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*(Paper No. 2157.)***“Dredging Operations and Appliances.”**

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IN all projected schemes for either the construction of harbours, docks, and canals, or for river-improvements, one of the most important questions to be taken into consideration is that of the dredging operations, and the form of appliances best suited for the existing conditions and requirements. The Author therefore proposes, first to mention briefly the nature of the different conditions and circumstances which render dredging operations necessary; and secondly, to describe the different appliances which have been used in connection with these operations.<sup>1</sup>

Dredging operations are generally carried out for the following objects, viz. (1) To prepare the surface of the ground under water for receiving the foundations of some structure, such as a breakwater, pier, quay-wall, or bridge-piers; (2) for deepening or widening some existing canal or river; (3) for cutting a new river-course, canal, or channel, or diversions of existing ones;

<sup>1</sup> Besides giving the results of his own experience and descriptions from published accounts, he is indebted to the following engineers for supplying him with information, or giving him every facility for obtaining it; viz. Mr. G. Fosbery Lyster, M. Inst. C.E., Engineer-in-Chief to the Mersey Docks and Harbour Board; Mr. R. A. Marillier, M. Inst. C.E., Engineer-in-Chief to the Hull Dock Company; Mr. H. H. Wake, M. Inst. C.E., Engineer to the River Wear Commissioners; Mr. P. J. Messent, M. Inst. C.E., Engineer to the River Tyne Commissioners; and Mr. W. Smith, M. Inst. C.E., Engineer to the Aberdeen Harbour Commissioners. Several of the patentees and manufacturers of special appliances, also, have kindly supplied him with drawings and information, and lent him their models.

(4) for removing obstructions to navigation, such as a bank or bar at the mouth of a river, harbour, or dock; (5) for removing the deposits which accumulate from different causes after any of the above works have been executed.

Wherever large amounts of material must be removed for forming or deepening a channel, it is expedient, if possible, by suitable works, to obtain the aid of natural scour for supplementing or dispensing with dredging. Thus, whereas the Suez Canal had to be constructed by excavation and great dredging operations, the improvements at the mouth of the Mississippi have been accomplished by training-works, and the resulting natural scour of the river. Dredging, in fact, should not be adopted where nature can be induced to do the work.

In nearly all works where excavations are dependent upon dredging alone, silting gradually takes place, and the dredging operations have to be continued for maintaining the channel; whilst, if a natural scour can be induced by the dredging, the works are more likely to be permanent. For instance, if it was attempted to form a channel through the bar of the Mersey by dredging alone, the result would be continued silting, and most probably, in this case, as rapidly as the excavations were made.

The bar which existed at the entrance to Carlingford Lough forms an exception to the above rule; for although it was removed by dredging alone, it is most probable that the removal is permanent. That bar, however, was not formed, like many bars, by the matter in suspension being deposited in the slack water caused by the meeting of two currents of water, but was evidently a continuation of the land formation into the sea, as it consisted of very stiff clay mixed with large boulders.<sup>1</sup> The bar at the entrance to Dublin Harbour was removed entirely by induced scour, caused by the construction of the south and north walls.<sup>2</sup>

Two of the most noted examples of extensive dredging operations and training combined, are those which have been carried out on the Clyde and on the Tyne; but much more interest attaches to the results on the Tyne, on account of the more permanent character of the improvement, and of the very short time occupied in carrying them out, compared with those on the Clyde.

In Glasgow harbour,<sup>3</sup> the depth at high-water has been increased from 5 feet 8 inches to 26 feet, and at low-water from 18 inches

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xlv. p. 132.

<sup>2</sup> *Ibid.*, vol. lviii., p. 104.

<sup>3</sup> Evidence of Mr. James Deas before the Select Committee of the House of Commons on the Manchester Ship Canal Bill, 1883.

to 15 feet; and although the various works of improvement on the Clyde have been in progress for nearly one hundred and thirty years, the present condition of the river is almost entirely due to the later dredging operations, about 60 million cubic yards having been removed within the last forty years. This improvement, however, cannot be called permanent, for a fleet of heavy dredgers is still necessary to maintain the channels; and about a million and a half cubic yards of material are dredged annually.

The works on the Tyne have produced more permanent results; and they have been mostly carried out since 1861, for the improvement of the river for a distance of  $19\frac{1}{4}$  miles from the bar. Before that time, the depth over the bar at low-water was not more than 6 feet; it is now from 20 to 24 feet. The nature also of the river, from the mouth to Wylam, has been almost entirely changed; vessels of 27 feet draught can now enter the river; the interval between the times of high-water at different points has been greatly decreased; the flood-line has been lowered considerably; and the scour has been greatly increased by the flow of a greater amount of tidal water into the river. These improvements have nearly all been effected, within the space of twenty-five years, by the aid of training-walls, piers, or breakwaters, the removal of obstructive rocks in the estuary, and by dredging, the latter operations no doubt contributing the most to the success. Since the year 1862, 46,000,000 cubic yards have been excavated by dredging. The deep water is being extended higher up the river; and to accomplish this, and maintain existing channels, extensive dredging operations are still being carried on.

The dredging for removing silt from docks involves often a large annual outlay; and it might be greatly reduced by preventing the influx of muddy tidal water, and replenishing the water in the dock, from some clear source, by pumping or other means. This plan has been successfully adopted by Mr. Abernethy, Past-President Inst. C.E., in the new Alexandra Dock at Hull; but unless the conditions of the site are particularly favourable for such a scheme, the first cost would swamp a small undertaking.

Another very important point is the disposal of the dredgings, which, under the most favourable conditions, is often a much more expensive operation than the dredging itself. Where the dredging is carried on outside a harbour, or very near to the open sea, there cannot be any dispute as to where the dredgings should be discharged; but where the operations are carried on many miles up some estuary, or broad river, opinions seem to differ. The natural temptation is to discharge the mud barges, or lighters, into the

deepest part of the estuary or river, on account of the great extra cost of taking them out to sea ; but, as a rule, the conservators of the river object to this, and insist upon their being taken away to sea, for fear of banks being gradually formed and navigation impeded. The disposal of the dredgings must depend upon the velocity and volume of the tidal water, the amount and character of the matter in suspension, the existence of a bar or otherwise, the nature and quantity of the dredgings, and the form of the estuary. In some cases, however, the dredgings are utilized for filling in, and making banks, as, for instance, in the construction of the Suez Canal.

#### DREDGING APPLIANCES.

The earliest recorded dredging operations appear to be those carried on by the Italians and by the Dutch ; and to the latter people we no doubt owe the introduction of the first dredging apparatus, commonly known as the "bag-and-spoon dredger." Although this dredger is very primitive in its design, yet it has been in constant use till within a very few years ; and even now a very similar arrangement is occasionally used for removing the accumulated deposits behind dock-gates.

The first dredging machine which was worked by steam-power,<sup>1</sup> as far as the Author has been able to ascertain, was that made in 1796 for cleansing Sunderland Harbour, the engine being made by Messrs. Boulton & Watt, of Soho, Birmingham.<sup>2</sup>

Since that time, numerous dredgers have been designed to meet different requirements ; but it cannot be said that the remarkable improvement which has characterized the development of many other classes of machinery, has been realized in the modern dredger ; for there is much to be accomplished yet, before a really efficient machine for heavy work is designed.

The different appliances may be classed as follows, viz.—(1) Miscellaneous dredging apparatus ; (2) Sand-pump Dredgers ; (3) Dip or Bucket Dredgers ; (4) Bucket-Ladder Dredgers ; (5) Hopper Dredgers ; (6) Hopper Barges.

<sup>1</sup> Encyclopædia Britannica, ninth edition, vol. vii. p. 464, "Dredging."

<sup>2</sup> The present firm, Messrs. James Watt and Company, have kindly supplied the Author with the following information about this dredger :—

"Our firm supplied, in 1796, a beam-engine, having a steam cylinder, 12½ inches in diameter, and 3 feet stroke, for working the spoons, which were previously worked by men, for cleansing Sunderland Harbour. These spoons were in the form of a truncated cone, the narrow end of which was closed ; and to the other, or open end, was fixed a spade bit. They were made of a hide of leather, having an iron rim. The engine was to be fixed in a boat, 20 or 22 feet wide by 60 feet long."

## MISCELLANEOUS DREDGING APPARATUS.

Under this head, several machines or appliances will be described, which perhaps can hardly be called dredgers, although they are used for cleansing and deepening rivers and harbours.

*Kingsfoot's Dredger.*<sup>1</sup>—Mr. Hays has described a very ingenious arrangement which was used for cleansing the River Stour. It consisted of a boat, with a broad rake fitted to the bow and capable of adjustment to different depths; at the sides of the boat were hinged two wings, of the same depth as the rake, and in a line with it. When the rake was dropped to the bottom of the river, and the wings extended to the side, they formed a sort of temporary dam, and the water began to rise gradually. As soon as a sufficient head was raised, varying from 6 to 12 inches, the whole machine was driven forward by the pressure, and the rake carried the mud along with it. A progress of about 3 miles an hour was made in this manner; and to prevent the accumulation of the dredgings, operations were commenced at the mouth of the river, and carried on backwards. The apparatus was very effective, and the river was cleansed thoroughly; but the distance travelled by the dredger must have been very great.

*Rietschoten's Propeller Dredger.*<sup>2</sup>—In 1876, J. J. van Rietschoten designed an apparatus for removing the shoals in the River Maas, and called it the "Propeller Dredger." It consisted of an old gun-boat fitted with a pair of trussed beams, one on each side, which carried a steel shaft, and were capable of being lowered or raised by means of a crab on board. An ordinary propeller, 3 feet 6 inches in diameter, was fixed to the lower end of each shaft; and by means of bevel-gear at the top, they were driven from a cross shaft by belting from the fly-wheel of a portable 12 HP. engine. The propellers were lowered until they nearly touched the shoals, and then set in motion at a speed of about 150 revolutions per minute. This operation scoured away the shoal most effectively; for in about forty minutes, it had been lowered 3 feet over a space 150 yards long by 8 yards wide.

*Lavalley's Injection and Suction Dredger.*<sup>3</sup>—Owing to the great difficulty of working an ordinary bucket-ladder dredger when there is even a small swell, Mr. Lavalley, in 1877, designed an arrangement for the harbour of Dunkirk, to overcome this

<sup>1</sup> Transactions Inst. C.E. vol. II. p. 181, and Plate 15.

<sup>2</sup> Minutes of Proceedings Inst. C.E. vol. lviii. p. 145.

<sup>3</sup> *Ibid.*, vol. lvi. p. 336.

difficulty. A pump injects water into the sand, down a pipe terminating in three nozzles, to stir up the sand; and another centrifugal pump draws up the mixed sand and water, and discharges it into a hopper, the pumps and all machinery being on board the hopper. To allow for the rising and falling of the vessel, either by the action of the tide, or by a swell, the ends of the pipes are made flexible. The hopper has a capacity of 190 cubic yards, and is propelled, and the pumps are worked, by an engine of 150 HP. From 50 to 80 cubic yards per hour can be raised by this dredger.

