entirely to the peculiarly tough nature of the formation, led for a short time to the supposition that the effect of the cutters on this rock under water would be nil. When starting actual work after these experiments, the cutters were moved forward of the lower tumbler, so that when working at from 30 to 36 feet of dredging depth they would always be in front of it. After being placed in position, the machine was pivoted on the central pivot, the cutters delivering a series of blows, 5 feet apart, while describing an arc about 65 feet broad by 8 feet long. When the first arc was finished, the vessel was advanced 10 feet forward, and the pivot again lowered. As the lower tumbler was now over the rock which had been operated on by the cutters, the bucket-chain was set in motion, and the second swing commenced, all the mechanism, cutters and buckets, working together. The dredger lifted the rock, but not easily, as shown by the frequent slipping of the friction-gear, when the buckets slid over or caught on solid rock. During the delivery of each series of ten blows, the manœuvring winches were stopped, and the swing of the vessel was interrupted, so that each row of cutters might deliver five blows in line. After each series of such blows, the machine was pivoted to the next position, and the operation repeated. As the buckets did not lift the rock with the ease to be expected had the rock been thoroughly disintegrated, it was decided to deliver the series of blows closer together than 5 feet, so as to leave almost no surface untouched. A diver, sent down, reported that the surface of the rock behind the machine was in small hills and valleys, running parallel to the axis of the vessel (Plate 9, Fig. 5). Each row of blows so crushed the rock that the buckets were able to penetrate and lift it. But where the rock was untouched by the cutters—the part represented by the hills—the buckets merely slipped over it, lifting the ladder, and sliding violently over the rock. The hills on the surface were exactly spaced between the lines of blows. To avoid this bad work, caused by delivering the blows

symmetrically spaced, it was resolved to pivot the dredger slowly, but uninterruptedly, through each swing, delivering blows continuously, and dredging at the same time. Before trying this, the rock was attacked with the buckets alone, to see whether it would not be possible to lift it without first indenting the surface with the cutters. This attempt, however, in spite of the great power and strength of the dredger, had to be immediately abandoned, as the buckets came up empty, and merely slipped violently over the rock, whipping on the ladder, and injuring the machine more than the conglomerate. The promiscuous delivery of blows gave better results in speed, and left a level surface; but, owing to the variable nature of the rock, the cutters were in a few days traversed nearer to the cutting bucket, and it was found advantageous to have the cutters thus alongside the buckets, because they acted on the rock immediately before and after the buckets. When a hard and brittle patch of rock was met with, requiring fewer blows to disintegrate it than the softer and tougher quality, no time was lost by delivering unnecessary blows, as the buckets showed instantly whether the rock was sufficiently loosened or not. Again, when a greater depth than 2 feet of rock had to be removed to attain the required section, it could be done in two or three swings, pivoting on the same spot. This was found to be quicker and easier, as the buckets lifted away the crushed or broken surface between the two rows of cutters, allowing the second row to have more effect on the rock, falling on a surface not covered by the debris resulting from the blows of the other row of cutters. After working for seven weeks on this peculiar conglomerate in the Red Sea, it was thoroughly proved that the best method of employing the machine, in that kind of rock, was to have the cutters close to the buckets, and to work with dredger and rock-cutters together, advancing about 1 yard each swing. As it was now clear that all the rock of this nature could be removed by the "Dérocheuse," it was decided to take the machine about 15 miles along the canal, to the Chalouf Rock, a very hard bed of rock, and quite different in nature and position from the Port Tewfik conglomerate.

