PUMP DREDGE

By T. Kobayashi.

The pump dredge can excavate non-cohesive material such as sand or gravel, semifluid substance such as mud or silt, and other substances, which can be diluted with water into a more or less homogeneous solution, such as vegetable soil, clay or soft chalk. The material raised can be delivered directly at a distance of 2,000 feet or more by the force of the pump, so that the dredge may be used economically for reclaiming land. The pump will raise and carry off stones or other hard substances of any size that will get into the suction pipe.

It is quite uniform in delivery and can work even in a rough sea, where other dredges can not be safely employed. It has special facilities to serve as a hopper dredge, for the dredging apparatus is handy and the hull is appropriate for a steamer. It can raise the dredged material just to the required height and not too high as is usual in the other dredges. It occupies less space while working and can afford good means of salvage. Moreover the wear and tear of the dredging apparatus is very small. This dredge is most economic in dredging sand, whence its name of "sand pump dredge." But the pump does not work well in cohesive substances, unless furnished with a disaggregating apparatus. The dredge, if not specially designed, excavates a number of small trenches, so that it is not suited for regular plain cutting. Its chief disadvantage is that it lifts a large quantity of water with the dredged material, and consequently much of the power applied is wasted. However, when the dredge is employed for reclaiming low lands, the pressure of water is necessary for distributing the dredged material over a large area, while the water is running.

Hull.

What the writer has said elsewhere about the ladder dredge, may also be applied to the pump dredge. But the site where the pump dredge may be effectively employed, is much exposed and heavy, being commonly an estuary or entrance channel of a river; so that the dredge is usually a

Table I.
Showing Comparative Proportions of Various Pump Dredges.

Dredge		Ukishima	Seine	Delta	Beta	Dunkirk	Shinyi	Boulogne II.	.. ....	Calais I	Bayonne	Beaver	Agues	Brancker
Destination		Osaka	Seine	Missis-sippi	Missis-sippi	Dunkirk	Osaka	Boulogne	Loire	Calais	Adour	Natal Govern-ment	Natal Govern-ment	Mersey
Length L.		98.′5.″	141.′0.″	175.′0.″	214.′0.″	137.′9.″	147.′7.″	154.′10.″	157.′5.″	159.′5.″	182.′0.″	154.′11.″	280.′ 0.″	320.′ 0.″
Breadth B.		24.′7.″	26.′2.″	38.′0.″	58.′0.″	27.′3.″	28.′2.″	29.′6.″	28.′2.″	27.′11.″	29.′2.″	30.′ 0.″	44.′ 0.″	46.′10.″
Depth D.		10.′10.″	11.′10.″	8.′4.″	6.′11.″	12.′6.″	13.′7.″	11.′10″	11.′0.″	11.′10.″	12.′6.″	12.′ 0.″	18.′ 9.″	20.′ 0.″
Draught	Light D_0	5.′0.″	6.′7.″	4.′6.″	4.′0.″	8.′2.″	11.′0.″	8.′2.″	7.′3.″	8.′10.″	9.′10.″	....	....	....
	Loaded D_1					11.′6.″	13.′2.″	10.′0.″	9.′2.″	10.′6.″	11.′6.″	....	....	16.′ 6.″
Dredging Depth Dd		30.′0.″	34.′5.″	20.′0.″	36.′0.″	36.′0.″	35.′0.″	49.′2.″	29.′6.″	38.′0.″	39.′4.″	40.′ 0.″	40.′ 0.″	47.′ 0.″
Dredging capacity in tons per hour Cd.		500	980	1,000	2,000	295	560	327.	490.	340.	690	1,000.	4,000.	4,000.
Hopper capacity in tons Ch.		0	0	0	0	392	500	744.	410.	440.	580	500.	2,000.	3,000.
I. H. P.		400	600	1,000	1,850	160	300	300.	500.	210.	450.	1,000.	3,500.	....
Suction Pipe	Number	1	2	1	2	1	1	1	1	1	1	2	1	1
	Diameter	20.″	24.″	34.″	33³/₄″	20.″	20.″	2.3.″	23⁵/₈″	....	....	18.″	48.″	36.″
Number of Pumps.		1	1	1	2	1	1	1	1	1	1	1	2	2
Number of Propellers.		0	0	0	0	1	1	1	1	1	1	2	2	2
Velocity when loaded in knots		0	0	0	0	5.	9.	6	8.5	6.	8.	9.75	9.	9.
L ÷ Dd.		3.28	4.10	8.75	5.94	3.83	4.22	3.15	5.34	4.19	4.63	3.87	7.00	6.81
B ÷ L.		0.25	0.19	0.22	0.27	0.20	0.19	0.19	0.18	0.18	0.16	0.19	0.16	0.15
D ÷ L.		0.110	0.084	0.048	0.032	0.091	0.092	0.076	0.070	0.074	0.069	0.077	0.067	0.063
$D_1 \div D_0$		0.051	0.047	0.026	0.019	1.41	1.20	1.22	1.26	1.19	1.17	....	....	....
$D_1 \div$ L.						0.083	0.089	0.065	0.058	0.066	0.063	....	....	0.052
Ch ÷ Cd.		0	0	0	0	1.33	0.89	2.28	0.84	1.29	0.84	0.50	0.50	0.75
I.H.P. ÷ Cd.		0.80	0.61	1.00	0.93	0.54	0.54	0.92	1.02	0.62	0.65	1.00	0.88	....

sea-going ship with a hopper, to which this dredge is best suited. For river or canal works some dredges are made so as to deliver the dredged material directly on shore, or to discharge it into barges; they have light hulls with flat bottoms.

The drawbacks of the hopper dredge will not be seriously felt in the pump dredge, because its dredging apparatus is very handy and its mooring is sufficient with one anchor instead of six. The only disadvantage is that the work becomes intermittent, a long time being spent in navigating and discharging; but this can not be avoided in a rough sea, where barges can not be moored along the dredge.

In the above table, it is to be seen that the proportions of the hull of the self-loading dredges are similar to those of the ladder dredges, except that the hopper wells are smaller in capacity. The reason is that some pump dredges have great dredging capacities up to 4,000 tons per hour, which can not be found in the ladder dredge, and it is not economical to build a large dredge with a hopper having such a relation to the dredging capacity as is usual in smaller dredges. In some cases, however, the hopper is made very large, which is especially necessary to make the light sand easily settle in the well.

In many of the earlier hopper dredges most of the machinery was placed near the stern, the result of this being to give excessive light draught. The arrangement has been discarded in all the recent large dredges. The machinery is now often placed amidships and hopper wells are located forward and aft of it. Either side of the hopper well often serves as an air chamber, which allows the trim to be adjusted by admitting water into it. The hull is sometimes composed of two barges or pontoons, which allows the dredge to pass through a narrow canal or lock. The propelling speed has recently increased up to ten knots per hour and twin screws have come to prevail. Some dredges are used as ice-breakers.

Engine and Boiler.

Engine:—

The direct-acting compound or triple expansion surface condensing engine is generally used for a common dredge. High speed of revolution is specially desirable for a centrifugal pump; and this is more readily obtained with a triple than a compound engine. The ratio of I. H. P. to the dredging capacity is from 0.6 to 1.0, which is quite the same as that of the self-propelling barge-loading ladder dredge. In pump dredges, as may be seen in Table I, two engines are rarely used to propel twin screws with only one dredging apparatus, which is generally the case in ladder dredges. This is why the I. H. P. of a common pump hopper dredge is much less than that of a ladder one. But some recent American pump dredges have separate engines both for pumps and propellers to be driven simultaneously, as will be seen in Table II.

Table II.—
American Hopper Dredges.

	Dredge	Gedney	Gen. Gillespie and Burton.	Gen. Abbot and Cumberland.	Manhattan and Atlantic.	Chinock.
	Destination	New York	Lake Michigan and Lake Erie.	Charleston.	New York.	Columbia River.
Hull	Length	150.′ 0.″	166.′ 0.″	185.′ 0.″	274.′ 0.″	445.′ 0.″
	Breadth	36.′ 4.″	38.′ 0.″	40.′ 0.″	47.′ 6.″	49.′ 0.″
	Depth	21.′ 6.″	19.′ 0.″	22.′ 0.″	25.′ 0.″	41.′ 6.″
	Light Draught	16.′ 0.″	9′. 1.″	12.′ 4.″	—	16.′ 10.″
	Loaded Draught	19.′ 0.″	—	18.′ 4.″	—	25.′ 4.″
	Hopper Capacity	Cub. yds 735.	935.	1,000.	2,125.	3,600.
Propelling Engine	Number	2.	2.	1.	2.	2.
	Size	$\frac{15''-26''}{22''}$	$\frac{15''-30''}{24''}$	22″-44″ / 3[illegible]″	$\frac{22''-44''}{36''}$	$\frac{22\frac{1}{2}-36\frac{1}{2}-60''}{48''}$
	I. H. P.	700.	650.	850.	1,700.	3,420.
Pumping Engine	Number	2.	2.	2.	2.	2.
	Size	15″×20.″	$\frac{12''-22''}{14''}$	$\frac{14''-26''}{18''}$	$\frac{16''-32''}{18''}$	$\frac{13''-20''-33\frac{1}{2}''}{18''}$
	I. H. P.	200.	340.	480.	762.	1,000.
Pump	Number	2.	2.	2.	2.	2.
	Size	15.″	15.″	18.″	20.″	20.″
	I. H. P. (Pumping Engine) / I.H.P. (Propelling Engine)	0.286	0.523	0.565	0.449	0.292

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 from 35 feet depth.	I. H. P. when propelling with a velocity of 9 knots.
"Shinyi" No 1.	260.5	292.8
"Shinyi" No 2.	246.1	287.4

Sometimes the engine is connected with the pump shaft by a friction clutch capable of being adjusted so as to slip, when an obstacle becomes lodged in the pump.

Boiler:—

No particular type is favoured, either watertube or multitubular boilers being used. But the watertube boilers are now generally employed for large dredges.

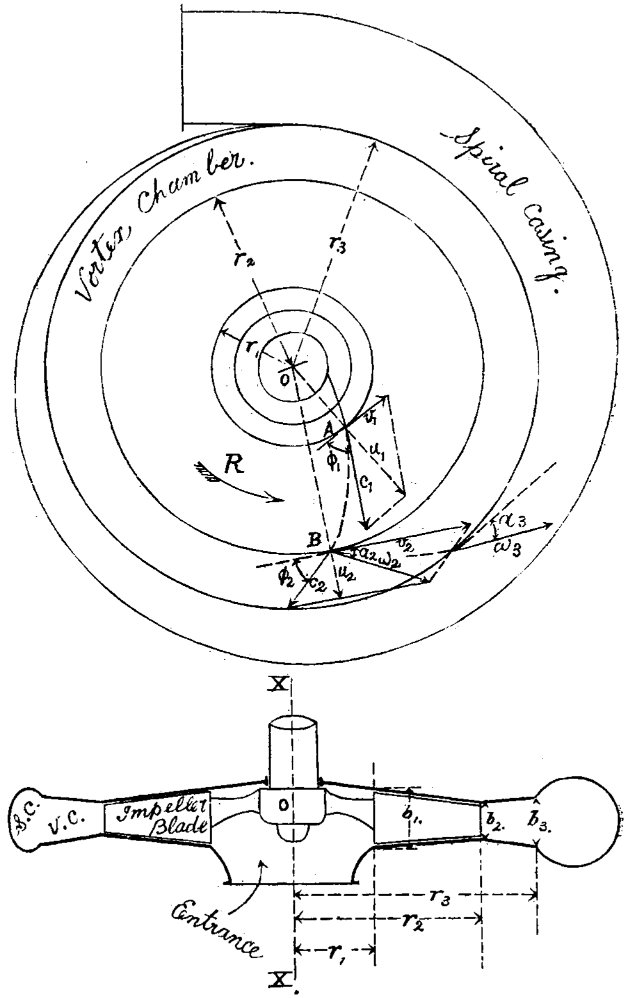
Dredging Apparatus.

