UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 300

Contribution from the Bureau of Public Roads
THOS. H. MacDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER Issued Nov. 10, 1915
Revised Aug. 22, 1922

# EXCAVATING MACHINERY USED IN LAND DRAINAGE

By

D. L. YARNELL
Senior Drainage Engineer

CONTENTS



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## INTRODUCTION.

The use of power machinery for the construction of drainage ditches and levees has become general in this country. Not only have new types of excavators been put on the market in recent years, but the older ones are being constantly improved to meet the requirements of drainage work. It is essential that the drainage engineer, upon whom rests largely the responsibility for the proper planning and execution of drainage undertakings, keep himself informed not only of the improvements constantly being made in excavating machinery but also as to the special advantages and limitations of the various types of machines. Contractors usually are required, when submitting bids, to describe in a general way the machinery they intend to employ. Only by being familiar with such machinery will the engineer be able to decide as to its suitability for his project or to estimate intelligently the cost of the work.

## DEVELOPMENT OF EXCAVATING MACHINERY.

Open drains were no doubt dug on wet agricultural lands during the early settlement of this country. Since only hand tools were then in use, the ditches were small. If the channel was too large to permit the material to be dug and thrown out in one operation, it was necessary to rehandle the dirt with shovels or to carry it out in baskets or wheelbarrows. These methods were very slow and expensive. Although the ditches then constructed served their purpose for the small agricultural tracts, which were generally on high ground, the increase in population and the resulting spread of agricultural operations to the lower lands soon demanded the construction of larger channels. Teams and scrapers were then used where conditions permitted. If the material was hard it was first loosened with a plow and then removed by means of slip or wheel scrapers. This method, however, became too expensive when still larger ditches were required. Moreover, drainage channels must frequently be constructed on lands so wet and soft as to preclude the use of teams. The increasing demand for suitable excavating machinery engaged the attention of many men of mechanical bent, and the result has been the invention of modern types of machinery, the development of which has been rapid. By the use of modern machinery the cost of drainage work has been so reduced as now seldom to afford valid excuse for failure to drain.

The early type of dipper dredge was equipped with the old-fashioned vertical spuds, and the hull was built wide to prevent tipping. The ditches desired at that time usually were small, and owing to the width of hull the operator was nearly always compelled to excavate more material than he was paid for. The bank spud, which runs directly from the side of the machine to the bank, was invented to do away with this unnecessary width of hull and consequent useless excavation. Although many delays and difficulties were encountered in the early stages of development, the cost of excavation by machinery was soon reduced much below that by hand labor. That achievement marks an epoch in the progress of drainage in this country.

In late years the so-called dry-land excavators of various types have been developed and have reduced the cost of excavation under conditions to which floating dredges are not adapted. The growth of the drag-line scraper excavator has been especially prominent. At present this machine probably has a wider field of usefulness than any other type of excavator made.

## COMPARISON OF KINDS OF POWER.

Excavating machinery may be operated by steam or internal-combustion engines or by electric motors. Coal, wood, and crude oil are suitable fuels for steam generation. Internal-combustion engines operate with gasoline, kerosene, or distillate. Electric current must be conveniently available and low in cost if motors are used, and if the greater convenience and labor saving through its use are to offset the increased cost of equipment. The selection is usually confined to steam and internal-combustion engines, because the work generally takes place out of reach of electric transmission lines.

### STEAM ENGINES.

The determination of the economical fuel to use for a steam plant requires a knowledge of the heating qualities of fuels and of their costs delivered at the machine. Of the fuels wood, coal, and oil, wood has the lowest heat value. The range in heating units is not as great in wood as it is in coal, because the ash and moisture contents of coal vary considerably. It is advisable to purchase coal containing as little ash as possible. Oils have a considerably greater heat value than either wood or coal. Some of them, such as Mexican oil, have a higher heating value than others, but are difficult to use on account of their greater viscosity.

The following is a comparison[1] between bituminous coal and crude oil from Beaumont, Tex., containing 19,060 British thermal units per pound:

*Comparative evaporative power of oil and coal.*

| | |
|---|---|
| 1. Pounds of evaporation per pound of coal with about 10 square feet of heating surface per boiler horsepower | 7.5 |
| 2. Pounds of evaporation per pound of Beaumont oil with about 10 square feet of heating surface per boiler horsepower | 14.8 |
| 3. Ratio of evaporation of oil to coal | 1.97 |
| 4. Number of barrels of oil equivalent to a ton of coal | 3.54 |

The coal used was measured by the gross ton of 2,240 pounds. It contained 3 per cent of water and was representative of the bituminous coal obtained from mines west of Ohio in the Central Western States. The oil weighed 7.66 pounds per gallon, or 322 pounds per barrel of 42 United States gallons. The figures give net evaporation after allowing for steam consumed to produce the forced draft necessary for burning the fuel.

Authorities generally estimate that 2¼ pounds of dry wood are equivalent in evaporative power to 1 pound of good bituminous coal, or 0.6 pound of average fuel oil. The American Society of Mechanical Engineers has adopted for tests the ratio of 1 pound of wood to 0.40 pound of coal. Solid bituminous coal weighs approximately 84 pounds per cubic foot, while loosely broken bituminous coal weighs 49 pounds per cubic foot. Assuming a cord of wood to weigh 2,000 pounds, 2½ cords are equivalent to 1 short ton of coal. In constructing channels in heavily timbered sections where the right of way

[1] Denton, Prof. James E. Power, February, 1902, p. 8.

must be cleared, it is frequently economical to use as fuel the wood cut in clearing.

It is estimated that 1 pound of coal will convert from 7 to 10 pounds of water into steam, and that there are about 13,000 British thermal units in 1 pound of coal. The heat loss from a bare boiler containing steam at 125 pounds pressure on an ordinary summer day is about 1,200 British thermal units per square foot per hour. This, allowing for fire-box losses, is equivalent to about $1\frac{1}{2}$ pounds of coal per square foot of bare boiler surface per shift of 10 hours, or on a boiler having 226 square feet a heat waste of 339 pounds of coal. The economy of covering boilers with insulating material is seen from the following calculation:

Boiler, 54 inches diameter by 16 feet long, contains 226 square feet surface.
125 pounds gage pressure represents 352° F. temperature.
Air temperature assumed to be 80° F.
Coal cost at dredge assumed to be $11 per ton.
Loss per square foot of bare surface per degree of temperature difference is 3 British thermal units per hour. (Authorities give this as from 2.7 to 3.)
Assume that 1 pound of coal produces 7 pounds of steam.
Latent heat of steam at 125 pounds gage=865 British thermal units.
The total loss from the bare boiler per hour will then be

$$\frac{3.0\times(352-80)\times226\times\$11.00}{865\times7\times2000}=\$0.167$$

Thus the loss per shift of 11 hours would be $1.84 and the loss per month of 52 shifts would be $95.68.

For a working pressure of 125 pounds per square inch, a boiler covering of about 2 inches should be used. In tests the efficiency of a 2-inch heat insulator has been found to be as high as 90 per cent. That means that by insulation 90 per cent of $95.68 can be saved or $86.11 per month. To cover a boiler, as described, costs about 60 cents per square foot. Thus, the boiler covering would be paid for in a little more than a month and a half of operation. The above calculations are based on an air temperature of 80° F. For lower air temperatures the saving would be correspondingly greater.

For convenience in reckoning the temperature corresponding to the pressure in the boiler registered by the gage, Table 1 is given:

TABLE 1.—*Steam temperatures at various pressures.*

| Gage pressure per square inch. | Steam temperature. | Gage pressure per square inch. | Steam temperature. |
|---|---|---|---|
| *Pounds.* | *°F.* | *Pounds.* | *°F.* |
| 0 | 212 | 100 | 338 |
| 10 | 240 | 150 | 366 |
| 25 | 267 | 200 | 388 |
| 50 | 298 | 250 | 406 |
| 75 | 320 | | |

The following formula[2] for determining the latent heat of steam at various gage pressures is based on experiments made by M. Regnault:

$$L \text{ (nearly)} = 965.7 - 0.7\ (t - 212°)$$

in which $t$ is the steam temperature in degrees Fahrenheit to be obtained from the preceding table.

It is convenient to remember that 1 horsepower per hour is equivalent to 2,545 British thermal units. Assuming 13,000 British thermal units in a pound of coal, the latter is equivalent to 5 horsepower-hours. From 18 to 20 pounds of bituminous coal per hour is burned with natural draft on 1 square foot of fire grate.

Very frequently too small a boiler is used on a machine, and the boiler must be worked to its utmost capacity to furnish the necessary amount of steam. This results in great waste of fuel, which could easily be avoided by using a boiler of the proper capacity. On a certain 1-yard steam-operated drag-line excavator with a 50-foot boom the coal consumption per cubic yard was found to be 10 pounds. The boiler was replaced later with another of 35 per cent greater capacity, for which the fuel consumption was only slightly over 7 pounds per cubic yard.

## ELECTRIC POWER.

The United States Reclamation Service used electrically operated drag-line excavators with 1¼-yard buckets and 50-foot booms, mounted on caterpillars, in the excavation of 3,800,000 cubic yards. The ditches varied from 5 to 10 feet in base width, had 1½ to 1 and 2 to 1 side slopes, and averaged 10 feet deep. The excavation per mile was approximately 40,000 cubic yards. Eighty-horsepower motors were used to move the machines while 40-horsepower motors operated the swinging drums. The average amount of current used was 0.88 kw. h. per cubic yard, including all line and transformer losses. In sandy-loam soil only 0.4 kw. h. per cubic yard was required. The transmission lines consisted of three No. 4 copper wires on 30-foot poles carrying current at 4,000 volts. This was transformed to 440 volts at the machines. The lines were torn down and rebuilt as the work progressed.

[2] Kent's Mechanical Engineer's Pocketbook, 7th ed., p. 462.

TABLE 2.—*Fuel consumption per unit of output for drag-line excavators used by the United States Reclamation Service.*

| Size of bucket. | Length of boom. | Traction. | Fuel. | Total excavation. | Fuel used per cubic yard of excavation. | | | | Lubricating oil per cubic yard. | Machine efficiency. | | | Power plant. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Coal. | Electric current. | Distillate and kerosene. | Gasoline. | | Operating. | Repairs. | Delays. | Main motor. | Swing motor. |
| *Cu. yds.* | *Feet.* | | | *Cubic yards.* | *Tons.* | *kw. h.* | *Gallons.* | *Gallons.* | *Gallons.* | *Per cent.* | *Per cent.* | *Per cent.* | | |
| 1¼ | 50 | Caterpillar | Electricity [1] | 485,963 | | 0.39 | | | | 80.8 | 8.0 | 11.2 | 80 h. p. | 40 h. p. |
| 1¼ | 50 | do | do | 1,563,052 | | .80 | | | | 72.5 | 14.7 | 12.8 | do | Do. |
| 1¼ | 50 | do | do | 581,986 | | .41 | | | | 75.9 | 11.5 | 12.6 | do | Do. |
| 1¼ | 50 | do | do | 1,210,923 | | .80 | | | | 73.8 | 13.4 | 12.8 | do | Do. |
| 1¼ | 50 | do | do | 1,887,715 | | .80 | | | | 74.2 | 17.5 | 8.3 | do | Do. |
| 1¼ | 50 | do | do | 125,405 | | .454 | | | | 77.4 | 14.3 | 8.3 | do | Do. |
| 1¼ | 50 | do | do | 1,593,175 | | .80 | | | | 73.7 | 17.5 | 8.8 | do | Do. |
| 1¼ | 50 | do | do | 106,690 | | .564 | | | | 65.8 | 23.7 | 10.5 | do | Do. |
| 1½ | 50 | do | do | 57,650 | | .373 | | | | 78.3 | 12.8 | 8.9 | 100 h. p. | 50 h. p. |
| 1½ | 50 | do | do | 27,855 | | .539 | | | | 54.4 | 34.1 | 11.5 | do | Do. |
| 1 | 50 | Wheel | Coal | 160,192 | 0.003 | | | | | 83.0 | 5.2 | 11.8 | 30 h. p. boiler | |
| 1 | 40 | Walking | Gasoline | 281,400 | | | | 0.043 | | 57.5 | 20.9 | 21.6 | 45 h. p. 3 cyl. engine | |
| 1 | 40 | Wheel | Distillate | 222,351 | | | [2] 0.107 | | | 66.0 | 22.0 | 12.0 | do | |
| 1 | 50 | do | do | 224,686 | | | [2] .067 | | | 79.0 | 15.0 | 6.0 | | |
| 1 | 40 | do | Coal | 566,904 | .0021 | | | | 0.0005 | 60.0 | 24.0 | 16.0 | | |
| 1 | 40 | do | do | 256,272 | .0017 | | | | | 54.4 | 22.8 | 22.8 | | |
| 1 | 40 | Walking | Gasoline | 159,000 | | | | .080 | | 69.0 | 9.3 | 21.7 | 50 h. p. 3 cyl. engine | |
| 1 | 40 | do | do | 204,300 | | | | .058 | | 57.7 | 19.2 | 23.1 | do | |
| 1 | 45 | do | do | 11,800 | | | | .110 | .0049 | 77.0 | 11.5 | 11.5 | 55 h. p. 3 cyl. engine | |
| 1 | 40 | do | do. [3] | 275,239 | | | [4] .017 | .072 | | 72.5 | 9.1 | 18.4 | 50 h. p. 3 cyl. engine | |
| 1 | 40 | do | do. [3] | 126,302 | | | [4] .023 | .094 | | 64.4 | 17.0 | 18.6 | 70 h. p. engine | |
| 1 | 40 | do | do | 110,317 | | | | .082 | | 60.9 | 8.3 | 30.8 | 55 h. p. engine | |
| 1 | 40 | do | do | 93,639 | | | | .059 | | 59.0 | 41.0 | 0 | 45 h. p. 3 cyl. engine | |
| 1 | 40 | do | do. [5] | 90,616 | | | [2] .046 | .071 | .009 | 56.0 | 31.0 | 13.0 | do | |
| 1 | 40 | do | Distillate | 183,018 | | | [2] .095 | .003 | | 87.2 | 9.1 | 3.7 | 45 h. p. engine | |
| 1 | 40 | do | do | 86,633 | | | [2] .119 | | | 70.5 | 20.1 | 9.3 | 50 h. p. engine | |
| 1 | 50 | do | do | 10,212 | | | [2] .088 | .009 | | 88.0 | 1.0 | 11.0 | | |
| 2½ | 55 | do | do | 148,268 | | | [2] .062 | .0049 | .0046 | 75.0 | 15.0 | 10.0 | 100 h. p. 2 cyl. engine | |
| 1¼ | 50 | Rollers | Coal | 595,619 | .003 | | | | | 64.3 | 17.5 | 18.2 | | |
| 1¼ | 50 | do | do | 789,894 | .0026 | | | | | 70.9 | 13.7 | 15.4 | | |

[1] All motors use current at 440 volts. [2] Distillate. [3] Kerosene used part time. [4] Kerosene. [5] Distillate used part time.

The data in Table 2 were compiled from information furnished by the United States Reclamation Service.

A drag-line excavator, having a 100-foot boom and a 3½-yard bucket was operated by electricity on work in the Miami Conservancy District. During two months' operation, in which 149,186 cubic yards were excavated, the electrical energy consumed was 106,200 kw. h., or 0.71 kw. h. per cubic yard.

In the operation of a 15-inch centrifugal pump,[3] having a 54-inch runner, a 500 horsepower synchronous motor, running at 720 revolutions per minute, was used. The pump was run at two speeds, 250 revolutions per minute and 300 revolutions per minute, the lower speed being used for discharge lines up to 1,500 feet long and to a lift of 10 to 12 feet, while the higher speed was used for greater discharge lengths and heads. The cutter head running at from 10 to 20 revolutions per minute, was driven by a 50-horsepower slip-ring motor, and the main hoisting drum by a 30-horsepower motor of the same type. Under average conditions the output was 5,600 cubic yards per day of two shifts, and the entire plant used approximately ¾ kw. h. per cubic yard.

## INTERNAL-COMBUSTION ENGINES.

On the Rio Grande project the United States Reclamation Service[4] has been using drag-line excavators, operated by internal-combustion engines on the construction of drainage ditches. The ditches average 10 feet deep, with 1½ to 1 side slopes and have from 10 to 30 foot bottoms. Three 8-hour shifts were run, each crew consisting of one operator, one engineman, and one helper. General repair and cleaning-up work was done on Sundays. In the construction of the ditches much quicksand was encountered. Table 3 gives operating data on 1½ cubic yard 50-foot boom drag-line excavators, mounted on caterpillars.

The total number of operating shifts for the four old machines using the 98-horsepower engines was 3,592. Of this time 49 per cent was spent in actual digging, 38 per cent in repairing, and 13 per cent in delays. The average excavation per shift of 8 hours was 409 cubic yards. The total number of operating shifts for the four old machines equipped with the 125-horsepower engines was 1,020. Of this time 60 per cent was spent in actual digging, 22 per cent in repairing, and 18 per cent in delays. The average excavation per shift of 8 hours was 486 cubic yards. The total number of operating shifts for the four new machines equipped with the 125-horsepower engines was 679. Of this time 64 per cent was spent in actual digging, 19 per cent in repairing, and 17 per cent in delays.

[3] Eng. News Rec., vol. 72 (1915), p. 136.
[4] Ibid., vol. 83 (1919), p. 543.

The average excavation per shift of 8 hours was 661 cubic yards. The total number of 8-hour operating shifts for all the machines for 73 months of operation was 5,291. Of this time 53 per cent was spent in actual digging, 33 per cent in repairing, and 14 per cent in delays. The average excavation per 8-hour shift was 456 cubic yards.

TABLE 3.—*Operating data for drag-line excavators used by the United States Reclamation Service on the Rio Grande project.*

| Time operating. | Length dug. | Excavation. | Fuel used. | Fuel consumption. Total. | Fuel consumption. Per shift. | Fuel consumption. Cubic yards per gallon. | Gasoline. Total. | Gasoline. Per shift. | Lubricating oil. Total. | Lubricating oil. Per shift. |
|---|---|---|---|---|---|---|---|---|---|---|
| FOUR OLD MACHINES EQUIPPED WITH 6-CYLINDER 98-HORSEPOWER ENGINES. | | | | | | | | | | |
| *Months.* | *Miles.* | *Cubic yards.* | | *Gallons.* | *Gallons.* | | *Gallons.* | *Gallons.* | *Gallons.* | *Gallons.* |
| 49.5 | 36.2 | 1,467,422 | Kerosene[a] | 25,859 | 41.0 | 7.3 | 4,039 | 6.4 | 1,866 | 3.0 |
| | | | Distillate | 70,964 | 37.9 | 12.3 | 8,607 | 4.6 | 8,949 | 4.8 |
| FOUR OLD MACHINES EQUIPPED WITH 4-CYLINDER 125-HORSEPOWER ENGINES. | | | | | | | | | | |
| 13.3 | 10.0 | 495,418 | Distillate | 42,292 | 41.5 | 11.7 | 5,386 | 5.3 | 2,902 | 2.8 |
| FOUR NEW MACHINES EQUIPPED WITH 4-CYLINDER 125-HORSEPOWER ENGINES. | | | | | | | | | | |
| 10.4 | 9.8 | 449,110 | Distillate | 33,168 | 48.8 | 13.5 | 3,739 | 5.5 | 1,691 | 2.5 |
| TOTAL AND AVERAGES FOR ALL MACHINES. | | | | | | | | | | |
| 73.2 | 56.0 | 2,411,950 | Distillate | 146,424 | 41.0 | 12.4 | 17,732 | 5.0 | 13,542 | 3.8 |

[a] Fuel and oil consumption are given for 1918 only, though time and excavation figures include work in 1917.

A study of Table 3 reveals some interesting facts. More kerosene than distillate was required per shift, whereas more lubricating oil was required per shift when using distillate than when using kerosene. When kerosene was used more gasoline was required per shift than when distillate was used. The average cost of kerosene per gallon was 13 cents, and that of distillate was 14.3 cents. Gasoline cost 25 cents and lubricating oil 61 cents per gallon. At these prices the fuel and oil cost per shift when using kerosene was $8.76 and when using distillate $9.49. It was stated that distillate was substituted for kerosene owing to the lubricating difficulties caused by kerosene, and that distillate proved to be a more efficient fuel for the great variation in loads.

During the time of operating, 73.2 months of three 8-hour shifts, $5,347.18 was spent for wire rope, an average of $0.0023 per cubic yard.

## DETERMINATION AND ANALYSIS OF COST DATA.

Cost data, if they are to have permanent value and be independent of fluctuating wages and prices, must be expressed in absolute terms, such as labor hours, fuel consumption per unit of output, average output per unit of time, etc. Moreover, the cost of operation alone does not give the cost of any project. The cost of securing the contract, assembling the machinery to do the work, together with the many items associated with assembly, must also be included, as well as repairs, depreciation, and interest, and the contractor's profit.

In estimating the unit cost of a project the cost of installing and operating the machine or machines to be used, together with interest charges, depreciation, and lost time, is computed and the amount divided by the engineer's estimate of yardage. The output will not be the same on all jobs; for this reason experience with different soils and conditions is valuable in estimating work. A record of quantities under different conditions is of greater value than a record of costs alone.

Let it be assumed that a floating dipper dredge is to be used on a project. The weight of the machinery and the number of cars required for shipping must be known. The same information must be had with respect to the material for the hull. With these data the freight charges can be determined. The number of men and the time required to dismantle the dredge, the number of wagonloads, the length of haul to the siding, the condition of the roads, and the time required for hauling must be determined, together with data on hauling the equipment from the railroad to the project and the number of men and the time required to assemble the dredge. These are all items which must be known and used in determining the cost of placing this machine on the job ready to work. In addition, the cost of dismantling and of building cabin boats, coal barges, and launches must be considered.

