Correspondence.

Mr. Berridge. Mr. HAROLD BERRIDGE observed that the Paper formed a useful extension of a previous Paper [1] by the Author. The types dealt with only included the ladder dredger, suction dredger, and dipper dredger; the grab dredger was not alluded to, though it had been extensively adopted for its special purpose in the Mersey and elsewhere. The vessels described were those built by the Author's firm, except the dippers, and the only variations from 1901 were as to growth in dimensions and capacity, which, although considerable, seemed to Mr. Berridge less than might be expected. The suction dredger had had its sphere of action enormously increased by the addition of the cutter head, and this was the principal point of interest in the Paper. With regard to all these vessels, the terms in which they were described in the Paper were too vague to be of much assistance, and possibly it was expecting too much to hope for more detail. "Engines sufficient to propel at a speed of about 7 knots" and such generalities did not contribute much more to the knowledge of the subject by the profession. A single set of observations on the indicated horse-power, velocity, loss of head, quantity delivered and similar data from the "Jinga," "Kalu" or "Pelican" would be of far more service than Tables such as IV and V. With regard to all such craft it was idle to ignore the great progress made by Continental builders in constructing light and yet efficient and powerful craft. British builders seemed to have settled down to a fixed type of solid construction, which was, however, extremely difficult to repair if anything went wrong in out-of-the-way spots such as dredgers often had to go to. Mr. Berridge's experience of these craft was that builders did not pay sufficient attention to the question of facility of replacement and repair. The work performed demanded that such renewals must be frequent to keep the machines working efficiently or even without danger. Changing buckets, links, and pins, was a daily—even (on some classes of work) an hourly—operation; yet the main engine was still the only apparatus for backing down the chain, with accompanying risk and lack of control. Caps of bearings and connecting-rods were still to be found, of malleable

[1] "Dredging and Modern Dredge Plant." Trans. Inst. of Engineers and Shipbuilders in Scotland, vol. xlv, p. 107.

and cast iron, though they ought all to be mild steel; and sometimes winches were supplied which had to be practically dismantled altogether before some essential part could be renewed. All these details had a great effect on costs of dredging. A stud to be replaced, or a small gear-wheel, the value of which was not ten shillings, might cost as many pounds from lost time due to standing charges. The belt drive to the main gearing of a ladder dredger working in soft material was perfectly satisfactory and saved a large sum in first cost and weight of engines and gearing; and in facility of maintenance and cost of working. The same applied to the overhead type of lifting-gear for ladder sheers, and built up buckets instead of those with cast-steel backs. The separate manœuvring winches on the continental type were quite small and took one man to work them instead of three, as did the combined type of head and side winches in England. The wire head mooring enabling a 700-foot cut to be taken was an enormous improvement on the heavy head chain. A novel method of leading away the side chains was adopted in the German barge-loading dredgers "Goliath" and "Herkules,"[1] two very fine craft used on the Kiel Canal. The chains were led through trunks in the bottom of the dredger and enabled attendant hoppers to come alongside and leave without the usual loss of time in dodging the dredgers' side chains. These craft had also electrically driven winches for lifting the ladder and working the manœuvring chains of the dredger and hauling the hoppers alongside; several of these winches were worked from a central control. These vessels also had a bathroom, which so far the writer had not seen on a British-built dredger. *Fas est ab hoste doceri:* all these features might be adopted with advantage by British firms. As to suction dredgers no mention was made in the Paper of the "Leviathan," the largest and one of the most interesting of these craft. The cutter head on the suction pipe came from America where it had been largely developed by Mr. H. Robinson. The "Fruhling" dredger, which had been used successfully in Germany and America, was also not touched on in the Paper. He ventured to repeat an opinion previously[2] expressed, that hoppers and hopper dredgers in most cases could not steam at anything like their economical speeds. However satisfactory all these machines might be, he ventured to submit that none of them was really adequate for its work. In England there must be a Mr. Berridge.

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[1] *Revue de Mécanique*, August, 1912.

[2] "The Economics of Ladder Dredgers and Steam Hoppers." Minutes of Proceedings Inst. C.E., vol. cc, p. 421.

Mr. Berridge. dozen independent harbour-boards of large resources and credits with numbers of these comparatively small craft working spasmodically and independently. He suggested the time had come for harbour-boards to have a conference jointly with shipping-interests and decide what was wanted in the way of dredging. By clubbing together they could buy dredgers as big as, say, battleships, and hoppers, say, as big as cruisers, and could tackle the different ports seriatim at a fraction of the time and cost now taken. The same thing applied in the East, only in a greater degree. The Suez Canal only took ships of 30 feet, and neither Aden, Karachi, Bombay, Colombo, nor Madras could take anything deeper, some of the ports not as much. There seemed to be little doubt that the deep ship was the economical one, and economies of some kind must be found. Competition with the Central Powers and other nations would be eventually keener than ever; sailors and engineers of all ranks would not willingly go back to old rates of pay; the prices of fuel and supplies would show a similar reluctance to recede from their present high-water mark. He ventured to suggest that the proper direction in which to seek lower costs of transportation was by combination and organization, on the main trade routes at any rate, to build and run the most economical form of ship and to provide corresponding depths of water where wanted. No doubt, when the time came, the Author would be found in the forefront with a "Super-Dreadnought" dredger leaving all others far behind in size and efficiency.

Mr. Burrows. Mr. T. E. Burrows considered that members of The Institution engaged in the outlying dominions on operations requiring the latest appliances suitable for their particular conditions would feel specially indebted to the Author for his Paper. In agreeing with him as to too much stress being easily placed on the cost of dredging, Mr. Burrows would point out the variability of the materials dealt with—often designated by the all-embracing names of silt or mud—which, when dealt with by dredger, were found to differ widely in their characteristics. The silt brought down from alluvial country formed a slurry that remained in a semi-liquefied form for months, and this had to be dealt with before it consolidated sufficiently to enable it to be lifted and disposed of as economically as it otherwise would be. If a pump were used on this material there was considerable difficulty in filling a hopper barge, owing to the fluid state of the silt preventing rapid deposition taking place, especially in regard to the upper portion of the load. The sides of the hoppers had to be raised as much as 2 feet, and provided with screens to enable the hopper to be well filled. Again, there was the stiffer kind of material which could only be dealt with by bucket dredgers or sand pumps fitted with cutting gear. He communicated the following notes on dredging plant in use in New South Wales. Mr. Burrows.

The latest type of bucket dredger had been constructed from the designs of Mr. A. E. Cutler, M. Inst. C.E., when Superintendent of Fitzroy Dock, Sydney Harbour. Two of these were now at work, one in Sydney Harbour for the Harbour Trust, and the other in Hobson's Bay, Melbourne. The third had been constructed, also under Mr. Cutler's direction, at Walsh Island Dockyard, Newcastle, N.S.W., and was for work at that port. This dredger was not a hopper dredger (though it was first arranged that it should be), but the experience gained as to the cost of shifting a dredger and taking up moorings after the depositing of silt, as well as the distance of the place of deposit from the dredging-site, demonstrated that the cost did not compare favourably with the cost of depositing in hopper barges and towing to sea for disposal. The three dredgers were :—

"John Stewart" .	Self propelled (Melbourne).
"Hercules" . .	Stationary (Sydney Harbour Trust).
"Hunter" . . .	Now being completed, stationary (Newcastle, N.S.W.).

In New South Wales clay-cutting, suction and reclamation dredgers comprised two classes: one type, cutting gear, was used principally for removing sand and depositing it on low-lying land near the channel to be deepened for reclamation purposes; the second type was fitted with cutting gear, and was able to deal with stiffer material, ranging from clay to soft rock. Of the first type on the various coastal rivers—apart from Sydney Harbour—a fleet of twelve dredgers were employed. These varied in size and comprised eight 16-inch and four 20-inch. It was, however, intended to standardize them into two or more types; the 16-inch would be eliminated in favour of a 20-inch, and the other standard size would be 28-inch. With the standardizing of the dredgers, the engines, boilers and pumps would be interchangeable, and spare parts could be kept in stock, so that the time occupied in repairs would be very considerably reduced. It was intended to follow the latest American practice, and increase the speed of the pumps, with a view to higher efficiency. Of the second type, pump dredgers with cutting gear, there were four at work, namely, "Glaucus," "Dictys," "Groper" and "Powerful." The "Glaucus," when employed in deepening the Carrington Basin, Newcastle, in 1907–8, was engaged pumping into 650-ton hopper barges, which were towed to sea for discharge—a return distance of 8 miles—lifted 1,051,000 tons of sand, at a cost of 1·01*d.* for dredging, including stores, fuel and maintenance expenses, but not depreciation or sinking-fund. The

Mr. Burrows. total cost, including towage and depositing, amounted to 1·94*d.* per ton. The work done was a record for this dredger, and the site was an exceptional one in respect of the quantity of material easily obtainable, although the difficulty of filling the punts, previously referred to, obtained here before the sides of the hoppers were raised and screens were provided. Four drag suction-dredgers were used, principally for deepening the bar entrances to the coastal ports of New South Wales, namely :—

Vessel.	Tonnage of Hopper.	Built by
"Jupiter"	750	Messrs. Simons and Company.
"Tethys"	300	,, ,, ,,
"Antleon"	250	,, ,, ,,
"Latona"	250	Fitzroy Dock, Sydney.

The "Jupiter" was the deepest draft of these vessels, and had been one of the most successful. The other bar or trailing suction dredgers varied in draft from 4½ to 7½ feet, and were used to deepen the shallow entrances of the smaller coastal rivers. No cutting plant was required on any of these vessels, as the material worked on consisted entirely of sand. The quantity of dredging effected annually, apart from the operations of the Sydney Harbour Trust, in improving the ports of New South Wales, averaged over 5,000,000 tons. Consideration was being given to the substitution of the dipper type of dredge in place of the small Priestman grab type, but grab types of a larger size (5 tons bucket-capacity) were also being constructed for working under special conditions of both situation and material to be removed. He appended the following details of the dredgers "Hunter," "Glaucus," "Dictys," "Groper" and "Jupiter" :—

"HUNTER."—Ladder dredger, non-propelling, of steel. Engines geared to drive tumbler shafting.