In small special works such as well-sinking, pneumatic or hydraulic apparatus is used for excavating sand, mud and loose soil. Sometimes piston pumps were employed for dredging mud, as at Saint Nazaire and Wilhelmshaven; but they are inadequate for dredging sand and other solid materials. On account of constant damage they have never been used unless with a special soft kind of mud. In America pulsometers are often employed for large dredging works. They are simple in arrangement and easy in setting up. But as they are liable to become clogged when large gravel or stone is sucked up, their use is limited to mud and small sand. Moreover the pulsometer is poor in efficiency due to excessive steam consumption. Now nearly all pump dredges are worked by the centrifugal pump, the chief advantages of which are that it has comparatively few working parts, that it has a good efficiency in moderate lifts, that valves are dispensed with and that the action is continuous in one direction so that the dredged material has no opportunity of settling.

Theory of the Centrifugal Pump:—

Special requirements of the centrifugal pump as a dredging apparatus are that it should raise as great a quantity of solid material as possible, that there should be no obstruction throughout the passage and that the pumped material should not settle in the delivery pipe.

In the following figure, AB represents one blade of the impeller, revolving in the direction of the arrow R round the axis XOX of the pump shaft.


Spiral casing.
Vortex Chamber.
r3
r2
r1
O
A
B
R
X
S.C.
V.C.
Impeller Blade
O
b1.
b2.
b3.
r3
r2
r1
Entrance
X.

Let w_1 and w_2 be the absolute velocities of the fluid at the inlet and outlet surfaces of the impeller respectively.

c_1 and c_2 the corresponding velocities relative to the moving blade.

u_1 and u_2 the corresponding radial velocities.

w_3 the absolute velocity of the fluid at the outlet of the vortex chamber.

v_1 and v_2 the velocities of the inner and outer circumferences of the impeller respectively.

ϕ_1 the angle between c_1 and the negative direction of v_1.

ϕ_2 the angle between c_2 and the negative direction of v_2.

α_2 the angle between w_2 and v_2.

α_3 the angle between w_3 and the tangent line to the outer circumference of the vortex chamber.

b_1 and b_2 the widths of the pump at the inlet aud outlet of the impeller, and b_3 the breadth of the pump at the outlet of the vortex chamber.

w_4 the velocity of the fluid in the delivery pipe.

h the height of the dredged fluid to be pumped up.

F the head due to frictional and other hydraulic resistances, expressed in the dredged fluid.

E the efficiency of the pump.

r_2 radius of the outer end of the blade.

r_3 radius of the outer circumference of the vortex chamber.

$b_2 \div b_3 = n.$

$r_2 \div r_3 = m.$

ρ_1 the density of the water.

ρ_2 the density of the dredged fluid.

$$h = \text{actual lift} + \frac{\text{dredging depth} \times (\rho_2 - \rho_1)}{\rho_2}$$

The direction of the flow of fluid before entering the impeller is assumed to be radial; and in order that a direct impact of the fluid on the blade of the impeller may be prevented at the inlet surface, the direction of the relative inflow velocity c_1 should be tangential to the first element of the blade at A.

Then
$$h + F + \frac{w_4^2}{2g} = \frac{1}{g} v_2 w_2 \cos \alpha_2.$$

$$E = \frac{h}{h + F + \dfrac{w_4^2}{2g}} = \frac{gh}{v_2(v_2 - c_2 \cos \phi_2)}$$

$$=1-\frac{g\left(F+\frac{w_4^2}{2g}\right)}{v_2'\,v_2-c_2\cos\phi_2)}$$

The above relation is clearly proved by Dr. Weisbach in "Mechanics of Pumping Machinery." The total loss of head, according to Prof. Inokuty (see Journal of the Society of Mechanical Engineers. Vol. VIII. No12) consists of the following quantities:—

(*a*). The loss of head due to the scouring action of water at the suction mouth and to frictional and other hydraulic resistances of the dredged fluid in the suction pipe up to the inlet of the impeller, expressed by

$$f_1\frac{c_2^2}{2g}$$

(*b*). The loss of head due to frictional and other hydraulic resistances of fluid coming to and moving over the impeller, also expressed by

$$f_2\frac{c_2^2}{2g}.$$

(*c*). The loss of head due to frictional and other hydraulic resistances of fluid moving over the inner surfaces of the pump casing touching to the vanes of the impeller

$$=f_3\frac{w_2^2}{2g}.$$

(*d*). The loss of head in the vortex chamber

$$=f_4\frac{w_2^2}{2g}.$$

(*e*). The loss of head due to the radial velocity of outflow from the vortex chamber

$$=\frac{m^2n^2(c_2\sin\phi_2)^2}{2g}$$

(*f*). The loss of head due to the sudden change of velocity in the spiral casing

$$=\frac{\{m(v_2-c_2\cos\phi_2)-w_4\}^2}{2g}$$

(*g*). The loss of head due to frictional and other hydraulic resistances of fluid in the spiral casing and the delivery pipe

$$=f_5\frac{w_4^2}{2g}.$$

Then

$$F+\frac{w_4^2}{2g}=(f_1+f_2)\frac{c_2^2}{2g}+(f_3+f_4)\frac{w_2^2}{2g}+(f_5+1)\frac{w_4^2}{2g}$$

$$+\frac{m^2n^2(c_2\sin\phi_2)^2}{2g}+\frac{\{m(v_2-c_2\cos\phi_2)-w_4\}^2}{2g}.$$

Put $f'=f_1+f_2.$
$f''=f_3+f_4.$
$f'''=f_5+1.$
$w_4=km(v_2-c_2\cos\phi_2).$

By reduction, we have

$$F+\frac{w_4^2}{2g}=\frac{1}{2g}\{Ac_2^2+a(v_2^2-2v_2c_2\cos\phi_2)\}.$$

where $A=m^2n^2\sin^2\phi_2+f'+f''+m^2\cos^2\phi_2\{(1-k)^2+f'''k^2\}.$
$a=m^2\{(1-k)^2+f'''k^2\}+f''.$

Therefore

$$E=1-\frac{\left(F+\frac{w_4^2}{2g}\right)g}{v_2(v_2-c_2\cos\phi_2)}=1-\frac{Ac_2^2+a(v_2^2-2v_2c_2\cos\phi_2)}{2v_2(v_2-c_2\cos\phi_2)}.$$

$$\frac{dE}{dk}=\frac{2m^2\{1-(1+f''')k\}(v_2-c_2\cos\phi_2)}{2v_2}$$

The efficiency is max. when $k=\frac{1}{1+f'''}$ or $\frac{1}{2+f_5}$.

Next assuming all f to be independent of $c_2\div v_2$ (say z).

$$\frac{dE}{dz}=\frac{d}{dz}\left\{1-\frac{Az^2+a(1-2z\cos\phi_2)}{2(1-z\cos\phi_2)}\right\}$$

$$=-\frac{1}{2}\,\frac{Az(2-z\cos\phi_2)-a\cos\phi_2}{(1-z\cos\phi_2)^2}.$$

Here put $1-z\cos\phi_2=\sin\phi_2'$.

$$\frac{dE}{dz}=-\frac{1}{2}\,\frac{A\cos^2\phi_2'-a\cos^2\phi_2}{\sin^2\phi_2'\cos\phi_2}$$

Equating the result to zero, we obtain the condition for maximum efficiency,.

$$\cos\phi_2' = \sqrt{\frac{a}{A}}\cos\phi_2.$$

$$\text{Maximum } E = 1 - \frac{a\sin\phi_2'}{1+\sin\phi_2'}.$$

Velocities and angles corresponding to the maximum efficiency are:——

$$v_2 = \sqrt{\frac{gh}{E\sin\phi_2'}}.$$

$$u_2 = v_2\tan\phi_2(1-\sin\phi_2').$$

$$w_2\cos a_2 = v_2\sin\phi_2'.$$

$$c_2 = \frac{1-\sin\phi_2'}{\cos\phi_2}v_2$$

$$\tan a_3 = n\tan a_2$$

$$\tan a_2 = \frac{\tan\phi_2(1-\sin\phi_2')}{\sin\phi_2'}.$$

It is also to be seen that the efficiency is increased by diminishing the discharge angle ϕ_2; but the peripherical speed of the impeller being then increased, the mechanical work wasted in shaft friction will become considerable. Both m and n relate to the radial velocity, which is wasted in the spiral casing, and m also to the tangential velocity at the end of vortex chamber. So by making m and n small, we can reduce the loss of head due to the radial velocity and that due to the sudden change of velocity in the spiral casing. However in a large dredge pump, it will require an extravagantly large vortex chamber to make m small. Moreover a high degree of divergence will not be of much practical value, as eddies may set in along the diverging walls.

We have said that the efficiency is maximum, when k of the discharge velocity $k.\ m.\ (v_2 - c_2\cos\phi_2)$ is equal to $\frac{1}{1+fm}$. For economy of dredging, however, a large output is necessary, and hence a high velocity, though wasteful in power, is frequently adopted. The velocity should also vary with the nature of the dredged material, so as to prevent all settlement in the delivery pipe. A velocity of 7—10 feet per second in clay or mud and

10 – 15 feet per second in sand will give good results, but a velocity of 15 – 20 feet is sometimes employed for moderate distances and a large output. The friction in the delivery pipe under such a high speed is a very large proportion of the total head, against which the pump works, amounting to 55 – 75 percent with 500 – 1,000 feet of floating delivery pipe.

Mr. Maltby, made the following experiments about friction in dredge pipes (see "Hydraulic Dredging on the Mississippi River," Transactions, Am. Soc. C. E. Vol. LIV.)

The frictional loss per 100 feet of straight pipe, 33 inches in diameter, discharging 15 – 30 percent of fine sand and mud.

Discharge velocity in feet per second.	Loss of pressure due to friction in pounds per square inch.
18	1.3
19	1.4
21	1.6

The frictional loss per average 100 feet of delivery pipe, consisting of straight pipes, each 100 feet long, connected with rubber joints, each 30 inches in length.

Dia. of pipe in inches	Discharge vel. in feet per sec.	Loss of pressure due to friction in pounds per sq. inch
34	14	1.1
34	16	1.3
33	18	1.5
33	21	2.0

The results though not accurate, serve to suggest roughly how much friction there is in the delivery pipe. It must be noted that the flow in the delivery pipe of a dredge pump is not absolutely steady on account of pulsations produced by the pump and of elasticity of the pipe wall.

The sectional area of the delivery pipe should be

$$S=\frac{Q}{V}.$$

where S = Sectional area of the delivery pipe.

Q = Discharge

$=b_1(2\pi r_1-nt_1 \operatorname{cosec} \phi_1)u_1$

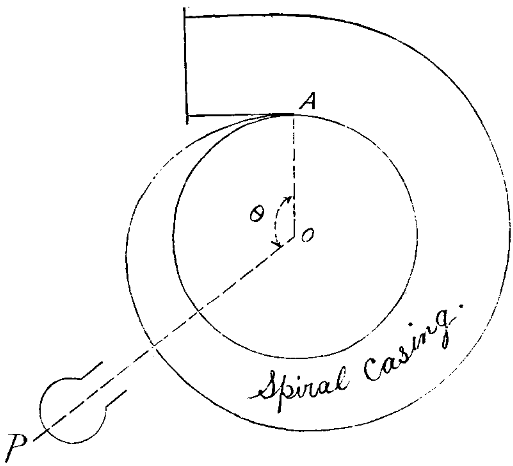
$=b_2(2\pi r_2-nt_2 \operatorname{cosec} \phi_2)u_2$

V = Velocity in the discharge pipe, 7 – 15 feet per second usually.

n = Number of the impeller blades.

t_1 and t_2 = Thickness of the blade at radii r_1 and r_2 respectively.

