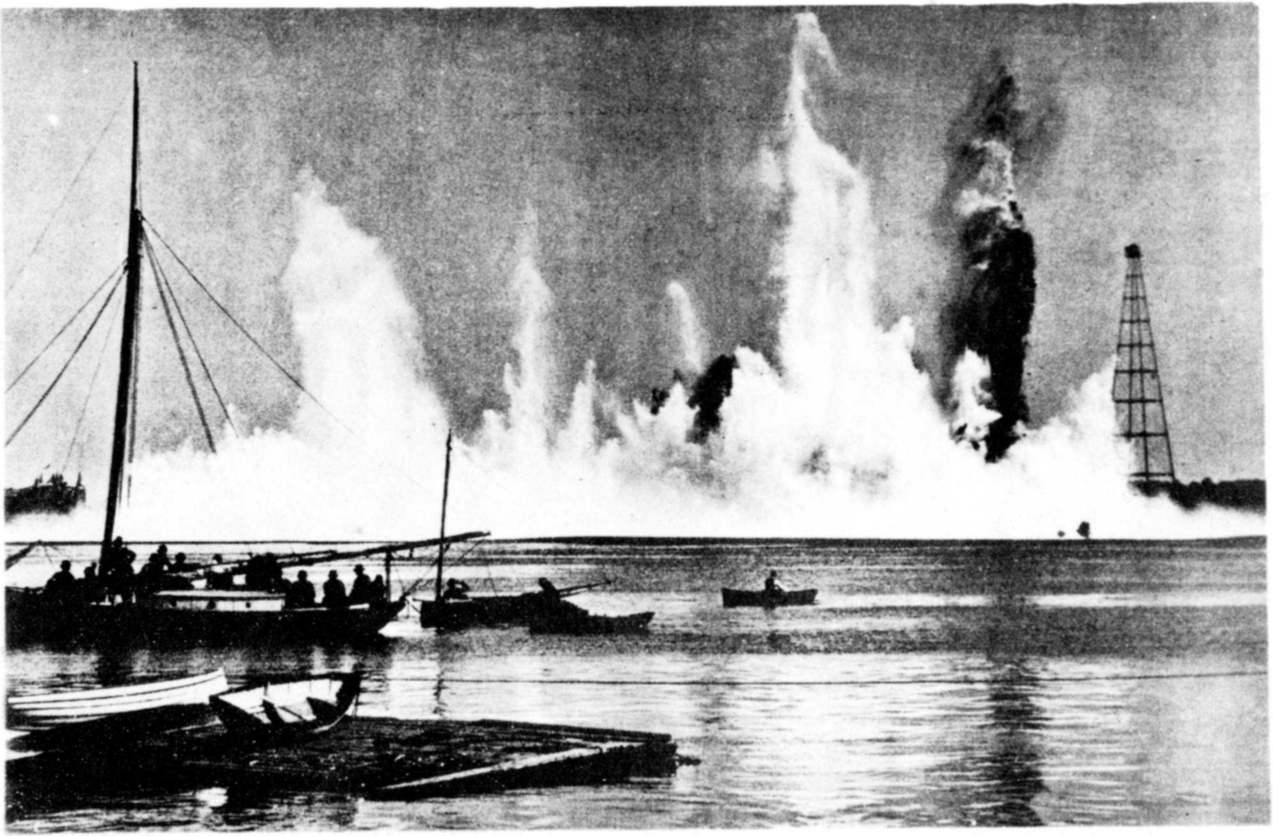

Frontispiece. The monster blast that shattered Flood Rock in Hell Gate on October 10, 1885, and cleared the way for deep-draught vessels traveling the East River. (Ingersoll-Rand Co.)

# A STUDY OF EXCAVATION OF SUBAQUEOUS ROCK WITH SPECIAL REFERENCE TO THE COLUMBIA RIVER

by

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## PREFACE

A review of the available literature on the subject of subaqueous rock removal has made possible the development of an outline of the progress in this branch of engineering. With this background Part II is devoted to a proposed method of removing rock from the Columbia River.

It should be mentioned that the subject is confined to the breaking and excavation of solid rock. Since much is known of the methods of excavation of loose material, a supplement to the extensive literature on dredging would be of little value. For this reason, particular attention will be directed to the drilling and blasting while the subsequent dredging will be treated moderately.

Acknowledgment is due particularly to Mr. L. A. Peacock of Siems-Helmers, Inc. for the useful information pertaining to their operations on the Columbia River. Valuable data were received from Mr. Chas. C. Hansen, Engineer, Ingersoll-Rand Co. and Messrs. Gordon and Finkbeiner, Portland Sales Agents for the Ingersoll-Rand Co. Acknowledgment is also due to Mr. T. G. Wier of the Worthington Co., to Mr. F. O. Groshong, and to those who have contributed much of their time in correcting the test.

Special credit is given to Dr. C. A. Mockmore, Head of the Department of Civil Engineering, under whose supervision and guidance this paper was written.

# INTRODUCTION

The removal of subaqueous rock is a phase of construction which has perplexed engineers since the first artificial channel or subaqueous foundation was visualized. Nevertheless, many million yards of submerged rock have been removed through the ingenuity of men confronted with the problems of improvement.

Although this work is being carried on to an increasing extent, it is unfortunate that the subject has been only moderately treated by engineering writers. Many articles of a very general nature have been written in recent years, but only a few writers have described their experiences accurately and in detail. The limited material treating of this work is so scattered and incomplete that it is difficult for a practising engineer to profit by the records of his predecessors. Many mistakes result which, although excusable to a pioneer in this field, could be avoided with some knowledge of previous experience.

Excavating a ship channel in the upper Columbia River presents itself as a significant problem. Even with the modern equipment in current use, the satisfactory removal of solid rock to form a channel in a river of this magnitude and velocity is a challenge to the engineering profession.

It is with the thought that the available literature on this subject of value in performing simialr work in the Columbia River, that the author compiles this treatise.

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SYNOPSIS

The purpose of this paper is to present a study of the methods employed in removing solid rock from below a water surface, applying the principles to the construction of a channel in the Columbia River. A description of the methods and machinery employed in Europe and America, beginning with the first crude tools used early in the nineteenth century, is presented as a background for current operations. The devices which have been used in the water-ways of the world are discussed and classified in the order of their importance as patterns for modern machines.

Many devices in current use are described, expanding upon those which are allied with excavation performed from a floating barge. The drill boat which is now employed extensively is analyzed in detail in order that its features may be understood and modified to fit specific conditions. Submarine blasting technique leads to the development of a method of spacing and loading drill holes in order to realize maximum benefit from the explosive employed. A moderate treatment of dredges and dredging methods concludes the discussion of general practices.

Attention is then devoted to the improvement of the natural channel in the upper Columbia River. A description of the adverse conditions and the channel requirements equips the reader with a concept of the problem. Two types of plant which have previously been proposed for removing the solid rock from the channel are presented for consideration.

The treatise includes the design of a drill boat to drill and blast the solid rock in the Columbia River, assuming a hypothetical project requiring the removal of fifty thousand cubic yards within a period of two years. Employing the principles which have been used in the past, and recognizing the conditions to be encountered, the plant is designed to meet the specific requirements of this work. It includes the dimensions of the hull, a discussion of all equipment, and computations relative to required sizes and power. This leads to an analysis of the distribution of weight and draught.

The importance of satisfactory auxiliary equipment, composed of a tugboat, work boats, and an anchor barge, is emphasized. A brief discussion outlines the type of machine to use for dredging the blasted material from the channel.

The organization of a competent crew and practical methods of operating the drill boat are presented as important factors for consideration. An analysis of the probable cost of operating the proposed plant concludes the discussion. The criterion employed for determining a satisfactory method of removing this rock has been safety to human life and economy of cost.

# A STUDY OF EXCAVATION OF SUBAQUEOUS ROCK WITH SPECIAL REFERENCE TO THE COLUMBIA RIVER

## PART I

## EXCAVATION OF SUBAQUEOUS ROCK

### HISTORICAL DEVELOPMENT

SURFACE BLASTING. The earliest known method of loosening subaqueous rock was to place explosives on the surface of the material to be removed. This scheme was used years ago on the Rhine and Severn Rivers in Europe. One method of removing the rock from the famous River Danube[48, 58] was to place bundles of powder on the bottom of armoured spuds and lower them to the surface of the rock where they were exploded. Unfortunately the spuds were usually damaged more than the rock. It was found that the first shot was effective to a depth of one or two feet but that the subsequent explosions in the same place were absorbed by the cushion of broken rock.

This procedure has had a varied history and is used occasionally even today where conditions are favorable. The Miami ship channel,[68] a soft porous limestone formation, was recently deepened at a nominal cost by this method of "dobying" or "surface blasting". Here small packets of 60% gelatin were weighted and lowered to the rock surface. All conditions being favorable, no wind or fast currents existing, this method proved more economical than drilling. The removal of boulders and pinnacles under the water surface is often performed in this manner, but in general it might be said that surface blasting has been very unsatisfactory in formations where ledges and large areas of flat bottom predominate. Most of the rock which has been dealt with in the past falls into this classification, therefore, it has been found advisable and important to resort to a more practicable method of removal.

## Pioneering in Europe

With attention centered about Europe during these years of pioneering many schemes for removing rock were attempted. The first method of which records are available was naturally that of drilling holes in rock by hand[27] and the use of black powder. The writings relate that the men stood on rafts and drilled through a pipe, one holding and rotating the steel, while others struck with sledges. In this early development of the hand method a caisson or diving bell was often employed. As long ago as 1814 men descended to the bottom of the Howth Harbor and drilled holes in the rock by hand and loaded with black powder. The diving bell and caisson has been used ever since but with many refinements.

THE JUMPER DRILL. Probably the first improvement was the use of the jumper drill in removing the marl beds along

Note:—— Numbers in text refer to bibliography.

The River Severn[49] in 1860. This tool, although hand operated, was more satisfactory than striking the steel with hammers, especially in soft rock formations. It was a heavy steel bar weighing about fifty pounds and equipped with a forged bit. As it was raised and dropped it was guided in an iron pipe so that it continued to penetrate in one place. The first combined unit was composed of a shaft on which a number of slip ropes were wrapped.[12] Each slip rope was attached to one of the jumper drills and as the shaft was rotated by hand, the bars were raised and dropped by pulling and releasing the ropes.

The first machine used for drilling rock in Europe was invented by Mr. Hipp in 1863.[7,49] This consisted of a heavy bar which, like the jumper drill, was raised and let fall at a single point of contact. The improvement rested in the fact that rather than using hand labor the shaft was rotated by steam power. This machine was short lived but was a valuable contribution to progress in subaqueous drilling. Many other improvements were made during this period. Although they were significant at the time, the advent of more satisfactory machines soon put them into obscurity.

POWDER. Engineers at that time were not only confronted with difficulties in drilling holes, but the black powder in use was inadequate for under water service. Black powder had long been known and used in firearms, but it was just beginning to find employment as a method of breaking rock.

In order to keep the black powder dry, as was necessary it was placed in canvas bags, which were tied and then dipped in pitch and tallow to close all the pores. A fuse, known as the Bickford fuse,[27] was inserted in the bag, then the entire unit was lowered into the hole. If the charge failed to explode, the workers were not discouraged but calmly heated a rod red hot and forced it quickly into the hole where it penetrated the bag, either firing it or wetting the powder so that it was no longer explosive.

The revolutionary invention of nitrogelatin dynamite by Alfred Nobel in 1863 completely changed submarine blasting technique. The electric blasting cap has replaced the fuse in this type of work, and nitro-gelatin is used satisfactorily today. This material may reamin submerged for a long period of time without serious depletion in strength. Water has a tendency to replace the nitro-glycerin in the gelatin but this action takes place very slowly, and consequently may be ignored in most operations.

THE ROCK BREAKER. The first machine which shattered the rock by impact and later became known as the Lobnitz Rock Breaker was built by a German, Mr. Nobiling, and used in the Rhine River.[13] In the early days of the Danube improvement Mr Krupp and Mr. Luther of Brunswick used a rock breaker. It was not until 1884 that this popular machine was built satisfactorily. When the necessity was seen for

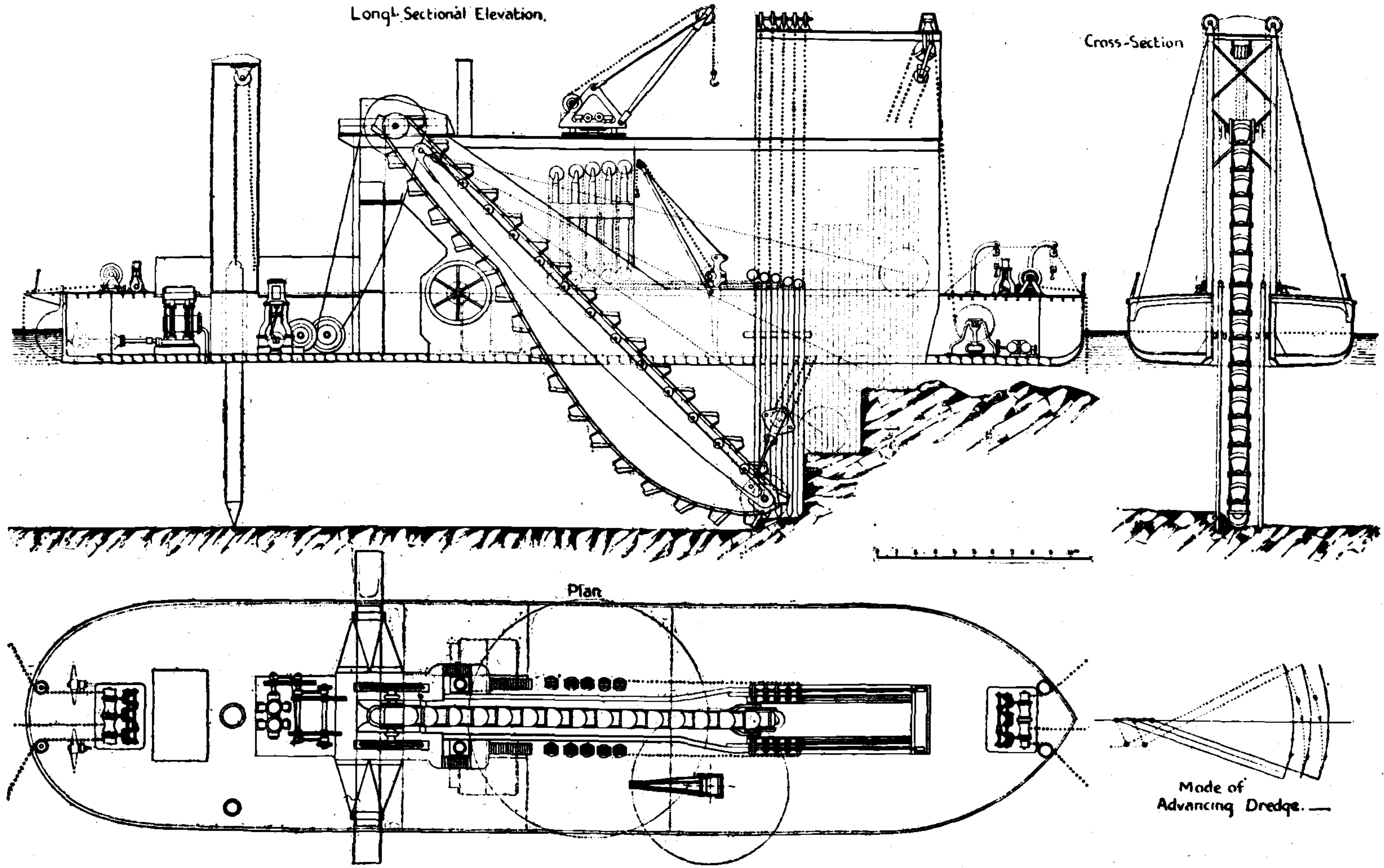


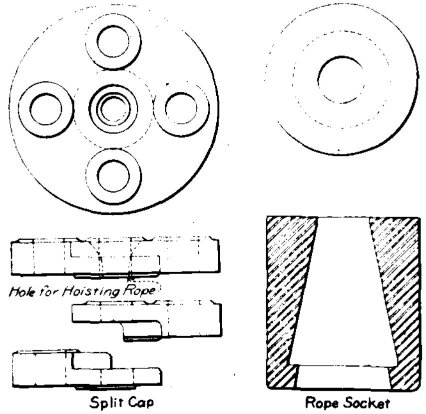

Fig. 1. The Lobnitz Rock-Breaking Dredge "Derocheuse".
(Engineering News)

improving and deepening the Suez Canal, Messrs, Lobnitz and Company of Renfrew, Scotland[7.62.] constructed a plant which combined the features of a ladder dredge and a rock breaker.