Length over all, 148 feet 6 inches ; breadth, moulded, 32 feet ; depth, 11 feet 6 inches ; mean draft, 6 feet 9 inches ; capacity per hour, 1,000 tons ; maximum dredging depth, 45 feet.

Compound surface condensing engines ; cylinders 20 inches and 40 inches diameter by 24-inch stroke ; working-pressure, 120 lbs. per square inch.

Return tubular boiler, diameter, 12 feet 9 inches ; length, 10 feet. Two Deighton corrugated furnaces.

Centres of tumbler shafts, 96 feet ; bottom tumbler five-sided, top four-sided ; thirty-five buckets on ladder ; buckets have cast-steel backs ; bucket shoot discharges on either side, "GLAUCUS."—Pump dredger with cutting gear; built of steel; square ends. Mr. Burrows.

Length over all, 152 feet; breadth, 36 feet; depth, 9 feet 10 inches.

Main pumping-engines, triple-expansion surface condensing; cylinders, $16\frac{1}{8}$ inches, $24\frac{3}{4}$ inches and $41\frac{1}{2}$ inches diameter by 24-inch stroke; about 200 I.HP. Sand pump of steel plates, with lining plates on periphery and sides; cast-iron impeller, 7 feet 9 inches diameter; maximum peripheral speed, 3,404 feet per minute.

Two return tubular main boilers 9 feet 3 inches diameter by 9 feet 8 inches long, and an auxiliary boiler 9 feet $1\frac{3}{4}$ inch diameter by 9 feet 8 inches long; working-pressure 150 lbs. per square inch.

Suction pipe, 28 inches in diameter, pivots in recess at forward end of dredger from trunnions secured to deck; discharge pipe, $28\frac{1}{2}$ inches diameter.

Cutter engines diagonal, with two cylinders 12 inches diameter by 11 inches stroke; working-pressure, 100 lbs. per square inch; operate twelve steel cutters at end of suction pipe by shaft and spur gearing (*Figs. 9*).

Dredger works to a depth of 32 feet.

"DICTYS."—Iron vessel with rounded ends.

Length over all, 100 feet 9 inches; breadth, 30 feet; depth, 7 feet 6 inches.

Main pumping-engines, compound surface-condensing; cylinders, $18\frac{1}{2}$ inches and 36 inches diameter by 24-inch stroke; about 250 I.HP. Sand pump has fan 6 feet $6\frac{3}{4}$ inches diameter, with maximum peripheral speed of 2,900 feet per minute.

Two return tubular boilers, 9 feet diameter by 10 feet 4 inches long; working-pressure, 80 lbs. per square inch.

Discharge-pipe, 20 inches diameter. Double suction pipe originally 15 inches in diameter. New square pipes since fitted.

Cutter engines, vertical compound surface condensing, 13 inches and 23 inches diameter by 15-inch stroke. These operate worm gear driving steel shaft 8 inches diameter, at the lower end of which is fitted a cutter ring having eight steel knives working at a radius of 3 feet $4\frac{1}{2}$ inches (*Figs. 10*). Speed of cutter-shaft varies from 12 to 15 revolutions per minute, according to material.

"Dictys" has been principally engaged on removal of soft rock or indurated sand at the Richmond River entrance; cost of excavating and depositing 15,163 cubic yards of rock measured in situ, 4*s*. $11\frac{1}{4}$*d*. per cubic yard.

Dredger works to a depth of 24 feet.

"GROPER."—Steel vessel, with one square end and the other semi-circular.

Length over all, 120 feet 3 inches; breadth, 50 feet; depth, 8 feet 6 inches.

Main pumping-engines, compound surface condensing, cylinders, 20 inches and $38\frac{1}{2}$ inches diameter by 24 inches stroke; about 350 I.HP. Sand pump of steel plates with lining plates on periphery and sides; impeller of cast iron, 7 feet 6 inches diameter; maximum peripheral speed, 3,400 feet per minute.

Two return tubular main boilers, 9 feet diameter by 10 feet 4 inches long, and an auxiliary boiler 6 feet 7 inches diameter by 9 inches long; working-pressure 100 lbs. per square inch.

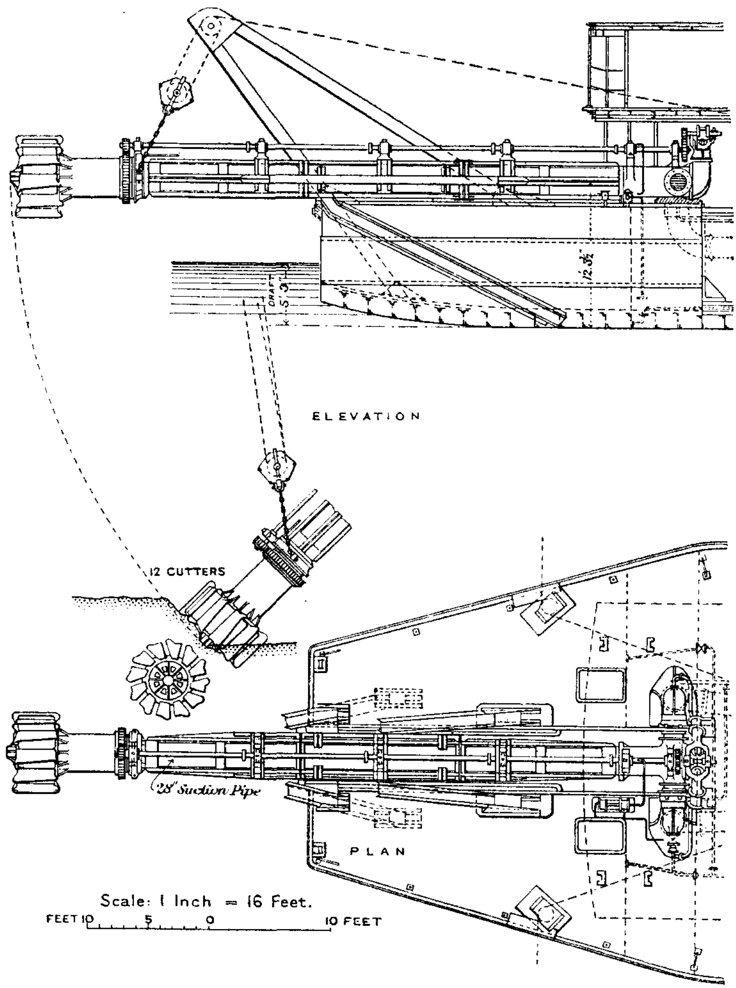
Suction pipe, 20 inches in diameter, telescopic, secured to a radial table movable in a circular direction for full width of dredger; discharge-pipe, 20 inches diameter.

Cutter-engines diagonal, with two cylinders 12 inches diameter by 12 inches stroke. These operate bevel gearing, driving a steel shaft 8 inches diameter, at the lower end of which is fitted a cutter-ring having eight steel knives working at a radius of 3 feet $4\frac{1}{2}$ inches (*Figs. 11*). Speed of cutter shaft varies from 6 to 10 revolutions per minute, according to material.

Dredger works to a depth of 20 feet.

Mr. Burrows. "JUPITER."—Now steel twin-screw pump hopper dredger with trailing suction-pipe aft on each side. Originally pump hopper dredger, built by Messrs. W. Simons and Company in 1892 fitted with 20-inch suction-pipe on each side of

Figs. 9.



CUTTER-GEAR OF "GLAUCUS."

the vessel leading forward, and 20-inch discharge-pipe from each pump delivering spoil into hopper.

Each engine was fitted with disconnecting friction clutches forward and aft, for use independently for propelling or pumping, as required.

Mr. Burrows.

Vessel lengthened 8 feet in 1907 at Fitzroy Dock, Sydney, and fitted with trailing suction pipes aft, having specially designed mouthpieces. Old sand pumps and pipes removed, and engines coupled to shafting for propelling only. Vertical triple-expansion engine, with all accessories for driving a hinged cover sand pump at each end of the crank shaft installed across the vessel forward of the propelling engines.

Length between perpendiculars, 168 feet; length over all, 173 feet; breadth, 32 feet; depth, 11 feet 6 inches.

Twin propelling engines, triple-expansion surface-condensing, having cylinders $11\frac{1}{2}$ inches, $18\frac{1}{2}$ inches and 30 inches diameter and 24-inch stroke; about 800 I.HP.

Main pumping engine triple-expansion surface-condensing; cylinders, $12\frac{1}{2}$ inches, 20 inches and $32\frac{1}{2}$ inches diameter by 20-inch stroke; about 450 I.HP. Two sand-pumps with cast-iron casings, having steel lining-plates on periphery and sides. Impellers, 5 feet 6 inches diameter; maximum peripheral speed, 3,110 feet per minute.

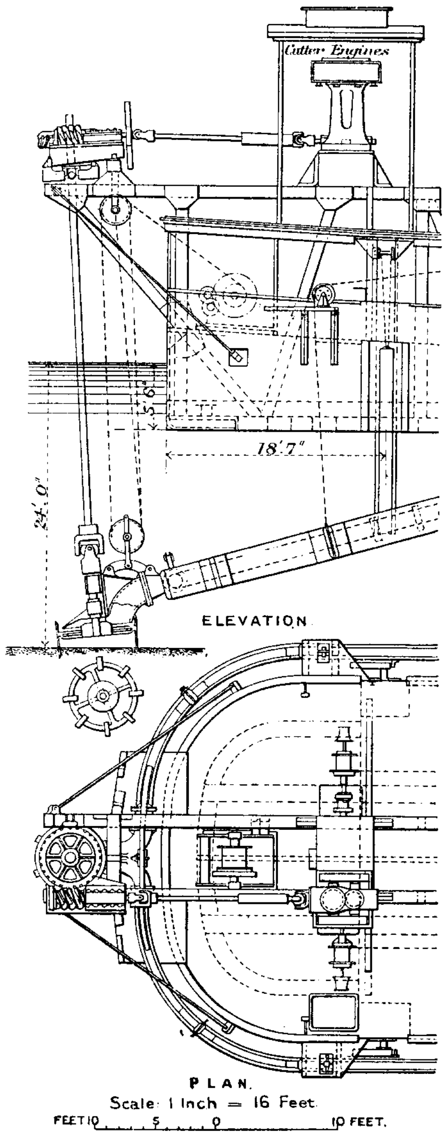
Two return tubular boilers, 11 feet diameter by 10 feet long; working-pressure, 160 lbs. per square inch.

