SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2143.*)

“Blasting-Operations at Hell Gate, New York.”

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

THE passage between New York Harbour and Long Island Sound was obstructed by numerous reefs, scattered across the East River between Astoria on Long Island and the opposite shores at New York and Ward's Island (Plate 6, Figs. 1 and 4). These reefs not merely constituted in themselves a danger to vessels, but also imperilled navigation by causing rapid tidal currents in the narrowed channels between them, attaining in places a velocity of $8\frac{1}{2}$ knots an hour. Wrecks were consequently of frequent occurrence; and the name of Hell Gate was appropriately given to the locality. Three channels existed past the reefs, namely, the main ship channel to the north-west of the Heel Tap and Mill Rocks; the middle channel between the Mill Rocks and the Middle Reef; and the east channel between the Middle Reef and Astoria, from which Hallett's Reef projected; and vessels, after having traversed one of these channels, had to avoid Hog's Back and several smaller reefs to the north-east of Hallett's Point on their way to sea. Vessels approaching New York by the main channel had to make such a detour to avoid Heel Tap Rock, that they were liable to be drifted by the current towards Rylander's Reef: the eddy produced by Hallett's Point rendered the most direct east channel very difficult to navigate, for vessels in avoiding Hallett's Reef were in danger of being driven on to the Gridiron Rock of the Middle Reef; and the middle channel was narrow.

When the first proposals were made for improving Hell Gate, in 1848, the cost of removing submerged rocks was so great that the lowering of the most dangerous peaks, by surface blasting, was alone suggested; and this system was adopted between 1851 and 1853. After this no further steps were taken till, in 1867, General Newton reported in favour of a comprehensive scheme of improvement by the removal of Hallett's Point, Middle Reef, and several smaller rocks, to a depth of 26 feet at mean low-water; and he

proposed that Pot Rock, Frying Pan, Way's Reef, and Shelldrake should first be removed, and that the more extensive improvements suggested should be deferred till cheaper processes were devised by extended experience.¹ Works were undertaken in 1868-9 for the removal of the four smaller reefs above mentioned, which originally had depths of only from 5 to 9 feet of water over them, and had been lowered from 8 to 12 feet, in 1851-3, by exploding cans of powder placed in contact with the rock, at a cost of £2,420. The areas of these rocks at the 26-foot contour, and their contents above that depth, together with Heel Tap Rock whose removal was recommended, were estimated in 1867 as follows:—

	Area. Square Yards.	Contents. Cubic Yards.
Pot Rock	1,347	1,170
Frying Pan	1,386	1,910
Way's Reef and Shelldrake	689	1,640
Heel Tap	2,555	1,960

Surface blasting involved a large expenditure of explosives in proportion to the results obtained, and was only applicable to slender projections which were the first removed. Holes had to be drilled for the explosives in attacking the broader and flatter portions of the reefs. General Newton had originally proposed to work the drills from staging; but the prospect of injury to the staging from drifting vessels led to the construction, instead, of a very strong timber steam scow,² capable of withstanding collisions, a necessary precaution, as in one year sixteen vessels collided with the scow with such force as to sink. The scow was provided with apparatus for working the drills, and built with a well in the centre, 32 feet in diameter, through which twenty-one drills could be worked; and an iron hemispherical dome, 30 feet in diameter, was lowered on to the rock, through the well, for the purpose of protecting the men when working in a strong current. The scow was first used in the winter of 1870-71. The cost per cubic yard of rock drilled, blasted, and removed, was £3 17s. at Way's Reef, and £4 12s. 6d. at Heel Tap Rock.

The removal of Hallett's Point was determined on in 1869; and eventually the remainder of General Newton's scheme was approved, consisting in the union of the middle and east channels by removing

¹ "Report from the Secretary of State for War," (United States) 1868, part ii., p. 730.