*The Aquamotrice.*<sup>1</sup>—This apparatus, designed by Mr. Popie, was used on the Garonne at Agen, and appears to be a modification of the old bag and spoon arrangement. A flat-bottomed boat, 51½ feet long by 6½ feet wide, was fitted at the bow with paddles, which were actuated by the tide. Connected with the paddles was a long chain, passing over a pulley on uprights, and under a roller; and a beam was attached to the chain, 14 feet 8 inches long, passing through a hole in the deck. At the end of the beam was an iron scoop, 2 feet wide and 2 feet 6 inches deep. When the tide was strong enough, it drew the scoop along by means of the paddles and chain; and the scoop, when full, was discharged by means of a lever opening it. About one discharge of the scoop was made every minute; and 65 cubic yards of gravel could be raised in twelve hours. When the tide failed, men worked the apparatus with a windlass.

*Rake Dredger on the Danube.*<sup>2</sup>—The Danube Steam Navigation Company removed the shingle in the shallow parts of the river by means of a triangular rake, with wrought-iron sides, 18 feet long, and fitted with thirty-four teeth of chilled cast-iron, 12 inches deep. This rake was hung over the bow of the steamer, 180 feet long by 21 feet beam, and dragged across the shallows, increasing the depth of water in one instance from 5 feet 6 inches to 9 feet, after passing over the bank three hundred and fifty-five times.

Mr. Bergeron has proposed a combination of the above raft and Mr. Lavalley's injection arrangement, for removing bars, namely, to have nozzles upon the rake, in connection with a force-pump; the jets of water would loosen the sand, and the rake would take it away.<sup>3</sup> The Author, however, cannot find any record of a practical application of this arrangement.

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<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xl. p. 318.

<sup>2</sup> *Ibid.*, vol. lx. p. 387, and Plate 17.

<sup>3</sup> *Ibid.*, vol. lviii. p. 132.

## SAND-PUMP DREDGERS.

*Woodford's Sand-Pump.*—One of the earliest applications of pumps for dredging was made by Mr. Woodford. It consisted of a horizontal disk, with two or more arms, working in a case, somewhat similar to the ordinary centrifugal pump. The disk was keyed to a vertical shaft, which was driven from above by means of belts, or other gear, coupled to an ordinary portable engine. The pump itself rested on the ground; the suction-pipe being so arranged that water was drawn in along with the sand or mud, the proportions of the two being regulated to suit the quality of the material. The discharge-pipe was rectangular and carried the vertical shaft; the whole apparatus being adjustable, to suit different depths of water. This arrangement was very effective, and has been used with advantage on many works in this and other countries.

*Burt and Freeman's Sand-Pump.*<sup>1</sup>—This pump is a modification of the "Woodford" Pump, and was used in the construction of the Amsterdam Ship-Canal, for which works it was designed. The excavations there had to be deposited on the banks, some distance away from the dredgers; and after being raised by the ordinary bucket-dredger, instead of being discharged into barges, they were led into a vertical chamber on the top side of the pump, suitable arrangements being made for regulating the delivery. The pump was  $3\frac{1}{2}$  feet in diameter, and made about 230 revolutions per minute; it drew up the water on the bottom side, and mixing with the descending mud on the top side, the two were discharged into a pipe, 15 inches in diameter. The discharge-pipe was a special feature in this work, and consisted of a series of wooden pipes, jointed together with leathern hinges, and floated on buoys from the dredger to the bank. In some cases this pipe was 300 yards long, and discharged the material 8 feet above the water-level. Each dredger and pump was capable of discharging an average of 1,500 cubic yards per day of twelve hours. A centrifugal sand-pump, designed by Mr. Hutton, was also used on these works.

*Schmidt's Sand-Pump.*<sup>2</sup>—This pump is supposed to be an improvement on the system adopted by Burt and Freeman on the Amsterdam Canal. It was designed by A. W. von Schmidt, and was used for dredging Oakland Harbour, California; the dredged materials

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. lxii. p. 23, and Plate 3, Figs. 7-9; and "Engineering," July 17, 1868, and November 8, 1872.

<sup>2</sup> Transactions of the American Society of Civil Engineers, 1884, p. 9.

being deposited on the banks, through floating-pipes, in a similar manner to that employed on the Amsterdam Canal. On the latter works, however, the material was first dredged, and afterwards pumped and discharged, thus entailing two distinct operations. In Schmidt's pump these two operations are combined in one in the following manner (Plate 1, Fig. 1). The ground was first cut up by means of a horizontal wheel A, 6 feet in diameter, on the underside of which were attached a number of ordinary plough-shaped cutters, the wheel being driven from above by a vertical shaft. Over this cutter a hood B was fixed, which just allowed the water to pass underneath; and to the top side of the hood was attached the 20-inch suction-pipe, C, of an ordinary centrifugal pump, 6 feet in diameter; the vertical shaft for driving the cutter working on the outside.

For driving the pump, an engine with two cylinders, 16 inches in diameter and 20 inches stroke, running at 134 revolutions per minute, was required. For driving the cutter, an engine with two cylinders, 12 inches in diameter and 12 inches stroke, running at 120 revolutions per minute, was used. The pressure of steam in both cases was from 90 to 95 lbs. per square inch. The material excavated, consisting of sticky, blue, clayey mud, was discharged through the pipes to a distance of from 500 to 650 yards; the best results being obtained when the proportion of mud to water was about  $6\frac{1}{2}$  to 1. The average quantity discharged per day was 1,300 cubic yards, and the maximum about 2,500 cubic yards.

*The Bazin Sand-Pump.*—Another form of centrifugal-pump dredger is that generally known as the Bazin dredger (Plate 1, Figs. 2, 3, and 4). This machine has been successfully used in France, Holland, and in this country at Lowestoft.<sup>1</sup> The apparatus which was used at Lowestoft was fitted to a boat, 60 feet long and 20 feet wide; the pump was 2 feet in diameter, and had a two-bladed disk. It was originally designed with four blades; but two of them having been broken off accidentally, it was found that the pump worked much more satisfactorily without them. The discharge-pipe was 12 inches in diameter, and, when the pump ran 350 revolutions per minute, it was capable of raising nearly 400 tons of sand, gravel, and stones per hour; but the average work was about 200 tons per hour. The engine had two cylinders, 9 inches in diameter and 10 inches stroke, and made 120 revolutions per minute. The pump could work in any depth

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<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. lxxxvii. p. 137; and Institution of Mechanical Engineers. Proceedings. 1882. p. 100.



from 7 to 25 feet. The most satisfactory results were obtained when working in sand or gravel; clay being too stiff for the pump to take up, and soft silt, being diluted with water, would not settle in time, and ran in suspension over the sides of the hopper barges. The best proportion of water to sand was found to be about 5 to 1.

An important addition was made to the disk by Mr. Ball, who, after trying several devices for protecting the disk and increasing the efficiency, secured a piece of thick india-rubber to the working face with very successful results.

In this, as in most other sand-pumps, it was found advisable to work it by belting, and not by gearing; for when the pumps got choked, and suddenly pulled up, the belt would yield, and so prevent any damage to the machinery.

*Kennard's Sand-Pump.*<sup>1</sup>—This arrangement is entirely different from those already described, and is a direct application of the ordinary lift-pump (Plate 1, Fig. 5). A wrought-iron box, A, has a suction-pipe, B, fitted at the bottom, rising about half-way up the inside of the box. On the top of the box is fitted the actual pump, C, and the flap valves DD. This apparatus was used principally in India for excavating the inside of bridge cylinders when sinking them. The apparatus was lowered by chains, and the pump actuated from above; and as soon as the box, A, was filled with sand, it was raised, the catches, E E, holding up the bottom released, and the contents discharged into a punt.

#### DIP OR BUCKET DREDGERS.

The origin of many of these machines is simply the action of an ordinary navvy's spade, and the one most like it is the Indian native "Jham"<sup>2</sup> (Plate 1, Fig. 6). This apparatus was used in India for excavating the inside of bridge cylinders. It consists of a large spade, A, about  $2\frac{1}{2}$  feet deep, and 2 feet wide at the top. Into the top of the spade was fixed a handle, B, which was also secured to the spade by a rod, C. The native stood with his feet on the top of the spade, holding the handle, B, firmly in both hands, and dived to the bottom, the spade entering into the ground. After pushing it in as far as his breath would permit him, he rose to the surface, and rested on a plank suspended from the top. The

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xxviii. pp. 334, 337, 345, and Plate 16, Fig. 4; and vol. liv. p. 77.

<sup>2</sup> *Ibid.*, vol. xxviii. p. 325, and Plate 16, Figs. 1 and 2.

gham was then hauled up by a rope, D, and the contents discharged. This primitive method of dredging has been superseded by many ingenious appliances, of which the principal ones will now be described.

*Ives's Excavator.*<sup>1</sup>—This excavator consists of a long weighted spear with a sort of large spade at the end of it. The spade is hinged at the top, and is capable of being turned at right angles to the spear, a chain being attached to the end of the spade for that purpose. The operation consists in driving the spade into the ground, and after releasing the catch which holds it in position during its descent; the spade is drawn up, at right angles to the spear, by the chain, carrying the material along with it, and is then raised to the top and discharged.

*Milroy's Excavator.*<sup>2</sup>—This apparatus has been extensively used, both in this country and in India, for excavating in bridge cylinders. Its action is very similar to that of Ives's excavator; but instead of having only one spade, it generally has eight, hinged to the periphery of an octagonal iron frame fixed to a central vertical rod. When these eight spades are drawn up by means of chains, at right-angles to the central rod, they form one flat table, or tray. In operation, the spades hang vertically, and are dropped into the material to be excavated; the chains are then drawn up, and the table thus formed holds the material on the top, which is lifted and discharged by releasing the spades. This excavator was successfully used in sinking the cylinders for the Glasgow Bridge.

*The Clam-Shell Dredger.*—This apparatus has been used to a large extent in America, both for dredging and for excavating in bridge cylinders.<sup>3</sup> It is different in its action from those previously described, and consists of two buckets, A A, which, when closed, form one semi-cylindrical bucket. There are many devices for opening and closing the buckets, but the one shown in Plate 1, Fig. 7, has been commonly adopted. The buckets are hinged to a side frame, B; at C, and at D, on each end of the bucket, is a pin carrying one end of the link E, the other end of the link fitting on the pin of the sliding block F, which slides in the slot of the side frame B. Joining these blocks, F F, is a cross-head G. On the bottom of the frames, B B, a shaft works, carrying the three pulleys H, I, H; a chain is fixed to the cross-heads, G G, and

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xxxix. p. 214, and Plate 12, Figs. 5-9.

<sup>2</sup> *Ibid.*, vol. xxviii. p. 329, and Plate 17.

<sup>3</sup> *Ibid.*, vol. lxiii. p. 265, and Plate 12, Figs. 1-10.

passed round the pulleys H H, and a chain passed the opposite way round the pulley I. The action of the machine is as follows: the buckets are held open by chains attached to the top of the cross-heads G G, and the machine is dropped on the top of the material to be dredged. The chains holding the buckets open are then released, the spears are held firmly in position, and the chain round the pulley I being drawn in, winds the chains round the pulleys H H, which in turn pull down the cross-heads G G, and so close the buckets by means of the links E E.

This dredger is a very useful machine, and is the origin of a number of appliances which have been since designed. It is also used in America for elevating grain.