Two trailing suction-pipes, 16 inches diameter; discharge-pipes to hopper, 16 inches diameter.

Hopper (capacity 750 tons) can be filled with sand in about 30 minutes when the pumps are at maximum speed.

Dredger works to a depth of 36 feet.

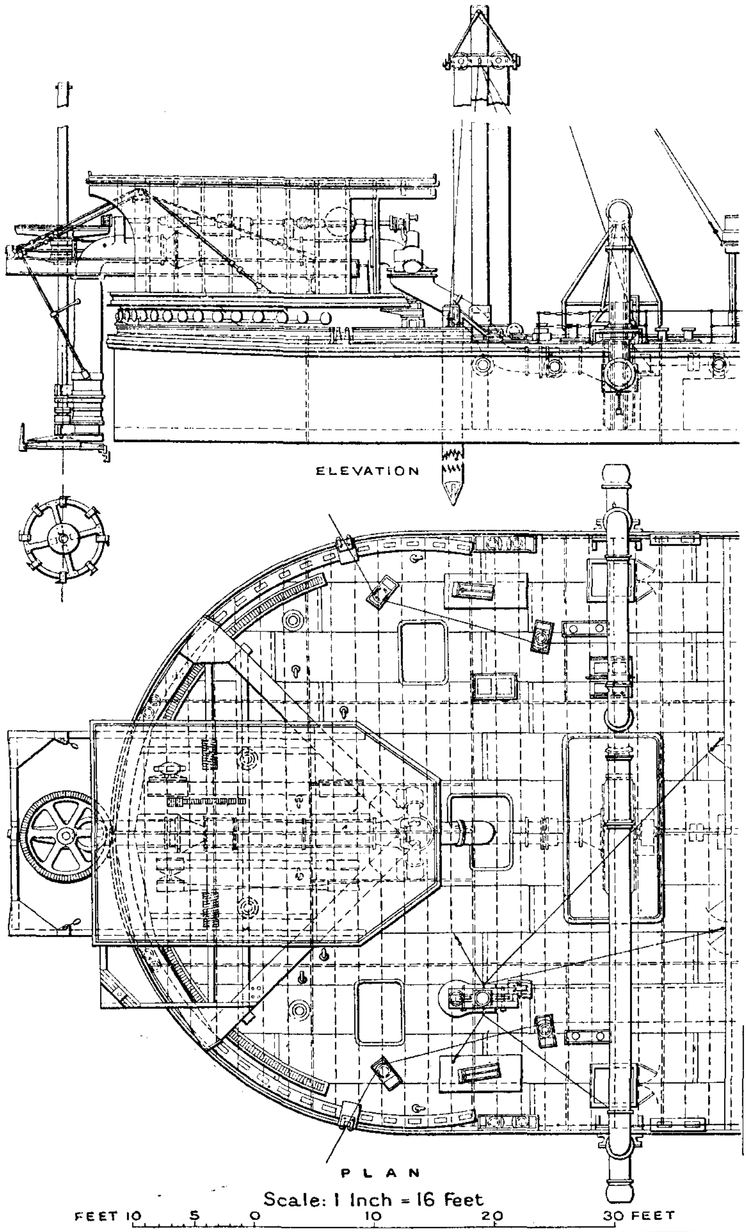
Figs. 10.



CUTTER-GEAR OF "DICTYS."

Mr. Burrows.

Figs. 11.



CUTTER-GEAR OF "GROPER."

Mr. J. M. S. CULBERTSON had read the Paper with great interest, the more so as several of the dredgers mentioned were now attached to his department in Mesopotamia, having been brought out on the recommendation, and now working under the orders, of Sir George Buchanan, M. Inst. C.E. The "Oswald" had just completed the reclamation of an area 1,000 feet by 350 feet with 6 feet of filling in 200 pumping-hours, giving an average of 388 cubic yards per hour in fine silt and sand, which spread the full width of 350 feet with a slope of 1 in 700 from front to back. The low average per hour was due to the dredger having to work across a sharply sloping bank, and at times losing her cut. The "Oswald" had now returned to her original work of dredging a channel through a stretch of marshes, where the "Lees" and "Campbell" would probably join her. No mention was made of the excellent small workshop on the "Oswald"; this was very useful and should form a part of all dredgers. Also she had excellent accommodation for the officers and crew, designed for tropical conditions. Even a small ice-plant would not have been an extravagance under the conditions of temperature in which she was working last year, namely, 115° F. on the bridge, 129° F. in the engine-room, and 147° F. in the stokehold, with the surrounding water 98° F. These conditions were, of course, exceptional; however, for ordinary tropical conditions the accommodation provided on most dredgers was insufficient and unsuitable, as had been found on the "Cormorant" and "Graham Lynn." The "Cormorant" had been dredging on the outer bar of the Shat-el-Arab regularly and efficiently. The upper surface consisted of river-borne silt, which, when deposited, showed a clayey consistency. In this material she filled her hopper in 20 minutes; below it a harder material was found, which her nozzle did not seem suited for. To overcome the difficulty the chief engineer of the dredger had designed a revolving plough to be fitted on the present nozzle, from which good results were hoped for. The dredging-master, Captain Gregory, had also pointed out the difficulty of dredging in comparatively shallow water due to the nozzle either dragging over the surface or jamming hard in; this could be overcome by having a ball joint between the nozzle and suction-pipe, so that the nozzle could be set at various angles according to the angle which the suction-pipe was making with the ground. The water-jets around the nozzle always became clogged and unserviceable. The accommodation provided had been increased by cabins for officers being built over those already provided. The lack of a workshop, which might easily have been

Mr. Culbertson.

Mr. Culbertson. provided for on the lower deck, was felt acutely. Particulars of the "Graham Lynn" had been given previously.[1]

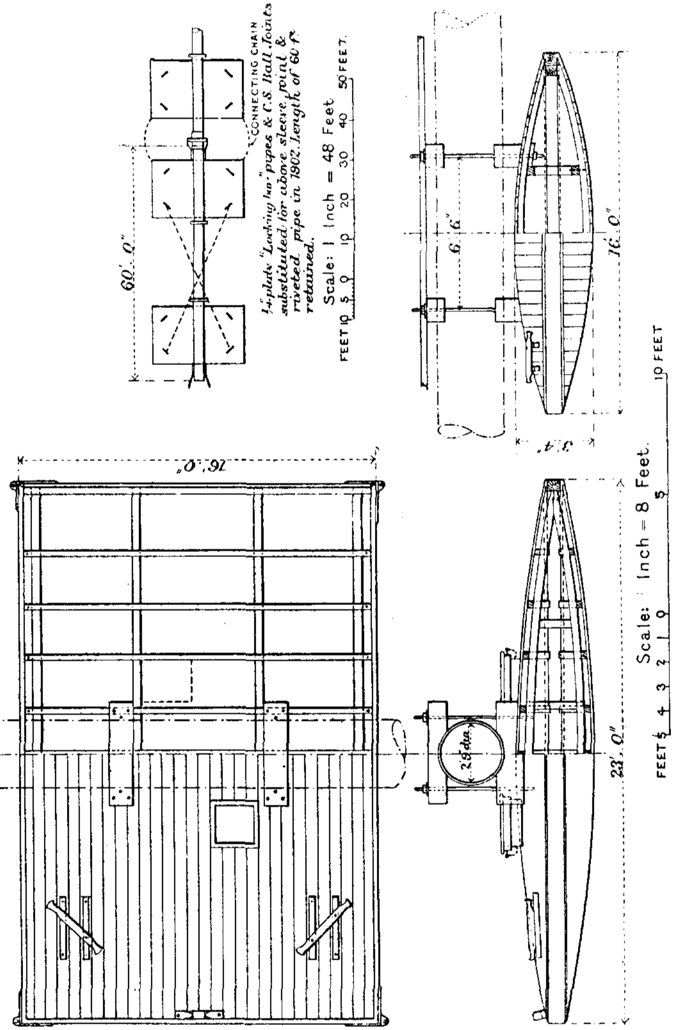
Mr. Cullen. Mr. E. A. CULLEN considered that the Paper would be very welcome to harbour-engineers, as a help in determining the most efficient method of dealing with the ever-increasing work of providing greater depths. As the necessary excavation increased year by year, so the desirability of procuring the most suitable machine became more pronounced. In the Brisbane river, about 20 miles of which was under improvement, the bottom varied from rock to soft mud. Since 1892, when Mr. Cullen became responsible for the direction of harbour-improvements in Queensland, about 63,875,000 tons had been removed from the river, of which 28,450,000 tons had been delivered ashore, and the dredging fleet employed thereon included all the types referred to by the Author, with the exception of the dipper type. One of the three bucket dredgers employed, the "Platypus," a twin-screw 800-ton hopper, was built by the Author's firm in 1883 to the order of the late Mr. W. D. Nisbet, M. Inst. C.E., who was Engineer for Harbours and Rivers in Queensland at that time; and the fact that the machine had been almost continuously at work since then, and was still in active service, bore eloquent testimony to the excellence of the design and workmanship. Mr. Cullen found that when working in sharp heavy river-sand, pins of special hardened steel did not give much better service than common pins; but in mud and clay the former gave the result that was claimed for them. He had the buckets driven at a speed of 18 per minute in ordinary material. Recently he had used cast-steel buckets, made locally, the bodies or crowns of which, about $\frac{5}{8}$ inch thick, were cast in one with the backs, and so far the results were quite satisfactory. The use of such large machines as those described by the Author, with buckets of 42 cubic feet capacity, opened an interesting question from the maintenance point of view, and any information on this latter subject would be very valuable. In his opinion, smaller machines would continue to prove most suitable for ordinary harbour-work apart from special undertakings such as that at Panama. The question of using close-connected buckets did not appear to be often referred to, if at all, but responsible mining engineers had informed him that they would not use any other type of bucket-chain in mining-dredgers, and as they worked for dividends, their opinion was interesting. He believed that most