The spiral casing surrounding the impeller or the vortex chamber, if there be, should smoothly guide the flow issuing from the impeller or the vortex chamber to the delivery pipe without losing much of the energy of the fluid. So the speed of the flow in the spiral casing should be the same as that in the delivery pipe.



Let θ = angle AOP measured from the beginning of the casing A.
S' = sectional area of the spiral casing cut by a radial plane OP.

Then $$S' = S\frac{\theta}{2\pi} = \frac{Q}{V}\,\frac{\theta}{2\pi}$$

To reduce the frictional resistance in the spiral casing, the section is usually made circular or elliptical. If it be circular, the radius r will be expressed by the following relation:—

$$\frac{Q}{V}\,\frac{\theta}{2\pi} = r^2\left(\pi - \sin^{-1}\frac{b_3}{2r}\right) + \frac{b^3}{2}\sqrt{r^2 - \frac{b_3^2}{4}}$$

Next we will treat of the limits of speed of the impeller for no delivery. If the speed is not sufficient, the water may rise to a certain height in the delivery pipe and remain stationary, simply balanced by the velocity of the impeller, while a few extra revolutions will cause the pump to deliver full bore. The discharge will commence when the speed of the outer circumference of the impeller is more than the following value of v_2.

$$h' + F' = v_2^2\left(1 - \frac{r_1^2}{r_2^2}\right)\frac{1}{2g}$$

where h' = height of the bottom of the delivery outlet above the water level.

F' = head due to frictional and other hydraulic resistances when the impeller and water are revolving bodily.

But when the pump is once started, this initial speed may be gradually reduced without stopping the delivery.

$$H + \frac{1}{2g}\left\{Ac_2^2 + a(v_2^2 - 2v_2c_2 \cos \phi_2)\right\} = \frac{1}{g} v_2(v_2 - u_2 \cot\phi_2).$$

$$A \sec^2 \phi_2 u_2^2 - 2av_2u_2 + 2v_2 \cot \phi_2 u_2 + 2gH + av_2^2 - 2v_2^2 = 0.$$

In the above equation, it is clear that in a centrifugal pump, whatever may be the discharge angle ϕ_2, the delivery of water will cease entirely when the speed of the impeller is reduced to

$$v_2 = \sqrt{\frac{2gH}{2 - a}}$$

where $H = h' + \frac{\rho_2 - \rho_1}{\rho_2} \times$ dredging depth.

$a = f_6$ = such a quantity that the head due to frictional and other hydraulic resistances, when the impeller and the dredged fluid are revolving bodily, may be expressed by

$$f_6 \frac{v_2^2}{2g}.$$

The efficiency of the pump, already treated, is that of a pump considered as a conveyor of the dredged fluid, and not as a dredging apparatus. In a dredge pump veloctiy is the only means of transportation. So it may be seen that, within certain limits, the proportion of sand to water or the sand-carrying capacity will increase with the velocity, and not only a larger volume of a mixture of sand and water will be moved in a given time, but the proportion of sand in that volume will be greater. The percentage of solid material to the total pumped fluid varies from zero to 80 percent. Soft material at short distances can be pumped with a small quantity of water, only enough to lubricate it on its passage. But if the material be hard, the percentage may fall off to a small figure. Thus in a pump dredge most of the power is expended in pumping a large quantity of water through a long delivery pipe at a wastefully high velocity and accomplishing the transport of a relatively small quantity of solid material. In general it is said that it is less difficult to transport a large percentage of solid material through a pipe line than it is to introduce it there uniformly and without choking. Therefore the appliances for feeding the dredge uniformly, that is, for disaggregating the material and introducing it into the suction pipe, are of the first importance.

Pump:—

The pump should be of such diameter that the required speed at the periphery of the impeller be obtained with a moderate number of revolutions, which is commonly 150–250 per minute. The pipe of the dredge used for pumping ashore has increased up to 36″ in diameter. But pumps in hopper dredges, not being subject to the necessity of handling the pipes, can be made to any desirable size.

The pump may have a single or double entrance, both of which have their own special advantages. The single entrance is prefered for the reason, that it gives larger passage with easier bend than the double entrance. The double entrance pump, on the other hand, is balanced and consequently does not need a thrust bearing; but it is subject to the objection of a shaft passing through the pipe.

The passage should be large having no sharp bend and should be parallel in the pump toward the periphery, not tapering as is usual in the water pump. This results in slight loss of efficiency, but is necessary to prevent solid matters from sticking in the pump. As great wear occurs on the face of the pump casing, liners of hard steel or chilled cast iron composed of two or more pieces are fitted all over the faces close to the impeller vanes. The casing should be arranged for conveniently being taken to pieces, as sometimes the fan needs sudden renewal owing to dredging up some obstacles, which may stick in the pump and break the fan. The pump is made of cast iron or steel; but steel is preferable. This is not, however, on account of the greater resistance to abrasion of cast steel as compared with cast iron, but it is due to the fact that the cast steel can be worn very thin before breaking.

The most advantageous number of blades that an impeller should have, has been a subject of considerable discussion. The usual number varies from 3 to 7. But it will be difficult to make an impeller with 6 or 7 blades of sufficient strength to withstand the rough work of dredging, without contracting seriously the available area for entrance, while a small number of blades such as 3 will be objectionable on account of loss in efficiency and discharge. As regards the form of the blade, it is impossible to ascertain by calculation what reduces the internal resistances to a minimum, as the resistances can not be represented by analytical expressions. Whatever the curve may be, the absolute path of the fluid should be as smooth as possible, changing the velocity of the fluid gradually. The ordinary simple form is a circular arc having the desired angles φ_1 and ϕ_2.

The impeller is sometimes encased, so as not to permit any slip over the blade edges; but this will cause excessive resistance. The open impeller with adjustable liners has better and smoother working. Of course the liners should be kept close to the periphery of the impeller in order to prevent any overflow there, but too small a clearance will cause great wear. The clearance commonly allowed is about $\frac{1}{4}''$. There are also blades of channel section, which are adjustable sideways so as to be always kept close to the sides of the pump.

The blade is generally of renewable forged steel riveted to cast iron arms. The shaft of the impeller is apt to wear and tear at the bearing point, so that the pump efficiency is reduced due to leakage of air. Generally the shaft is constantly fed with a jet of water under pressure by a special pump to release its friction. It is sometimes fitted with automatic grease plungers, by means of which a supply of grease is constantly fed inwardly through the bearing, precluding sand from working out and cutting the bearing. But as the fluid round the pump is charged with sand, such a remedy for the wear of the shaft can not be thought excellent. There is another device, called Lobnitz patent shaft protector, which consists of a short cylinder of india rubber encircling the shaft and fitting into a groove in the impeller and also into a groove in the pump check. When at work, the vacuum expands the rubber ring outward against the grooves and prevents any inrush of air. When at rest, the head of fluid compresses the ring against the inner sides of the grooves and also shuts off any leakage of sandy water. The shaft is lubricated with oil as usual.

To facilitate the starting of the engine, the top of the pump and also that of the suction pipe are sometimes placed lower than the light draught water line. But this construction, not giving an easy access to the flexible joint of the suction pipe, is not generally adopted; and the top of the suction pipe is placed above the water, and a water pump and a steam ejector are provided for priming.

Suction Pipe:—

The suction pipe is attached to the hull a little above the water line by means of a flexible joint and is suspended by a wire rope passing through sheave-blocks to a hoisting drum worked by a special winch. Its length should be such that the dredge may reach the maximum dredging depth with the pipe at a maximum inclination of 45 degrees. So far as friction is concerned, the pipe should be as large as possible, but a large pipe is objectionable on account of difficult management. So it is commonly made equal in diameter to the delivery pipe. The number of pipes is generally the same as that of pumps employed. But some large dredges, as the "Brancker", "Grumpus", etc. have each one suction pipe for two pumps and on the other hand, Bates' system dredges have two or more suction branch pipes for one pump.

The pipe may be placed at bow or stern or at side according to the requirement. The bow or stern of the hull is sometimes cut open to receive the suction pipe in the well. The bow suction pipe enables the the dredge to cut its own flotation, and is adopted to a dredge without hopper and delivering the dredged material directly on shore, and especially to a dredge with cutting apparatus. The side or stern suction pipe, being loosely connected with the hull, is suited to a hopper dredge without any cutting apparatus. The side suction pipe may be either projected towards the bow or trailed aft. Although the former is much used, yet the writer is of the opinion that the latter is better for dredging non-cohesive substances especially in a heavy sea where the pipe mouth may be much disturbed by lateral motions of the vessel.

The mouthpiece of the suction pipe may have many different shapes. Theoretically speaking, the quantity of solid materials dredged is dependent upon the sectional area of the pipe and also the velocity of the current of water at the pipe mouth. The mouthpiece, therefore, should concentrate and not waste the scouring velocity obtained by the pump. It is clear that every kind of soil seems to prefer a certain shape that suits it best.

The bow pipe, which is usually armed with a cutter, is straight throughout or curved a little at end. The straight one is used with a dredge which works pushing the pipe forwards, and the curved one is employed for deep cutting. The projecting side pipe has its mouth cut square and the trailing side pipe has its mouthpiece shaped like a Japanese tobacco-pipe bowl, both being often armed with gratings. The grating is to keep off large solid materials, which might injure the impeller of the pump. It consists of iron bars fixed at the pipe mouth leaving clearance of 3–7 inches. The grating creates rapidly an accumulation of certain substances and chokes the mouth, so that the pipe must often be raised to take the obstacles away. In practice the pipe should be left open, if possible. A special mouthpiece invented by Mr. Lyster has an area three times that of the pipe, and is perforated at the back with a number of holes, 3″ or 4″ in diameter. This form is certainly good for non-cohesive substances. There is another novel mouthpiece which is applied only to a trailing pipe. It is a great plough-head, having a sharp cutting edge, 10–18 feet in breadth. The mouthpiece, when dragged over the bottom, is filled completely with the soil so as to exclude the surrounding water. The confined soil is then stirred up by jets of water under pressure from a pump and diluted with water let through inlet holes, which can be opened and closed by a valve from the deck. The quantity of the water to be mixed is thus reduced to the smallest percentage that allows the soil to be sucked up by the pump. When used for dredging mud, it enables the pump to raise more than 60 percent of solid material in ordinary circumstances, which can hardly be attained by any other form of mouthpiece. Moreover it ensures regular plain cutting, clearing a channel of its own width. But it can not be advantageously applied to a work in hard soil.

The pipe is of iron or steel, having lateral break-joints and rivets countersunk inside. is raised or lowered by means of a steam or hydraulic lifting apparatus, so that the end may describe a circular arc about a fixed part of the pipe. Its maximum inclination is 45 degrees. A special kind of the pipe is that of Von Schmidt's dredge, which hangs vertically down, the lower part being connected with a telescopic joint and the whole being able to turn around the semicircular bow.

The pipe is connected with the hull by means of a flexible or movable joint. The common joint is a rubber or leather pipe stiffened with internal iron bands. The length of such a flexible joint should be more than twice the diameter of the pipe. Sometimes the joint is used under water, so that in case of an accident air will not get through; but this is not recommendable. The Bates' dredge has its suction pipe furnished with a revolving telescopic joint. The pipe is supported at the hull by two trunnions, which are carried by strong cast steel bracket bearings and are bored out around the centre of rotation. When one suction pipe is employed for two pumps, the top of the pipe is T shaped. This T head has two swivelling gears, which serve as a trunnion, round which the pipe can swing. Besides these, a ball and socket joint is often resorted to. When a dredge is to be worked in a very rough sea, the suction pipe is sometimes provided with another flexible joint at its lower end, so that it can move a few feet in the direction of its axis.