² Minutes of Proceedings Inst. C.E., vol. lviii., p. 385; and "Scientific American," July 19, 1879.

the Gridiron, Flood, and other rocks of the Middle Reef to a depth of 26 feet at mean low-water, (Plate 6, Fig. 4), so as to increase the width of channel from 600 to 1,200 feet, obliterate these dangers to navigation, and reduce the current to 4 knots; the removal also of the Heel Tap and other minor rocks to the 26-foot depth, and the construction of sea walls on the Hog's Back and the Great and Little Mill Rocks formed part of the scheme. The cost of lowering these rocks by surface drilling, blasting, and removing débris, was estimated in 1867 at £9 4s. 6d. per cubic yard, giving a total cost of £1,810,970. This method of execution, however, whilst suitable for small detached reefs, would have been slow and costly for the large areas of Hallett's Reef and Flood Rock. Accordingly the plan of sinking a shaft in the reef, driving a network of galleries under the rock throughout the area within the 26-foot contour, leaving pillars for supporting the roof, and finally shattering the roof and pillars by the simultaneous explosion of a number of cartridges placed in them, was adopted for Hallett's Point and Middle Reef, the débris of rock being subsequently removed by grapple dredgers down to the requisite depth. (Plate 6, Figs. 1, 2, 3, 5, and 6.) By this modification, the estimated average cost per cubic yard of rock removed was reduced to between 62s. and 93s., and the total estimate to £977,050, or little over half the original estimate. The period required for the work was reckoned at ten years.

Hallett's Point.—Work was begun at Hallett's Point in 1869 by enclosing a portion of the reef, which was dry at low-water, within a strong cofferdam connected with the shore at both ends (Plate 6, Fig. 2); and the sinking of a shaft within the protection of the cofferdam was commenced the same year; but the completion of the shaft, to a depth of 33 feet below mean low-water, was delayed till late in 1870, owing to want of funds. Tunnels were then driven radiating from the shaft, intermediate galleries were formed in the wider intervals, and cross galleries were constructed as shown on the plan (Plate 6, Fig. 2). The galleries extended under the whole of the reef within the 26-foot contour, which stretched out 325 feet from the shore and covered an area of 3 acres; their total length was 7,425 feet, and the roof was supported by one hundred and seventy-two pillars. The drilling was at first done by hand; but steam drills were introduced in 1871. The greatest rate of progress occurred in 1872–73, during which year 2,731 feet of galleries were driven, and 9,554 cubic yards of rock were removed. The progress, however, was necessarily slow, as shallow holes and small charges had to be used, owing to the small

thickness of rock above the workmen, and owing to the small adhesion between the dipping strata of rock, consisting of foliated hornblende gneiss with numerous veins of quartz. Moreover the work was delayed by the insufficiency of the yearly appropriations granted by Congress; so that the work of preparation for the explosion, which might have been completed in four years, extended over six years and ten months. The galleries were completed in June 1875, the excavations amounting to 49,480 cubic yards; and the drilling of holes for inserting the cartridges in the roof and piers was then commenced. The roof was left 20 feet thick in places where the rock was unsound, and elsewhere varied from 6 to 15 feet; whilst the columns averaged 10 feet in thickness, and were from 8 to 22 feet high. The holes were placed from 6 to 10 feet apart; 5,375 3-inch holes were drilled in the roof, and 1,080 3-inch, and 286 2-inch holes in the piers; the 3-inch holes averaged $8\frac{3}{4}$ feet in length, and the 2-inch holes $6\frac{3}{8}$ feet: they were completed in March 1876.

Experiments during the progress of the work showed that as much rock could be broken with 10 ounces of rendrock or vulcan powder as with 8 ounces of nitroglycerine, whilst their cost was less than half that of nitroglycerine; and also the use of the pure liquid explosive was less convenient than its solid compounds. Accordingly dynamite, rendrock, and vulcan powder were used in the cartridges for the final explosion. Altogether, 9,127 lbs. of rendrock, 11,853 lbs. of vulcan powder, and 28,935 lbs. of dynamite, giving a total of 49,915 lbs. of explosives, were employed for shattering the 63,135 cubic yards of rock contained in the roof and piers.