[1] Minutes of Proceedings Inst. C.E., vol. ccii, p. 223.

of the mining-dredgers in the Malay States and in the western United States had close-connected buckets. He had had no opportunity of testing the matter personally, but perhaps the Author would express an opinion on the question. His experience did not lead him to endorse, as generally correct, the statement quoted by the Author respecting an Admiralty cutter dredger putting out double the quantity of hard material that a powerful bucket dredger could do. In the operations under his direction any really hard material was left for the bucket dredgers to deal with, as being the most economical method: much, however, depended on what was meant by the term "hard." Since 1901 a cutter dredger had been in continual service on the Brisbane river and had dredged and piped ashore 16,055,050 cubic yards, measured in excavation, up to June, 1916. This machine, the "Hercules," designed by Mr. Lindon W. Bates, Assoc. Inst. C.E., and built by Messrs. Armstrong, Whitworth and Company in 1900, steamed out to Brisbane and had been working continuously since; her length was 230 feet, breadth 38 feet, draft 7 feet. Suction- and delivery-pipes were 33 inches in diameter, the former working in a bow well, and the vessel was operated by swinging the bow through an arc of 200 feet, the stern being pivoted on a spud. There were two spuds, so disposed that by alternate use the vessel advanced 3 feet 6 inches on the centre-line of cut with each swing. The essence of effective work with this type of machine, assuming adequate power, lay in keeping the cutter engaged with the material; and in cutting in an open area subject to tidal currents there was no doubt that the use of spuds was highly advantageous in regard to output and economy in working-time. The spuds in the "Hercules," which were 24 inches square and 60 feet long, were built of four pieces of Australian hardwood, bolted and dowelled together, and weighing with the shoe about 8 tons each. In 1902, Mr. Cullen added cutting mechanism to an 800-ton hopper drag suction dredger with a 22-inch pump built to his requirements in 1896 by Messrs. Fleming and Ferguson, and he also provided spuds, considering that a mechanical cutter could be worked to greater advantage with them in areas subject to currents. The Author gave the velocity of discharge in the "Jinga" and "Kalu" as being 11·7 feet per second. With the pump which Mr. Cullen had found it necessary to put in the "Hercules" in place of the original, velocities up to 26 feet per second were obtained on low duty, but for general work with about 1,800 feet of pipe-line and about 15 feet lift above water-level, velocities of 18 to 20 feet per second were easily maintained and Mr. Cullen.

Mr. Cullen. would transport all the material, of any nature, that could be fed. With lower velocities, working in heavy sand, deposits occurred in

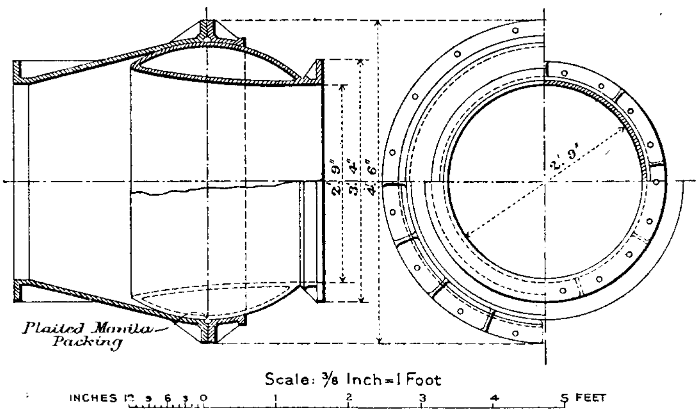
Figs. 12.



PONTOONS FOR PIPE-LINE.

the pipes, throttling the discharge, and annoying delays, for the purpose of washing out the pipes with clean water, took place. The remarkably good output of the "Jinga" and "Kalu" with such relatively low velocity of discharge indicated that the material was of low specific gravity. In machines of this type a suitable floating pipe-line was a very important factor; originally the "Hercules" had a pipe, contained within a steel pontoon of nearly equal length and elliptic cross section, in 50-foot lengths. A very neat combination gimbal ring and ball joint connected the pipe-ends. In a tideway of 2 to 3 knots this line failed completely: it offered too much resistance to the current to be easily held in position, and the joints could not stand against the leverage exerted on them at times, notwithstanding the use of check-chains. The pipe-line finally adopted, with entire success, consisted of "locking-bar" pipes in two 28-foot sections, making one 56-foot pipe of $\frac{1}{4}$-inch plate carried on Mr. Cullen.

Figs. 13.



S.D. "Hercules": C.S. Ball Joint for Pipe-Line.

two wooden floats, which had only sufficient buoyancy to carry the load, and were of such shape that waves ran up on them with minimum oscillation, reducing torsion, and the resistance to the current was rendered easy, no matter from what direction it came (*Figs. 12*). The 56-foot pipes were connected by cast-steel ball-and-socket joints, which had proved quite watertight, making a 60-foot length between centres (*Figs. 13*). A short 10-foot length, with a ball joint at each end, was used to connect the line with the hull. The "Hercules" has a triple-expansion engine indicating up to 1,750 HP. to drive the pump and two compound engines each of 175 I.HP to drive the cutters. The following Table illustrated the capacity of the "Hercules," it being understood that much of the material dealt with was a very stiff mud which discharged in lumps up to the size of

Mr. Cullen. a man's head, and that the quantities were measured by the excavation made:—

Year Ending 30th June.	Cubic Yards.	Cost per Yard.	Average Output per Dredging-Hour.
		d.	Cubic Yards.
1907	1,243,570	2·43	753
1908	1,156,050	3·03	727
1909	1,051,630	4·09	803
1910	1,209,390	3·86	822
1911	937,410	4·26	620
1912	1,121,790	3·08	883
1913	1,271,090	3·03	923
1914	1,386,110	2·73	917
1915	854,760	4·39	562
1916	1,048,320	3·74	762

The cost of labour and coal increased about 20 per cent. during this period.

During the period 12th August to 19th September, 1914, the bulk of the material dredged was free heavy river-sand, and the average hourly output for that period was 1,350 cubic yards. In 1911 he procured two trailing suction dredgers, one for the Harbours and Rivers Department and one for the Cairns Harbour Board in Northern Queensland. These were generally of the type of the "Cormorant" and "Canterbury," described by the Author, with a little more power and longer hull, but without the bow jet steering-arrangements, the lack of which did not appear to be felt. In both dredgers the results obtained were very satisfactory, and he considered that this type offered a very favourable solution for many dredging problems. As the Cairns dredger was to work on a long mud bar, and the nearest dock was 900 miles off, he specified a dry hopper without doors, and that dredger depended entirely on her pumps for discharging the load. These two dredgers were 214 feet in length and 38 feet beam, with hoppers of 27,000 and 30,000 cubic feet respectively; they loaded with mud in 20 minutes and discharged with pumps in 10 minutes. In heavy sand they required about 30 to 40 minutes to load and 45 minutes to pump the load out. Both dredgers were arranged to pump the load ashore, and the one in the Brisbane river disposed of most of her spoil through a line up to 800 feet in length with lifts up to 16 feet. There were two pumps, each with 16-inch suction and delivery; the 22-inch shore discharge-pipe received both deliveries. Each pump and each propeller was driven by a triple-expansion engine of 300 I.HP., of which there were four, so placed that two engines could be coupled to one pump or to one propeller at will. In ordinary work one engine drove a pump and one drove a propeller. Mr. Cullen.

Mr. Hindmarsh. Mr. R. F. HINDMARSH observed that in the case of the dredger "Silurus" the gearing between the main engines and the upper tumbler was stated to consist of cast-steel bevel and spur wheels having machine-cut teeth, and the tumbler appeared to be driven from a central shaft and driving-wheels on each side of the tumbler. This method was preferable to that adopted in some dredgers of comparatively recent date, where the tumbler was driven by a single driving-wheel consisting of a mixture of steel and iron and a vertical shaft which was not central, as in such a case it had been found that trouble was caused by a racking movement causing the breakage of a large number of the teeth on the wheel. It was also of advantage to make the tumbler shafts of forged steel, keyed to the tumbler with fixed sleeves fitted to take the wear on the shaft. A great deal of time was lost in changing from one size of buckets on a dredger to another size, and it was doubtful whether it was worth while to provide two sizes, especially on a dredger with two speeds of buckets, as the low speed could be used for hard material and the higher speed for soft material; and in the majority of cases this was all that was required without changing buckets. Lips of manganese-steel had been tried on the Tyne, but their use had been discontinued. Lips of mild steel were fitted on all the Tyne dredgers, and were found to be satisfactory when secured by at least two rows of rivets, even when dredging hard material. Manganese-steel pins were, however, used in the bucket-links of all the dredgers. The Paper did not state whether the ladder on the "Silurus" could be lowered on the brake or when in gear with the engine; the latter practice appeared to be much safer than throwing the engine out of gear and lowering by brake. The highest daily record for material dredged on the Tyne by one dredger and deposited 3 miles at sea had been obtained recently by the removal of 13,680 tons of material dredged in 24 hours. This work had been done by a stationary bucket dredger, working on low-speed gear and in blue silt and gravel with boulders, at a depth of 38 feet at L.W.O.S.T. The comparison of the work carried out by the dredger "Kuphus" when working as a stationary dredger and when working as a hopper dredger transporting its own dredgings was interesting; it would probably be found, however, that in the majority of cases a much larger output could be obtained from a stationary bucket

Mr. Hindmarsh. dredger sufficiently supplied with hopper barges than by means of a hopper dredger transporting its own dredgings, owing to the time lost by the dredger in travelling to and fro, and to the time lost in dropping and picking up moorings, etc. With regard to clay-cutting suction and reclamation dredgers, a large Admiralty cutter suction dredger had recently been employed on the same work on the Tyne on which bucket dredgers were employed, the material dredged being blue silt and gravel, the maximum day's output of $10\frac{1}{4}$ hours from the cutter suction dredger being about 4,000 tons, or 390 tons per hour, and in the case of the largest of the bucket dredgers about 11,280 tons per day of $22\frac{1}{2}$ hours, or 501 tons per hour. The depth being dredged in this case was 53 to 55 feet at L.W.O.S.T. Suction dredgers appeared to be particularly suitable for sand and fine gravel.