The results of the work in the conglomerate were as follow. At first the cube done each day varied greatly; but, after the first few weeks, the output became more regular, owing to the crew becoming more skilled in the working of the machine, for the conglomerate was very variable, at one place hard and tough like malleable iron, it would often change quite suddenly to hard brittle patches, surrounded by softer and more elastic parts rich in gypsum. Pockets of yellowish clay were also sometimes met with,

embedded in the rock, and in these the cutters often stuck fast. One or two of the neighbouring hydraulic chains were then attached to the cutter, which extracted it in a minute or two. The total outlay for working expenses and repairs during the last five weeks at Port Tewfik, for the breaking and extraction of 2,100 cubic yards of pure rock, was £354. Thus the cost per cubic yard of pure rock, lifted in pieces weighing from $\frac{1}{4}$ to 2 cwt., and put into the barge, was about 3s. 5d., exclusive of insurance, interest, depreciation, or management.¹

Before leaving Suez the machine was put into as good condition as when it first began work. New guides were made for the cutters, as the original ones proved too weak. The cost of these repairs, and of all alterations and improvements, is included in the above price of 3s. 5d. per cubic yard. While operating in the deep water on the conglomerate, no breakages occurred; the guides only of the cutters wore out, being made of unprotected wood and not strong enough. This shows that a machine, properly made for a conglomerate, could remove it at least as fast as the "Dérocheuse," and without more wear and tear than in an ordinary dredger working in sand.

The machine commenced operations on the hard rock at Chalouf on the 30th of May, 1888. Instead of a variable tough conglomerate, the Chalouf bed consisted of unstratified hard rock, varying in thickness from 5 to 10 feet, with clay strata below. A strip of this rock, about 20 yards wide and 200 yards long, had to be removed on the Asiatic side of the canal. This work, the first stage of the widening of the canal at this point, is now finished. The depth of water over the surface of the rock where the machine worked varied from 8 feet to 22 feet, as the rock inclines towards the north (Plate 9, Fig. 6). An almost vertical wall of rock was left towards the African side when the channel was excavated dry in making the canal; and this face was disadvantageous to the work of the machine, as large unmanageable pieces sometimes broke off. When the cutters fell on this rock they gave a clear metallic ring, quite different from the dull thud that usually followed a blow on

¹ Working days, 25. Working hours, 244. Pure rock excavated, 4,048 tons, say 2,100 cubic yards, exclusive of 1,401 tons of clay, sand, and pulverized rock excavated.

Working expenses	•	•	•	•	•	•	•	£205	} £354.
Repairs and alterations	•	•	•	•	•	•	•	£149	
								£354	
Cost per cubic yard	$\frac{£354}{2,100 \text{ cub. yds.}}$								= 3s. 5d. per cubic yard.

the conglomerate in the Red Sea. A cutter being lowered on to the surface of the rock, which had been previously all scraped free of clay, &c., by another dredger, and the depth of immersion noted, it was allowed to fall on the rock from a height of 6 feet. The immersion of the cutter, however, was unchanged, which showed that it had not indented the rock as would have been the case at Port Tewfik. After a second and third blow on the same spot, the cutter was seen to penetrate, and was found to have pierced through the bed to a depth of 5 feet. A fourth blow on the same spot gave no metallic ring, the cutter sticking deeply in the clay strata below the rock. Regular work was then commenced, a surface of rock being shattered by blows of the cutters working alone. The diver, on examining the surface worked over, reported that the rock was completely broken up and disintegrated, the fragments varying greatly in size. Sufficient surface having been operated on by the cutters to allow the bucket-ladder to effect an entrance into the rock, the dredger was put to work, and immediately the buckets brought up freshly-broken stone of very hard quality in pieces weighing up to $\frac{1}{2}$ ton. These blocks fell in the shoot of the dredger with a noise like thunder, and rattled down into the barge in a continuous stream. To receive the shock of such pieces, a heavy iron flap-door had been suspended on the end of the shoot, next the barge, to prevent the latter from being injured or sunk; and, where the broken rock falls over the upper tumbler, a mild steel armour-plate, 10 inches thick, receives the shocks, and prevents injury being done to the framing of the dredger. The barge was filled with 350 tons of rock without any other mishap than the smashing of the flap-door suspended on the shoot to protect the barge from the falling stones. The diver, on examination, found several blocks of rock weighing each about $1\frac{1}{2}$ ton on the otherwise perfectly dredged surface. These blocks had been rolled before the buckets, which could not lift them owing to their size; and, as they rested on the soft surface of the clay strata, there was no possibility of breaking them smaller by a blow from a cutter. As it would have been imprudent to dredge again with such stones behind the lower tumbler, owing to the risk of rolling them into the traffic channel alongside the bed of rock, it was decided to lift them at once with the crane, the diver attaching a sling to each. However, the operation of lifting these blocks with the diver's aid, notwithstanding good appliances, took as long as the loading of the first barge had done; and the rock so lifted cost several pounds per cubic yard. Hoping to avoid breaking off such large pieces, the blows of the cutters were spaced closer together, and the work