The "Derocheuse", as this sea-going dredge was christened, was equipped with a battery of five rams arranged in a row on each side of the ladder as shown in Figure 1. As these four ton rams were raised and dropped, shattering the rock, the bucket ladder immediately removed the loose material, leaving a clean surface on which the rams continuously operated. By using a spud at the stern of the boat as a pivot it was possible to control the area of operation and then to advance upon the completion of each arc made by the dredge.

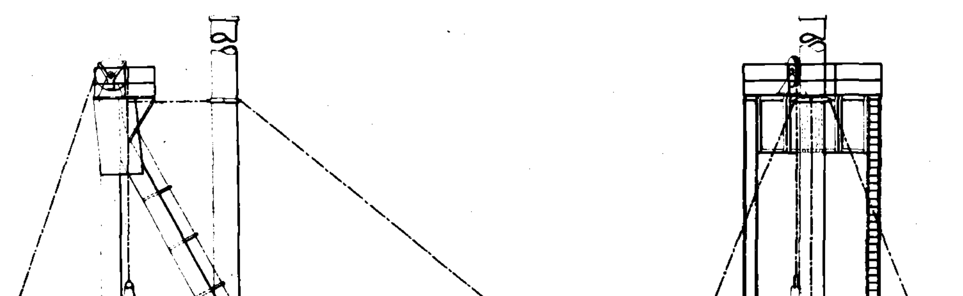
Although the Derocheuse successfully completed the work for which it was designed, it was too large and cumbersome in a confined area. The operation of the entire plant was dependent upon each unit, therefore when one of the rams failed to function properly the progress ceased. For this reason it was found more satisfactory to separate the rock breaking from the dredging. While breaking soft material the rams often penetrated and stuck fast resulting in a great loss of time.

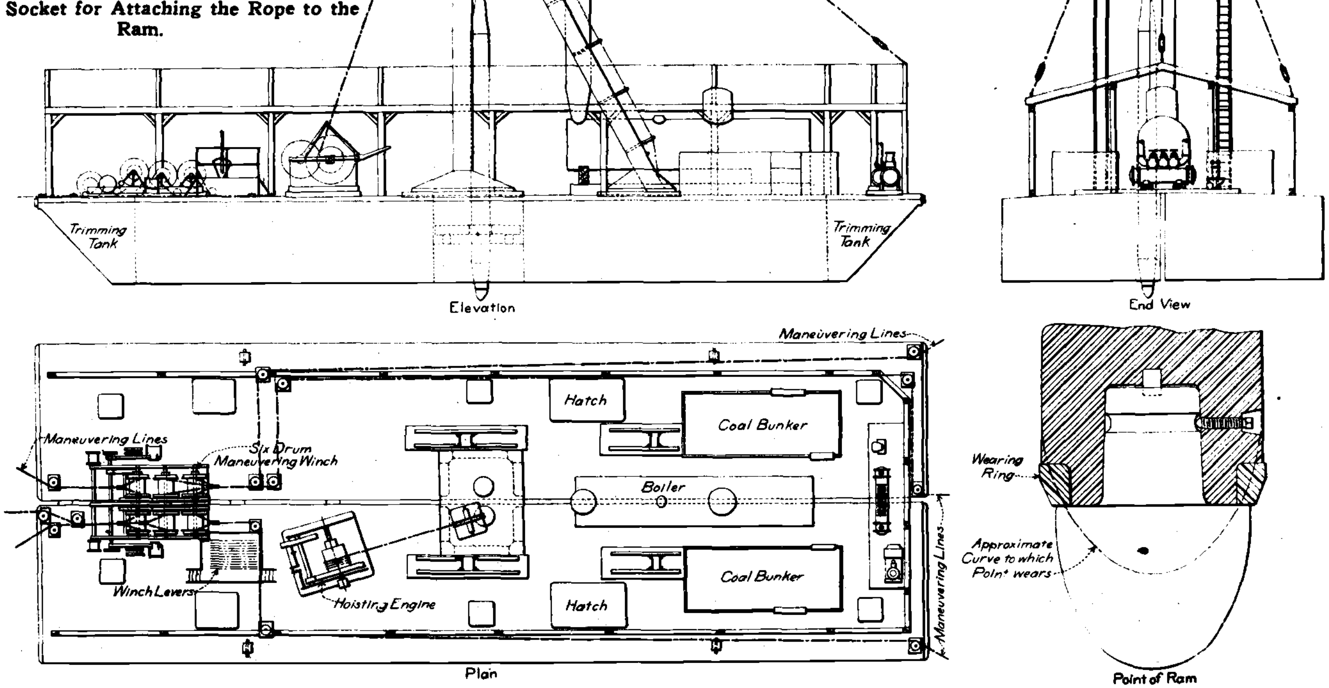
The later rock breakers were mounted on separate barges and operated independently of the dredge. These rams usually ranged in weight from four to twenty tons, depending upon the hardness and depth of rock to be removed.[8.49.] When using




**Cap and Socket for Attaching the Rope to the Ram.**

Fig. 2. General Arrangement of Rock Breakers Used in Black Rock Harbor, Buffalo, New York, 1910. (Engineering Record)





heavy rams it was more economical to place only one or two on a small barge which could be manouvered easily, as shown in Figure 3. These mammoth chisels mounted on barges are interesting from a historical standpoint since they have been used extensively in breaking rock in all parts of the world.[3,44,63] Even today they may be found operating in Europe where conditions are favorable. The ram was long and cylindrical in shape, usually tapered slightly at both ends. The main body of this massive column was solid mild steel equipped with specially tempored removable points. The points were ogival in shape, Figure 4, and harder at the center than near the edges[2] consequently were self sharpening.

These rams were raised and dropped in guides in much the same way as the pile driver is operated, the distance depending upon the conditions and the ability of the equipment to resist the shock. The life of the wire rope used to raise the ram was very short, owing to the continuous bending at the point where it was attached to the ram. This led to the development of a follow socket in the head, which permitted the line to follow into the ram about three feet after it struck the bottom. This improvement was first used in removing rock from Black Rock Harbor as shown in Figure 2 and was found very successful.[47] Anchor spuds were commonly used to stabalize the barge while in operation, but these were not always necessary and were omitted when inconvenient.

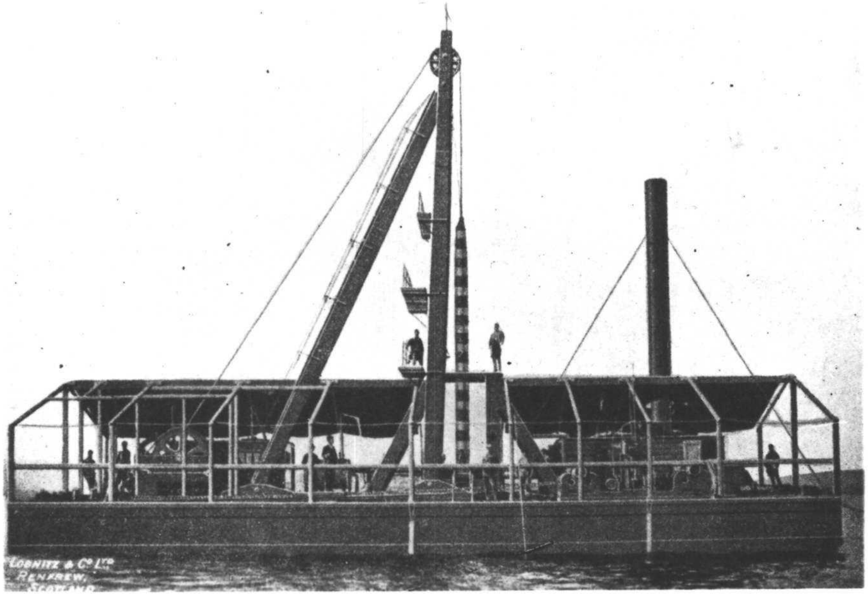



Fig. 3. The Lobnitz Rockcutter with Center Well.
(John Wiley & Sons' "Sub-Aqueous Foundations")

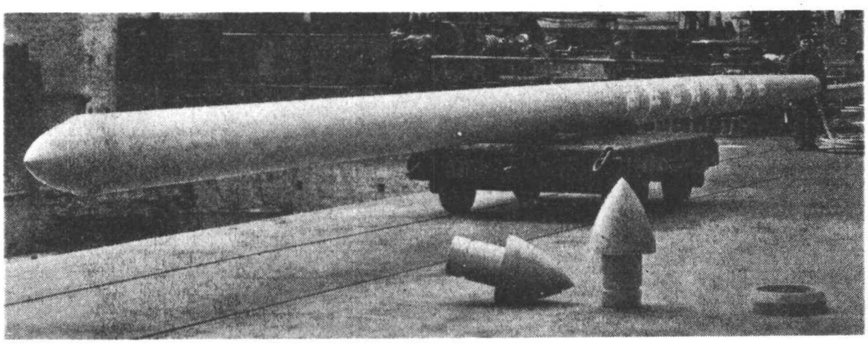


Fig. 4. A twenty ton mild steel ram with removable points. (Engineering Record)

The rock breaker was economical in that it eliminated the use of powder, but it operated very slowly. Because of the great weight of the ram, the average number of blows seldom exceeded one hundred fifty per hour and the effective depth to which the ram broke the rock decreased very rapidly as the ram penetrated the bottom. This was due to the cushion of broken rock formed on the surface which absorbed the force of impact. As a result the rock was broken and dredged in layers about two feet in depth. In soft rock the machine was very unsatisfactory because the ram failed to fracture the rock but simply penetrated and stuck firmly. This machine has had a very interesting history and is practicable where labor costs are low and time is of little importance.

THE DIAMOND DRILL. At approximately the same time that the Lobnitz rock cutter was first used the diamond drill, which is a rotating machine, equipped with diamonds or some other hard material as a cutting agent, was introduced by J. Th. Jones and J. H. Wild of Leeds, England.[58.] These diamond drills were freely suspended from floating barges and permitted to operate in much the same manner as they do on land today. These were later used by Fontaine and Tedesco on the Danube River and the Panama Canal.[12.] The diamond drill has never been thoroughly successful in this type of work since it operates very slowly and must be carefully held in position. It has given way to the more popular piston or hammer drill which cuts by impact rather than boring.

THE SCOTT & GODSIR CUTTER. The Scott and Godsir Cutter was designed by Messrs R. M. Scott and A. Godsir of Sidney, New South Wales in 1897. This machine incorporates a combination of the principles of the rock cutter and the steam drill. A very heavy rod was directly connected to a steam piston. The reciprocating motion caused the rod equipped with a bit to strike the rock bringing about its fracture and pulverization. This machine operated faster than the Lobnitz rock breaker but usually struck the lighter blow since the weight of the moving parts rarely exceeded three and one half tons. The number of blows was approximately fifty per minute when operating under full steam. This type of plant was used for a few years in Europe but gradually disappeared with the new improvements in other machines.

## Progress in America

At the same time that European engineers were confronted with improving navigation, similar problems were present here in the United States. The first attempts made in this country to remove solid rock were quite naturally the methods of hand drilling and blasting with black powder.

THE STEAM PUNCH. The first improvement upon this practice was Mr. Chas. T. Harvey's "Steam Punch",[49.] which he used successfully in breaking a ledge of rock in the St. Marys Fall Ship Canal in 1854. This machine consisted of a shaft which dropped and struck the submerged rock with an estimated force of twenty tons per square inch. This shaft consisted of a heavy wrought iron base which tapered down to a steel bit one inch square. To the upper end of this base was attached a heavy oak timber operating in guides. This mammoth chisel or punch, as it was called, when dropped from the top of the guides struck with terrific force.

THE CHISEL BOAT. Upon this same principle Major J. G. Floyd of the U. S. Engineers designed and built what was called a "chisel boat" in the Des Moines Rapids the following year.[55.76.] It was composed of a heavy steel cap tied with rawhide to an oak timber studded with rails which worked in guides. This boat did not operate very well on the Des Moines Rapids where it was necessary to remove large boulders. It was later used more successfully to remove a thin layer of ledge formation in the Rock Island Rapids of the Mississippi River where navigation was hazardous. This chisel boat was improved upon and used continously until 1889 when it was discarded and replaced by more modern equipment.

An interesting observation is that although the Lobnitz Rock cutter is generally considered a European invention, in reality the same principle was used at leat three places in the United States many years before the birth of the "Derocheuse".

THE DRILL BOAT. As river and harbor improvements became more imperative in the United States, Mr. C. F. Dunbar, [5.7.] who was[69.] actively engaged in this type of work, was carrying on drilling operations using the jumper drill, hand steel, and crowbars. These rough devices mounted on rafts, coupled with experiments with a steam operated machine for drilling on land, led to his invention of what proved to be the prototype for the modern American drill barge. Mr. Dunbar was in charge of a drilling operation to remove rock from Port Colborne Harbor in Lake Erie. The rock was so hard that three men could drill only one foot per day by hand methods. In 1872 he acquired an old barge and equipped it with two steam piston drills mounted on movable towers placed on tracks along one side of the barge. Steam piston drills had just begun to be used for drilling holes in rock quarries and other types of dry excavation.