It is important that the flexible or movable joint bears neither tension nor compression. Therefore the side pipe has two eye bars attached to its upper end, which hang in shackles from the sponson and are protected with fore and aft chains fixed to the side of the hull. These chains keep the shackles from having too much play, at the same time making a connection which allows the pipe the necessary motions occasioned by waves. The American bow-pipe dredge has usually a ladder, which is hinged at its upper end to the front of the hull, so as to swing up and down supporting the suction pipe. A preventer wire rope should always be fixed to the pipe, to be used in case of an accident in the lifting apparatus.

Disaggregating Apparatus:—

The disaggregating apparatus is used to loosen cohesive substances, such as clay or sand mixed with mud. The apparatus is, therefore, chiefly attached to a river or canal dredge, which can deliver the dredged material directly on the shore.

(a) Water jet:— In America the water jet apparatus has been used for about forty years. It absorbs much power and is not convenient for disaggregating hard clay. It is said to be very poor in efficiency as compared with rotary cutters, unless the soil is very soft. The perfect arrangement of the jet should be so as to disintegrate the bed in the ray of aspiration, and not to provoke currents which keep the suspended matter away from the ray.
A small number of great jets is not so good as a great number of small jets.

(b) Fixed rake or knife:— The fixed rake or knife is chiefly used with a dredge working in a rough sea and having its suction pipe trailing aft.

(c) Rotating knife:— Screw or helicoidal knives, to which rotary motion is transmitted, are sometimes used. There are also some knives worked by the current caused by the suction of the pump. But such cutters are not adequate for a great performance.

(d) Milling cutter:— The milling cutter is the best apparatus yet devised for disaggregating hard soil. It is composed of a large hollow rotating cutter attached to the extremity of the suction pipe. There are many patents which are however divided into two classes from their forms:— semi-spherical and cylindrical. The semi-spherical cutter is said to be appropriate for non-compact soil, the cutting edges being convergent towards the extremity. It has the shape of a truncated cone and is armed with steel blades and arranged to revolve axially on a steel shaft, which runs from a thrust bearing at the middle of the bow to the end of the pipe. The cutter head is slotted so that materials loosened by the blades may pass inside the cutter head to the mouth of the suction pipe. The cylindrical cutter is used for disaggregating hard soil. It has a disc attached to the lower part of the suction pipe, which turns round like a hollow shaft. The motor of the cutter is generally mounted in the hull or on the pipe ladder. In the latter case vibration causes serious disadvantages, so that it can not be recommended.

The diameter and also the length of the best cylindrical cutter must be three times the diameter of the suction pipe. With such dimensions the current caused by suction is strong enough to overcome the centrifugal force caused by the rotation of the cutter. The cutter wears very rapidly in its lower part, especially at the end of the blades. It is so constructed as to be fit for use again by turning before renewal. In the interior of the cutter the lower part of the suction pipe is telescopically jointed to regulate the velocity of the aspired current. Clutches fixed to the extremity of the suction pipe prevent the cutter from being obstructed by hard substances when at work.

The cutter is usually driven by an independent engine through a mitre gear. The bearings, which are under water, are to be protected chiefly by a constant stream of water fed to the centre of each journal at a pressure of 60 pounds or more from a special pump. Removable covers with hand holes are to be placed over all gears which are under water.

There are some authorities who insist that cutters are very wasteful in the matter of power, as they are up to 10 tons in weight and necessitate engines of some two or three hundred horse power for driving. Power is however relatively cheap and not the most important factor in the efficiency of a dredge. It is reasonable to suppose that any kind of soil, which can be disintegrated with adequate mechanical means, can be worked advantageously by the pump dredge. Several improvements have been made in the direction of accomplishing this object, but still there remains much to be done.

Method of Discharging the Material:—

(a) Self-loading delivery pipe:—

The self-loading delivery pipe is used with a hopper dredge which is employed in the open sea. The pipe starting from the pump, projects upon the deck and is divided into two branches. The branch pipes run horizontally upon the hopper well, leaving a foot-path between them. At the lower part of the pipe there are many hinged doors which can be opened or closed for distributing the solid material equally over the hopper well. The solid matter alone settles in the hopper and the decanting is facilitated by placing a plain or curved plate-iron strainer with small holes beneath each discharge pipe to break the flowing stream. The strainer serves also for the equal distribution of the dredged material. The water, silt and very fine sand in suspension return to the sea over the sides of the hopper in a muddy stream.

It is to be added here, that some pump dredges have very novel discharging doors. Each hopper partition has one discharging aperture in the centre of its bottom, towards which the bottom slopes from all sides. The aperture is furnished with a gate, opened and closed by a rod operated at the top. The gate is very small in area as compared with the ordinary hopper door, so that the sand is cleared out of the hopper by means of water issued through pipes set round the sides of the hopper. Such a construction, however, is applicable only to coarse sand.

(b) Barge-loading delivery pipe:—

The barge-loading delivery pipe is used with a small dredge working in a protected site, especially when the site is far distant from the discharging place. The pipe is of an inverted U shaped bend, the outlet being able to reach the centre of the hopper barge, which is to be loaded.

(c) Long shoot:—

The long shoot is just the same as what the writer has already described in the ladder dredge. The only difference is that the pipe is always closed and the shoot may have any inclination.

(d) Floating pipes, or a combination of floating and land pipes:—

The delivery pipe departs from the hull at the side or stern and is connected with the floating pipe line by means of flexible joints. When the dredged material is to be discharged into the sea, the end of the pipe should be moved so as to distribute the material over the site. But when the material is to be delivered on shore, the floating pipe line is connected with land pipes laid upon the beach or supported on a trestle. The length of such pipes is commonly from 1,000 to 2,000 feet, but may be increased to 6,000 feet or more.

The delivery pipe is 8—25 feet in length and one-eighth inch or more in thickness, and is solid enough to resist its full load, when laid on two or three supports. From the point of durability, the pipe is sometimes built of cast iron; but being very heavy, it is not commonly used. The writer changed the sheet iron pipes fitted in the hull of the dredges "Shinyi" No 1 and No 2 for cast iron ones, which proved to be more durable and economical.

The durability of the pipe is affected by mechanical and also by chemical action. The chief agents are sand and shingle set in motion by the current; but some acids in the dredged fluid play also an important part in the process of disintegration. The erosive power of sand is well illustrated by sand-blast used for sharpening hard steel files. Usually the lower one-third of the pipe is apt to wear soon and the rivets, if used, give away inspite of their countersunk heads; It would be better if the pipe could be built without using rivets, and without increasing its weight. Its life, however, will be prolonged by turning at times.

In America a wooden rectangular caisson is used for supporting the delivery pipe. When the pipe is specially long, two such pontoons are employed laterally one at each end of the pipe. But in Europe, iron or steel pontoons seem to prevail. The common floater consists of two circular cylinders, placed parallel and rigidly connected to each other by angle irons and wooden bearers, upon which is mounted a delivery pipe. One of the pontoons is made a little smaller in diameter than the other, so that the smaller one can be inserted into the other for easy transportation. Such a floater, though it has a great stability, is much affected by winds, currents, and waves. In order to preserve the pipes from the action of winds or waves, they are sometimes submerged as much as two-thirds of their depth. There exists also an elliptical pontoon, through the centre of which the delivery pipe is introduced, the pontoon proper forming an elliptical jacket for the delivery pipe. This form is the one least influenced by winds, waves or currents, and has also an advantage over the circular one in having less draught. The usual length of floaters is 15—100 feet, a longer floater being less affected by waves than a shorter one. A foot-path should be provided upon the pontoon, enabling the men to walk freely along the pipe line.

For every one or two floating pipes, a movable or flexible joint is used according to the flexibility required. There are leather and india-rubber, as well as ball and socket joints now in use. The ball and socket joint is apt to bend up to 10 degrees, while the flexible joint up to 30 degrees. More acute bending is to be avoided, as it causes obstruction in the flow of the discharge. Some flexible joints are armed with net-wire works and strengthened additionally with steel rings which prevent the outside wearing, and also give some elasticity. To prevent the folding of the joint, its length should be 2—3 times the diameter of the pipe, when the diameter is up to 20 inches; but if the latter is above 30 inches, the length of the joint must not be greater than the diameter, as it suffers bending due to the weight.

In order that the flexible joint bears neither tension nor compression, it is guarded with springs. Sometimes consecutive pontoons are jointed with tongues attached to them, or with an universal joint. The tongue is made of a steel plate having an oval hole for a pin at the outer end. The plate being horizontally fixed to the pontoon, the connection is only used in still water. The universal joint consists of four strong eye-bars, two being riveted to the top and bottom of one delivery pipe and the two others to both sides of the other pipe. These eye-bars are connected by pins with a ring having four corresponding oval holes. The ring is greater than twice the diameter of the pipe, so as to make no obstruction to the bending of the flexible joint.

When the dredged material is to be discharged into the sea, the end of the discharge pipe should be moved so as to distribute the material over the site. This motion can be obtained by means of anchors, or a hydraulic deviator. Sometimes a baffle-plate, which acts like the rudder of a vessel, is employed. It is a single plate held by stays at a distance from the end of the pipe and perpendicular to the discharging stream, whose impact it receives. It can be adjusted in its distance and angle to the pipe line by means of cords and winches. But it must be used together with chains and anchors, which obstruct navigation and necessitate some loss of time due to their displacement. To avoid these inconveniences there is a wedge-shaped plate called hydraulic deviator. The plate is normally in the middle of the discharge stream, dividing it into equal parts and deflecting both equally to right and left. On the back of this wedge is a horizontal rack moved by a fixed pinion, which receives its rotation from the pontoon through a worm gear. By moving this wedge to one side or the other, the balance of the deflected stream is destroyed, and transverse motion to the pontoon is thus imparted. To more fully and freely handle the pontoon line, when not discharging, twin screws are often employed in addition to the hydraulic deviator. The propellers are fixed to the front end of the last pontoon with a certain angle and driven by an electric or steam motor which is installed in a compartment of the pontoon. The motor, if electric, can be controlled by the operator on the dredge.

Methods of Feeding the Dredge.

Proportion of Solid Material and Its Testing Apparatus:—

The colour of the fluid in the delivery pipe will serve as a guide for roughly determining the proportion of the solid material when the dredge is used for discharging on shore. A gauge attached to the suction pipe will also show the degree of vacuum in the pipe. When the indication is low, it is sure that the pump is dredging very poor percentage of solid material or there is some leakage of air in the suction pipe. When the indication is very high, the pipe is choking with soil or other obstacles. Commonly the pump works well with the indication of 10″—20″; but it chokes with that of 25″ or more. The dredges in the Osaka Harbour Works indicate 10″—15″ in good working and choke when the indication is over 25″, the soil being very soft clay.

A jet of fluid through a branch of the delivery pipe is the best means of testing a shore-delivering dredge, though it is a little waste of power. When the stream of fluid is slow and light colored, this is due either to leakage of air or to some obstructions in the suction pipe, which causes can be easily distinguished from each other by the number of revolutions of the impeller. When the stream is slow and dark colored, the suction pipe is too deeply immersed into the soil and is about to choke. Thus the vacuum gauge is suited to the hopper dredge, and a jet of fluid together with a gauge is necessary to the dredge discharging ashore.

All these means indicate, in one form, the work which is being done. But it is desirable that these informations should be supplemented by actual measurement of the mixed proportion. To suit this requirement, the branch pipe should be put close to the outlet of the pump and at the level, at which is found an average percentage of the whole quantity of sand contained in the stream.

