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DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

CRANE AND LADDER DREDGES.

By T. Kobayashi.*

Generally speaking, there are four kinds of dredges; crane, shovel, ladder and pump dredges. The first two are intermittent in their work and limited in their capacity, while the others are of greater dredging capacity and able to work continuously. In the Osaka Harbour Works all kinds of dredges, except shovel dredges, are now being used. There are:

5 Priestman's "B" type dredges,
2 200-ton non-propelling ladder dredges,
2 600-ton self-propelling ladder hopper dredges,
2 500-ton non-propelling and shore-delivery pump dredges,
2 500-ton self-propelling, pump system, hopper dredges,
5 tugboats, each of 33 tons,
32 100-ton bottom-hopper barges.

Now, as it is very difficult to treat of all the dredging plant within the general limit of 10 000 words, the writer takes crane and ladder dredges as the subject of this paper.

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* Engineer in charge of dredging in the Osaka Harbour Works, Japan.

CRANE DREDGES.

These dredges are commonly known by the names of the makers, as Priestman's, Stothert and Pitt's, Morris and Cuming's, Fouracre's, Bruce and Batho's, etc. Sometimes they are named from the form of bucket used, as grab, clam-shell or digger dredges. Whatever the name may be, the essential part of the dredge is the bucket, which may be raised or lowered by a crane. Being connected with a chain or chains, the bucket raises the material vertically, and can work in any depth, and in spite of wave action.

As this type requires a small staff and occupies a very small space, it is exceedingly useful for working in wells, docks, or other confined spaces, and also for dredging a detached bar which extends over a comparatively small area. Moreover, it lifts material with a smaller percentage of water than any other. The efficiency of the bucket to penetrate the material does not depend upon the force with which it falls, the jaws being framed so as to draw down and penetrate as soon as an upward strain is put on the lifting chain, when the resistance of the soil is not great. But if the resistance is great, the bucket is liable to slip along the surface, instead of penetrating, therefore it cannot be used in hard soils. Moreover, it is not suited for regular plain cutting, as it is designed to dig a number of consecutive holes, and its action is discontinuous.

Bucket.

Chief Points in Bucket Construction.—The following are the chief points to be noted in bucket construction:

1.—It should penetrate the ground easily, without slipping and tumbling.

2.—It should cause itself, when being closed, to be full of earth.

3.—It should open and close automatically.

4.—It should close readily and tightly, permitting no leakage.

5.—No earth should be washed over or drop out when being raised through water.

6.—It should readily discharge its contents, and not require clearing.

7.—It should be simple in construction, have as few wearing parts as possible, and be easily repaired.

Almost every kind of work and earth requires a specially shaped bucket, the suitability of which causes success or failure.

Capacity of Bucket.—As to the relative merits of bucket capacities, opinions have been somewhat divided; however, in a large dredge the weight of the bucket is less in proportion to the quantity of material raised than in a smaller dredge, as may be seen from the following table of Messrs. Wilson and Co.'s grabs:

Capacity of grabs........................	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	cu. yd.
Approximate weight..................	17	22	28	35	cwt.

Thus the weight will have the following relation:

$$W = 13 + 14\,V + 8\,V^2$$

where W = weight, in hundredweights, and
V = capacity, in cubic yards.

Therefore, the bucket of $\frac{1}{4}$ cu. yd. capacity has a dead-weight 1.95 times that of the bucket of 1 cu. yd. capacity, in proportion to the material to be contained. Mr. John Newman said that in a very large bucket the weight may be as little as 0.75 of that of the earth lifted, while in a small bucket it may vary from 1.2 to 1.7 times the weight of the earth, so, in proportion, much more dead-weight has to be raised each time. But it must be kept in mind that the increase in weight, as will be seen later, is necessary for increasing the penetrating power of a bucket.

Form of Bucket.—Some of the old primitive buckets have a single spade, as in the Ives' dredge, or eight spades forming a flat table or tray, as in the Milroy's dredge. At present, the bucket has, commonly, two scoops, which close in a semi-cylindrical form. This form, however, is not fitted for sinking cylinders, because of the so-called "nestling" at the bottom, that is, the material cannot be cleared away from the sides of the cylinders. A modification of this form is a semi-octagonal prism, as in the Stothert and Pitt's or Grafton and Co.'s buckets, which is suitable for a bucket or grab on account of its easy construction. Another kind of bucket having many leaves forms a hemispherical shape when closed, as the Priestman's special bucket, 2 leaves; Bruce and Batho's and Grafton & Co.'s, 3 or 4 leaves; the Knight's patent, 6 leaves, etc. This shape is more suitable for cylinder sinking than the others. Being circular in plan, it can be made of nearly the same size as the internal diameter of the cylinder, and will cut out the material close to the edge of the curb, and avoid the necessity of what is called undercutting.

Now, in order to lessen the quantity of earth washed away while raising a bucket through water, the bucket must have a minimum surface exposed to the water. Comparing the spherical bucket with the semi-cylindrical bucket, having a square plan, as is usual, and an equal volume, the ratio of contact surfaces will be 1 : 1.2. In this respect the former will be better than the latter; but, having a greater number of leaves, it will be more liable to leak. Mr. H. J. Coles, who used a semi-cylindrical bucket for clearing out a well, 300 ft. deep, found that the amount of material brought up through 150 ft. of water was not perceptibly different from that brought up through 5 ft. of water. Much more, therefore, need not be said as to the bucket's holding spoil in passing through water.

The cutting edge of the bucket, when opened, should be so directed that the tangent plane at that edge will be vertical. Moreover, the bucket, in order to discharge the dredged material easily, has an oval form.

Type of Bucket.—Among the many types of semi-cylindrical buckets, each specially adapted to dredge a particular kind of soil, are the following:

1.—The plain plate bucket, for lifting soft mud, dry sand, grains, etc.;

2.—The plain plate bucket with outside tines, having more digging power than the plain bucket, and closing more tightly than a half-tine grab, and so retaining wet material better;

3.—The corrugated plate bucket, a very strong light grab bucket;

4.—The half-tine grab, suitable for excavating hard sand, earth, gravel, coal, or any other material that requires a considerable amount of digging power, this being the form of grab which has the widest range of utility for general work;

5.—The whole-tine grab, used for hard clay, sand, blasted rock and boulder, for clearing weedy growth from canals and rivers, and for other purposes where the maximum digging power is necessary. For some kinds of work the end tines are entirely removed.

Mouthpiece or Cutting Edge and Tine.—As the force with which a bucket can be dropped into the soil is simply that of its own weight falling a certain distance, special provision should be made for extra strength in the bucket edges. The mouthpiece of a plate bucket is, therefore, of a special steel, about 12 by $\frac{5}{16}$ in. This piece, not being pointed, serves only to strengthen the edge, and not to increase the penetrating power, for which it would be necessary to increase the weight of the bucket and to apply a certain number of tines. A tine, although pointed, has a thickness of $\frac{1}{2}$ or $\frac{3}{4}$ in. and a width of 1 or $1\frac{1}{4}$ in. It is obvious, however, bearing in mind the extent of the cutting edges of a bucket, that a tine, having a penetrating area of, say, less than 1 sq. in., has a greater power of penetration than in a plate blade, whether corrugated or not. Moreover, the tine will increase the weight of the bucket, so as to keep it from slipping or scraping along the surface of the soil. The increase in weight of the half-tine grab over that of the plate bucket is from 20 to 30%, and that of the whole-tine grab is about 90 per cent. This increase in weight, which is necessary to withstand severe shocks, will also serve to increase the penetrating power in proportion.

Penetrating Power of Bucket when Closing.—Fig. 8 represents a plate bucket, where $A\ B$ and $A\ C$, the length of which $= a$, are hinged at A, B, and C.

$B\ D\ E$ and $C\ D\ F$ are semi-cylindrical scoops, hinged at D, the radius being b. $W =$ gross weight of bucket. $f =$ total penetrating power of a scoop, supposed to be distributed only along the edge.

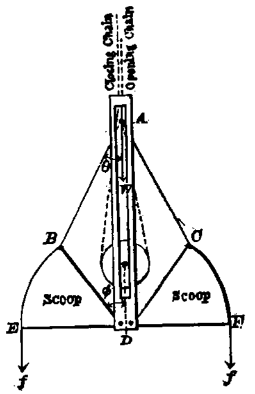

Fig. 8.

When the lifting chain of the crane is acting, the pin at H is pulled down by the closing chains, and the mouthpieces of the scoops tend to penetrate the earth, as long as the tension in the former chain is less than W, neglecting friction.

$$f = \frac{1}{2} W \frac{\sin.(\theta + \phi)}{\cos.\theta},$$

$$\text{where } \sin.\theta = \frac{b}{a} \sin.\phi.$$

The work done by the mouthpiece traversing from ϕ_1 to ϕ_2.

$$\omega = \int_{\phi_1}^{\phi_2} f\, b\, d\phi = -\frac{1}{2} b \varpi \left[\frac{a}{b} \sqrt{1 - \frac{b_2}{a_2} \sin.^2\phi} + \cos.\phi \right]_{\phi_1}^{\phi_2}$$

The space-average force will be

$$f_{mean} = \frac{\omega}{b\,(\phi_2 - \phi_1)} = -\frac{1}{2} \frac{\varpi}{(\phi_2 - \phi_1)} \times$$

$$\left[\frac{a}{b} \sqrt{1 - \frac{b_2}{a_2} \sin.^2\phi} + \cos.\phi \right]_{\phi_1}^{\phi_2}.$$

ϖ or f_{mean} is maximum when a is greatest; but the usual proportion is $a = 1.5\, b$.

Substituting 15° for ϕ_1, 105° for ϕ_2, 3 ft. for a and 2 ft. for b. as found in a Priestman's bucket, we have

$$f = \frac{1}{2}W\left\{\frac{\frac{2}{3}\sin.\phi\cos.\phi}{\sqrt{1-\frac{4}{9}\sin.^2\phi}} + \sin.\phi\right\}.$$

$$\omega = 2.28\ W.$$

$$f_{mean} = 0.36\ W.$$

Again, tracing f,

$f = 0.21\ W$, when the bucket is fully opened;

$f = 0.6\ W$, when $B\ D$ is ⊥ to $A\ B$;

$f = \frac{1}{2}W$, when $B\ D$ is horizontal;

$f = 0.37\ W$, when the bucket is closed.

Next, let K represent the linear velocity of the point A, which is uniform; then the linear velocity of B or C, called V, will be represented by the following equation:

$$V = K\operatorname{cosec.}\phi\left(\frac{a\cos\theta}{a\cos.\theta + b\cos.\phi}\right)$$

$V = K$, when $B\ D$ is ⊥ to $A\ B$.

$V = 0.83\ K$, when $B\ D$ is horizontal.

From these calculations, it will be seen that the penetrating force entirely depends upon the gross weight of the bucket, and the bucket, when closing, exerts a very poor force at the beginning, but a tolerable one at the end of the work, the latter being necessary in order to close the bucket tight. The weight, however, cannot be increased, as it would cause a great loss of work in raising the bucket, and, from the capacity of the bucket, the upper edge of each scoop cannot be made to take the horizontal position, when the bucket is entirely opened. Thus, it may often happen that a bucket working in hard soil closes itself, merely scraping the surface.

The writer, finding that the Priestman's plate bucket, newly armed with outside tines, or even the half-tine grab cannot work well in fine sand, used a "loosing" method, as he called it. When the bucket is dropped, a slight pull is given to the lifting chain, which is soon let go. Repeating this two or three times, the surface is sufficiently loosened to allow the mouthpieces to exert a greater penetrating force. The effect is good, any loss of time being compensated by certainty of action, the bucket being full or nearly so. But this method is not advisable for common use on account of great wear on the friction rollers.

Opening and Closing Methods.—There are two methods of opening and closing buckets; one by a single chain, and the other by double chains. The Gatmell or some other primitive single chain bucket has to be laid on a platform before it can be discharged, and the discharge has to be made by an attendant. But under the Wild's or Cole's patent, an ingenious arrangement of dogs and disengaging apparatus is used to work quite automatically. In this method, however, the apparatus necessitates lifting the bucket to a certain fixed height at each dip, even when coming up empty, in order that the dogs may enter the disengaging ring to effect the opening of the bucket previous to the next descent. The lifting height cannot be adjusted in accordance with the free board of a barge which is being loaded. When dredging where pile stumps and wreckage prevail, this defect often necessitates either sending a diver below to open the bucket, or the use of a special arrangement of chain slinging. Moreover, the dog sometimes becomes clogged with dirt and grit, and refuses to act, preventing the bucket from closing. These drawbacks are obviated in the Priestman's or Morris and Cuming's bucket by using two chains in connection with the machine, one chain to open the bucket and the other to close it. One defect in this system is that the apparatus cannot be worked by an ordinary crane, but requires a special crane fitted with two chain barrels, as in the Morris and Cuming's dredge, or with a counterweight, as in the Priestman's dredge, for working a second chain. The depth at which this arrangement can operate the bucket is limited, and any increase of depth would cause a great alteration. The complication of the crane requires greater skill to operate it; but when the operator is accustomed to it, it is quicker in motion than the single-chain crane, which has more motions to make in discharging. Mr. J. L. Stothert, as one of the judges to examine the dredging appliances at Tynemouth Exhibition, stated that the Priestman's dredge was much in advance of the others, notwithstanding that he was a member of a firm that had a special dredge of its own: the Wild's patent.

Guide-Frame, Poles, Spear, Cylindrical Weight. etc.—The cross-head, which is connected to the links of a bucket, is so constructed as to slide in a guide-groove, in the Priestman's dredge, or sometimes in a single-chain dredge. This guide acts like a diagonal line in a quadrilateral, and transmits equal force to each of the two halves of a bucket, when opening and closing. Without this, each scoop of a bucket is liable to trace unequal lengths of path; and, moreover, the bucket is obliged to have its chain barrel shaft in the same position with the connecting pins of the two halves, which causes the barrel to be buried in mud, so that it does not work smoothly. The

Dick, Kerr and Co.'s double-chain bucket is without this contrivance. To obviate this defect, Mr. Cockburn adopted a guide tube, which slides in the catch of a single-chain bucket, and through which the closing chain works.

Bruce and Batho's dredge is furnished with a spear, which, according to Mr. George Boswell, is to keep the bucket mouth vertically downwards; without it the bucket, when in contact with an uneven bottom, would turn over on one side, and as a natural consequence would come up empty. It consists of a tapered spruce pole about 50 ft. long and works loose through thimbles at the jib end. The guide-poles attached to the frame of the bucket in American dredges are said to be used for similar purposes; but they will also guide the bucket to prevent its revolving around the lifting chain and giving torsion to the chain. No doubt, when the bucket is cutting into the material, the spear and the guide-poles will add much to the efficiency of the machine in shallow water; but where there is any considerable depth of water, the extra weight will more than counterbalance any gain in the dredging capacity.

Sir John Coode designed a patent cylinder-sinking grab for increasing its penetrating power. The grab is fitted with a patent circular guard, which forms a guide in the cylinder. It is also furnished with the double system of tines, which work with a peculiar "pick-and-shovel" action, both digging np the bottom and breaking down the side material in a most effective manner. At Casteries Harbour, St. Lucia, where these grabs were used for putting down concrete cylinders, stiff clay was penetrated with results such as had never been achieved by any other grab.

Crane.

Much depends upon the lifting power available, for the larger the capacity of the dredge, and the more cohesive the earth to be excavated, the more power is necessary in the lifting apparatus. The excess of power, according to Mr. Newman, may be as much as three times the weight of the excavation to be lifted, for the weight of the bucket and the adhesion of the earth are to be resisted. To overcome these forces, and also to maintain a high rate of speed, the ample margin given in Table 8 is allowed in the lifting power of the crane by Stothert and Pitt.

TABLE 8.