The barge was moved and held in position by lines and heavy breasting chains attached to anchors. A steam boiler installed on the barge furnished power to the drills and to the drums which controlled the lines and chains. A wooden anchor spud placed in vertical guides at each of the four corners of the barge served as an additional stabilizer during the drilling operation. When the boat was moved to the desired location the spuds were forced down to the bottom with hand winches until the barge was raised a few inches above its normal buoyancy line, thus transmitting part of the weight of the scow to its legs.

The wooden towers upon which the drills were mounted

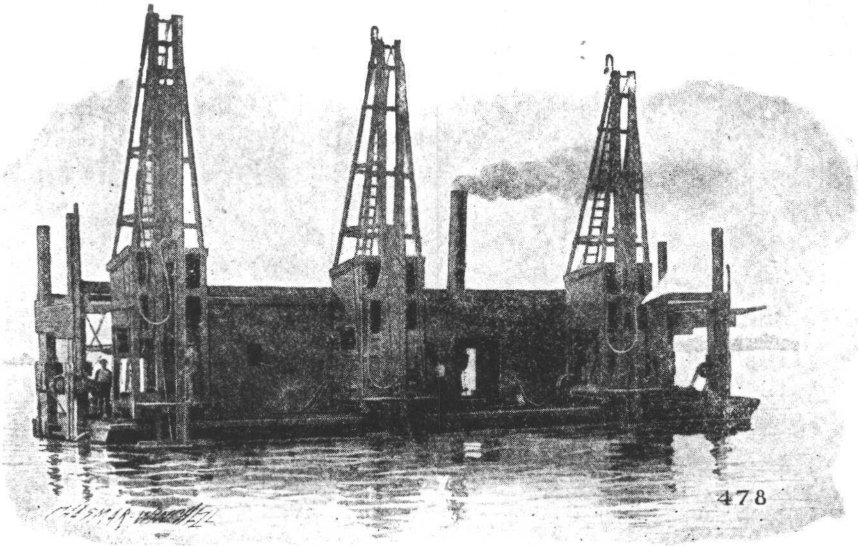



Fig. 5. The Ingersoll Drilling Scow.
(D. Van Nostrand Co., "Dredges & Dredging")

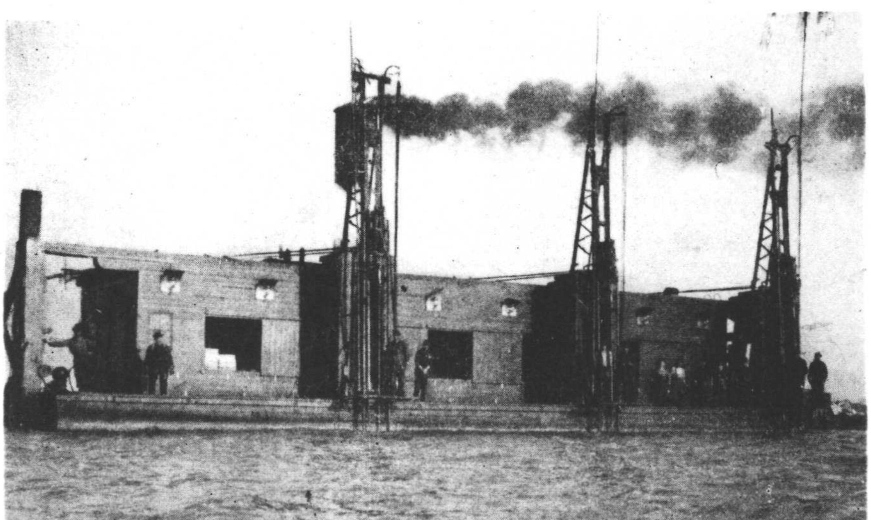


Fig. 6. Buffalo Boat No. 1 used on Livingstone
Improvement in 1909
(John Wiley & Sons, "Rock Drilling")

were designed to move along the full length of the fifty foot barge. By skidding these towers along the track with crowbars eleven holes spaced at five foot intervals could be drilled without moving the boat. The drills were mounted on the towers in vertical guides overhanging the side of the barge. They were controlled by hand winches and could operate for a vertical distance of nine feet before it was necessary to exchange the bit for a longer one. The drill steel was connected directly to the piston rod by means of a U-bolt chuck and moved the full length of the stroke which was about seven inches. These drills struck at a rate of 250 blows per minute, which was a great increase over the hand operation.

Upon the completion of each hole, it was loaded and blasted without moving the barge. When a row of holes was finished, the barge was moved six feet from the range and the operation was repeated. After a large area of the rock was broken it was removed by ordinary dredging methods.

Within the following few years Mr. Dunbar installed hydraulic rams to move the towers and to feed and hoist the drill in the guides. In order to keep the overburden and the loose cuttings from falling into the drill hole a casing or "mud pipe" was used to penetrate the overburden and rest on the surface of the solid rock. This also served as a guide when loading the hole with powder.

A water jet was later inserted in the hole either during the drilling or when the bit was withdrawn for the purpose of washing out the cuttings and fine particles from the bottom of the hole. The successful removal of cuttings increased the speed of drilling and alleviated the difficulty of sticking the bit due to "sanding in" as it is called. This was one of the major improvements in drilling history.

The drill boat was so successful that many new ones were built in the region of the Great Lakes shortly afterwards.[7] The Ingersoll drill scow, Fig. 5, and the Rand drill boat soon made their appearance. The united States Army Engineers built one to improve the channel in Rock Island Rapids. Figs. 6 & 7 show more recent boats used on the Livingston Improvement of the Detroit River and in Black Rock Harbor, respectively.

THE DRILL STAGE. The drill stage, invented by Mr. W. L. Saunders and used successfully in the removal of Black Tom Reef in New York,[49] incorporated the same principle but the anchor spuds were designed to lift a light stage clear of the water in order to avoid high tides and wave action. Upon this platform were mounted ordinary tri-pod drills commonly seen on land. The drills were moved about the platform and the drilling was done through holes in the deck. The steam boiler and all appurtances were installed on a tender barge moored alongside in order to remove as much weight from the stage as possible. This method was

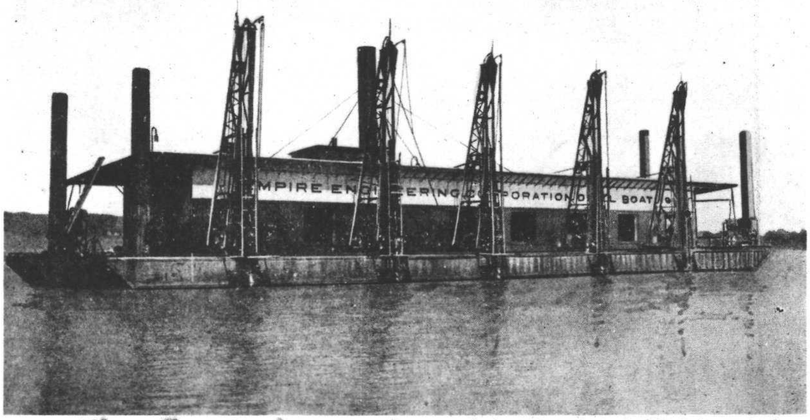


Fig. 7. Empire Engineering Corporation Boat in Black Rock Harbor, Buffalo, New York, 1911.
(John Wiley & Sons, "Rock Drilling")

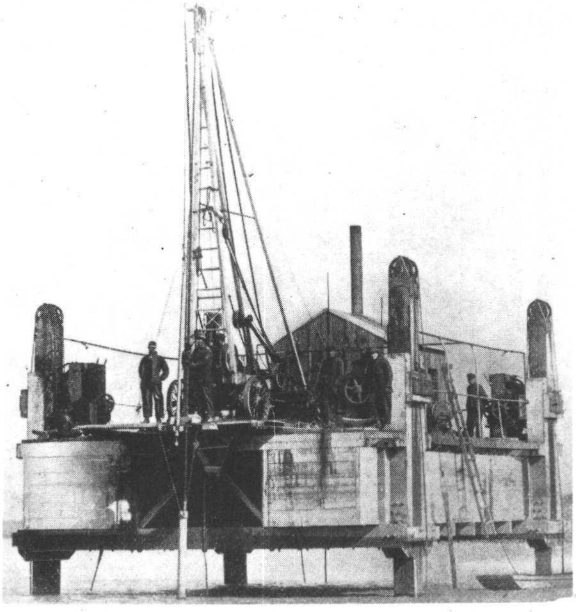


Fig. 8. A drill boat which lifts itself clear of the water operating at Port Weller, Ontario on the Welland Ship Canal, 1914. (Engineering News)

used extensively in many places where tides and winds made drilling from a floating barge impracticable. This type of plant shown in Fig. 8, has found current use where shallow water is encountered.

The Danube River

During this time progress in drilling in the United States and Europe had been made separately and independently. When it became necessary to remove the "Iron Gates" from the River Danube,[9.48] the work on this treacherous river was of sufficient character to enlist world wide interest. As a result practically every known type of machine for drilling and breaking rock was used. Although conditions were very unfavorable with the swift currents and an irregular bottom the engineers were to be commended for the calibre of work done in removing rock from this section of the Danube. With the crude devices in use at that time the European Commission of the Danube removed 200,000 cubic yards of rock from Stenka Rapids, the Greben section, Kozla-Dojke Rapids and the "Iron Gates". It is doubtful if any project as difficult as this one has been performed since.

This extensive work brought together all of the more advanced details of subaqueous rock removal where it was possible to compare the equipment in use at that time. From the results obtained it was found that the Lobnitz rock cutter and the American drill boat were the two most satisfactory types of machines. Although much grief was experienced with both of these, it was found that each one possessed advantageous features not found in the other.

The rock breaker was not satisfactory in shattering more than two feet at a time. As the surface rock became pulverized it formed a cushion which protected the rock below. This necessitated dredging after two feet of rock were broken and then a repetition of the same process. For this reason the drill barge was used in areas where more than two feet were to be removed, and use of the rock breaker confined to shallow excavation.[13.74.81.] This rule was quite generally observed for years afterward where both types of plant were used on the same project.

The drill barge was difficult to hold in position in the swift current while in operation. The slight shifting often caused the bit to stick in the bottom of the hole resulting in a great loss of time and equipment. Its operation in the Tachtalia and Juez Rapids of the Danube[48] was moderately successful and introduced the drill scow to the Europeans.

The general outcome of this famous project was the elimination of nearly all equipment in favor of the rock breaker and the drill boat. The Lobnitz rock cutter has continued to be popular in Europe where labor costs are not prohibitive and the slow operation concurs with European psychology. It has also been used in the Panama Canal[3.81.] in

Black Rock Harbor in Buffalo, New York[47] and in Canadian improvements[44]. An accurate record of its operation and costs in the Harbors of Aviles, San Estaban de Pravia and Port de Bilbao in Spain is available.[53]

The drill boat has continued to be more popular in the United States. In the last fifty years millions of cubic yards of rock have been removed from harbors and channels throughout the world.[57,60,71,75] A great majority of the work has been performed in the region of the Great Lakes and in East River in New York where drill scows have operated continuously since the nineteenth century.[1] It is an expensive plant to operate and therefore must function rapidly and continuously in order to avoid excessive unit cost. In view of this fact many mechanical refinements have been added in order to increase the speed of operation.

## The Drill

In discussing the evolution of the drill scow, the major interest has centered about the drill itself. In general the development of the drill used in subaqueous work has followed the improvements made on the land drill.[55] As the channel depth requirements increased from six to forty feet it was necessary to improve the drill mechanism in order to handle the longer steel and greater weight. With these changes the drill began to differ somewhat from the land-operated machine. The inertia of the reciprocating steel necessitated a very heavy slab-back on which the drill was mounted in order to avoid vibration as much as possible. The screw feed was slow and inconvenient, necessitating steel changes every few feet. This inadequate device was replaced by a hydraulic cylinder and later the drill was hoisted and fed into the hole by a steam winch and lines passing over a sheave at the top of the tower and down to the drill. Smaller winches and capstans were also mounted on the tower to handle the steel and sand pipe during the changes. The full tower was not always used but a column was employed where the range in tide was a number of feet. This column was similar in construction to the anchor spuds and rested on the bottom where it worked freely in vertical guides on the barge. The drill with the feed mechanism and sand pipe was mounted on the outboard side of this spud. Upon the completion of each hole the column was raised and moved along the barge to the next position. The advantage of this design was that it operated independently of the barge and was not affected by surge. This method was not too satisfactory because the long screw feed was very slow, and the position of the operator in a small cage at the top of the spud was coveted by none.

The two most common types of piston drill in use were the tappet-valve and the steam-thrown-valve designs. In the tappet-valve design the piston had to strike the valve in order to reverse the port opening to the piston. A full stroke of the piston was necessary to operate this machine. Obviously vibration difficulties were experienced when the drill was running under full speed and when it was crowded close to the rock. The steam-thrown-valve design known as the "Eclipse" operated on the principle of unbalanced pressure. It was not necessary for the piston to strike the valve, therefore, any length of stroke would operate the valve mechanism. This feature afforded the operator the opportunity of regulating the length of stroke and the weight of the blow by proper feeding of the drill.

During the period that these improvements were being made, the drills were also being built with a larger bore and stroke. The first submarine drills were of only a five-inch bore. As the drilling depth increased and the drill steel was longer and heavier the drills were increased until the longest of the piston drills was made with a piston $6\frac{1}{8}$ inches in diameter. This increase is reasonable since a $2\frac{1}{4}$ inch drill steel sixty feet long used to remove rock to a depth of forty-two feet at low tide weighs eight hundred pounds.

The most recent development in subaqueous drilling is the adoption of the air-driven hammer drill, which has entirely replaced the piston drill on all land work. Although the old piston drill is fast becoming obsolete it has served a valuable purpose. Through its use many waterways in all parts of the world are now avenues of commerce where ships may pass without danger of striking hidden obstructions.

Although there is no written record of some of the practices which have been used in submarine rock removal, the ingenuity of engineers confronted with these problems has contributed greatly to the development of modern methods. The modern drill boat with its submerged hammer drills and diesel powered air compressors portrays a vivid past and suggests an interesting future.

# EXCAVATION OF SUBAQUEOUS ROCK

## MODERN METHODS

Rock has been removed from beneath the water surface in many ways. A thorough discussion of the methods employed by engineers would involve a very extensive discourse in the field of engineering. It is the purpose of this paper to emphasize only that type of work which is allied with the improvement of water-ways where the rock is in such a position that it is not feasible to remove the water. To clearly define the relative position of the drill boat and the rock cutter an outline of the common methods will be included but only the practices realtive to the drill boat will be expanded.

The most logical procedure in summarising methods in general use would be to divide them into four classifications. These are honeycombing, employing the cofferdam, working in caissons and operating from a floating barge.