In determining the cost of operation, the number of men required, the average output per shift, the fuel consumption per shift or unit of output, and the transportation of fuel and supplies to the machine are items which must be considered. The time lost in moving due to weather conditions should also be taken into consideration. In the Northern States frost in the ground delays the work from three to four months each year. Likewise the cost of repairs, depreciation, interest, insurance on the dredge, and workmen's liability insurance must be taken into account. The same cost items must be reckoned for any type of excavator.

front end of the hull should always be of double thickness to prevent damage and possible sinking should the dipper strike the hull.

In the larger sizes built at the present time the practice is to make the hull of the same width, top and bottom. On some of the smaller machines, especially those with steel hulls, the top is made wider than the bottom. Hulls must be very carefully calked, since in operating the dredge the strains will tend to loosen poor calking.

Hulls are always built upon blocking at the place where the proposed work is to begin and usually are launched sidewise into the stream or pit. If there is no natural channel available for launching the hull, an artificial pit must be excavated. This may be done by means of teams and slips, the excavated material being deposited on the sides of the pit for holding the water. Where the ground at the launching site is so wet as to preclude the use of teams and slip scrapers, a small tower and scraper device may be used. In one case, with such an arrangement, the scraper was operated by a small tractor. Some operators blast out their pits with dynamite. It is not advisable to launch a hull in less than 2½ feet of water.

It often is necessary to dismantle a dredge in order to move it from one project to another. A wooden hull is frequently used on more than one job if the shipping distance between projects is not too great, but a hull usually requires some new timbers when it is rebuilt. If the hull is to be used two or more years without rebuilding, longleaf yellow pine is probably the best material for construction. Should the hull be rebuilt every other year or so, Douglas fir is more desirable. To build a wooden hull of new lumber usually takes about one-third longer than to rebuild an old hull. This is due to the fact that the new timbers must be cut to dimensions and all bolt holes drilled. Some contractors use electric drills operated by generators run by gasoline engines and thus save much time in drilling bolt holes.

Steel hulls usually are assembled much more quickly than wooden hulls, but require more cars for shipping.

Some manufacturers furnish pontoon hulls of either wood or steel, the pontoons being built and calked at the factory. The sections can easily be shipped and the hull assembled in a short time, the pontoons being placed crosswise of the hull. They not only make a rigid hull, but comprise separate compartments, making it practically impossible for such a dredge to sink. The draft of a dipper-dredge hull is approximately one-half the depth of the hull.

The machinery for a dredge ordinarily is placed on the main deck of the hull. Sometimes, however, it is placed below the main deck in order to gain head room. The boiler and coal bins are sometimes placed on a deck from 1 to 3 feet lower than the main deck.

### THE BOILER.

The boiler most commonly used on floating dredges is of the locomotive type, with either open or water bottom. This type is adapted to burning the various kinds of fuel. The Scotch marine return-flue boiler is the more economical of fuel and is used to some extent. It does not burn wood as well as the locomotive type. The ordinary working pressure in these boilers ranges from 125 to 150 pounds. The capacity of the boiler should be at least 25 per cent greater than that theoretically required to operate the engines. Because foul water must often be used, the boiler should have two separate feeds, usually an injector and a duplex pump. In addition to these, some operators include an inspirator.

Boiler compounds frequently are used to prevent foaming. Where the water is muddy, it can be filtered through hay or gravel in a box or barrel through which the feed water is pumped. Clear water may sometimes be obtained by extending the intake pipe behind the dredge a hundred feet or so, supporting it on barrels or similar floats.

Manufacturers generally designate boilers by their size instead of their horsepower, although users prefer to designate them by the horsepower produced. Makers usually consider that 10 square feet of outside heating surface covered by water is necessary for each horsepower developed. Table 4 gives the sizes of locomotive-type boilers ordinarily furnished for the various sizes of floating dipper dredges.

TABLE 4.—*Dimensions and cost of locomotive-type boilers.*

| Capacity of bucket. | Size of boiler. | Heating surface. | Grate area. | Weight. | Approximate price. |
|---|---|---|---|---|---|
| *Cu. yds.* | | *Sq. ft.* | *Sq. ft.* | *Pounds.* | |
| 1 | 50 inches by 12 feet | 410 | 14.5 | 10,200 | $2,275 |
| 1½ | 54 inches by 16 feet 4 inches | 667 | 21.4 | 14,400 | 3,175 |
| 2 | 54 inches by 18 feet 8 inches | 808 | 21.4 | 15,750 | 3,325 |
| 2½ | 60 inches by 20 feet 7 inches | 1,147 | 28.8 | 21,800 | 4,975 |
| 3 | Two 54 inches by 16 feet 4 inches | | | | |
| 4 | Two 60 inches by 17 feet | 1,886 | [1] 21.9 | [1] 18,000 | |
| 5 | Two 60 inches by 20 feet 7 inches | 2,294 | | | |

[1] Each.

### ENGINES.

Floating-dipper dredges are of three types, according to the method in which the hoisting rope is reeved; that is, the dipper is operated by either a one, two, or three-part cable. With a single-line hoist the power of the engines is compounded through gears, whereas with the double and triple hitch the power is compounded between the point of the boom and the dipper by means of sheaves attached to the dipper bail. The speed of the main engines and of the bucket, as well as the digging pull on the bucket, are practically the same for any one size of dredge on all three types of hoist, the variation in the cable speed being taken care of in the diameter of the hoisting drum and the ratio of the gears. Thus a single-line hitch requires heavier machinery and a higher gear-ratio, while a triple-line hitch has a lower ratio of gears and a greater cable speed than either of the other two types.

The hoisting and backing machinery for all three types follows the same general design and construction. With a triple-line hitch the hoisting drum is mounted directly ahead of the main engines and is geared directly to the engine pinion, while with the single and double-line hitches the hoisting drum is compound-geared from the engines so as to decrease the cable speed and increase the pull. The engines are of double nonreversible type, throttle-controlled. On the larger sizes of dredge the hoisting and backing drums have grooved surfaces and are moved by steam-set frictions of the outside-band type, the cylinders for operating the frictions being attached to the spokes of the larger gears and connected to the friction bands by levers keyed to crank pins inserted through the gears near their rims. The entire mechanism is mounted on a structural-steel base and is kept in alignment by means of cross braces and gusset plates.

Floating dipper dredges are designed with the pulls on the dipper bail shown in Table 5.

TABLE 5.—*Pull on dipper bail for various sizes of dipper.*

| Capacity of machine. | Pull. |
|---|---|
| *Cubic yards.* | *Pounds.* |
| 1 | 30,000 |
| 1½ | 39,000 |
| 2 | 45,000 |
| 2½ | 56,000 |
| 3 | 63,000 |
| 4 | 80,000 |
| 5 | 104,000 |

The swinging engines are of the double-reversible type, compound-geared to either a single drum or to a long shaft which has a drum at each end for direct leads to the swinging circle. Only one lever is required to reverse and control the engine. On the small dredges, which have little deck space for machinery, the swinging is usually done by means of friction drums operated by either the main engine or the hoisting and backing engines.

The machinery for operating the spuds varies both with the type of spud used and with the make of dredge. Telescopic bank spuds may be raised by a friction hoist and the pinning up of the dredge accomplished by swinging the boom. In this case the spuds must be fitted with racking. The raising of the spuds and the pinning up of the dredge may also be accomplished by means of independent units for each spud. The engines for the side spuds are compound-geared to grooved drums carrying two lines of cable, one for hoisting the spud and the other for pinning up the dredge. After the dredge is raised or pinned up the spuds are held in place by brake bands on the spud machinery.

For lighting equipment on steam-operated machines many contractors prefer the steam-driven impulse-type turbine, direct connected to the generator. Steam is used from the boiler which supplies the engines on the dredge, and thus no extra power equipment is needed to drive the generator. A turbine generator suitable for a steam-driven excavating machine will cost approximately $210.

### A FRAME.

The **A** frame is a tower composed of timber or steel members securely anchored on the deck near the front and joined at the top by a cast-steel head (see Pl. I). The **A** frame may have either two or four legs. In the latter case the two front, or main, legs are set in a vertical plane. If only two legs are used they are inclined slightly forward. The **A** frame must be strongly guyed and held rigidly in position, as the severe stresses from the outer and loaded end of the boom are carried by the top of this tower. Failure of any part of the **A** frame may result in serious damage to the dredge, and even loss of life. The height is governed by the required elevation of the end of the boom, which in turn is determined by the depth of excavation and the distance to which the excavated material must be placed. On the top of the head block is a large pin on which the yoke revolves, this latter being a short beam to the ends of which are attached the cables which support the outer end of the boom.

### SWINGING DEVICE.

The swinging device used on the different makes of dredge varies greatly. In some cases it consists of a circular double-channel frame, firmly anchored to the deck, with several sheaves bolted at intervals in the circumference of the frame to carry the cable that travels over them in swinging the boom. In this fixed type of swinging device a circle of large diameter can be used. There is also the movable type of swinging circle. This generally consists of a solid iron circle mounted on a pivot. The heel of the boom is over the point of the pivot, and the boom is braced to the circle. This type requires more deck room than does the first named. The turntable may be placed on deck (Pl. I, fig. 1) or overhead, but the deck plan is generally used.

### SPUDS.

Spuds are heavy timber or steel members, the purpose of which is to hold the dredge in position while operating. One is placed on each side near the front and the third in the center line of the boat at the stern. Vertical spuds extend directly downward at the side of the hull and rest on the bottom of the excavated channel. They are used on deep-water dredges or on those for excavating large channels.

For a dredge with a narrow hull, bank spuds which extend outward and rest on the ground surface are preferable, since they give a large bearing surface and the footing is usually on solid ground. These are important features, as a longer boom and a larger bucket can then be used on a narrow hull.

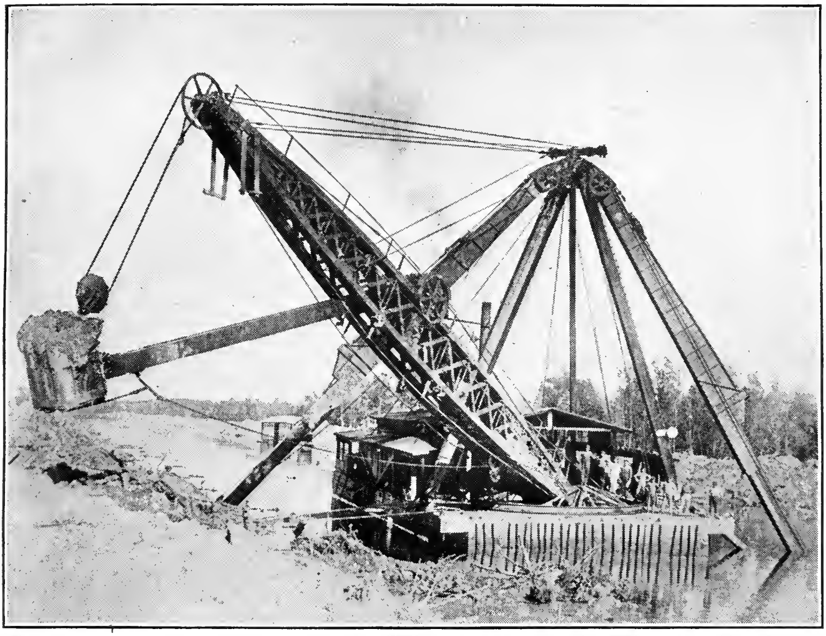
There are various patented bank spuds. One is the convertible bank and vertical power spud. This type can easily be changed from a bank spud into a vertical spud and is convenient in crossing old channels, digging cut-offs, or making a double cut. Another type is the telescopic bank spud, so designed that the spud is either lengthened or shortened by means of a telescopic device. There are other styles of bank spuds which, although they possibly do not have as wide a range as the telescopic type, can nevertheless be operated successfully several feet above or below the water surface. Plate I, Figure 1, shows a dipper dredge equipped with telescopic bank spuds.

TABLE 6.—*Sizes of spud feet generally used on bank-spud dredges.*

| Capacity of dredge. | Size of spuds. |
|---|---|
| *Cubic yards.* | *Feet.* |
| 1 | 3½ by 4½ |
| 1½ | 4 by 5½ |
| 2 | 5 by 6 |
| 2½ | 6 by 6½ |
| 3 | 7 by 7 |
| 4 | 7½ by 8 |
| 5 | 8 by 9 |

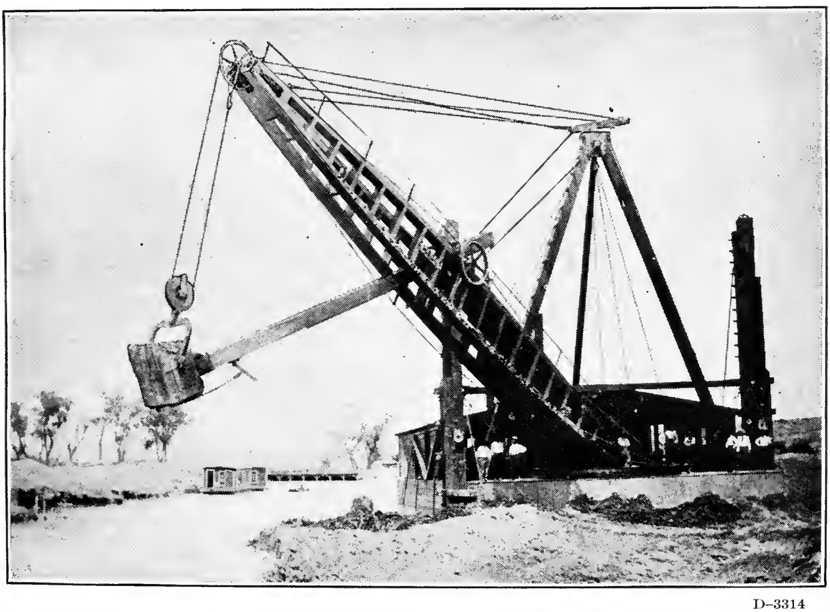
A useful rule to remember for obtaining the distance from center to center of spud shoes on bank-spud dredges is to add from 3 to 5 feet to the length of the boom.

The vertical spuds of various makes are more nearly alike. The rear spud is always of the vertical type and is used to keep the stern of the boat from swinging from side to side as the dredge is operated. It is equipped with an iron point instead of a foot. The spuds are raised and lowered by steel cables connected with the spud machinery. Compressed air is sometimes used to aid in releasing the foot of the spud from the mud; less power is thus required to raise



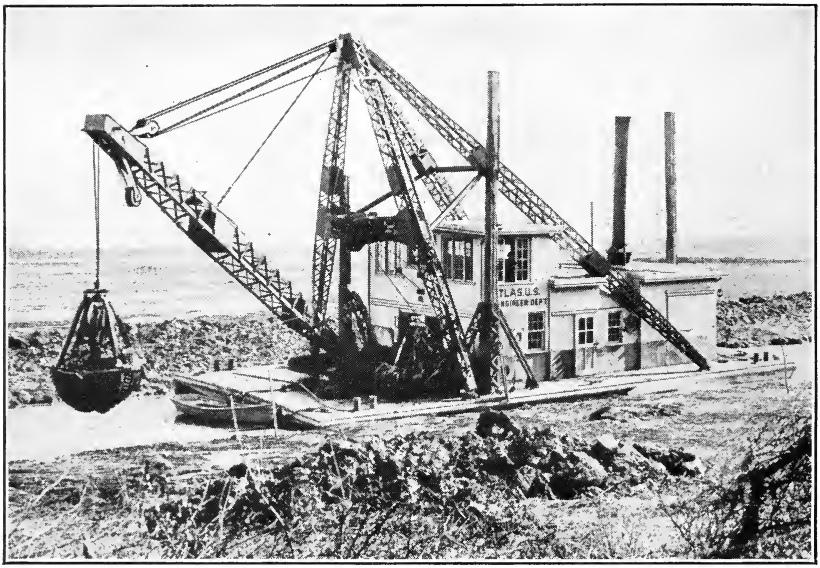
D-2586

FIG. 1.—THREE AND ONE-HALF YARD DIPPER DREDGE EQUIPPED WITH TELESCOPIC BANK SPUDS.



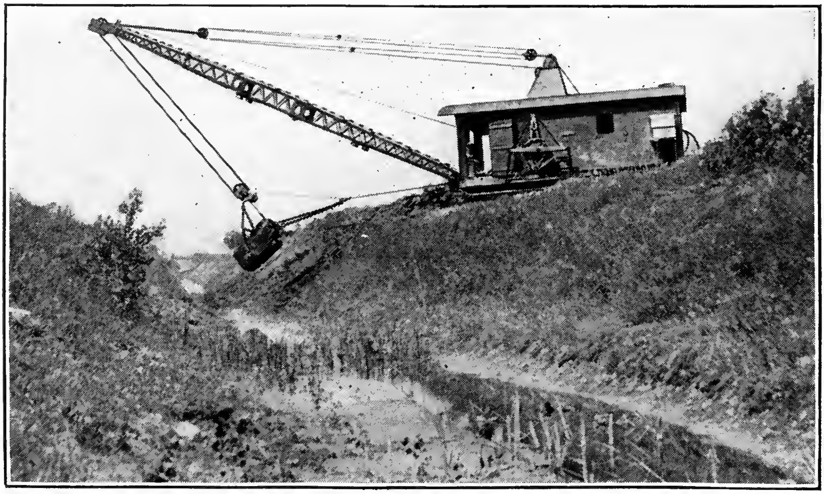
D-3314

FIG. 2.—THREE CUBIC YARD DIPPER DREDGE EQUIPPED WITH VERTICAL SPUDS.




D-701

FIG. 1.—A TYPICAL ORANGE-PEEL DREDGE.



D-3193

FIG. 2.—ENLARGING AN OLD DITCH BY ROTARY DRAG LINE EXCAVATOR WORKING FROM BANK.

the spud. All types of spuds must be equipped with a strong locking device; they must also be so designed that little time is lost in raising or lowering them. A dipper dredge with vertical spuds is illustrated in Plate I, Figure 2.

### THE BOOM.

The boom may be built of either steel or wood. In the former case it is made of standard structural sections strongly riveted together. Wooden booms are used quite extensively, as they are more flexible and will spring back to their original shape if deflected slightly out of line. Of wooden booms several different styles are built. One which is spread wide at its foot makes possible the swinging of long booms with the revolving deck-swing circle. Long booms (75 feet or over) are always of the open or knee build with a solid filler at the lower end and the chords sprung over posts or cross bulkheads (Pl. I, Fig. 1). This construction greatly reduces wind pressure when swinging. The intermediate lengths differ somewhat in design and are of both the solid-filler type and the open type. All booms are trussed on the top, bottom, and sides. They are usually suspended at an angle of 30° from the horizontal.

Practice has taught that the length of boom must bear a definite relation to the width of the hull. Even on a large dredge it is not advisable to have the boom longer than 80 to 90 feet, although manufacturers will build them 100 feet long if desired. Large dredges with long booms are much slower in operating. The same number of men is required for operation in either case.

The lower end of the boom is pivoted. The upper and outer end is connected to the yoke at the top of the A frame by means of adjustable wire cables. A sheave at the outer end of the boom carries the cable leading from the dipper through the fair-lead sheaves at the lower end of the boom and thence to the hoisting drum.

On the early type of dipper dredge, chains were used for hoisting and backing. These were hard to install and would break without warning. Steel cable has entirely replaced the chain, since it is less expensive, easier to install, clean, and noiseless; also its weakening, due to wear, is more readily detected and accidents are therefore less likely.

### DIPPER AND DIPPER HANDLE.

Dipper handles are usually of combined wood and steel construction. Those made entirely of steel have not given satisfaction, as a sudden stress may throw them permanently out of line. In the combination type the elasticity of the wood allows some deflection without permanent injury. The wooden handles are covered with steel plates on top and bottom; on the larger sizes all sides are armored.

On the under side is a cog rack which moves over pinions mounted on the upper side of the boom. The handle must be of sufficient stiffness to prevent bending when the dipper is being filled.

The method of attaching the dipper to the lower end of the handle is practically the same for all sizes of dredges; the connection is made by means of castings, pin-connected to the back of the dipper, so that the pitch of the dipper may be changed to suit the kind of material excavated.

On dredges ordinarily used in drainage work the dipper or bucket varies in size from three-fourths to 4 or 5 cubic yards. The dipper varies somewhat in shape with different manufacturers. For work in ordinary material the cutting edge is made of a single steel plate, preferably manganese steel; but if the material is hard, large steel teeth are used to reinforce the cutting edge. The bottom of the dipper is a heavy steel plate, which is hinged to the back and held in place by a spring latch on the front of the dipper. The latch is operated by the craneman, who thus dumps the contents of the dipper. The bottom is so hinged that as the dipper is lowered into the ditch the weight of the bottom causes it to close and latch automatically.

The larger the dipper used the larger must be the engine and boiler and, in fact, all of the parts, including the hull. Thus the size of a dipper dredge is determined by the capacity of its dipper. Table 7 gives the dimensions, weights, and approximate prices for the various sizes of dippers.

TABLE 7.—*Dimensions, weights, and prices of dippers.*

| Capacity of bucket. | Inside length. | Inside top width. | Inside bottom width. | Height. | Weight. | Approximate price. |
|---|---|---|---|---|---|---|
| *Cu. yds.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Pounds.* | |
| ½ | 28 | 30¾ | 31½ | 27 | 1,725 | $500 |
| ¾ | 31½ | 34½ | 35½ | 30 | 2,700 | 690 |
| 1 | 34 | 40½ | 41½ | 35 | 3,450 | 810 |
| 1½ | 40 | 43½ | 44½ | 37 | 4,600 | 955 |
| 2 | 43 | 48 | 49 | 42 | 7,100 | 1,325 |
| 2½ | 44½ | 52 | 52 | 46 | 11,500 | 2,170 |
| 3 | 48 | 56 | 57½ | 50 | 12,975 | 2,330 |
| 4 | 53 | 58½ | 60 | 53 | 14,025 | 2,550 |
| 5 | 54 | 66 | 66½ | 54 | .......... | .......... |

## ACCESSORY EQUIPMENT.

To keep a floating dipper dredge in operation barges must be provided for transporting the fuel to the dredge. These barges are generally towed by launches. The fuel barges and the hull for the launch are built at the time the dredge is assembled. The launches are propelled either by a screw propeller or a paddle wheel driven by an internal-combustion engine of from 8 to 12 horsepower.