Capacity of bucket, cubic yards........................	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{3}{4}$	1
Approximate quantity of mud lifted per					

hour, in tons	12	16	25	35	50
Weight of plate bucket, in hundredweights	12	19	23	26	30
" " half-tine grab, in hundredweights	14	25	27	34	40
" " whole-tine grab, in hundredweights.	—	35	42	48	55
" " material in bucket, in hundredweights.	7½	10	15	22½	30
Pull required on chain, in tons	1½	2	2½	3½	5
Nominal power of crane, in tons	2	3	5	7	10

The ordinary crane is fitted with double cyilnders. The boiler is usually of the cross water-tube type, which requires less care and attention than any tubular boiler when using dirty or salt water. Its working pressure is commonly 75 lb. per sq. in. It stands on a tank, from which the feed-water is drawn by a pump driven direct from one of the engine crossheads. The cover of the tank forms a platform for the driver and the floor of a coal bunk. The boiler and tank act as a counterweight when the crane is loaded. The driver's position should be such that he can take a clear view of the work to be done, as well as of the engines and gearings The operating levers should all be brought together, and so arranged that the driver has thorough control with the least amount of exertion.

The superstructure is carried on four rollers, or sometimes on two, which rest on the roller path, a solid or a loose ring. The resistance due to the friction of the ring upon its seat should be ample to allow the crane to be turned or slewed at a rapid rate, but not sufficient to permit the breakage of any of the teeth of the gear, if the engine be suddenly started, stopped or reversed, or the swinging of the crane be by any means arrested. The slewing motion should be such that the crane may swing in either direction without reversing the engines. The derrick gear, though not common in dredges, should be worked by worm and wheel, with safe arrangement to prevent the jib's running down

A roof of light structure, covered with sheet iron, to protect the mechanism and the operator, will be of great service in exposed situations. In cold climates a considerable economy in the consumption of fuel is effected by covering the boiler with hair felt and wood lagging, over which is placed a casing of sheet iron, whilst in hot climates it is indispensable to the driver's comfort.

Table 9 is a table of cranes made by Messrs. Stothert and Pitt.

TABLE 9.

Power of crane, in tons	2	3	4	5	10
Radius of jib, in feet	14	16	16	16	16
Diameter and stroke of cylinder, in inches.	5½x9	6½x9	9x10	9x10	9x12
Approximate weight in tons	7½	11	13	15	20

The radius of the jib should be such that the bucket can discharge and distribute its contents over a barge to be loaded.

In the Priestman's dredge, the chain barrel is worked by friction rollers, which are set in contact by means of an eccentric. A special counterweight is used to bring back the small chain, when the bucket is being lifted. The bucket is opened by holding that chain with a brake and letting go the larger chain.

Some American or so-called "clam-shell" dredges have two working drums, one for hoisting and one for lowering chains. The drums are supplied with friction gear, so that the engine does not require to be reversed, the weight of the bucket being sufficient to lower it when the friction gear is thrown out. The dredges have independent booms and stays.

Similarly, in a self-propelling dredge it is usual to have an independent boiler of the marine type, and in this case the crane is to be provided with a counterweight, fixed or adjustable.

The common dredge has a lifting velocity of about 100 ft. per min., and a slewing velocity of about 20 sec. for one complete revolution, the bucket being fully loaded. In 10 to 20-ft. depths of water, a skilful driver is said to make one dip per min. Now, assuming the lowering velocity to be equal to the raising velocity and that one-half revolution is necessary for discharging, the number of minutes required to make one dip in any depth will be represented by the following:

$$T = \frac{1}{3} + 0.02\,d + C.$$

T = number of minutes for one dip,

d = height to be raised, in feet,

C = number of minutes required for opening and closing the bucket and also for working the necessary handles, which is about one-third for a skilful driver.

$$\text{Thus, } T = \frac{2}{3} + 0.02\,d.$$

Barge.

The dredge can be readily put afloat by simply mounting it on any pontoon or barge of sufficient stability. The following dimensions for buckets are suggested by Messrs. Stothert and Pitt:

Size of bucket, in cubic yards	½	¾	1	1½
Length of barge, in feet	35	40	50	60
Breadth " " " "	15	20	25	25
Depth " " " "	5	5	6	6½

For the Osgood dredge the following dimensions seem to be used commonly:

Size of bucket, in cubic yards	3	5	7
Length of barge, in feet	100	100	100
Breadth " " " "	30	35	40

The Priestman's standard sizes for barges are as given in Table 10.

TABLE 10.

Type.	Z.	Y.	A.	B.	C.	D.
Capacity of bucket, in hundredweights	2½	5	10	20	30	40
Capacity of crane, in tons	¾	1¼	2½	4	6	8
Radius of jib, in feet	12	14	18	18	18	18
Length of barge, in feet	30	38	45	50	55	60
Breadth " " " "	12	14	15	19	21	22
Depth " " " "	3½	4¼	4½	5	5½	6

A square pontoon of timber or iron, with a circular end, over which the crane will work, makes the best and steadiest platform for the crane, but ordinary barges, well balanced, will answer the purpose in narrow canals, and when the dredge must pass through locks, the required stability may be given to the barge, when at work, by attaching a pair of timber or iron pontoons to each side.

For temporary work, a crane with all motions can be put on the barge, even without removing the wheels, if the amount of work to be done is small; or the wheels and axle boxes can be taken away, and the wrought-iron frame be bolted down securely to the deck or to some beams carried up from the floor of the barge, the center of the crane to be near one end of the barge, so that the dredge can cut its own flotation and work at each side and around the end, or dredge over the end and deliver into a barge at one side, or, in narrow canals and rivers, directly on the banks.

For Permanent use, the vessel should be built of iron, with properly designed hull, having a suitable hopper well, with a capacity proportioned to the size of the bucket, the crane without a boiler to be placed forward, and the vessel to be fitted aft with the ordinary inverted engines and marine boiler. Such a dredge will be able to fill its own hopper, and, if necessary, one or more barges, and then tow away to sea for discharging.

Performance.

For the dredging work at Hakodate Harbour two Priestman's "D" type dredges were used, the radius of the jib being 18 ft., and the dredging depth 32 ft. below water level. The barge has the following dimensions: 64 by 22 ft. by 5 ft. 10 in.

The tidal range at the harbour is 2 ft. 8 in. The site to be dredged was originally 14 ft. 6 in. in depth, and was to be dredged to 24 ft. 6 in.

The bottom consists of two layers of soil: the first layer, which is about 3 ft. in thickness, consists of 15% mud and 85% sand; and the second of 10% mud, 84% sand and 6% shell. At the mouth of the dry dock the soil is somewhat different, being 10% mud, 80% sand, 4% shell and 6% round pebble. For dredging such hard earth, whole-tine grabs were used. The two dredges worked in the harbour, 1 200 ft. off the dock, in 1900, and at the mouth of the dock in 1901.

The following shows the cost of dredge:

Two dredges received at Yokohama	25 816.93	yen
Freight and insurance of the transport from Yokohama to Hakodate	2 141.802	"
Two barges	12 831.73	"
Total	40 790.462	"

Tables 11 and 12, given by Mr. Tsujimura, represent the working hours and running expense during the short interval specified.

In the Osaka Harbour Works, 5 Priestman's "B" type dredges are being used. The capacity of the bucket is 20 cwt. The crane can lift 4 tons, with a radius of the fixed jib of 18 ft. The barge is 54 ft. 6 in. long, 22 ft. wide and 6 ft. deep, having a mean draft of 2 ft. 6 in. The crane is mounted on the stern of the vessel. The dredging depth was originally 25 ft., but was increased to 35 ft. below water level in 1902. This alteration was made by changing the diameter of the chain barrel from $11\frac{1}{4}$ to $13\frac{1}{2}$ in., the counterweight from 1 760 to 2 300 lb., and elevating the height of sheaves of the smaller chain. The dredges are called "*Asahigata.*" The depth of the site to be dredged varies from 0 to 6 ft. below low water, and it is intended to deepen it to 10 ft.

TABLE 11.

Year.	Month	Numder of days.	Number of hours.	TIME LOST, DUE TO Weather.	Repairs.	Cleaning.	Waiting for barge.	Other causes.	Total.	Dredging hours.	QUANTITY DREDGED. TSUBO.* Total	Per working hour.	Per dredging hour.
				h. m	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.			
1900	May	62	744	115 25	93 05	12 00	....	36 20	256 50	487 10	408	0.55	0.84
1900	June	60	720	50 00	16 00	31 15	....	17 30	114 45	605 15	559	0.78	0.92
1901	Jan.	62	744	148 40	4 20	29 00	188 20	72 00	442 20	301 40	289	0.39	0.96
1901	Feb.	56	672	213 20	14 10	....	110 10	24 00	361 40	310 20	314	0.47	1.00
1901	March	62	744	121 50	1 20	13 30	184 55	....	321 35	422 25	307	0.53	0.70
Total		302	3 624	649 15	128 55	85 45	483 25	149 50	1 497 10	2 126 50	1 967	0.54	0.93
Average per dredge per day		1	12	2 9	0 26	0 17	1 36	0 30	4 58	7 20	6.5	0.54	0.93
Percentage		....	100	17.9	3.5	2.4	13.3	4.2	41.4	58.6	....	....	....

* 1 tsubo = 8 cu. yd.

TABLE 12.

Year.	Month.	Number of days.	Wages. Yen.	COAL.		Other Expenses. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Yen.
				Tons.	Cost. Yen.					
1900 ..	May	62	198.29	20	160.00	73.31	339.92	169 96	941.48	2.31
	June	60	190.99	25	190.00	69.37	339.92	169.95	960.24	1.72
1901...	Jan.	62	226.53	10	81.00	73 92	339.92	169.96	891.34	3.08
	Feb.	56	182.38	20	162 00	56.22	339.92	169 96	910.48	2.90
	March	62	231 53	20	162.00	81.00	339.92	169.96	984.41	2.48
Total		302	1 029.72	95	755.00	353.82	1 699.60	849.80	4 687.95	2.38*
Average per dredge per day		1	3.41	0.03	2.50	1.17	5.63	2.81	15 52	....
Percentage		....	22.0	....	16.1	7.5	36.3	18.1	100.0	....

The crew consisted of 1 chief engineer, 2 second engineers, 2 firemen and 2 sailors.
1 yen = 50 cents.
* 2.38 yen per tsubo = 14.9 cents per cu. yd.

The upper 2 or 3 ft. of the bed consist of fine sand, which is very difficult to dredge. The next 3 or 5 ft. consist of mud mixed with fine sand. Below this is a soft mud. In 1898 the dredge used plate buckets, except two, which had half-tine grabs. In 1899 all used plate buckets furnished with outside tines; in some cases, however, half-tine grabs were used whenever coarse sand or gravel was found. The maximum tidal range in this harbour is 6 ft. 6 in.

The *Asahigata* Nos. 1, 2, 3 and 4 began work April 18th, 1898; No. 5, July 11th, and No. 6, August 1st. The machine of No. 1 was replaced by a common crane and used for other purposes after October 31st. 1899.

The dredging site was open to the sea; so that when south or west winds prevailed the dredges had to be towed into the refuge place.

The cost of the plant was as follows:

The Priestman dredge, "B" type, with one extra plate bucket, received at Osaka..	6 533.333 yen
Wooden barge. including the mounting of the machine............	3 321.40 "
Cost of one dredge..	9 854.733 "

Besides this, 2 extra grab buckets were supplied, each costing 975 yen.

Tables 13 and 14 represent the working and running cost of the dredges.

The dredging capacity, as can be seen, increases year by year, the driver becoming more skilful by practice. The working cost, on the contrary, decreases each year. To the premium given in the table, the writer will refer later.

Concluding Remarks.

The cost of working does not increase with the dredging depth, for a dredge of this type can be efficiently used at any ordinary depth with but little additional expense. However, it is generally agreed that the shape of the bucket has much to do with the success or failure of the apparatus.

For removing cohesive or hard compact soil, ordinary buckets have too much surface to penetrate the earth readily, and may be unable to do so. Fine sand or even coarse sand, if under a considerable head of water, may be difficult to penetrate with ordinary scoops, which may not bite or enter sufficiently to enable the bucket to gather its proper quantity of soil, and it then often merely scrapes the surface. Boulders are also difficult to dredge, one piece only being lifted, if it be caught at the joint where the two halves make contact. The bucket is often apt to tilt and become ineffectual, if a small piece of rock happens to get under the cutting edge. Grabs, therefore, together with other special appliances, are required to plow the soil.

The means of lowering, closing and raising a bucket or grab have been well considered, and it is in the direction of increased efficiency of the cutting and breaking apparatus, so as to feed the bucket or grab, and cause it to fill quickly and easily, that the greatest scope for improvement exists.

Experience points to the advisability of an effective use of a mechanical tool, such as a cutter or jumper, to disintegrate the material, and then of a grab or bucket to raise the loosened soil, rather than to attempt to excavate, collect, and raise the material with one machine at one operation.

TABLE 13.—PERFORMANCE OF PRIESTMAN'S "B" TYPE DREDGES.

Fiscal year.	Number of days.	Number of working hours.	TIME LOST, DUE TO											Dredging hours.	QUANTITY DREDGED. TSUBO.			Average quantity per working hour. Tsubo.	Average quantity per dredging hour. Tsubo.
			Steaming.	Towing out to site.	Shifting moorings.	Weather.	Repairs.	Towing into refuge.	Feeding water.	Waiting for barge.	Cleaning.	Other causes.	Total.		Ten-tsubo barge.	Smaller barge.	Total.		
		h. m.	h. m	h. m.	h. m	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.					
1898 ..	1 169	12 097 25	1 557 00	57 20	101 45	142 10	414 05	......	223 05	493 45	611 40	682 00	4 292 50	7 804 35	......	18 803	18 803	1.55	2.41
1899...	1 946	21 445 00	1 929 20	21 20	171 30	2 251 50	4 238 40	9 00	226 20	591 10	1 277 50	326 50	11 043 50	10 401 10	421	22 499	22 920	1.07	2.20
1900...	1 753	19 618 20	1 996 00	83 20	268 20	2 426 50	2 034 50	43 00	288 10	697 00	1 184 30	191 00	9 213 00	10 405 20	1 460	26 843	28 307	1.44	2.72
1901...	1 760	20 070 20	1 768 00	356 30	187 50	2 386 00	3 396 20	267 00	121 30	441 20	1 039 10	167 50	10 131 30	9 938 50	12 807	21 592	34 399	1.71	3.46
1902...	1 775	20 264 30	1 848 00	368 10	640 10	2 558 00	2 667 20	164 00	10 50	501 30	897 00	842 30	10 497 30	9 767 00	10 380	29 176	39 556	1.95	4 05
1903...	1 765	20 237 10	1 652 00	44 50	519 30	3 355 50	3 273 00	62 40	13 50	648 30	963 40	591 50	11 125 40	9 111 30	11 782	28 677	40 459	2.00	4 44
Total..	10 168	113 732 45	10 750 20	931 30	1 889 05	13 120 40	16 024 15	545 40	893 45	3 373 15	5 973 50	2 802 00	56 304 20	57 428 25	36 854	147 590	184 444	1.62	3.21
Average per dredge per day.........		11 11	1 04	0 05	0 11	1 17	1 35	0 03	0 05	0 20	0 35	0 17	5 32	5 39	....	....	18.14	....	....
Percentage.....		100.00	9.45	0 82	1.66	11.53	14 10	0.48	0.79	2.97	5.25	2.46	49.51	50.49	....	....	....	. .....	....

1 tsubo = 8 cu. yd.

The amount is measured by barge and is calculated to be 1¼ times place measurement.

TABLE 14.—RUNNING EXPENSE FOR PRIESTMAN'S "B" TYPE DREDGES.