The percentage of solid material varies greatly with the kind of soil and also with the disaggregating apparatus used. The "Brancker" dredged 25 percent of sand on an average and 45 percent under the best conditions. A dredge of the Chicago Drainage Canal handled about 25 percent, sometimes 80 percent of muck. The "Suwanee" on the west coast of Florida handled 15—30 percent of mud and sand, and the "Aurore II" of Ostend 20 percent of sand. A pulsometer dredge used at Coney Island worked with 50 percent of sand, and another one with 25—50 percent and sometimes 70—80 percent of mud and sand. In the Osaka Harbour, the shore-delivering dredges, "Ukishima" No 1 and No 2, work with an average proportion of 7—10 percent of soft clay and the hopper dredges, "Shinyi" No 1 and No 2, handle 30 percent in ordinary conditions and sometimes 50—70 percent when the soil falls dead at the suction mouth.

The proportion of solid material is not uniform throughout the cross section of the discharge pipe, but varies greatly increasing from the top towards the bottom of the pipe. Mr. Maltby made several experiments for determining the distribution of sand in the pipe (see "Hydraulic Dredging on the Mississippi River", Transactions, Am. Soc. C. E. Vol. LIV.) The following are the results obtained:—

Table III.
Distribution of Sand in the Delivery Pipe.

Distance from the top of pipe in inches.	Proportion of Sand	
	Dredge Delta.	Dredge Kappa.
4.	0.047	0.123
8.	0.048	0.172
12.	0.089	0.146
16.	0.094	0.155
20.	0.100	0.174
24.	0.187	0.185
28.	0.187	0.198
32.	—	0.238
33.	0.250 bottom)	(bottom)

The above measurements were made each at the centre of the second floating pipe, which is about 100 feet from the stern of the dredge. The material was fine sand mixed with a very small quantity of blue mud. The mean discharge velocities were not specified, but seem to be 10—15 feet per second. The distribution varies, however, greatly with the nature of solid material, the discharge velocity and the distance of the measuring point from the pump and also with the form of the pipe line.

Methods of Shifting the Dredge:—

The motion of the dredge when working, may be divided into the three following kinds:— (1) radial motion, (2) longitudinal motion and (3) transverse motion. Some dredges make these motions simultaneously, while others sucessively. The radial motion may be given to the dredge either by the suction pipe while the vessel remains stationary or by oscillating the vessel radially round an anchor spud or an imaginary centre by means of chains. The former method was originally designed by Mr. Hoffman and followed by Messrs. Von Schmidt and Bates. As to the latter method, the Americans use an anchor spud; but in Europe chains are usually resorted to. The longitudinal and transverse motions are made by means of chains or stepping spuds.

The methods of shifting the dredges are:—

(a) by free motion.
(b) by propeller.
(c) by one head chain.
(d) by mooring chains.
(e) by anchor spuds.

(a) By free motion:—

This is the simplest method of shifting. For this method of shifting, the suction pipe may project towards the bow or be trailed aft. By the sucking action of the pump, the dredge is driven forward slowly. This method, however, is to be used only in a site where there is no current or wind, and where the dredging scope is not limited. The writer used it with the hopper dredges in the Osaka Harbour Works and obtained a good result.

(b) By propeller:—

This method, in which the pump and propeller are driven simultaneously, is suited to a site where there is a strong current or wind. The suction mouth should be trailed aft as in many recent American hopper dredges. In the New York Harbour, it is said, the best condition is obtained when the dredge is propelling against the stream with a velocity of 2—3 miles. This method, however, is not generally used except in America.

(c) By one head chain:—

This is the common method generally applied to the hopper dredge with a projecting suction pipe. For dredging a short channel or working in a narrow navigable river, it is said to be better than the former methods. The only drawback is the loss of time due to dropping and raising of the anchor. For working, one bow anchor is dropped and its cable paid out; and the dredge is allowed to take its natural position due to the current and wind. But when the current is extraordinarily strong, another anchor is to be thrown. The pipe is then lowered till it comes down a few feet below the bottom and the pump is set in motion. The anchor chain is wound up so as to press the end of the pipe against the soil It usually takes 15 minutes to anchor and lower the pipe, and 6—8 minutes to heave up the anchor.

(d) By mooring chains:—

This method is advantageously used with a shore-deli veriug or barge-loading dredge, working in a sheltered site. The dredge is moored by means of fore aud aft chains and is swung from side to side by four side-chains, just as in the case of the ladder dredge. Such chains, however, make some obstructions to navigation, so that this method can not be used in a navigable path. For allowing the dredge to swing safely, from side to side, the bow or stern well suction pipe is thought to be suitable, though some side pipe dredges are also worked in this method.

(e) By anchor spuds:—

The anchor spud is a wooden or metallic pole inserted in a hole situated in the hull. It may be a cylindrical pole around which the dredge can oscillate or a square pole whose point can turn. It must be immersed into the soil to be able to resist the shocks of the dredge or to shift the hull; hence the spud must have a sufficient length corresponding to the dredging depth and be armed with a cast iron shoe. The wooden pole is made of one solid beam, or built with four pieces bolted together when the section is square; while the metallic one is a watertight pipe, whose weight is adjusted for easy manoeuvring. It is usually handled with steam, hydraulic or electric power. For a specially large spud, a jet of water is provided by means of which it is easily inserted into the soil. The spud can dispense with chains and be used in a narrow or closed spot as it does not interrupt navigation. It is easy to handle and can save the loss of time due to shifting moorings. But it can not be used in a rough sea or in a very deep cutting. According to Mr. Bates, he used anchor spuds in a depth of 52 feet and also in a current of 3 feet per second; but this must be thought extraordinary.

Generally two spuds are used in the pump dredge having a cutting apparatus. They may be both vertical spuds, or one vertical spud combined with an inclined propulsive or stepping spud. The spuds are provided at the stern when the dredge is to make a wide cut, or at the bow when it is intended to make a narrow cut able to let the dredge through. The distance between the axes of the spuds and the angle of oscillation determine the dredging scope.

The radial motion is given to the dredge by the suction pipe when the cut is very narrow. Thus the Von Schmidt's dredge has a turntable, by means of which the suction pipe can revolve round the bow, and some Bates' dredges have oscillating suction pipes supported by caissons. But where there is ample space to swing the dredge, propellers are often resorted to. Two propellers are thus provided at the bow, either one of which can be used for moving the vessel. In exceptionally hard soil both propellers are driven simultaneously. The spuds and propellers may be worked and controlled by the dredging master in the central station

Management of the Suction Pipe:—

The proportion of solid material depends in a very large degree upon the proper management of the suction pipe, which requires the best skill and jndgement of the operator. If the suction pipe is too deeply immersed into the soil, too much solid matter is carried into the pump and clogs it; while water only is pumped out, if it is kept too far from the soil. When the pump is choked, much time is lost in clearing, for work is to be stopped while clear water is being forced through. Sometimes the suction pipe is constantly kept at a given depth; but this method is not recommendable for the bottom is not perfectly level, so that the dredge will be choked at one time and will pump water at the other. The mouth of the suction pipe should, therefore, be adjusted to the varying depth from time to time.

The best position of the suction mouth should be determined from the proportion of solid material. The usual depth of the suction pipe immersed into the soil is 1.5—2.0 times the diameter of the pipe; and the distance from which the solid material flows into the pipe varies from 2 to 5 times the diameter of the pipe, according to the nature of the soil. So when the dredge is moved by its free motion, by propellers, or by head chain, the dredged spot will be a continuous narrow channel; and successive series of such a channel will tend to deepen the site.

When the dredge is furnished with a cutting apparatus and is moved by means of mooring chains or anchor spuds, it can make a regular cutting as the ladder dredge does. The cutter in this case should be adjusted in speed so as to take in an appropriate proportion of the solid material, the usual velocity being 10—20 revolutions per minute. The cutter brought in contact with the soil by shifting the dredge sideways and kept at one level usually, moves with the vessel as far as it can go in one direction, when it is lowered a little from 6 inches to 3 feet according to the hardness of the soil and is carried back, still cutting its way to the other side Again another lowering of the cutter takes place and the process is repeated. The swinging motion of the dredge is continued without moving the position of the anchor spuds, until the desired depth is obtained. The usual length of each advance is 3—5 times the diameter of the suction pipe It will be seen that this method ensures a level bottom leaving neither lumps nor holes in the channel.

Clay in passing through the pump will be formed into balls up to 5 inches in diameter, and boulders as large as two cubic feet can be forced through the pipe. Clay can be easily handled when mixed with sand or gravel; but when pure it can not be dredged with advantage. Coarse sand is apt to settle in the discharge pipe and reduce its capacity, sometimes entirely choking up the pipe. The delivery pipe should therefore be provided with a man-hole for convenience of clearing the deposit. When the material is very fine sand, it often happens that the hopper dredge works for a few hours without increasing the depth of the sand in the hopper more than a few inches. It then becomes a question whether it is better to go to sea for discharging with the hopper not completely full, or to waste time in trying to fill it, when most of the sand is running overboard.

A moderate agitation of the water augments the efficiency of the dredge, as waves, 1.0—1.5 feet in height, make the suction mouth immerse deeper without danger of stopping the pump. The pump dredge, as we have said, can safely work in a rough sea, where no other dredge can be employed. The hopper dredges, "Shinyi". No 1 and No 2, are accustomed to work in a swell not less than 3 feet.

Performance.

In the Osaka Harbour Works, four pump dredges have been used. Two of the dredges, the "Ukishima" No 1 and No 2, are non-propelling shore-delivering dredges, each with a capacity of 500 ton per hour, and a maximum dredging depth of 30 feet. They have projecting side suction pipes and are moved by means of four mooring chains. They are able to discharge the dredged material ashore through a system of floating and land pipes to a distance of 2,100 feet and a height of 13 feet above water. They were mainly employed for reclaiming land, and worked in pools where hopper barges loaded by ladder dredges discharged their contents. When the material was to be delivered into a deep site, the discharge pipe consisted of 20 floating pipes; but for reclamation above low water, 10 floating pipes and 10—50 fixed pipes were used, and the fixed pipes were laid on a trestle and raised up to 15 feet above low water according to the height of the reclaimed land.

The other two dredges, the "Shinyi" No 1 and No 2, are hopper dredges, each of 560 ton capacity. Their maximum dredging depth is 35 feet. While working, the dredges were left free using no mooring; but if the current or wind was strong, head anchors were used. They worked on bottoms from 12 to 28 feet deep to dredge to their maximum depth. The nature of the bed was mud down to 20 feet below low water, where a soft blue clay was found. When dealing with mud, it was difficult to fill the hopper completely, most of the mud running overboard; so that the dredges had to go to the sea for discharging, when only, half loaded. The transportation distance is 2.0—2.5 miles. The dredges may be also used like the "Ukishima" for discharging on shore. In 1905 the "Shinyi" No 2 was used for salvage of the Russian cruiser "Varyag" sunk in Chemulpho and was afterwards sold to the Imperial Navy.

The dredging apparatus in the four dredges is similar in construction. The pump has a cast steel body and cast iron covers lined with chilled cast iron facing plates. The impeller is of cast steel, blades being bolted on arms. The impeller shaft is fed with a jet of water under pressure forced by the bilge pump. The suction pipe, 20 inches in diameter, is cut square at the mouth and protected with a grating, and is connected with the hull by means of a leather joint. The delivery pipe, 22 feet in length and 20 inches in diameter, is built of one-eighth inch steel plates. The flexible joint, 3'. 3". in length, is made of leather, armed with a steel network strengthened with four steel rings. The floating pipe is carried on two cylindrical pontoons coupled by steel angles and wooden beams and bearers, as shown

The principal dimensions of the machinery are as follows:—

Dredge	"Ukishima."	"Shinyi."
Pump		
Outer radius of impeller in m. m.	1,130.	950.
Inner 〃 〃 〃	390.	370.
Breadth of impeller in m. m.	280.	280.
Discharge angle in degrees.	30.	37.
Number of blades	4.	4.
Suction pipe in m. m.	500.	500.
Delivery pipe in m. m.	500.	500.
Engine		
H. P. in m. m.	525.	525.
L. P. 〃 〃	845.	845.
Stroke 〃 〃	550.	460.
Revolutions per min.	175.	165.
I. H. P.	400.	300.
Boiler		
Number	2.	2.
Diameter in m.	2.8	2.6
Length in m.	3 0	2.6
Number of furnaces	2.	2.
Total heating surf. in sq. m.	160.	120.
Total grate area in sq. m.	48.	48.
Pressure in atmospheres.	6.	6.