House boats with either a one-story or two-story superstructure must be built as living quarters for the dredge crews. The one-story house boat usually contains three rooms—a combined office and sleeping room for the foreman, a sleeping room for the two dredge operators, and a large room for the rest of the crew. Another house boat is used for the galley and mess room. On the two-story boats the first floor contains the galley and mess room and the upper floor the crew's quarters.

### COST OF FLOATING DIPPER DREDGES.

The cost of dredges advances rapidly as the size and capacity are increased. Dredges of the same rated capacity also vary somewhat in cost with different manufacturers. All the machinery is usually made at the shops of the manufacturer. The material for the hulls may also be supplied by the manufacturer, but often the purchaser obtains lumber in the open market and builds the hull in the field. The cost of hauling the material and machinery from the railroad to the place of erection, the local price of labor, and the conveniences for housing and feeding the workmen are factors which enter into the cost of a machine of any type.

Table 8 gives the approximate costs of the equipment for the various sizes of dredges of the type shown in Plate I as well as the weight and the number of cars required for shipping. To this cost must be added the cost of material for the hull, the cost of assembling, and of freight and hauling.

TABLE 8.—*Weight and cost of dipper-dredge equipment, exclusive of hull.*

| Size of bucket. | Length of boom. | Approximate cost (1919). | Weight. | | Cars required for shipping. |
|---|---|---|---|---|---|
| | | | Telescope bank spuds. | Vertical spuds. | |
| *Cu. yds.* | *Feet.* | | *Pounds.* | *Pounds.* | |
| 1 | 40 | $12,600 | 92,000 | 85,000 | 3 |
| 1½ | 50 | 18,600 | 150,000 | 125,000 | 4 |
| 2 | 60 | 25,200 | 190,000 | 160,000 | 5 |
| 2½ | 70 | 31,500 | 250,000 | 220,000 | 6 |
| 3 | 80 | 37,000 | 335,000 | 300,000 | 7 |
| 4 | 85 | 50,000 | 440,000 | 400,000 | 9 |
| 5 | 95 | 66,000 | ........... | ........... | .......... |

The number of cars required for shipping the hull material varies from one to three, depending upon the size of the machine. A three-fourths yard dipper dredge with 30-foot boom equipped with steel pontoon hull will cost about $12,000.

### METHOD OF OPERATING.

With a floating dredge the construction, where practicable, should begin at the upper end of the ditch and proceed downstream. Sometimes it is not feasible to transport the machinery and material to the upper end of the ditch and the dredge must then work upstream.

This is undesirable, unless the fall be slight, since in working upstream dams must be built behind the boat to maintain the necessary water level. The cost of excavation increases with the amount of face, or exposed surface of ditch side. This should not be over 2 feet, and any extra expense required to maintain the water at that level means increased cost of excavation. In working downstream the ditch remains full, and the dredge, floating high, can dig a much narrower bottom than if working upstream in shallow water. Moreover, when floating low the dipper may not properly clear the spoil bank. Again, in working downstream, any material dropping from the dipper into the ditch will be washed ahead of the dredge and picked up later, whereas if working upstream any material dropped or any silt washed behind the dredge is left to settle in the bottom of the ditch.

The dams may be constructed in various ways. A common method is driving two lines of sheet piling about 6 feet apart directly across the ditch, the piling being held in place by longitudinal timbers across the channel. The space between the piling is filled with earth. The second line of piling is sometimes omitted, and dirt is banked directly against the one line, a method requiring more earth than the other. Some operators cover the piling with canvas to prevent leakage; in this case the piling must be strongly braced. Hopper, or V-shaped, dams are also built. These are constructed by inclining the piling and filling the space between with earth. Some operators provide spillways in dams to take care of any unusual rise of water caused by heavy rains. Boxes of dynamite are often buried in these temporary dams for demolishing them after they have served their purpose.

The floating dipper dredge moves itself ahead by means of the dipper. The spuds are first loosened from their bearings, and the dipper is run ahead of the machine and rested on the natural ground surface in front of the ditch. The spuds are then raised, and the engines operating the backing drums are started; the dredge, being free, is thus pulled ahead. The spuds are then lowered, the dredge pinned up, and excavation resumed.

In timbered country the right of way must be cleared. In many cases the timber cut will supply sufficient fuel for the dredge. The removing of logs from the right of way by the dredge decreases the output materially; therefore they should be cut in lengths of 16 to 20 feet, so that they can be handled readily. Although it is possible to excavate stumps with the larger floating dredges without first blasting them, it is preferable to shatter them with dynamite to avoid the strain on the machinery, which shortens the life of the dredge. Special care must be taken to loosen stumps near the banks of the new ditch, for the dirt can be dug away from but one side of them.

An engineer, a craneman, a fireman, and one or more deck hands are required to operate a dipper dredge. The output, loss of time due to breakdowns, and cost of repairs depend almost wholly upon their skill and efficiency. The engineer should be an all-round mechanic, experienced in dredging. The cost of repairs depends largely upon the operator; a careless operator will cause unnecessary breakdowns. It is not only repairs of machinery but also the time lost that increases the cost of the output. It is well established that it is not the initial cost of a dredge or of any machine that consumes the profits, but, rather, the operating and overhead expenses. So important a matter is the efficiency of the operator and craneman that where mosquitoes are troublesome electric fans are often used.

### COST OF OPERATION.

The cost of dredge work depends upon a number of factors: The locality of the work, the kind of soil, repairs, delays, labor, etc., influence the actual cost of any work. If the water level can naturally be maintained within a foot or so of the surface of the ground the cost of excavation can be reduced very low with this type of machine. One great item is labor cost.

To obtain economical results there must be a certain minimum yardage for the dredge to remove, for installation charges must be included in the cost of the work. Any excess in yardage over this minimum would reduce the cost per cubic yard, but this unit cost decreases very slowly as the yardage increases and finally becomes practically fixed.

Table 9 gives for each size of dredge the size of job above which an increase in amount of excavation will not result in an appreciably lower cost per cubic yard, as well as the average output per month, the average coal consumption per 10-hour shift (using a good grade of coal), and the time and number of men required to erect and dismantle.

TABLE 9.—*Data useful in estimating cost of excavation by floating dipper dredge.*

| Size of dipper. | Usual length of boom. | Number of men and time required— | | Minimum economical yardage. | Average output per month with double shift (52shifts). | Average coal consumption per shift. |
|---|---|---|---|---|---|---|
| | | To assemble dredge with old hull. | To dismantle dredge. | | | |
| *Cu. yds.* | *Feet.* | | | *Cu. yds.* | *Cu. yds.* | *Tons.* |
| ¾ | 30 | 8 men, 30 days[1] | 8 men, 1½ weeks | 100,000 | 20,000 | 1½ |
| 1 | 40 | 10 men, 2 months | 10 men, 3 weeks | 300,000 | 27,000 | 2 |
| 1½ | 50 | 12 men, 2 months | 12 men, 3 weeks | 500,000 | 37,000 | 3 |
| 2 | 55 | 12 men, 3½ months | 12 men, 1½ months | 800,000 | 47,000 | 3½ |
| 2½ | 65 | 15 men, 3½ months | 15 men, 1½ months | 1,000,000 | 55,000 | 3¾ |
| 3 | 80 | 20 men, 6 months | 20 men, 2 months | 1,500,000 | 70,000 | 4 |
| 3½ | 80 | do | do | 2,000,000 | 75,000 | 4¾ |
| 4½ | 90 | | | 3,000,000 | 80,000 | 6 |

[1] Dredge equipped with steel pontoon hull.

A single month may show an output greatly exceeding the above figures. They are given as an average output on an entire project, including all delays and breakdowns.

To determine the haulage costs from railroad siding to the place of erection the length of haul and the condition of roads must be known. For hull material, on fairly dry roads, from 800 to 1,000 feet B. M. is considered a load; and for machinery about 3,000 pounds. It is often necessary to use the 8-wheeled log wagon for hauling.

In operation the cable expense is an important item. A hoisting cable ordinarily will dig 60,000 yards before it must be discarded, although some operators count on using one a month. The worn part can sometimes be used for backing or swinging lines, depending on the place of the break.

When new equipment is purchased some contractors expect the job to pay for the new machine as well as render a profit. Contractors using old equipment have little advantage over purchasers of new equipment when bidding for work unless they can float the dredge, already assembled, to the new job. When a contractor has several machines on one job he usually installs, at a central point accessible to a railroad, a completely equipped machine shop, so that he can make all necessary repairs in the shortest possible time. The expense of this plant must also be included in the contract price. All successful contractors operate two shifts, as the time of completion is thereby reduced nearly one-half and the overhead charges reduced accordingly. The output of the day shift compared with that of the night shift is a disputed question. Some operators say that the day shift will excavate more material than the night force, while others maintain the reverse; some assert that the increased output of two shifts over that of one shift is about 75 per cent. The night shift has the advantage that minor repairs are left for the day shift; moreover no fuel is taken on during the night, nor do visitors come to interfere with operations.

Many contractors pay their crews, in addition to a fixed monthly wage, a bonus for every yard dug over a certain figure fixed for each job as the conditions warrant. These bonuses are divided among the men in proportion to their base pay. When two shifts are operated the bonus is computed on the total output for the month and not on the output per shift. Crews are usually changed from day to night shifts and vice versa once a week. When operating several machines on one project, contractors save by shifting men from a machine which is idle on account of repairs to other machines to take the place of the crews taking time off. If the men can not be used on other machines they may be used in the repair shop. Experience has shown that keeping men busy reduces breakdowns.

Of the various sizes of floating dredges, most operators agree that the $2\frac{1}{2}$ or 3 cubic-yard dredges are the most economical in cost per cubic yard.

## SELECTION OF DREDGES.

The floating dipper dredge is admirably adapted to the excavation of drainage ditches having sufficient width and depth and the necessary supply of water for floating the machine, especially where the ground is swampy or covered with trees or stumps rendering impracticable the use of teams or dry-land machinery. No other type of excavator is so well fitted for digging ditches in timbered country or where large stumps will be encountered. The dipper dredge, however, is not well adapted to digging channels of less than 100 square feet in cross-section, although it is used in the construction of smaller ditches. Standard types of dipper dredges are not adapted to digging ditches more than 1,200 square feet in cross-section, although ditches with 123-foot base and 11 feet deep have been dug with a 90-foot boom, vertical-spud dredge. As ordinarily operated, the dipper dredge constructs a more or less ragged and irregular ditch, yet in the hands of a skilled operator very good results can be obtained.

In the construction of ditches in the Piedmont section of the southern Atlantic Coast States, floating dipper dredges equipped with $\frac{3}{4}$-yard dippers and 30-foot booms and mounted on sectional steel hulls are used rather extensively. The ditches have ordinarily a top width of from 14 to 20 feet and a length of 5 or 6 miles, involving the removal of 100,000 cubic yards or more of earth. Since the ditches frequently cross an old channel, the floating dredge is better adapted to this work than dry-land machines. Contractors state that the cost of installing a dredge of this size on a job is about $5,000. To justify the installation of this size of machine, a job should cost about $20,000 or more.

A $1\frac{1}{2}$-yard dredge having a 40 or 50 foot boom, a hull 20 to 22 feet wide, and a draft of 3 feet is an economical machine for digging small ditches. A dredge of this size will excavate a ditch through timbered land cheaper than any other type of small excavating machine. On a project adapted to floating dredges, with plenty of water for floating the machines, and where there are a few small laterals with bottom widths of 4 or 5 feet and ranging in depth from 7 to 8 feet, the construction of these small laterals, if dug by the machine used on the larger ditches, will invariably cost more per cubic yard than ditches with 14-foot bottoms, owing to the excess yardage which must be removed by the dredge.

The size of the dredge that should be used depends upon various factors. Not only the greatest and least, but the intermediate cross-sectional dimensions of the proposed ditch should be known and the relative amount of each class, also the width of berm and the side slopes. On small ditches the spread of the spud feet usually determines the width of berm. The total amount of excavation, nature of the material, and whether the dirt is to be dumped on one or both sides are factors that must be considered. A knowledge of the depth of water which can be maintained at a minimum expense is also necessary, and information as to the number and size of stumps to be encountered is of the highest importance. Owing to the expense of knocking down, transporting, and setting up a dredge, it is necessary to select or use one of the size that will do the most work at one building. This requires intimate knowledge of the layout of the proposed work and of the accessibility of the different portions.

The size of ditch best fitted for any size of dredge is one which gives just sufficient clearance for the moving of the dredge. The ditch, at its top, should be about 4 feet wider than the hull of the dredge.

It is the opinion of many contractors that the use of dredges with hulls 18 feet wide or less is to be avoided, except where the ground is so hard that the bank spuds rest firmly and bear the weight of the swinging load; in soft ground it may be cheaper to use a wider hull, even though it is necessary to make the ditch wider than specified.

To determine the particular dredge required for a project, it is necessary to know the limitations of the various sizes of machine and the distances a machine of a given length of boom and dipper handle will dig below water line and dump above water line. The hull, of course, must be of such dimensions as to accommodate machinery of the required dimensions. Table 10 gives the approximate dimensions of different sizes of dipper dredges equipped with different types of bank spuds. The dimensions vary somewhat for different makes of dredges. The size of hull can be varied to suit the needs of the particular job. When material is excavated it swells and occupies more space than before removal. The amount of swell varies, with the excavated material, from 10 to 25 per cent. The angle of repose of the excavated material varies with the character of that material. It is usually taken as a 1 to 1 or 1½ to 1 slope, but in soft, wet material the angle of repose is much flatter.

Table 10.—*Dimensions and limitations of operation of floating dipper dredges.*

| Size of dipper. | Length. Boom. | Length. Dipper handle. | Depth it will dig below water. | Height it will dump above water. | Distance center of hull to center of dump. | Hull. Bank spuds. Size of hull. | Hull. Bank spuds. Lumber M feet. | Hull. Vertical spuds. Size of hull. | Hull. Vertical spuds. Lumber M feet. | Telescopic or convertible spuds. Vertical range of platform. | Telescopic or convertible spuds. Spread of platform. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cu. yds.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *B. M.* | *Feet.* | *B. M.* | *Feet.* | *Feet.* |
| ½ | 20 | 14 | 6 | 5 to 7 | 18 to 20 | 48×10×4 | ...... | ...... | ...... | ...... | ...... |
| | 22 | 15 | 6½ | 6 to 8 | 20 to 22 | 48×11×4 | ...... | ...... | ...... | ...... | ...... |
| | 25 | 17 | 7½ | 7 to 9 | 22½ to 25 | 48×12×4 | ...... | ...... | ...... | ...... | ...... |
| ¾ | 25 | 19 | 8 to 10 | 6 to 8 | 20 to 25 | 54×12×4½ | ...... | 54×18×4½ | ...... | ...... | ...... |
| | [1] 30 | 21 to 22 | 9 to 12 | 8 to 10½ | 25 to 31 | 56×14×4½ | ...... | 56×20×4½ | ...... | ...... | ...... |
| | 35 | 23 to 25 | 10 to 14 | 9½ to 12 | 28 to 35 | 56×16×4½ | ...... | 56×20×4½ | ...... | ...... | ...... |
| 1 | 30 | 24 | 11 | 9 to 12 | 29 to 34 | 65×14×5 | 20 | 65×22×5 | 30 | 12 | 33 |
| | 35 | 25 to 27 | 10 to 13 | 11½ to 15 | 33 to 40 | 66×16×5 | 22 | 65×23×5 | 31 | 14 | 38 |
| | [1] 40 | 28 to 30 | 14 to 14½ | 12 to 17 | 37 to 44 | 70×17×5 | 25 | 70×25×5 | 36 | 16 | 43 |
| | 45 | 31 to 33 | 15½ to 16 | 15 to 18 | 41 to 49 | 70×19×5 | 28 | 70×27×5 | 40 | 18 | 48 |
| | 50 | 34 | 17½ | 18 to 21 | 45 to 50 | 70×22×5 | ...... | 70×30×5 | ...... | ...... | ...... |
| | 55 | 37 | 19 | 21 to 24 | 50 to 55 | 80×24×5 | ...... | 80×32×5 | ...... | ...... | ...... |
| | 60 | 40 | 20½ | 24 to 27 | 55 to 60 | 80×26×5 | ...... | 80×34×5 | ...... | ...... | ...... |
| 1½ | 35 | 26 | 11 | 14 | 35 to 40 | 72×16×5 | ...... | ...... | ...... | ...... | ...... |
| | 40 | 28 to 30 | 13 to 14 | 12 to 16½ | 35 to 45 | 75×18×6½ | 36 | 75×26×6½ | 52 | 16 | 44 |
| | 45 | 31 to 33 | 15 to 16 | 15 to 19 | 40 to 49 | 75×20×6½ | 40 | 75×28×6½ | 56 | 18 | 49 |
| | [1] 50 | 34 to 36 | 16 to 17 | 17 to 21½ | 45 to 5[illegible] | 80×22×6½ | 46 | 80×30×6½ | 63 | 20 | 54 |
| | 55 | 35 to 39 | 17 to 18½ | 20 to 24 | 50 to 60 | 80×24×6½ | 50 | 80×32×6½ | 67 | 22 | 59 |
| | 60 | 38 to 40 | 18 to 20 | 22 to 26 | 55 to 65 | ...... | ...... | ...... | ...... | ...... | ...... |
| | 65 | 38 to 43 | 18 to 21½ | 23 to 29 | 60 to 70 | ...... | ...... | ...... | ...... | ...... | ...... |
| | 70 | 46 | 18 | 26 | 70 to 75 | ...... | ...... | 96×34×7 | ...... | ...... | ...... |
| 2 | 40 | 28 | 13 | 10 to 13 | 35 to 40 | 85×20×6½ | ...... | 85×28×6½ | ...... | ...... | ...... |
| | 45 | 31 | 14½ | 13 to 15 | 40 to 45 | 85×22×6½ | ...... | 85×30×6½ | ...... | ...... | ...... |
| | 50 | 34 to 37 | 16 to 17½ | 15 to 22 | 45 to 55 | 85×24×7 | 57 | 85×30×7 | 72 | 20 | 55 |
| | 55 | 37 to 40 | 17½ to 19 | 18 to 24½ | 50 to 61 | 85×26×7 | 62 | 85×32×7 | 76 | 22 | 60 |
| | [1] 60 | 40 to 43 | 19 to 20½ | 21 to 27 | 54 to 66 | 90×28×7 | 70 | 90×34×7 | 85 | 24 | 65 |
| | 65 | 43 to 46 | 20½ to 22 | 24 to 29½ | 59 to 71 | 90×30×7 | 75 | 90×36×7 | 91 | 26 | 70 |
| | 70 | 46 | 22 | 27 to 30 | 65 to 70 | 100×32×7 | ...... | 100×40×7 | ...... | ...... | ...... |
| | 75 | 49 | 23½ | 30 to 33 | 70 to 75 | 100×34×7 | ...... | 100×44×7 | ...... | ...... | ...... |
| | 80 | 52 | 25 | 33 to 36 | 75 to 80 | 100×36×7 | ...... | 100×46×7 | ...... | ...... | ...... |
| | 85 | 55 | 26½ | 36 to 39 | 80 to 85 | 100×38×7 | ...... | 100×46×7 | ...... | ...... | ...... |
| | 90 | 58 | 28 | 39 to 42 | 85 to 90 | 110×40×7 | ...... | 110×48×7 | ...... | ...... | ...... |
| 2½ | 40 | 28 | 13 | 10 to 13 | 35 to 40 | 85×22×7 | ...... | 85×30×7 | ...... | ...... | ...... |
| | 45 | 31 | 14½ | 13 to 15 | 40 to 45 | 85×24×7 | ...... | 85×32×7 | ...... | ...... | ...... |
| | 50 | 34 | 16 | 15 to 18 | 45 to 50 | 90×26×7 | ...... | 90×34×7 | ...... | ...... | ...... |
| | 55 | 37 | 17½ | 18 to 21 | 50 to 55 | 90×28×7 | ...... | 90×36×7 | ...... | ...... | ...... |
| | 60 | 39 to 43 | 18 to 20½ | 22 to 26½ | 54 to 66 | 90×29×7½ | 76 | 90×35×7½ | 100 | 24 | 66 |
| | 65 | 42 to 46 | 18 to 22 | 23 to 29 | 59 to 71 | 95×31×7½ | 86 | 95×37×7½ | 108 | 26 | 71 |
| | [1] 70 | 46 to 49 | 20 to 23½ | 26 to 31½ | 63 to 76 | 95×33×7½ | 92 | 95×39×7½ | 114 | 28 | 76 |
| | 75 | 49 to 52 | 23½ to 25 | 30 to 34½ | 67 to 80 | 100×35×7½ | 105 | 100×41×7½ | 125 | 30 | 81 |
| | 80 | 50 to 52 | 22 to 25 | 30 to 36 | 75 to 85 | ...... | ...... | ...... | ...... | ...... | ...... |
| | 85 | 55 | 26½ | 36 to 39 | 80 to 85 | 100×40×7½ | ...... | 100×48×7½ | ...... | ...... | ...... |
| | 90 | 58 | 28 | 39 to 42 | 85 to 90 | 110×42×7½ | ...... | 110×50×7½ | ...... | ...... | ...... |
| 3 | 60 | 40 | 20 | 21 to 24 | 55 to 60 | 90×28×8 | ...... | 90×36×8 | ...... | ...... | ...... |
| | 65 | 43 | 21½ | 24 to 27 | 60 to 65 | 90×30×8 | ...... | 90×38×8 | ...... | ...... | ...... |
| | 70 | 46 to 50 | 23 to 24 | 27 to 32 | 63 to 77 | 100×33×8 | 105 | 100×39×8 | 130 | 28 | 76 |
| | 75 | 49 to 53 | 24½ to 25½ | 30 to 34½ | 67 to 83 | 100×35×8 | 110 | 100×41×8 | 135 | 30 | 81 |
| | [1] 80 | 52 to 56 | 26 to 27 | 33 to 37 | 71 to 88 | 105×37×8 | 120 | 105×44×8 | 150 | 32 | 86 |
| | 85 | 55 to 59 | 27½ to 28½ | 34½ to 39½ | 76 to 94 | 110×40×8 | 135 | 110×46×8 | 165 | 34 | 92 |
| | 90 | 58 | 29 | 39 to 42 | 85 to 90 | 110×40×8 | ...... | 110×48×8 | ...... | ...... | ...... |
| 3½ | 60 | 40 | 20 | 21 to 24 | 55 to 60 | 90×30×8 | ...... | 90×38×8 | ...... | ...... | ...... |
| | 65 | 43 | 22 | 24 to 27 | 60 to 65 | 90×32×8 | ...... | 90×40×8 | ...... | ...... | ...... |
| | 70 | 46 | 23½ | 27 to 30 | 65 to 70 | 100×34×8 | ...... | 100×42×8 | ...... | ...... | ...... |
| | 75 | 49 | 25 | 30 to 33 | 70 to 75 | 100×36×8 | ...... | 100×44×8 | ...... | ...... | ...... |
| | 80 | 52 | 26½ | 33 to 36 | 75 to 80 | 100×38×8 | ...... | 100×46×8 | ...... | ...... | ...... |
| | 85 | 55 | 28 | 36 to 39 | 80 to 85 | 110×40×8 | ...... | 110×48×8 | ...... | ...... | ...... |
| | 90 | 58 | 29½ | 39 to 42 | 85 to 90 | 110×42×8 | ...... | 110×50×8 | ...... | ...... | ...... |
| 4 | 75 | 53 | 25½ | 29½ to 34 | 68 to 83 | 105×37×8½ | 125 | 105×43×8½ | 150 | 30 | 83 |
| | 80 | 56 | 27 | 32 to 36½ | 71 to 88 | 110×39×8½ | 138 | 110×45×8½ | 165 | 32 | 88 |
| | [1] 85 | 59 | 28½ | 34½ to 39 | 76 to 94 | 110×41×8½ | 145 | 110×47×8½ | 175 | 34 | 93 |
| | 90 | 62 | 30 | 37 to 41½ | 81 to 99 | 115×44×8½ | 160 | 115×49×8½ | 190 | 36 | 99 |
| 5 | 85 | 59 | 28½ | 34 to 38½ | 76 to 94 | 115×41×9 | 155 | 115×47×9 | 190 | 34 | 93 |
| | [1] 90 | 62 | 30 | 36½ to 41 | 81 to 99 | 120×45×9 | 180 | 120×51×9 | 215 | 36 | 100 |
| | 95 | 65 | 31½ | 39 to 43 | 85 to 104 | 125×49×9 | 200 | 125×55×9 | 240 | 38 | 107 |