As the reef was near inhabited buildings, it was important that the shock caused by the explosion should be as small as possible. It was estimated that the shock transmitted through the roof and piers to the shore would be mainly due to the charges required for their disruption, and that the effect of the additional charges for breaking up the rock might be neglected; and that by keeping down the amount of the individual charges, and giving each their full proportion of useful work, the shock would be immaterial. In order also to prevent a concentric explosion, due to the convergence of the galleries towards the shore, the charges were increased towards the outer zones, giving immediate vent through the roof, and causing a somewhat dispersive explosion which threw some of the débris beyond the reef. On the average, 0.97 lb. of explosive was required to dislodge a cubic yard of rock in enlargements, from which the formula

$C = 0.038 L^3$ was obtained, giving the charge C of explosive in lbs. for the holes in the roof, where L is the line of least resistance in feet. The charges for the holes above the piers were calculated by the formula $C = n L^3$, where n was made successively 0.038, 0.05, and 0.06 from the shaft outwards.

The explosives were placed in tin cartridge cases, varying in diameter from $1\frac{3}{8}$ to $2\frac{1}{2}$ inches to suit the tapering holes; and 4,427 holes were charged with 13,596 cartridges, mostly 22 inches long. The priming charges of $\frac{3}{4}$ lb. were next inserted, placed in brass tubes and containing a detonating fuse of 20 grains of fulminate of mercury. The firing was effected by means of 23 zinc and carbon batteries, each of which served for 160 mines divided into eight groups of twenty each. General Newton describes in detail, in his Report of December 1876, the method he adopted for each set of 160 mines, to ensure the simultaneous discharge of the whole system.¹ The lead-wires of each group were connected with one pole of the battery, and the other pole was attached to a brass pin; whilst the return-wires were connected with a brass cup containing mercury. The twenty-three brass pins of each set protruded through a wooden disk suspended by a cord over a set of the mercury-cups. The cord was attached to a dynamite cartridge which, when fired by electricity from the shore, severed the cord, causing the pins to fall into the cups, and thus completed the circuit for all the batteries simultaneously, which, by aid of a small platinum wire placed in each detonator, exploded the mines. The actual number of mines fired by the batteries was 3,640, as the current failed for two groups at the last test, raising the number of unconnected mines, exploded merely by concussion, to 822.

The galleries and shaft were flooded by means of a 12-inch siphon on September 23rd, 1876, and the explosion was effected on the 24th. Spray, mingled with vapour and gases, rose 123 feet at the highest point; but the volume of water raised was small, no windows were broken, and the transmitted land-tremor was slight. The débris of the 63,135 cubic yards of solid rock shattered by the explosion measured 87,000 cubic yards. The proposed plan of excavating a receptacle large enough to receive the whole of the débris, which was partially carried out at Blossom Rock, would have involved the removal of all the piers, replacing them by more slender supports, and the formation of a cavity having a volume $1\frac{1}{2}$ times that of the solid contents of the roof; and it was considered

¹ Report of the Chief of Engineers (U.S.A.) for 1877, part i., p. 237.

both safer and more economical to remove the débris, down to the depth of 26 feet, by grapple dredgers. As only blocks of 5 tons could be easily raised, and blocks exceeding 10 tons could only be lifted under favourable conditions, a good deal of the rock had to be reduced in size by surface blasting, increasing the cost from 9s. 6d. to 14s. per ton. The removal of the débris, amounting to 90,588 tons (equal to 45,294 cubic yards), was completed in March 1882, having cost on the average 11s. 6d. per ton. The expenditure on the galleries and the explosion was £198,355; and the cost of removing the débris was £52,065; so that the total cost of the removal of Hallett's Point amounted to £250,420.