### Honeycombing

The honeycombing method of rock removal is favorable only when a large body of rock can be approached from above the surface of the water through either a shaft or an inclined tunnel. The procedure is very similar to that of quarrying or removing large masses of rock commonly encountered in land improvements. The only essential difference in working under the surface of the water is the trouble encountered in seepage due to the presence of a water head at an elevation exceeding that of the operation. In this type of work the rock is perforated with a network of tunnels and shafts commonly known as coyote holes. These holes are subsequently loaded with powder and blasted, using an electric cap system which is often supplemented with cordeau to insure proper detonation. After the obstruction has been broken into fragments it is removed by ordinary dredging methods. Hole Rocks in the Rhine River, part of the "Iron Gates" of the Danube[48] and many other ledges have been removed by this process. Probably the most widely known instance was the blasting of Flood Rock in Hell Gate in New York Harbor by General John Newton of the U. S. Army Engineers.[7,8,55] Fortunately a good picture was taken at the time and a replica is used as a frontispiece.

This famous rock had obstructed traffic in the narrow and crooked water-way where the East River passes between Blackwell Island and Wards Island. The channel was so dammed by this obstruction that a difference of water level of almost two feet was often observed at high tide. The consequent currents plus unfavorable weather caused an average of one out of fifty boats to be damaged by striking this rock. The work proved to be a mammoth undertaking and the United States Army Engineers met with no little difficulty. The famous blast on October 10, 1885 is heralded as the largest subaqueous blast in history. Many methods were previously attempted in removing this rock but it was found that honeycombing was the most satisfactory and economical at the time. If that work were to be done today it is probable that a different method would be used due to the rapid advance in the efficiency of the drill barge.

## Cofferdam

A common practice in removing subaqueous rock in connection with dam construction and the preparation of foundations is the use of the cofferdam. The area to be excavated is surrounded by some form of temporary dam and is then unwatered. In reality the area is converted to dry excavation and from this point the work is conducted in the same way as on land. One of the famous projects executed in this manner was the removal of the large rock at Henderson's Point in Portsmouth Harbor.[38.] Although many similar jobs have been performed since, this is outstanding in the history of the cofferdam because of its great size and natural difficulties encountered. A circular wooden cofferdam was built to an elevation above the water surface and the interior was pumped dry, then excavated to the required depth below the mean water level. Long drift holes were then drilled horizontally under the base of the cofferdam. These were loaded and the entire volume composed of 35,000 cubic yards of rock plus the cofferdam was lifted by a single blast. The wrecked cofferdam was pulled away and the loose rock was excavated with dredges.

Blossom Rock in San Francisco Bay[10,55] was removed by a combination of the cofferdam and honeycombing. Since the rock did not project above the water surface a small circular dam was built. As soon as a shaft was sunk in the rock, tunnels were run in all directions. They were loaded with black powder and the charge was detonated by electricity from a boat.

An interesting piece of work of this type was recently performed in the Yangtse River in China[26] where it was found necessary to remove two large rocks from the channel. Using Chinese labor exclusively, Mr. R. G. Everest of the Cinese Maritime Customs built two small cofferdams and sank shafts into the rocks. Many canals have been improved and deepened in this manner by placing temporary dams at the ends of the operations. The Welland Canal[65] was recently deepened using methods comparable to those on land. The cofferdam has been used extensively in conjuction with dam construction within the last few years. A notable example is the mammoth structure employed on the Bonneville Dam. This method is practicable only where a large mass of material may economically be isolated by comparatively cheap construction.

## Caisson

The caisson method of excavation is extensively used where accuracy is essential over a comparatively small area. Its use is commonly associated with the preparation of foundations. This device incorporates the principle of a steal shell open at the bottom which descends to the surface of the rock. The water is prevented from entering the caisson by the use of air pressure on the inside equal to the pressure of the water. This method and the diving bell, which is closely related, are not confined alone to the work mentioned above but have been used in channel improving. Many rocks have been removed in the Rhine River under German supervision. The diving bell was used in excavating for a Quay wall at Nantes, France.[78.] Colonel Newton attempted the use of the caisson in the removal of Flood Rock but concluded that honeycombing was more satisfactory. Probably the most notable employment of the caisson has been its use in preparing the rock for the piers of the two bridges now being built in the San Francisco Bay. An extensive treatment of the use of caissons is found in Mr. Chas. E. Fowlers "Treatise on Sub-Aqueous Foundations".[2.]

## The Floating Barge

Of all the methods used to remove subaqueous rock the bloating barge is the most popular in channel improvements. There are a number of types of floating plant which should be discussed separately with special attention directed to the drill boat which is speedily usurping nearly all work of this type.

LOBNITZ ROCK CUTTER. The Lobnitz rock cutter is still found occasionally in the rivers and harbors of Europe, but its demise is predicted within a short time. This machine was described in the historical development as a valuable tool where conditions are favorable for its operation. Practically no revisions have been made in its construction other than the minor refinements in machinery. To summarize its advantages[36,69] the rock breaker is economical to operate and it breaks the rock into small fragments which in many cases aids materially in lessening the cost of dredging. Its disadvantages rest in the fact that it is not effective to a depth of more than two feet without removal of the broken rock. The rock breaker is unsatisfactory in soft rock and it operates very slowly causing the labor cost to be excessive where the wage rates are comparable to those in the United States.

THE PLATFORM. The platform which is classified as a floating barge because it is usually floated into place, is commonly used where the water is too shallow for the regular floating barge and where wave action and currents are so excessive as to make drilling from a floating hull impracticable.[5,34,70] This plant incorporates the some principle as the barge and is held in position by legs at each corner which rest on the bottom. By thrusting the legs down as shown in Fig. 8, the platform is raised clear of the water where it is maintained in a stable position by means of lines. Drilling operations are carried on through holes or slots in the deck where temporary sand pipes are placed and held in position. Ordinary land drills are used, mounted either on a tri-pod or with the recent wagon mounting which has been used successfully on land projects. In very shallow work the ordinary jackhammer may be employed instead of the larger drill. A tender-barge carrying the shop and the compressors is moored alongside. In the event that the work is near shore the air line may be carried out from the bank.

THE DRILL BOAT. The drill boat is commonly used in all parts of the world today. The developments since Mr. Dunbar's invention have not been drastic, but are comprised of refinements and improvements. Fig. 9 shows a modern drill boat used in New York Harbor. Progressive changes are steadily taking place with the construction of each new plant, which ranges in size and type in order to fit the conditions for which it is designed. The barge is of wood or steel construction and built rigidly in order to realize maximum stability. The steel is commonly adopted where the work is continuous and a longer life is desirable. Anchor spuds are usually placed at the four corners and designed to move vertically in the spud wells. These are steel or wood with armoured points and studded with angles on the

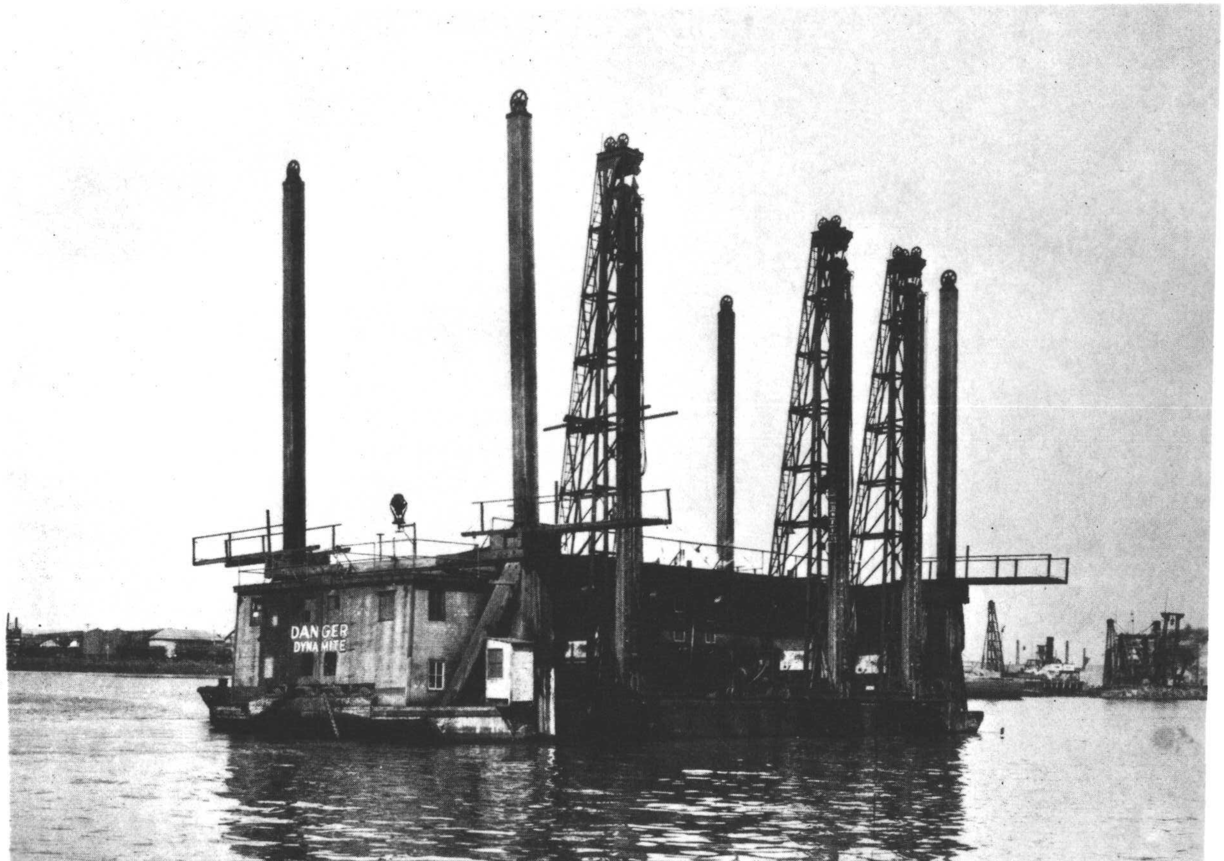



Fig 9. Arundel Corporation drill boat "East River" drilling a 42 foot channel in New York Harbor. (Ingersoll-Rand Co.)

corners. Although the rack and pinion are still seen in the older boats on all of the new barges, the spuds are hoisted and lowered with lines attached to winches powered by steam, air or internal combustion engines. In order to develop sufficient force on the spud the line ratio is usually about four to one, thus producing a vertical load equal to four times the pulling force of the winch, minus the loss due to friction. These winches are ordinarily back geared and consequently develop a great pulling force at the expense of speed.

The lines used to move the barge and to hold it in a fixed lateral position during operation are also handled with drums powered in the same manner. The number of lines employed depends upon the conditions and usually varies from four to six. The drums are arranged in two general systems depending upon the type of power which is used to actuate them. When they are rotated by direct drive from an engine they are designed in two or three drum units and placed with their axes of rotation perpendicular to the longitudinal center line of the barge. Fair leads and sheaves are employed to change the direction of the lines in order that they may be fed out at the required angle with respect to the craft.

If steam or air is employed the lines are handled by single drum units, which are commonly placed in such positions that the cables extend in a straight line from the anchors to the drums. This eliminates sheaves and fair leads, except those which are utilized as guides and placed at the gunwale for the breast lines and on the transoms for the bow lines. This set-up is advantageous in that it reduces friction loss and increases the life of the rope when the bending stesses are avoided. Steam or air driven winches are especially satisfactory in that they are more flexible and easier to handle under varying line pulls than a drum directly connected to a heavy duty engine. This system is generally adopted on the plants employed in the rivers and harbors today.

In order to facilitiate movement of the barge a centralized control of all drums is incorporated into the modern design. The pilot house or lever room, Fig. 11, is usually located about amidships at a point where the operator can observe the ranges himself or can receive signals from another who is directing the moving operation. With this centralization one man is able to handle all of the winches necessary to move the barge without the simultaneous cooperation of others.

The cables commonly used to hold the boat in place and to move the spuds are 6 x 19 "regular lay" plow steel wire ropes with wire centers. These are adaptable since they are specially designed to withstand heavy loads under static conditions. The wire strand center increases the stiffness but adds to the strength of the rope and aids in maintaining a uniform cross section when under stress. This type of rope is not used on moving lines where flexibility is desirable but serves very well in holding and occasionally moving the drill scow. A stiff rope of this type demands the use of large diameter drums and sheaves in order to realize full value in the life of the rope. This fact is often ignored in practice and fair leads which are much too small are employed to guide the lines.

Until a few years ago steam power was most commonly utilized on all drill boats. Although these barges with the steam piston drill are still in use the modern trend has been toward diesel-driven air compressors which provide power to the winches and the drills. In some cases the compressors have been powered by gasoline, electricity or steam, but the modern boats are being equipped with diesel-powered compressors of sufficient size to provide air to all machinery. Fortunately the steam winches may be operated by air, so the change has been possible in some of the old drill boats. In 1927 U. S. Engineers' drill boat "No. 426" used in Rock Island Rapids was converted to an air operated plant,[55] and the old piston drills were supplanted by modern hammer drills. This new plant has proved far more satisfactory than its predecessor.

Two arguments supporting the use of air in preference to steam are the convenience of handling without danger of

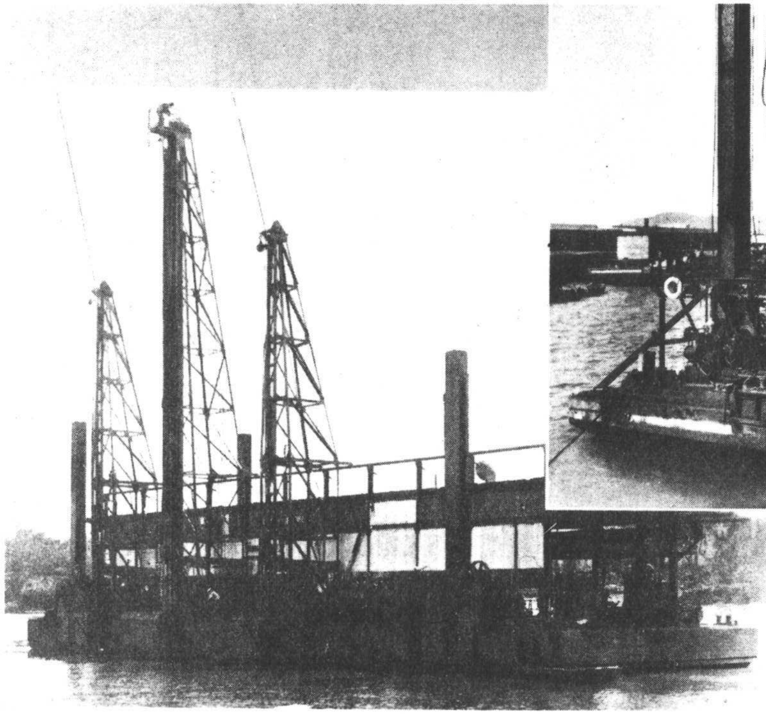


Fig. 10. Government drill boat "Terrier No 2" engaged in testing a hammer type drill and tower.