[1] Length of boom ordinarily used wirh corresponding size of bucket.

By adopting special methods contractors sometimes accomplish seemingly impossible work with dredges. In a drainage district[5] having a main ditch ranging in size from a 14-foot base with ½ to 1 side slopes to a 35-foot base with 1 to 1 side slopes, a 1½-yard bank-spud dipper dredge having a 55-foot boom and mounted on a 30-foot hull was used. The berms specified were 10 feet in width. The top width of the ditch at its largest section was 55 feet. The distance from center to center of spud feet was about 59 feet, which did not quite give sufficient reach for the feet to span the ditch. These conditions were met by the contractor in the following manner: One-half of the width of the ditch was dug for the entire length of the wide section, all of the material being placed on one side. The dredge then "kicked" back to the beginning. The contractor then bolted two logs 22 feet long and having a minimum diameter of 15 inches to the spud foot next to the excavated channel. The logs were laid parallel on opposite sides of the jack arm, one end of each log being placed on the hull while the other rested on the bank. The outer ends of the logs, which extended several feet beyond the spud foot, were bolted together on both top and bottom with 6 by 8 inch timbers. Timbers of the same size were placed against each side of the spud foot and bolted to the logs. Thus the machine had a spud bearing on both banks and still maintained the specified berm. This unique attachment eliminated the necessity of installing a longer boom, with possible overloading of the machinery.

On another project a contractor using a floating dipper dredge was unable to dispose of all the excavated material. A centrifugal pump and gasoline engine were mounted on a barge, and by forcing water through a nozzle sufficient pressure was obtained to wash the excavated material back over the adjacent land away from the ditch. This method is economical in reducing inconveniently large waste banks. On very wide ditches, over 80 feet in base width, in order to obtain a stable toe for the large waste bank, pilot cuts are often made and the excavated material placed to form the inner toe of the waste bank.

Frequently the overhead and width clearances of a dredge must be known to determine whether the dredge can pass a bridge. This information is given in Table 11.

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[5] Eng. Rec., vol. 75 (1917), p. 77.

TABLE 11.—*Clearance of dredges fitted with telescopic or convertible spuds.*

| Capacity of dipper. | Overhead clearance. | | | Width clearance. | |
|---|---|---|---|---|---|
| | Telescopic bank spud. | Vertical spud. | Convertible spud. | Telescopic bank spud. | Vertical spud. |
| *Cu. yds.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| ½ | 18 | 18 | 14¾ | 14 to 16 | 20 to 22 |
| ¾ | ........ | ........ | 14¾ | ........ | ........ |
| 1 | 18 | 20 | 17½ | 16 to 21 | 24 to 29 |
| 1½ | 19 | 22 | 20 | 20 to 26 | 28 to 34 |
| 2 | 20 | 24 | 20¼ | 26 to 32 | 32 to 38 |
| 2½ | 21 | 26 | 21 | 31 to 37 | 37 to 43 |
| 3 | 22 | 30 | 22 | 35 to 42 | 41 to 48 |
| 3½ | ........ | ........ | 23 | ........ | ........ |
| 4 | 22 | 34 | ........ | 39 to 46 | 45 to 51 |
| 5 | 22 | 38 | ........ | 43 to 55 | 49 to 61 |

The overhead clearance is figured from bottom of hull to top of cabin, with A frame lowered and with spuds unshipped. Figures for width clearance are for minimum and maximum lengths of boom.

When designing a ditch the engineer should always have in mind the limitations of the type and size of machine adapted to the work. Consistent with other considerations a ditch system should be so designed as to give the contractor the greatest amount of excavation for a given size of dredge. This point may be illustrated by a practical example: Suppose a ditch is designed with a bottom width varying from 16 to 46 feet and a cut of 7 feet throughout the length of 15 miles. The ditch as planned is too wide at its lower end to be constructed by a dredge of ordinary size, unless it be equipped with telescopic or convertible power spuds. By making the cut deeper at the lower end the width of the ditch can be made considerably less, and a dredge of ordinary size can dig the ditch throughout. To use two dredges of different sizes on such a comparatively small job would increase the unit cost.

If ditches are planned for one machine to do all the work the cost of construction will be reduced, but the time required to do it all with one machine may be so great that the district would rather pay the additional cost involved in installing two plants.

A contract may include a number of ditches, all but one of which are suited to a given size of machine, this one being too wide to be cut by the dredge at one cutting, with yardage insufficient to justify the installation of another dredge. That difficulty may be overcome by making a double cut, which, however, requires the use of either vertical or convertible spuds.

Parallel small lateral ditches, each having a separate outlet into a large main canal, are difficult to construct. The dredge required to excavate the main ditch is too large for the economical construction of the laterals, and the latter are too small and too short to warrant installation of a separate machine. The laterals are usually constructed after the main canal has been completed, so that a dam must be built in the main ditch to hold the water at the desired elevation when constructing the laterals. Where topography and other conditions permit, a better plan would be a supplementary ditch parallel to the main channel, with short laterals of such length as not to require dams to maintain the water level. With such a layout the supplementary canal and laterals may be constructed by one dredge much cheaper than if each lateral had an outlet into the main ditch. The topography of the ground would determine the feasibility of this plan and the length of the laterals. The water should be at such height, if practicable, that not over 2 feet of face is exposed.

## THE FLOATING GRAB-BUCKET DREDGE.

The floating grab-bucket dredge differs from the dipper type in the appliances for handling the material and in the operating machinery. Instead of using a dipper and dipper handle, an orange-peel or a clam-shell bucket is suspended from the end of the boom. The bucket of orange-peel type is generally used for drainage work, as it operates more satisfactorily in stumpy ground and on materials of varying density.

The floating grab-bucket dredge may be of the gravity-return or of the bull-wheel-swing type, and it can be operated by a single engine of uniform speed. Hoisting and swinging are accomplished by drums operated by friction clutches. In Plate II, Figure 1, a typical orange-peel dredge is shown.

A much longer boom can be used with the grab-bucket dredge than with the dipper dredge. From 75 to 90 feet is about the maximum length of boom that can be successfully operated on a dipper dredge, while booms as long as 240 feet, operating 6-yard buckets, have been used on grab-bucket dredges. This feature is of especial importance in levee construction, where it is desired to deposit the material as far from the stream as possible.

While the dipper dredge pulls itself ahead by means of the dipper, some kind of pull-ahead line is necessary with a grab-bucket dredge. Generally three auxiliary drums are provided, two for operating the spuds and one for drawing the pull-ahead line which is secured to the bucket. The bucket is dropped into the material, the hoisting line is slackened, and the pull-ahead line is drawn taut, pulling the dredge ahead. In other cases the pull-ahead line may be anchored to a deadman buried some distance ahead of the machine.

For depositing at some distance from the edge of the ditch material excavated by floating grab-bucket dredges equipped with short booms, steel chutes have been used successfully in the reclamation of swamp lands in New Zealand. Two chutes, one on each side of the hull, are mounted on steel frames. The saturated material is dropped into the upper end of either of the chutes, which have slope enough for the material to slide down and fall on the ground some distance from the edge of the ditch.

Owing to its long reach, the grab-bucket dredge is often used for levee construction. It is not extensively used for the excavation of drainage channels, although under certain conditions it can be used to greater advantage than can the dipper dredge. It excels in handling the muck found on the prairie lands of southern Louisiana and in certain other localities. The dipper type, however, is preferable for digging hard soil or where there are many stumps.

There are a great many makes of both orange-peel and clam-shell buckets. The dimensions and weights for the several makes vary somewhat, although these factors differ but little for the machines used on drainage work.

## THE DRAG-LINE SCRAPER EXCAVATOR.

The drag-line scraper excavator is a dry-land machine that has come into prominence only within the last few years. It has made feasible the cheap construction of much larger ditches and levees than is possible by the use of any other type of machine.

In the type most commonly used the engine platform, engine house, and boom are connected and revolve on a turntable which is secured to a lower platform built up of structural-steel sections. This is known as the revolving or rotary type and is illustrated in Plates III, IV, and V. Upon the upper surface of the lower platform is riveted the track upon which the swinging circle revolves, and in its center is the pivot bearing. The turntable is a steel-frame circle supported by several dolley wheels which rest upon the track. The number of dolley wheels varies with the different makes as well as with the size of machine, a sufficient number being used in each case to insure the required bearing for steady operation. The upper platform, which is also built up of standard steel sections, is held to the lower platform by the central pivot.

The rotation or swinging of the machine is accomplished by two methods. The method almost universally used is the rack-and-pinion method. On the lower platform is a circular rack with cut or cast steel gears. In Plate III, Figure 1, both the rack and dolley wheels are shown. On the upper platform are the swinging engines which drive a pinion, which in turn meshes into the rack (Pl. III, Fig. 2) on the lower platform. By this mode of rotation the machine can revolve any number of times in either direction.

There is also the cable-swing excavator in which the swinging is done by means of two cables having dead ends on the perimeter of the turntable. These cables run to drums on the upper platform which are operated by the swinging engines. This mode of swing is not as popular as the rack-and-pinion swing, due to the fact that although the machine can revolve nearly a full circle, it must return in the direction from which it has revolved. The cable-swing machine is the lighter.

In the nonrotating drag-line machine the engine platform is fixed; the boom is pivoted at its lower end and is the only part of the machine which swings. This type is illustrated in Plate VII, Figure 2.

The crew necessary to operate a drag-line excavator consists of two men, an operator and a fireman on a steam machine, an operator and an oiler on a gasoline or electrically driven machine. In addition, two or more trackmen are required, except in the case of the walking and caterpillar types.

Where the ground is uneven or cut up with old channels and surface ditches it is necessary for all excavators not of the rotary type to block or bridge across the depressions, laying heavy timbers on which to move the machine. When a machine weighs 25 tons or more the expense of providing a solid foundation is an important item. In the rotary type of excavator the machine can be revolved to build its own foundation of earth.

## THE ROTARY TYPE.

### METHODS OF PROPELLING.

There are three kinds of mountings used with revolving drag-line excavators. The one in general use is the skid-and-roller mounting. The machine travels on a track of plank laid on the ground and is moved by partly filling the bucket and using it as an anchor upon which to pull. Plate IV, Figure 1, shows a machine with skid-and-roller mounting transferring a section of its track ahead so that it can move up. The skid-and-roller mounting can be used under all machines except those weighing over 80 tons. Black-gum rollers are ordinarily used, being cheaper and easier to obtain than hard maple. Heavy machines are very hard on wooden rollers; consequently trucks running on tracks are used for the large sizes. Where trouble is expected from crushing and splitting of wooden rollers, 6-inch steam pipe may be used instead. In Figure 1 is shown a sectional track for a drag-line excavator with skid-and-roller mounting. This figure, taken from Engineering and Contracting, volume 46 (1916), page 158, shows the arrangement of the track units. Each unit is 24 feet long, 10 being used for the machine in question, 5 under each side. It will be noted from the figure that the ends of the top timbers are staggered, while the ends of the bottom timbers are placed even. The staggered ends make possible a more rigid connection and also provide means of taking curves while still preserving a solid bearing for the rollers. The rigging to pick up the track sections consists of $\frac{5}{8}$-inch chain, two pieces 3 feet 9 inches long and two pieces 3 feet 3 inches long. With uneven chain lengths one end of the track section is held higher than the other, which lightens the labor in making track connections. It is asserted that a section can be swung ahead and placed in one and one-half minutes. With this type of track a contractor has moved his machine 2,600 feet in 10 hours.

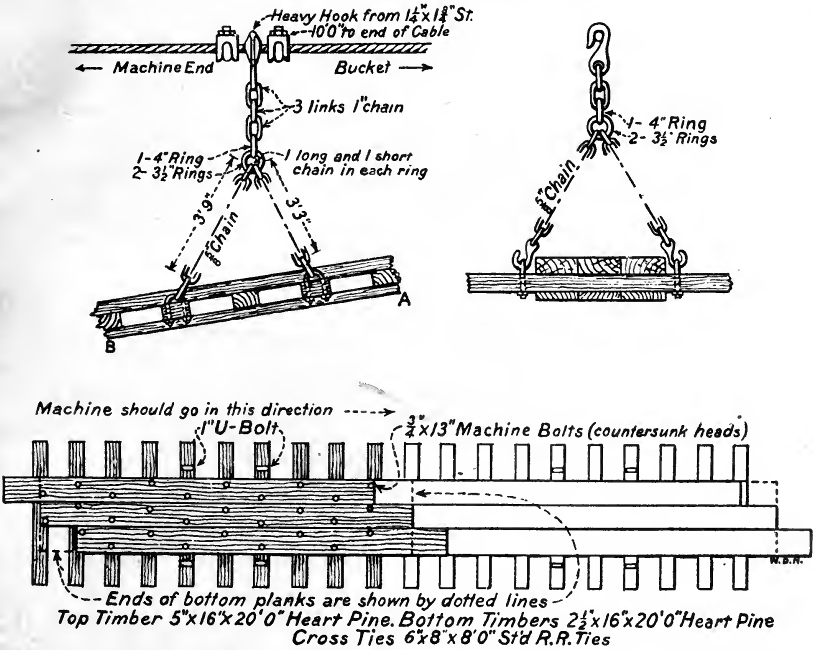



FIG. 1.—Sectional track for a rotary-scraper excavator with skid and roller mounting.

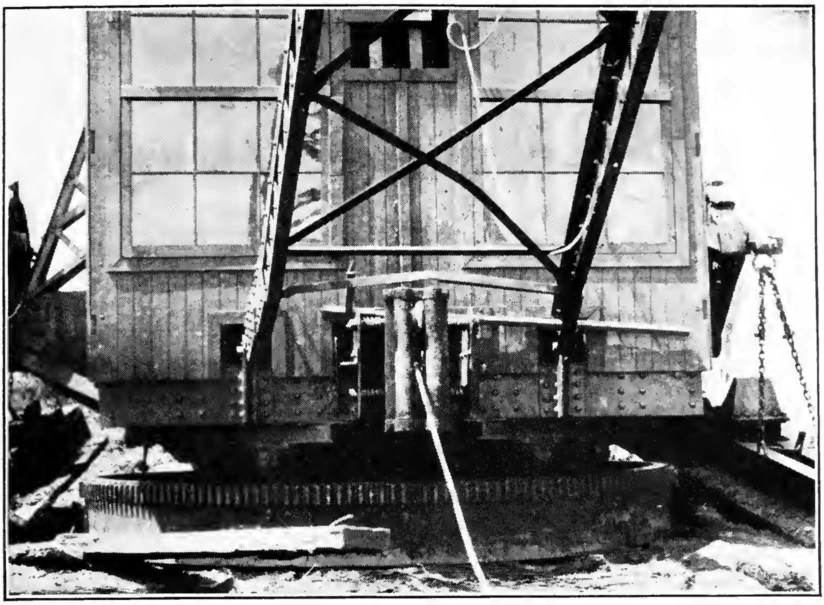
A drag-line excavator mounted on skids and rollers moves ahead by pulling on the bucket left partly filled in the earth to be excavated, the anchor blocks in front of the machine having been previously removed. There are instances where the surface material may be so soft as to preclude this method unless the top material is first excavated down to a stiff subsoil. To avoid this extra labor it is possible, after swinging the machine through 180°, to hitch the bucket to a cable run through the bed of the machine and anchored to the track, and thus to move the machine by backing it up. The weight on the track of the machine that is being moved will ordinarily furnish sufficient anchorage. This method has been used successfully in muskeg swamps, thus sparing the excavation of several feet of the soft surface to reach the underlying clay.

The caterpillar or apron-traction mounting eliminates the trackmen necessary with the skid-and-roller mounting. For small machines two caterpillars (Pl. IV, Fig. 2) are commonly used. In one make of light drag-line excavator a combination of two wheels and two caterpillars is used. The heavier machines require four caterpillars. A skillful operator can turn a drag-line excavator mounted on caterpillars in its own length.

Large machines usually are mounted on four 4-wheeled equalizing trucks (Pl. V, Fig. 1), though any size may be furnished with this mounting if desired. These trucks may all be nonpropelling, in which case the machine moves in the same way as if mounted on skids and rollers, or two of the trucks may be driven by power from the main engines of the machine. On the smaller machines one truck usually is mounted under each corner of the lower platform, while on the larger machines three of the trucks are generally mounted on an equalizing beam. This latter method is preferable, as by its use the weight of the machine is always evenly distributed, and thus the platforms are not subjected to severe stresses.

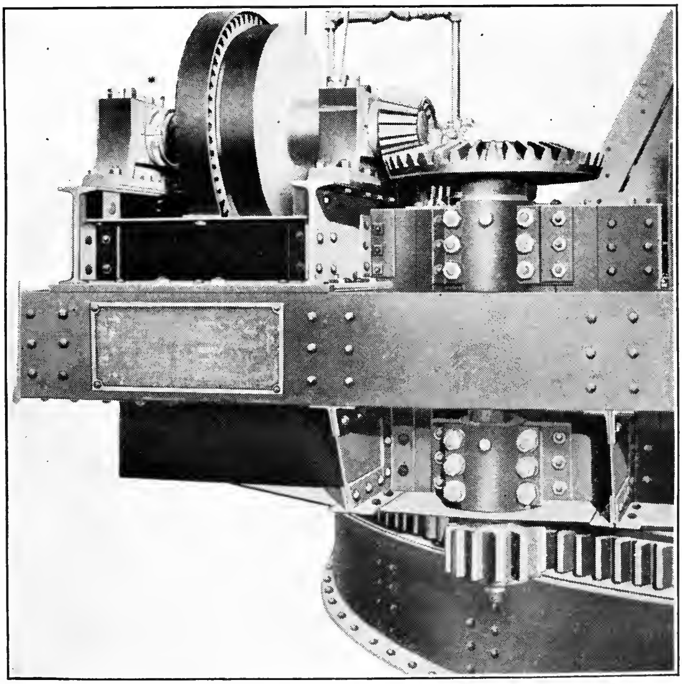
There is another type of mounting in which a novel method of moving is employed. Attached to the upper platform and extending through the machine in a direction at right angles to that of the boom is a heavy steel shaft, on each end of which is a wheel segment (Pl. V, Fig. 2). The shaft also carries a large gear wheel which meshes with a pinion on the loading-drum shaft of the main engine. Suspended from the middle arm of each segment by means of a carrying beam and chains is a long shoe, which affords a bearing for the segment as it rotates and propels the machine forward. To move in a given direction the excavator is rotated until the boom is pointing in the opposite direction; the side shoes are lowered by rotating the shaft supporting the wheel segments, and the weight of the machine is thrown on to the side shoes; the segments cause the machine to rise and move ahead 8 feet. This excavator has an advantage over other types of self-propelling machines in that it can move in any direction. The machine can be walked at a rate of 25 to 30 feet a minute. When digging, the machine rests upon a large circular base. The average bearing pressure when working is from $3\frac{1}{2}$ to $4\frac{1}{2}$ pounds per square inch.