proceeded. The cutters were kept in front of the buckets, and the rock broken during one swing was dredged in the next. It was speedily found that the cutters, although not working quite close to the cutting edge, still had an enormous effect, breaking off from 25 to 50 cubic yards per hour. However, this result was quite useless under the circumstances in Egypt, because the dimensions of the pieces broken off by this method were quite beyond control; and the buckets could not catch and lift any block above 1 ton in weight. At each swing the buckets rolled the large blocks to one side, lifting only the small and medium-sized pieces; and, as the traffic channel had to be kept free from blocks, it was not possible to work with safety so long as the rock could not be broken quite small. Moreover, the diving work was very costly, especially as the tidal currents interfere with such work at Chalouf. Whilst working close to the cutting edge, it was found impossible to prevent large pieces being broken off, reaching 4 and even 8 cubic yards. To enable the rock to be broken smaller, the operations of dredging and rock-cutting were separated, so as to allow the cutters to work farther away from a face. In this way the blows of the rams fell on rock supported on all sides; and, instead of being cracked off in blocks weighing from 1 ton to 15 tons, the rock was broken up quite small by the repeated blows, something like ballast for concrete making. Naturally, more time was required to thus pulverize the rock, as repeated blows had to be delivered on the same spot in order to pierce the bed, which was, however, always accomplished with certainty even with a thickness of 10 feet of rock. Only five of the ten cutters were used in this system of working, as it was found that, for separate rock-cutting and dredging, one row of cutters was more convenient for accurate work than two rows. From 10 to 15 cubic yards of rock were broken to ballast size per hour of rock-cutting. Dredging the rock pulverized in this way caused no undue efforts to the bucket-chain, which lifted the rock as if it were gravel at the average rate of 30 cubic yards per hour. The dredger would have lifted about 50 cubic yards per hour if it had not been necessary to dredge in one direction only, and swing back without advancing, so as not to risk rolling any debris into the traffic channel alongside the rock. This method solved the difficulties experienced at first, although several items in the machinery required modification. For instance, while dredging the pulverized rock for the first time, one of the blocks got between the buckets and the lower tumbler, causing the chain to ride over the flanges of the latter. A new tumbler of special design was accordingly substituted for the original one, which was of

a type well adapted for dredging clay or soil, but not for dealing with rock where large blocks might occasionally be met with. At the same time larger chains were put on to the hydraulic hoists, as the chains, 1 inch in diameter, originally fitted, were too small to stand any wear with the additional hydraulic pressure put on to draw the cutters out more quickly when they stuck fast. The ten original cutters were also replaced by ten heavier ones differently shaped to reduce the vibrations in the shallow depths at Chalouf. These improvements occupied the latter part of the month of June and the first three weeks of July, 1888, as the various parts had to be sent to Egypt from Glasgow.

After the alterations, the "Dérocheuse" worked for forty-two days from 5 A.M. to 7 P.M., Sundays and week-days, without stoppage, except when the canal traffic required it. In the beginning of September the boilers were cleaned, being dirty with deposits from the Nile water; and the pins in the bucket-chain were changed for the first time, being worn with the gritty debris of the rock. A similar overhaul is required monthly for all machines on the Suez Canal. Towards the end of September, the "Dérocheuse" was acquired by the Suez Canal Company, being found capable of removing the rock in the channel without inconvenience to the navigation, and with greater speed and economy than could otherwise be done.