*Bull's Dredger.*<sup>1</sup>—This dredger has been extensively used in India for dredging, and for excavating in bridge cylinders (Plate 1, Figs. 8 and 9). It is somewhat similar in action to the clam-shell, but simpler in its arrangement. The buckets, A A, when closed, form a semi-cylindrical bucket, and have the curved wrought-iron arms, B B, fixed to each end. The buckets are held open by the catch C, which can be released by the rope D. The hoisting chain, E, passes round the pulleys, F F, at the end of the curved arms B B; so that when the bucket has been dropped on to the material, the catch is released, and by hoisting the chain E, the ends of the curved arms are drawn together, and so close the bucket with the material inside, which is then drawn up and discharged.

*Gatmell's Excavator.*<sup>2</sup>—As Bull's dredger was found to be ineffective in dealing with clay, a foreman excavator, named Gatmell, devised an apparatus to overcome this difficulty.<sup>3</sup> This was simply a combination of the jham and Bull's dredger. The two special shaped jhams, A A, were hinged at B B, back to back, to a heavy frame C. The apparatus is shown in Plate 1, Fig. 10, in the act of descending; the sharp points of the jham are driven into the clay by the great weight of the apparatus, and then by hauling up the lifting-chains, which are arranged as in Bull's dredger, the jhams assume a horizontal position.

*Fouracres' Dredger.*—This apparatus consists of two segmental scoops or buckets, A A, hinged to a cross-head which, in the dredger used for soft silt or sand, is attached to the lifting-chain, and, in the machine for stiffer material (Plate 1, Fig. 11), to two wrought-

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xxxix. p. 213, and Plate 12, Figs. 1-4; and vol. liv. pp. 65, 83.

<sup>2</sup> *Ibid.*, vol. lxxv. p. 248, and Plate 3, Figs. 6-10.    <sup>3</sup> *Ibid.*, vol. xlviii. p. 103.

iron spears, B B, terminating in the spears, C C. Two metal collars, D and E, slide freely on the spears, the upper one being connected to the buckets by the light iron rods F F, and the lower one by the chains G G. One end of these chains is connected to the lower collar, and the other, passing through one of the sheaves H, is attached to the end of the angle-irons I I. These chains cross each other, and, when drawn up, tend to close the buckets, the angle-irons, I I, passing each other. These angle-irons slide against a friction-roller on the same pin which carries the pulleys H H. The main lifting-chain is wove round the sheaves inside the collar E, in the type shown; but in the dredger for light material it is fixed direct to the cross-head. Stops, J J, are provided to prevent the buckets from going too far back and getting jammed. The two buckets are held open by the floating catch K; and at the jib-head are two catches with sloping faces, which allow the clutch collar, D, to rise past them, afterwards preventing it from descending, and so take the whole weight of the bucket. In the small dredgers, the catch is released by hand; but in the large ones, it is worked by a small compressed-air or steam cylinder, and the spears, C C, are retained by a clutch-rack actuated by another compressed-air or steam cylinder.

The action of the dredger is as follows: the two buckets being held back by the floating catch K, the whole apparatus is dropped to the surface of the mud; this blow slightly opens the buckets and releases the catch K, when, through the action of the floating ball attached to the catch, it is thrown out of gear. In the large dredger, the spears are then gripped and the lifting-chain tightened, when, through the action of the sheaves and the chains G G, the bucket is closed, gradually enclosing the mud or sand. It is then raised, until held by the clutches L L, which, when the apparatus is lowered, cause the buckets to open, and so discharge their contents.

This dredger has been used very successfully in India on the Patna Canal<sup>1</sup> and other places.

*Bruce and Batho's Dredger.*—This dredger, when closed, is of the hemispherical form, the bucket being composed of three or four blades (Plate 1, Figs. 12 and 13). It can be worked either by a single chain, or by means of a spear, the latter being generally

<sup>1</sup> The leading dimensions of a Fouracres' dredger working on the Patna Canal are: length 50 feet, breadth 15 feet, depth 4 feet, mean draught 1½ foot, nominal HP. 6, capacity of bucket 16 cubic feet, greatest depth to dredge 8 feet; and the average quantity dredged per day with the machine was 135 cubic yards.

used for stiff material. The advantage of this form of dredger bucket is that the steel points of the blades are well adapted for penetrating hard material. The blades, A, are opened and closed by means of the rods B, which are attached to the cross-head, C, at one end, and to the top of the blade at the other, and form a kind of knuckle-joint with the inside rods D. The catches, E E, sustain the bucket when open; and in this position, it is dropped to the surface of the mud or clay (Plate 1, Fig. 12). Several ingenious arrangements are made for closing these blades; in Fig. 13, it is by means of a rod F, working inside the tube rod G, and actuating the knuckle levers D. In Fig. 12, it is by means of two chains actuating alternately the bottom and top cross-heads H and I, the spear being retained by a lever and cam arrangement, J, at the cross-head.

These dredgers have been used in many places, giving most satisfactory results with all kinds of material. On one occasion, in the Author's experience, one of these dredgers brought up a 70-lb. rail, 32 feet long, from the bottom of a dock.

*Priestman's Dredger.*—This dredger bucket<sup>1</sup> is of the clam-shell type, and is opened and closed by a similar arrangement to that already described; but Messrs. Priestman have devised a very neat arrangement for working the lifting, and opening or closing chains (Plate 1, Fig. 14). The cross-head, C, works freely in the wrought-iron frame D, and to it are attached the chains E E, which are wove round the drums F F; and to the top of the cross-head is attached the opening chain, G, which is passed over the jib-head to a combination of sheaves which take up the slack. The lifting chain is wound round the large drum H; and after the bucket has been dropped on the top of the mud, being held open by the chain E, the act of tightening the lifting chain turns the drum H, which, turning the drum F, draws the cross-head, C, down, thus closing the bucket.

This apparatus gives very good results for mud, gravel, and soft sand, and is also used for grain; but it cannot excavate hard sand or stiff clay, which is the general defect of this class of dredgers, unless they are not entirely dependent upon the force of the blow in falling, and the weight of the apparatus, for the penetration and grip of the material. A dredger of this type, with a bucket capable of holding one ton of mud, when working under the Author's superintendence, dredged during six days, in 19 feet of water, an average of  $52\frac{1}{2}$  tons, and a maximum of  $68\frac{1}{2}$  tons per

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. lxx. p. 310, and Plate 5.

hour; and during twelve days, in 16 feet of water, an average of 48 tons, and a maximum of 58 tons per hour; at a cost of 1·63d. per ton, exclusive of cost of discharging, interest on capital, and depreciation.

*Duckham's Pneumatic Dredger.*—Mr. F. E. Duckham, M. Inst. C.E., engineer to the Millwall Dock Co., has introduced a system of discharging the dredged material, which has been successfully adopted at the Millwall Docks and elsewhere. The material, after being dredged, is discharged into capacious cylindrical tanks on board the dredger, or on barges alongside. These tanks when full are closed by air-tight doors; air is then forced into them by means of special air-compressing engines, and the dredged material is discharged, either into the sea, or through long iron pipes on to the land. The apparatus used at the Millwall Docks consisted of an ordinary bucket-ladder dredger, 113 feet long, 27 feet beam, and 12 feet deep, with a loaded draught of 8 feet; and two cylindrical tanks were placed one on each side of the well, having a combined capacity of 240 cubic yards. The same engines were used for either propelling the vessel, dredging, or working the pneumatic cylinder; they were compound engines of 25 nominal HP.; and the pneumatic cylinder was 20 inches in diameter. The discharge-pipe was 15 inches in diameter, and 150 yards long, the pneumatic pressure being about 15 lbs. per square inch. From experiments made with one of the first apparatus constructed on the above principle, the Author found that, with clay or stiff mud, if the nozzles of the air-injection pipes were too small, the compressed-air, instead of driving out the material, simply pierced holes through it, escaping through the discharge pipe, and carrying along with it all the liquid and thin material in the tanks. This defect was easily rectified by re-arranging and increasing the size of the injection nozzles, and the apparatus now gives most satisfactory results.

#### BUCKET-LADDER DREDGERS.

The first bucket-ladder dredger appears to have been constructed for cleaning the Old Dock at Hull, now called the Queen's Dock. This dredger commenced to work about five years after the opening of the dock in 1778, and is described by Mr. Timperley in the Transactions Inst. C.E.<sup>1</sup>

The first bucket-ladder dredger driven by steam was designed

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<sup>1</sup> Transactions Inst. C.E. vol. I. p. 8.

for cleaning Sunderland Harbour.<sup>1</sup> Almost contemporaneous with this machine was one constructed for cleansing the Humber Dock at Hull, and designated a "Mud machine" in the records of the Hull Dock Company. It consisted of a square flat-bottomed boat, 80 feet long, 20 feet broad, and 5 feet draught. It had a single ladder with twenty-nine buckets, and was worked by an engine, with a cylinder 18 inches in diameter, 24 inches stroke, and making 40 strokes per minute. Under favourable conditions, it was capable of dredging 120 tons per hour; but the average work was 45 tons per hour.

To obtain the most favourable results with a bucket-ladder dredger, it should be designed for the work it has actually to perform; and the circumstances and conditions of each particular case should be taken into consideration.

*Single and Double Ladders.*—One of the first points to settle is whether a dredger should have a single, or a double ladder, each type having its own special advantages.

As a rule, the single-ladder dredgers are smaller machines than the double ones; though many of the powerful dredgers now working in British and foreign ports have single ladders. The single ladder has the advantage of being able to discharge into a barge, on either side of the vessel, by regulating the shoots; whereas, with a double ladder, each one can only discharge on its own side. The single ladder has thus an advantage in working near a dock-wall, or when one of the double ladders is disabled. In some dredgers with double ladders, a cross-shoot has been fixed to overcome this difficulty; but either this shoot must be at too flat an angle to carry off the material by gravitation, or the regular shoots are at too great an angle. As the ladder in a double dredger is nearer to the side of the hull than in a single one, it can work nearer to a dock- or quay-wall; but the difficulty of discharging still remains. This is partially met by working the dredger at an angle to the wall, when it is then possible to get in a small hopper-barge between the dredger and the wall; and if the ladder is well forward, or projecting at the ends, the dredging can be carried on close to the foot of the wall.

<sup>1</sup> The following is an extract from "Sykes' Local Record" of 1833:—

"October, 1811.—A very curious machine, for cleansing and deepening Sunderland harbour, was set to work. A steam-engine of great power was erected upon a floating barge, which continually drove round a number of iron buckets fastened to a chain, which filled themselves with sand and gravel at the bottom of the harbour, and successively emptied themselves at the top of the shaft into a spout ready to receive them. This machine could lift 55 tons of ballast in thirty-five minutes."

Single-ladder dredgers have been constructed with the ladder overhanging one side, so as to be able to work close to a wall; but there is not much gained by this arrangement, for it necessitates the raising of the shoot, to enable it to pass the material over the vessel to the mud barge, and consequently increases the height of the top tumbler.

If the material to be dredged is very stiff, it is possible the double dredger may have an advantage over the single one; for if the tumbler can be arranged so that the two buckets shall not be doing their heaviest work simultaneously, the power required to work two smaller buckets would probably be less than that required to work one of equal capacity to the two. The friction, however, would be greater with the two ladders, and might possibly outweigh any other advantage. For heavy work, double dredgers are certainly preferable; on the Tyne and elsewhere there are double dredgers working with buckets of 14 to 16 cubic feet capacity; and buckets of twice this capacity would be very unwieldy.