Middle Reef.—The success of the system adopted at Hallett's Point was so fully assured in 1874, that General Newton urged the commencement of a similar work for lowering the Middle Reef. This Reef, frequently termed the Flood Rock, which formed its most prominent excrecence and in which the shafts were sunk, contained also other projecting rocks called the Gridiron, Hen and Chickens, and Negro Heads, and covered an area of 9 acres above the 26-foot contour (Plate 6, Fig. 1.). Work was commenced in June 1875 by sinking two shafts 65 feet apart, the larger shaft being made 10 feet by 20 feet, and carried down 60 feet below mean low-water, and the smaller shaft 12 feet square. A series of parallel galleries were then driven, with other galleries at right angles, under the whole area to be lowered (Plate 6, Figs. 5 and 6). The work was carried on irregularly owing to deficiencies in the appropriations granted: the greatest advance of the galleries was accomplished in 1880–81, amounting to 7,312 feet; and the maximum excavation, of 21,870 cubic yards, in 1881–82; whilst in 1877–78 the works were suspended, and in 1883–84 the work was almost wholly confined to pumping to keep the galleries from being flooded. As the surface of Flood Rock above water was small, the materials from the earlier excavations were deposited between it and the Gridiron, providing an area of 2,600 square yards for the erection of the machinery. The total length of the galleries was 21,669 feet; they averaged 10 feet by 10 feet in section, but varied in places from 4 to 33 feet in height. The roof, from 10 to 20 feet thick, and averaging 18·8 feet, owing to the risk of an inrush of water if it had been made thinner, was supported by 467 pillars about 15 feet square and 25 feet apart. The amount of rock excavated was 80,232 cubic yards, requiring 2·3 lbs. of explosive and 11·97 feet of drilling for each cubic yard, owing to the great caution needed to avoid breaking into large seams in the rock; whilst the contents of the roof and pillars to be shattered, to a

depth of 30 feet, amounted to 270,717 cubic yards. The galleries were not completed till 1884-85, being delayed by want of funds, and by the uncovering of a seam near the north end, which discharged large quantities of water. One seam encountered was 10 inches wide and 100 feet long; and another, from 1 to 4 inches wide, extended right across the reef, over 400 feet in length; they were filled up with Portland cement as they were opened out.

The drilling of the holes for the final explosion was commenced in May 1882. The holes had a diameter of about 3 inches, and averaged 9 feet in depth; 772 holes were drilled in the pillars, extending down to 33 feet below mean low-water, and 11,789 holes in the roof, being placed about 5 feet apart in the pillars and 4 feet in the roof, at angles respectively of 45° and 60° . The cost of preparing the mine for the reception of the final charge, per cubic yard of rock eventually broken up, was only 11s. 2d., as compared with 33s. at Hallett's Point.

The charging of the holes was commenced at the end of July 1885. Rackarock, composed of seventy-nine parts of potassium chlorate and twenty-one parts of nitrobenzol, was used instead of dynamite for the bulk of the cartridges, as its ingredients, being harmless previous to their admixture, could be stored in large quantities, and conveyed, without danger, to Great Mill Rock where the mixing was done.¹ The great value of this kind of explosive, composed of a solid and a liquid, consists in the facility and safety with which the mixture of the ingredients is effected by the simple absorption of the liquid by the solid; whereas two solids, equally harmless apart, could not be thoroughly mixed, on the spot, in large quantities to form a similar explosive, without such great risk as practically to prohibit the adoption of the process. Rackarock, moreover, is an inert explosive, and whilst costing little more than half as much as dynamite, it possesses somewhat greater efficiency under water. The holes were nearly

¹ This explosive was invented in 1870 by Dr. H. Sprengel, F.R.S., a German chemist resident in London, who first suggested and investigated a series of explosives of this class ("Chemical News," vol. lii., p. 215). He patented this and other safety-explosives of the same type in England on April 6th and October 5th, 1871; and described them fully in the "Journal of the Chemical Society," 1873, under the title, "On a new class of explosives which are non-explosive during their manufacture, storage and transport." Mr. S. R. Divine, of New York, claims to have invented this explosive about the same time ("Chemical News," vol. lii., pp. 271 and 295); but he appears not to have published or patented it till 1880. (See Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 351; and "The Hell-Gate Explosion and so-called 'Rackarock,'" by H. Sprengel. London. E. and F. N. Spon. 1886.)