Mr. Hunt. Mr. H. L. HOLMAN HUNT remarked that the Paper described the work carried out on the Twante Canal during the first 3 years. More than a year had elapsed since then. The Paper read rather as if the shortness of the overhangs of the terminal pontoons had prevented the project from being a success, whereas the project was being completed in considerably less than the estimated time and showed a saving in cost of more than 30 per cent. The dredgers were named after Mr. Oswald Campbell Lees, M. Inst. C.E., late Chief Engineer of the Public Works Department, Burma, who had had dredger experience in Bengal, and who inaugurated the Twante Canal project. On completion of this work it was intended to employ the dredgers upon improvement of the many waterways in the Irrawaddy Delta. It was apparent when the dredgers first started work on the Twante Canal that the overhangs of 80 feet were much too short for work at the Rangoon end, and Mr. Hunt had to try to get them lengthened. Sanction for this, necessitating the purchase of at least one and possibly two new terminal pontoons, at a cost of about £10,000 each, had been difficult to obtain, and it had been decided that 6 months' trial should be given to them before incurring such additional capital expenditure. He was away on short leave on the expiry of the 6 months' trial, and found on his return that through some misunderstanding it had been decided to carry on with the existing plant. It took some months to alter this decision and to obtain Government sanction to the ordering of a new terminal pontoon with a 200-foot overhang. When war broke out the pontoon was still within a few weeks of completion. It arrived in Burma in November, 1915, was erected by March, 1916, and was first used in April, 1916. Had it been ordered a month or so earlier it would have been in

Burma about one year sooner. Since its arrival, everything had gone smoothly; practically no coolies were required to deal with the spoil, and work was possible at all states of the tide. The working-expenses of the dredger came to about £1,000 per month, and as, apart from the saving of about £100's worth of coolies monthly, the dredging-hours in the 20 feet range of tide zone had practically been doubled, the economy of the longer pontoon was obvious; in fact, in places where land-slides had occurred, the completion of the work would have been impossible, as the shorter overhang would not have reached over the damaged bank, even at high water. The "Campbell" was making use of the old pontoon of the "Lees" with a 24-inch diameter pipe 120 feet long; this did not allow her to work all day at the Rangoon end, but it was a great improvement on the old conditions. As the Author stated, pending the arrival of the larger terminal pontoon the diameter of the pipes on the old pontoons had been reduced, thus obtaining a longer overhang. This reduction of bore was necessary, because the jibs were not strong enough to carry more than the designed weight. It certainly allowed dredging for longer hours; but the throttling of the discharge had a bad effect upon the output, as it increased the back pressure with a corresponding decrease in the vacuum on the suction side of the pump. The result was that whenever a large output was attempted, the heavy back pressure overcame the pump, which churned the spoil instead of forcing it through the discharge-pipe; the vacuum then fell more, and failed to suck up further spoil, which allowed the engines to race. The jet pump had then to clean the discharge-pipe, and dredging was interrupted; it was therefore always a case of trying for a large out-turn with continual interruptions, or of working at 75 per cent. efficiency. In any similar dredger intended to deal with spoil that was not extremely soft he considered the spoil should be capable of being deposited, at any state of the tide, at least 100 feet behind the marginal embankment; even in the case of light spoil, which flowed well, it was not advisable to deposit it near the edge, as in that case the banks were likely to be equally soft and more likely to slip. One of the principal mistakes which had been made in maintenance, and one which should be guarded against by others using dredgers, was that the spoil-pipes were allowed to wear too thin before being lined with wearing-plates. This resulted in pipes becoming so thin that they burst, and had to be entirely replaced. He recommended that all spoil-pipes should have liners fixed in them at the start. All bolts or rivets should be countersunk perfectly level with the surrounding surface, and the fewer used the better, Mr. Hunt.

Mr. Hunt. especially at the bottom of the pipes where wear was greatest; however well countersunk a bolt or rivet might be, it invariably scoured out round its edges. As to general design, the pump-cases gave a certain amount of trouble at the start; the builders, however, had rectified everything, and any of their future productions would benefit accordingly. In several minor details saving of time or wear and tear could be effected as the result of experience. Regarding interruptions to dredging, it should always be borne in mind how much money was wasted during a dredger's enforced idleness. If a dredger cost Rs.500 a day to work, it was obvious economy to spend an extra Rs.300 in hurrying a job so as delay her 1 day less. With regard to the return of the water into the waterway, pains must be taken to let it return as clean as possible, as, if it were heavily laden with silt, much of the work must be done over again. The outputs of the dredgers, as given by the Author, showed how satisfactorily they had worked. The success had been greatly due to the loyal work and help of two dredging-masters, Mr. Robert Renfrew and Mr. John Campbell. These two engineers came out with the dredger from Messrs. Simons and Company and had given complete satisfaction. If a dredging-master were intelligent and zealous he could arrange to carry out at one time several operations such as passing traffic, lengthening and shortening pipe-line, changing moorings, repairing machinery, repairing breached bund, etc.; whereas an inferior dredging-master invariably stopped work to carry out one operation, and found that he must stop again almost as soon as he had started. The best output was obtained by forcing the cutter into the spoil just short of choking the discharge-pipe; if choked, the spoil was heavier, but only discharged half or quarter bore, besides overstraining the machinery; if not on the verge of choking there was an unnecessary quantity of water. The happy medium gave the maximum output.

Mr. Howkins. Mr. J. D. HOWKINS stated that the tendency at Hartlepool, where the Port and Harbour Commission had preserved records of dredging-costs, etc., for many years past, had been to develop the barge-loading type of bucket dredger as against the hopper type. In fact, the only hopper dredger, which the Commissioners became possessed of in 1902, had been a complete failure as such, and only moderately successful as a barge loader, as her shoots, etc., were so constructed that a large portion of the spoil fell into the well, and she had to make a trip to sea every second day in order to get rid of this. She was eventually sold in 1913, and a new barge-loading self-propelling hopper dredger was obtained in her stead. In his opinion it did not by any means follow that a dredger which was successful at one port would necessarily be so at another, as local conditions, size and shape of buckets, and the distance to be covered for the deposition of spoil, rendered the laying-down of hard and fast rules an impossibility. Generally speaking, he considered that if the spoil had to be carried, say, more than 2 miles, and there was room to work with barges alongside, the non-hopper type would be more successful. At Hartlepool the distance to be traversed was 3 miles out and 3 miles back, and it had been ascertained that the hopper dredger steamed two-thirds of the time, and worked only one-third. A point to be observed was that most modern hopper dredgers were fitted with twin screws, and required both engines for propelling purposes, but only one engine was used at a time for dredging. The latest dredger, which was now under construction, of the Hartlepool Port and Harbour Commission was non-propelling, but here powerful steam hopper barges were available for towing, and the distance from the harbour to the working-ground was inconsiderable. A few years ago an interesting experiment was made, an exchange of dredgers for a week being effected with the North Eastern Railway Company. The Commissioners worked a channel for the Company with a bucket dredger, and used the Company's hopper suction dredger in their channel. Although, to those who did not know the character of the material, the conditions would have been considered fairly good for a suction dredger at the latter place, as about 8 feet of sand overlay the clay, the suction dredger was not a success, as the sand was of such a lively description that the inrush of fresh sand and water never permitted what was already in the hopper to consolidate, and the suction dredger never succeeded in filling herself with more than $\frac{1}{4}$ sand to $\frac{3}{4}$ water. Mr. Howkins.

Mr. D. C. LEITCH remarked that the very interesting figures relating to the cost of dredging, given in the Paper, would have their value greatly enhanced if some particulars of such charges as interest on first cost, amortization, and insurance could be given. These items were said to be included in the costs quoted in Table IX, which gave, however, only total costs per ton. Table VI included interest and amortization, though the provision seemed hardly adequate under existing conditions, and the conditions might not be much easier for some considerable time to come. The other tables of costs apparently omitted the items in question, although, in some cases at least, they were likely to form a considerable percentage of the total. He suggested that at present interest on first cost could hardly be put lower than $5\frac{1}{2}$ to 6 per cent. Amortization, Mr. Leitch.

Mr. Leitch. assuming the life to vary in different classes of dredging-plant from 12 to 18 years, would call for $3\frac{1}{2}$ to 6 per cent. Insurance might vary, according to conditions of working, from $2\frac{1}{2}$ to 3 per cent.; when the plant was not insured an equivalent addition to the rate of interest on cost, or a provision for contingencies, would be required. These items made up a total of $11\frac{1}{2}$ to 15 per cent. per annum on cost of plant. In small jobs, where plant was hired, or contract work resorted to, these figures might have to be materially increased. It was hardly possible to form any useful opinion of the efficiency and economy of dredging-plant unless the cost of it was known. Economies in working-costs might be purchased too dearly if they increased unduly the cost of the plant; improvements which did not pay for themselves did not deserve the name. It would add very much to the value of the Paper if the Author could give some information as to the cost of the plant described. His remarks, in the second paragraph of the Paper, were fully concurred in; but surely if it was necessary, as he said, to take account of all physical and mechanical conditions in comparing costs, it was equally necessary to provide for charges imposed by financial conditions.