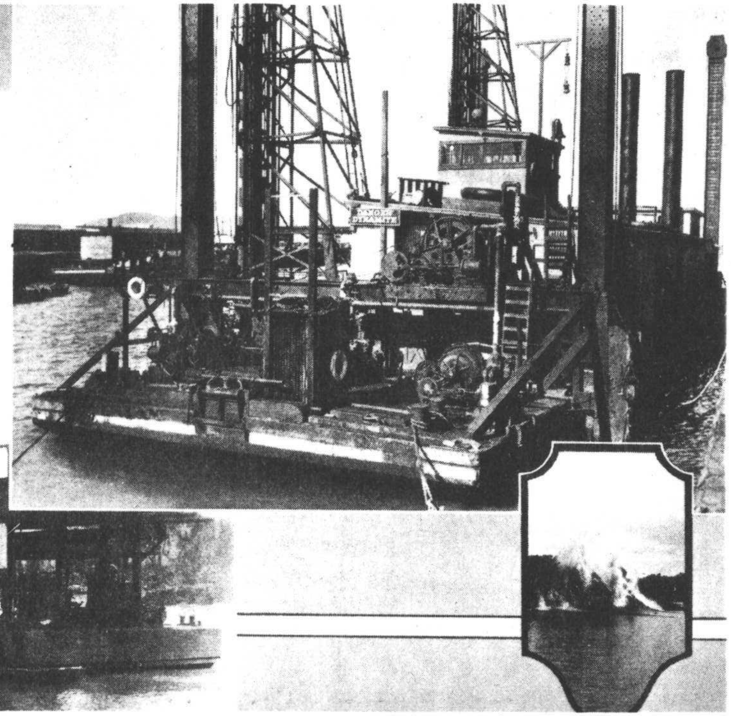



Fig. 11. A Siems-Helmers, Inc., drill boat at work in San Francisco Harbor, showing the spud and anchor engines.
(Ingersoll-Rand Co.)

being burned by the exhaust from the drills, and the elimination of frozen machinery during cold weather. When the work is interrupted the air pressure can be obtained in a relatively short time as compared to firing the old steam boiler.

In addition to the power plant, the modern drill boat is equipped with a shop including a forge and sharpener if forged steel bits are used or a bit grinder if the detachable bits are employed. An adequate shop equipped to repair and replace parts quickly is found to be economical over a period of time and is part of the equipment on all modern boats. The stock includes spare parts for the drills and for any mechanism which is subjected to use and in constant danger of breaking or wearing beyond repair.

The modern drill boat does not confine its activity to the hours of day light, so a lighting plant is installed, powered by a separate unit or receiving air from the compressors. Throughout the entire boat lights are mounted in such a position that the work may be carried on just as readily at night as during the day. If an electric welding machine is used, the generator may supply current to this during the day when the lights are not burning.

A piston pump designed to supply water under a pressure of approximately two hundred pounds per square inch and at a rate of about fifty gallons a minute per drill is installed on the barge. This equipment may be driven by a separate motor.

An element of danger accompanies a drilling and blasting operation. When adverse weather conditions, fast currents and rocks are added to this danger, certain safety precautions must be taken. A bilge pump, usually of the centrifugal type, is placed in such a position that it is in constant readiness to serve in the case of mishap. The design of the barge generally precludes the danger of sinking unless it is subjected to a terrific shock. The modern barge is divided into a number of compartments separated by solid bulkheads running the full length and width of the scow.

The Drill Tower. The drill tower on the current drill barge is a most interesting and complete mechanism, an example of which is found in Fig. 12. It is this unit which distinguishes the drill boat as unique among all water craft. The number of towers on a boat is dependent upon the type of work for which it is designed. Many boats have one or two drills, while the "Corlear," a U. S. Engineer boat in East River,[49] is mounted with eight churn drills in a fixed position on one end of the mammoth steel barge.

The towers are sometimes placed on the barge in a fixed position; they may be designed to operate in pairs, moving along with a constant distance between them; or they may be single units capable of moving the full length of the barge. The latter method is more popular allowing certain flexi-

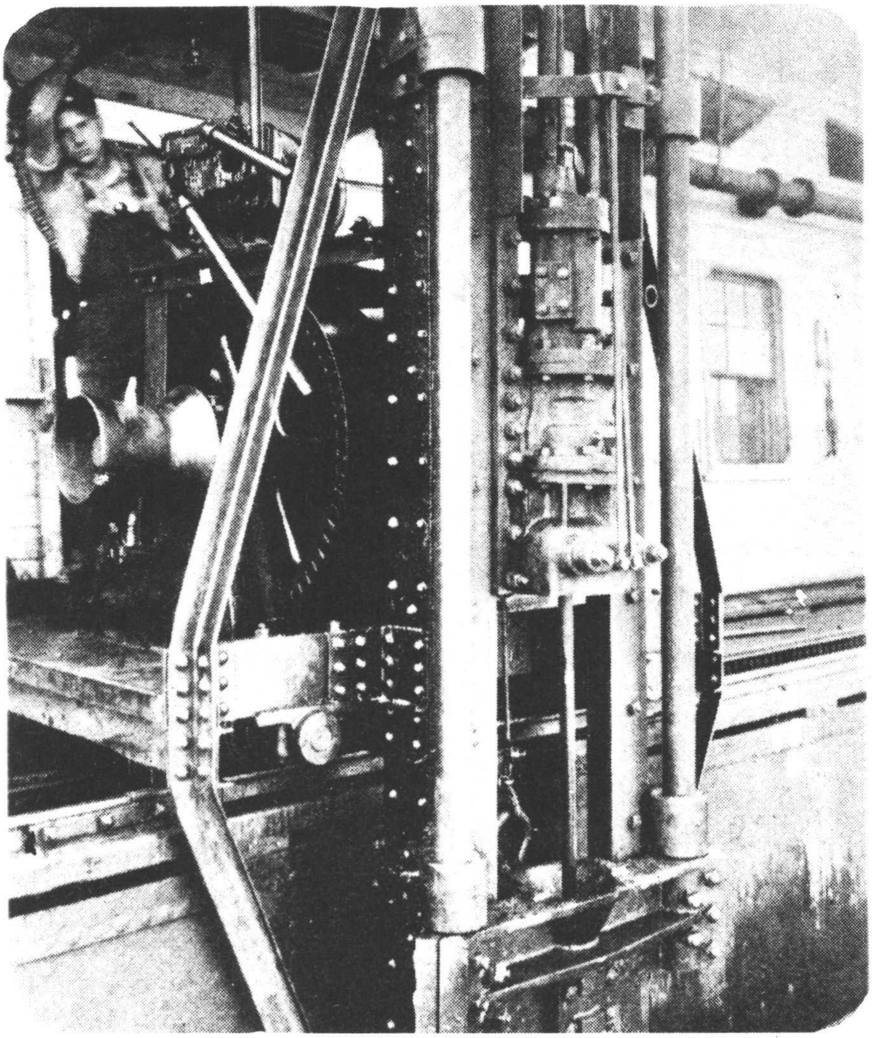


Fig. 12. A modern hammer drill on the U. S. Engineer drill boat "No 426" working in Rock Island Rapids. (Ingersoll-Rand Co.)

bility and permits the maximum range of operation without moving the barge. These towers have wheel or skid mountings and operated on a track at the edge of the hull. A reversable winch or hydraulic cylinder is employed to move them. In light construction a small air hoist is very satisfactory but the heavy towers with a skid mounting are more easily handled with the ram.

The details of construction of the tower are dependent upon the depth of the water and the type of drill used. The boat "No. 426" which was used in Rock Island Rapids where drilling was only a few feet below the surface has short towers, while the work in New York Harbor or San Francisco Bay necessitates the use of derricks which extend more than sixty feet above the deck, as shown in Fig. 10. The drill towers are of steel construction rigidly braced to withstand the vibration and force of currents when the drill is operating. A heavy load is thrown on these towers under some conditions and it is imperative that they hold the drill in line directly above the hole.

The design of the tower depends somewhat upon the type of drill employed. In the few surviving cases where the piston drill is still in use, it is mounted firmly upon a heavy slab-back which operates vertically in guides. Because of the excessive vibration accompanying the operation of this drill it must be heavily weighted and the equipment must be adapted to the handling of this unit. The telescoping sand pipe is mounted on a separate frame which operates in the guides below the drill. Sheaves are placed at the top of the tower, over which the lines from the drill and the casing pass and return to the winches mounted at the base of the tower. An additional winch and line is sometimes employed to handle the steel during changes and to aid in loading the holes.

The ordinary land type hammer drill is sometimes employed in shallow work. This drill is mounted in the same manner but upon a much lighter slab-back where the vibration is relatively smaller. The sand pipe which serves as a guide may be a single unit of carbon steel casing equipped with a tempered shoe for penetrating the overburden to the surface of the rock.

The latest hammer drill used for deep subaqueous drilling is designed so that it may be submerged to the surface of the rock. This eliminates the use of long steel and a sand pipe extending from the surface of the water to the rock. On the other hand, steel of a length equal to the desired depth of the hole and a sand pipe long enough to penetrate the overburden are all that are necessary.

It becomes obvious that some form of extension must be used on the tower in order to hold the drill in position. This is accomplished by use of a drill ladder or column which is a long frame operating in the guides of the tower.

THE DRILL LADDER IS GUIDED ON A DRILL COLUMN, WHICH IN TURN IS SUPPORTED FROM THE DRILL COLUMN HOISTING HEAD THE DRILL COLUMN HOISTING HEAD IS GUIDED AND HOISTED IN THE DERRICK THE DRILL COLUMN IS ALSO GUIDED BY THE DRILL COLUMN GUIDE CYLINDERS. THE LOWER END OF THE SPUD IS PROVIDED WITH A SAND PIPE AND FUNNEL, EITHER FIXED OR MOVABLE, DEPENDING ON THE CONDITION OF THE OVER BURDEN, SO THAT IN ALL CASES THE SAND PIPE WILL LAND ON THE ROCK. THIS IS ASSISTED BY MEANS OF A SHORT DRILL STEEL EXTENDING ABOUT 4" BELOW END OF SAND PIPE WHEN DRILL AND LADDER RESTS ON SAND PIPE FUNNEL, AS THE WEIGHT AND VIBRATION OF DRILL LADDER WILL ASSIST IN PENETRATING THE OVERBURDEN, AND WITH A STREAM OF WATER THROUGH THE DRILL STEEL, WILL CLEAN THE MATERIALS OUT OF SAND PIPE.

THIS CONSTRUCTION IS MOST SUITABLE FOR PLACES WHERE CURRENT IS STRONG, CONSIDERABLE TIDE AND ROUGH WATER DUE TO WAVE ACTION OR WASH FROM PASSING STEAMERS

IF THE DRILL SPUD IS PROPERLY LANDED ON ROCK SO THAT THE SAND PIPE PREVENTS MATERIAL AND SMALL STONES FROM FALLING IN THE HOLE WHEN DRILLING VERY LITTLE TROUBLE IS EXPERIENCED IN DRILLING THE HOLE

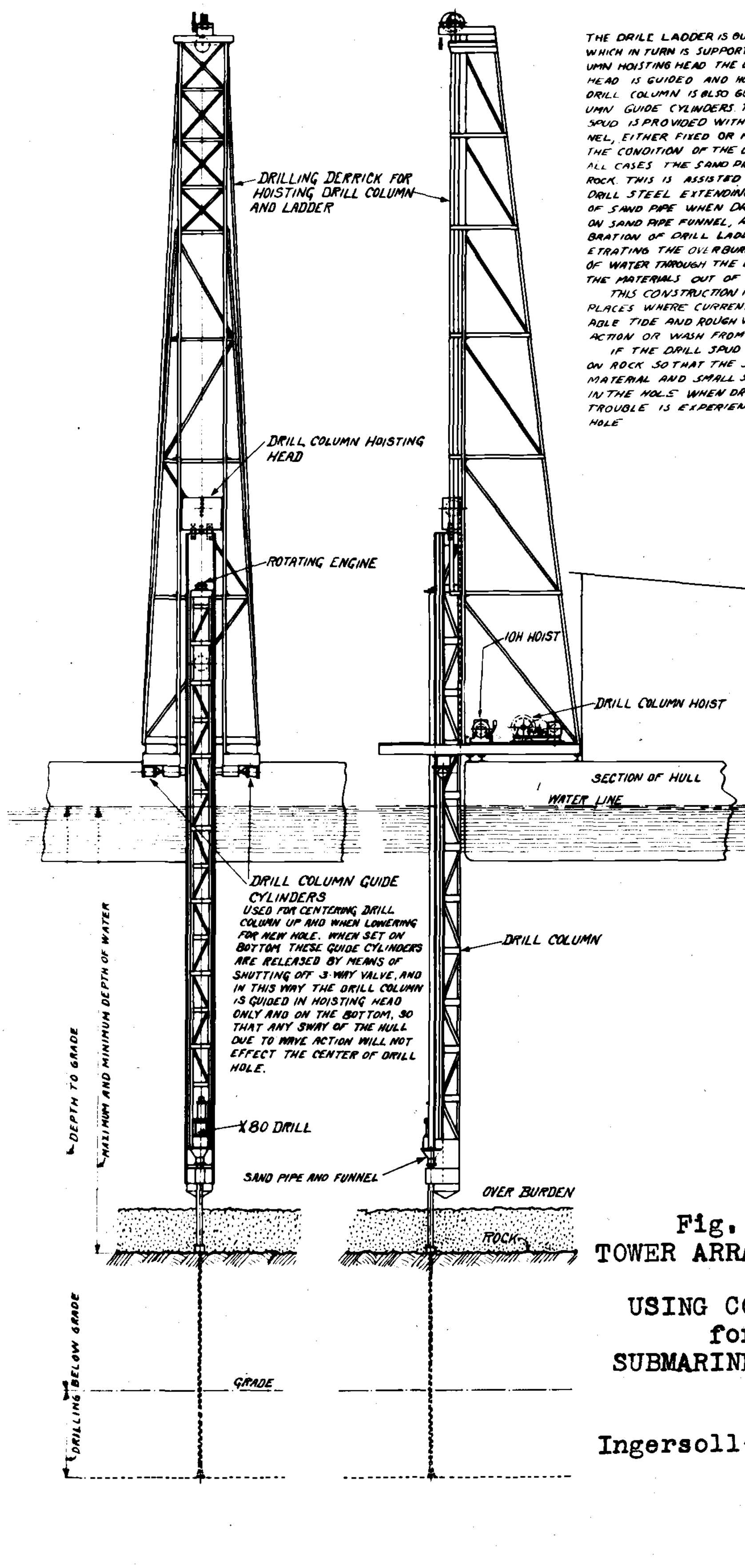



**Fig. 13**
**TOWER ARRANGEMENT**

**USING COLUMN**
**for**
**SUBMARINE DRILL**

Ingersoll-Rand Co.

The drill is mounted in a fixed position on the bottom of the frame and as the drill is lowered the entire column descends in the guides. The casing is handled with another drum and line from a separate and lighter frame outside of the drill ladder. A volume of words is expressed in the single drawing, Fig. 13. This is the most recent development in submarine drilling and the general principles with modifications are used on current improvements where depth predominates.