All self-propelling machines do without trackmen when working over reasonably stable ground. In soft ground extra bearing surface may be required to prevent the machine from sinking. On one occasion a 3-yard, 70-foot boom, walking, drag-line excavator, working in unusually soft ground, required additional bearing surface. Eight pontoons were used, each 7 feet by 30 feet, the machine always



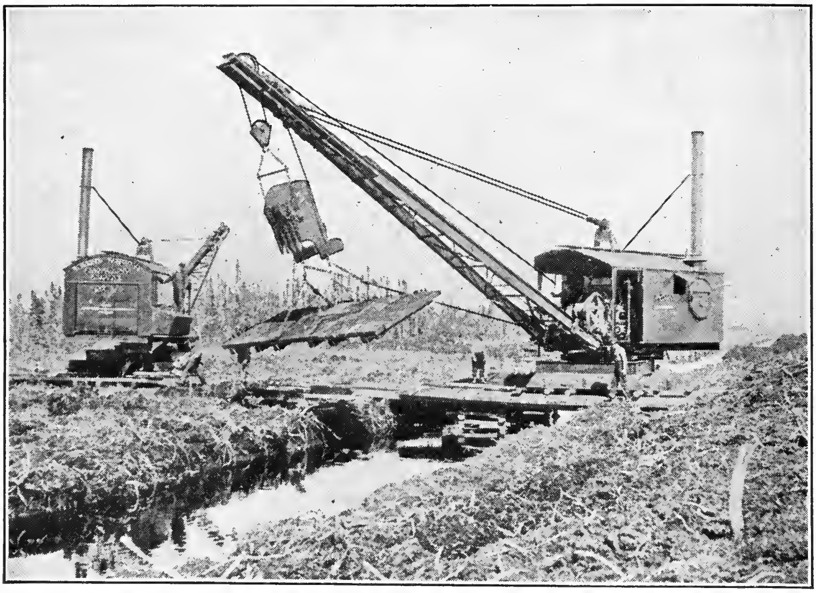
D-613

FIG. 1.—RACK AND DOLLEY WHEELS.



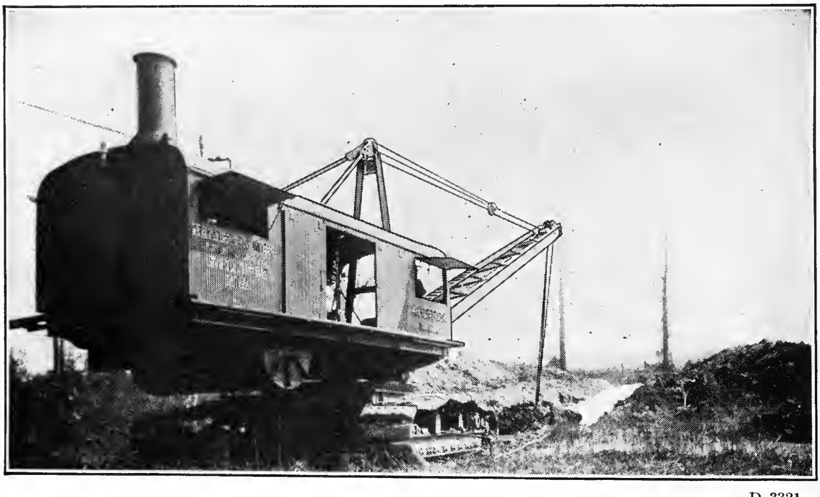
D-3197

FIG. 2.—MECHANISM FOR OPERATING PINION AND SWINGING DEVICE FOR RACK-AND-PINION TYPE OF DRAG-LINE EXCAVATOR.



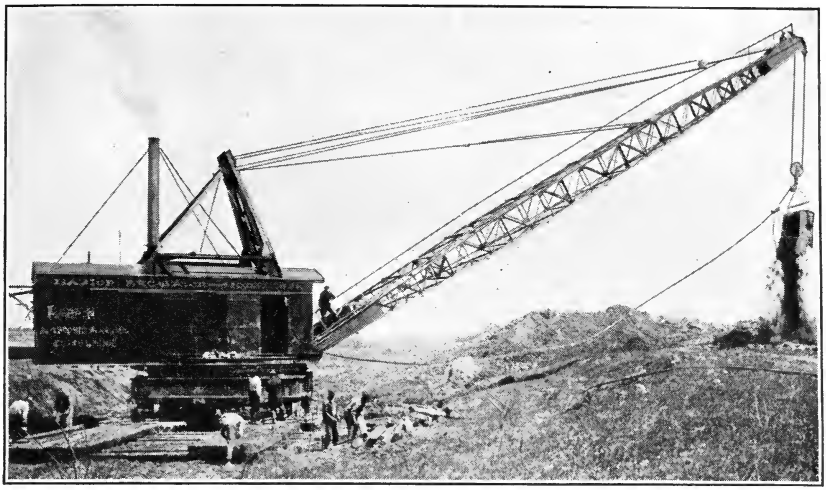
D-3281

FIG. 1.—DRAG-LINE EXCAVATOR ON SKID-AND-ROLLER MOUNTING TRANSFERRING A SECTION OF TRACK AHEAD.



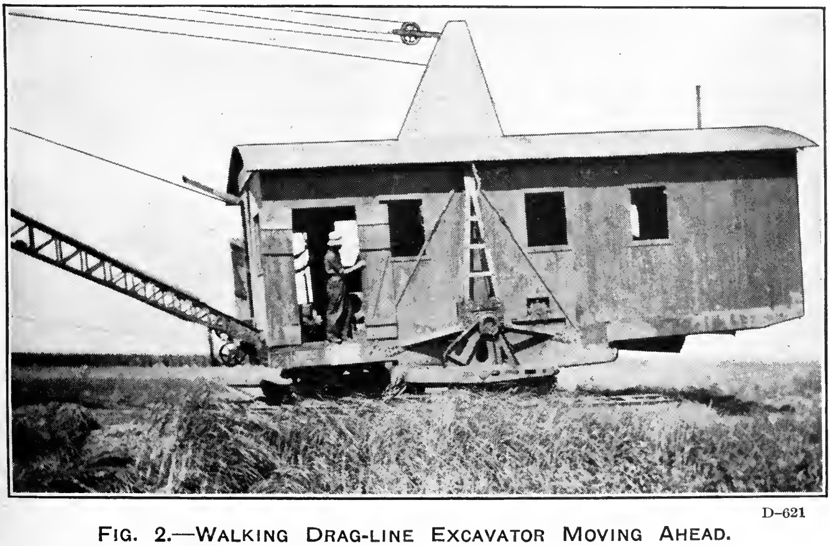
D-3321

FIG. 2.—DRAG-LINE EXCAVATOR MOUNTED ON TWO CATERPILLARS.



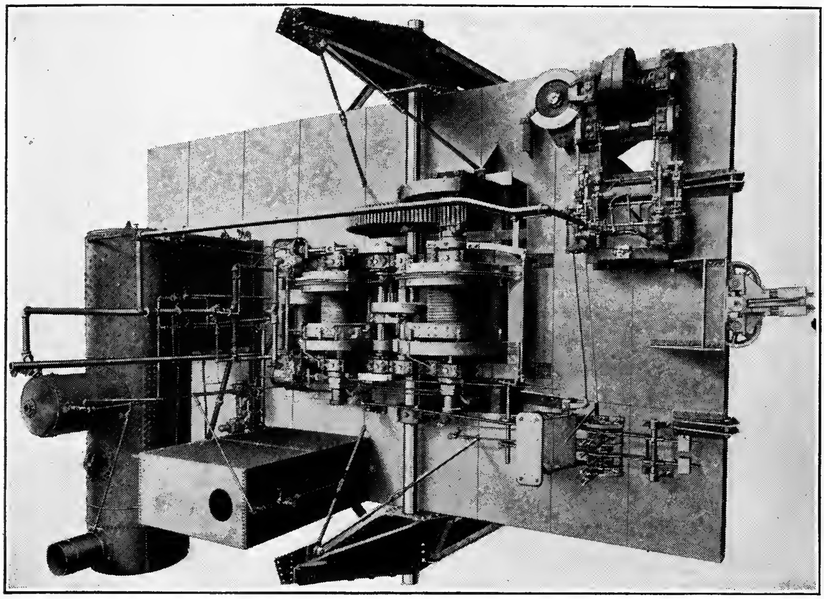
D-3322

FIG. 1.—DRAG-LINE EXCAVATOR MOUNTED ON FOUR 4-WHEELED TRUCKS.



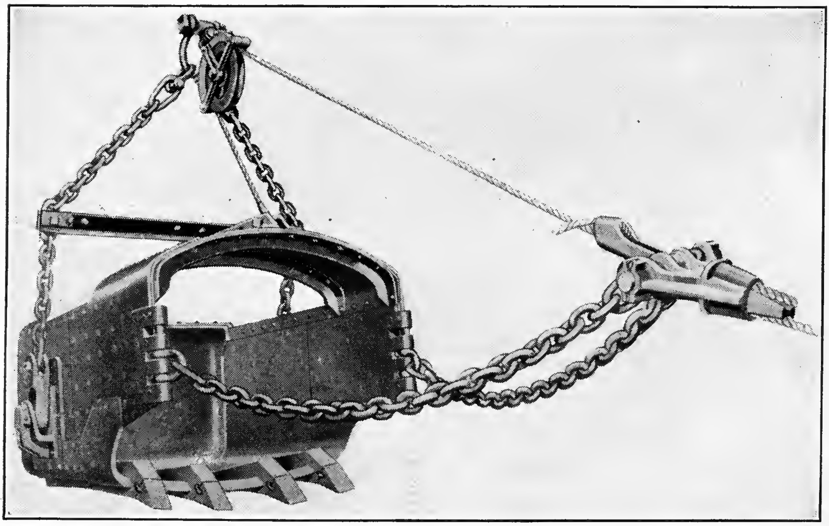
D-621

FIG. 2.—WALKING DRAG-LINE EXCAVATOR MOVING AHEAD.



D-3198

FIG. 1.—ARRANGEMENT OF MACHINERY ON A STEAM-OPERATED DRAG-LINE EXCAVATOR.



D-3092

FIG. 2.—TWO-LINE SCRAPER BUCKET OF THE SOLID TYPE.

resting on three pontoons. With three pontoons the bearing pressure was 1½ pounds per square inch.

## MACHINERY AND EQUIPMENT.

The power equipment of the drag-line excavator may be either steam, gasoline, or electric. On drag-line scraper excavators the internal-combustion engine has been used with success. In some places the quality of water obtainable for use in boilers and the absence of electric power may determine the use of internal-combustion engines.

The machinery for operating the drag-line excavator is placed on the upper platform. On excavators operated by internal-combustion engines the engine may be either gear-connected to the operating drum or belt-connected. On steam-operated machines the main engines are of the double-cylinder, friction-drum type, mounted on a structural-steel base (Pl. VI, Fig. 1). The main engines operate the hoisting and loading drums. For rotating the excavators, separate engines of the double-cylinder type are used. The boilers may be either vertical or locomotive type. Tables 12 and 13 show the dimensions of engines, boilers, and accessories, average fuel consumption, and shipping weights of drag-line excavators of various capacities.

93127°—22——3

TABLE 12.—*Data pertaining to drag-line excavators with traction, skid, and truck mounting.*

| | Capacity of bucket, cubic yards. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\frac{3}{4}$ | $1\frac{1}{2}$ | 2 | $2\frac{1}{2}$ | $3\frac{1}{2}$ | 4 | 5 | 7 | 9 |
| Length of boom, feet | 40 | 45 | 60 | 85 | 100 | 125 | 155 | 125 | 100. |
| Digging-rope diameter, inches | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{3}{4}$ | 2. |
| Standard length, feet | 62 | 80 | 100 | 132 | 163 | 160 | | | |
| Hoisting-rope diameter, inches | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$. |
| Standard length, feet | 170 | 220 | 250 | 374 | 430 | 500 | | | |
| Main engines (double-cylinder) | $6\frac{1}{2}$ by 7 | 8 by 8 | 8 by 12 | 9 by 12 | 11 by 14 | 12 by 15 | 14 by 16 | 14 by 16 | 14 by 16. |
| Swinging engines (double-cylinder) | 5 by 5 | 5 by 5 | 6 by 6 | $7\frac{1}{2}$ by 7 | 8 by 8 | 9 by 9 | 10 by 10 | 10 by 11 | 10 by 11. |
| Boiler dimensions | 54 inches by 7 feet 6 inches. | 50 inches by 10 feet. | 58 inches by 9 feet 7 inches. | 54 inches by 13 feet 7 inches. | 58 inches by 16 feet. | 64 inches by 15 feet 10 inches. | 76 inches by 18 feet. | 72 inches by 19 feet. | 72 inches by 19 feet. |
| Water-tank capacity, gallons | 300 | 450 | 600 | 850 | 1,170 | 2,500 | 2,750 | 3,200 | 3,200. |
| Water consumption in 10 hours, gallons | 2,700 | 3,100 | 3,500 | 5,200 | 6,400 | 8,900 | | | |
| Coal consumption in 10 hours, tons | 1 to $1\frac{1}{2}$ | $1\frac{1}{2}$ to 2 | 2 to 3 | $2\frac{1}{2}$ to $3\frac{1}{2}$ | 3 to 4 | 4 to 5 | | | |
| Shipping weight (skid mounting), tons | | 34 | 55 | $92\frac{1}{2}$ | 121 | 157 | | | |
| Working weight (skid mounting), tons | | 39 | $62\frac{1}{2}$ | 116 | $144\frac{1}{2}$ | 203 | | | |
| Number of cars required to ship | | 2 | 2 | 5 | 6 | 7 | | | |
| Shipping weight, tons, mounted on | Traction, $29\frac{1}{2}$ | Traction, 55 | Traction, 81 | Trucks, 109 | Trucks, 142 | Trucks, 173 | Trucks, $247\frac{1}{2}$ | Trucks, 245 | Trucks, 245. |
| Number of cars required to ship | 2 | 2 | 3 | 6 | 7 | 8 | | | |

TABLE 13.—*Data pertaining to drag-line excavators with walking mounting.*

| | Capacity of bucket, cubic yards. | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 2 | 3 | 3 |
| Length of boom, feet | 45 | 60 | 60 | 60 | 60. |
| Digging rope diameter, inches | 7/8 | 1 | 1 | 1 1/8 | 1 1/8. |
| Standard length, feet | 68 | 90 | 90 | 100 | 100. |
| Hoisting rope diameter, inches | 3/4 | 3/4 | 3/4 | 3/4 | 3/4. |
| Standard length, feet | 125 | 190 | 190 | 250 | 250. |
| Diameter of circular base | 11 feet 6 inches | 15 feet 6 inches | 15 feet 6 inches | 19 feet 6 inches | 19 feet 6 inches. |
| Bearing surface of base, square feet | 104 | 188 | 188 | 298 | 298. |
| Dimensions of walking shoe | 2 feet 6 inches by 16 feet 8 inches. | 3 feet 6 inches by 21 feet 6 inches. | 3 feet 6 inches by 21 feet 6 inches. | 4 feet by 24 feet 6 inches. | 4 feet by 24 feet 6 inches. |
| Bearing surface of walking platform, square feet | 83 | 150 | 150 | 196 | 196. |
| Type of engine | Internal combustion. | Steam | Internal combustion. | Steam | Internal combustion. |
| Horsepower of internal combustion engine | 55 | | 70 | | 90. |
| Capacity of cooling tank, gallons | 125 | | 320 | | 320. |
| Capacity of oil tank, gallons | 65 | | 250 | | 310. |
| Main engines (double-cylinder), inches | | 9 by 10 | | 10 by 10 | |
| Swinging engines (double-cylinder), inches | | 6 1/4 by 8 | | 6 1/4 by 8 | |
| Size of boiler | | 54 inches by 12 feet 3 inches. | | 54 inches by 13 feet 7 inches. | |
| Capacity of water tank, gallons | | 800 | | 1,100 | |
| Shipping weight, tons | 29 | 70 | 70 | 85 | 85. |
| Number cars required to ship | 1 | 3 | 3 | 3 | 3. |
| Fuel consumption, 10 hours | 60 gallons | 2 to 3 tons | 80 gallons | 3 to 4 tons | 90 to 100 gallons. |
| Number men and time to assemble | 4 men 5 days | 8 men 6 weeks | 8 men 6 weeks | 10 men 1 month | 10 men 1 month. |
| Number men and time to dismantle | 4 men 5 days | 8 men 10 days | 8 men 10 days | 10 men 10 days | 10 men 10 days. |
| Shipping weight (skid mounting), tons | | 55 | 55 | 65 | 65. |

### BOOM.

In the smaller drag-line excavators the boom is generally constructed of two channels with cross bracing (Pl. IV, Fig. 1), while in the larger machines two cross-braced lattice girders are used (Pl. V, Fig. 1). The lower ends of the two main members of the boom are spread apart to give stability, while at the upper end the two members are joined, and at that point one or more sheaves are placed. On some of the smaller machines the top of the boom is guyed to the top of the A frame, which is located near the front of the main engine. The lower ends of the A frame are bolted to the platform; the upper end is guyed to the rear corners of the platform. The length of the boom for drag-line excavators varies from 30 to 150 feet. On most machines it is suspended by a cable running to a drum on the platform. For raising or lowering the boom this drum may be operated either by power or by hand.

### BUCKET.

There are various forms of scraper buckets made for use with drag-line excavators. A type of bucket in common use is shown in Plate VI, Figure 2. This bucket can be operated with two lines, a loading and a hoisting line. For holding the bucket horizontal when hoisting, a patented device is used which consists of a cable secured to the top of the bucket at its front end, which, after passing through a sheave at the hoisting connection, runs down to the loading bail. With the loading line kept taut the bucket maintains a horizontal position. To dump the bucket, the loading line is merely released.

The sizes, weights, and approximate prices of this bucket of standard type are shown in Table 14.

TABLE 14.—*Weights and prices of scraper buckets.*

| Capacity. | Width of cutting edge. | Weight without teeth. | Price. |
|---|---|---|---|
| *Cu. yds.* | *Inches.* | *Pounds.* | |
| $\frac{3}{4}$ | 36 | 2,200 | $660 |
| 1 | 45 | 2,500 | 698 |
| $1\frac{1}{4}$ | 45 | 2,800 | 780 |
| $1\frac{1}{2}$ | 48 | 3,200 | 862 |
| 2 | 51 | 4,850 | 1,043 |
| $2\frac{1}{2}$ | 57 | 5,850 | 1,191 |
| 3 | 60 | 6,550 | 1,357 |
| $3\frac{1}{2}$ | 60 | 7,000 | 1,510 |

Many operators experience trouble with scraper buckets of the smaller sizes from their failure to clean themselves when working in sticky clay. To obviate this a skeleton scraper bucket has been made for very sticky clay. This bucket cleans itself more readily in sticky material than the solid type. It is made in five-eighths cubic yard size only.

OPERATION.

It is impracticable to give exact figures on the time required to assemble a drag-line excavator, as the time will vary greatly with the make of machine, the length of boom, and the style of mounting. Operators generally agree that more time is required to assemble a machine mounted on caterpillars than one mounted on skids and rollers. In general, the time required for 8 men to assemble a drag-line excavator varies from 1 week for the small 1-yard walking type to 6 weeks for a 3½-yard caterpillar machine. The actual time consumed in erecting a 3-yard, 70-foot boom, walking, drag-line excavator equipped with internal-combustion engines was 2,137 man-hours. The assembling by 12 men took 19 days. The machine made 26 wagonloads and was hauled from the siding to the project, a distance of 3½ miles, in 9 days.

The fuel consumption for drag-line excavators depends on the character of the soil and the distance of hoisting. The average consumption of fuel for both steam and gasoline operated drag-line excavators has been given (Tables 12 and 13).

Cable expense is greater on drag-line excavators than on floating dredges. The life of cables depends largely on the nature of the work, regardless of the size of machine. Some operators consider the life of a digging cable as about 25,000 cubic yards and of a hoisting cable about 100,000 cubic yards. Other operators state the life in days of double-shift operation. In earth a digging rope will last from 2 to 3 weeks and a hoisting rope from 1 to 2 months, depending on the number of shifts and the condition of the sheaves and drums. In cemented sand and gravel a digging rope may wear out in 3 working shifts; usually in hard material its life is not longer than 10 shifts.

The life of a cable is increased by proper lubrication. Incorrect lubrication or neglect of it results in increased wear within the rope. Even though the cable may appear bright and in good condition, this interior wear may be going on. The lubricant to be used depends upon the work which the cable is required to do. A hoisting cable which travels at considerable speed requires a different lubricant from track cables which move more slowly.

Drag-line excavators with 50 to 60 foot booms operate more rapidly than machines with long booms of 90 feet or more. Therefore work which requires a short hoist and a small angle of swing can be done more rapidly than work which requires a long hoist and a large angle of swing. Rack-and-pinion swing machines have an advantage over cable-swing machines in that when a swing of 180 degrees is required the machine can complete the full circle and return to the loading point, whereas the cable-swing machine must be reversed with loss of both time and energy.