Mr. Methven. Mr. CATHCART W. METHVEN remarked that few shipbuilding firms had done more for the development of dredging-plant than that of which the Author of this valuable Paper was the head. As Mr. Methven was Engineer-in-Chief of the Durban harbour-works during their most critical period as regarded the improvement of the entrance and the removal of the bar, he was thoroughly acquainted with the conditions before and after dredging on a large scale was commenced. Indeed the first of the large dredgers, the "Octopus," was built by the Author's firm to Mr. Methven's specification. He had recognized at an early date, and pointed out in 1890, in his first report after studying the conditions of the very difficult problem of removing the sand bar at Durban, that dredging would have to be resorted to in order to aid the available natural forces in increasing the depth at the entrance. After being appointed Engineer to the Natal harbour-works in 1888, his first step was to visit Holland and inspect the dredging-operations with sand-pump dredgers then proceeding at the mouth of the river Maas. Sand-pump dredgers in those days were small craft compared with the vessels now employed, the lead having been given by Liverpool in the direction of the larger and more powerful craft afterwards used at Durban, of which the "Octopus" was the first. In 1888, before coming out to Durban, he specified, and got Messrs. Simons & Co. to build and send out to that port, a sand-pump dredger, the "Beaver," of 500 tons hopper-capacity, and provided with two 18-inch suction pipes leading towards the stern. This vessel, though intended for dredging on the bar as well as inside, was not of sufficient power for the former work, and was mainly used for inner work; she was nevertheless employed by him from time to time for experimental dredging on the bar before the arrival, towards the end of 1895, of the "Octopus," which had a hopper-capacity of 1,200 tons, two powerful centrifugal pumps, and a suction-pipe 42 inches in diameter—a diameter not exceeded in any of the craft subsequently obtained, although the later ones were of much larger hopper-capacity. The hopper-capacity of the "Octopus" was fixed by the Port Captain, whose duty it was to work these dredgers, and who considered that a boat of this size was as large as could be safely handled at the entrance as it stood in 1894, when Mr. Methven drew the specification. Two sister ships, the "Walrus" and the "Grampus," were then obtained, and set to work in 1898 and 1900. Owing to the configuration of the entrance-works, the southern breakwater up to 1898 overlapping the northern work by about 700 feet, a tongue of sand grew rapidly under the lee of the projecting breakwater right across the entrance, diverting the channel to the northward round the head of the north pier. Persistent opposition to his earnest recommendation that the northern work should be immediately extended resulted in a continuance of these adverse circumstances, and dredging on the bar with such plant as was available up to the starting of the "Octopus" in 1896 proved worse than useless. The tides tended to form a channel round the end of the shorter northern work, while the only line on which a dredger could work end on to the seas was immediately under the lee of the south breakwater, and in the direct line of the Bluff channel. Under such conditions therefore (as more fully described in his Paper on Durban Harbour [1]), the natural forces were opposed to the artificial device of dredging, and of course could only result, as he persistently pointed out to the authorities, in failure. Such temporary channels as were dredged in fine weather were immediately blotted out in rough weather, and in spite of all he could say and do, it was not until Sir Charles Hartley's and Sir John Wolfe Barry's advice was obtained, and was found to corroborate his as to the necessity for immediate extension of the northern work, that it was brought out abreast of the breakwater, and the conditions became such that dredging could be applied so as to work in conjunction with the natural force of the induced scour from the inner bay, instead of

Mr. Methven.

[1] Minutes of Proceedings Inst. C.E., vol. cxciii, p. 1.

Mr. Methven. in a direction opposed to it. This and the dredging together had made the present splendid navigable channel of about 36 feet at L.W.O.S.T. The Author, apparently through not being so well acquainted with the facts as Mr. Methven was, had therefore somewhat over-estimated the actual work performed by the dredgers in the formation of this channel, though Mr. Methven in no way desired to underrate the importance of this work: had it not been for the powerful dredgers, whose use he had been the first to advocate at Durban, the channel of to-day would not have existed. But it must not be overlooked that the tidal volume flowing in and out of Durban Bay was a large one, now amounting to at least 30 to 40 million cubic yards. It was not therefore correct to credit the dredgers, as the Author did, with 29 feet 3 inches out of the 36 feet 5 inches which he gave as the low-water depth of the present channel, and which he stated had been in the main obtained by dredging. In support of this he cited the depth in 1884, when, he said, the low-water channel was only 7 feet 2 inches. But he seemed to ignore the fact that not only was no dredging of any consequence whatever done until the arrival of the "Octopus" in 1895, but in 1884 the outer works were in a very incomplete state. Indeed when, some time previous to that date, Mr. Methven consented to place the "Beaver" on the bar—in order, if possible, to satisfy those in opposition to the extension of the north pier, of the futility of dredging under such conditions as then existed, at all events with such plant as the Harbour Board then possessed—her work was wiped out almost as fast as it could be accomplished. It might, in fact, be accepted that for all practical purposes no dredging was done on the Durban Bar until 1896. Yet in 1892 a natural channel was created of 13 feet 8 inches average depth for the year at L.W.O.S.T., and in 1893 of 13 feet 4 inches average depth. Owing to weather conditions and the continued delay in extending the northern work, this fell off to 12 feet 1 inch in 1895, and under those same conditions, and a year's dredging with the powerful dredger "Octopus" in 1896, it increased to 15 feet 11 inches, or only 2 feet 3 inches in excess of the depth of 1893. But in 1899 the two piers were brought abreast, and with steady continuous dredging on a line which the natural force of scour was then made to follow, and by dredging away accumulations of sand to windward of the breakwater, co-operation between the dredgers and the scour was made possible, and that had gradually brought about the present results. In 1902 the average depth of the channel was only 18 feet 5 inches, or 4 feet 9 inches in excess of what it was in 1893 when no dredging had been done, Mr. Methven.

although the "Octopus" had been at work for 7 years, and a sister ship, the "Walrus," for about 5 years. Other powerful dredgers of much larger hopper-capacity were then obtained, and the depth has steadily increased up to its present very satisfactory figure. It was obvious that no one could pretend to say exactly how much of the present depth at low water was due to the entrance-works and the induced scour, and how much to dredging; but it was very clear that the natural forces were accountable for the 13 feet 8 inches at low water in 1893, which was obtained without any dredging on the bar, and this in spite of the fatuous policy of extending the south work alone on the weather side of the entrance, and literally, by its means, building up one of the worst sand-bars in the world immediately under its lee. It was clear, therefore, that with the north pier extended abreast of the south pier, and the scour thus concentrated and directed on to the same line as worked on by the dredgers, they must greatly assist each other; and having regard to the improvement effected before there was any dredging at all on the bar, and when the works were in a very unfavourable position, the honours must now be pretty equally divided between the effect of the works and the effect of dredging. He had endeavoured to make this clear, as he knew from experience that there were ardent advocates of dredging who were disposed to under-estimate the immense importance of utilizing to the full all the natural agents which could, by means of judiciously-designed works, be made to contribute very materially towards success, and that if such means were fortunately to hand, but were neglected, the cost of dredging-operations would be not only very materially increased, but much of the work would be undone after weather during which the dredgers could not work. In Table VII the Author gave the dredging done outside the breakwater from 1884 to 1903 as 4,017,655 tons, but hardly any of this was done until 1896. The "Beaver," the first dredger that could attempt to dredge on the bar at all, only arrived in the colony in 1889. Why, therefore, in face of these facts, deduct the depth of 7 feet 2 inches in 1884 from the present depth of 36 feet 5 inches, and say that the difference of 29 feet 3 inches was "mainly due to the dredgers"? Such splendid machines as those constructed by the Author's firm had practically solved the engineering difficulties of dealing with sand-bars where the available scour was insufficient, but they had by no means done away with the necessity for engineers to make the utmost possible use of the natural means to hand, provided these were sufficient to justify the cost of the necessary works. The most

Mr. Methven. economical and successful policy in such cases was undoubtedly a well-considered scheme for the combination of the two, and the practical results of this were exemplified at Durban. As the Engineer responsible in the first instance for the employment of powerful dredgers for open-sea work on the bar at Durban, he gladly endorsed the Author's testimony as to the invaluable work accomplished by them; but he could not shut his eyes to the other important factors which had contributed to the success that had been attained, nor could he ignore the fact that before any serious dredging was done on the bar, the cross-sectional area of the channel just within the works, at L.W.O.S.T. was 1,300 to 1,400 square yards, and in the beginning of 1915 it was 2,200 square yards, or a little over half as much again.

Mr. Mitchell. Mr. JAMES MITCHELL remarked that harbour- and dock-engineers in particular would be grateful to the Author for bringing before them particulars of some of the fine dredgers built in recent years by his firm, representing as they did the best practice in this important class of machinery. The design and location of harbours and docks had been influenced to a large extent by the evolution of dredging-machinery, which had solved problems that otherwise would have been insoluble with any reasonable expenditure of money. Commerce had thus been promoted and facilitated, at places where the natural conditions were of a very unfavourable character. The Author very properly directed attention to the general question of costs. Many years ago the late Mr. Harrison Hayter, Past-President, in the discussion on the late Mr. John J. Webster's Paper[1] on "Dredging Operations and Appliances," drew attention to the wide difference between many of the figures published as costs of dredging, and the prices that could be obtained from contractors for similar work. The conditions in the case of, say, a river-conservancy, where there was constant work for the dredging-plant throughout a long period, were, of course, very different from those with which a contractor was faced, with their chances of prolonged unemployment, and costly lying-up or unsalability of plant. In addition to this, it was often possible, in the former case, to provide sufficient work of a uniform type to keep machines of the most suitable kind fully employed, while in the latter case plant had generally to deal with very varied conditions, for some of which it would probably be indifferently fitted. Allowing, however, for all this, and for profit in the case of the contractor, it seemed probable that Mr. Hayter's remarks had still considerable

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix, p. 2.

force. The Author's remark that "too much stress can easily be put on the question of cost" was one that should never be lost sight of in comparing costs of dredging work. The cost of labour, stores, etc., varied considerably from place to place, as did also the difficulties and delays due to traffic, while the nature of the material to be dredged in one place was seldom, if ever, exactly the same as in another. Every engineer who had experience of payment by bonuses, for dredging done under conditions where silt accumulated rapidly, knew the temptation to evade work which militated against large tonnage results. The remark that "different methods of accounting must be reduced to common terms" pointed to a very common cause of discrepancies in the published costs of dredging. Figures that left out of account the items of depreciation and interest were apt to be very misleading. A plant having a high initial cost and low running-costs might or might not be as economical, under similar circumstances, as a plant in which the conditions were reversed. Again, a plant might be designed so as to be practically worn out after completing a given work, all the scantlings, etc., being light; obviously, in comparing such a plant with one that had been built to have a life three times as long, interest and depreciation were very important factors. The excessive wear and tear to which dredging-plant was subject and the liability to damage through grounding, collision, etc., made the cost of repairs very heavy, and the need for repairs, both to the hulls and to the other portions of the plant, increased with its age. It was very important, therefore, in dealing with costs of dredging done by new plant to keep this fact in view, and to make the necessary allowances. Mr. Mitchell.