The Drill. The hammer drill, which is seen in all land operations, is rapidly replacing the piston drill for submarine work. The essential difference in design, rests in the fact that the piston is free running and does not reciprocate the steel. On the other hand the air pressure moves the piston back and forth striking the steel with terrific force on each stroke; thus it is properly named when referred to as a "hammer" drill.

One of the marked improvements is the period in which the blows are transmitted to the rock and the consequent drilling speed. Piston drills seldom exceed four to six hundred blows per minute while the hammer drill hits approximately two thousand. The common drifter used on land is manufactured by a number of reputable companies and in consequence a great variety in valve and piston design is available. These may be used satisfactorily where it is practicable to keep the drill above water.

Rotation of the steel is necessary during the hammering action in order that the cutting edge of the bit may come in contact with the entire area of the bottom of the hole. This rotation is absolutely essential and the success of drilling without sticking the bit is largely dependent upon the rotation. This is accomplished in two ways in modern drills. Most of those used above water, including the land drills, rotate the steel by means of a ratchet. This ratchet is actuated by the reciprocating piston and rotates the chuck which, through the use of lugs on a hexagonal shank, turns the steel. It is apparent that this rotation is dependent upon the hammering action and occurs simultaneously.

Two drills are now made with independent rotation. This is accomplished by means of a separate air motor which turns the steel and may be controlled and operated in the absence of the hammering action. This feature has been found very convenient when operating under water and in deep holes.

The Ingersoll-Rand X 80 submarine drill is specially designed so that it may be submerged. It is equipped with a bell exhaust at the bottom of the drill which acts as an air seal excluding the water from the moving parts of the drill. An air rotation motor is mounted at the top of the ladder where it will not be submerged. The rotation is transmitted to the steel by a hollow shaft equipped with a driving pinion along the ladder which engages a spud gear on the chuck. The speed of rotation of this shaft serves as an indicator to the operator for the proper feeding of the drill.

The Worthington No. 321 submarine drill is a smaller machine, but operates in much the same manner. The rotation motor on this machine may be controlled independently but the motor itself is integral with the drill and descends to the depths with the rest of the mechanism. It is situated at the head of the chuck and employs a cam principle to rotate the steel. Both of these machines are designed especially for subaqueous work, while the more common drills may be used in a variety of departments.

<u>The Water Jet.</u> The water jet used in conjunction with drilling to remove the cuttings at the bottom of the drill hole flows from the side or the center of the bit. The water is introduced at the top of the drill and passes through a long tube into the center of the hollow steel. This tube is stationery with respect to the drill and passes through the piston wheih is bored to accommodate it. Due to the pressure of approximately two hundred pounds per square inch, it is necessary to extend the tube some distance into the steel in order to avoid a great loss at a point where the steel is chucked in the drill. The tube cannot be too long, however, because it is often broken

during operation. Much difficulty is encountered here, which sometimes leads to the use of an improvised packing gland. This is not altogether satisfactory since it must be loose enough to permit free rotation when feeding the drill and it is very inconvenient when steel changes are necessary.

Drill Steel. The steel commonly employed in drilling is a high carbon steel especially tempered to resist fatigue.[19.32] Diameters between the limits of one inch and one and three quarters inches, depending upon the depth and the size of hammer, are employed. An entirely satisfactory steel has not been manufactured as yet, and great loss is sustained due to breakage. Proper care in forging and tempering is one of the major aims of the modern operator.

Bits. The bits in general use are of two types: the forged bit made from the steel and the detachable bit.[54.] It has been only in recent years that the detachable bit has become popular, so the tendency is to retain the older customs based upon a long service. The arguments presented by the manufacturers of the detachable bit to the effect that less steel is necessary, which is conducive to a faster operation, is well founded. The contention that the bits can be made of a special material which resists abrasion as an objective is also reasonable. The two types are waging a battle for supremacy which will probably continue for many years.

The drill tower is often equipped with an outboard platform with a railing around the drill column at an elevation even with the deck to facilitate in steel changes and in loading the holes. Stagings are also placed at different levels in the tower with ladders running between them. All controls for the drill are centrally located so that one man may operate the entire mechanism, while the helpers are stationed at other points to handle the steel, the drill and all appurtenances. It becomes apparent that the drill tower is a very complete unit in itself. A successful drilling operation is dependent upon the competent operation of that machinery directly associated with the drill.

SUBMARINE BLASTING

Blasting rock under water is more difficult than most any other kind of blasting.[73.] Much has been spoken and written about the use of dynamite in quarries, in mines and in general excavation, but the subject of submarine blasting has been given very little attention. In connection with harbor and river improvements this has become a highly important class of work where the cost exceeds that of almost any other kind of rock excavation. In water ways where heavy tides, wave action and currents are encountered this type of work is extremely difficult. Since the work is done in obscurity one cannot afford to take any chances. Therefore, it has been found economically sound to make sure by allowing a big safety factor or margin; consequently, holes are drilled deeper and loaded heavier than they would be in open work. In connection with the drilling of the holes the drill boat is carefully lined up by shore ranges or floating buoys in order that the proper spacing may be realized.

The spacing and drilling of holes in connection with submarine blasting is extremely important when considering the efficiency of the use of powder.[49] In studying the conditions which exist many rules and formulas have been worked out with reference to blasting, but these are seldom of value because the variables met with in excavation are so numerous that rules will not hold. The practices followed in this kind of work are based for the most part on experiments and precedent. For this reason it is commonly stated that the successful removal of rock is 75% experience and intuition and only 25% theory.

To advance a few of the fundamental principles of blasting rock an intelligent discussion of spacing and drilling is compatible. Most of the work done in river and harbor improvement permits a depth of one to two feet below grade for which part or full pay is received. This gives the contractor or engineer some margin within which to operate. It has been the general rule followed in deep water work to drill the holes about as far below grade as they are spaced apart. In this way the depth of hole is dependent upon the spacing and the spacing becomes dependent on the depth of excavation.

In theory when a charge explodes in a drill hole the break in a homogeneous material follows approximately the surface of a 45 degree cone, the center of which would be at the center of the charge. It is upon this rule that the spacing is fundamentally based. However, it is also dependent upon the type of rock, the current, the velocity of the powder and other factors. It is often found that a rule of spacing and drilling holes which is adequate on one job may very often be unsuccessful in other work. Because of these variable conditions a margin or safety factor is usually allowed due to the seams and strata existing in the rock. It is the 45 degree theory plus the safety factor that has led to the practice of drilling to the same depth below grade as the spacing.

To choose a hypothetical case for example, assume a shoal three feet deep with allowable over depth of one foot for which full pay will be received. If the holes were spaced five feet apart in both directions the diagonal distance between them would be approximately seven feet. From Fig. 14, which is a diagonal cross section, it is seen that when the holes are spaced five feet apart the 45 degree lines from the center of each hole will intersect midway be-the holes and at a point one foot below grade or at the limit of the pay depth. As the cross section shows it would then be necessary to drill the holes 7½ feet deep. In theory this would be sufficient but for most work it is probable that more satisfactory results would be realized if these holes were drilled at least five feet below grade or a total of eight feet.

A study of the geometry of solids clearly indicates that more linear feet of hole per cubic yard of rock must be drilled when excavating a thin strata of rock than when excavating a thick one. Likewise it is commonly found that more powder is necessary per cubic yard when removing a thin strata of rock. For this reason it has often been found economically sound to space the holes farther apart, drill deeper and break the rock farther below grade. Although the quantity of material blasted is greater the actual cost per pay yard may be less. Records generally show the excavation of a thin strata and small pinnacles to be the most expensive type of subaqueous rock removal. For this reason it is desirable to get a full break to grade upon the first shot because to return and redrill, or to "sandpaper" with a dredge is extremely expensive with little value received.

The type of powder commonly used in submarine work is a nitro-gelatin ranging in strength from 60% to 90%. This has been found more satisfactory than straight dynamite since the water has little effect upon its detonation. Although

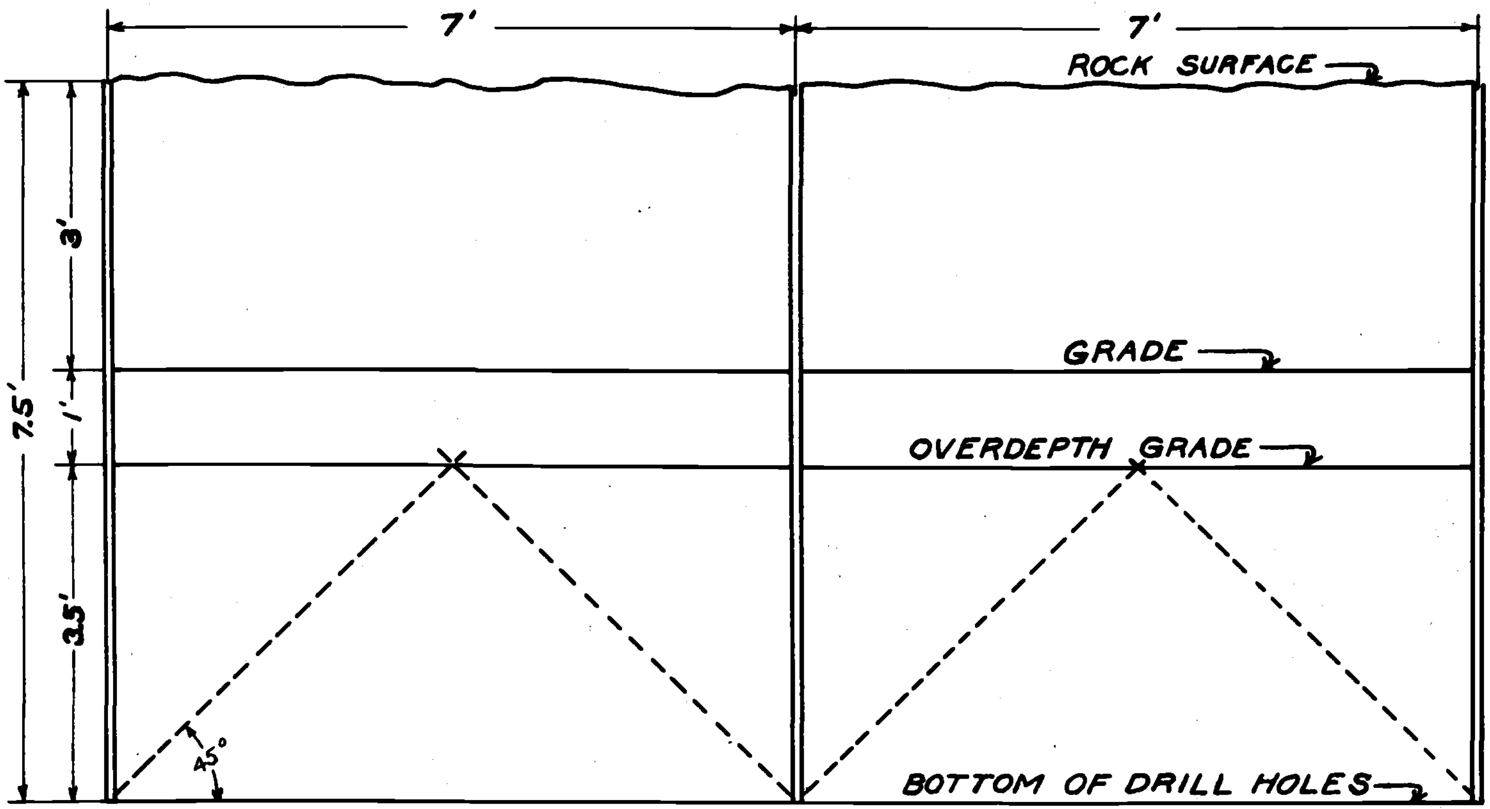



Fig.14. Spacing drill holes for submarine blasting. Diagonal section showing the required depth to drill holes, assuming spacing of 5 feet by 5 feet, depth of 3 feet to grade, and allowable overdepth of one foot.

this material is very satisfactory for under water work it has one disadvantage in that it does not readily explode. With all gelatin it has been found most practicable to use a strong cap in a 60% straight primar placed in each hole because it is almost impossible to fire nitro-gelatin by propagation. Straight dynamite may be detonated by propagation when the holes are spaced close together in a good firm material but misfires and unsatisfactory breaks are frequent, consequently it is not recommended by authorities. The use of nitro-gelatin with a cap in each hole is more expensive, but the desirability of being assured that the shot has broken the rock to grade overshadows the other features. When gelatin dynamite is employed a 60% straight primar is usually placed either in the center of the charge or near the bottom of the hole. The high strength powder is nearly always used in this type of work because it is desirable to place the maximum quanity of powder in minimum space. This permits the drilling of comparatively small holes and the convenient handling of equipment and powder.

The method of inserting and keeping the powder in the hole is a unique operation in submarine drilling. In nearly all modern plants each drill is equipped with a special charging tube.[46.60.] This pipe is equipped with a slot in the side to provide for the wires and has an outside diameter slightly less than that of the hole so that it might be readily inserted. In the bottom of this tube is inserted the full charge to be placed in the hole in much the same way as shells are placed in the magazine of a gun. These are held in position with a small wooden wedge or a piece of paper used in packing the powder. This charging tube is then inserted through the sand pipe to the bottom of the hole. Through a much smaller pipe which serves as a handle for this tube posses a loose wooden tamping rod. The tamping rod holds the charge in position while the tube is withdrawn, thus forcing the wedge and the powder out of the tube where it remains at the bottom of the hole. The sand pipe is then withdrawn and the wires are carried to a pin rail on the barge where they are later connected in parallel to the main leads of the charger. When blasting in fast currents both stemming and a wooden plug are inserted in the hole to keep the powder in position. In most practices it is only necessary to use the stemming but under unusual conditions the wooden plug is found invaluable.

Fortunately most of the reputable powder companies have service men who are well qualified to act as consultants in this type of work. It is common practice for the manufacturers to deliver a large order of powder in metal containers of the proper shape to adequately meet conditions. With these facilities and this authoritative information the engineers are often relieved of the burden of working out the details of blasting.

An outline of the estimated quantity of powder used in this type of work is difficult in that it covers a very wide range.[73] In general it might be said that for most submarine excavation between two and six pounds of gelatin dynamite is necessary per cubic yard of rock. The quantity of gelatin is dependent upon the depth of the water since much of the strength of the powder is consumed in overcoming the inertia of the water itself. As expressed previously when excavating a very thin ledge of rock much powder proportionately is also consumed in its removal. Under these conditions it is common to use from five to eight pounds per cubic yard. The amount of powder necessary is also dependent upon the type of the rock. A very tough and heavy material such as granite will naturally require more dynamite than a soft limestone formation. All of these conditions must be taken into consideration when estimating the quantity of powder.