Fiscal year.	Number of days.	LABOUR.					MATERIALS.					Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
		Number of crew.	Salaries. Yen.	Boarding. Yen.	Premium. Yen.	Total. Yen.	Coal used. Pounds.	Cost of coal. Yen.	Oil etc. Yen.	Other expenses. Yen.	Total. Yen.					
1898...	1 672	7 822	3 628.365	....	....	3 628.365	742 750	2 821.564	295.402	831.973	3 948.939	2 077.861	5 435.480	2 717.740	17 808.385	94.7
1899...	2 039	10 360	4 350.204	1 170.660	361.271	5 882.135	962 950	3 592.583	481.150	1 057.479	5 131.212	3 204.701	5 608.059	2 804.030	22 630.137	98.7
1900 ..	1 825	9 091	3 949.044	1 156.560	1 116.052	6 221.656	923 350	3 164.774	356.538	1 043.775	4 565.087	4 426.858	5 024 867	2 512.433	22 750.901	80.4
1901...	1 825	9 046	4 056.858	1 169.870	1 804.488	7 031.216	1 001 700	4 100.719	494.341	994.013	6 589.073	7 424 936	5 024.867	2 512.433	27 582.525	80.2
1902...	1 825	9 051	4 064.660	1 166.110	2 600.248	7 831.018	1 111 900	3 346.170	327.896	100.282	3 774.348	7 490.152	5 024.867	2 512.433	26 632.818	67.3
1903...	1 830	8 887	3 991.630	1 145.710	2 612.092	7 749.432	1 157 000	2 809.142	407.644	75.590	3 292.376	8 389.251	5 024.867	2 512.433	26 968.359	66.7
Total..	11 016	54 257	24 040.761	5 808.910	8 494.151	38 343.822	5 899.650	19 834.952	2 362.971	4 103.112	26 301.035	33 013.759	31 143.007	15 571.502	144 373.125	78.3*
Average per dredge per day.........		4.9	2.182	0.527	0.771	3.480	535.5	1.801	0.215	0.372	2.388	2.997	2.827	1 414	13.106	....
Percentage.		....	16.65	4.02	5.89	26 56	....	13.74	1.64	2.84	18.22	22.87	21.57	10.78	100.00	....

The fiscal year begins April 1st. The number of days in Table 13 does not include holidays and those during which the dredges were used for other purposes.

1 yen = 50 cents.

The cost of transportation is not included in Table 14.

* 78.3 sen per tsubo = 4.9 cents per cu. yd.

LADDER DREDGES.

The essential apparatus of the ladder dredge is an endless bucket chain, which turns around two tumblers placed at the extremities of a ladder. The ladder is composed of metallic girders, connected to the top of a frame by a shaft, which permits the girder to revolve so as to change the position of the lower end.

Generally speaking, the dredge is adapted to homogeneous material, and where a regular cut can be taken over a large area. Hard soil, however, presents no obstruction to this type of dredge, provided it is constructed with sufficient strength. The great power and strength of the machines enable them to work in any kind of soil that can be penetrated or excavated by mechanical means. It is only a question of strength of the apparatus and steam to overcome resistance. In some dredges, the power of the engines limits the strain on the bucket chains, and they are made sufficiently strong to withstand safely any resistance with the throttle wide open and full pressure of steam.

This type is a favorite in Europe, though not so popular in America. In dredging, it is necessary to give sufficient pull to the front chain, or to force the cutting edges of the buckets into the material to be dredged, causing them to penetrate partly by their weight, and partly by the mooring chain. When working in a channel or a narrow space the mooring chains cause some restraint to navigation. It is not generally adapted to work at the entrance of a harbour or other exposed site, because heavy waves cause violent shocks to the ladder on account of its rigid connection. When the wave height is more than 2 or 2.5 ft., it becomes dangerous to work with this type of dredge. Moreover, it has the great disadvantage of having to lift the spoil to a height much greater than required for discharging it into the hopper well or barges.

Hull.

The form of the hull depends entirely upon the condition of the work. The length is closely related to the dredging depth, and also to the capacity of the spoil well, if any. When the dredge has to pass through a narrow dock entrance, or other openings, its width is limited. When it has to work in an open sea it should be wide. These conditions, together with the working capacity and the depth of the site, will affect the depth and also the draft. The frames, their pitch, plating, etc., are, of course, to be proportioned to the work. The hull of the dredge is generally made of iron or steel, but steel is preferable for the bottom plating, as it is sometimes exposed to grounding.

Stationary Barge-Loading Dredge.—This dredge is usually of small capacity and used only in calm water, as in a canal or river. The vessel is lightly constructed, with a flat bottom, the material being steel, iron or sometimes wood. Table 15 gives some existing examples from which the following relations, which will suggest the usual proportions of the dimensions of the hull, are obtained.

$$\frac{\text{Length}}{\text{Dredging depth}} = 3.0 \text{ to } 5.0$$

$$\frac{\text{Breadth}}{\text{Length}} = 0.2 \text{ to } 0.3$$

$$\frac{\text{Depth}}{\text{Length}} = 0.075 \text{ to } 0.12$$

$$\frac{\text{Draft}}{\text{Length}} = 0.035 \text{ to } 0.06$$

$$\frac{\text{Length} \times \text{Breadth} \times \text{Draft}}{\text{Hourly dredging capacity}} = 1.2 \text{ to } 2.5$$

Self-Propelling Barge-Loading Dredge.—This kind of dredge has a moulded hull, like that of a cargo boat, and is so constructed as to be able to navigate in an open sea with a velocity of from 6 to 10 knots. It is commonly used for the up-keep of ports or channels of estuaries, where barge loading can be done safely in calm weather, but occasional swells necessitate the dredge's retiring to headquarters. It can also be used to tow the barges, if necessary. The dredging capacity is much greater than that of a stationary dredge.

Some existing examples are shown in Table 16.

The relations are as follows:

$$\frac{\text{Length}}{\text{Dredging depth}} = 4.3 \text{ to } 5$$

$$\frac{\text{Breadth}}{\text{Length}} = 0.18 \text{ to } 0.23$$

$$\frac{\text{Depth}}{\text{Length}} = 0.07 \text{ to } 0.075$$

$$\frac{\text{Draft}}{\text{Length}} = 0.045 \text{ to } 0.055$$

TABLE 15.—SHOWING COMPARATIVE PROPORTIONS OF VARIOUS LADDER DREDGES.

Dredge.	*Nos. V* and *VI.*	*Asanagi* and *Yunagi*	*Von Dömming.*	....	....	....	*Nearchus.*	*No. 2.*	*No. 3.*	*No. 4.*	*No. 5.*	....	....	....	....	*No. 4.*	*Ichimatsu.* and *Koroku.*	....
Destination.	Yodogawa, Japan.	Osaka.	Stra'sund.	Loire.	Vienna.	Toulon.	Karachi.	Tees.	Tees.	Tees.	Tees.	Weser.	Ostend.	Panama.	Kaiser Wilhelm Canal.	Garonne.	Atsuta, Japan.	Stettin Swinmund.
Length, L	59-0	79-5	95-1	105-0	88-7	108-3	160-0	112-0	125-0	135-0	140-0	110-0	114-10	108-3	115-1	114-10	118-0	127-3
Breadth, B	15-0	23-11	27-11	23-7	19-8	21-4	28-0	29-0	34-0	34-6	34-6	20-0	19-8	21-4	19-8	26-3	23-0	29-6
Depth, D	7-2	7-10	10-10	8-2	7-10	8-6	11-0	9-0	9-6	10-6	10-6	8-6	8-10	8-2	9-10	10-10	9-2	8-10
Draft. Dt	3-1	3-5	4-7	4-7	3-11	3-11	10-0	....	....	....	....	4-11	3-11	4-3	4-5	7-5	4-3	5-11
Dredging depth, Dd	6-0	15-0	20-4	29-6	23-0	62-4	32-0	....	....	....	....	23-0	29-6	....	36-1	44-3	32-0	32-10
Bucket capacity. Cubic feet	4	6.5	6.4	8.8	8.8	8.8	9	9	9	9	9	10	10 6	12.4	13.5	14.1	15	12.4
Bucket velocity	16	16	18-24	16·17	....	....	12-15	....	....	....	....	13	14	....	13	15	16	12½
Dredging capacity. Tons, C	100	200	246	213	....	....	300	....	....	....	....	279	205	....	328	410	410	....
I. h. p.	36	70	....	90	50	60	130	....	....	....	....	90	150	80	150	160	125	150
$\frac{L}{Dd}$	9.89	5.29	4.68	3.56	3.85	1.74	5.00	....	....	....	....	4.78	3.89	....	3.19	2.59	3.69	3.89
$\frac{B}{L}$	0.254	0.301	0.294	0.225	0.222	0.197	0.175	0.259	0.272	0.255	0.247	0.182	0.171	0.197	0.171	0.229	0.195	0.232
$\frac{D}{L}$	0.122	0.099	0.114	0.078	0.088	0.079	0 069	0.080	0.076	0.078	0.075	0.077	0.077	0.076	0.085	0.094	0.078	0.070
$\frac{Dt}{L}$	0.053	0.043	0.048	0.044	0.044	0.036	0.063	....	....	....	....	0.045	0.034	0.039	0.038	0.065	0.036	0.046
$\frac{L \times B \times Dt}{C}$	1.26	1 50	2.30	2.47	....	....	6.91	....	....	....	....	1.76	2.00	....	1.46	2.52	1.30	....

21.6 cu. ft. of the dredged material are supposed to weigh 1 ton, or the weight of 1 cu. ft. = 103.7 lb.
The length, breadth, depth, draft and dredging depth are given in feet and inches.

TABLE 16.—Showing Comparative Proportions of Some Self-Propelling Ladder Dredges.

Dredge.	*Amélie.*	*Dolphin.*	*Shinchiku,*	*Merak.*	*Ville de Rochefort.*	*Lyster.*	*Melbourne.*	*Andrée.*	....
Destination.	Boulogne.	Casteries, St. Lucia.	Keelun, Japan.	Batavia.	Charente.	Mersey.	Melbourne.	Le Havre.	Vladivostok.
Length, *L*........	127- 5	130-0	140- 0	159-11	160- 2	196- 0	200-0	182- 0	164- 0
Breadth, *B*.....	24- 1	30-0	33- 0	30- 0	32-10	35- 6	35-0	33- 7	32-10
Depth, *D*........	9- 2	8-0	15- 0	12- 0	11- 2	13- 0	11-6	13- 1	12- 6
Draft, *Dt*..	6-11	5-9	10- 0	7- 6	8- 2	....	9 0	8-10	8- 6
Dredging depth, *D d.*	28- 8	30-0	35- 0	27-11	32-10	45- 0	....	39- 4	35- 1
Bucket capacity. Cubic feet............	10.6	7	12	12	26.5	20	21	26.5	21.2
Bucket velocity	....	....	12-18	13-14	15	15-10	....	....	....
Dredging capacity. Tons, *C*......	164	200	400	360	574	400	800	574	820
Engine............	......	2 compound.	2 compound.	......	2 compound.	2 triple.	2 compound.	......	2 compound.
Pressure. Pounds........	....	90	100	....	114	180	90	....	105
Position of ladder........	....	bow.	stern.	....	stern.	bow.	Stern.	....	....
Number of propellers.....	....	2	2	....	2	2	2	....	2
I. h. p...........	250	600	600	75	500	....	500	500	800
Velocity of vessel. Knots........	5	7¼	6	6	6	10¼	7	7.5	8¼
$\frac{L}{Dd}$............	4.44	4.33	4.00	5.73	4.88	4.36	....	4.63	4.68
$\frac{B}{L}$............	0.189	0.231	0.236	0.188	0.205	0.181	0.175	0.185	0.200
$\frac{D}{L}$............	0.072	0.062	0.107	0.075	0.070	0.066	0.058	0.072	0.076
$\frac{Dt}{L}$............	0.054	0.044	0.071	0.047	0.051	....	0.045	0.049	0.052

The length, breadth, depth, draft and dredging depth are given in feet and inches.

Self and Barge-Loading Dredge.—This is a sea-going vessel, arranged to be used as a dredge as well as a barge. This is what chiefly distinguishes it from the barge-loading type. Its best field is where the depositing site is not more than three miles from the dredging ground. The advantage which the hopper dredge possesses over the ordinary dredge is that the first cost of plant is less, no barge being required. It is a convenient machine to operate in a rough sea, where barges cannot be moored alongside. It can be advantageously used where, on account of great range of tide, or from other causes, dredging can be done during a portion of the tide only. In that case the vessel and the crew may be more economically employed in taking the dredged material out to sea and depositing it than in idly waiting for the time to resume work whilst the dredged material is being conveyed by other vessels and crews. In canals and narrow channels, where hoppers alongside a barge-loading dredge will be inconvenient, and in navigation of great length, where small quantities of dredged material might be required at intervals, the self-contained arrangement of the hopper dredge will be of advantage.

On the other hand, a hopper dredge, when going to discharge, has to transport the useless dredging apparatus, which is placed in a position unfavorable for maintaining the stability of the vessel. This inconvenience is seriously felt when the dredge has to travel a great distance in a rough sea for discharging. With a hopper dredge, dredging becomes more intermittent and irregular, and it is difficult, after each trip, to find the previous cutting front. There is a loss of time due to taking and dropping mooring chains when going to discharge; and, moreover, a long time is spent in navigating and discharging. The net dredging capacity is, therefore, greatly reduced. Hence, when the quantity of soil to be dredged is great, when many dredges are to be worked simultaneously, or when a large number of barges is at the service continuously, a hopper dredge is never used, except in an open sea, or when there are some special inconveniences. Moreover, it has a greater draft, so that it cannot be used in shallow water without danger of grounding, although it is constructed so as to be able to cut its own flotation.

There are some authorities who insist that a hopper dredge can work with a smaller number of men and the cost of dredging and transport is less than with a stationary dredge and barges. The first cost of plant is sure to be lower, but a greater efficiency and economy in dredging will be obtained with an ordinary barge-loading dredge supplied with barges. So it is yet to be proved that a vessel with a dead-weight of machinery, etc., considerably in excess of its cargo, and with a much larger crew than necessary for the purpose, can convey to sea a hopper load of dredged material at a cheaper rate than a vessel having only a sufficient capacity and crew for its cargo.

TABLE 17.— SHOWING COMPARATIVE PROPORTIONS OF VARIOUS HOPPER DREDGES.

Dredge.	*Manche.*	....	*Shunkai, No. 1.*	*Shunkai, No. 2.*	*Pas-de-Calais.*	....	*William Price.*	*La Puissante.*
Destination.	Dieppe.	Bulgaria.	Osaka.	Osaka.	Boulogne.	Bristol.	Karachi Port Trust.	Suez Canal.
Length. L......	168	137-9	170-0	170-0	179-9	218-0	236-0	275-0
Breadth, B... ..	30-2	27-3	33-6	36-0	33-2	43.0	42-6	47-0
Depth, D........	14-0	12-2	14-3	15-0	14-0	17-0	16-0	19-0
Draft, light, D_0.	8-8	....	9-3	10-0	9-6	10-6	....	....
Draft, loaded, D_1	12-4	....	11-6	12-6	12-2	14-6	....	16-5
Dredging depth, Dd...	31-2	32-10	35-0	35-0	41-0	36-0	43-0	40-0
Bucket capacity. Cubic feet	12.4	8.8 and 13.4	17.	21.	11.3 and 17.7	17.7	22. and 12.	31.
Bucket velocity.	16	....	16	12-18	10-15	16-18	....	18-20
Dredging capacity. Tons, Cd	328	590	600	600	492	1 000	1 250	1 150
Hopper capacity. Tons, Ch.	525	500	600	600	525	1 000	....	2 200
Engine	....	1 compound.	2 compound.	2 compound.	....	2 triple.	2 triple.	2 triple.
Pressure. Pounds	....	103	120	150	....	140	160	160
Position of ladder........	....	bow.	bow.	stern.	bow	stern.	bow.	stern.
Number of propellers	....	1	2	2	2	4	2	2
I. h. p............	500	....	650	500	660	1 300	1 840	1 620
Velocity when loaded. Knots	7.0	7.0	7.0	7.0	6.25	9.0	10.0	$9\frac{3}{4}$
$\frac{L}{Dd}$..............	5.39	4.20	4.86	4.86	4.38	6.06	5.49	6.87
$\frac{B}{L}$..............	0.180	0.198	0.191	0.212	0.184	0.197	0.180	0.171
$\frac{D}{L}$..............	0.083	0.088	0.084	0.088	0.078	0.078	0.068	0.069
$\frac{D_1}{D_0}$..............	1.42	....	1.24	1.25	1.28	1.38	....	....
$\frac{D_1}{L}$..............	0.073	....	0.068	0.074	0.068	0.067	....	0.060
$\frac{Ch}{Cd}$..............	1.60	0.85	1.00	1.00	1.07	1.00	....	1.91

The length, breadth, depth, draft and dredging depth are given in feet and inches. The relations are given in Table 18.