Cost of the plant:—

Dredge "Shinyi" built in 1899.	yen
Hull and machinery	206,976.94
50 delivery pipes	8,785.00
10 floaters	5,350.00

20 flexible joints	4,014.00
	225,125.94
Dredge "Ukishima", built in 1899.	yen
Barge	24,848.80
Machinery and its mounting	96,325.56
50 delivery pipes	8,785.00
10 floaters,	5,350.00
20 flexible joints	4,014.00
	139,323.36

Premium rate:—

The premium rate is directly proportional to the monthly dredged amount, as

$$P=K.D$$

where P=premium in sen.

D=monthly dredged quantity in tsubo.

K=constant, varying with D.

Table IV. Value of K.

Dredged quantity	When D is less than 5,000.	When D is greater than 5,000, but less than 10,000.	When D is greater than 10,000.
Captain and engineer.	0.39	0.47	0.55
Mate and second	0.20	0.24	0.28
Boatswain and chief fireman	0.12	0.14	0.17
Steersman and oiler.	0.08	0.09	0.11
Sailor, fireman and cook	0.06	0.08	0.09
Boy.	0.03	0.03	0.04

The monthly dredged amount was calculated from the barge measurement of the soil transported and discharged by hopper barges during the month and the difference of the place measurements of pools made at the beginning and end of the month. But the amount of work done by the hopper dredges was measured *in situ* at the end of the month.

In Tables VI, VIII and X, expenses due to superintendence and soundings and also profit are not included. Moreover the cost of trestles supporting the delivery pipes is not counted in the depreciation and interest

Table V.

Performance of the Dredges, "Ukishima" No. 1 and No. 2, Combined.

Fiscal year.	Number of days.	Number of working hours.	Time lost due to: Steaming.	Time lost due to: Going to the site.	Time lost due to: Shifting moorings.	Time lost due to: Connecting and disconnecting delivery pipes	Time lost due to: Weather.	Time lost due to: Clearing suction mouth	Time lost due to: Clearing delivery pipe	Time lost due to: Repairs.	Time lost due to: Going to the refuge.	Time lost due to: Cleaning	Time lost due to: Other causes.	Time lost: Total	Dredging hours.	Length of delivery pipes.	Height of delivery above low water.	Dredged quantity, Tsubo.	Average quantity dredged per working hour. Tsubo.	Average quantity dredged per dredging hour. 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.					
1899	206.	2,394.00.	262.30.	20.50.	5.00.	45.10.	216.30.	0.00.	0.00.	98.40.	4.30.	165.30.	146.00.	964.40.	1,429.20.	900′-1,150′.	12′.	4,869.9	2.03	3.41
1900	702.	15,936.00.	364.00.	102.15.	274.05.	303.10.	2,257.25.	41.30.	61.00.	1,743.55.	86.45.	524.30.	155.25.	5,914.00.	10,022.00.	1,100′-1,200′.	12′.	62,271.7	3.91	6.21
1901	704.	16,896.00.	239.25.	49.00.	22.40.	269.40.	1,728.05.	98.00.	13.25.	1,110.15.	49.55.	185.20.	1,510.45.	5,276.30.	11,619.30.	550′-1,120′.	12′.	143,980.0	8.52	12.39
1902	702.	15,428.00.	271.05.	43.45.	23.00.	441.20.	1,826.50.	60.50.	9.45.	1,265.15.	42.25.	128.25.	484.45.	4,597.25.	10,830.35.	530′-1,890′.	9′-15′.	187,437.0	12.15	17.31
1903	706.	15,652.30.	241.50.	41.20.	8.00.	235.45.	1,785.50.	118.05.	5.40.	974.00.	40.30.	155.25.	248.25.	3,854.50.	11,797.40.	620′-1,240′.	12′-15′.	230,613.0	14.73	19.55
1904	704.	15,319.30.	134.25.	14.45.	31.50.	138.15.	784.35.	169.35.	0.55.	1,230.20.	15.45.	197.15.	114.50.	2,832.30.	12,487.00.	490′-1,290′.	9′-15′.	158,977.0	10.38	12.73
1905	705.	13,785.45.	207.50.	13.10.	2.00.	101.00.	930.40.	162.45.	0.40.	1,417.40.	14.25.	346.05.	332.15.	3,528.30.	10,257.15.	600′-1,880′.	9′-15′.	94,975.0	6.89	9.26
1906	704.	14,723.40.	100.20.	3.30.	1.00.	22.20.	239.40.	177.40.	6.10.	1,740.55.	3.00.	229.40.	86.35.	2,610.50.	12,112.50.	670′-1,650′.	9′-12′.	102,594.0	6.97	8.47
Total	5,133.	110,135.25.	1,821.25.	288.35.	367.35.	1,556.40.	9,769.35.	828.25.	97.35.	9,581.00.	257.15.	1,932.10.	3,079.00.	29,579.15.	80,556.10.			985,717.6	8.95	12.23
Average per dredge per day		21. 27.3	0.21.3	0.03.3	0.04.3	0.18.2	1.54.2	0.09.7	0.01.1	1.52.0	0.03.0	0.22.6	0.36.0	5. 45.7	15.41.6			192.0	8.95	12.23
Percentage		100.00	1.65	0.26	0.33	1.41	8.87	0.75	0.09	8.71	0.23	1.75	2.80	26.85	73.15					

The dredges worked day and night.

The number of days does not include holidays and those during which the dredges were used for other purposes.

Table VI.

Expenses for the Dredges, "Ukishima" No 1 and No 2, Combined.

Fiscal year	Number of days.	Labour. Number of crew.	Labour. Salary. Yen.	Labour. Boarding. Yen.	Labour. Premium. Yen.	Labour. Other expenses. Yen.	Labour. Total. Yen.	Materials. Coal. Quantity. 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.	Dredged quantity. Tsubo.	Unit cost per tsubo. Yen.
1899	216	3,169	1,444.780	372.670	0.	13.433	1,830.833	1,010,000.	3,344.640	299.127	294.109	3,937.876	4,288.861	8,244.889	4,122.445	22,424.954	4,869.9	4.605
1900	730	13,512	5,417.454	1,652.350	0.	1,826.621	8,896.425	6,660,000.	22,883.319	1,363.719	977.921	25,224.959	14,279.612	27,864.672	13,932.336	90,198.004	62,271.7	1.448
1901	730	14,244	5,814.975	1,744.020	1,250.360	551.985	9,361.340	7,510,000.	31,192.090	1,335.558	685.828	33,213.476	9,349.958	"	"	93,721.782	143,980.0	0.651
1902	730	14,452	5,902.610	1,769.550	3,962.180	796.040	12,430.380	7,950,000.	24,963.000	720.253	550.817	26,234.070	12,874.746	"	"	93,336.204	187,437.0	0.498
1903	732	14,481	5,845.610	1,771.000	5,186.493	0.	12,803.103	9,876,000.	24,094.116	738.542	524.036	25,356.694	20,623.628	"	"	100,580.433	230,613.0	0.436
1904	730	14,505	5,704.920	1,772.860	3,266.506	0.	10,744.286	10,993,000.	23,885.118	639.777	519.482	25,044.377	13,529.563	"	"	91,115.234	158,977.0	0.573
1905	730	14,492	5,778.330	1,777.370	1,838.308	0.	9,394.008	8,914,000.	40,854.994	610.161	508.029	41,973.184	11,254.564	"	"	104,418.764	94,975.0	1.099
1906	730	14,472	5,852.740	1,776.980	1,867.226	0.	9,496.946	10,437,000.	44,212.660	764.443	1,080.442	46,057.545	10,313.185	"	"	107,664.684	102,594.0	1.049
Total	5,328	103,327	41,761.419	12,636.800	17,371.073	3,188.079	74,957.371	63,350,000.	215,429.937	6,471.580	5,140.664	227,042.181	96,514.117	203,297.593	101,648.797	703,469.059	985,717.6	0.714
Average Per dredge per day.		19.4	7.838	2.372	3.260	0.599	14.069	11.890.	40.433	1.215	0.965	42.613	18.115	38.156	19.078	132.031	185.01	0.714
Average per tsubo.			0.042	0.013	0.018	0.003	0.076	64.3	0.219	0.007	0.005	0.231	0.098	0.206	0.103	0.714		
Percentage			5.94	1.80	2.47	0.45	10.66		30.63	0.92	0.73	32.28	13.72	28.90	14.44	100.00		

Table VII.

Performance of the Dredges, "Shinyi" No 1 and No 2, when used for discharging the dredged material ashore.

Fiscal year.	Number of days.	Number of working hours.	Time lost, Due to: Steaming.	Going to the site.	Shifting moorings.	Connecting and disconnecting delivery pipes.	Weather.	Clearing suction mouth.	Clearing delivery pipe.	Repairs.	Going to the refuge.	Cleaning.	Other causes.	Total.	Dredging hours.	Length of delivery pipes.	Height of delivery above low water.	Dredged quantity, Tsubo.	Average quantity dredged per working hour, Tsubo.	Average quantity dredged per dredging hour, 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.					
1900	351.	8,311.00.	106.20.	21.35.	137.30.	86.00.	1,344.00.	70.40.	20.10.	410.00.	17.30.	69.20.	729.20.	3,012.25.	5,298.35.	1,070′-1,210′.	12.′	37,216.2	4.48	7.02
1901	704.	16,896.00.	166.20.	40.55.	52.10.	138.50.	2,252.10.	125.30.	9.50.	826.15.	41.15.	61.05.	1,214.40.	4,929.00.	11,967.00.	490′-1,210′.	12.′	163,9[illegible]4.0	9.70	13.70
1902	293.	6,262.30.	48.00.	8.20.	10.30.	67.35.	248.45.	40.30.	1.40.	787.45.	9.40.	0.30.	477.05.	1,700.20.	4,562.10.	740′-1,240′.	15.′	72,284.0	11.54	15.84
1904	171.	3,620.00.	30.40.	4.55.	15.50.	10.20.	287.40.	35.45.	4.20.	157.40.	6.40.	47.40.	3.05.	604.35.	3,015.25.	510′.	9.′	40,1[illegible]2.0	11.09	13.31
1905	97.	1,312.30.	2.30.	0.00.	0.00.	0.00.	0.0.	4.30.	2.00.	659.10.	0.20.	106.40.	34.30.	809.40.	502.50.	850′-990′.	15.′	6,601.0	5.03	13.13
1906	65.	1,009.00.	3.30.	1.00.	0.00.	9.30.	0.00	2.50.	3.00.	533.00.	1.30.	22.00.	0.00.	576.20.	432.40.	1550′.	12.′	1,973.0	1.96	4.56
Total	1,681.	37,411.00.	357.20.	76.45.	216.00.	312.15.	4,132.35.	279.45.	41.00.	3,373.50.	76.55.	307.20.	2,458.40.	11,632.20.	25,778.40.			322,140.2	8.61	12.50
Average per dredge per day		22.15.3	0.12.8	0.02.7	0.07.7	0.11.1	2.27.5	0.10.0	0.01.5	2.00.4	0.02.7	0.11.0	1.27.8	6.55.2	15.20.1			191.64	8.61	12.50
Percentage		100.00	0.96	0.20	0.58	0.83	11.01	0.75	0.11	9.02	0.20	0.82	6.58	31.09	68.91					

The dredges worked day and night.