Examples of some of these variations may be expressed by observing some of the records of projects which have been successfully completed. In the Livingston Channel where the material is limestone of medium hardness approximately 2¼ pounds of 60% gelatin per cubic yard was required.[1] Florida canals, where coral rock predonimates, require only one pound of 60% gelatin dynamite. In the days of the Rock Harbor excavation an average of more than five pounds of gelatin per cubic yard was consumed. In small jobs where it is necessary to remove an extremely thin strat composed of small pinnacles as much as 10 poundsper cubic yard is sometimes expended. In summarizing it is to be observed that the proper use of powder in connection with this work is subject to many variables. An economic operation is the result of experience and intelligent observation.

ORGANIZATION AND PERSONNEL

The successful performance of a drilling operation is not entirely dependent upon the plant alone. Like all other types of work proper organization is far more important than any of the machinery no matter how well designed.[55]. This phase cannot be over-emphasized when discussing the subject of subaqueous rock excavation. Competent ment are absolutely necessary and the cost of the work may be traced directly to the ability of each member of the crew to perform his function with speed and adeptness.

A drill boat carrying two drills will employ about fourteen men and at least five of these have a definite responsibility which must be carried at all times in order to avoid delaying the operation. The operating costs inclusive of labor are very high and only the period during which the drills are operating is productive. The cycle of operation in drilling and loading one hole may be divided into about ten different steps of which the drilling is only one. It is estimated that the average drilling period is only about forty percent of the total time consumed. It is therefore consistant to study the other operations and properly equip the boat with men and machinery capable of performing the cycle with a minimum of loss. A study of this type of work is not complete without a careful analysis of the organization and personnel.

## DREDGES AND DREDGING

The subsequent dredging which follows the drilling and blasting of rock is often a very expensive operation in itself. The dredging of loose material in river and harbor improvements has been carried on extensively for many years and a wide knowledge of this work has been recorded.[5,6,7,8] Engineering writers have contributed much in describing their experiences through many volumes which have been published consistently as the mechanical methods have evolved. For this reason the author feels that an extended discussion would be of little value as a supplement to the already existing records.

The type of equipment in common use and the methods employed in removing blasted rock will be presented in a very general form. Throughout the water ways of the world five types of dredges are constantly operating. These are known as the hydraulic dredge, the grab bucket, the dipper dredge, the elevator or ladder dredge and the dragline excavator.

THE HYDRAULIC DREDGE. The hydraulic or suction dredge is operated in the excavation of sand, mud or gravel where large quantities are to be removed. A centrifugal pump sucks the material from the bed and deposits it in scows, into a hopper, or forces it through a pipe line to its destination. This machine operates very economically but has definite limitations. It has been used successfully in the construction of large canals and artificial water ways; notable are the Chicago Drainage Canal, the New York State Barge Canal and the Panama Canal. It is employed in the improvement of many rivers of the world where millions of yards are removed annually.

THE GRAB DREDGE. The grab bucket dredge is composed of either the common clam shell or the orange peel bucket suspended on lines from a boom operated by a stiff leg derrick or a mechanical plant. This popular machine has a long and varied history and is used successfully where the material is soft and not too compact. It has been employed in the excavation of gravel and fine broken rock for many years, but it has been found very unsatisfactory where the material is large or when it is cemented and keyed together.

THE DIPPER DREDGE. The dipper dredge, Fig. 15, is very commonly used in the excavation of blasted rock. It is the aquatic brother of the ordinary power shovel used on land operations and is designed in the same manner. Although it is made in many sizes and with some modifications for particular work, the principles are much the same for all machines. A stiff leg derrick is commonly mounted on a barge to which the boom is attached with heavy guy lines. The power plant has followed the development of the land shovel, but steam is still commonly used on the dredge. The spud mechanism which accompanies this machine is operated in the same manner as those found on the drill barge. The spud placed at the stern is used as a pivot around which the dredge may rotate. In order to excavate to a depth of thirty or forty feet these dredges are made very large and powerful with extremely heavy members used in their construction.

THE LADDER DREDGE. The ladder dredge is the most versatile machine which is commonly used today. Because of its complex structure and expensive operation its activities are confined chiefly to the removal of tightly compacted material or blasted rock. It is composed of a continuous chain equipped with buckets which scrape the bottom and carry the material to the surface where it is deposited in a scow or hopper. This machine is very powerful and has been used in the porous limestone formation in Florida where it dug and removed the rock without blasting. It has been found very satisfactory where an even bottom is required. By virtue of its design it is possible to drop the ladder to the desired depth and excavate with a small tolerance. This is a very

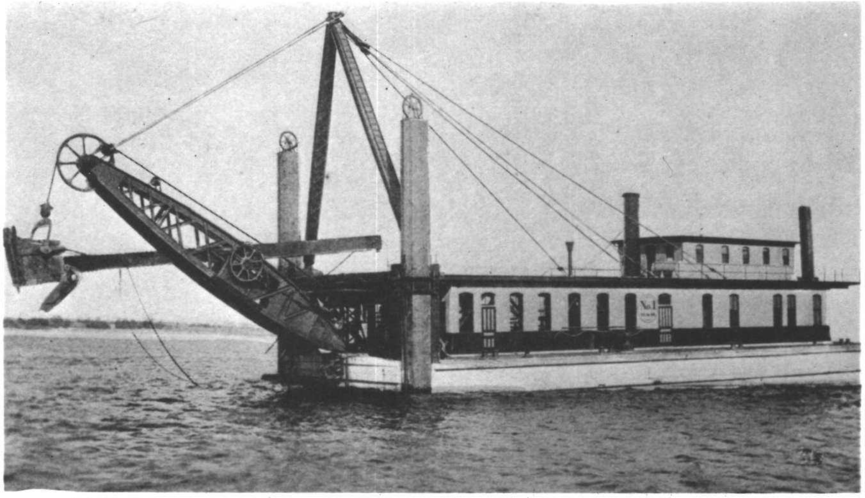


Fig. 15. Six yard Bucyrus dipper dredge owned by Daly & Hannon. (The Bucyrus Co.)

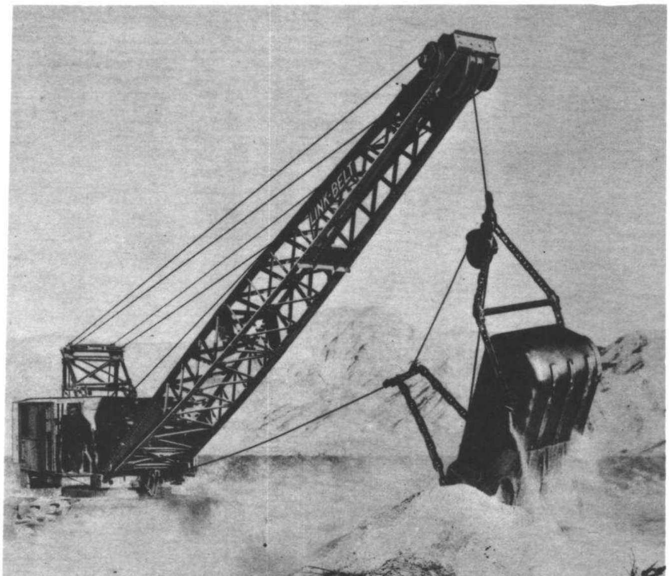



Fig. 16. A dragline excavator. (The Link-Belt Co.)

expensive machine that can be used economically only where a large quantity of material is to be removed. Due to its great size it is often difficult to manouveur in a confined area, nevertheless its speed of excavation has revolutionized the operation of removing rock from below the water surface.

THE DRAGLINE. To the above group of dredges must be added a type which twenty-five years ago was unknown. The dragline excavator, seen in Fig. 16, is now recognized as being the best fitted to meet the requirements of many big jobs of excavation.[31.] It is equally adaptable to work beneath the surface of the water as well as to dry excavation. Its long reach enables it in many cases to deposit material dug into fill or waste bank in one operation. Revolving on its base through a full circle it can dump anywhere within a radius determined by the length of its boom.

Prior to the time when the modern dragline excavator came into use many construction men had made use of movable stiff leg derricks equipped with drag buckets. Even today it is not uncommon to see such outfits performing certain work very economically. The stiff leg derrick is very adaptable to the installation of a dragline on a barge. When this mechanism is used the boom swings with respect to the body of the barge. The swing is usually acctuated by employing what is commonly known as a "bull wheel". This wheel is rotated at the base of the boom by two cables passing around the periphery of the wheel in opposite directions. The modern machine is a compact unit of all steel construction. The boom does not swing with respect to the body of the machine but maintains the same relative position and consequently is always counterbalanced. The machine rests on a large pad on the barge and rotates on this pad by use of a rack and pinion. This method permits a complete revolution of the machine any number of times in either direction.

One of the most common types of bucket used in connection with the dragline is the Page bucket as illustrated in Fig. 16. The bucket is hung so that when on the ground and being pulled toward the machine by the drag line it digs and loads itself then when loaded the hoist line is put into play and lifts the bucket out of the ground. By means of a short piece of cable running from the bail of the bucket over the sheave at the hoist connection and out to the drag connection, the bucket is held in a horizontal position as long as the drag line is kept taught. When the bucket is hoisted and swung to the desired position the drag line is released and the bucket dumps. In the excavation of a hard abrasive rock, manganese steam teeth are used. In some cases it has been found economical to improve upon these teeth by placing a special material on their surfaces with an electric or an acetylene torch. It is possible in certain types of excavations to place a haul-back line on the bucket which passes through a sheave at the far end of the areasof excavation and back to the machine. In this way the bucket can be used effectively over a longer distance than the actual length of the boom. This is particularly adaptable under certain conditions of channel excavation.

In connection with this work a 6 by 19 improved plow steel "Lang lay" wire rope has been found very satisfactory as a hoisting line. The drag line is usually a 6 by 19 plow steel with a wire center. It has always been found excellent practice to use good fair leads and sheaves in connection with this work. The additional expense of auxiliary equipment is always equalized in saving on wire rope. In summarizing one might say that the dragline has become extremely popular for purposes of excavation in recent years, since it is a simple and less expensive machine and may perform with very satisfactory results under diverse conditions.

An observation of the many types of equipment used for the purposes of excavation discloses the fact that the ladder dredge, the dipper dredge and the dragline excavator are most applicable to the removal of blasted rock.[8.] The unique features of each of these machines may make them particularly adaptable to a project depending upon the surrounding conditions. Occasionally these machines may be used interchangeably or side by side on one job, but more often the problem of excavation is not so easily answered. The choice of excavation machinery is dependent upon the amount of material to be removed and upon the conditions under which the equipment must operate.

In concluding the study of subaqueous rock excavation a summary of the important features of this work should be repeated. It is a difficult type of construction carried on through an obscuring medium where exact calculations and observations are impossible. The same type of equipment is not universal on all jobs but must be modified to fit the conditions of each individual project. The proper choice of equipment is no more important than the organization of a competent crew. It is a field which permits the men in charge to exercise unlimited ingenuity and resourcefulness.

PART II

# E X C A V A T I O N  O F  R O C K

# I N  T H E

# C O L U M B I A  R I V E R

# PART II

## EXCAVATION OF ROCK IN THE COLUMBIA RIVER

### HISTORY OF THE COLUMBIA RIVER

A passage-way of fresh water in the vicinity of latitude forty-six degrees north had long been sought by all nations of the world without success, but on May 10, 1792 Robert Gray in command of the Columbia sailed along the western coast of North America into a large river of fresh water. He bestowed the name of his ship upon his discovery for the United States.

The Columbia has been navigated by boats of every description. The hollow log of the savage was the first mode of travel and was followed by the bateaux of the trapper and flat boat of the emmigrant. Sailing ships of every description crowded to the "silver gates of the river" and before long the "fire canoes", as the natives called the first steamers, put in an appearance. As early as 1836 a small Hudson Bay Company steamer was sent from England, and in 1850 the first American steamship crossed the bar. The same year river boat service was established between Portland and Astoria. The first steamer to run between the Cascades and The Dalles was the Eagle. It was brought in sections from the east and was put together above the Cascades.

In the next few years many boats appeared on the river and at the close of the Indian Wars in 1859 a well established river service was running from Portland to The Dalles. The steamers connected by means of portages of five miles at Cascade Rapids. In 1879 the Oregon Railroad and Navigation Company came into being and steamboating on the river became secondary. The Dalles was joined to tide water by the opening of the Government Locks at the Cascades in 1896, and with the completion of the Celilo Canal the Inland Empire was connected to the sea by a direct water route.

Although river boats have continued to follow this famous water course, navigating the upper river has always been a hazardous journey. The river captains who know every whim of the Columbia and Snake live in constant fear of losing their boats and cargoes. The rivers have remained true to their fears and old hulls can be found along the banks, marking points where man-made craft has succombed to the natural forces.

The U. S. Engineers have performed a few improvements but the traffic within the last thirty years has not warranted the vast expenditure necessary to build an artificial channel. Pursuant upon the demand for the removal of major hazards, for many years the Government maintained a small drill barge above Celilo. The work was difficult and the equipment limited, so with the excavation of a few dangerous rocks operations were discontinued.

Steamers still penetrate as far as Lewiston, Idaho during high water, but hazards are so numerous and the mortality of boats so high that an extensive commerce will never be established until a program of channel improvement becomes effective.

PRESENT CONDITIONS

In order to provide a safe channel for river commerce above Celilo Falls the War Department is considering a program of river improvement extending from Celilo to the mouth of the Snake River, thence up the Snake to Lewiston, Idaho. The initial step was taken in August 1935, when bids were advertised for the excavation of a channel 150 feet wide and seven feet deep at low water between the upper end of Celilo Canal and Canoe Encampment Rapids, a point sixty-four miles upstream.

This portion of the Columbia River does not lend itself to a simple description. Probably no other navigable river in the world is comparable to this turbulent cataract with a mean annual flow of 210,000 cubic feet per second. The flow of many rivers of the world is temporarily obstructed by chains of solid rock at a few points along their courses, but the Columbia is a continuous series of rapids and pools throughout its entire navigable length above Celilo.

The solid rock ledges which project into the channel or extend from one bank to the other one are the result of a lava flow. This basalt rock is extremely hard and resistant to natural forces as well as to the concentrated efforts of man to effect its removal. It is fractured in perpendicular planes forming small cubes which are tightly interlocked suggesting the descriptive name of "diced basalt". Throughout the major part of its course the natural flow of the river has created a channel of sufficient depth between the outcrops, therefore the problem of channel improvement is directed to the removal of rock in the treacherous rapids. Some gravel must be removed from bars formed in the proposed channel but this work is not considered a major difficulty. The average slope of the river in this section is approximately 1.4 feet per mile. Of course the major fall occurs at points which total about one tenth of the entire distance. Obviously the slope is much increased at these points producing maximum velocities of fifteen miles an hour during high water. It is here that the solid rock is to be removed.

Records of the readings on Umatilla gage since 1897 indicate that the river level is within four feet of low water datum approximately nine months of the year. With the advent of warmer weather in the upper reaches of the drainage area the snow begins to melt late in April and the water reaches its peak flow in June. It then begins to recede and in September the low water season is again in existance.