Twin screws are adopted for a stern-well dredge, which has its ladder well in the stern, and a single screw, generally, for a bow-well dredge. The former gives a better form to the bow of the vessel, and the stern, being large enough to shelter the propellers, necessitates the use of two rudders. This insures great maneuvering power and, at the same time, offers a great displacement for supporting a heavy bucket chain.

Examples of this type will be found in Table 17.

When the dredge is to work in a narrow canal or channel, it is sometimes constructed with four propellers, two in the bow and two in the stern, so as to develop equal speed ahead and astern. The four propellers necessitate the construction of shafting tunnels through the hopper, if any, which may be so arranged as to add materially to the strength of the vessel.

TABLE 18.

Proportion.	Stationary dredge.	Self-propelling barge-loading dredge.	Hopper dredge.
$\frac{L}{Dd}$	3.0 to 5.0	4.3 to 5.0	4.8 to 6.0
$\frac{B}{L}$	0.2 to 0.3	0.18 to 0.23	0.18 to 0.20
$\frac{D}{L}$	0.075 to 0.12	0.07 to 0.075	0.07 to 0.088
$\frac{D_1}{D_0}$	....	....	1.3 to 1.4
$\frac{D_1}{L}$	0.04 to 0.06	0.045 to 0.055	0.067 to 0.07
$\frac{Ch}{Cd}$	....	....	1.0 to 2.0

Engine and Boiler.

Engine.—The marine compound surface condensing engine is generally used for a common dredge. As the work of a dredge is quite variable, it is very necessary to have a superior and efficient engine. Hopper dredges with stern wells are usually provided with two compound surface condensing engines, sometimes with triple-expansion engines. The ratio of i. h. p. to dredging capacity, in tons, varies greatly with the kind of dredge thus:

KIND OF DREDGE.	I. h. p. / Capacity, in tons.
Non-propelling	0.35 to 0.45
Self-propelling barge-loading	0.60 to 1.00
Self and barge-loading	0.80 to 1.50

The i. h. p. of a non-propelling dredge depends, of course, upon the work done in raising the soil and also upon the work done in overcoming the resistance of the earth. The resistance, however, being much greater, the i. h. p., roughly speaking, will have a certain ratio to the dredging capacity. As to the self-propelling dredge, it will have some relation to the displacement of the vessel, or to (displacement)$^{\frac{2}{3}}$, not to the dredging capacity. That is why the ratio is much greater in a self-propelling dredge than in a non-propelling dredge. The following is a table of the power required for both dredging and propelling, as determined by the writer in his experiments at the Osaka Harbour Works:

Dredge.	I. h. p. when dredging with a velocity of 18 buckets per min.	I. h. p. when propelling with a velocity of 7 knots.
Shunkai No. 1	118.9	514.1
Shunkai No. 2	135.2	322.2

The power required for dredging varies with the kind of soil and also with the height to which the soil is raised, together with the friction of the machinery; so that it is very difficult to find a general expression for the horse power required. However, Mr. Molesworth proposed the following relation:

$$\text{i. h. p.} = C(0.004H + K),$$

where C = number of cubic feet dredged per minute,

H = height, in feet, to which the material is raised, that is, (height of the upper tumbler above water) + (dredging depth),

K = constant, = 0.35 for stiff clay and gravel, = 0.15 for soft clay and mud.

The writer took several indicator diagrams of the engines of self and barge-loading ladder dredges of the Osaka Harbour Works. The heights of the upper tumblers are:

Dredge.	Height of upper tumbler above water.	Maixmum dredging depth.
Asanagi and *Yunagi*..................................	26 ft. 6 in.	15 ft.
Shunkai No. 1..	26 "	35 "
Shunkai No. 2..	36 "	35 "

Each indicator diagram differs greatly from the others, on account of the irregularity of the bottom, the discontinuousness due to alternate bucket and link of the chain, and variation of moment of force, due to the square form of the upper tumbler, even when the nature of the soil, the dredging depth and the initial tension of the bucket chain remain the same. It is very difficult to find the true i. h. p. from such varying diagrams. But the writer observed that the absorption of the horse power of the machinery, when it is running light, is from 50 to 70% of the total i. h. p. exerted when it is fully loaded, while the theoretical horse power for raising the soil is only from 20 to 30% of the total i. h. p.

Now, treating the theoretical horse power for raising the soil as unity, horse power due to friction of machinery when running light = 2 to 3.

Horse power due to earth resistance and additional friction of machinery due to full load = 0.5 to 1.0 (the earth being mud or soft clay).

From the results, it will be seen that the ladder dredge has a very poor efficiency as a machine, and, moreover, that the material is lifted to a height nearly double that required. The first drawback comes from the rough structure of the bucket chain, and the second from the construction of the shoot. To reduce these disadvantages, the initial tension of the chain should be made as low as possible, and every part of the chain be well lubricated. The upper tumbler should be placed as low as possible, or the shoot should be dispensed with, if possible, and replaced by another discharging apparatus.

Boiler.—The boiler is commonly of the marine tubular type. One boiler is used for a dredge having a single engine, and two, or sometimes three, for a dredge having a pair of independent engines. The boilers are so arranged that each may be worked independently of the others.

Transmission of Power.

Power is transmitted to the top tumbler supported on a strong solid frame, the height of which is determined by the easy discharge of shoots. The transmitting machinery must be simple in construction and elastic

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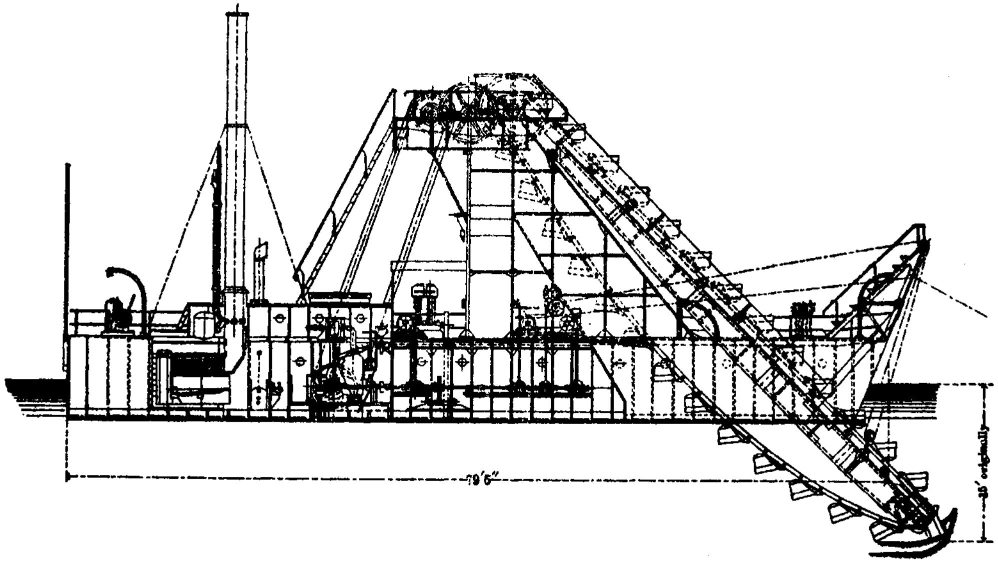
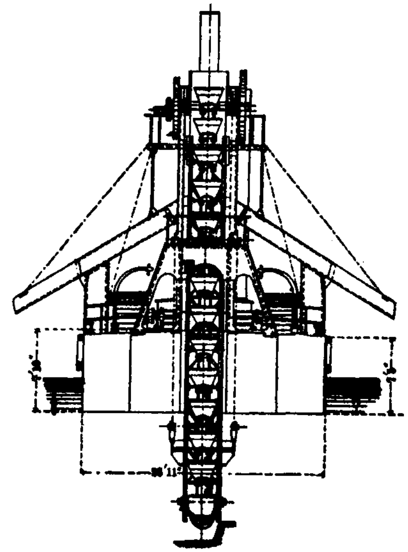
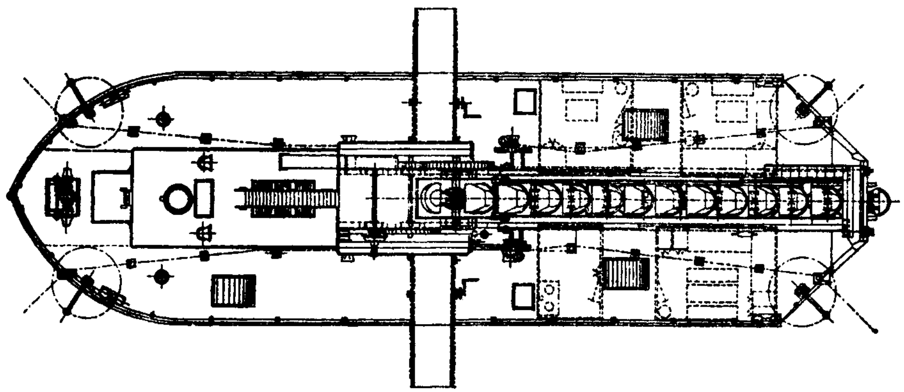
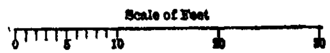






ASANAGI AND YUNAGI



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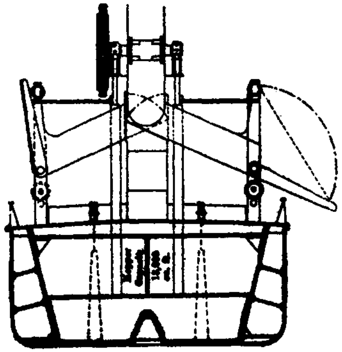
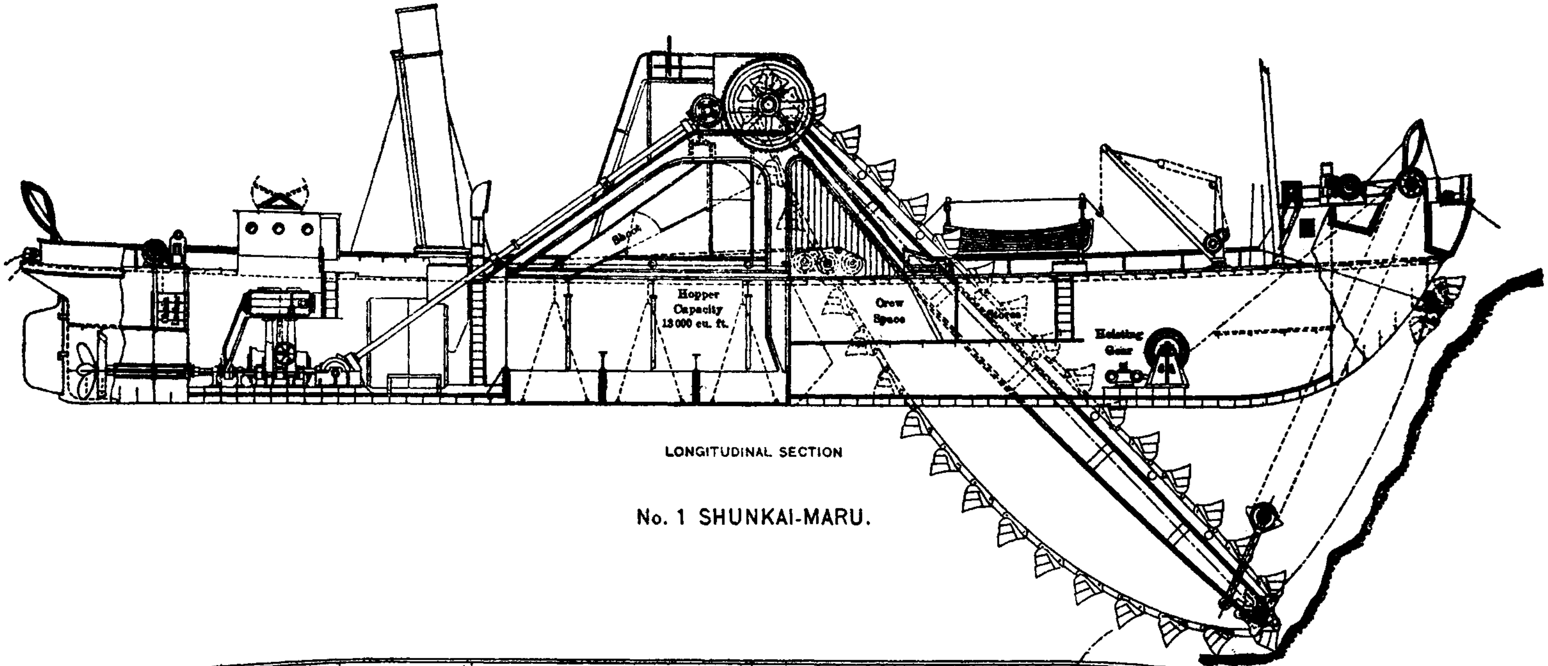


SECTION THROUGH HOPPER



LONGITUDINAL SECTION

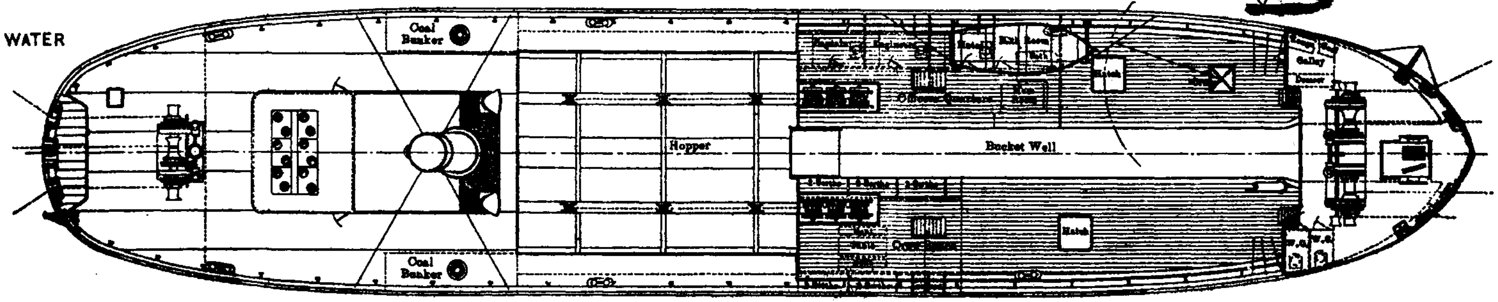
No. 1 SHUNKAI-MARU.

DIMENSIONS

Length between perpendiculars	178'0"
Breadth moulded	33'6"
Depth "	14'3"

Scale of Feet

DREDGE TO 35 FEET DEPTH OF WATER



DECK PLAN

enough to resist shocks. Belting, shafting and pitch-chain gearing are resorted to. Whatever may be used, a frictional gearing must be interposed, to avoid the danger of fracturing any part of the machinery in case of a sudden shock received by coming in contact with unusually hard substances. The hydraulic clutch is commonly used on the German small dredge. Often the top tumbler shaft is driven by a surging wheel, the friction wave of which is so large that it does not interfere with the structural strength of the rim.

Belt gearing is practically noiseless and can be easily started and stopped. As the belt tensions are different in the driver and in the follower, slips occur, causing the follower to revolve at a slightly decreased rate. This gives a dredge an advantage in case of shocks. However, as it is difficult and expensive to use for heavy pressure, it is rarely used for a dredge with a large capacity.

Shafting is used in connection with spur gearing. It is practically noiseless, but considerable power is required merely to turn the shaft.

Spur-wheel gearing, on the other hand, is noisy, especially when reversed. The teeth are liable to break under shocks for lack of slip, unless a slipping clutch be introduced.

Pitch-chain gearing is as useful as belt driving, decreasing the number of working parts, while modifying the power. It provides positive transmission and may be used with a heavy load. It is much more elastic than shafting. Mr. Fred. Lobnitz prefers it to the others on account of its elasticity, and even in case of breakdown it is generally easier to repair than spur wheels. The increase of pitch after wear, however, causes excessive friction and bad working.