A 3-yard, walking, drag-line excavator having an 80-foot boom was used to build a levee averaging 15 feet high. The machine traveled on the berm, taking dirt from the borrow pit, which did not exceed 10 feet in depth, and depositing the material on the levee site. The angle of swing was about 145 degrees. To fill the bucket required 30 seconds; to hoist, swing, and dump took 25 seconds; and 30 seconds were required to return to the borrow pit. The entire operation thus consumed 85 seconds. In the excavation of a ditch 36 feet deep in which the angle of swing was 90 degrees and the distance of hoist 60 feet, a 2-yard machine with a 75-foot boom was used. Filling the bucket required 25 seconds; to hoist, swing, and dump required 20 seconds; and to return to fill the bucket consumed 20 seconds. Thus the entire time of one operation was 65 seconds.

The output of drag-line excavators of various sizes will vary greatly with the length of boom, depth of cut, angle of swing, and character of digging. The figures given in Table 15 will serve as an approximate guide.

Table 15.—*Output of drag-line excavators.*

| Size of bucket. | Length of boom. | Economical size of job.[1] | Output per month, with double shift. |
|---|---|---|---|
| *Cu. yds.* | *Feet.* | *Cubic yards.* | *Cubic yards.* |
| 1 | 40 | 250,000 | 18,000 |
| 1½ | 50 | 300,000 | 25,000 |
| 2 | 60 | 400,000 | 30,000 |
| 2½ | 65 | 500,000 | 35,000 |
| 3 | 70 | 800,000 | 40,000 |
| 3½ | 80 | 1,000,000 | 50,000 |
| 4½ | 100 | 1,500,000 | 70,000 |

[1] By economical size of job is meant the yardage below which the machine can not be installed and operated without appreciably increasing the cost per cubic yard of excavation.

These figures give only the average output, including all lost time; they may be greatly exceeded in any particular month during continuous operation. On one contract a 2-yard, 60-foot-boom drag-line excavator averaged 70,000 cubic yards a month with double shift while building a levee containing 1,100 cubic yards per station.

In the excavation of quicksand great care must be used in handling the bucket. The hoisting line is kept taut, holding the back end of the bucket a foot or so above the sand, while the cutting edge, or lip of the bucket, is pulled into the material. The output of a machine in quicksand is about one-fourth that in ordinary earth.

*Cost.*—Table 16 gives the approximate cost of rack-and-pinion-swing, rotary drag-line excavators.

TABLE 16.—*Costs of rack-and-pinion-swing, rotary, drag-line excavators, 1921.*

| Size of bucket. | Length of boom. | Kind of power. | Style of mounting. | Approximate cost. |
|---|---|---|---|---|
| *Cu. yds.* | *Feet.* | | | |
| ½ | 30 | Oil engine | Caterpillar | $11,000 |
| ¾ | 40 | Steam | do | 14,800 |
| ¾ | 40 | Oil engine | do | 18,650 |
| 1 | 40 | do | Walker | 15,700 |
| 1½ | 45 | Steam | Skid and rollers | 20,850 |
| 1½ | 45 | do | Caterpillar | 29,200 |
| 2 | 60 | do | Walker | 31,000 |
| 2 | 60 | do | Skid and rollers | 26,700 |
| 2 | 60 | do | Caterpillar | 38,300 |
| 2½ | 85 | do | Skid and rollers | 38,300 |
| 3 | 60 | do | Walker | 36,500 |
| 3½ | 100 | do | Skid and rollers | 46,900 |
| 3½ | 100 | do | Trucks | 56,800 |
| 3½ | 125 | do | do | 71,000 |
| 5 | 155 | do | do | 97,500 |

To equip boilers for burning oil fuel costs from $450 to $550, depending on the size of the boiler.

### CABLE-SWING EXCAVATOR.

A cable-swing, drag-line excavator (Pl. VII, Fig. 1), with a 1-yard bucket and a 40-foot boom, has been placed on the market recently. The machine is mounted on four apron tractors and is operated by a 55-horse power, two-cylinder opposed-type engine. The weight is about 20 tons. The road speed is one-half mile per hour. The hoisting line is five-eighths inch and the loading line three-fourths inch. The machine costs $7,000, including the bucket. It can be operated by one runner and one oiler and consumes about 35 gallons of gasoline in 10 hours of operation. The bucket measures 35 inches wide. The over-all clearance of the machine is 10 feet 3 inches by 26 feet. The machine has a 10-foot turntable. The vertical distance from the ground to the fair lead sheaves is 5 feet 2 inches, and the horizontal distance from the boom pivot to the center of the turntable is 6 feet 9 inches. The machine can be shipped, assembled, on one car. Only the boom and A frame are dismantled for shipping.

### NONROTATING DRAG-LINE EXCAVATORS.

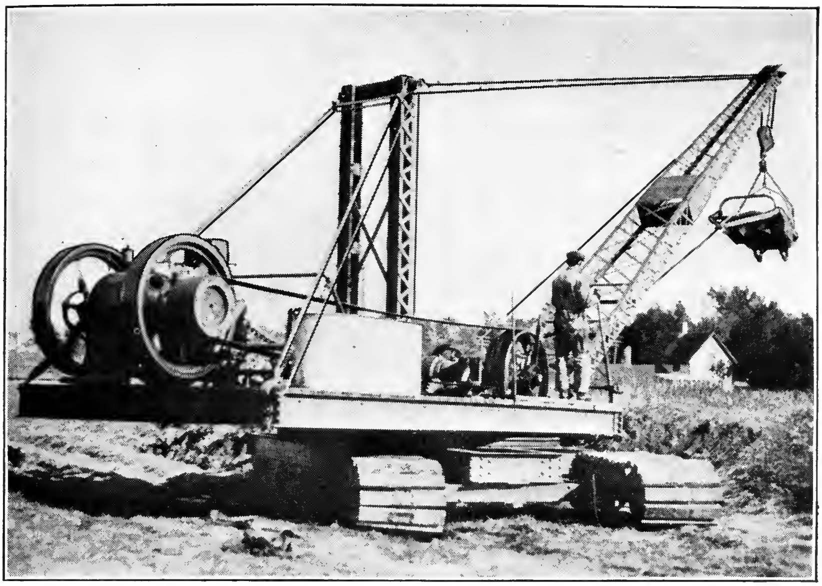
A light drag-line excavator of the nonrotating type is being used rather extensively (Pl. VII, Fig. 2). The machine is built entirely of steel. The main frame is 24 by 24 feet, but can easily be made wider or narrower if desired. The platform is 12 by 30 feet. The frame is mounted on four steel wheels, each 5 feet high and 3 feet wide. The boom is 40 feet long and can be extended 10 feet more if it is desired to use the machine for tile trenching or lowering large tile into place. A 45-horsepower, 2-cylinder, opposed-type oil engine is used for power. The bucket has a capacity of five-eighths cubic yard and is 43 inches wide. One man is required to operate the machine and one man to handle the track in soft ground. About 30 gallons of gasoline or 40 gallons of kerosene are required per 10-hour day. The machine is moved ahead by means of a cable attached to a dead-man or to stakes. The large wheels will travel over fairly firm ground without track; no trackman is therefore needed, except in quite soft ground or swamp. The machine, complete, weighs 12 tons. When dismantled it can be loaded on one flat car or if transported by team will make 12 wagonloads. The heaviest load is the engine, which weighs 5,640 pounds.

To assemble the machine takes five men four or five days. The same number can dismantle it in two days. The hoisting line is one-half inch cable 125 to 140 feet long. The loading line is three-fourths inch cable 60 feet long. In single-shift operation a loading cable will ordinarily last 10 days and a hoisting cable two weeks. The machine will excavate about 300 cubic yards per shift or about 15,000 cubic yards per month with double shift. The maximum ditch which it will dig at a single cut has a 42-foot top, 12-foot base, and 8-foot depth. The machine may be had in widths of 36 or 40 feet and costs approximately $5,500.

In enlarging an old ditch averaging 6 feet deep so as to have a channel 13 feet deep with a 10-foot base, a five-eighths yard non-rotating excavator, with a 40-foot boom, was used. The material removed averaged 10 cubic yards per linear foot. The angle of swing was 75 degrees, and the boom was suspended at an angle of 35°. A direct-line swing was used, the swinging cables being attached directly to the boom instead of running through sheaves on the boom and then back to the corner of the cross-frame. This kind of hitch gave a much quicker swing. A time study made of 75 dips gave the following information: To load the bucket took 8 seconds; to hoist, swing, and dump, 8 seconds; to return the bucket to the ditch, 8 seconds; the entire time to complete one dip was, therefore, 24 seconds. To move the machine ahead a distance of 9 feet required 9 seconds.

Another type of nonrotating excavator has been developed which has a double boom with bull-wheel swing instead of pivot swing. The machine is made in two sizes, five-eighths yard and 1 yard. The smaller size can be furnished with either the caterpillar mounting or the regular sliding-track mounting, while the larger size is furnished only in the sliding-track mounting.

The smaller machine has a five-eighths-yard bucket, 24-foot boom, and a 32-horsepower oil machine; the machine, complete, weighs 32 tons. The track shoes are each 30 feet long and 30 inches wide, and

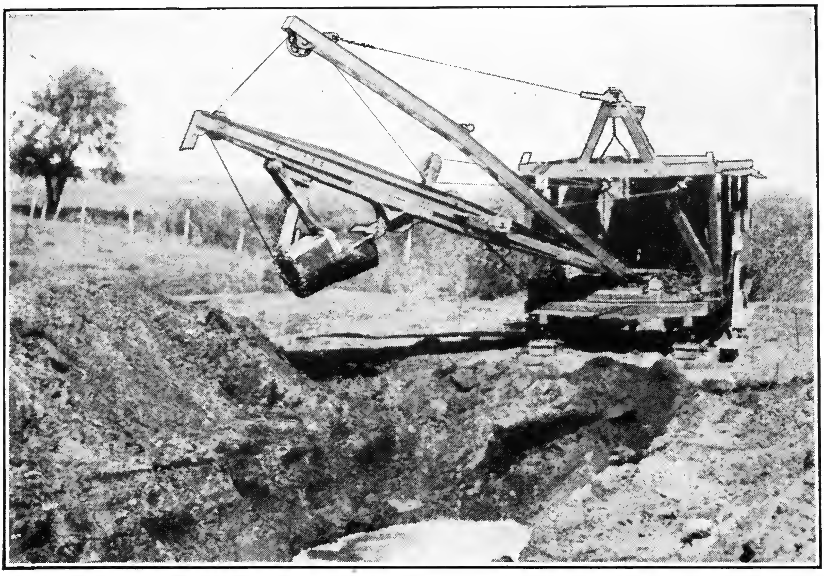


D-3320

FIG. 1.—CABLE SWING DRAG-LINE EXCAVATOR WITH CATERPILLAR MOUNTING.

D-3078

FIG. 2.—NONROTATING TYPE OF DRAG-LINE EXCAVATOR WITH WHEEL MOUNTING.



D-3308

FIG. 1.—NONROTATING SCRAPER EXCAVATOR WITH SLIDING TRACK MOUNTING.

D-3343

FIG. 2.—WALKING DRY-LAND DIPPER DREDGE.

the spud feet are 12 feet long by 8 inches wide. The bearing pressure when working is about 3 pounds per square inch. The distance covered at each move of the spud feet is 5 to 6 feet, and it requires about 30 seconds to move the machine ahead this distance. The road speed is 1¼ miles in 10 hours. About 30 gallons of kerosene are required per 10-hour shift. For operation three men are required—one runner, one craneman, and one trackman. The machine can be shipped on one car and requires four men one day to assemble and the same time to dismantle. The average output is from 500 to 800 cubic yards in 10 hours. The ditch best suited for the small machine is one with a 6-foot top and 4 feet of depth, although it can dig a ditch with a 20-foot top and 12 feet in depth. The machine costs about $12,000 with the sliding-track mounting and $15,000 with caterpillar mounting.

The larger machine (Pl. VIII, Fig. 1) has a 1-yard bucket, 32-foot boom, and 45-horsepower engine, and weighs, complete, 45 tons. The track shoes are each 34 feet long by 40 inches wide, and the spud feet 2 feet wide and 12 feet long. The bearing pressure when working is 2.8 pounds per square inch. The distance covered at each move of the machine is 5 to 6 feet, 45 seconds being required to make the move. The road speed is about three-fourths mile in 10 hours. About 40 gallons of kerosene are required per 10-hour shift. The machine requires three men for operation—one runner, one craneman, and one trackman. Two cars are needed to ship the machine. Four men can assemble it in five days and dismantle it in the same time. The average output is from 700 to 1,000 cubic yards per 10-hour shift. The size or ditch best suited for the machine has a 20-foot top and 7 feet in depth. It can, however, dig a ditch with a 35-foot top and 14 feet deep. The machine costs about $18,000. Over dry earth roads four men with four teams have hauled the large machine 4 miles in three days. The smaller machine can be shipped already assembled, whereas the larger machine must be dismantled for shipping.

This type of machine when digging does not straddle the ditch, but works along the center line when a new ditch is being dug or on one bank when an old ditch is being enlarged or cleaned out. No earth "roll" is left on the bank to fall back into the ditch. On these machines the average life of a loading line is 15,000 cubic yards; of a hoisting line, 40,000 cubic yards; of the track lines, 60,000 cubic yards. For the larger machines the minimum economical project is about 200,000 cubic yards with double-shift operation. For the smaller machines the job should have about 30,000 cubic yards. Contractors state that for the smaller machine they do not want to take a job costing less than $8,000.

## ACCESSORY EQUIPMENT.

For housing men employed in the operation of drag-line excavators many contractors use camp wagons, consisting of portable houses mounted on wagons. The most common size is 8 feet wide by 18 feet long. The structure costs about $200 and a wagon with 4-inch tires about $100.

## SELECTION OF SCRAPER EXCAVATOR.

In selecting a scraper excavator, the purchaser, in addition to choosing the most desirable kind of power and the means of moving

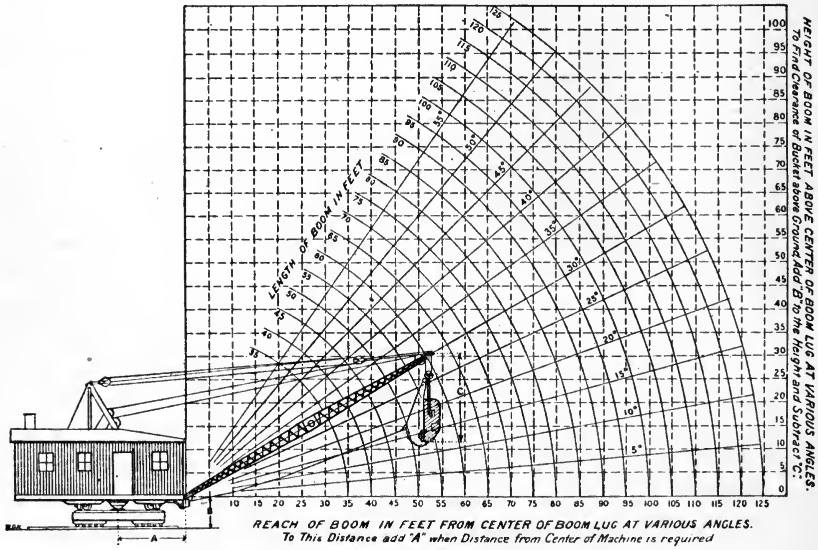



FIG. 2.—Diagram of scraper excavator showing relation between the length of boom and the effective reach of machine.

over the ground best suited to his particular case, must determine the length of boom best suited to his needs.

Figure 2 is a diagram showing the relation between the length and angle of elevation of the boom and the effective reach of the machine. In this diagram all distances are referred to the heel of the boom. If it is desired to refer horizontal distances to the center of the machine, the correction *A* must, of course, be added; this distance varies somewhat with the different makes of machine. The distance *B* of the heel of the boom above the ground likewise varies slightly in different machines.

To determine the maximum clearance of the bucket above the ground for different lengths and positions of boom the distance *B* must be added to the vertical heights given on the right-hand margin of the diagram, and from this sum must be subtracted the distance *C* which depends upon the kind of bucket used. Thus for a 70-foot boom elevated at an angle of 35 degrees the horizontal distance from the center of the machine to the bucket would be $57+A$, and at that position of the boom the bucket would just clear a waste bank of the height $40+B-C$. In using the diagram for nonrotating excavators the distance $A$ is not added, since the boom of this type of machine swings at its pivot. Table 17 gives the approximate distances $A$ and $B$ in figure 2 for the various sizes of machines on the different styles of mountings. The distances will vary slightly for different makes of excavators.

TABLE 17.—*Limitations of operation of drag-line excavators.*

| Size of bucket. | Length of boom. | Diameter of turntable. | | Type of mounting. | Distance A.[1] | | Distance B.[1] | |
|---|---|---|---|---|---|---|---|---|
| *Cu. yds.* | *Feet.* | *Feet.* | *in.* | | *Feet.* | *in.* | *Feet.* | *in.* |
| ½ | 30 | 4 | 7 | Caterpillar | 2½–3 | | 4–4½ | |
| 1 | 40 | 11 | 3 | Walker | 6 | 4 | 3 | 5 |
| 1 | 42 | 7 | | Caterpillar | 4 | 3 | 5 | 6 |
| 1 | 42 | 7 | | Skids and rollers | 3 | 3 | 4 | 5 |
| 1½ | 45 | 9 | 6 | Caterpillar | 7 | 5 | 9 | 5 |
| 1½ | 45 | 9 | 6 | Skids and rollers | 7 | 5 | 7 | 4 |
| 2 | 60 | 14 | | Caterpillar | 7 | 5 | 9 | 5 |
| 2 | 60 | 14 | | Skids and rollers | 7 | 5 | 6 | 5 |
| 2 | 50 | 15 | | .....do | 9 | 6 | 6 | 6 |
| 2 | 50 | 15 | | Walker | 10 | | 4 | 6 |
| 2½ | 85 | 20 | | Skids and rollers | 12 | 2 | 7 | 8 |
| 2½ | 85 | 20 | | Trucks | 12 | 2 | 11 | 6 |
| 3 | 60 | 17 | | Walker | 10 | 8 | 4 | 9 |
| 3 | 60 | 17 | | Skids and rollers | 11 | 8 | 7 | |
| 3½ | 80 | 20 | | .....do | 12 | 6 | 8 | |
| 3½ | 100 | 24 | | .....do | 12 | 2 | 7 | 10 |
| 3½ | 125 | 24 | | Trucks | 12 | 10 | 13 | |
| 4 | 80 | 24 | | Skids and rollers | 12 | 6 | 8 | |
| 4 | 100 | 24 | | .....do | 15 | | 8 | 6 |

[1] See figure 2.

The clearance distance $C$ (Fig. 2) varies with the size of bucket and size of sheaves used. Table 18 gives the approximate values of $C$ for the various sizes of bucket shown in Plate VII, Figure 1.

TABLE 18.—*Clearance of buckets for drag-line excavators.*

| Size of bucket. | Distance C.[1] | Size of bucket. | Distance C.[1] |
|---|---|---|---|
| *Cu. yds.* | *Feet.* | *Cu. yds.* | *Feet.* |
| ½ | 12 | 3 | 15½ to 16 |
| ¾ | 12½ | 3½ | 15¾ to 16½ |
| 1 | 12 to 12¾ | 4 | 17½ |
| 1½ | 12½ to 13 | 4½ | 18¾ |
| 2 | 14½ to 15 | 5 | 19 to 23 |
| 2½ | 14¾ to 15½ | | |

[1] See figure 2.

The factor governing the size of the ditch which a certain machine can dig is not ability to excavate, but, rather, to dispose of the material excavated, especially where the ditch is deep and the yardage per linear foot relatively large. An experienced runner can drop

1 to 2 miles in 10 hours. It is very useful on projects where the yardage per 100-foot station is small and where there are many short laterals.

A dry-land dipper dredge made of steel but equipped with a different device for walking than the machine just described is illustrated in Plate IX, Figure 2. The machine when working rests on two skids, each 3 feet wide by 30 feet long. The auxiliary skids each measure 3 feet wide by 28 feet long. When being moved the weight of the machine is shifted to the auxiliary skids, and the machine is skidded ahead. The auxiliary skids are then pulled forward. The machine will move either forward or backward. It is made with various widths of span from 14 feet up to 45 feet and in three sizes, $\frac{5}{8}$, 1, and $1\frac{1}{4}$ cubic yards. The length of boom varies for the different sizes from 25 feet to 55 feet.

A dry-land dipper dredge which employs the same method of walking as the machine illustrated in Plate VIII, Figure 2, but which is equipped with a different type of bucket, is used to some extent on drainage work. This machine (Pl. X, Fig. 1) is built almost entirely of wood, longleaf yellow pine being used, as this wood has greater resiliency than fir. The boom is of wood reinforced by truss rods. This machine as ordinarily built will span a ditch with a top width of 28 feet. It has a 40-foot boom and a $1\frac{3}{4}$-yard dipper. Booms of 30 or 50 feet can be used. For power a 60-horsepower internal-combustion engine is used. The dipper or scoop (Pl. X, Fig. 2) is 5 feet wide at its cutting edge. By virtue of the peculiar shape of the scoop, $2\frac{3}{4}$ cubic yards are easily removed at each dip.

This excavator is mounted on six shoes or feet, one at each corner of the platform and one on each side of the machine at the center. The four corner shoes are attached directly to the framework of the machine and move with it. The machine moves by shifting its weight to the center feet and sliding forward on the four corner shoes. The center feet are then pulled forward by means of chains attached to a drum. The machine in operation weighs 160 tons, but on account of the large bearing surface of the shoes the pressure per square inch is slightly less than 10 pounds. The front shoes are 6 by 10 feet; the rear shoes, 6 by 9 feet; while the middle shoes are 7 by 14 feet; these sizes, of course, can be varied. When operating, the entire weight is on the four corner shoes.

To dismantle or assemble an old machine of this type takes 15 men about 30 days. To build an entirely new machine would take the same number of men from 60 to 90 days. The machine can be shipped on four cars.