The total expenses of the work during two months at Port Tewfik, and three months at Chalouf, were £2,017, while 7,659 tons, or, say, 4,000 cubic yards of pure rock were lifted, making the cost about 10s. per cubic yard.¹ As the total cost of working the machine was about 3s. per cubic yard of pure rock extracted, and the abnormal repairs and alterations, chiefly owing to the novelty of the apparatus, amounted to about 7s. per cubic yard excavated, it is apparent how economical the system should really be. With the pure rock, 2,177 tons of clay were also lifted, but the results for pure rock only are given. These were the results of the experimental period of the work of the "Dérocheuse." But during August

¹ Expenditure at Port Tewfik and Chalouf during the first five months:—

	£.
General expenses, crew, coal, stores, &c. (74 working days)	603
Improvements, alterations, and repairs	724
Replacing cutters, and two broken	286
Transport and storage	404
Total expenses (74 working days)	<u>£2,017</u>

Pure rock removed, 7,657 tons = 4,000 cubic yards. Working hours, 474.

the crew and all the machinery got into working order, and in September a careful record was kept for sixteen days, during which 1,936 tons of pure rock, say 1,000 cubic yards, and 249 tons of clay were lifted in one hundred and eleven hours' work, the average working day at Chalouf being under seven hours, owing to the navigation. Ordinary repairs only were required, and the following Table therefore shows the normal expenses of the machine working in hard rock. The barge which carried the broken rock 20 miles away is not counted, as this factor varies so greatly with circumstances.

DETAILS of EXPENDITURE of the LAST SIXTEEN DAYS at CHALOUF.

	£	s.
Crew (twenty-three men) at 11s. 6d. per hour, 140 } hours' pay }	80	10
Coal at 30s. per ton, 3 cwt. per hour for 140 hours . .	31	10
Oil and stores	8	16
Fresh water, sixteen days at 10s. 6d.	8	8
Upkeep, sundries, &c.	1	14
Total expenses for 1,000 cubic yards	£130	18

$$\text{Cost per cubic yard of pure rock} = \frac{\text{£130 18s.}}{1,000} = 2\text{s. 8d.}$$

Although the 1,000 cubic yards of hard rock were excavated at a cost of 2s. 8d. per cubic yard, it would be quite wrong to treat this figure as a basis for continuous working, for at the end of a year's work many parts of the dredger would be worn, and the repairs required each year would probably double the cost per cubic yard excavated. Thus, in the Author's opinion, the probable cost per cubic yard would be about 5s. for a machine similar to the "Dérocheuse," which could remove about 20,000 cubic yards of average rock in a year, at a cost of about £5,000 per annum. This estimate does not include the transport of the broken rock in barges, nor the depreciation, interest, and insurance of the plant.¹

¹ In order to make the records, from which the figures cited are taken, as exact as possible, the measurements of the cube excavated were done as follows: Before commencing the trials, an empty barge containing a measured quantity of water in the tanks and boiler and a given quantity of coal, was loaded with weighed sand. Marks were cut corresponding to loads of 10 tons, 200 tons, 300 tons, &c., so that the weight excavated could be exactly known. The Author has called the working hours those in which the machinery was in motion. In making up the expenses, the total wages paid to the crew or other workmen were charged. The time taken by passing vessels was deducted from the cost of wages. The blocks lifted by the diver at Chalouf have not been

The hot season of the year was far from being favourable to the energy or perseverance usually necessary for the successful application and improvement of any new kind of machine, as the temperature, even at midnight, was often above 100° Fahrenheit; and the scene of operations was in the desert, far from workshops and other conveniences. But the most prominent disadvantage was the continual interruption of the work to get out of the way of passing vessels, and the care which had to be taken to keep the channel clear. On an average, the length of time during which the machine could work without being interrupted by the traffic was from forty minutes to one hour at Chalouf, where the actual working time was only from four to ten hours per day. In spite of being obliged to lose the position from five to ten times per day, about 50 cubic yards were generally excavated each day at Chalouf, without once interfering with the navigation. When working at Port Tewfik, the passing vessels caused much less inconvenience, and the cube excavated each day was generally over 100 cubic yards, working from eight to eleven hours per day according to the traffic.