The number of days does not include holidays and those during which the dredges were used for other purposes.

Table VIII.

Expenses for the Dredges, "Shinyi" No 1 and No 2, when used for discharging the dredged material ashore.

Fiscal year.	Number of days.	Labour. Number of crew.	Labour. Salary. Yen.	Labour. Boarding. Yen.	Labour. Premium. Yen.	Labour. Other expenses. Yen.	Labour. Total. Yen.	Materials. Coal. Quantity. 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.	Dredged quantity. Tsubo.	Unit cost per tsubo. Yen.
1900	374	8,759	3,730.844	1,092.220	1,785.460	244.200	6,852.724	3,399,000.	11,773.400	1,009.044	362.741	13,145.185	4,084.776	22,581.433	11,290.717	57,954.835	37,216.2	1.567
1901	730	17,150	7,457.859	2,149.840	2,298.230	674.485	12,580.414	6,925,000.	26,681.090	1,436.946	698.415	30,816.451	8,217.594	45,025.188	22,512.594	119,152.231	163,934.0	8.721
1902	295	6,733	2,929.717	850.810	1,784.516	484.260	6,049.303	2,880,000.	10,427.100	313.660	203.764	10,944.524	4,229.466	18,195.110	9,097.555	48,515.958	72,284.0	0.671
1904	182	3,579	1,643.270	463.760	1,066.170	0.	3,173. 002	2,709,000.	5,887.328	238.397	168.557	6,294.282	3,875.629	11,225.458	5,612.729	30,181.298	40,132.0	0.752
1905	101	1,739	828.450	203.367	145.177	0.	1,176 994	448,000.	1,132.800	51.840	69.054	1,253.694	1,207.906	6,229.512	3,114.756	12,982.862	6,601.0	1.967
1906	71	1,320	603.087	164.984	42.458	0.	810.524	360,000.	1,369 800	49.718	132.460	1,551.978	1,376.133	4,379.162	2,189.581	10,307.378	1,973.0	5.224
Total	1,753	39,280	17,193.227	4,924.981	7,122.006	1,402.945	30,643.159	16,721,000.	59,271.518	3,099.605	1,634.991	64,006.114	22,991.494	107,635.863	53,817.932	279.094.562	322,140.2	0.866
Average per dredge per day.		22.4	9.809	2.809	4.063	0.800	17.481	9538.	33.811	1.768	0.933	36.512	13.116	61.401	30.700	159.210	183.77	0.866
Average per tsubo.			0.053	0.015	0.022	0.004	0.094	51.9	0.184	0.010	0.005	0.199	0.072	0.334	0.167	0.866		
Percentage			6.16	1.77	2.55	0.50	10.98		21.24	1.11	0.58	22.93	8 24	38.57	19.28	100.00		

Table IX.

Performance of the Hopper Dredges, "Shinyi" No 1 and No 2, 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.	Transportation of spoil.	Cleaning.	Other causes.	Total.	Dredging hours.	Dredged quantity. Tsubo	Average quantity dredged per working hour. Tsubo.	Average quantity dredged per dredging hour. 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.			
1899	400.	4,589.05.	333.35.	50.20.	157.55.	477.20.	702.20.	46.10.	293.45.	218.10.	98.45.	2,378.20.	2,210.45.	21,093.0	4.60	9.54
1900	351.	3,984.00.	269.40.	38.25.	190.30.	223.00.	820.00.	41.00.	278.30.	173.00.	136.30.	2,170.35.	1,813.25.	38,758.0	9.73	21.37
1902	409.	5,841.15.	539.40.	25.55.	145.35.	541.25.	435.50.	27.45.	910.20.	195.20.	44.40.	2,866.30.	2,974.45.	129,426.0	22.16	43.51
1903	706.	9,857.00.	745.50.	7.30.	455.15.	818.05.	1,616.00.	7.00.	1,496.00.	380.40.	121.10.	5,647.30.	4,209.30.	153,27[illegible].0	15.06	36.41
1904	335.	4.631.20.	308.00.	2.10.	235.20.	101.00.	1,312.35.	2.00.	809.55.	134.30.	1.30.	2,907.00.	1,724.20.	73,751.0	15.92	42.77
1905	255.	3,585.35.	385.20.	60.20.	19.30.	218.50.	288.20.	53.55.	642.15.	158.20.	105.05.	1,931.55.	1,653.40.	36,256.0	10.11	21.92
1906	287.	4,237.10.	333.30.	3.00.	72.10.	73.05.	762.05.	7.00.	695.05.	25.30.	0.00.	1.971.25.	2,265.45.	38.497.0	9.09	16.99
Total	2,743.	36,725.25.	2,915.35.	187.40.	1,276.15.	2,452.45.	5,937.10.	184.50.	5,125.50.	1,285.30.	507.40.	19,873.15.	16,852.10.	491,954.0	13.41	29.22
Average per dredge per day		13.23.3	1.03.9	0.04.1	0.27.9	0.53.6	2.09.9	0.04.0	1.52.1	0.28.1	0.11.1	7.14.7	6.08.6	179.5	13.41	29.22
Percentage		100.00	7.95	0.51	3.47	6.67	16.17	0.50	13.96	3.50	1.38	54.11	45.89			

The number of days does not include holidays and those during which the dredges were used for other purposes.

Table X.

Expenses for the Hopper Dredges, "Shinyi" No 1 and No 2, Combined.

Fiscal year.	Number of days.	Labour. Number of crew.	Labour. Salary. Yen.	Labour. Boarding. Yen.	Labour. Premium. Yen.	Labour. Other expenses. Yen.	Labour. Total. Yen.	Materials. Coal. Quantity. Pounds	Materials. Coal. Cost. Yen	Materials. Oil, etc. Yen.	Materials. Other expenses. Yen.	Materials. Total. Yen.	Repairs. Yen.	Depreciation of 7.5 per cent. Yen.	Interest of 5. per cent. Yen.	Total. Yen.	Dredged quantity. Tsubo.	Unit cost per tsubo. Yen.
1899	5:6	7,684	3,501.337	904.390	0.	113.659	4,519.386	1,560,000.	5,518.564	527.931	510.049	6,556.544	968.303	22,380.522	14,913.681	49,338.436	21,093.0	2.339
1900	356	5,458	2,512.578	705.180	0.	44.650	3,262.408	1,474.000.	4,992,090	312.256	328.557	5,632.903	3,807.969	15,240.504	10,093.670	38,037.454	38,758.0	0.981
1902	435	8,007	3,744.728	1,023.390	3,748.787	0.	8,516.905	2,860.000.	7,823.600	438.585	200.694	8,462.879	6,202.772	18,600.326	12,333.558	54,116.44'	129,426.0	0.418
1903	732	13,013	6,167.932	1,661.950	3,616.743	0.	11,446.625	5,690.000.	13,687.280	666.061	387.781	14,741.122	10,984.323	31,046.541	20,697.694	88,916.305	153,273.0	0.580
1904	338	5,939	2,872.5 0	761.090	1,853.450	0.	5,487.090	2,898.000.	6,476.088	271.444	170.613	6,918.145	7,197.597	14,374.974	9,583.316	43,561.12:	73,751.0	0.591
1905	264	4,957	2,329.940	615.773	734.147	0.	3,679,860	2,690.000.	13,316.316	322.626	275.544	13,914.486	3,157.297	11,227.787	7,485.192	39,464.622	36,256.0	1.088
1906	294	5,297	2,438.243	646.166	768.714	0.	3,853.123	2,894.000.	12,667.540	399.663	554.999	13,622.202	5,698.353	12,503.675	8,335.784	44,013.137	38,497.0	1.143
Total	2,945	50,355	23,567.308	6,317.939	10,721.841	158.309	40,765.397	20,066.000.	64,481.478	2,938.566	2,428.237	69,848.281	38,016.614	125,374.329	83,442.895	357,447.516	491,054.0	0.728
Average per dredge per day		17.1	8.002	2.145	3.641	0.054	13.842	6.814	21.895	0.998	0.824	23.717	12.909	42.572	28.334	121.374	166.74	0.728
Average per tsubo.			0.048	0.013	0.022	0.	0.083	40.9	0.131	0.006	0.005	0.142	0.078	0.255	0.170	0.728		
Percentage			6.57	1.76	3.01	0.05	11.39		18.04	0.82	0.68	19.54	10.64	35.08	23.35	100.00		

DREDGE SHINYI.