After all, since the introduction of cast steel, shaft gearing has been generally adopted for a large dredge, and belting for a medium-size dredge, while pitch-chain gearing is used only by some special dredge makers. Whatever means may be used for driving the tumbler, the most approved practice is to have two wheels on the top tumbler shaft so as to have equal torsion and smooth driving. For the same reason, two sets of belt or pitch chains are to be used.

To make the tumbler revolve 7 or 8 times per min. a set of spur wheels and pinions is used. Some dredges are so constructed as to have different port and starboard engine gears, having different velocity ratios. This is necessary when the soil to be dredged is of variable nature. Sometimes the gearing which transmits the motion from the engine to the tumbler shaft is so arranged that the speed can be varied independently of that of the engine.

There is another method of power transmission, which answers well for some special requirements, and is proposed by Mr. Bates and Mr. H. F. Smulders, namely, electrical transmission.

The following advantages are claimed by Mr. Bates for electrical transmission used on dredges in harbours and canals:

1.—The hull of the dredge may be smaller, and the first cost, therefore, cheaper.

2.—The central station will serve to supply energy for other installations destined for the construction of quay walls, etc., if there be such. It may also be utilized for lighting the harbour, working cranes, and moving bridges, lock gates, etc., even after the dredging is finished.

3.—Every part of the mechanism of the dredge may be set in motion without delay, and the control is very perfect and easy.

4.—The power is transmitted by a cable, enclosed in a sheath forming a floater, which supports the cable on the surface of the water.

This method is useful where a group of non-propelling dredges and elevators are used; but it cannot be applied to self-propelling dredges, nor adopted at a site where obstruction to navigation is seriously felt.

Dredging Apparatus.

Bucket Chain.—There are two types of bucket chains: one is an open-connected type and the other a close-connected type. The former consists of buckets and links alternately connected, and is used for general work. The latter is a thorough connection of buckets only, and is used for specially soft and homogeneous mud. For dredging different kinds of soil, some dredges are constructed to have two sets of chains, which differ only in the bucket contents.

The velocity of the bucket chain is usually denoted by the number of buckets traversed per minute. It should be such as easily to give a regular and uniform feed of soil to the buckets, in order that they can, at all times, work to their full capacity without causing any severe strain. The velocity is now commonly from 14 to 18 bucktes per min. for ordinary soft material, and from 10 to 13 for hard substances. Thus the linear velocity of the bucket chain will be proportional to the pitch of the link.

If the chain is open-connected, and used for soft material,

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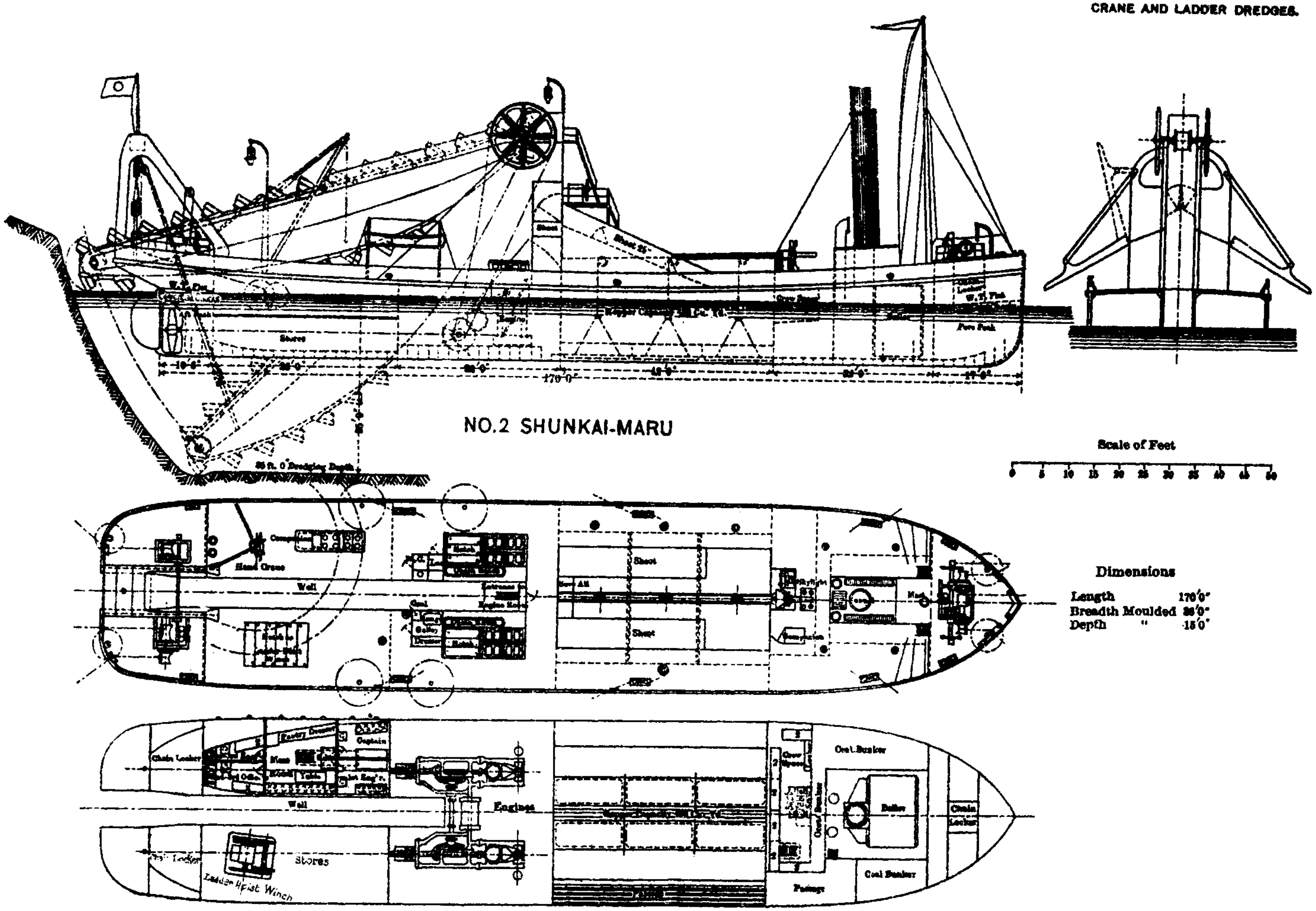


NO.2 SHUNKAI-MARU

Dimensions

Length	170'0"
Breadth Moulded	36'0"
Depth "	15'0"

$$V = 2\ (14 \ldots\ldots 18)\ P,$$

where V = velocity per minute,

P = pitch of chain.

The bucket chain, as has been said, should have sufficient strength to withstand safely the immovable resistances encountered. The resistances, of course, varying with the nature of the soil, make it very difficult to determine the requisite strength of chain required. Table 19 gives some relations between the dredge capacity, bucket capacity, pitch of chain and the diameter of the pin, which have been successful in practice.

TABLE 19.

Dredge:	Destination.	Dredging capacity. Tons per hour.	Bucket Capacity. Cubic feet.	Pitch of chain. Inches.	Width of chain. Inches.	Diameter of pin. Inches.
Shunkai No. 1	Osaka.	600	17	33	25⅜	3
Shunkai No. 2	Osaka.	600	21	39⅜	24⅜	3
Shinchiku	Keelun.	400	12	32	17½	3¼
Koroku and *Ichimatsu*	Atsuta.	400	15	28⅜	28	2⅜
Asanagi and *Yunagi*	Osaka.	200	6.5	26	14⅜	1¾
No. V and *No. VI*	Yodogawa.	100	4	20	11⅝	1¼

Thus bucket capacity, in cubic feet $= \left(\frac{3}{100} \text{to} \frac{4}{100}\right)$ dredging capacity in tons.

Pitch of chain = $(1 \text{ to } 1.2)\ \sqrt[3]{\text{bucket capacity}}$.

Width of chain = $(1.0 \text{ to } 0.55) \times$ pitch.

Diameter of pin, in inches $= (0.6 \text{ to } 0.8)\ \sqrt{\text{bucket capacity in cubic feet}}$.

Bucket.—The bucket should be such that it can easily excavate the material without deformation, fill itself and discharge the contents into the shoots. It should also contain a quantity of water, just sufficient to clear the contents from the shoots. In capacity the bucket may be from 3 to 35 cu. ft., according to circumstances.

The buckets were formerly made of wrought iron, either welded solid or with riveted plates. The double links were of forged iron or of malleable cast steel, being riveted to the back; but with the continual jarring in working, the rivets soon became loose, then the holes began to wear. If taken off, they could be refastened with larger rivets, and so made to serve a little longer, but new backs had to be put on soon afterward. These repairs, being smithwork, were very expensive, and renewals had to be effected every half year. Now the buckets are generally made of cast steel, the back and the bottom, together with the double links, being in one piece, with flanges at the sides and bottom for receiving the front. The front piece is usually of steel plate, reinforced with a renewable cutting piece of special steel, or armed with tines when the soil is hard. Claws are sometimes used between the buckets for loosening hard clay and conglomerate.

The surface adhesion of the bucket varies with the square of the pitch of the bucket chain, while the contents vary with the cube; so that the larger the capacity of the bucket, the smaller will be the ratio of the adhesion to the contents. Again, to make the discharge easy, the longitudinal section of the bucket, both vertically and horizontally, is tapered.

In the old form of bucket many small holes were punched around the sides to drain out the water; but recently these have all been abandoned except one in the center of the front of the bucket, which is used only for transportation. Each pinhole of the double link should be bushed and a recess cast to prevent the pin from turning.

Link.—The link should have a large bearing surface, especially at the pinhole, and the pinhole should be bushed with a ring of hard steel. There are two kinds of links: the single link, used for the connection of two consecutive buckets; and the double link, which is fixed to the back plate of the bucket, and the end of which is connected to the single link by a pin. The double link of a large dredge is now generally cast in one piece with the back of the bucket. But in a smaller dredge it is sometimes made of cast steel, or, rarely, built of steel bars, as in the dredges of the Atsuta Harbour Works, where the connecting link consists of two separate bars.

To economize material, a smaller section is sometimes given to the body of the single link than that around the pinhole, as may be seen in Figs. 9, 10 and 11.

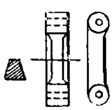


Fig. 9.

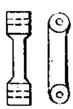


Fig. 10.

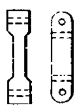


Fig. 11.

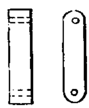


Fig. 12.

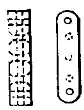


Fig. 13.

But as the lower side of the link strikes against the face of the upper tumbler, these sections will not answer well in the long run. The two former do not permit the link to be reversed, which is necessary when wear sets in. The form shown in Figs. 12 and 13, though clumsy in appearance, will be better for such rough work as dredging. For a small dredge the form shown in Fig. 12 is used, and for a large one the link is built up with three or more plates welded and riveted, as shown in Fig. 13.

There is another kind of link called the "hunting link", which is used to adjust the length of the bucket chain. This link serves to connect a bucket and an ordinary link, so as to lessen one pitch in the chain, and also to prevent the uneven wearing of the tumbler, caused by the buckets, coming on the same face.

The hunting link, however, reduces the dredging capacity, and is used only on a large dredge, where other convenient means of adjusting the bucket chain cannot be adopted. Suppose there are 30 buckets and a hunting link in the chain, then the loss of material dredged will be $\frac{1}{61}$ of the original capacity if the hunting link were not used. For this reason, the lower tumbler, or the upper end of the ladder of some small dredges, such as the *Asanagi* and *Yunagi* of the Osaka Harbour Works, is made to slide in a groove in order that the chain may be adjusted easily.

The usual proportions of height to thickness in single links is shown in Table 20.

TABLE 20.

Dredge.	Destination.	Bucket capacity. Cubic feet.	Height of link. Inches.	Width of link. Inches.
No. V and *No. VI*	Yodogawa.	4	$2\frac{3}{4}$	$1\frac{3}{8}$
Asanagi and *Yunagi*..........	Osaka.	6.5	$4\frac{5}{16}$	2
Koroku and *Ichimatsu*.........	Atsuta.	15.0	6	Two bars, each $1\frac{1}{8}''$ thick.
Zuiho..............................	Keelun.	....	7	4 at end, $2\frac{1}{2}$ at middle.
Shinchiku.........................	"	12	$7\frac{3}{4}$	$5\frac{5}{8}$
Shunkai No. 1	Osaka.	17	$6\frac{3}{4}$	$4\frac{1}{4}$ at end, $2\frac{3}{4}$ at middle.
Shunkai No. 2	"	21	7	$2\frac{1}{2}$
Vladivostock.....................	Vladivostock.	22	$7\frac{8}{10}$	$3\frac{9}{10}$

Thus,

Height, in inches $= (1.4 \text{ to } 1.7)\ \sqrt{\text{bucket capacity, in cubic feet.}}$
Thickness, in inches $= (0.4 \text{ to } 0.7) \times$ height.

On a small dredge sometimes the double link is not protected with bushes; but the contact surface is liable to be crushed, as is the case with the single link. The bush is a ring, $\frac{5}{32}$ to $\frac{7}{16}$ in. thick, made of a hard steel. It is desirable to prevent the bush from turning in the hole.

Pin.—The head of the pin is generally square or rectangular and fits into a groove of the same form in the double link, which prevents the pin from turning. Theoretically speaking, the form of the pinhead should correspond with the form of the upper tumbler, so as to allow the pin to be used with the same number of turns as the pinhead has sides, when wear sets in. In practice, however, it is better to turn the pin twice for a square tumbler, and perhaps three times for a pentagonal one, to make the wear around the surface equal. The other end of the pin is furnished with a split-pin or a split cotter. Washers are sometimes used to keep the pinhead firmly in the recess, and also to prevent bushes from getting out.

Formerly the pin was made of scrap-iron, case-hardened, or of mild steel, hardened, but the life of such a pin was quite short. Since the introduction of manganese steel the life of a pin has been made considerably longer.

The great delay and expense incident to the wear of the pins and links is still one of the disadvantages of the ladder dredge. To obviate this, there is Robinson's patent improved protected and lubricated joint connection. The pin is of unusually large diameter, and has a large and wide bearing, the whole width of the rear end of the bucket, the pin being held fast in the narrow bearings at the front end. A removable bush of manganese steel is used, which, together with the use of a self-expanding packing ring and proper provision for lubrication, constitutes the most perfect and durable construction.

Tumblers.—The upper tumbler should transmit the driving power to the bucket chain smoothly and discharge the contents of the bucket upon the shoots instantly, so as to clear the bucket and the shoots.

For the first purpose it is necessary to make the polygon of the tumbler as nearly circular as possible.

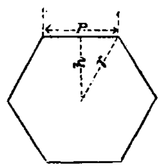


Fig. 14.

Now, in Fig. 14,

p = pitch = side of polygon,
n = number of sides of tumbler,
r = radius of described circle,
h = distance of the side from the center.

$$h = \frac{1}{2} p \cot. \frac{\pi}{n} \quad r = \frac{1}{2} p \operatorname{cosec.} \frac{\pi}{n}.$$

The change of lengths, h and r, causes a corresponding change of moments in driving the chain. Again, the time required for a bucket, after touching the tumbler, to come to a vertically downward position will be

$$T, \text{ in minutes} = \left(\frac{\pi}{2} + \theta\right) \div \frac{4\,k\,\pi}{n} = \frac{n\left(\frac{\pi}{2} + \theta\right)}{4\,k\,\pi}.$$

where

k = number of buckets traversed per minute (assume = 16),

θ = angle of the driving chain to a horizontal line, say $= \frac{\pi}{4}$; or,

$$T, \text{ in seconds} = \frac{60 \times n \times \left(\frac{\pi}{2} + \frac{\pi}{4}\right)}{4 \times 16 \times \pi} = 0.703 \times n.$$

From Table 21 it will be seen that the smaller the number of sides of the tumbler the swifter will be the discharge, while the greater the number of sides the smoother the driving of the tumbler and the less the deflection. With small deflection, however, there will be danger of the tumbler's slipping. So the best results seem to be obtained with a five-sided or a four-sided tumbler. Generally, a square form is adopted for the common dredge; but there are many dredges with five-sided tumblers.

TABLE 21.