*Hull of Dredger.*—The form of the hull is dependent almost entirely upon the conditions of working the dredger. It may have to pass through a narrow dock entrance, or other opening, or it may have to work in a seaway; a narrow dredger would be required in one case, and a wide one in the other; and these two considerations affect the depth. The length of the dredger is dependent, in a great measure, upon the length of the ladder; though it may be constructed with an overhanging gallows. The strength of the frames, plating, &c., is of course dependent upon the work the dredger has to perform. In double-ladder dredgers, the ladder, in some cases, works clear on the outside; but in others, it works in a well. With the former plan, it is perhaps possible to dredge nearer to a wall, and the barges can get a little nearer to the shoots; but with the well, the vessel is decidedly more stable, and the ladders receive additional support when dredging, either radially as in an open seaway, or sideways as in a dock. With very long ladders, the forward end of the well has to be open to allow the ladder to be drawn up; but as this plan is objectionable, in one or two instances the ladder has been made with a hinge, so as partially to double up and pass through. If the dredger has to cut its own channel, as is often the case, the ladder must project beyond the bow of the vessel; and with this object in view a very novel arrangement has been devised and adopted by several makers, notably Messrs. W. Simons and Co. of Renfrew, and Messrs. Fleming and Ferguson of Paisley, whereby the top tumbler and bucket-ladder is constructed to traverse fore and aft on the upper framing, the bevil pinion



driving the tumbler shaft working on a feather key; by this arrangement the bottom end of the ladder can be brought a long distance in front of the dredger, thus enabling the channel to be dredged in advance.

*Engine and Boilers.*—The high-pressure compound marine engine and boiler gives very good results, and is now generally used. As the work of a dredger is very variable, it is very necessary to have an efficient automatic expansion-valve; and, what is of more importance still, a very heavy fly-wheel. By referring to the indicator diagram of No. 4a dredger (Plate 2, Fig. 10), the advantage of this is evident. The indicator diagram was taken when the buckets and all the machinery were in gear, with the ladder out of the water; and consequently the work being done was perfectly uniform, and there should have been only one line on the card. The indicated oscillation of the pencil was due to the governor balls being made too light; and had it not been for the action of a heavy fly-wheel, damage would no doubt have been done to the gearing. After this card had been taken, the governor was weighted, and a diagram with a steady line was then obtained. The suction-pipe for the circulating and feed pumps should not be taken from the well, which is conveniently situated, but from the after-end of the vessel, the water being there much clearer than that in the well, on account of being farther away from the buckets. It is very necessary to have convenient indicator-gear fixed to the engines, and that cards should be periodically taken to ascertain the condition of the cylinders and valves.

*Driving and hoisting gear.*—The top tumbler is driven from the main engine, either by means of spur-gearing or by a countershaft and bevel gearing, the latter making the most convenient arrangement. This gearing should be thrown in and out of gear by means of a friction-clutch, so as to take the strain gradually; and, in addition to this, there should be a safety friction-clutch for each tumbler, so adjusted, that when an abnormal strain comes on the buckets, as when fouling wreckage, &c., the clutch will slip, and prevent an accident to some part of the machinery.

For driving the hoisting gear of the ladders, separate engines are sometimes used; but generally a countershaft is taken from the main engine. This latter plan has many advantages; and although it entails the constant running of a shaft which is only used occasionally, it is a very satisfactory arrangement. The master of the dredger has to keep a constant look out upon his buckets; and by the quantity of material in them he can tell whether to raise or lower his ladder. In either case, he has to

release the brake first; and this action has caused more damage to the hoisting gear than almost anything else, for it is almost impossible to release the brake and then commence hoisting immediately; the consequence is, that either the hoisting gear is put into gear with the brake on, or the brake is released first, and the ladder gains considerable impetus before it is checked. In each case there is a sudden check on the gearing, which is often very disastrous. This difficulty, however, is overcome by the adoption of a differential brake, such as Napier's, which the Author has successfully applied on many dredgers (Plate 2, Fig. 2), where the power applied is the difference of the lengths of the arms A B, and A C, into the length of the arm of the power. This power is so enormous that scarcely any weight is required for the strap to clip the drum, and it is in fact self-acting. On the other hand, the power the other way is decreased in the same ratio; so when the lifting power is applied, the brake immediately releases itself. By the use of this brake for the hoisting gear of a dredger, the lifting power can be applied with the brake on, so the man in charge has only one handle to manipulate at once; and as soon as the hoisting stops, and the ladder attempts to fall, the strap immediately grips the drum automatically. With this arrangement, it is very convenient to have the hoisting gear driven direct from the main engine, as it is quicker in its action than having to start a pair of steam cylinders, and it does not require the same care and attention, and is much less costly.

In the case of the bow and stern winches for working the side, head, and tail chains, it is preferable to have separate engines; for they have always to be working with a varying power and varying speed, which could not well be regulated if worked from the main engine.

*Top and bottom tumblers.*—The top tumbler is generally made either square or pentagonal in section; and as this tumbler transmits the power to the buckets, it is advisable to have it as small as practicable, so as to reduce the amount of the intermediate gearing. For this reason the square section has an advantage; but there are other more weighty reasons why this form should not be adopted. In the first place, it necessitates the use of a "hunting-link" in the chain, to prevent uneven wearing of the tumbler by the buckets always coming on the same two faces. In the next place, there is an unnecessary loss of power in raising each bucket, on passing over the tumbler, a height equal to the difference between the side and diagonal of the square; and the falling of the bucket this distance on the tumbler causes unnecessary wear

and tear. The nearer the surface approaches a circle, the less these evils become; but as the length of the sides of the tumbler are at present governed by the size of the buckets, it would be impracticable to have more than five or six sides; and even with six sides, there would be a danger of there not being sufficient grip and the tumbler slipping. This objection might possibly be overcome by using much shorter links than those at present adopted, and allowing the buckets to be suspended between, so as not to touch the tumbler in passing over it.

The top tumbler has to withstand great wear and tear, and has to be made of great strength in consequence. It should be made either wholly of cast-steel, or with chilled cast-iron faces, the latter plan giving very satisfactory results. With either material, it is very advisable to have loose corner pieces, for it is at this point that the greatest wear takes place; they must, however, be firmly secured by dovetailing them into the body of the tumbler, otherwise they would soon shake loose.

The bottom tumbler should have not less than six or seven sides; for as the power is not transmitted through its shaft, the larger the diameter of the tumbler the less will be the friction. This tumbler has generally large flanges cast on it to guide the buckets; they should not be circular, as is often the case, but of the same form as the body of the tumbler; otherwise the excessive depth at the centre of a face offers unnecessary resistance when side dredging, and in stiff material prevents the buckets from being properly filled. This tumbler should also have cast-steel or chilled cast-iron faces.

*Buckets, links, and pins.*—The buckets should not only excavate the material, but should also be able to discharge it readily into the shoots. This latter condition is very often not considered, and consequently, with stiff clay, the buckets fail to discharge their contents into the shoot; and it is necessary to have a man at the top, with a pricker, to help the buckets to be cleared. A large bucket has an advantage in this respect, for the surface adhesion varies as the square, whereas the contents vary as the cube. The fault generally lies in making the bucket with parallel sides; but, to enable the clay to pass out freely, the longitudinal section, both vertically and horizontally, should be tapered. Another fault consists in carrying the mouthpiece too far forward (Plate 2, Fig. 3), when, if soft material is being dredged, the bucket cannot possibly be filled; but if it be put further back (Plate 2, Fig. 4), a full bucket can be carried to the top. The latter form is also better adapted for discharging stiff material.

The buckets were formerly made of wrought-iron, either welded solid, or with plates riveted together; the double links, which were either of forged iron, or of malleable cast-iron, being riveted to the back. They are now made wholly of steel, the jaws for receiving the links being cast in one with the back, and having flanges at the sides and bottom for receiving the fronts. Thick steel mouthpieces are also riveted to the fronts, tapering from the main cutting-edge to the back. A number of holes should be punched all over the front to allow any water to get away. The links may be made of wrought-iron, or of steel; but, in either case, they should be bushed with steel, the bush being either driven in, or the eye of the link shrunk on, to prevent it from turning. The pin should be of large diameter: for a bucket of about 8 cubic feet capacity, it should be not less than 3 inches in diameter, and of steel hardened on the working surface. It should have either a square or triangular head, which is let into the bucket back, thus preventing any wear in the eyes of the bucket by turning. The pins should be turned round periodically so as to present a different working face alternately, thus ensuring uniformity of wearing; the life of a pin is from 12 to 18 months, according to the nature of the material dredged. For dredging in stiff clay with boulders, it is advisable to have strong prickers fixed at intervals on the chain, for removing or loosening the boulders.

*Shoots.*—The angle of the shoots is entirely dependent upon the nature of the material to be dredged; and this angle, in conjunction with the point of discharge, determines the height of the top tumbler. The following are found from experience to be the best angles for the different materials: for soft mud, 1 in 10; soft clay, 1 in 12 to 14; hard clay, 1 in 14 to 16; and fine sand and water, 1 in 20 to 25. It is very advisable to have a strong force-pump delivery-pipe near the shoot, to clear it, and to assist any material that might stick. The shoots should be well covered in, to prevent splashing on the deck.

In constructing the Suez Canal, most of the dredged material was placed upon the banks; and as the Canal was increased in width, very long and special shoots were required, designed by Mr. Lavalley<sup>1</sup> (Plate 2, Fig. 8). The top tumbler of the dredger was 48 feet above the level of the water; and the shoot itself was 230 feet long. The framing carrying the shoot was supported on a separate barge A, which carried the central pivot B. This centre could be raised or lowered by hydraulic pressure, to regu-

<sup>1</sup> Institution of Mechanical Engineers. Proceedings. 1867. p. 192.

late the fall and facilitate transit; and the whole shoot could be turned fore and aft of the vessel. The shoot, C, was semi-elliptical, 5 feet wide by  $2\frac{1}{2}$  feet deep; and, to assist the delivery of the material when the shoot was very flat, a continuous band D, with rakes worked from the dredger, pushed the material the whole length of the shoot. The shoot was connected with the dredger by means of a flexible leathern pipe, and was moored and adjusted by chains.

A longitudinal section of a double-ladder dredger, capable of excavating 450 tons per hour of stiff mud, or 600 tons per hour of soft silt, is shown on Plate 2, Fig. 1; and its principal dimensions are given in Appendix I.