filled with 6-lb. rackarock cartridges, 24 inches long and $2\frac{1}{4}$ inches in diameter, the cases being made of copper 0.005 inch thick (Plate 6, Fig. 9). An exploder was inserted in the outer end of each cartridge, consisting of a tube containing dynamite, in which was another tube filled with 30 grains of fulminate of mercury (Fig. 7). A 3-lb. dynamite cartridge, 15 inches long and $2\frac{1}{4}$ inches in diameter (Fig. 10), was last inserted in each hole; and its end, containing a 30-grain fulminate exploder, projected about 6 inches out of the hole (Fig. 12). Four brass wires were fastened at the end of each cartridge, which projecting outwards pressed against the side of the hole and kept the cartridge in its place. Each cartridge, when filled, had its lid soldered on by an alloy whose melting point was 160° Fahrenheit.

The 42,500 cartridges placed in the holes, containing 240,399 lbs. of rackarock and 42,331 lbs. of dynamite, were exploded by sympathy, being unconnected with the batteries used for firing the mine. The primary explosion was effected by five hundred and ninety-one exploders placed along the galleries at intervals of 25 feet, as it had been proved by experiment that a 10-lb. charge of dynamite would discharge with certainty, under water, another charge of dynamite in a thin elastic case at a distance of 27 feet. The exploder consisted of a brass cylinder, 8 inches long and 2 inches in diameter (Plate 6, Fig. 11), filled loosely with $\frac{1}{2}$ lb. of dynamite so as not to be affected if water should get in, into which the fuse was inserted, consisting of a copper tube containing 30 grains of fulminate of mercury, in which a second tube fitted holding the two conducting wires, which were held in place by a packing of sulphur, and were connected at their ends by a small platinum wire inserted in the fulminate (Fig. 8). The brass cartridge was tied on to two thin copper cartridges (24 inches by $2\frac{1}{4}$ inches), packed tight with 10 lbs. of dynamite so as to explode by sympathy if the fuse should fail; and these cartridges were lashed on a beam fixed across the gallery at a height of from 3 to 12 feet above the floor according to the height of the gallery (Plate 6, Fig. 12). The exploders were arranged in twenty-one circuits of twenty-five each, and three circuits of twenty-two each; and adjacent exploders were placed on different circuits, so that they might explode by sympathy, if one of the circuits failed. All the circuits were simultaneously closed by the arrangement shown on Plate 6, Fig. 13. The carbon, zinc, and potassium bichromate battery comprised sixty cells, all coupled in one series, with two large cups of mercury forming the poles, into one of which the twenty-four lead-wires dipped. A third cup received the twenty-four return-wires, between

which and the second cup, forming the negative pole, the circuit closer was placed. The circuit closer consisted of a strong iron vessel containing mercury, in which stood a thin glass tumbler, also containing mercury; and the mercury in the vessel was connected with the negative pole, while the mercury in the tumbler was connected with the cup into which the return wires dipped, so that the glass of the tumbler alone prevented the completion of the circuits. A $\frac{1}{4}$ -inch iron rod, with a disk on the top, rested vertically with its point on the bottom of the tumbler. A 30-grain fuse was placed on the disk; and the firing of this fuse, by wires leading to a battery at Astoria, drove down the rod and, breaking the tumbler, closed the circuits.¹ An automatic arrangement was devised by Lieutenant Derby for firing the mine in the event of failure of the connection with Astoria, by which a slow flow of mercury into a cup connected with one pole would have raised the level of the mercury, in fifteen minutes, so as to come in contact with a suspended pin connected with the other pole, and thus have closed the circuit; but eventually this provision was dispensed with.