Number of sides of tumbler.	T, in seconds.	Deflection of the consecutive sides.	r.	h.	$\frac{r}{h}$, or, ratio of moments of force.
3	2.1	$\frac{2}{3}\pi$	$0.58p$.	$0.29p$.	2.00
4	2.8	$\frac{1}{2}\pi$	$0.71p$.	$0.50p$.	1.41
5	3.5	$\frac{2}{5}\pi$	$0.85p$.	$0.69p$.	1.24
6	4.2	$\frac{1}{3}\pi$	$1.00p$.	$0.87p$.	1.15
7	4.9	$\frac{2}{7}\pi$	$1.15p$.	$1.04p$.	1.11

The function of the lower tumbler is to guide the buckets for excavating soil, and not to transmit power. It is, therefore, necessary to give a smooth velocity to the mouthpiece of the bucket, so as not to cause a severe strain on the bucket.

Now, the angular velocity of the tumbler,

ω per second $= 2k\frac{2\pi}{n} \times \frac{1}{60}$,

where k = number of buckets per minute.

n = number of sides of tumbler.

Suppose

$k = 16$ and $R = h + 1.2p$

The linear velocity of the cutting edge of the bucket

$$V = R\omega = R\frac{4 \times 16 \times \pi}{n \times 60}.$$

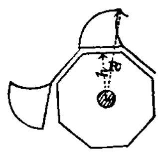


Fig. 15.

TABLE 22.

Number of sides of polygon.	Radius of inscribed circle.	R.	V per second, in terms of pitch.
3	0.29p.	1.49p.	1.66p.
4	0.50"	1.70"	1.42"
5	0.69"	1.89"	1.27"
6	0.87"	2.07"	1.16"
7	1.04"	2.24"	1.07"

Hence, the greater the number of sides, the slower will be the excavating velocity, and the greater will be the diameter of the tumbler. When the tumbler is of great diameter, it will cause some obstruction to the side cutting of the dredge. In practice, the lower tumbler is made hexagonal when the upper one is five-sided, and pentagonal when the upper one is four-sided.

It must be noted that the soil is excavated by the bucket mainly when it rides on and is guided by the lower tumbler, and that otherwise the pins undergo severe shocks, and the rivets of the bucket soon work loose. Taking this into consideration, the buckets will work more effectively if we augment the number of sides of the tumbler, and thus increase the contact surface of the bucket with the soil. Although a large number of sides for a tumbler will cause some obstruction to the side cutting, yet the writer is of the opinion that better work may be done by giving the lower tumbler five sides for a soft material, and six sides for a stiff material which does not allow a deep cutting.

The top tumbler has to be made very strong, as it has to withstand great wear and tear. It is now commonly made of cast steel or, sometimes, of chilled cast iron. As the corner of the tumbler suffers the greatest wear, some old cast-iron tumblers are furnished with renewable corner-pieces of hard steel dovetailed into the body, or the faces are covered with steel plates firmly riveted. The top tumbler of some small dredges is made in two parts, but this is liable to become loose.

The lower tumbler is of cast steel, in one piece, having very deep and strong flanges. Some small dredges have cast-iron tumblers. The tumbler is fitted with a cast-iron bush, the full width of the tumbler, and revolves loosely on a wrought-iron shaft fitted to the ladder eyes by cross-dovetailed keys; or it is made to run in brackets at the lower end of the ladder, the axle being furnished with cast-iron bushes. The flanges are bevelled to suit the form of the buckets, the play being about 2 in. It is desirable that the bearings of the bottom tumbler be so arranged that they can be readily renewed without disconnecting the bucket chain. There are some arrangements for lubricating the lower tumbler, but they are not used.

There is another tumbler, sometimes found on French dredges, as on the *Pas-de-Calais*, and the dredge for Charente. It is used behind the following or suspended portion of the bucket chain, to deflect it, and may be called the intermediate tumbler. This is claimed to have the following advantages:

First.—It gives the buckets a better direction for attacking the soil;

Second.—It increases the dredging depth, and

Third.—It makes thorough discharge of the contents of buckets with a small inclination of the ladder. This tumbler, however, causes a great shock to the bucket chain. The tumbler, after being struck by a bucket, takes a revolving motion, which increases the intensity of the following shock. But this shock can be somewhat lessened by using a brake.

Ladder.—The lower tumbler is attached to the free end of the ladder, the other end of which is hinged to the bridge a little below the upper tumbler, and which is suspended by chains or a wire rope, so that the free end may be adjusted to any depth required. There are two methods of mounting the tumbler, one is fixed and the other is movable. The latter method, which is used only for a smaller dredge, affords very convenient means for adjusting the slack of the bucket chain. The shaft supporting the upper end of the ladder is placed about 6 ft. below the upper tumbler shaft measured in the direction of 45 degrees. As the ladder is apt to be exposed to severe shocks, some French dredges are fitted with buffer springs at the upper end of the ladder, to lessen the shock and allow the shaft bearing to slide in a groove when extra resistance is met.

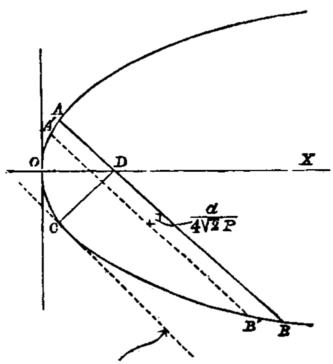
The bucket chain, like a belt, is liable to cause the upper tumbler to slip without driving the chain if it be too slack for the distance apart of the tumblers. The writer found that the maximum slack of the chain, measured, normally, from the link center of the upper chain to that of the lower, when the ladder is lifted, would best be $\frac{1}{6}$ of the tumbler distance for a hard soil, and $\frac{1}{5}$ or, rather, $\frac{2}{11}$ for a soft material.

The bucket chain, when suspended, will take the form of a catenary. But suppose it to be a parabola represented by $A\ O\ C\ B$ in Fig. 16.

$$u = y - \sqrt{p}\, x^{\frac{1}{2}} = 0,$$

$O\ Y$ and $O\ X$ are the co-ordinate axes.

Now, in order to prevent the chain from overriding the tumbler at A, it is necessary, at least, that the ladder, $A\ B$, when it is at the maximum inclination of 45°, will be normal to the curve at the point, A, or will make an angle of less than 90° with the bucket chain, $A\ O\ C\ B$, at the point, A.



Parallel to $A\ B$ and tangential to the curve

Fig. 16.

If the ladder is normal to the chain, the following relations must be fulfilled:

$$\frac{d\,u}{d\,y} = -1\frac{d\,u}{d\,x},$$

$$y = \sqrt{P}\, x^{\frac{1}{2}},$$

whence $x = \frac{1}{4} P$ and $y = \frac{1}{2} P$,

which are co-ordinates of A.

Next, the co-ordinates of B will be

$$y - \frac{1}{2}P + \left(x - \frac{1}{4}\right) = 0,$$

$$y - \sqrt{P}x^{\frac{1}{2}} = 0,$$

$$y = -\frac{3}{2}P \text{ and } x = \frac{9}{4}P.$$

Again, the co-ordinates of the contact point, C, of the tangent line which is parallel to $A\ B$, are

$$\frac{d\,u}{d\,x} + \frac{d\,u}{d\,y} = 0,$$

$$y - \sqrt{P}x^{\frac{1}{2}} = 0,$$

$$x = \frac{1}{4}P \text{ and } y = -\frac{1}{2}P.$$

Hence, the normal at C will pass through the intersection of $A\ B$ and $O\ D$.

$$\text{Length, } C\ D = \frac{1}{\sqrt{2}}P \text{ and } A\ B = \sqrt{8}\ P.$$

The ratio of the slack of the chain to the distance of the tumblers is $\frac{1}{4}$.

Again, treating of another, $A\ B$, which makes an angle of less than 90° with the curve, or, reducing the length, $C\ D$, by $\frac{a}{4\ \sqrt{2}}P$, where a is some constant, the length of $A'\ B'$ will be $P\sqrt{2(4-a)}$.

$$\text{So the ratio} = \frac{\sqrt{4-a}}{8}.$$

Hence, $\frac{1}{4}$ is found to be the allowable maximum limit, when the ladder is at its maximum inclination, that is, 45 degrees.

But the same length of chain will have another relation, if the ladder, $A\ B$, is kept horizontal.

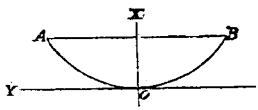


Fig. 17.

$$A\,B = \sqrt{8}\,P.$$

$$\text{Curve } A\,O\,B = \left\{ \frac{y\sqrt{y^2+\left(\frac{P}{2}\right)^2}}{P} + \frac{P}{4}\log.\left(\frac{y+\sqrt{y^2+\left(\frac{P}{2}\right)^2}}{\frac{P}{2}}\right) \right\}_0^{\frac{P}{2}}$$

$$+ \left\{ \frac{y\sqrt{y^2+\left(\frac{P}{2}\right)^2}}{P} + \frac{P}{4}\log.\left(\frac{y+\sqrt{y^2+\left(\frac{P}{2}\right)^2}}{\frac{P}{2}}\right) \right\}_0^{\frac{3}{2}P}$$

$$= 3.4006\,P.$$

Then the new parabola, $y^2 = P'x$, where

$$2\left\{ \frac{y\sqrt{P^2+\left(\frac{P'}{2}\right)^2}}{P'} + \frac{P'}{4}\log.\left(\frac{y+\sqrt{y^2+\left(\frac{P'}{2}\right)^2}}{\frac{P'}{2}}\right) \right\}_0^{\sqrt{2}\,P} = 3.4006\,P.$$

By solving the equations, we get $P' = 1.625 \times \sqrt{2}\,P$. whence

$$\frac{2y}{x} = \frac{2 \times 1.625 \times \sqrt{2}\,P}{\sqrt{2}\,P} = 3.25.$$

Thus the ratio will be 3.25 when the ladder is horizontal.

But in practice, the ratio $\frac{1}{5}$ to $\frac{1}{8}$, measured when the ladder is lifted, has been taken by the writer for the dredge of the Osaka Harbour Works. The smaller the ratio, the more will be the initial tension of the chain, while a larger ratio will not be permissible, as the chain is apt to override the lower tumbler. In general, however, a smaller ratio is adaptable for hard soil, and a greater ratio for soft mud.

The ladder must not be inclined too much. The maximum work is said to correspond to an inclination of 45°, and to diminish greatly when the inclination gets beyond 60°. Sometimes the ladder is constructed in two parts, so that the lower part may always have an inclination of 45 degrees.

The length should be such that the dredge may reach the maximum depth with a ladder at a maximum inclination of 45°, and discharge the spoil easily into the hopper or barge.

Some old dredges are so constructed as to have the ladder at the side of the hull. With this arrangement, the dredge may have two ladders, and can dredge close to the foot of quay walls at a great depth. Some authorities have claimed that dredges with two side ladders can do more work than those with a central ladder, being able to work with one ladder while the other is being repaired; and may afford easy access to the ladders and the bucket chains.

But friction, wear and tear are greater with two ladders. and may outweigh these other advantages Also the double ladders make the dredge wider, and are apt to be exposed to a great shock when used in an open sea, and to break away from the hull, when dredging toward the side where there is no guide for the ladder. Two bucket chains do not work equally well, the bottom not being of absolutely the same quality, nor of equal depth at both sides of the dredge. Moreover, the dredge, when it has loaded a barge with spoil, has to wait for another, because each bucket chain can discharge only on its own side.

To meet these inconveniences, it is customary for the modern dredge to have a central ladder, which allows it to have two or more barges lying along both sides of the hull, and it may load either barge without any interruption. There are two kinds of central ladder wells: the close-ended, having a ladder well in the middle of the hull; and the open-ended. The close-ended well is an old form, adopted when the open end was thought objectionable. It is now used only in a special case, where there is no shallower depth of bed to be dredged than the draft of the vessel. The open-ended well is now generally used, as it can cut its own flotation. The bow-well is used for a single-screw dredge, and the stern-well for a twin-screw; the latter can develop a greater speed, as the bow may have the regular moulded lines of a vessel, but its first cost is greater than that of the former.

"Traversing gear" or other similar devices have been used on some large dredges to enable them to clear the foot of walls at a great depth. But they have been dispensed with since the introduction of the open-ended well.

Horizontal and Vertical Rollers.—For the purpose of guiding and supporting the bucket chain, a series of cast-iron rollers, sometimes chilled, and having projecting checks. are fitted horizontally to the bucket ladder. Some dredges have two or more vertical cast-iron rollers, which only act as guides to the bucket, but which can be dispensed with if the horizontal ones have large flanges. Rollers and their bearings should be so arranged that they can be readily renewed without disconnecting the bucket chain. The usual pitch of the rollers is 2 to 3.5 times that of the bucket chain; however, a small proportion, such as 2 or 2.5, will give a smooth working.

The diameter of the roller varies from 6 to 12 in., according to the pitch and the capacity of the bucket. The spindles, forged of wrought iron and bushed with cast iron, work in renewable cast-iron bushes in their brackets, securely fixed to the ladder. A device which would keep the axle clear of mud and sand and lubricated with grease would be a great improvement.

The upper and lower one or two rollers are subjected to severe shocks due to the vibration of the chain. On this account, they should have larger axles than the common rollers, and their diameter should be made so large as to follow the inclination of the chain and thereby to reduce the shock. The upper rollers are sometimes fitted with springs.

Ladder Well.—The ladder well must be proportioned to the length of the ladder. In the self-propelling bow-well dredge, the ladder, when raised, rests wholly in the well, while it projects one or two buckets beyond the hull in some stern-well dredges. There are often non-propelling dredges which have their ladders projecting three or more buckets beyond the vessel.

The well also serves as a guide to the ladder when the dredge is side-cutting. So suitable rubbing pieces formed of elmwood and strengthened with flat bars are to be fixed to the upper and lower flanges at both sides of the ladder, and the well-plating also has fenders of steel plates on each side. A breakwater is to be fitted to the after end of the well, if it be a bow-well, to throw the current of water under the bottom of the vessel when steaming ahead.

Main Framing.—The top of the main framing should have an ample height to insure the easy discharge of the spoil on the barges or into the hopper well. It should have ample strength and stiffness and be easily painted. All parts should be arranged so as to be easily and conveniently accessible by ladders and gratings, and made thoroughly tight, so that the dredgings cannot splash on the deck When the material to be dredged is muddy, a canvas or sheet-iron cover should be placed over the upper tumbler, allowing the buckets to pass under it; otherwise the spoil will spread over the deck.

Hoisting Appliance.—The hoisting sheers should be constructed of a height sufficient to permit the bottom tumbler to be raised about 2 ft. clear of the water. They are well trussed and so arranged as to meet the various working strains effectively, and are firmly secured to the deck plating and floors. The cross-beams are suitably arranged for receiving and carrying the tackle required for hoisting the ladder, and a suitable platform and ladder with a socket and mast complete are provided.

For hoisting, independent engines are commonly used on large dredges, but sometimes a countershaft is taken from the main engine. The action of the latter is simpler and quicker than that obtained by starting a pair of steam cylinders, and it does not require the same care and attention; but it entails the constant running of a shaft which is only used occasionally. In either case it is advisable to control the lifting and lowering of the ladder by handles so arranged on deck that one man can operate them. Two sets of chains are sometimes used for suspending a small ladder; but a wire rope is preferable for smooth and easy management. The purchase gear consists of two blocks with from 3 to 5 sheaves. The upper sheave hangs from the forecastle, and the lower is fitted into a cross-head, which is to be connected to the straps at the lower end of the ladder by side rods. The wire rope is wound on a barrel with a helical groove, whose development is to be sufficient to take the whole length of the rope, without overriding, and 2 or 3 turns more.

The engine, usually having two cylinders, should have sufficient power to raise the lower tumbler at a rate of more than 6 ft. per min. Some gears are so constructed as to raise the ladder at two speeds, say, one of 7 ft. and the other of 13 ft. per min.

There is a pair of preventer wire ropes secured to the lower end of each side of the bucket ladder, which are to be used in case of accident to or failure in the working gear. They are lashed to forks cast on brackets for bucket-rollers. To release the main wire rope, when the dredge is not at work, two chains or rods hung from the forecastle, for suspending the ladder, or sometimes a wooden block is provided under the ladder and over the ladder well. A gauge for showing the depth of the buckets under water is to be marked on deck or on the side of the ladder well.