In the preliminary experiments on land in 1886, much difficulty was experienced in making points for the cutters, which would break hard rock, and yet keep always sharp; and almost a year elapsed before this detail was satisfactorily settled. The angle given to the cutting-edge of the rams, when new, was about 60° (Plate 9, Fig. 7). In the soft rock at Port Tewfik, after some fifty thousand blows, the angle of the wedge-shaped points of the cutters had become about 70° instead of 60° . The same rams, after they had worked for some time on the hard rock at Chalouf, became sharper, having cutting edges with an angle of from 43° to 45° ; and this angle was found to remain constant. The cutters, accordingly, gradually became sharpened automatically to an angle suitable for a special rock, and do not require to be sharpened by mechanical means. The secret of this peculiarity is that the points are hard inside and soft outside, so that they wear sharper on a hard substance in much the same way as a rodent's tooth; and practically the rams do not wear. They, however, require to be of greater section than those used in the "Dérocheuse," as the vibration there necessitated the reduction of the drop of the cutters to

taken into account, as they arose from exceptional circumstances; and at the conclusion of the ninety working days for which the exact results have been given, about 300 yards of broken rock remained unlifted at Chalouf. These have not been counted, the cube carried away being the basis of the records.

about 6 feet; whereas with stouter cutters, a greater fall, and consequently more effect, would have been obtained.

Perhaps if the rams had been put on a separate barge, and the debris removed by a separate dredger when convenient, the expense would have been less than with a combined machine. However, under the special circumstances in Egypt, it was necessary for many reasons to have the machine as it is. Although the dredging machinery was idle at Chalouf while rock-cutting was going on, still little or no time was lost, as, when the barge was loaded, it generally took half a day for her to go to the emptying ground and come back, during which time sufficient rock could be broken to start dredging again when the barge returned. Again, the rock on the canal often occurs in small patches, which must be found by the buckets, so that it is more convenient to have one universal machine which can work in all depths, and finish any one spot before leaving it. Besides, it would be inconvenient, owing to the traffic, to have floating plant divided into several parts.

When tried in the Western Tidal Harbour of the James Watt Dock, Greenock, on hard rock mixed with quartz, before going to Egypt, the "Dérocheuse" averaged over 20 cubic yards per hour's work, not requiring to leave a given section behind her. But during the work on the Canal, the required section and depth had to be carefully attained; and any projection left had always to be corrected before proceeding. It was, therefore, to be expected that, in a definite work, the output would be less than when the only object in view was to lift the maximum amount possible. However, in rock with horizontal stratification, a greater cube per hour could be sufficiently broken up for dredging than in Egypt, where the rock was devoid of stratifications. Some of the blocks broken off in the early part of the work at Chalouf measured 10 to 11 feet in the direction of the thickness of the bed. Some of these blocks weighed 12 to 15 tons; and they were put ashore with a floating crane. For convenience of transport, holes were made in them, and they were blasted, several blasts being required to reduce them sufficiently. The stone is so hard that the holes, $1\frac{1}{2}$ inch in diameter, could only be made $\frac{1}{2}$ inch deep per hour's work of three powerful Arabs; and the tool broke constantly, although made of suitable steel. This illustrates how tedious and costly it would have been to remove the Chalouf rock by explosives.

To remove a difficulty experienced in Egypt, an automatic catch was designed, which will greatly facilitate the hooking of the rams on to the chain after a blow has been delivered. When