*Power required to Dredge.*—To ascertain the actual power required to work dredgers, the Author has taken a series of indicator diagrams from a large number of dredgers, and has had others kindly supplied to him. From these diagrams, and from observations taken at the time, as to the quality and quantity of material being dredged, height of delivery, depth of dredging, &c., he has attempted to frame a formula for ascertaining the indicated HP. required to dredge different qualities of material under varying conditions of lift, &c. It is impossible to deduce a formula that will be absolutely correct, for there are such a number of varying factors to be considered; but the following empirical formula will be found to give sufficiently accurate results. If H is the height of the top tumbler shaft from surface of ground to be dredged, and W the number of tons per hour to be dredged, then the indicated HP. required is,

$$\begin{aligned}\text{I.H.P.} &= 0.04 \ W \sqrt{H} \text{ for very stiff clay or mud;} \\ &= 0.034 \ W \sqrt{H} \text{ for hard clay and indurated mud;} \\ &= 0.026 \ W \sqrt{H} \text{ for soft mud and light sand.}\end{aligned}$$

All the indicator diagrams were taken under the following conditions; namely, (1) with the engine running alone; (2) with the buckets in gear but not dredging; (3) with the dredger working with full buckets. The cards from four separate dredgers are shown on Plate 2, Figs. 11 to 22, the dredgers being numbered 1, 2, 3, and 4. These cards are taken as being fairly representative of the lot; and although most of them show defects in the engines, they do not in any way affect the results. It will be seen from the Table in Appendix II. what an enormous percentage of the power is absorbed in simply driving the machinery. If dredger No. 2 which was dredging 450 tons per hour of stiff mud and raising

it 40 feet, be taken, it is found that the total indicated HP. required was 97·8, and for working the machinery about 59·0; which leaves a difference of 38·8 HP. for doing the necessary dredging. Now it is not right to assume that the whole of this balance of 38·8 HP. is absorbed in the actual excavating and raising of the material, for no doubt a portion of it would be again absorbed in the extra friction caused by the increased load. The actual HP. required to raise 450 tons 40 feet in one hour is about 21; which thus leaves 17 HP. for the increased friction, and for the power required in excavating. All the other dredgers give similar results, showing the very low efficiency of the bucket-ladder dredger as a machine.

*Cost of Dredging.*—In ascertaining the cost of dredging, it is very necessary that the data upon which such cost is calculated should extend over a large number of years; otherwise, it is possible that the following year such repairs and renewals would have to be made as would materially raise the price per ton. Again, it is not of the slightest use comparing the cost of dredging at one place, with that at another; for the circumstances of the case cannot possibly be the same. The cost of dredging at different places is very useful to have as a guide; but all the conditions under which the machine works should be taken into consideration. Many of the published results of the cost of dredging are very misleading; and there is an inclination for advocates of any special scheme of dredging to put the costs at a minimum, and possibly to leave out some important item.

The following are a few items of cost, either supplied to the Author, or obtained by him from published results. At Hull, the cost of dredging, including everything except interest on capital and depreciation, is 2·1*d.* per ton. The material is mud, varying in consistency; and it is discharged about 1½ mile from the docks by steam hoppers, and by ordinary mud barges and tugs.

On the Clyde,<sup>1</sup> the average cost, including everything, depreciation, interest, and carrying in hopper-barges 27 miles, is as follows: very hard clay, boulders, and sand, 30·15*d.* per cubic yard; hard silt, gravel, and sand, 24·17*d.*; silt, clay, and sand, 8·49*d.*; silt, gravel, sand, clay, and mud, 8·08*d.*; and silt and sand, 7·94*d.* per cubic yard.

On the Tyne, the cost varies from 2*d.* to 6½*d.* per ton, according to the nature of the material. One dredger has dredged over

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xxxvi. p. 169.

1,000,000 tons in one year, and including discharging a distance of 17 or 18 miles, the cost per ton was a little over  $3\frac{1}{2}d.$

The cost of removing the bar at Carlingford Lough,<sup>1</sup> including everything, Parliamentary expenses and insurance of plant, was about 1s. 9d. per ton. Taking the cost for one season, it was 1s. 4d. to 1s. 5d. per ton, or 2s. to 2s. 3d. per cubic yard. The material was hard clay and boulders.

At Aberdeen, the cost of dredging and transporting about 2 miles beyond the bar, including insurance, but not depreciation and interest, is 1·2d. per ton for dredging, and 2·9d. for discharging; giving a total of 4·1d. per ton.

On the Wear at Sunderland, the total cost of dredging, including everything but depreciation and interest, is 2·37d. per ton. The material consists of sand, gravel, and clay.

On the Tees,<sup>2</sup> at Stockton and Middlesbrough, the cost of dredging sand, gravel, and occasionally boulders, including the conveyance of the deposit out to sea, a distance of about 12 miles, is 4·96d. per cubic yard, or about  $2\frac{1}{2}d.$  per ton. This amount includes everything except interest of capital expended on dredging plant.

The above prices are all for bucket-ladder dredgers; the Author has been unable to obtain reliable prices for dredging with other apparatus, for they have not been engaged in any extensive operation for a sufficient length of time to furnish reliable definite data. The bucket, or dip dredgers, however, under certain conditions and circumstances, give very satisfactory and economical results.

#### STEAM HOPPER-BARGES.

The dredged material was formerly discharged into small mud barges, or lighters, and taken to the discharging ground by a tug. As this was found in most cases to be a very inconvenient and expensive method of disposal, steam hoppers were introduced, and are now generally used. These vessels, unlike a long string of lighters behind a tug, are easy to handle, and can in most cases get out of dock, go to the discharging ground, and be back in dock before the gates close. There are certain conditions, however, when it is found to be more economical to tow the mud lighters to the discharging ground; as, for instance, when the same tug can be used

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xliv. p. 135.

<sup>2</sup> Evidence of Mr. John Fowler, M. Inst. C.E., before the Select Committee of the House of Commons on the Manchester Ship Canal Bill, 1883.

for either moving ships about the docks, or for towing them into or out of the harbour, whilst the barges are being filled or possibly lying idle. In any case it is advisable to have a number of ordinary mud barges, for the steam hopper-barges are also very powerful tugs, and will take in tow almost as much material as they carry in their own hopper.

A steam hopper-barge, capable of carrying 500 tons of dredgings, is shown on Plate 2, Fig. 7; and the principal dimensions of the barge are given in Appendix III.

#### HOPPER-DREDGERS.

A comparatively new feature in dredging appliances, is the introduction of a combination of the dredger and the steam hopper-barge. There are probably one or two conditions under which the combination of the cumbersome bucket-ladder dredger and the steam hopper might be advantageous, such as for outside work where the discharging ground is not far away. In docks, they certainly have the advantage of taking up less room than a number of lighters attending the dredgers; but in most cases, if the dredger left the dock, it would not be able to get back before the gates were closed. Again, all the moorings have to be taken up or buoyed, and the ladder shipped; and such a cumbersome machine must be very unhandy, and cause inconvenience to shipping passing in and out of the dock.

*Hopper-Barge with Priestman Buckets.*—The details of a large hopper-dredger, made for the Mersey Docks and Harbour Board, are shown on Plate 2, Figs. 5 and 6. It consists of a modified form of steam hopper-barge, with four Priestman dredger buckets attached as shown. The buckets are supplied with steam from the same boiler which supplies the main engine for propelling. The vessel is 195 feet long, 35 feet wide, and  $15\frac{1}{2}$  feet deep. The capacity of the hopper is from 1,000 tons to 1,200 tons, according to the nature of the material. Each bucket is capable of holding 36 cubic feet of deposit inside the plates; but with stiff material, heaped up, it will hold 6 or 8 feet more. The weight of the empty bucket is 1 ton 9 cwt.

The engines for working the buckets consist of two cylinders, 9 inches in diameter with 12 inches stroke, making 130 strokes per minute. The jib of the crane has a radius of 14 feet; and the bucket is arranged to dredge to a depth of 34 feet below the water-line. The bucket is raised, when full, at a speed of 80 feet per minute. Each bucket is capable of making from sixty to



sixty-five lifts per hour, but sixty lifts per hour is considered very good work. When there is plenty of mud, the hopper can be filled in three and a-half to four hours; but when the mud is scarce, it takes from five to six hours to fill. About 2 tons of coal are consumed in filling the hopper, and another ton is consumed in taking the hopper to the discharging ground, about 8 miles away, and back again. The average time taken to discharge the material is from three to four hours, this time depending of course entirely upon the wind and tide; the quickest time in which it has ever been done is two hours and forty minutes, everything being favourable. The ordinary hopper-barges do it in a little less time, because, on account of their lighter draught, they have not the same distance to travel.

The number of men required to work these hopper-dredgers is twenty-one: viz. a captain, a landing captain, a mate, a chief engineer, a second engineer, a third engineer, four crane men, four firemen, and seven sailors.

*Bruce and Batho's Hydraulic Dredger.*—Messrs. Bruce and Batho have designed a novel dredger, consisting of one of their buckets already described, but worked entirely by hydraulic power. The dredger of this design was made for working on the Tyne, and is shown in Plate 2, Fig. 9. The excavator, or dredger, A, is fixed to the end of a beam which is actuated by two hydraulic cylinders, one, B, being used for raising the bucket, and the other, C, for lowering it, the hydraulic power being supplied from the pumps in the engine-room. The bucket is opened and closed by means of the hydraulic cylinder D. A novelty in the design is the ingenious way in which the lever, in ascending, draws the shoot under the bucket to receive its contents, and draws it away again as the bucket descends. The hydraulic cylinder at the end of the beam is carried on gimbals, to allow for the irregularities of the surface being dredged. The hydraulic pressure is 700 lbs. per square inch; and as it is not advisable to have the pressure from the pumps taken direct to the cylinder, the water is pumped into a steam accumulator.<sup>1</sup>

#### GENERAL REMARKS.

In describing in this Paper the many varieties of dredging appliances now in use, the Author has not in any way attempted

<sup>1</sup> The following are the leading dimensions of the dredger now working, and shown on Plate 2, Fig. 9:—Length of vessel, 80 feet; beam, 18 feet; depth, 6 feet; draught, 3 feet; diameter of excavator, 6 feet; depth to dredge, 15 feet; and four men required to work the dredger.

to advocate or depreciate any particular class; for it is obvious that the form of dredger to be selected for any special work depends entirely upon the nature of the material to be excavated, its depth below the surface, the site, and other physical and local conditions, each dredger having its own special merits and advantages when dealing with the work for which it was designed. When comparing any results with the object of obtaining reliable deductions, it is very necessary that all the conditions under which the experiments were made should be identical. Now with a dredger, it is almost impossible to obtain such conditions, for it would require a small fleet of dredgers, each one varying from the other in one particular only, such as the form of buckets or tumblers, and a uniform depth and consistency of material to be dredged, &c. It is possible, however, to make one or two general deductions which may have a practical value.

The sand-pumps, such as were in use at the Amsterdam Ship-Canal, Lowestoft, Oakland Harbour, and other places, gave most satisfactory results; and, judging from the nature of the material and other local considerations, it is evident they were the best appliances to be used under the circumstances. The disadvantage of all sand-pumps is that in addition to lifting the sand or mud, they have to take up a large proportion of water; this means not only an extravagant expenditure of power in the pumps, but also in the hopper barges; for in most cases the mud is of such a nature that it cannot possibly settle before being discharged, and consequently a large proportion of the water is carried out to sea in the hoppers. Sand-pumps have, however, the advantage of reducing the height of the lift of the material to a minimum, the discharge-pipe being capable of being placed at the level of the hopper gun-wales if necessary; and by the use of telescopic suction-pipes, they can be made quite independent of the variation of the water-level due to the tide or waves.