Methods of Discharging the Material.—There are many methods of discharging the material, which differ greatly from each other, according to the purpose of the discharge. The common method is to discharge into spoil wells in barges or on the vessel itself. This apparatus is called the self or barge-loading shoot. There is another kind of shoot, called the long shoot, which is used to discharge into an enclosed spot to be reclaimed. These shoots discharge material by gravitation. Other methods are used to transport the spoil mechanically: by transporting platform and by floating pipes or a combination of floating and land pipes. The former is used to load wagons waiting on the bank, and the latter to deposit the material on shore.

The self or barge-loading shoot, or simply the shoot, is an inclined plane by which the dredged material is discharged by gravity into wells, either of barges or of the dredge itself. If it is for self loading, the shoot usually consists of two closed inclined channels, or, sometimes, of one channel for a dredge of small bucket capacity. Each channel has a certain number of hinged doors for distributing the spoil equally over the well. If it is for barge loading, the upper part of the shoot is fixed and closed, while the lower part, projecting overboard, is open and hinged, so that it may be raised or lowered. The barge-loading shoots are generally situated at both sides of the hull; but when it is necessary to dredge hard by a quay wall, or to work in a small canal where the transporting barge cannot lie alongside the dredge, the shoot is so constructed that the spoil may be discharged into the opposite side of the ladder.

The inclination of the shoot varies with the nature of the soil to be dredged. Wet clay will slide down a shoot inclined 1 in 5 to 1 in 3, if comparatively free from sand; but wet sand or gravel will not slide down an incline of even 1 in 2 without a free flow of water to aid it; otherwise it requires much pushing. So the shoot is sometimes supplied with water continuously from a service pump or a special auxiliary pump. The usual slope of the fixed part of the shoot is 25 to 35° or 1 in 1.5 to 1 in 2.2, but an inclination of from 1 in 1.8 to 1 in 2 is preferable. As to the hinged part, the slope is somewhat less than that specified: 1 in 2 to 1 in 5. It changes with the freeboard of barges to be loaded.

To give the shoot such an inclination, the upper tumbler should, naturally, be placed high. To obviate this, Messrs. Fleming and Ferguson designed a dredge having its top tumbler slightly above the deck, the remainder of the elevation being effected by a light elevator. Mr. Hunter has devised a screw placed in a trough a few feet above the deck, by which the dredged material may be led to any part of the vessel. But the advantage gained by not lifting so high is not more than counterbalanced by the extra friction and the extra wear and tear of these devices.

The usual shoot is 6 to 4 ft. in breadth, and 4 to 2 ft. in depth. The section is commonly rectangular, but the bottom is sometimes curved. The end of the shoot is often covered, having a curved trumpet mouth, so as to guide the material, when the spoil well is too small. This is what the writer used in the dredges of the Osaka Harbour Works, where the dredged material splashed over the deck of the hopper barge of 100 tons capacity.

The rocking plate at the top, which directs the dredged material to any shoot, is hinged on strong brackets having large surfaces properly fastened and worked from the deck with proper back balance weight. The plate is formed of two steel plates riveted to an iron frame, the space between the plates inside the frame being filled with timber and properly riveted, caulked and balanced. The turning of the rocking plate and the folding of the hinged shoots are generally accomplished by a hand winch, or by a steam steering winch, which the writer adopted in the dredge *Shunkai No. 2*. Some dredges have an independent engine for hoisting and lowering the shoots.

The long shoot should be well covered in to prevent splashing on the deck. The shoot is conical or circular in section. Its dimensions vary with the capacity of the dredge, but the usual diameter is 1½ to 3 ft., widened in the highest point to 1.8 times, nearly. It is made slightly conical by enlarging the diameter 8 in. or more at the delivering extremity, so that it will not choke with large materials. Sometimes a closed conduit is used. The advantage of this is that with a jet of water the material can be pushed out with much force.

The slope of the long shoot is entirely dependent upon the nature of the material to be discharged. The inclination, together with the height of the point of discharge above water, determines the height of the top tumbler. According to Mr. Webster, the following are found from experience to be the best angles for different kinds of soil: for soft mud, 1 in 10; for soft clay, 1 in 12 to 14; for hard clay, 1 in 14 to 16; and for fine sand and water, 1 in 20 to 25. Moreover, from experiments made in the Suez Canal, it was found that fine sand, mixed with an equal quantity of water, would flow down a slope of 1 in 25; but with a flatter slope, no matter how much water was used, the sand would separate from the water and form a hard cake on the bottom of the shoot. The usual inclination adopted is 1 in 10 for the upper part and 1 in 20 for the lower part. The dredged material tumbles on a conduit placed about 6 ft. lower than the tumbler, where it is mixed with water pumped out. An appropriate proportion of water seems to be 2 to 3 times the solid matter in volume. It is necessary to supply a grating at the beginning of the conduit so as not to admit hard masses or large pieces of material before they are mixed with water.

The shoot is supported by wire ropes fastened to the head of a sheer-legs, which is mounted on the dredge, or on a special pontoon rigidly connected to the hull of the dredge. The back-guys of the sheers are connected to a pontoon which lies on the opposite side of the dredge and has a pump and an engine for providing water ballast.

The transporting platform or conveyor which has been generally used, consists of beams guiding and supporting an endless band composed of steel plates connected by pins. The dredge discharges material upon this band, which is driven by a special independent steam engine. The platform is used for discharging the dredged material directly ashore wherever the banks are low and within reach. It can transport material to a distance of more than 1 000 ft., and also to a height greater than that of the dredge. It is specially suited for a dry and firm soil, which is intended to be transported by wagons. Though excellent, this apparatus is liable to stop the dredging, for it has to wait for wagons to charge. The dredging quantity is, therefore, said to be reduced to $\frac{6}{7}$ that of a barge-loading dredge of similar construction and of equal capacity.

The rubber belt conveyor, by which muddy or even liquid material can be transported, has been introduced recently. The apparatus is formed of a steel frame carrying a great number of rollers, formed of steel tubes. On these rollers runs a heavy rubber belt, made especially for the purpose, and the rollers are carried in improved dirt-protected, balanced bearings. A small belt, about 120 ft. long, can be supported entirely from the dredge. Some conveyors are so constructed that they can revolve and thus be used on either side of the dredge.

Floating pipes, or a combination of floating and land pipes, are used for discharging the dredged material into the sea or on shore, by pumping. The material raised by the buckets is discharged directly from the upper tumbler into a reservoir containing bar-screen for breaking up the material and preventing large stones or boulders from entering the pipe. An independent centrifugal pump delivers a large volume of water through a series of jets, pulverizing and breaking up the material, which can then be dealt with by the discharge pump. Water is also introduced by an inlet from the sea to the bottom of the reservoir and opposite the inlet to the discharging pump. The discharge pipes are led over the deck and connected to the floating pipe line by a flexible joint. The floating pipes are supported by floaters, and connected with flexible joints to allow a free motion to the dredge and to each floater. When the dredged spoil is to be discharged into the sea, the end of the discharge pipe should be moved so as to distribute the spoil over the site. This motion can be obtained by chains and anchors, a hydraulic deviator or propellers. But when the spoil is to be delivered on shore, the floating pipe line is connected to land pipes laid upon the beach or supported on a trestle. The length of such pipes is commonly from 1 000 to 2 000 ft., but may be increased to 6 000 ft. The writer will not enter into the details of such mechanisms, as they belong properly to the pump dredge.

Hopper and Hopper Door Winches.—The self-loading dredge usually has a bottom hopper well. The well is rectangular in plan, and in the longitudinal section; but in the transverse section it sometimes tapers toward the bottom. This is to make the door small so as to be easily manageable. It frequently occurs that the spoil does not get out. On this account the sides of the well are generally made nearly vertical. The doors are usually built of iron plates with wooden lining in two thicknesses, stiffened around the edge with angles. Each door has two or three stout iron hinges and two eye bolts to be hung on two chains. The two chains are attached to a balance, which is suspended to a chain passing through a pulley. This chain has a wedge holder; a wedge with hardened faces bears on a proper chock for sustaining the load on the door chains during the operations of loading and transporting. All chains above the wedges are connected to an iron bar worked by steam or hydraulic power. Sometimes the doors are actuated by a steam screw gear, so arranged that they need be only partly opened, when desired, which allows the spoil to be discharged in shallow water.

Mooring Means.—Anchor spuds are rarely used on some non-propelling dredges working in a narrow canal. But for working in an open place, where there is abundance of room to move the dredge from side to side, the spuds are dispensed with and anchors are generally resorted to.

(*a*) *Maneuvering Winches.*—For a long time, there has been used on the middle of the deck, a simple but strong windlass, around which the mooring chains wind. But this is inconvenient since, in case of damage, the swinging motion cannot be continued. On the contrary, the use of two separate winches, one on the stern, and one on the bow, has the advantage that the dredging can be proceeded with even when one of the winches gets out of order. Of course, the former needs less labour; but, a certain number of the crew being necessary on deck for other work may also be used for watching the winches. Moreover, several separate winches, being able to treat a great number of chains at the same time with different speeds, are thought to be advantageous.

Formerly there were many dredges which had their winches driven by the main engine. Some authorities were of the opinion that it was preferable for the head and tail chains to be worked by separate engines; but the quarter chains were best connected with the main engine. On a perfectly level bottom, with soil of uniform quality, the action of the winches, for side chains, will coincide with the buckets; and, as there is a close relation between the two operations, these winches are more economically worked by the main engine, both as regards power and attendance. The tail winch, from which the chain is paid out on the brake during the operation of dredging, and which is driven rapidly in taking in the tail chain, is advantageously worked by separate steam cylinders. However, as a perfectly level bottom never exists in harbours, docks or rivers, the motion of the buckets and chains must vary considerably, and should be independent in their action; separate winches being advisable, not only to meet this irregularity, but also for manipulating the vessel when not dredging. Yet the writer is of the opinion that in a small non-propelling dredge all movements should be effected by the main engine, using friction clutches, arranged so that it will be possible to put each mechanism in or out of gear independently, or to go ahead or astern, reversing gear being provided.

(*b*) *Anchors and Chains.*—Six anchors and six chains are used for dredging. The head anchor is usually larger than the tail anchor, except in a stern-well dredge, which has two similar anchors. The other anchors are smaller than these, being used only for quarter mooring. The chains, all of short links, should be of lengths to suit the widths of the channel to be dredged, respectively. The two fore chains have commonly a greater diameter than the aft. All chains should be provided with swivels to release the torsional force. Short pitch shackles are to be provided for each set of chains, to connect them quickly when broken. For wide cutting, the front chain should be kept afloat by means of buoys or a boat with a water-tight deck, so as to allow the dredge to describe a great arc. When the chain is small and the site is sheltered, a boat is convenient; otherwise buoys are thought better.

Performance.

In the Osaka Harbour Works, four bucket ladder dredges are used for dredging. Two of the dredges, *Asanagi* and *Yunagi*, are non-propelling barge-loading dredges, each with a capacity of 200 tons per hour, and able to cut its own flotation. Their maximum dredging depth was 15 ft., which the writer increased to 22 ft. by lengthening the ladder and augmenting the chain with four buckets. All movements of the dredge are actuated by the engine, by means of friction-clutches, which make it possible to put each mechanism in or out of gear, the shoots only being raised by hand winches. The movement of the bucket chain and the upper tumbler are effected by belt and wheel gearing fitted with a hydraulic clutch. The shaft of the lower tumbler is so constructed as to be able to move 4 in. in a groove at the end of the ladder. The dredging site was open to the sea, so that the dredges were obliged to be towed into refuge during a swell of more than 2 ft. in height. The bottom was usually 0 to 6 ft. deep below low water, and was to be dredged formerly to 9 ft. below low water and to 15 ft. after the modification of the dredge. The upper 2 or 3 ft. of the bed was fine sand, which was very difficult to dredge, next 8 to 10 ft. of mud, and then blue soft clay. The dredged spoil was charged into hopper barges of 100 tons capacity; and four barges were usually served to each dredge. A steam tugboat was used for both dredges when the discharging spot was within 1 600 yd. from the dredges.

The other two dredges, *Shunkai No. 1* and *No. 2*, are hopper dredges of 600 tons capacity, able to cut their own flotation. Their maximum dredging depth is 35 ft. *Shunkai No. 1* is of the bow-well type. while *No. 2* is of the stern-well type. Each has two steam winches for mooring chains, one at the bow and the other at the stern. It has also a steam winch for hoisting the ladder, and a dynamo for electric lamps. The bucket chain is driven by shafting in Dredge *No. 1* and by two sets of pitch chains in Dredge *No. 2*. The dredges were used where the depth changed from 6 to 28 ft., to dredge to their maximum depth. They were worked whenever the waves did not exceed 2½ ft. in height; though the dredges can work in a swell greater than that, but the barges, all being of 100 tons capacity, are not large enough to resist the wave action. The nature of the bed was fine sand, 2 to 3 ft. in thickness, where the original depth was 6 to 12 ft., and mud where the bed was deeper. At 20 to 24 ft. below low water there was found a soft blue clay. The spoil was usually charged into hopper barges; but before sunrise, and after sunset, or when waves were too high to use the barge, the spoil was loaded into the hopper of the dredge. Eight to ten barges were used for each dredge. A steam tugboat was used for each dredge when the transporting distance was not great; but three tugs were often used for both dredges when the depositing site was distant 1 200 yd or more.

Cost of Transportation.—As may be seen in Table 26, some of the dredged material is transported by the dredges themselves. Thus, 2 152 hours 35 min. are spent for the transportation. If we suppose the average rate of expense is paid for the whole number of working hours, the cost of transportation will be 27.8 sen per tsubo, or 1.7 cents per cu. yd., and the true dredging cost will become 53.3 sen per tsubo, or 3.33 cents per cu. yd.

The transportation distance is from 400 to 2 000 yd. Usually, the dredged material is conveyed by tugs and hopper barges.

TABLE 23.—PERFORMANCE OF THE STATIONARY DREDGES, *Asanagi* AND *Yunagi*, COMBINED.

Fiscal year.	Number of days.	Number of working hours.	Time lost, due to: Steaming.	Going to the site.	Shifting moorings.	Weather.	Repairs.	Going to the refuge.	Waiting for barge	Cleaning.	Other causes.	Total.	Dredging hours.	Ten tsubo barge-loading: Number.	Quantity. Tsubo.	Small barge-loading: Number.	Quantity. Tsubo.	Total quantity dredged. Tsubo.	Average dredged quantity per working hour. Tsubo.	Average quantity per dredging hour. Tsubo.
		h. m.	h. m.	h.m.	h. m.	h. m.	h.	h.m.	h. m	h. m	h. m.	h. m.	h. m.							
1898......	173	1 916 00	312 00	3 30	114 20	13 50	54 40	....	217 20	201 30	8 40	925 50	990 10	223	2 230.0	3 478	6 738.25	8 968.25	4.68	9.06
1899......	704	8 110 50	826 20	21 00	317 50	543 50	2 138 00	5 10	275 45	414 50	88 20	4 631 05	3 479 45	3 902	39 020.0	1 835	3 861.50	42 881.50	5.29	12.32
1900......	702	8 863 40	908 00	.. ..	250 15	607 05	2 579 35	....	....	570 47	511 43	5 427 25	3 436 15	5 264	52 640.0	...	....	52 640.0	5.57	15.32
1901.....	704	9 192 20	1 093 30	.....	307 25	743 05	2 015 55	....	2 40	597 25	411 25	5 171 25	4 020 55	6 624	66 240.0	160	320.0	66 560.0	7.24	16.55
1902.....	702	9 237 30	906 50	.....	164 00	694 15	1 485 50	....	8 30	742 50	642 50	4 645 05	4 592 25	8 501	85 010.0	518	1 036.0	86 046.0	9.31	18.74
1903	706	9 126 00	1 073 20	.....	196 55	603 30	1 598 50	....	26 10	758 25	240 10	4 497 20	4 628 40	9 839	98 390.0	67	180.0	98 570.0	10.80	21.30
Total.....	3 691	46 446 20	5 120 00	24 30	1 350 45	3 205 35	9 872 50	5 10	530 25	3 285 47	1 903 08	25 298 10	21 148 10	34 353	343 530.0	6 058	12 135.75	355 665.75	7.66	16.82
Average per dredge per day..........		12 25	1 23	.....	0 22	0.52	2 41	0 00	0 09	0 53	0 31	6 51	5 44	....	93.07	.....	3.29	96.36	.....	......
Percentage......		100.00	11.02	0.05	2.91	6.91	21.26	0.01	1.14	7.07	4.10	54.47	45.53	....	....	.....	....	....	.....	......