working in rough water, the bell-mouth of the counterbalance weight can be prolonged in the form of a tube, enclosing the head of the ram, so that it will attach itself almost automatically to the hoisting-chain after a blow. When no great variety of depth has to be worked in, the framing supporting the pulleys for hoisting the cutters can be made considerably lower than in the "Dérocheuse," which had to break and dredge rock from 10 to 40 feet below the water-line; and the extensive mechanism for traversing the cutters fore and aft would, except in special circumstances, be quite unnecessary. In fact, in most cases a more simple machine than the "Dérocheuse" would be suitable. The dredging-engine could, when not working the buckets, drive the hydraulic pumps; or the propelling engine could be used for this purpose. The only other engine necessary on board, in many cases, would be one to hoist the ladders; so that, when not required to be universal, a combined rock-cutter and dredger need not be a complicated apparatus. For general purposes, independent rock-cutting barges may be more convenient and economical. After a little practice, the men working the cutters know exactly what is going on below the surface. With cutters graduated to show the depth of immersion, no difficulty is experienced in preparing the rock to any required section, in such a way that a dredger following can remove the debris without meeting isolated peaks or unwieldy blocks. An essential point in the work in Egypt was the certainty with which any desired number of blows could be delivered on the same spot, owing to the machine having a pivot-pile to keep it exactly in position. With the light cutters used, it was generally necessary to give a number of blows on the same spot to attain the depth required. The Author is of opinion that heavier cutters should be employed, so that one blow might generally suffice to do the required work, as this would be more convenient in subaqueous excavations. The Chalouf rock could be fractured by a blow which the Author estimated at 5 tons pressure per square inch; but in order to crush the rock to ballast size, a blow having a pressure of about 7 tons per square inch was necessary. A heavy weight with a moderate drop effects more than a light weight with a high fall. Where navigation necessitates the frequent moving of the machine, as at Chalouf, a pivot is of great use for shore work. The centre of the pivot can be set off with a taut wire from a parallel on shore, and squared to the point abandoned, and then lowered, in from three to five minutes; but to find the position again by trial with the cutters would often cause waste of time.

At the end of the work in Egypt, the eighteen cutters remaining

were apparently in as good condition as when new. The two broken cutters, mentioned in the expenditure Table, gave way in the early part of the work at Chalouf; but the remaining cutters delivered ten to twenty times as many blows as the two that broke without suffering. One of the cutters broken was 42 feet long, and $4\frac{1}{4}$ tons in weight, and it fractured 8 feet from the upper end. The other, of similar length, $3\frac{3}{4}$ tons weight, broke 16 feet from the point. There is no danger to the men in the breaking of a cutter, as they stand above the heads of the cutters. About three or four hours were required to replace a cutter. In the Author's opinion, the fracture of these two cutters, which occurred soon after starting work in the shallow water at Chalouf, was owing to the shallowness of the water. The thin cutters, suitable for working in depths of 38 feet, when used in 9 to 12 feet of water, were subject to severe vibrations, as the guide had to be kept at the water-line to provide for the deep water alongside the rock. When working in deep water, the vibration is of less consequence; but for all depths stout cutters should be used. If they require to be long at the same time, the weight may be increased to 6, 8, or 10 tons, so that a good stiff section may be had. The cutters of the "Dérocheuse" were $8\frac{1}{2}$ to 9 inches square.

The foregoing remarks show how useful, in the enlargement of De Lesseps' great work, the application of rock-cutting rams has proved; and the Author considers that the principle can be adapted to suit other works with equal advantage.

The Paper is accompanied by some photographs and two sheets of drawings, from which Plate 9 has been prepared.

REMOVAL OF ROCK UNDER WATER,
WITHOUT EXPLOSIVES.

Fig: 1.

LONGITUDINAL SECTION OF ROCK DREDGER "DÉROCHEUSE."

Fig: 3.

ROCK DREDGER "DÉROCHEUSE."

Fig: 5.

IRREGULAR EXCAVATING WITH RAMS IN CONGLOMERATE
AT PORT TEWFIK.

Scale: $\frac{1}{40}$.

Fig: 2.

PLAN.

Scale for Fig: 1 & 2, - 2.5 Feet = 1 Inch.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet.

Fig: 4.

GEOMETRY OF PIVOT SYSTEM
OF ADVANCING.

Scale: $\frac{1}{1000}$.

UNUSED.

60°

SOFT ROCK.

70°

HARD ROCK.

45°

POINTS OF ROCK CUTTING RAMS.
Scale: $\frac{1}{40}$.

ARRANGEMENT OF POINTS.
Scale: $\frac{1}{40}$.

Fig: 6.

SECTION OF ENLARGED CANAL SHOWING ROCK REMOVED.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet.

Scale for Fig: 6, - 80 Feet = 1 Inch.

100

140

200 Feet.