The dip or bucket dredgers of the clam-shell type are very convenient for working in confined places, such as the corners of docks, and behind dock-gates, and are specially suited for canal work, where they can, if necessary, be worked from the bank so as not to interfere with the traffic. This class of dredger has the same advantages as the sand-pump with regard to the height of lift, and working in a tideway or rough water. The wear and tear, especially of the closing chains and the mouthpieces, is rather severe. A large number of these dredgers are now working very successfully in different countries; but for regular heavy work, such as is undertaken by the bucket-ladder dredgers, with the

exception of the large dredger now working in Liverpool fitted with four of Priestman's buckets, they have not been tried on any extensive scale; and although this dredger promises to give most satisfactory results, it has not been working a sufficient length of time for a definite opinion to be given.

For steady heavy work, the bucket-ladder dredger is undoubtedly well adapted; in fairly smooth water it will do its work well, uniformly, and comparatively cheaply. It cannot, however, work in shallow water, or if there is much oscillation of the boat from the effects of rough water or a swell. Although this dredger gives apparently such satisfactory results, in watching it working it is impossible to help being struck with the very small amount of material being gradually tumbled out of such an immense structure; and by referring to the indicator diagrams (Plate 2, Figs. 11 to 22) and the Table in Appendix II, it is evident that there is great room for improvement somewhere in the design.

One source of waste of power in the bucket-ladder dredger is in having to lift the material about 24 feet above the water-line, when it is only actually required to be lifted over the gunwales of the mud lighter. So long as the material is discharged by retarded gravitation from the top tumbler to the hopper this objection cannot be removed; the hopper dredger, however, has a slight advantage on account of the centre of the hopper being nearer to that of the tumbler. The Author is of opinion that certain advantages would be gained if the material was discharged at a lower level into a trough, and carried to the hoppers by horizontal helical creepers. By this means, the weight of the framework would be greatly reduced; the tumbler shaft would be nearer the engine, thus reducing the amount of intermediate gearing; the length and weight of the ladder, and the number of buckets and links, would be greatly diminished; the dredged material could be discharged on either side of the vessel; and by a proper arrangement of doors at the bottom of the creeper, extra facilities would be offered for distributing and discharging the material.

By referring to the indicator-diagrams, it is seen what an enormous percentage of the power is expended in simply driving the machinery; and from the Table it appears that this loss of power increases with the size of the buckets, which naturally follows from the increased weight of the buckets and links. The greater portion of the power is absorbed in dragging the buckets and links round the bottom tumbler, and often also owing to the bad arrangement of the rollers on the top of the ladder. The

advisability of having the bottom tumblers as large as possible, and the carrier rollers at short intervals is at once apparent; and the Author is of opinion that if the bottom tumblers were to receive assistance from the engine, more economical results would be obtained.

A very important matter in connection with dredgers, as well as all classes of machinery, is the careful preparation of complete plans and comprehensive specifications when any machine is required. This is expedient both for the engineer and the contractor; for as such work is generally submitted for competitive tenders, unless all the contractors have the same definite data to work from, there is a great temptation to put in inferior designs and workmanship to ensure being at the bottom of the list, and unfortunately, as a rule, having the work to carry out. It is quite a mistake to leave too much to a contractor, who may have any speciality. The engineer is the person who should know best what is needed for his own work; and if he has his plans and specification prepared accordingly, it is his own fault if he does not then get what he requires.

The Paper is accompanied by drawings, from which Plates 1 and 2 have been engraved.

## APPENDIXES.

## APPENDIX I.

## DOUBLE-LADDER DREDGER.

(Plate 2, Fig. 1.)

	Ft.	Ins.
Extreme length . . . . .	125	0
„ breadth . . . . .	32	0
Height from underside of floors to top of deck amidship.	10	3
Draught in working trim. . . . .	6	6
Depth to which dredger will work . . . . .	28	0
Sheer fore and aft . . . . .	0	9
Crop of deck . . . . .	0	6
Height of top tumbler shaft from water-line . . . . .	23	0
Width of bucket wells . . . . .	4	6
„ „ „ where swelled at ends . . . . .	6	0
Frames, 4 inches by 3 inches by $\frac{7}{16}$ -inch angle-iron, 2 feet apart.		
Plating of bottom and bilges . . . . .	$\frac{1}{2}$	inch.
„ sides . . . . .	$\frac{7}{8}$	„
„ wells . . . . .	$\frac{3}{8}$	„
Deck beams . . . . .	6 inches by $\frac{3}{4}$	„
Floors, 12 inches deep by $\frac{3}{8}$ inch, with angle-irons $2\frac{1}{2}$ inches by $2\frac{1}{8}$ inches by $\frac{5}{8}$ inch.		
Length of bucket-ladder between centres . . . . .	72	feet
Capacity of bucket . . . . .	8	cubic feet
Diameter of pins . . . . .	3	inches
Engines, compound—		
High-pressure cylinder. . . . .	19 inches diameter by 24 inches stroke	
Low „ „ . . . . .	34 „ „ by 24 „ „	
Air-pump . . . . .	16 „ „ by 15 „ „	
Circulating pump . . . . .	8 „ „ by 15 „ „	
Boiler, diameter . . . . .	10	feet
„ length . . . . .	9 feet 6	inches
„ heating surface . . . . .	8,002	feet
„ working pressure . . . . .	55	lbs.
Cost . . . . .	£14,000	

## APPENDIX II.

Number of Dredger.	No. 1.	No. 2.	No. 3.	No. 4.
Kind of ladder . . .	Double	Double	Double	Single
Capacity of bucket in cubic feet . . .	4½	6	10	14
Class of engine . . .	Side lever—jet-condenser	Compound—surface-condenser	Diagonal—surface-condenser	Compound—surface-condenser
Diameter of cylinders .	30 ins.	{ 19 ins. and 3½ ins. }	33 ins.	{ 21½ ins. and 40 ins. }
Stroke . . . . .	36 „	24 ins.	36 „	30 ins.
Steam-pressure in lbs. per square inch . . .	15 to 17	55	32	65
Nature of material dredged . . . . .	Very stiff mud }	Stiff mud	Soft mud	Clay
Tons dredged per hour	300	450	400	450
Height of top tumbler from surface of ground	43 ft.	40 ft.	43 ft.	41 ft.
(a) I.H.P., engine running empty . . .	10·5	16·79	16·16	36·6
(b) I.H.P., buckets in gear, but not dredging . . .	35·5	59·05	44·17	67·5
(c) I.H.P., dredging with full buckets . . .	80·0	97·83	66·0	99·0
I.H.P. absorbed in excavating and raising the material = difference of (b) and (c) . . .	44·5	38·78	21·83	31·5
Percentage of total I.H.P. absorbed by friction . . . . .	44·4	60·6	68·0	68·5

When dredger No. 1 was in full gear the engine was driving, in addition to the tumblers, the gear for lifting the ladders, and also the winches for the head and side chains; the other three dredgers had separate engines for the head and side chains, the ladder lifting-gear being driven by countershafts from the main engines.

## APPENDIX III.

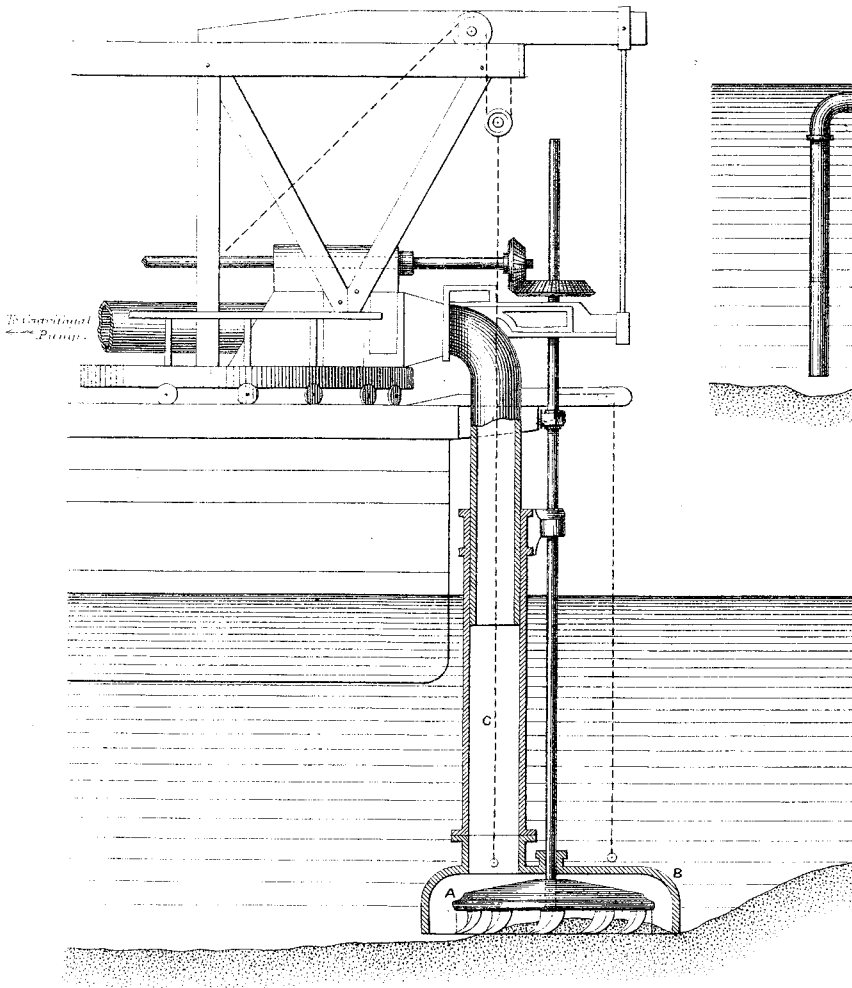
## STEAM HOPPER-BARGE.

(Plate 2, Fig. 7.)