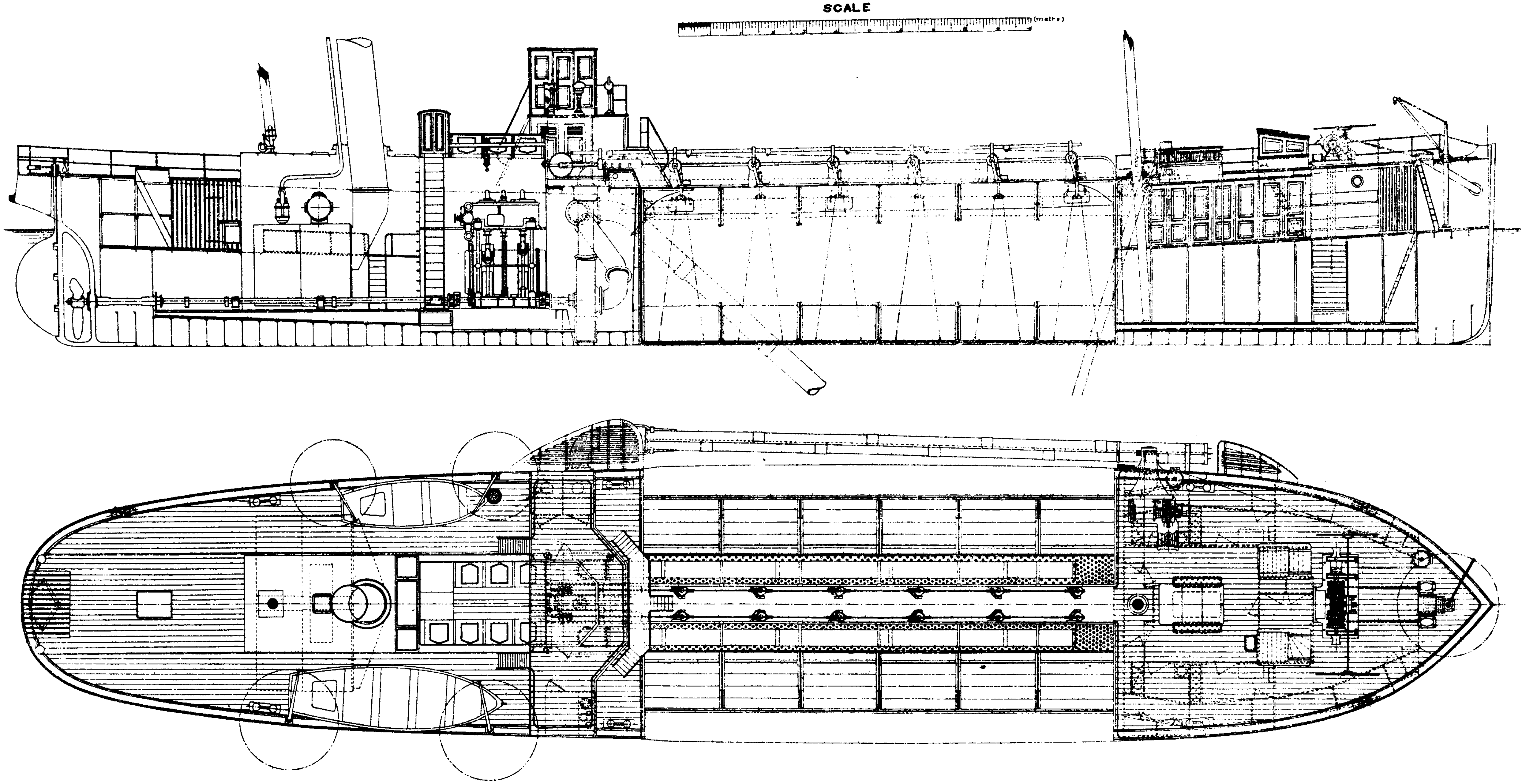
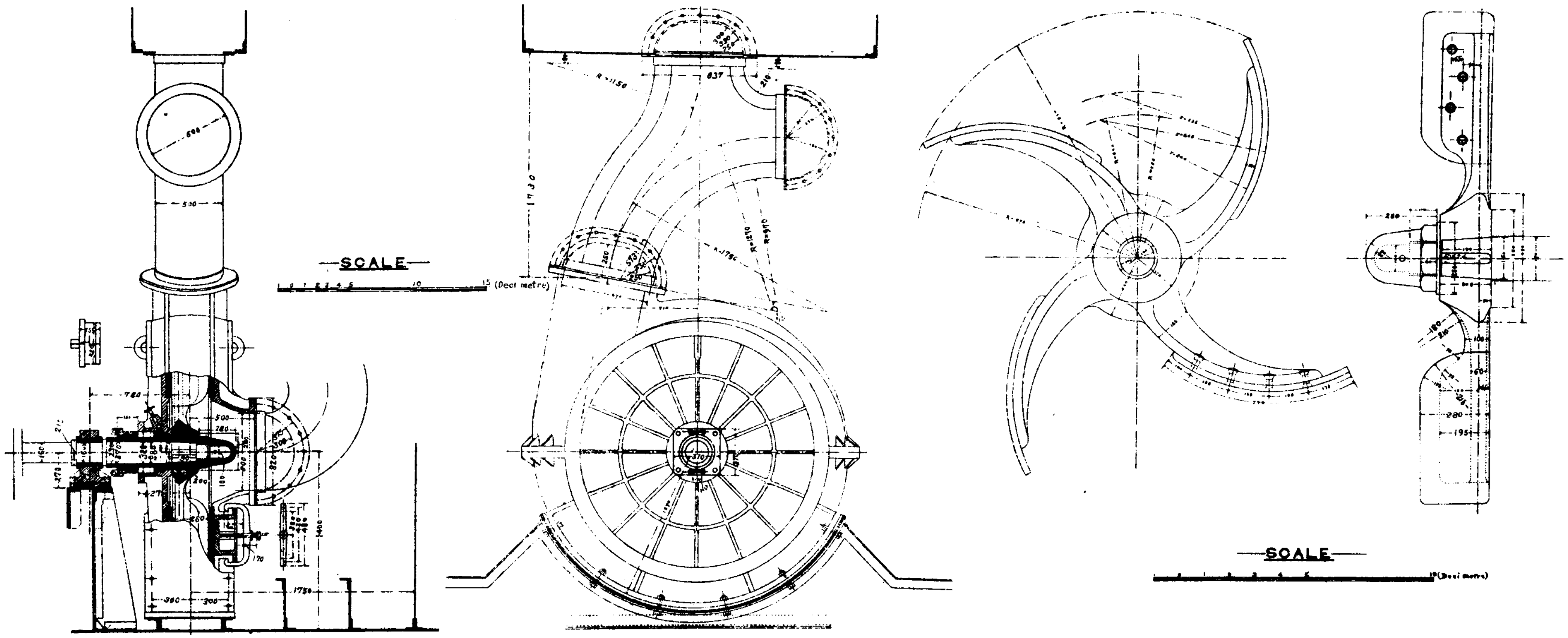


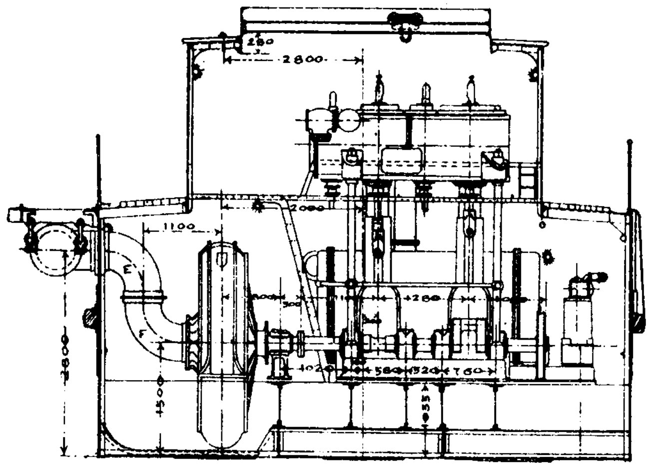
PLATE II.

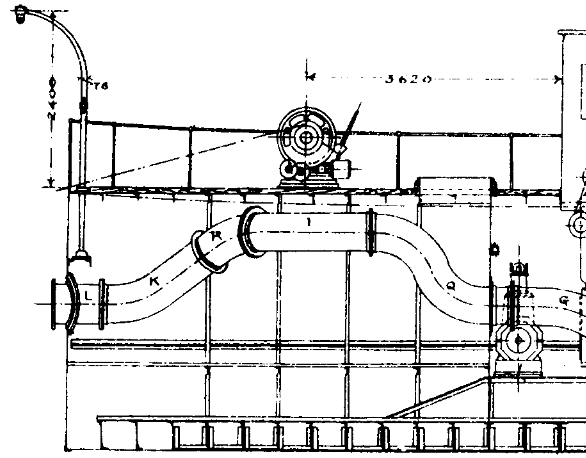
DREDGE SHINYI.

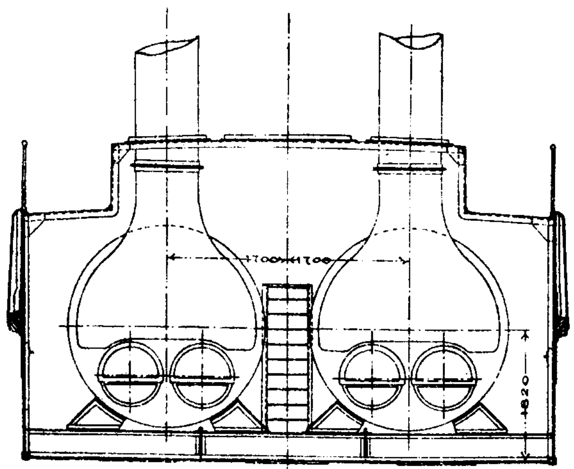
PUMP AND IMPELLER.

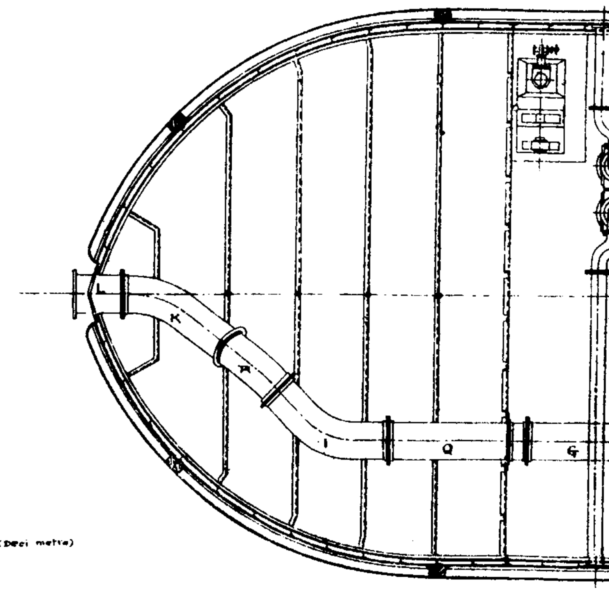


DR





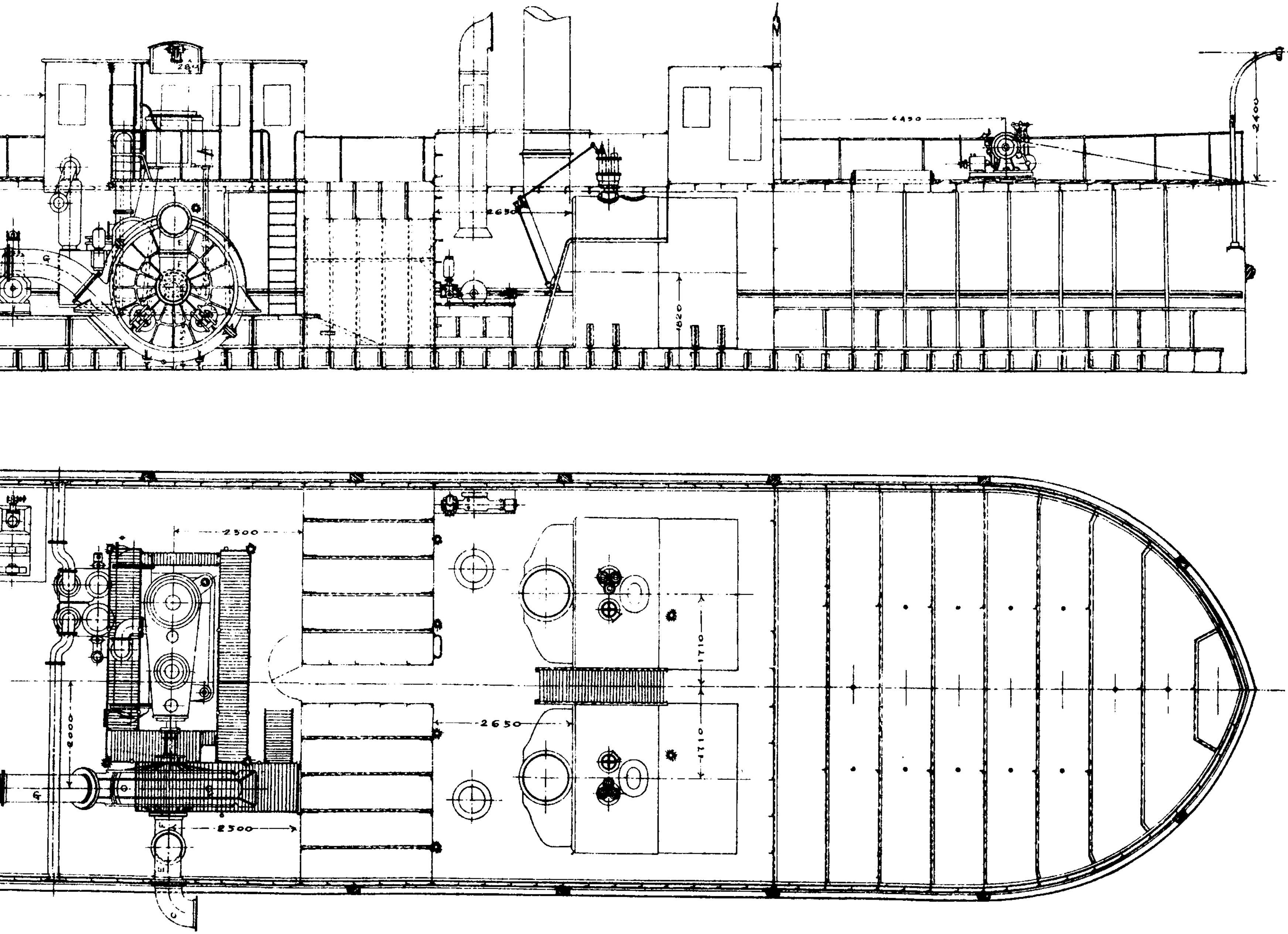




SCALE

0 2 5 10 15 20 25 30 40 50 (Deci metre)

DREDGE UKISHIMA



DELIVERY PIPE.