For this machine the minimum economical yardage of any one job is 1,000,000 cubic yards. The machine will excavate an average of

60,000 cubic yards a month with double shift; with steady running it will greatly exceed this amount. Its operation requires 4 men—1 runner, 1 craneman, 1 engineman, and 1 oiler. The runner handles the hoisting and backing lines, the craneman the swinging and dumping lines. The amount of fuel required per shift is 75 gallons of kerosene and 1 gallon of gasoline. About 5 gallons of cylinder oil are used per 24 hours, or two shifts. The ditch for which this machine is best adapted is one with a 14-foot base, 1 to 1 side slopes, and 7 to 8 feet deep.

From a motion study made of the time of operation of this machine the average time for 50 dips was obtained. To fill the bucket required 10 seconds; hoisting, swinging, and dumping, 9 seconds; returning to the channel to dig, 8 seconds; entire time for one complete operation, 27 seconds. Moving ahead a distance of 6 feet required about 18 seconds.

### THE DRY-LAND GRAB-BUCKET EXCAVATOR.

Dry-land grab-bucket excavators of both the rotary and nonrotating types are used to some extent in drainage reclamation. A machine of the former type having an orange-peel bucket is illustrated in Plate XI, Figure 1. The excavator moves on skids and rollers or is mounted on four trucks which move on a track built in sections so that it can be taken up and relaid ahead of the machine as the work progresses. In the revolving type this shifting of track is done by the machine itself.

The machine illustrated is operating a 2½-yard orange-peel bucket on levee work. The boom is 90 feet long. The main engines are 12 by 16 inches and the boiler, vertical in type, 74 inches in diameter. The track gauge of the machine is 26 feet from center to center; the rotation speed is 2 revolutions per minute.

A type of dry-land grab-bucket excavator which has been used on rice plantations and on marsh lands along the eastern coast for digging ditches and building small levees is shown in Plate XI, Figure 2. This machine is made in four sizes, with either automatic or bullwheel swing. The general dimensions, weight, and price for each size of machine and each type of swing are given in Table 20.

TABLE 20.—*Dimensions and costs of dry-land grab-bucket excavators with orange-peel bucket fitted with bull-wheel and automatic swing.*

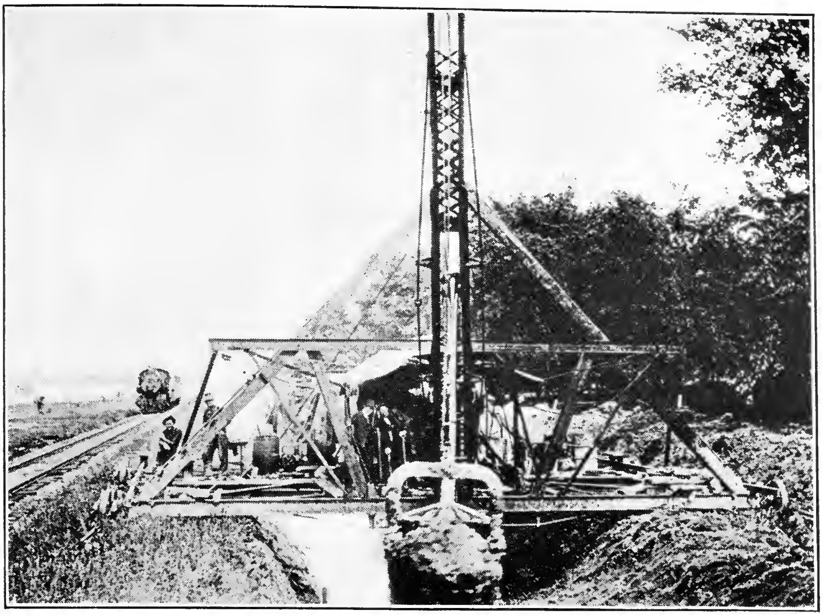
| Bucket capacity. | 9 cubic feet. | 15 cubic feet. | 21 cubic feet. | 1 cubic yard. |
|---|---|---|---|---|
| Common dimensions: | | | | |
| Boom, length, feet | 30 | 40 | 50 | 54 |
| Size of platform— | | | | |
| Length, feet and inches | 21 6 | 26 3 | 33 5 | 33 5 |
| Width, feet | 10 0 | 15 0 | 18 0 | 18 0 |
| A frame— | | | | |
| Height above bottom of skids, feet and inches | 15 9 | 17 6 | 25 0 | 25 0 |
| Extreme overall width of machine, feet and inches | 11 8 | 17 0 | 21 0 | 21 0 |
| Bull-wheel diameter, feet | 6 0 | 8 0 | 10 0 | 12 0 |
| Engine, internal combustion type with two friction drums, tandem, horse power | 10 | 20 | 30 | 40 |
| Bull-wheel swing: | | | | |
| Clearance under bucket, feet | 9 | 11 | 15 | 15 |
| Radius of swing from center of A frame, feet and inches | 28 9 | 38 6 | 47 0 | 52 0 |
| Weight, including drums and swinging gear, pounds | 10,500 | 11,000 | 15,000 | 17,000 |
| Timber to build machine, feet b. m | 2,300 | 3,950 | 7,400 | 7,600 |
| Approximate price not including timber of machine | $5,470 | $6,630 | $8,760 | $9,725 |
| Total weight set up for work, tons | 13 | 18 | 27½ | 31½ |
| Automatic swing: | | | | |
| Clearance under bucket, feet | 8 | 10 | 13 | 13 |
| Radius of swing from center of A frame, feet and inches | 26 9 | 36 4 | 45 | 50 |
| Weight, including drums, pounds | 8,500 | 9,000 | 13,000 | 15,000 |
| Timber to build machine, feet b. m | 2,200 | 3,750 | 7,000 | 7,200 |
| Approximate price, not including timber | $4,410 | $5,280 | $7,480 | $8,855 |
| Total weight of machine set up for work, tons | 11½ | 16 | 26½ | 30 |

## THE WHEEL EXCAVATOR.

There is a type of wheel excavator which has a steel frame which supports on the front end the power equipment and on the rear end a pivoted steel framework holding the digging wheel (Pl. XII, Fig. 1). The steel frame is mounted on two broad-tired wheels at the front end and on two apron tractors at the rear end. The large bearing surface permits the machine to operate in soft, swampy ground. The power equipment may be either a steam or an internal-combustion engine. The latter is used the more extensively.

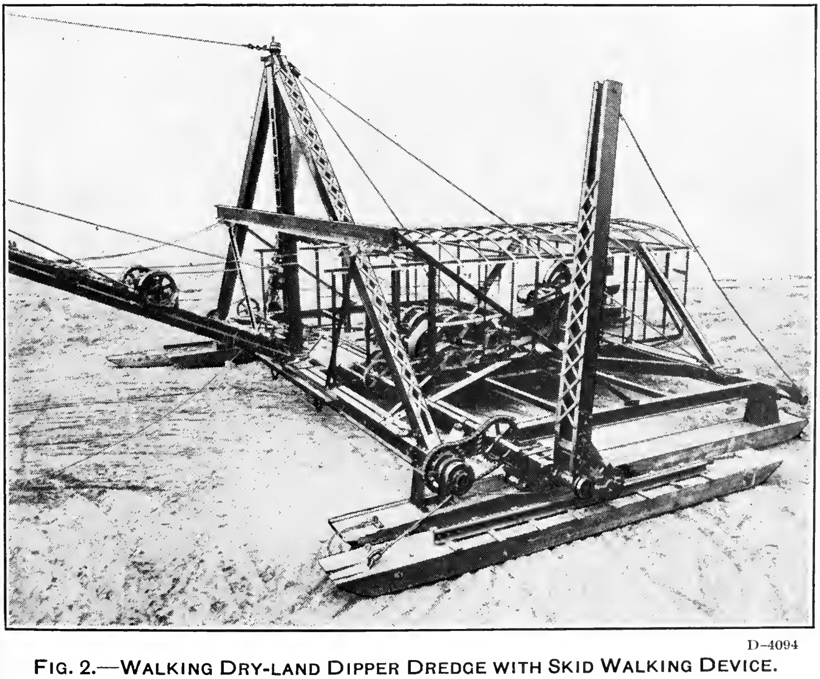
The excavating wheel revolves upon antifriction wheels placed just outside its rim. The excavating scoops or buckets are placed on the circumference of the excavating wheel. The front of each scoop is provided with a cutting edge which takes a thin slice from the face of the trench as the wheel rotates. When the bucket reaches the top of the wheel the earth falls onto a belt conveyor, which deposits it on the waste bank at one side of the ditch.

Table 21 gives general data concerning each size of machine, the dimensions of ditch each will dig, and the approximate cost of the various machines.



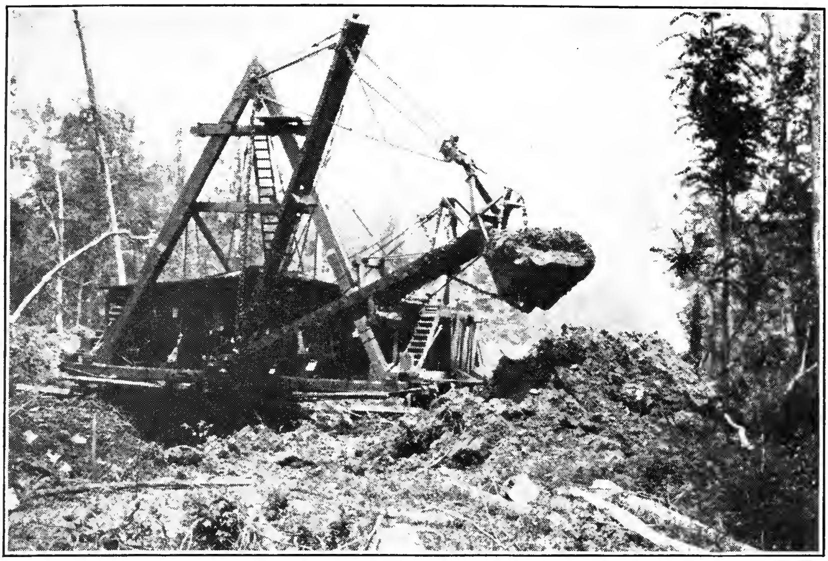
D-266

FIG. 1.—DRY-LAND DIPPER DREDGE MOUNTED ON TRACK.



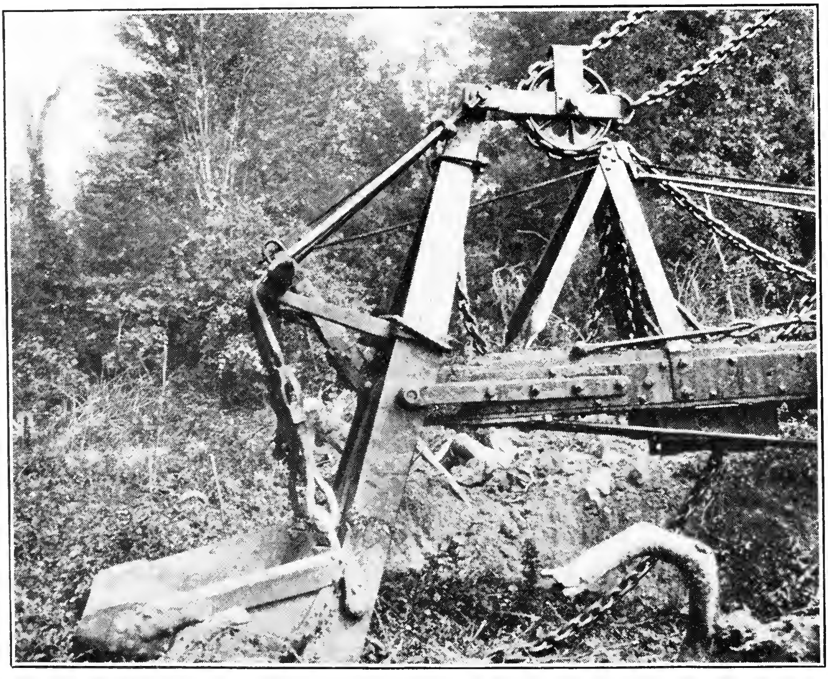
D-4094

FIG. 2.—WALKING DRY-LAND DIPPER DREDGE WITH SKID WALKING DEVICE.



D-3074

FIG. 1.—WALKING DRY-LAND DIPPER DREDGE WITH DOUBLE BOOM AND SCOOP BUCKET.



D-3076

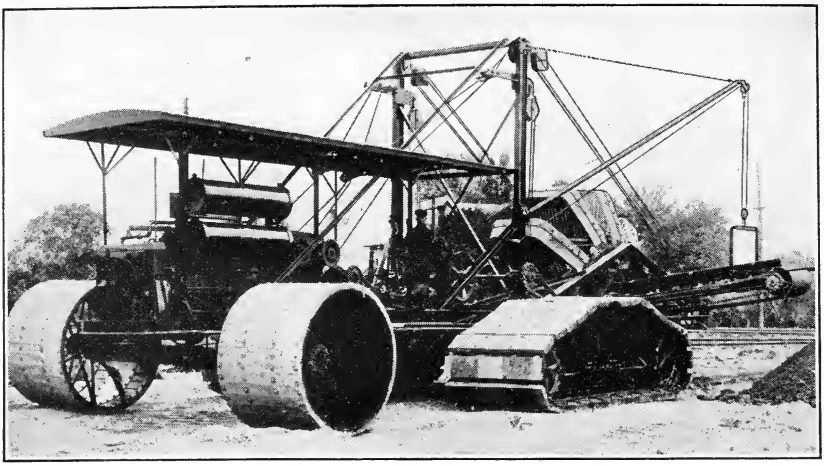
FIG. 2.—SCOOP BUCKET OF DRY-LAND DREDGE

D-3335

FIG. 1.—DRY-LAND ROTARY GRAB-BUCKET EXCAVATOR.

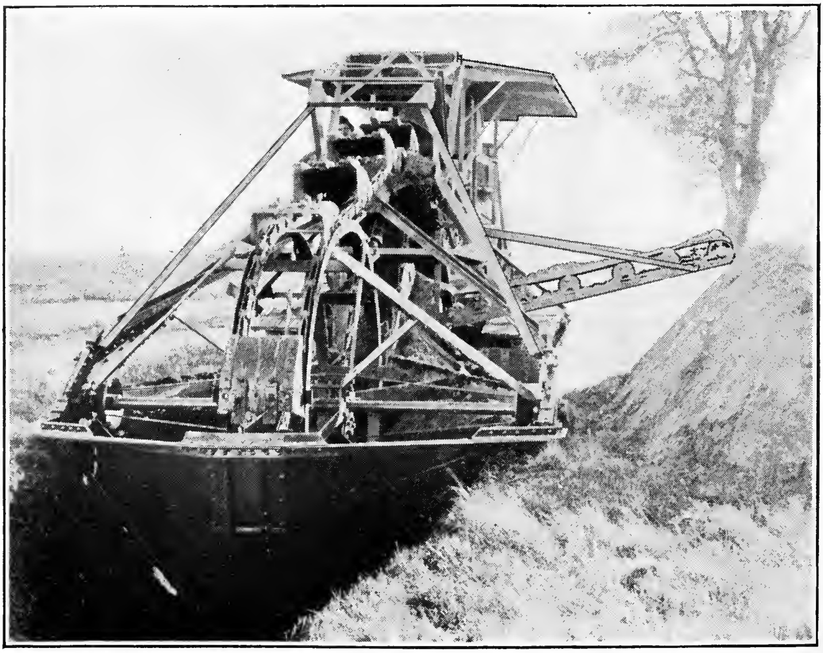
D-2921

FIG. 2.—NONROTATING DRY-LAND GRAB-BUCKET EXCAVATOR.



D-3324

FIG. 1.—NONCONVERTIBLE TYPE OF WHEEL EXCAVATOR.



D-3325

FIG. 2.—CONVERTIBLE TYPE OF WHEEL EXCAVATOR.

TABLE 21.—*Data pertaining to the wheel excavators.*

| | Clearance length of machine, feet. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 35 | 44 | 46 | 48 | 50 | 52 | 52 | 55 | 55 |
| Clearance width, feet | 13½ | 18 | 21½ | 23½ | 25 | 28 | 28 | 30 | 32½ |
| Size of front wheels, feet | 4½×3 | 5×4 | 5×4 | 6×5 | 6×5 | 6×5 | 6×5 | 6×5 | 6×5 |
| Size of apron wheels, feet | 10×3½ | 12×5 | 12×5½ | 12×5 | 14×6 | 14×7 | 16×7 | 16×7 | 16×8 |
| Engine, horsepower | 30 | 40 | 50 | 50 | 60 | 75 | 80 | 90 | 100 |
| Gasoline consumption in 10 hours, gallons | 27 | 36 | 45 | 45 | 50 | 60 | 70 | 80 | 90 |
| Cutting speed, feet per minute | 3 to 12 | 4 to 16 | 4 to 16 | 3 to 15 | 3 to 15 | 2 to 12 | 2 to 12 | 2 to 12 | 2 to 12 |
| Weight, tons | 18 | 21 | 25 | 28 | 32 | 38 | 42 | 46 | 50 |
| Top width of ditch, feet and inches | 2 6 | 4 6 | 6 0 | 7 0 | 8 0 | 9 0 | 10 0 | 11 0 | 12 0 |
| Depth of ditch, feet and inches | 3 0 | 3 6 | 4 6 | 5 2 | 5 6 | 5 6 | 5 6 | 5 6 | 5 6 |
| Approximate price | $7,200 | $8,300 | $10,000 | $11,500 | $13,200 | $15,400 | $16,300 | $17,100 | $19,300 |

The road speed of all sizes of the above machine is about 1 mile per hour. Two cars are required for shipping. Four men can unload and assemble one of these machines in three to five days.

There is a wheel type of trench excavator so designed that by adding side knives a ditch with sloping sides can be dug. This machine is illustrated in Plate XII, Figure 2. A series of buckets attached to two parallel chains travel over the circumference of a wheel which is supported by a central shaft. The cutting knives slice the earth from the sides of the ditch, the dirt falling into the path of the buckets. The excavator is made in two sizes. The smaller size will dig a ditch 5 feet deep and 3 feet in bottom width, with side slopes 1 to 1. The larger size will dig a ditch 6 feet deep and 5 feet in bottom width, with 1 to 1 side slopes. The machine is mounted on caterpillar tractors. For the small size, 4 by 6 foot tractors are used; the large machine requires 4½ by 11 foot tractors. Either steam or gasoline power is employed, the latter being more popular. The smaller excavator weighs 15 tons and requires a 24-horsepower engine; the larger machine weighs 20 tons and is operated by a 40-horsepower engine.

Both types of wheel excavators when equipped with internal-combustion power require two men to operate. If the work is in extremely soft ground two or more additional men are required. In addition a team and teamster are needed for hauling fuel and other supplies.

No average operation figures can be given as to the amount of work per shift that a wheel excavator will accomplish, as these vary greatly with the character of the soil, the conditions under which the work is being done, and the operator. In one of the Gulf States a wheel excavator equipped with a 30-horsepower gasoline engine, digging a ditch 4 feet deep, 4 feet wide at the top, and 2 feet wide at the bottom, made an average distance of 2,250 linear feet in 10 hours. The soil was a hard, yellow, sandy clay, overlain by a turfy muck varying in depth up to 2½ feet. The total length of ditches dug was 165 miles, two machines of the same size being used. The maximum distance dug in 10 hours was 6,600 feet. The fuel consumption per shift of 10 hours was 50 gallons of gasoline.

On another project a wheel machine of the same size was used. The soil was a silt loam, firm and uniform, but not tenacious. The average length of ditch cut per day was 800 feet, while the maximum was 1,950 feet. The total length of ditch cut was 117,000 feet.

Wheel excavators are adapted to the excavation of ditches in soils free from stumps, buried timbers, bowlders, or rock. They have been used extensively in the Gulf States on flat, swampy prairie lands.

## THE HYDRAULIC DREDGE.

The hydraulic dredge has been used only to a limited extent in the construction of drainage ditches, due to the fact that nearly all such ditches are too small to be dug economically by this method. Hydraulic dredges are suitable for digging ditches 800 or more square feet in cross section, for building levees under favorable conditions, and especially for building up tidal flats and lowlands.

The principal parts of the hydraulic dredge are a centrifugal pump, the power machinery to drive the pump, and the hull on which the machinery is mounted. When the dredge is operating the material to be excavated, mixed with water, is drawn in through the suction pipe and discharged where desired through a line of pipe sometimes several thousand feet long. Coarse sand, gravel, muck, and silt are easily handled in this way, and by the use of a rotary cutter on the end of the suction pipe comparatively hard clay can be removed. The machine does not work well where there are stumps, logs, large stones, or other such obstructions.

The dredge must be moved frequently. This is usually accomplished by cables operated by a hoisting engine and attached to deadmen on the shore or, if working in a large stream, to anchors dropped into the stream. Either one or two spuds are arranged at the stern of the dredge, which hold that end of the hull in position. By swinging the head of the dredge the amount of material delivered to the pump can be regulated so that the dredge will handle the maximum percentage of solids.

To determine whether the dredge is working properly a vacuum gauge is attached to the suction pipe and a pressure gauge to the discharge pipe. The operator by means of the vacuum gauge can tell when the pump is handling the proper amount of material, as the reading on the gauge is greater when pumping solid material than when pumping water only. The reading on the pressure gauge varies with the length of the discharge pipe used and with the elevation to which the material is pumped. An experienced operator, however, can tell when the operations are being carried on properly. The reading in inches on the vacuum gauge can be reduced to the equivalent head in feet by multiplying the number of inches by 1.13. The reading on the pressure gauge, in pounds per square inch, can be reduced to the equivalent head in feet by multiplying the gauge reading in pounds by 2.30. The practical maximum discharge pressure is from 45 to 55 pounds, depending somewhat upon the size of the pump. For extra high heads, relay or booster pumps are used; that is, the first pump delivers the material through a certain length of discharge pipe into the suction line of the relay pump. An auxiliary pump is often used to discharge water continuously into the shell of the dredging pump to aid in moving the material pumped.