1 tsubo = 8 cu. yd.

The amount is measured by barge, and is calculated to be 1¼ times place measurement.

TABLE 24.—RUNNING EXPENSES FOR *Asanagi* AND *Yunagi*, COMBINED.

Fiscal year.	Number of days.	LABOUR.					MATERIALS.					Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
		Number of crew.	Salaries. Yen.	Boarding. Yen.	Premium. Yen.	Total. Yen.	Coal used. Pounds.	Cost of coal. Yen.	Oil etc. Yen.	Other expenses. Yen.	Total. Yen.					
1898..	327	2 576	1 397.105	....	....	1 397.105	217 000	787.692	300.176	446.431	1 534.299	1 155.644	7 646.407	3 823.203	15 556.658	173.5
1899..	730	5 737	2 628.200	634.100	....	3 262.300	589 250	2 163.100	814.843	1 117.971	4 095.914	5 691.845	15 292.813	7 646.407	35 989.279	83.9
1900..	730	6 582	3 044.330	827.360	1 398.906	5 270.596	590 000	2 020.090	962.707	952.286	3 935.083	10 090.079	15 292.813	7 646.407	42 234.978	80.2
1901...	730	6 531	3 017.397	805.670	655.545	4 478.612	705 200	2 916.598	720.734	668.548	4 305.880	10 904.284	15 292.813	7 646.407	42 627.996	64.0
1902..	730	6 604	2 977.680	820.240	2 029.942	5 827.862	700 000	2 206.550	504.317	261.255	2 972.122	9 331.380	15 292.813	7 646.407	41 070.584	47.7
1903..	732	6 658	2 971.678	824.640	2 472.481	6 268.799	795 800	1 932.295	618.665	279.305	2 830.265	9 287.028	15 292.813	7 646.407	41 325.312	41.9
Total..	3 979	34 688	16 036.390	3 912.010	6 556.874	26 505.274	3 597 250	12 026.325	3 921.442	3 725.796	19 673.563	46 460.260	84 110.472	42 055.238	218 804.807	61.5*
Average per dredge per day.........		8.7	4 030	0.983	1.684	6.661	904	3.022	0.986	0.936	4.944	11.677	21.139	10.569	54 985	.....
Percentage...		....	7.34	1.79	2.98	12.11	....	5.50	1.79	1.70	8.99	12,24	38.44	19.22	100.00	.....

The fiscal year begins April 1st. The number of days in Table 23 does not include holidays and those during which the dredge was used for other purposes.

The dredge *Asanagi* commenced work Oct. 18th, and *Yunagi* Oct. 27th.

1 yen = 50 cents.

The cost of transportation is not included in Table 24.

* 61.5 sen per tsubo = 3.84 cents per cu yd.

TABLE 25.—EXPENSES FOR HOPPER DREDGES *Shunkai No. 1* AND *No. 2*, COMBINED.

Fiscal year.	Number of days.	LABOUR.					MATERIAL					Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
		Number of crew.	Salary. Yen.	Boarding. Yen.	Premium. Yen.	Total. Yen.	Coal used. Pounds.	Cost of coal. Yen.	Oil, etc. Yen.	Other. expenses. Yen.	Total. Yen.					
1900..	491	14 125	6 450.048	1 810.810	....	8 260.858	1 940 000	6 728.850	1 458.189	792.915	8 979.954	14 923.583	39 784.284	19 892.142	91 840.821	1 30.1
1901...	730	25 219	10 627.067	3 127.870	3 092.930	16 847.867	5 875 000	24 246.825	2 092.203	1 016.825	27 355.853	25 553.739	56 206.215	28 103.108	154 066.782	51.6
1902...	730	22 351	9 699.629	2 811.630	6 531.117	19 042.376	5 155 000	15 898.400	1 314.003	500.479	17 712.882	34 743.034	56 206.215	28 103.108	155 807.615	46.9
1903...	732	20 462	8 929.477	2 564.250	4 437.641	15 931.368	5 885 000	14 249.270	1 479.186	558.490	16 286.946	31 861.951	56 206.215	28 103.108	148 389.588	56.5
Total..	2 683	82 157	35 706.221	10 314.560	14 061.688	60 082.469	18 855 000	61 123.345	6 343.581	2 868.709	70 335.635	107 082.307	208 402.929	104 201.466	550 104.806	57.0*
Average per dredge per day..........		30.6	13.308	3.845	5.241	22.394	7 028	22.782	2.364	1 069	26.215	39.911	77.675	38.838	205.033	....
Percentage...	....		6.49	1.88	2.55	10.92	....	11.11	1.16	0.52	12.79	19.47	37.88	18.94	100.00	....

The fiscal year begins April 1st. The number of days in Table 26 does not include holidays and those during which the dredges were used for other purposes.

Dredge No. 1 Commenced work July 4th, and No. 2 August 17th, 1900.

1 yen = 50 cents.

Expenses due to tugs and barges are not included in Table 25.

* 57 sen per tsubo = 3.56 cents per cu. yd.

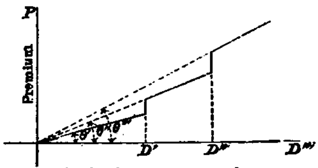
Cost of Plant

5 Steam tugs, each of 33 tons	81 265.80 yen
26 Wooden hopper barges, each of 80 cu. yd.	295 651.80 "
10 Steel hopper barges, each of 80 cu. yd.	160 000.00 "

In 1901 four of the wooden barges were converted into pontoons for floating cranes.

The running expense will be seen in Table 27.

Premium Rate.—A premium proportional to the dredged quantity was awarded to the crew. At first an appropriate monthly standard amount of work was assigned to each dredge, tug and barge, respectively. Then a premium was paid only for the quantity of work which was done after that standard had been reached. Afterward the premium was discontinued be-



Quantity dredged or transported per month

Fig. 18.

cause the crew remained idle when the amount of work was sure not to reach the standard. The rate now used is directly proportional to the dredged amount, as

$$P = KD,$$

where P = premium,

D = quantity dredged or transported,

K = constant, varying with D.

Thus, $K = \tan.\theta'$, when $D \not> D'$.

$= \tan.\theta''$, when $D' < D \not> D''$.

$= \tan.\theta'''$, when $D > D''$.

D' and D'' are certain limits.

Now, taking P in sen and D in tsubo, we have the following values of K respectively within specified limits of D' and D''.

TABLE 27.—Cost of Transportation (Tugs and Hopper Barges).

Fiscal year.	Vessel.	Labour. Salary. Yen.	Labour. Boarding. Yen.	Labour. Premium. Yen.	Labour. Other expenses. Yen.	Labour. Total. Yen.	Materials. Coal. Quantity used. Pounds.	Materials. Coal. Cost. Yen.	Materials. Oil, etc. Yen.	Materials. Other expenses. Yen.	Materials. Total. Yen.	Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Quantity transported. Tsubo.	Unit cost, in sen per tsubo.
1899	Tug....	2 762.388	757.600	....	....	3 519.988	937 100	3 347.808	601.770	491.808	4 441.386	3 457.049	3 502.193	1 751.097	16 701.413		42.0
	Barge..	2 752.285	....	....	2 255.155	5 007.440	....	....	707.304	346.558	1 053.862	12 902.815	24 076.867	12 038.434	55 078.918		138.6
	Total...	5 514.373	757.600	....	2 255.155	8 527.128	937 100	3 347.808	1 309.074	838.366	5 495.948	16 380.364	27 579.060	13 789.531	71 780.331	39 731.0	180.6
1900	Tug....	5 577.681	1 695.740	1 371.746	....	8 645.167	[illegible]	7 947.750	1 299.071	886.412	10 133.233	5 944.717	5 864.080	2 932.040	33 519.237		28.4
	Barge..	9 736.077	....	561.830	2 149.665	12 447.572	....	....	1 397.624	572.917	1 900.541	21 781.844	45 565.180	22 782.590	104 477.727		88.6
	Total...	15 313.758	1 695.740	1 933.576	2 149.665	21 092.739	2 365 400	7 947.750	2 696.695	1 459.329	12 033.774	27 726.561	51 429.260	25 714.630	137 996.964	117 934.0	117.0
1901	Tug....	7 741.295	2 342.060	4 329.283	....	14 412.638	3 788 200	15 323.585	1 536.046	829.158	17 688.789	6 736.853	8 126.580	4 063.290	51 028.160		16.2
	Barge..	15 064.610	....	2 344.320	2 574.635	19 983.565	....	....	990.502	684.363	1 674.865	29 152.184	42 631.847	21 315.923	114 758.384		34.1
	Total...	22 805.905	2 342.060	6 673.170	2 574.635	34 396.203	3 788 200	15 323.585	2 526.548	1 513.521	19 363.654	35 889.037	50 758.427	25 379.213	165 786.534	336 127.0	49.3
1902	Tug....	7 807.030	2 353.690	4 993.170	....	15 153.890	3 822 200	11 860.583	956.098	513.459	13 330.140	11 068.615	8 126.580	4 063.290	51 742.515		13.7
	Barge..	15 007.690	....	8 526.380	1 767.080	25 301.150	....	....	805.068	778.250	1 583.318	21 499.656	41 165.180	20 582.590	110 131.894		29.2
	Total...	22 814.720	2 353.690	13 519.550	1 767.080	40 455.040	3 822 200	11 860.583	1 761.166	1 291.709	14 913.458	32 568.271	49 291.760	24 645.880	161 874.409	377 310.0	42.9
1903	Tug....	7 961.610	2 350.880	4 367.801	....	14 680.491	4 059 000	9 905.365	1 062.174	525.583	11 493.112	9 607.600	8 126.580	4 063.290	47 971.078		14.1
	Barge..	15 048.200	....	7 584.360	1 170.120	23 802.680	....	....	886.000	806.632	1 692.632	22 887.924	41 165.180	20 582.590	110 131.006		32.3
	Total...	23 010.010	2 350.880	11 952.161	1 170.120	38 483.171	4 059 000	9 905.365	1 948.174	1 332.215	13 185.744	32 495.524	49 291.760	24 645.880	158 102.079	341 195.0	46.4
Entire Total.	Tug....	31 849.904	9 499.970	15 062.000	....	56 411.874	14 972 900	48 385.081	5 455.159	3 246.420	57 026.660	36 844.834	33 746.018	16 873.007	200 962.385		16.6
	Barge..	57 608.862	....	19 016.890	9 916.655	86 542.407	....	....	4 716.498	3 188.720	7 905.218	108 223.923	194 604.254	97 302.127	494 577.929		40.8
	Total...	89 458.766	9 499.970	34 078.890	9 916.655	142 954.281	14 972 900	48 385.081	10 171.657	6 435.140	64 991.878	145 068.757	228 350.267	114 175.134	695 540.317	1 212 297.0	57.4*
Percentage.....		12.86	1.37	4.90	1.42	20.55	....	6.96	1.46	0.92	9.34	20.86	32.83	16.42	100.00	....	......

The fiscal year begins April 1st. The figures in the columns, "Other expenses," under "Labour," represent the wages of assistant workmen.
1 tsubo = 8 cu. yd. 1 yen = 50 cents. *57.4 sen per tsubo = 3.59 cents per cu. yd.

TABLE 26.—PERFORMANCE OF THE HOPPER DREDGES, *Shunkai No. 1* AND *No. 2*, COMBINED.

Fiscal year.	Number of days.	Number of working hours.	Time Lost, Due to														Dredging hours.	Self-loading.		Barge-loading.		Total quantity dredged. Tsubo.	Average quantity dredged per working hour Tsubo.	Average quantity dredged per dredging hour. Tsubo.
			Steaming.	Going to the site.	Shifting mooring.	Taking off and up mooring.	Weather.	Repairs.	Going to the refuge.	Transportation of spoil.	Coaling.	Waiting for barge.	Feeding water.	Cleaning.	Other causes.	Total.		Number.	Quantity. Tsubo.	Number.	Quantity. Tsubo.			
		h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.							
1900	474	5 261 30	369 45	33 30	273 15	114 10	659 15	1 606 35	16 30	154 00	2 10	165 05	......	279 35	123 35	3 812 25	1 449 05	113	6 780	6 383	62 830	70 610	13.42	38.12
1901	704	9 398 35	760 40	48 40	391 05	37 40	788 25	1 841 50	6 55	743 05	6 30	98 15	4 30	326 35	91 00	4 940 10	4 458 25	695	41 640	25 722	257 080	298 720	31.80	67.03
1902	702	9 199 40	764 10	43 20	249 50	......	841 25	1 797 40	......	685 45	.....	63 00	......	229 40	11 30	4 686 20	4 513 20	822	50 490	28 192	281 920	332 410	36.13	73.65
1903	706	8 719 30	648 30	27 40	261 10	......	755 00	2 393 05	......	417 55	.....	72 30	......	231 55	263 50	5 065 35	3 653 55	527	31 590	23 104	231 040	262 630	30.12	71.88
Total.	2 586	32 579 15	2 541 05	153 10	1 105 20	151 50	2 989 05	7 640 10	23 25	2 000 45	8 40	398 50	4 30	1 067 45	419 55	18 504 30	14 074 45	2 157	130 500	83 401	833 870	964 370	29.60	68.52
Average per dredge per day.		12 36	0 59	0 04	0 26	0 03	1 09	2 57	0 01	0 46	.....	0 09	......	0 25	0 10	7 09	5 27	......	50.46	......	322.46	372.92	......	......
Percentage.		100.00	7.80	0.47	3.39	0.47	9.17	23.45	0.07	6.15	0.03	1.22	0.01	3.28	1.29	56.80	43.20	......	......	......	......	......	......	......

1 tsubo = 8 cu. yd.
The amount is measured by barge, and is calculated to be 1¼ times place measurement.

TABLE 28.—Value of K.

Crew.	PRIESTMAN'S DREDGE.			200-TON DREDGE.			600-TON DREDGE.			TUG.			BARGE.		
	$D \ngtr 400.$	$400 < D \ngtr 800.$	$D > 800.$	$D \ngtr 2\,000.$	$2\,000 < D \ngtr 4\,000.$	$D > 4\,000.$	$D \ngtr 10\,000.$	$10\,000 < D \ngtr 20\,000.$	$D > 20\,000.$	$D \ngtr 8\,000.$	$8\,000 \quad D \ngtr 16\,000.$	$D > 16\,000.$	$D \ngtr 800.$	$800 < D \ngtr 1\,600.$	$D > 1\,600.$
Captain	.....	.....	.....	.....	.....	.....	0.18	0.21	0.24	0.17	0.20	0.24	.....	.....	.....
Engineer	2.2	2.7	3.1	0.78	0.94	1.09	0.22	0.26	0.30	0.17	0.20	0.24	.....	.....	.....
Mate and second	.....	.....	.....	.....	.....	.....	0.11	0.13	0.15	.....	.....	.....	.....	.....	.....
Boatswain and chief fireman	.....	.....	.....	.....	.....	.....	0.07	0.08	0.09	.....	.....	.....	.....	.....	.....
Steersman and oiler	0.8	0.9	1.1	0.16	0.19	0.22	0.04	0.05	0.06	0.07	0.08	0.10	.....	.....	.....
Sailor, fireman and cook	0.8	0.9	1.1	0.12	0.15	0.18	0.04	0.04	0.05	0.05	0.06	0.07	.....	.....	.....
Boy	.....	.....	.....	.....	.....	.....	0.02	0.02	0.02	0.03	0.03	0.03	.....	.....	.....
Labourer	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.70	0.80	0.95