		Ft.	Ins.
Length between perpendiculars . . . . .		150	0
Breadth moulded. . . . .		26	0
Depth from top of beam amidships to top of keel . . .		12	4
Capacity of hopper to level of top of deck beams . . .	500 tons		
Length of hopper. . . . .		60	0
Breadth " top . . . . .		20	6
" " bottom . . . . .		8	10
Depth of hopper . . . . .		12	0
Draught loaded, forward . . . . .		10	9
" " aft . . . . .		11	3
" " light, forward . . . . .		4	4
" " aft. . . . .		8	7
Sheer " forward . . . . .		2	8
" " aft . . . . .		1	8
Plating garboard strake $\frac{3}{4}$ length . . . . .		0	$\frac{9}{16}$
" " " remainder. . . . .		0	$\frac{1}{16}$
" sheer strake . . . . .		0	$\frac{1}{2}$
" bottom " $\frac{3}{4}$ length . . . . .		0	$\frac{1}{2}$
" " " remainder . . . . .		0	$\frac{3}{8}$
" bilges " $\frac{3}{4}$ length . . . . .		0	$\frac{1}{2}$
" " " remainder . . . . .		0	$\frac{3}{8}$
Engines, compound—			
High-pressure cylinder. . . . .	20 inches diameter by 30 inches stroke		
Low " " . . . . .	38 " " by 30 " "		
Air-pump. . . . .	14 " " by 16 " "		
Circulating pump . . . . .	9 " " by 15 " "		
Boiler . . . . .	11 $\frac{1}{2}$ feet " by 10 feet long		
" heating surface . . . . .	1,250 square feet		
" working pressure. . . . .	70 lbs. per square inch.		
Cost . . . . .	£7,000		

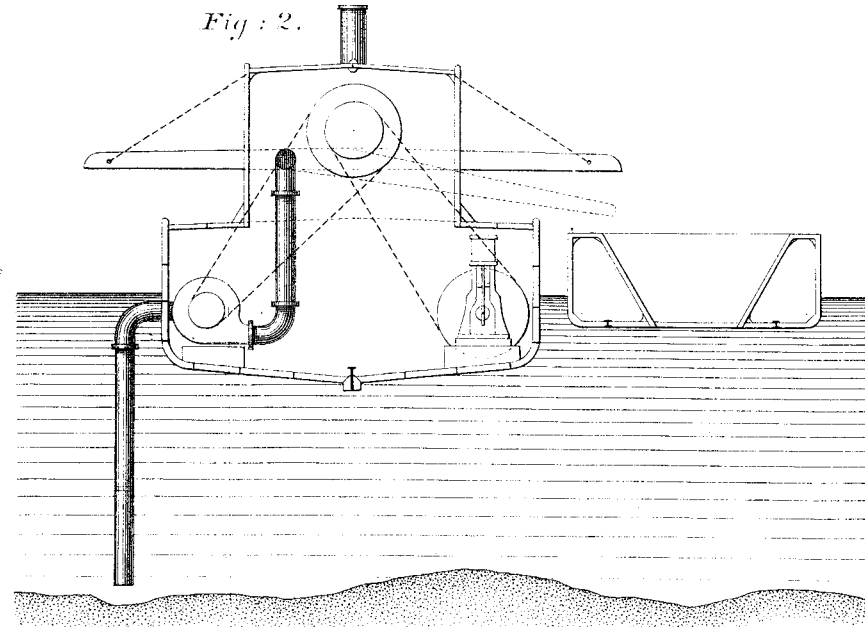
[DISCUSSION.]

Fig: 1.



SCHMIDT'S SAND-PUMP DREDGER.

Fig: 2.



BAZIN SAND-PUMP DREDGER.

Fig: 3.

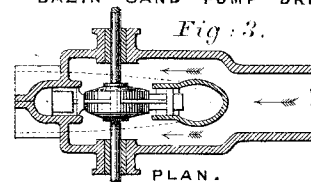


Fig: 4.

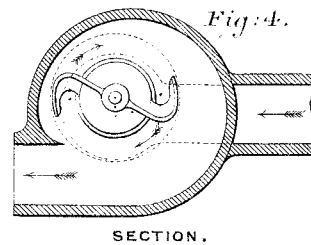
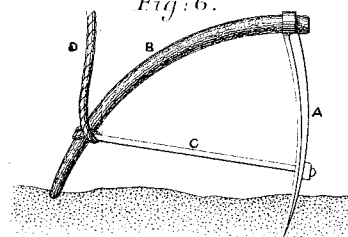
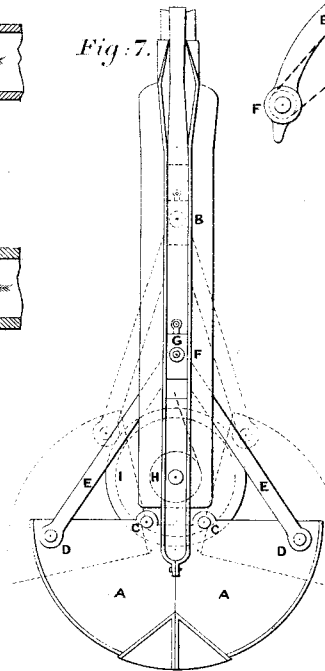


Fig: 6.



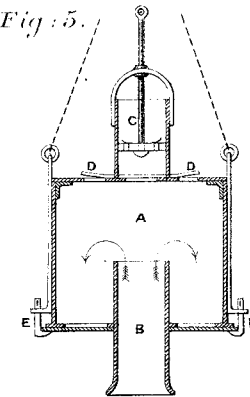
JHAM.

Fig: 7.



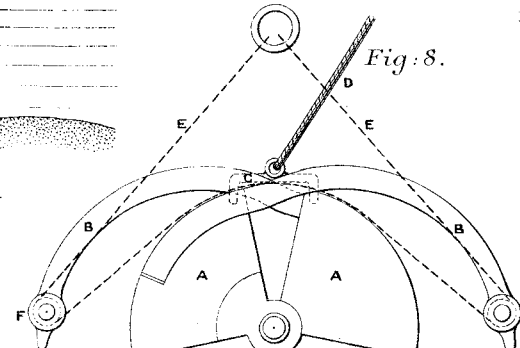
CLAM-SHELL DREDGER.

Fig: 5.



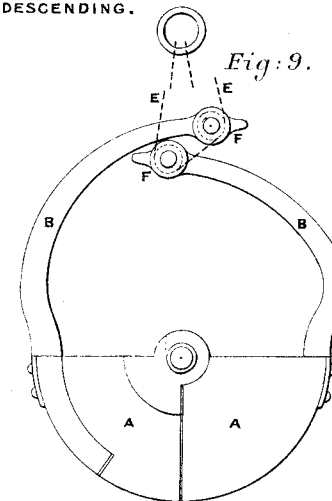
KENNARD'S SAND-PUMP.

Fig: 8.



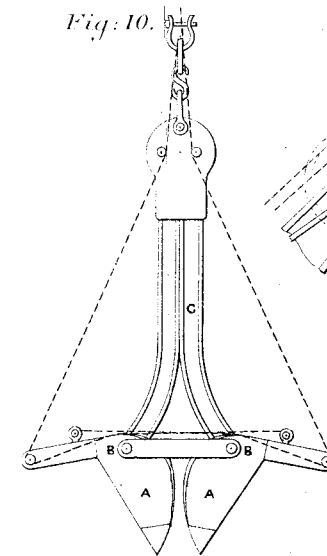
BULL'S DREDGER,  
DESCENDING.

Fig: 9.



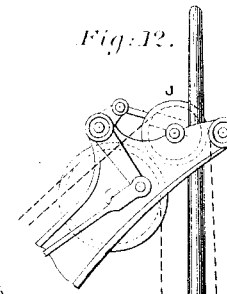
BULL'S DREDGER,  
LIFTING.

Fig: 10.



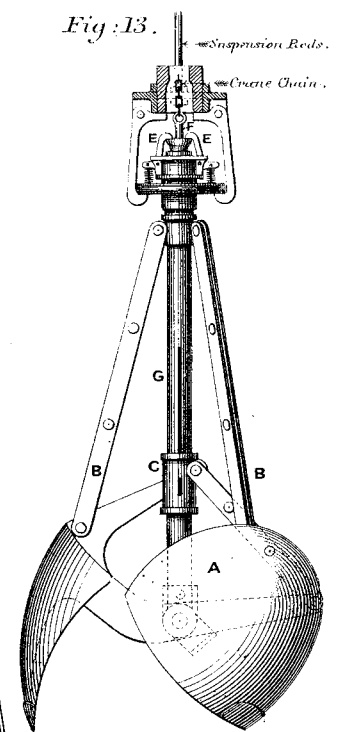
GATMELL DREDGER,  
DESCENDING.

Fig: 12.



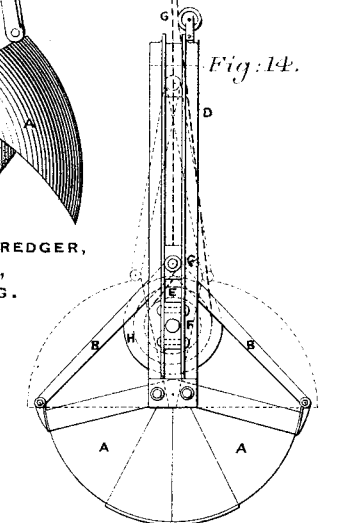
BRUCE & BATHO'S DREDGER,  
WITH SPEAR,  
DESCENDING.

Fig: 13.



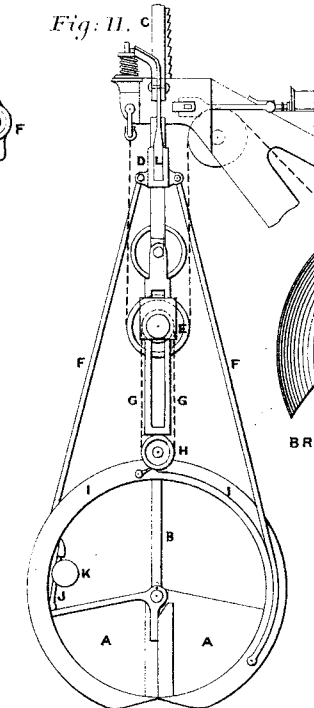
BRUCE & BATHO'S  
SINGLE CHAIN DREDGER,  
DESCENDING.

Fig: 14.



PRIESTMAN DREDGER.

Fig: 11.



FOURACRES' DREDGER.

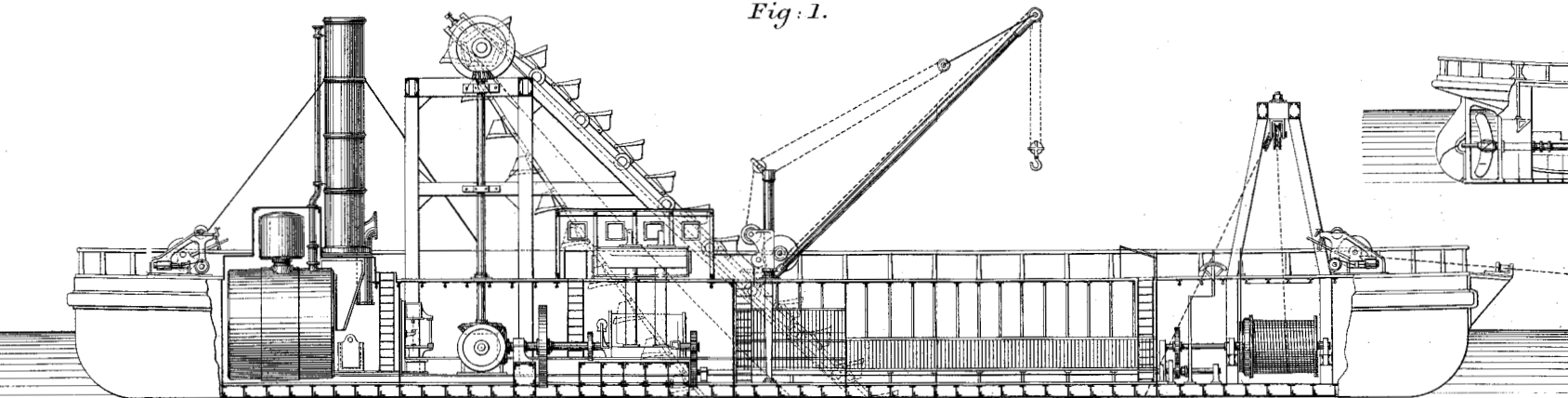


# DREDGING APPLIANCES.

PLATE. 2.

BUCKET—LADDER DREDGER.