Mr. R. T. Napier noted that in the experiment on the rate of flow in the discharge-pipe of the "Jinga" (p. 219), the quantity of water accompanying the dredged material touched 20,500 cubic feet per hour. Would the Author say whether in reclamation work this water could always be trusted to get away without taking the lighter spoil along with it. It was very interesting to know that the dredger "Cormorant" could be satisfactorily steered by water-jets; and the thought naturally arose as to the workability of using hydraulic propulsion for such a vessel. The centrifugal pump and side-jet fittings being installed in any case, not much extra cost would be involved in further adapting these to hydraulic propulsion, and the cost and weight of everything connected with screw propulsion would be saved. The Author must necessarily have had such considerations before him. Mr. Napier would be much interested to know the fatal objection. A dipper dredger Mr. Napier.

Mr. Napier. handling 60-ton rock fragments was a great advance on past practice, and Mr. Napier would like to hear the subsequent story of such rock fragments; there seemed to be limits to the possibility of dropping them into the scows, and further limits in regard to their clearing the bottom doors. Another question, not connected with dredging, was why, in the case of the "Silurus," the Author, with 150 lbs. steam-pressure, did not use the obvious three-cylinder compound engine instead of the less economical two-cylinder engine described.

Mr. Wentworth-Sheilds. Mr. F. E. WENTWORTH-SHEILDS remarked that the information given in the Paper would be exceedingly valuable in assisting engineers to decide what type of dredger was likely to be the most efficient to perform a certain class of work. In 1914 the London and South-Western Railway Company were faced with a small problem of the kind, in connection with their maintenance dredging. The plant at that time consisted of a small bucket dredger and three steam hoppers, which served to remove about 300,000 cubic yards of silt per annum from the basins and riverside berths at Southampton Docks. Owing to large dock-extensions being brought into use, it became necessary to increase the plant, and, after consideration, it was decided to purchase the bucket dredger "Cadiz," and to increase the number of steam hoppers from three to five. The "Cadiz" was a non-propelling vessel of the following dimensions:—

Length	144 feet.
Breadth	25 feet 6 inches moulded.
Depth	10 feet 6 inches.
Mean draught	6 feet 6 inches.

Under normal conditions she could dredge to a depth of 42 feet, but her ladder was capable of being lowered so as to dredge to 50 feet. Her chain contained forty buckets of $15\frac{1}{2}$ cubic feet capacity, which were usually driven at a speed of about 16 per minute. Her engines were of the marine compound surface-condensing type, having cylinders of $14\frac{1}{4}$ inches and 23 inches diameter, with a stroke of 18 inches. The engines were usually worked at 160 revolutions per minute. Steam was provided by one boiler of the marine type, 10 feet 6 inches in diameter by 10 feet 9 inches long, suitable for a steam-pressure of 125 lbs. per square inch. When working in mud a pressure of about 100 lbs. was used. The engine-room contained the usual auxiliary plant, such as independent circulating and feed-pumps, bilge-pumps, etc., and a dynamo for electric light. On deck were winches for head and side chains, with special leads to allow the vessel to be brought

Mr. Went-worth-Sheilds.

close to a quay-wall. The hoppers were all single-screw vessels, holding about 400 to 576 cubic yards, and had a speed of about 8 knots. This plant would be called upon to remove about 750,000 cubic yards annually, the material for the most part being a soft and sticky mud, which, when stirred up with water, settled but slowly. This had to be taken to the far end of the Isle of Wight, a distance of about 27 miles. Moreover, nearly the whole of the material had to be removed from alongside of or near the quays, and consequently the dredger had to work among a fairly heavy traffic of vessels. Having regard to these facts it was decided that any sort of pumping-plant would be unsuitable, as it would be difficult to obtain a dredger of this type which would work among the traffic and lift the mud in such a form that it would lie in the hopper-wells. The problem had not been altogether satisfactorily solved, because the hoppers invariably carried a large quantity of water to sea. This was owing to the fact that the soft mud from the dredger mixed with the water that happened to be in the hopper-well, instead of displacing it as virgin soil would, and therefore the contents of the hopper were in a semi-liquid form. It was estimated that for every cubic yard solid of mud removed, 1·7 cubic yard of mud and water had to be taken to sea in the hopper. Unfortunately, owing to war restrictions, the plant had never been able to show its full capacity, but it might be mentioned that during the past year 622,000 cubic yards of material (measured in barge) had been removed, and that the cost of doing so had been about 1·7*d.* for dredging and 5·4*d.* for taking to sea, per cubic yard in barge. These figures included 8 per cent. on the cost of the plant for interest, depreciation, and insurance. Of course, with wages and stores at a normal figure, this cost would be lower.

Mr. Stevenson.

Mr. CHARLES A. STEVENSON hoped that though this interesting Paper dealt chiefly with suction and grab dredgers, which had been improved so much in recent years, the steady improvement in bucket hopper dredgers and in barge-loading dredgers would not be forgotten. Often a difficulty was found by Harbour or Navigation Boards, who had to undertake certain dredging-operations which would take only a year or two to complete and would require little after-maintenance, as to whether it would be better for them to hire plant or to build their own. In the latter case the engineer might have to consider what type and size of plant would be most certain to find a good market on completion of the operations. Mr. Stevenson regretted that no practical results as to the capability of the "Silurus" would be available, as unfortunately she had drifted from her moorings and sunk at the head of the Gareloch. The

Mr. Stevenson. standardizing of dredging-plant was impossible in any way, as the engineer had such varying circumstances to consider before recommending a particular type of dredger or as to details of her construction. It was very important to have full details of all the various important parts of dredging-plant, as engineers had to specify very carefully such details, especially as avoidance of breakdowns was the chief factor in reducing the cost of dredging-operations. Messrs. D. and C. Stevenson had recently specified and directed the building of a dredger and hopper barges for the Clyde Lighthouse Trust which had done exceedingly good work on the Clyde in hard boulder clay, and also at Admiralty work at an east-coast port, where she took out about 20,000 cubic yards of sand, clay, and blaes in a week. The vessel was a centre-ladder bucket dredger 140 feet in length, had a speed of 5 knots, and could dredge to 47 feet. The barges had a capacity of 24,000 cubic feet and could steam loaded at $9\frac{1}{2}$ knots.

Mr. Walmisley. Mr. A. T. Walmisley, referring to the Author's figures (p. 236) for the specific gravity of grey clay (1·88, 1·64 and 1·43)—respectively equivalent to about 18·6, 21·3 and 24·5 cubic feet per ton—thought it might be interesting to record that mud taken at the foot of the slipway in Dover harbour was found to give 25 cubic feet, in the Wellington basin 23·82 cubic feet, and in the Tidal harbour 21·64 cubic feet, per ton. These figures, which averaged 23·48 cubic feet per ton, showed how variable mud in a harbour was in consistency as compared with sea water averaging 35 cubic feet per ton. A bucket ladder dredger might be regarded as an underwater planing-machine, and in this respect differed from a mechanical excavator. Central ladder dredgers lay upon an even keel and were found to navigate or tow better than a side-ladder dredger, the hull being symmetrical, but in contracted areas the narrow passages demanded a dredger that could clear up alongside, and a side-bucket dredger or a bag-and-spoon barge was therefore usually employed in such cases. For hard material a large vessel, being heavy, was expedient where space allowed its use, because it was less likely to rise and lose the power of the buckets; but where the material to be dredged was alternately hard and soft the bucket dredger might be provided with two or more speeds of gearing, so that the buckets might be driven at a rate suited to the nature of the material to be dredged. In, say, chalk of moderate hardness every fifth or sixth bucket of the ladder might be removed, and a special fang substituted to loosen the material. A bucket ladder dredger when at work was preferably placed with the ladder to face the current in a tideway, and was regarded as a satisfactory machine to remove stiff clay or compact silt. The current then kept the vessel square with her cut. The efficiency of suction dredgers depended (other things being equal) upon the action of the nozzles. In sea-sand, gravel or soft mud, a plain nozzle without a cutter would work well, as the cutting machinery should be as simple as possible and free from unnecessary gearing below water. But, as shown by the Author, in fine hard sand, clay or stiff material, some form of scraper or cutter was essential, and when large stones were liable to be drawn up during the progress of pumping, the advantage of a grid in the nozzle to screen obstructions was indisputable. Grab dredgers could not compete with either bucket or suction dredgers, but were frequently useful when worked from a pontoon or barge in conjunction therewith, and especially when the ground was interspersed with masses of rock, submerged timber, or other solid deposits. Tines were generally added to grab dredgers to deal with hard material. A dip bucket suspended by a chain from a crane carried upon a floating barge could be arranged to work to any reasonable depth, as it was only necessary to have this hoisting chain long enough for the required maximum depth. With a double chain, the risk of fracture was diminished, and the loss of a bucket would only occur in the event of both chains giving way. The buckets were made to open wide to enable them to enclose and discharge material. A grab bucket was, however, intermittent in action, and even when it was fitted with rising and falling sheave-blocks to aid the working into side barges or into a self-contained hopper, the time occupied in raising each load was longer than with the use of a bucket ladder, as it was obvious that the distance traversed by the buckets in a ladder dredger was less affected by the depth than a dipper grab was. Moreover, the grab bucket picked out holes in the ground under water, leaving a pitted surface, so that it was almost impossible to obtain a uniform depth with such appliances. If a grab bucket were allowed to descend too often in the same place, it might form a nest, in which the segments would simply close without raising any material. Where large quantities of sand and gravel had to be raised, a sand-pump hopper-steamer, when the material was moderately clean, would give satisfaction. Hopper dredgers were more economical than separate dredgers attended by hopper barges, but the process of dredging was necessarily suspended during discharging at sea. A self-contained steam hopper dredger had to leave her moorings to go to sea, deposit the dredged material, and return to work at fresh moorings; but the excavated material was collected into hoppers on board with less

Mr. Walmisley.

Mr. Walmisley. exposed surface than when it was deposited in separate barges. Delay occurred when the weather was too rough to go to sea, both in the case of hopper dredgers and separate barges, but in the latter case an empty barge might be available to enable some dredging to be executed in the meanwhile. Preferably, the best period for dredging in harbour-maintenance was during neap-tides when the water was in a sluggish condition. At spring-tides it was evident the water might not only be too high for a favourable angle of ladder in a bucket dredger, but the current might run too rapidly for efficient work.