The flooding of the galleries was commenced by two siphons on October 9th; and the explosion was successfully effected at 11.13 A.M. on October 10th, 1885. The water rose in mass over the site of the reef, the spray shooting up in peaks at some points between 100 and 200 feet in height. An idea may be formed of the width and length of this action from the illustrations drawn from photographic views taken from Blackwell's Island and Astoria (Plate 6, Figs. 14 and 15). No loud report or great shock occurred; and the damage was confined to the breaking of a few panes of glass, the falling of some loose ceilings, and the shaking off of some loose bricks from a chimney at Astoria. A slight vibration was observed at Cambridge, Mass.; and vibrations were recorded at Harvard College, 185 miles distant, two hundred seconds after the explosion, indicating a rate of transmission of 4,900 feet per second. The cost of the final explosion was £22,190, which compares extremely favourably with the expenditure of £16,894 at Hallett's Point, considering that the blast was more than five times larger: this saving was due both to the employment of rackarock, and to the sympathetic method of explosion adopted. The total cost of breaking up the Middle Reef, per cubic yard of rock mined and shattered, was 12s. 5½d., making the total expenditure £218,612 hitherto. The rock shattered by the final explosion, however, has

¹ "The Sanitary Engineer," New York, December 3rd, 1885, p. 10.

still to be dredged away before the contemplated improvement in the channel can be fully realized. The first contract, for the removal of 30,000 tons (15,000 cubic yards), has been let for 13s. 3½d. per ton; and it is estimated that the whole could be removed in three years' time if adequate appropriations are granted.

The success of the explosion at Flood Rock was complete, and the advantage of the system has been fully established; but it has been suggested that the cost of the work of mining under Middle Reef was greater than at Hallett's Point; that a portion of the final explosion was of the second order, as indicated by the coloured fumes observed; and that the rock has not been sufficiently broken up.¹ The first objection is at variance with the official figures given above. With regard to the second objection, Lieutenant Derby states that he has often observed fumes in exploding dynamite or rackarock under water; and that if not naturally a product of an explosion of the first order, they are probably due to the action of these products, at a high temperature, on the finely-divided water. The price of the initial dredging seems to indicate that the rock has not been so much broken up as at Hallett's Point; but, on the other hand, Lieutenant Derby considers that the top layer is the most difficult to remove. Moreover, though the greater thickness of roof at Flood Rock has probably caused a larger proportion of explosive, per cubic yard of rock, than at Hallett's Point (1·04 lbs. as compared with 0·79 lb.), to produce a less thorough breaking-up of the rock, it is likely that prudential considerations led General Newton to limit the charge in the case of an explosion of unprecedented magnitude, preferring an increased cost in subsequent dredging to the risk that might be incurred in fully breaking up the rock by a greater explosion.

The total estimated cost of the Hell Gate Improvement Works, including also the expenditure incurred in lowering Diamond and Coenties reefs in New York harbour, and a reef near the North Brothers in Long Island Sound, amounted to £1,070,650, of which £736,700 had been appropriated at the end of June, 1884, leaving £333,950 at that date still to be expended.² The works, when

¹ "The Engineering and Mining Journal," New York, October 24, 1885, pp. 288-291.

² The Author has obtained many details about the Hell Gate Improvement Works from General Newton's yearly reports from 1867 to 1884, published in the Reports of the Chief of Engineers (U.S.A.); and he has gathered several particulars about the Flood Rock, or Middle Reef, works from an article by Lieut. G. McC. Derby, engineer officer in charge of the works, published in the "Sanitary Engineer" (New York), Dec. 3, 1885. He is also indebted to the

fully completed by the removal of the débris on the Middle Reef, will afford New York an excellent direct channel to the ocean through Long Island Sound.

"Scientific American," Oct. 10, 1885, for some details about the cartridges used at Flood Rock, and to Mr. T. J. Long, M. Am. Soc. C.E., for photographs of the explosion. Accounts and illustrations of the works will also be found in the "Engineering and Mining Journal," Sept. 30, 1876, and Oct. 24, 1885; the "Scientific American," July 25, and Oct. 17, 1885; "Engineering News," Oct. 17, 1885; the "New York Herald," Oct. 11, 1885; the "Daily Graphic," Oct. 10, 1885; and in "Engineering," vol. xxii., p. 346, and vol. xl., p. 143; and the "Engineer," vol. xlii., p. 217.

Fig. 12.
FUSES AND FIRING CARTRIDGES IN PLACE.