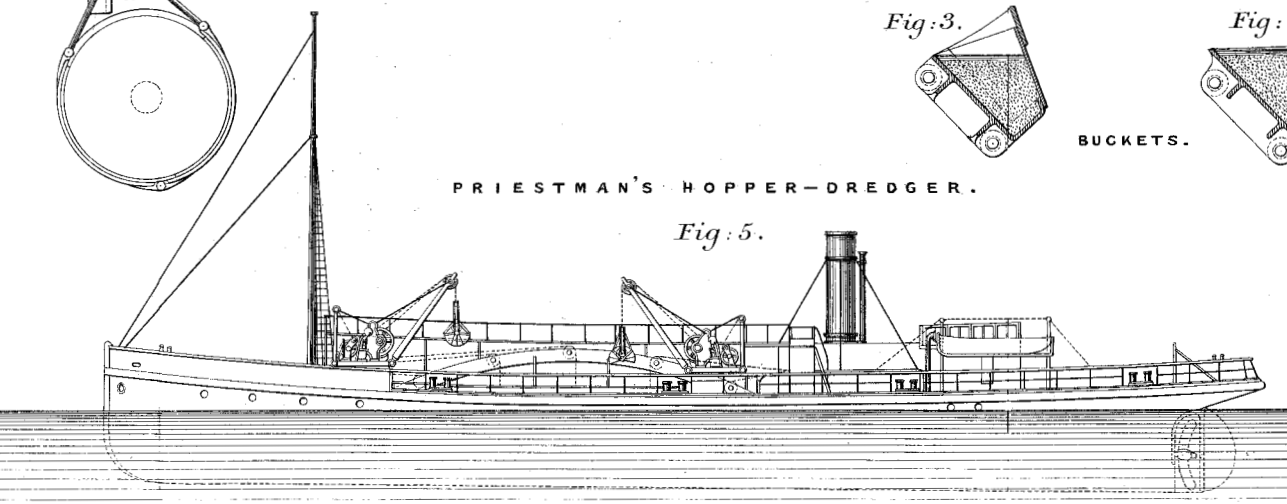
Fig: 1.



LONGITUDINAL SECTION.

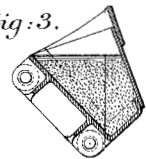
PRIESTMAN'S HOPPER—DREDGER.

Fig: 5.



LONGITUDINAL SECTION.

Fig: 3.



BUCKETS.

Fig: 4.

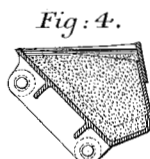
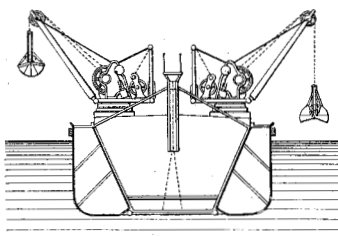


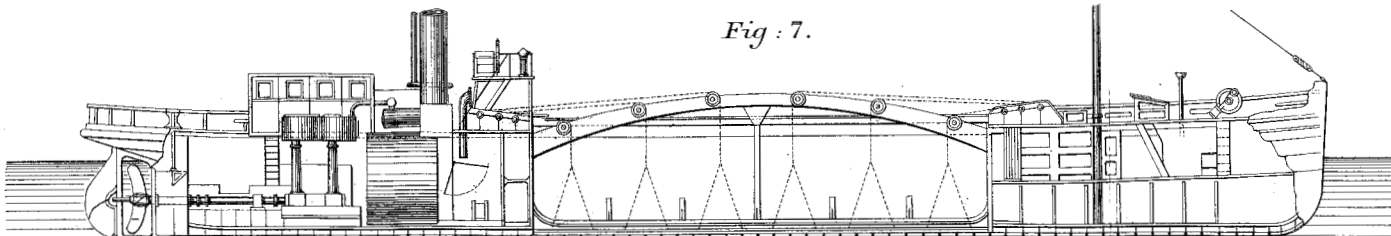
Fig: 6.



SECTION.

STEAM HOPPER—BARGE.

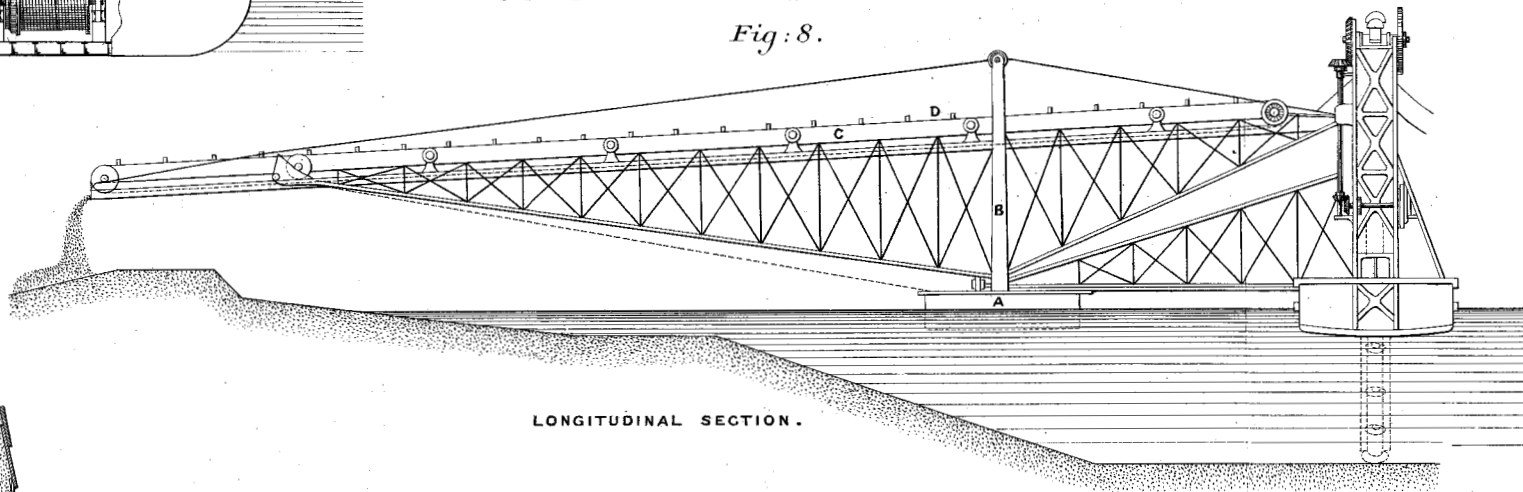
Fig: 7.



LONGITUDINAL SECTION.

SUEZ CANAL DREDGER—SHOOT.

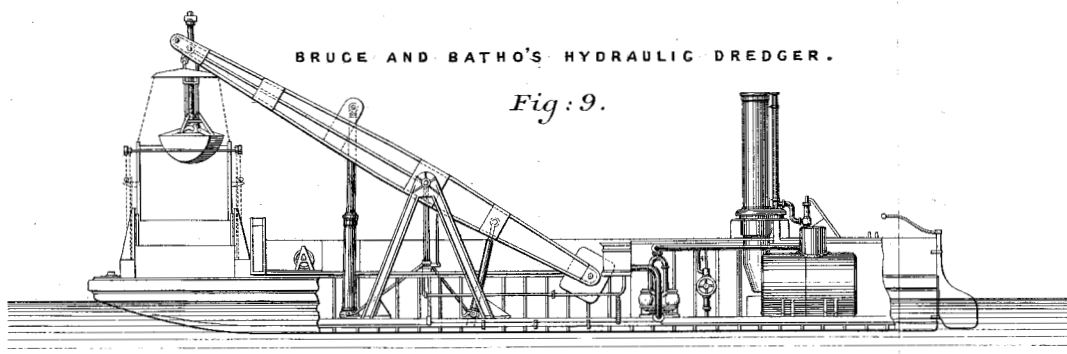
Fig: 8.



LONGITUDINAL SECTION.

BRUCE AND BATHO'S HYDRAULIC DREDGER.

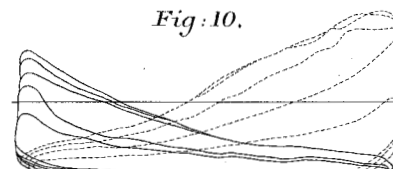
Fig: 9.



LONGITUDINAL SECTION.

DREDGER NO 4.

Fig: 10.



DREDGER NO 3.

DIAGONAL CONDENSING ENGINE.

Fig: 11.

Scale: 1/32.

ENGINE RUNNING ALONE, I.H.P.=16.16.

Steam=32 lbs. Vacu=27 in. Revs=65.

Fig: 12.

Scale: 1/32.

ENGINE AND BUCKETS WORKING, BUT NOT DREDGING.

Steam=30 lbs. Vacu=26 in. Revs=60.

I.H.P.=44.3.

Fig: 13.

Scale: 1/32.

DREDGING WITH FULL BUCKETS, I.H.P.=66.

Steam=30 lbs. Vacu=25 1/2 in. Revs=62.

DREDGER NO 1.

SIDE LEVER CONDENSING ENGINE.

Fig: 14.

Scale: 1/32.

ENGINE RUNNING ALONE, I.H.P.=10.5.

Steam=20 lbs. Vacu=29 in. Revs=60.

Fig: 15.

Scale: 1/32.

ENGINE AND BUCKETS WORKING, BUT NOT DREDGING.

Steam=21 lbs. Vacu=29 in. Revs=60.

I.H.P.=35.5.

Fig: 16.

Scale: 1/32.

DREDGING WITH FULL BUCKETS, I.H.P.=80.

Steam=20 lbs. Vacu=29 in. Revs=56.

DREDGER NO 2.

COMPOUND ENGINE.

Fig: 17.

I.H.P.=8.08.

Scale: 1/24.

TOTAL I.H.P.=16.79.

I.H.P.=8.71.

Scale: 1/16.

ENGINE RUNNING ALONE.

Steam=55 lbs. Vacu=29 in. Revs=48.

Fig: 18.

I.H.P.=38.67.

Scale: 1/48.

TOTAL I.H.P.=59.05.

I.H.P.=20.38.

Scale: 1/16.

ENGINE AND BUCKETS WORKING, BUT NOT DREDGING.

Steam=55 lbs. Vacu=27 in. Revs=48.

Fig: 19.

I.H.P.=58.13.

Scale: 1/48.

TOTAL I.H.P.=97.83.

I.H.P.=39.7.

Scale: 1/16.

DREDGING WITH FULL BUCKETS.

Steam=55 lbs. Vacu=26 in. Revs=48.

DREDGER NO 4.

COMPOUND ENGINE.

Fig: 20.

I.H.P.=20.3.

Scale: 1/60.

TOTAL I.H.P.=36.6.

I.H.P.=16.3.

Scale: 1/16.

ENGINE RUNNING ALONE.

Steam=65 lbs. Vacu=26 in. Revs=62.

Fig: 21.

I.H.P.=40.6.

Scale: 1/60.

TOTAL I.H.P.=67.5.

I.H.P.=26.9.

Scale: 1/16.

ENGINE AND BUCKETS RUNNING, BUT NOT DREDGING.

Steam=65 lbs. Vacu=26 in. Revs=62.

Fig: 22.

I.H.P.=58.0.

Scale: 1/60.

TOTAL I.H.P.=99.0.

I.H.P.=41.0.

Scale: 1/16.

DREDGING WITH FULL BUCKETS.

Steam=65 lbs. Vacu=25 1/2 in. Revs=62.