Mr. Williams. Mr. C. J. R. WILLIAMS considered that The Institution was indebted to the Author for an interesting and instructive summary of recent practice in dredger-construction and its results; but while the Author had dealt at some length with the actual designs, the various solutions of the problems to be dealt with which had led up to those designs had been only lightly touched upon. If the various engineers who had been responsible for the development of these designs would give their experiences in connection with them, a very complete work on modern dredging would be formed. For the last 14 years Mr. Williams had been in charge of the harbour of Lyttelton, N.Z. The harbour itself was enclosed by moles, and was situated 5 miles up an open arm of the sea about 1 nautical mile wide. The depth at the sea entrance was 9 fathoms, gradually shoaling to 3 fathoms at the entrance between the moles. The bottom of the harbour consisted of grey clayey mud very suitable for dredging by the ordinary bucket dredger; but when the entrance-channel, which extended for 2 miles seaward, had been cut to 28 feet at low water, it was found that the bucket dredger, removing 700,000 tons of material per annum, could only maintain a working depth of 25 feet at low water, because it took the dredger so long to cut its way down the channel that by the time it was at the bottom end the top end had silted up to that extent. To maintain such a channel a vessel traversing the whole channel daily and skimming off the daily deposit was the ideal machine, and after examining the work of drag suction dredgers in various parts of the world in 1910, Mr. Williams arrived at the design of the "Canterbury" as the class of machine most suitable for the purpose. One of the main difficulties with drag suction dredgers dredging without moorings was that of keeping the vessel on its course with a cross wind, and to assist in this the "Canterbury" was fitted with water-jets on either bow, these jets being controlled from the navigating-bridge. While the vessel kept on the move

Mr. Williams.

these jets served their purpose, but it was found that when the drag brought the vessel to a standstill, which occasionally happened in the very obstinate material in Port Lyttelton, the jets were not powerful enough to prevent the ship from paying off and losing its direction. In the case of the "Canterbury" the water-jets were supplied by the same pump as the jets in the suction cutter head, and the opening of the steering-jets took away the water from the cutting-edge jets, with great loss of dredging efficiency; so that when referred to by the Consulting Engineers in charge of the construction of the later dredge "Cormorant," he advised that the water for the steering-jets should be supplied from a separate pump, and this modification had apparently been adopted with satisfactory results. At Lyttelton the steering-jets had been abandoned for the reasons given above, experience showing that the prevailing winds there were sufficiently in line with the main channel to avoid serious difficulty. Had this not been so some very considerable modifications would have been necessary. In this connection the experience of Messrs. Conrad of Rotterdam in constructing dredgers for the Argentine was interesting. They had evidently given very considerable thought to this question, and had arrived at a design which might fairly be described as a "push suction" dredger, the suction pipe being pushed along the bottom instead of being dragged as in the "Canterbury." When Mr. Williams saw the vessel in an almost completed state at Haarlem he, while appreciating that this was a complete solution of the steering difficulty, expressed doubts as to the safety of such a device. Mr. Conrad, however, stated that he had experimented on a large scale on the actual ground where the vessel was required to work, and that he was quite satisfied. Subsequent experience had, Mr. Williams understood, justified his confidence, as his first vessel was so successful that a duplicate was obtained. The dredger above referred to was a large vessel approximating in capacity to the "M.O.P. 210 C" and "M.O.P. 211 C" referred to in the Paper, and in a vessel of this size the fitting of the pipe in a central well in the middle of the ship did not create such serious difficulties in the general arrangement of the ship as it would in a smaller vessel. As long as the difficulty of keeping the vessel in its course while dredging could be got over by devices independent of the rudders, the stern-well drag suction dredger would retain its popularity. His experience, however, had convinced him that there was room for very considerable extension of the limit of usefulness for the dredger working without moorings, and that

Mr. Williams. the "push suction" system was the direction in which further experimenting should be done. In the case of the work at Lyttelton it was expected that the material would not settle in the hoppers sufficiently to allow of a hopper overflow, and therefore a system was adopted which would provide for a mixture being brought up of sufficient density to justify the whole load of clay and water being carried away. On the other hand, under Mr. Williams's instructions, the Board's dredge-master had made such experiments as convinced him that the drag suction system could not be successful, and that when the drag was lowered into the clay the vessel would be brought to a standstill; and in no case of successful drag suction dredging personally inspected by Mr. Williams was the material dealt with of such an obstinate nature as the Port Lyttelton clay. However, samples of the material lifted by the "M.O.P. 210 C" at Buenos Aires had convinced him that the experiment of obtaining such a dredge as the "Canterbury" was worth making, and the success of the vessel had exceeded his expectations. On the other hand, the risk of applying this system at all to Lyttelton was a sufficient risk for any engineer to take, so no fresh experiments were made in the design of the dredger, the design being merely an adaptation of details all proved successful in previous practice. The Author had so accurately described the results of the "Canterbury's" work that there was little to add, except to emphasize that in the "Canterbury" there was no provision for overflow from the hoppers, which had been raised since the vessel's arrival in New Zealand. Everything brought up—clay and water—was retained, the load consisting of about $\frac{1}{3}$ water and $\frac{2}{3}$ clay. This absence of provision for overflow from the hoppers had necessitated some provision for pumping directly overboard until the mixture brought up was of sufficient density to justify its being put into the hoppers. This was provided in the form of a by-pass in intimate connection with the discharge into the hopper, the diversion of the dredgings overboard or into the hoppers being made by quick-closing hydraulic valves operated by two levers side by side in the operating-house. With this device, after the hopper had been pumped out and while the cutting edge was being lowered into the bottom, the discharge was sent overboard until the mixture was dense enough. This avoided the flooding of the hopper with water, and without this device these dredgers would not be successful in places where the dredgings would not settle in the hoppers. It was not expected that the drag suction arrangement would deal with the ground which had not formerly been gone over by the bucket dredger, and consequently the "Canterbury" was fitted with a cutter which could be mounted in place of the drag suction head. It was found, however, that by taking advantage of the tide, wind, propellers, and the send of the seas, new material could be dislodged by the drag, and the cutter was not used. It was fortunate that the cutter was not required, as when a trial was made with it in 1916 it was found that the slurry brought up would not settle in the hopper, the overflow containing 10 per cent. of solids; it took 101 minutes to get with the cutter a load of equal density to that obtained in about 20 minutes with the drag, and during the period of dredging a quantity of about five loads of spoil went overboard in the overflow. Further, had the material come up in large lumps as had been hoped, it could not have been pumped out of the hopper, as the bottom part of each ordinary load was so dense and sticky owing to the slices referred to by the Author that it could not all be dislodged by the water-jets in the hopper, and the hoppers had periodically to be cleared with pick and shovel. Although the "Canterbury" was fitted with hopper doors as a safeguard in the event of failure to pump out a load, they were never used, the spoil being pumped overboard even when it was necessary to send a load to sea, the watertightness of the doors being very important, and not to be sacrificed for any temporary convenience. The Author's figures relating to the time occupied by the "Canterbury" on various operations might be usefully supplemented thus:— Mr. Williams.

Average time dredging a load	16·3	minutes.
Average time steaming to and from depositing ground . .	28·0	,,
Average time mooring and unmooring each load	4·2	,,
Average time pumping the load ashore into reclamation-area	16·0	,,
Average time of round trip	64·5	,,

The Author, in reply to the Discussion and Correspondence, expressed his gratification, particularly having regard to the present conditions, at the widespread discussion which his Paper had evoked, and his appreciation of the references made to his Paper. These same conditions made it impossible for him to reply in detail on the various points raised, though in ordinary times nothing would have given him greater pleasure. The Author.

With regard to Mr. Lowcock's reference to the use of bevel gearing in the dredger "Silurus," in many dredgers arrangements

The Author. had been made to eliminate bevel gearing; but this necessitated the engines being placed considerably above the deck. While such an arrangement could be suitably fitted to a barge-loading dredger, it raised serious questions of stability in vessels of the sea-going hopper type, such as the "Silurus." In order to overcome the difficulty when dealing with very fine silt mixed with sand, to which Mr. Clark had referred, the Author had had fitted on drag nozzles plates that could be adjusted to reduce the amount of opening of the nozzle, and thereby limit the amount of surplus water passed into the hopper. He had also had fitted an arrangement of baffles in the hopper which very materially reduced the percentage of silt contained in the overflow. He greatly regretted that he was quite unable to cover all the interesting points raised by Mr. Berridge, but he would point out that dredgers of a light type, as made by Continental builders, had not found favour with British harbour authorities, mainly on account of the varied nature of the work to be done in most harbours, ranging from soft to, at times, very hard material. A dredger of more solid construction was needed to meet these varied requirements. A very large proportion of the dredgers built by the Author's firm in recent years had been fitted with bathrooms. He had not referred to the dredger "Leviathan," because all the details of this vessel had already been published. Referring to Mr. Cullen's valuable contribution, the Author had no actual experience of the use of close-connected buckets for ordinary harbour dredging work; but he understood that mining engineers were divided into two camps on this question, the point at issue being the greater wear and tear on the ladder-chain and the driving machinery, due to the close-connected bucket-chain being much heavier than the open-connected type. In reply to Mr. Hindmarsh's question as to the hoisting-gear of the "Silurus," it was so arranged that the ladder could be lowered with the engine either in or out of gear. The Author would have been happy to meet Mr. Leitch's request for cost of plant, but regretted he was not a free agent in this matter. The improvement effected at Durban was, he thought, one of the best illustrations of the association of "civil" and "mechanical" engineering. He cordially recognized the intimate knowledge that Mr. Methven had of the improvements effected at Durban, and had certainly no desire to underrate the importance of the effect of the training-works built there. In reply to Mr. Napier's query regarding the quantity of water accompanying the dredged material from the discharge-pipe of the "Jinga," no trouble was experienced in this case, and the quantity of light spoil carried away by the water was altogether negligible. The experiments made with hydraulic propulsion would not lead the Author to advocate its adoption in vessels of the "Cormorant" type. The compound engines in the "Silurus" had been adopted by the owners of the vessel because they were convinced from their experience of working dredgers that this type was most suitable for the work they had in contemplation. The Author.