The suction head is the distance from the surface of the water to the center of the pump plus pipe friction and losses of head through the rotary cutter and at the entrance of the suction pipe. The total suction head should not ordinarily exceed 25 feet, a condition easily met by the hydraulic dredge. The discharge head is the difference in level between the pump shaft and the point of discharge, plus the friction in the discharge pipe.

For priming the pump a small centrifugal pump is commonly used. The method is to raise the suction pipe until its end is higher than the dredging pump and prime until priming water discharges from the suction pipe; the suction pipe is then dropped into the water and the dredge pump started.

## SELECTION OF EQUIPMENT.

In order to select the proper equipment several ruling factors must be considered. The character of the material to be excavated, the maximum depth of water from which the material is taken, the maximum elevation at which the material is to be deposited, and the maximum and minimum length of discharge pipe to be used, are conditions which must first be determined. Likewise the quantity of material to be excavated per shift must be decided upon, as well as the type of power equipment and method of drive.

The percentage of solids moved depends upon the character of material pumped and the velocity in the discharge pipe. In mud or silt 20 per cent or more solid material may be handled with the water; in sand and gravel probably not more than 10 per cent. Light silt or fine sand are easily carried in suspension, and for these a larger diameter of discharge pipe with a lower velocity may be used than for coarse sand and gravel. The maximum velocity of discharge is reached when the friction head begins to increase too rapidly. The velocity at which the abrasive action on the internal surface of the discharge pipe begins to be serious occurs at about 12 feet per second for pipes 20 inches in diameter. The gain in the proportion of solids transported at high velocity may be offset by the cost of more frequent renewals of discharge pipe. Discharge pipes having a diameter of 15 inches and a thickness of wall of eleven-sixty-fourths inch, and containing from 0.5 to 0.6 per cent of carbon and from 0.6 to 0.7 per cent of manganese, have passed more than 300,000 cubic yards without wearing out. Since the wear is chiefly along its bottom, the pipe may be marked and rotated a quarter turn occasionally to insure even wear.

The smaller the diameter of the discharge pipe the higher the velocity for a given discharge, and the greater the percentage of solids which will be transported. The larger the discharge pipe the greater the volume of mixture carried for a given amount of power. The amount of power must be determined that will give sufficient velocity to carry the material in suspension and deliver the maximum amount of solids. With 6-inch pipe or less, sand mixtures will flow well with a pipe velocity of 5 feet per second. In a 20-inch pipe it has been found that a velocity of 10 feet per second will transport sand.

The smaller pumps, 12 inches and under, may be either belt-driven or direct-connected to the power unit. The larger pumps are usually direct-connected to the power unit, this method of drive being the most economical. When there happens to be great variation in the length of discharge pipe it is advisable to have impellers of different diameters—one of large diameter when long discharge pipes are used and a smaller impeller with a short discharge pipe. By using the proper size of impeller the engine is better able to maintain its normal speed.

## DETERMINATION OF SIZE OF PLANT.

To determine the amount of power required to operate the pump the following factors must be considered: (1) diameter of suction and discharge pipe; (2) kinds of pipe and length of each kind; (3) character of end connections; (4) static head; (5) efficiency of pump and engine (which may vary from 30 to 70 per cent); and (6) nature of material and percentage of solids transported.

The required horsepower of the engine may be obtained by multiplying the weight of the mixture transported by the total head in feet, and a coefficient dependent upon the combined efficiencies of the pump and engine. Efficiencies over 50 per cent are rarely obtained in a hydraulic dredge pump. Table 22, compiled from data published by manufacturers of hydraulic dredges, gives the capacities and required power for pumps of various sizes.

TABLE 22.—*Capacities and required power of hydraulic dredges.*

| Diameter of suction and discharge pipes. | Normal capacity. | Solids pumped per hour. | | | Approximate horsepower required for each foot of head. |
|---|---|---|---|---|---|
| | | 10 per cent. | 15 per cent. | 20 per cent. | |
| *Inches.* | *Gallons per minute.* | *Cubic yards.* | *Cubic yards.* | *Cubic yards.* | |
| 4 | 450 | 12 | 18 | 24 | 0.4 |
| 5 | 700 | 20 | 30 | 40 | .6 |
| 6 | 1,000 | 30 | 45 | 60 | .8 |
| 8 | 1,800 | 50 | 75 | 100 | 1.5 |
| 10 | 2,800 | 90 | 135 | 180 | 2.5 |
| 12 | 4,000 | 130 | 195 | 260 | 3.0 |
| 15 | 6,300 | 200 | 300 | 400 | 5.0 |
| 18 | 9,000 | 300 | 450 | 600 | 7.0 |
| 20 | 13,000 | 375 | 560 | 750 | 8.0 |
| 24 | 17,000 | 500 | 750 | 1,000 | 10.0 |

Suppose it is desired to select pump and power equipment for a hydraulic dredge to be used in building a levee with a top elevation 20 feet above the water surface, the maximum length of discharge pipe to be 2,000 feet, the material to be pumped being sand which it is desired to pump at the rate of 130 cubic yards of solids per hour. In pumping sand it is assumed that 10 per cent of the discharge is solids. Table 22 shows that a 12-inch pump will deliver the required amount of material.

To determine the size of the power unit to work the pump efficiently it is necessary to determine the head against which the pump is to operate. This includes static head, entrance loss, and friction in suction and discharge pipes. Table 23 shows the velocity of flow and friction head per 100 feet for water in clean iron pipe, as given by pump manufacturers. To obtain the friction head for the mixture pumped by a hydraulic dredge, the figures given in Table 23 should be increased from 40 to 75 per cent, depending upon the character of the material pumped.

TABLE 23.—*Friction head per 100 feet and velocity of flow of water in clean iron pipe.*

| Gallons per minute. | | Inside diameter of pipe in inches. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 15 | 18 | 20 | 22 | 24 |
| 450 | Friction head, feet. | 13.9 | 4.6 | 1.9 | | | | | | | | | |
| | Velocity, feet per second. | 11.4 | 7.3 | 5.1 | | | | | | | | | |
| 750 | Friction head, feet. | | 11.3 | 5.1 | 1.2 | | | | | | | | |
| | Velocity, feet per second. | | 12.2 | 8.4 | 4.8 | | | | | | | | |
| 1,000 | Friction head, feet. | | | 9.0 | 2.2 | 0.74 | | | | | | | |
| | Velocity, feet per second. | | | 11.3 | 6.4 | 4.0 | | | | | | | |
| 1,800 | Friction head, feet. | | | | 6.92 | 2.3 | 0.94 | | | | | | |
| | Velocity, feet per second. | | | | 11.5 | 7.4 | 5.1 | | | | | | |
| 2,500 | Friction head, feet. | | | | 13.3 | 4.39 | 1.78 | 0.84 | | | | | |
| | Velocity, feet per second. | | | | 15.9 | 10.2 | 7.09 | 5.2 | | | | | |
| 3,000 | Friction head, feet. | | | | | 6.3 | 2.55 | 1.19 | | | | | |
| | Velocity, feet per second. | | | | | 12.2 | 8.5 | 6.3 | | | | | |
| 4,000 | Friction head, feet. | | | | | | 4.65 | 2.10 | 1.45 | | | | |
| | Velocity, feet per second. | | | | | | 11.5 | 8.9 | 7.2 | | | | |
| 6,000 | Friction head, feet. | | | | | | | 4.8 | 2.9 | 1.43 | | | |
| | Velocity, feet per second. | | | | | | | 13.4 | 10.8 | 8.2 | | | |
| 7,500 | Friction head, feet. | | | | | | | | 4.4 | 2.18 | 1.30 | | |
| | Velocity, feet per second. | | | | | | | | 13.5 | 10.3 | 8.26 | | |
| 10,000 | Friction head, feet. | | | | | | | | | 3.67 | 2.25 | 1.39 | |
| | Velocity, feet per second. | | | | | | | | | 13.7 | 11.0 | 9.0 | |
| 12,500 | Friction head, feet. | | | | | | | | | | 3.06 | 1.87 | 1.25 |
| | Velocity, feet per second. | | | | | | | | | | 13.0 | 10.5 | 9.0 |
| 14,000 | Friction head, feet. | | | | | | | | | | 4.25 | 2.64 | 1.79 |
| | Velocity, feet per second. | | | | | | | | | | 15.4 | 12.6 | 10.79 |
| 17,000 | Friction head, feet. | | | | | | | | | | | 3.8 | 2.6 |
| | Velocity, feet per second. | | | | | | | | | | | 15.3 | 13.1 |

The loss of head due to an elbow in a 12-inch pipe line may be estimated at 2 feet. The entrance loss is usually considered equivalent to 2 or 3 feet of head. The minimum velocity that will transport sand in a 12-inch pipe has been found by experience to be approximately 8 feet per second. Table 23 shows that for clear water the friction loss per 100 feet of 12-inch and 14-inch pipe is 4.65 feet and 2.10 feet, respectively, and that the velocity of flow is 11.5 and 8.9 feet per second, respectively. As the velocity in the 14-inch pipe is sufficient to transport the 10 per cent mixture to be pumped, this size of pipe should be used, because there is less friction than with the 12-inch pipe.

The 2,000 feet of discharge pipe would therefore develop a friction head of 20 by 2.10 feet, or 42 feet, with clear water; with a 10 per cent sand mixture this head should be increased at least 50 per cent, or to 63 feet.

If the pipe lines make four elbow turns and the friction loss in the suction pipe, which is seldom more than 25 to 40 feet long, is omitted, the total head to be pumped against is as follows:

| | Feet. |
|---|---|
| Static head (difference in elevation of water surface and top of levee) | 20 |
| Friction loss in 2,000 feet of 14-inch discharge pipe | 63 |
| Loss of head in 4 elbow turns | 8 |
| Entrance loss | 2 |
| Total head to be pumped against | 93 |

Table 22 shows that approximately 3 horsepower is required for each foot of head to make a 12-inch centrifugal pump deliver 130 cubic yards of solids per hour in a 10 per cent mixture. It would, therefore, be necessary to have 279 horsepower available to pump against the required head of 93 feet. As it is advisable to have ample power available, a 300 or preferably a 350 horsepower engine should be used. If electric power is used, a 400-horsepower motor should be installed, as electric equipment can not successfully be subjected to overload as can steam equipment.

In determining the size of plant required it is important to provide ample reserve power and capacity. This is necessary because of the many variable and unknown factors entering into the operation of hydraulic dredges. A choked suction pipe, pump, or discharge pipe can frequently be corrected without serious loss of time if ample reserve power is available.

### OUTPUT.

The amount of material pumped in a unit of time and the fuel consumption per cubic yard pumped vary, of course, with the kind of material pumped and the conditions under which operations are conducted. The information given in Table 24 is representative of this type of dredge.

In the operation of hydraulic dredges there is considerable lost time, due to delays caused by such items as changes in discharge pipe, choked suction pipe, pump, or discharge pipe, repairs, and renewals. Not more than 50 to 75 per cent of the time will be spent in actual operation.

TABLE 24.—*Operating data for United States hydraulic dredges.*[1]

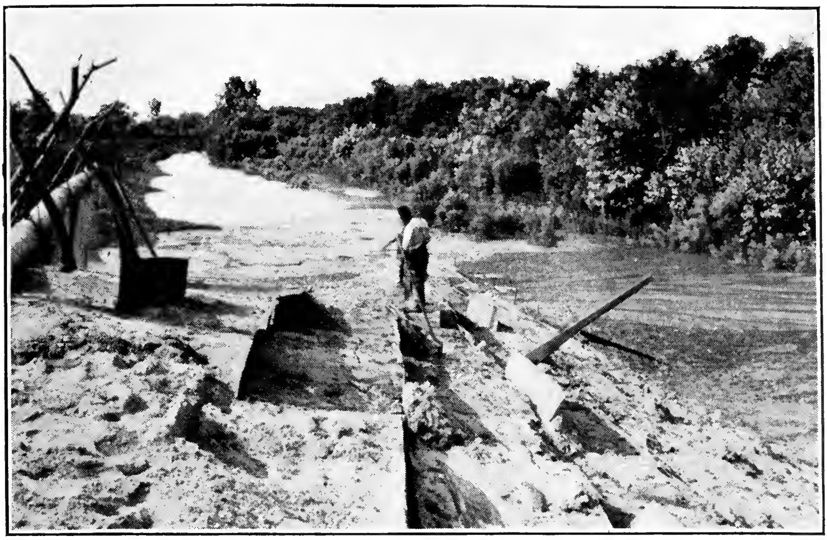
| Diameter of discharge pipe. | Material. | Average gauge pressure in discharge pipe. | Average vacuum in suction pipe. | Total head. | Average output per hour of pumping. | Coal used per cubic yard pumped. | Total excavation. |
|---|---|---|---|---|---|---|---|
| *Inches.* | | *Pounds per square inch.* | *Inches.* | *Feet.* | *Cubic yards.* | *Pounds.* | *Cubic yards.* |
| 10 | Sand | 14 | 15 | 49 | 89 | 13.3 | 163,288 |
| 12 | Sand and shells | 9 | 20 | 43 | 97 | 15.63 | 9,172 |
| 12 | Sand, gravel, shells | 18 | 10 | 53 | 199 | 6.5 | 16,889 |
| 12 | Sand | 18 | 12 | 55 | 107 | 6.35 | 55,131 |
| 12 | Sand and gravel | 14 | 9.7 | 42 | 76 | 14.4 | 123,959 |
| 12 | .....do | 10 | 14 | 39 | 105 | 12.6 | 165,028 |
| 12 | Mud | 16 | 15 | 54 | 181 | 4.22 | 376,079 |
| 15 | Mud, clay, sand | 12.6 | 16.9 | 48 | 141 | 9.8 | 230,257 |
| 15 | Gravel and sand | 12 | 20 | 50 | 257 | 6.79 | 310,370 |
| 15 | Silt, clay, and sand | 22 | 18 | 71 | 172 | 8.64 | 488,875 |
| 15 | Mud and silt | 18 | 12 | 55 | 293 | 3.2 | 792,807 |
| 15 | Mud, clay, and sand | 3.5 | 11 | 21 | 309 | 2.71 | 1,078,285 |
| 15 | Sand, mud, and shells | 16 | 7 | 45 | 551 | 3.35 | 1,298,597 |
| 18 | Sand and mud | 14 | 18 | 53 | 113 | 15 | 228,263 |
| 18 | Sand and mud, some rock | 22 | 9 | 61 | 286 | 6.7 | 1,045,689 |
| 20 | Sand and rock | 15.4 | 16 | 54 | 336 | 5.27 | 365,433 |
| 20 | Mud, sand, and shell | 28 | 14 | 80 | 1,130 | 4.31 | 444,665 |
| 20 | Sand, mud, and stiff clay | 25 | 12 | 71 | 180 | 8.41 | 527,360 |
| 20 | Mud and clay | 28 | 18 | 85 | 685 | 2.45 | 636,417 |
| 20 | Mud and sand | 32 | 12 | 87 | 503 | 7.33 | 1,270,703 |
| 20 | Mud and clay | 21 | 15 | 65 | 827 | 2.48 | 1,341,835 |
| 20 | Silt, quicksand | 32 | 12 | 87 | 369 | 3.75 | 1,687,476 |
| 20 | Mud, sand, clay | 26 | 8 | 69 | 1,046 | 3.07 | 3,697,875 |
| 24 | Sand and gravel | 9 | 13.5 | 36 | 542 | 10.4 | 59,702 |

[1] Annual Report, Chief of Engineers, United States Army, Floating Plant (1915).

## USE IN LEVEE CONSTRUCTION.

The hydraulic dredge can be used successfully in constructing levees where water and soil conditions are suitable and where there is sufficient yardage to pay for the installation of such a machine. Suitable soils are those largely composed of sand with some silt or clay. If a large amount of silt or clay is present there is a tendency for the material to remain in suspension for considerable time and it is difficult to form the levee. Plate XIII, Figure 1, illustrates the method of forming the desired slopes by means of steel boards. These boards, made of No. 14 gauge steel, about 18 inches wide and 10 feet long, with angle-iron top, are light enough to be easily moved by one man. They may be placed in a continuous single line along the intersection of the side slope with the natural slope at the end of the fill, or they may be placed in a staggered line along the slope as shown. Several men equipped with shovels are necessary to distribute the material evenly and to move the slope boards ahead as the levee is built up.

A hydraulic dredge (Pl. XIII, Fig. 2) with hull 90 by 24 by 5½ feet, having a centrifugal pump with 12-inch suction pipe, 14-inch discharge pipe, a 250-horsepower tandem compound engine, and a locomotive-type boiler nominally rated at 150 horsepower, was used in constructing a section of levee along the Mississippi River near



D-3079

FIG. 1.—BUILDING A LEVEE BY MEANS OF STAGGERED SLOPE BOARDS.

D-3080

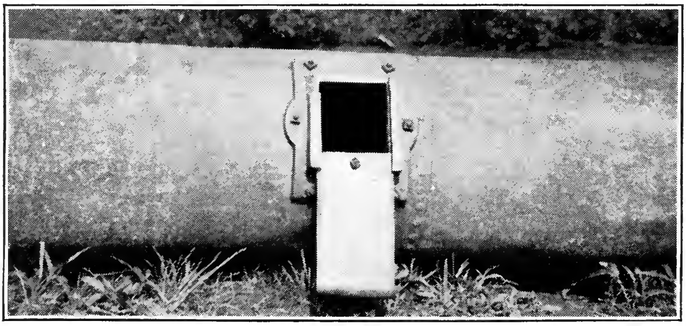
FIG. 2.—HYDRAULIC DREDGE BUILDING LEVEE.

D-3077

FIG. 3.—A TYPE OF CUTTER HEAD USED ON THE HYDRAULIC DREDGE.

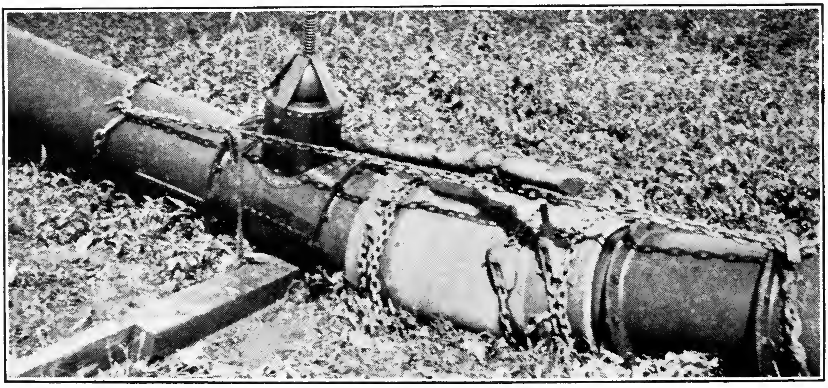
D-3088

FIG. 1.—DISCHARGE PIPE OF HYDRAULIC DREDGE SHOWING MATERIAL PASSING THROUGH OPENINGS IN BOTTOM OF PIPE.



D-3084

FIG. 2.—DISCHARGE PIPE OPENING WITH SHUTTER.



D-3083

FIG. 3.—RELEASE VALVE IN DISCHARGE PIPE.

Muscatine, Iowa. The material was sufficiently hard to require a cutter head (Pl. XIII, Fig. 3). The mechanism for running the cutter head was operated by a vertical two-cylinder steam engine. For moving the dredge a 6 by 9½ inch double-cylinder, three-drum hoisting engine was used, the cable being secured to a deadman on the shore at one end and to a heavy anchor in the river at the other. One drum was used to raise and lower the suction pipe. The hoisting engine used steam from the main boiler. For operating the pump a rope drive was used, the rope being four-strand and 1¼ inches in diameter. Rope transmission is believed to be less affected by moisture than leather belting; moreover, there is less slippage with rope drive.

The discharge pipe was carried from the dredge to the shore on barges, each 40 by 14 by 2 feet. The material was deposited on the levee through 4 by 6 inch openings in the bottom of the discharge pipe (Pl. XIV, Fig. 1). The openings were equipped with shutters (Pl. XIV, Fig. 2), so they could be opened or closed as desired. The discharge pipe was divided into 25-foot lengths, each of the last 10 lengths being equipped with three openings or gates. The pump became clogged occasionally with masses of roots, and to prevent damage to the discharge pipe from the resuction in the pump a joint of pipe having a release valve which allowed air to enter (Pl. XIV, Fig. 3) was inserted in the pipe. Resuction will cause a 14-inch discharge pipe of 14-gauge material to collapse unless release valves are provided. The pump was equipped with pressure and vacuum gauges to enable the operator to gauge the working of the dredge.

The operating crew for one shift consisted of a foreman, an operator, a fireman, and a deck hand. From 5 to 10 men were required at the end of the discharge pipe, depending upon whether an old levee was being enlarged or a new levee built. The coal consumption averaged from 4 to 5 tons per 11-hour shift. When the condenser was not used about three-fourths ton more fuel per shift was needed. With steady running the dredge pumped from 2,000 to 2,400 cubic yards in 11 hours; on the job as a whole, however, the average was from 1,000 to 1,200 cubic yards per shift.

The open type of impeller with five blades was used on the dredge described. This impeller has adjustable shoes which can be replaced when worn.

To build a hull for a dredge of this description takes 8 men 6 weeks; to assemble the machinery, 6 men about 6 weeks; to build a coal barge 75 by 16 by 5 feet, and 5 pontoons, each 40 by 14 by 2 feet, will take 8 men 6 weeks. The cost of the dredge complete is about $30,000, including barges and pipe.

In excavation where many roots are encountered, it has been found that the inclosed impeller having two blades works exceptionally