This section of the river does not freeze every winter but adequate provisions should be made in anticipation of ice. It is not uncommon for the river to become covered with flow ice with only a few hours warning; a condition extremely hazardous to any floating craft. The river may remain in this condition for a few days or the period of closure may be two months.

Prevailing winds blow upstream a greater part of the year, and at times with sufficient intensity to cause all small boats to seek a cove. These are some of the conditions to cope with in excavating a channel in the upper Columbia River.

THE SIEMS-HELMERS DRILL BOAT. Siems-Helmers, Inc. were awarded the first contract to remove a total of 31,000 cubic yards of solid rock and to excavate 73,000 cubic yards of gravel. The plant which they propose to use in drilling this rock is one of the most modern drill barges in the United States. Views of this barge are shown in Figs. 17, 18 and 19. It is a large and powerful craft equipped with two moveable drill towers.

The barge is of wood construction 110 feet long with a beam of approximately forty feet. Its draught in still water with the spuds up is five and one half feet. Mounted on the barge are three diesel-driven portable compressors with a capacity of 930 cubic feet of air per minute. These furnish power to all machinery on the boat employing a 2400 gallon receiver as a reservoir.

The six lines are handled by separate back-geared winches arranged in such a way that the lines feed directly

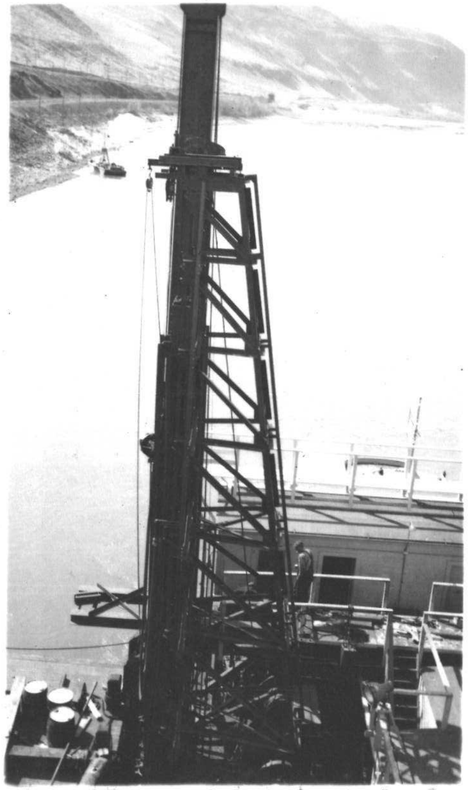


Fig. 17. A drill tower and anchor spud on the Siems-Helmers, Inc. drill boat. An anchor barge in the distance

Fig. 18. The drill boat with a background of quiet water below John Day Rapids.

Fig. 19. Siems-Helmers, Inc. drill boat being equipped with spuds to operate on the Columbia River.

without the use of sheaves. Four are used as breast lines and pass over the gunwales near the corners. The other two extend directly over the ends of the barge from winches located on the longitudinal center line and about 15 feet from the transoms. These lines are all one-inch regular lay 6 by 19 plow steel wire rope with a wire center, having a breaking strength of about forty tons.

The anchor spuds are each composed of two 24-inch I beams with the webs separated 20 inches by a plate equipped with four angles. These mammoth spuds, seventy feet long, weigh approximately sixteen tons each and are moved vertically in the wells by individual winches and 1½-inch wire ropes passing over sheaves at the top and bottom.

The drill towers extending approximately fifty feet above the deck are mounted on skids which slide along steel beams placed on the deck and separated nine feet. The towers are equipped with Ingersoll-Rand X 80 drills mounted on columns which move vertically in the guides. A five foot sand pipe is mounted and controlled separately. Three hoists are employed on each tower to handle the equipment with the large winch attached to the drill column and a smaller one used to lift the sand pipe. A small capstan hoist is used as an auxiliary to handle steel and perform miscellaneous operations. Both the detachable and the forged bits with diameters of three and one half inches equip the ends of the

1½-inch hollow drill steel.

A unique feature of this drill barge is a steel loading frame which runs the full length of the boat and is situated out-board of the boat proper. This frame is a catwalk protected with railings on both sides from which the holes will be charged. A range of holes will be drilled and pipes will be inserted in each hole then the boat will be withdrawn to the next range where the drills will operate at the same time that the first row of holes is loaded with powder.

Across one end of the barge is a fity foot bridge, the railing of which is graduated in feet. At the other end is a row of vertical rods which will be used to line the boat from the bridge to the channel ranges placed on shore. In this way the barge will always be parallel to the channel. Two rows of flags are placed along the shore at intervals of 100 feet. Since the barge is 110 feet long it is always possible to determine its exact position.

A fully equipped shop with a forge and drill sharpener is placed amidships. An auxiliary steam boiler maintains a continous head of steam in the event that the compressors fail. A small generator furnishes electricity to lights situated at various points on the barge permitting the operations to be carried on at night as well as during the day. A duplex pump operated by an air motor supplies water to the drills.

The drill boat is a composite of all the modern details employed in the removal of subaqueous rock. Its great power and stability indicate definitely that the contractor views the removal of this rock as a job of no small proportions. It is thought by many men associated with the Columbia that this plant is too big and cumbersome to operate satisfactorily in the confined areas of tortuous waters which will be encountered. The weight and draught preclude the use of a tug boat in the rapids, consequently all maneuvering must be done by employing the lines and winches mounted on the barge. Because of the many shoals, much of the work can be done only when the river is a number of feet above low water datum.

THE PROPOSED DRILL PLATFORM. In view of some of these difficulties, Mr. Chas C. Hansen of the Ingersoll-Rand Company proposed a method based upon the principle of the drill stage which has been used successfully in the past. A drawing of the suggested equipment has been reproduced and is incorporated in this paper, Fig. 20. This plant is composed of a stiff-leg derrick boat or a Whurley which handles a steel drill platform equipped with a spud on each of the four corners. Upon the derrick boat a well constructed wooden hull of nominal size, would be placed a ten ton derrick with an eighty foot boom, capable of operating within a radius of 60 feet. Four lines and winches would be installed to hold the boat in fixed position while it acted as a tender to the drill stage. Upon the boat would be installed a power plant of sufficient capacity to operate all machinery and to funish air to the drill operating from the platform.

The drill platform would be approximately 22 feet square and framed with spud wells at the four corners as shown on the drawing. The deck would be of wood and perforated with holes at a desired spacing through which the drill could operate. The frame would be of steel construction and braced so as to resist the bending moment exerted on the spuds. The proposed spuds would be ten inch H- sections equipped with steel shoes on the bottoms and chain sheaves in brackets on the tops. The derrick would hold the platform at the desired elevation while the spuds were dropped and chains were inserted in clamps on the spud housings, thus transmitting the weight of the platform through the chains to the anchor spuds. This may prove unsatisfactory under certain conditions so the alternative of controlling the spuds with hand winches and wire ropes is also mentioned in this design.

After mooring the derrick barge securely the drill platform would be removed from the deck of the barge, where it is carried in transit, and placed in the desired position over the area to be drilled. Upon the completion of this area it could be moved to two adjacent locations before it would be necessary to move the barge. The drill platform is connected to the barge by a small gangplank with wheels on one end to permit any relative motion between the two rigs. Over this gangplank the air and water line may be conveyed with proper valves and connections convenient to the drill.

The drill would be an ordinary land type drifter placed on a wagon mounting. In this way it could be moved conveniently over the wooden deck to a new position as each hole was completed. The sand pipe would be placed in the hole previous to the drilling operation and then removed upon the completion of the loading. Three such pipes would facilitate speed of operation since one could be placed ahead of the drill, one used at the drill and the third employed as a guide while loading the last hole drilled. As a result the drilling operation would be practically continuous with no time lost due to sand pipe changes.

The small relative cost of this plant in comparison to the drill boat is sufficient incentive to view this type of construction with favor. The platform has been used satisfactorily where tide and wave action were encountered, and the principle has stood the test of time, having been used since the removal of rock on the Danube. Undoubtedly the platform would be very successful in some locations on the

Columbia where the bottom is fairly level and the current is not too swift. In removing rock from the Snake River where the low water flow is approximately 10,000 cubic feet per second in contrast to the Columbia's 70,000 this method would overshadow all others and will probably find extensive use.

In the Upper John Day Rapids or Indian Rapids where the depth changes abruptly from five to more than thirty-five feet and the maximum current may approach ten miles per hour even at a medium stage of the river, it would be extremely difficult to place this platform with a feeling of security. During the placing operation the platform would be suspended from the end of the boom on a line. Even though spring lines were used to guy it into position, no little difficulty would be encountered in setting its legs on terra firma at the appointed location.

The large drill boat and the platform represent a wide diversity of opinion with regard to the proper method to use in removing rock from the river depths. Unfortunately no precedent has been established in operating under the various conditions found here. Projects which may be considered comparable involve certain features which limit their value as a pattern for present operations. The extensive work on the Danube was carried on with equipment which is now obsolete. To rejuvenate that type of equip-

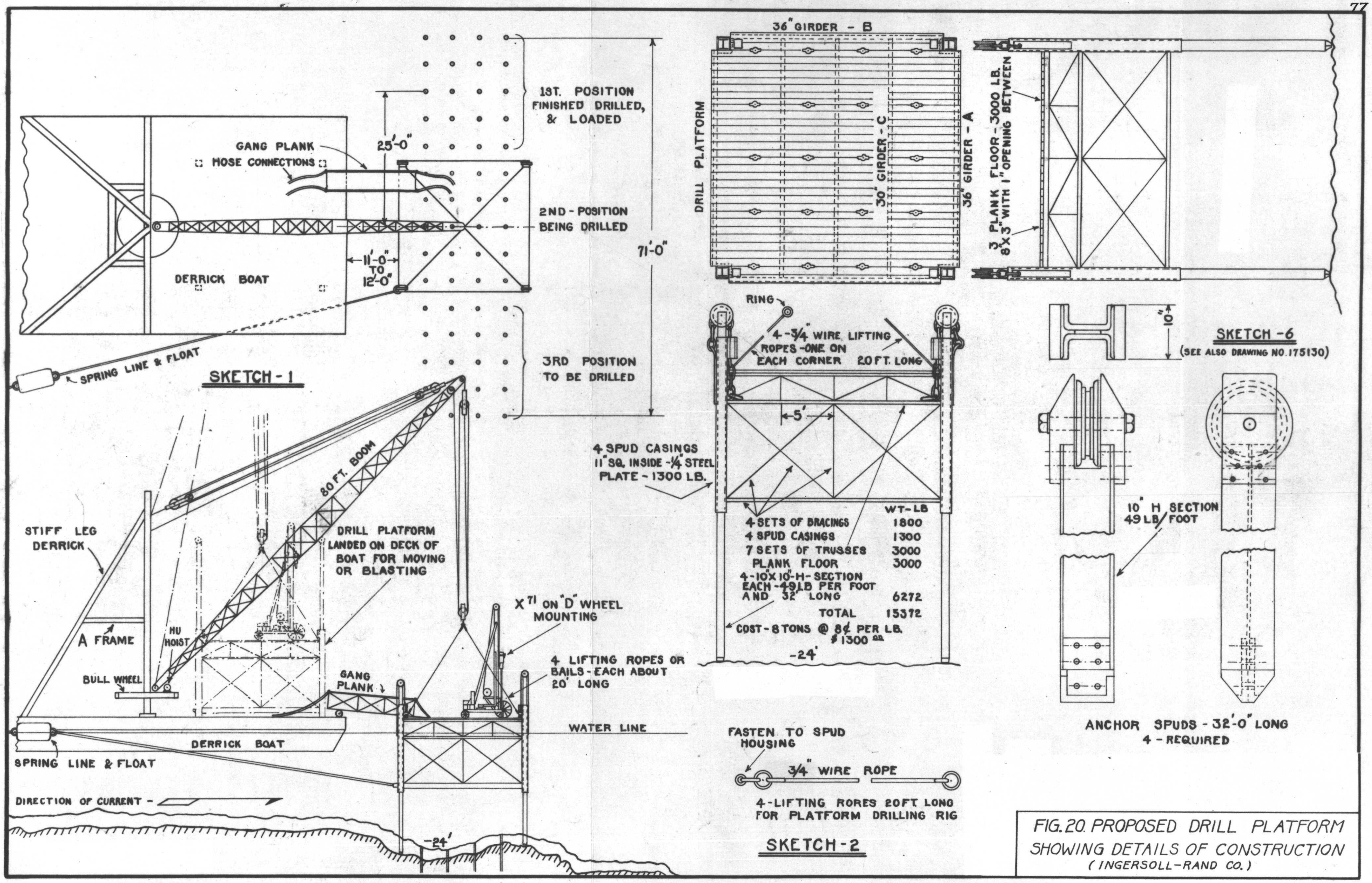



*FIG. 20. PROPOSED DRILL PLATFORM SHOWING DETAILS OF CONSTRUCTION (INGERSOLL-RAND CO.)*

ment and operate as slowly and inefficiently with the present wage scale would make the work extremely expensive. The two locations which are at all similar are the project in Galop Rapids on the St. Lawrence River[1,74] performed in 1910 and the work which has been carried on continuously in the Rock Island Rapids of the Mississippi River[55,77] until the recent construction of a dam. In both cases the work is dissimilar in many respects and only a few ideas can be borrowed and applied on the Columbia.

## DESIGN OF A DRILL BOAT

The proposed drill boat is not a new design, but embodies the same principles which have been employed for fifty years. The aim is to plan a machine which will operate efficiently under the specific conditions encountered on the Columbia River. This incorporates the use of machinery and equipment of porper size and strength so that it will be adequate for the purpose for which it is intended. The successful functioning of such a plant is measured in terms of safety to human life and cost of operation. These two factors are the basis for the development of the design.

Before progressing further a few assumptions must be made in order to justify the choice of equipment and the costs entailed. To present a hypothetical project, let it be assumed that a total of fity thousand cubic yards of solid rock are to be removed in a period of five hundred working days. Under normal conditions this would be two years, since the working days are computed only when the river is below the ten foot stage and free from ice. The contract provides for full pay to a depth of eighteen inches below t the seven foot grade, but it is only required that the rock be removed to grade. Approximately fifty percent of this rock exists above the seven foot elevation. Since little work of this nature is carried on in the northwest a conservative plan would be to attach no value to the drill boat upon the completion of the project. This is not accurate because much of the machinery may be used for other purposes, but the salvage value of this type of equipment is often very small. Taking into consideration these specifications and the natural conditions to be encountered it is possible to outline a method of attack.

THE BARGE. A creosote-treated Douglas fir barge of rigid construction would be satisfactory as a hull for the drill boat. This type of construction has been used extensively in the northwest for all classes of work where barges are employed. Wood is chosen in preference to steel because the higher cost of steel is not justified on a temporary plant. The average life of treated Douglas fir has been found to be approximately ten years.

A drawing of this barge is found in Fig. 21 showing a

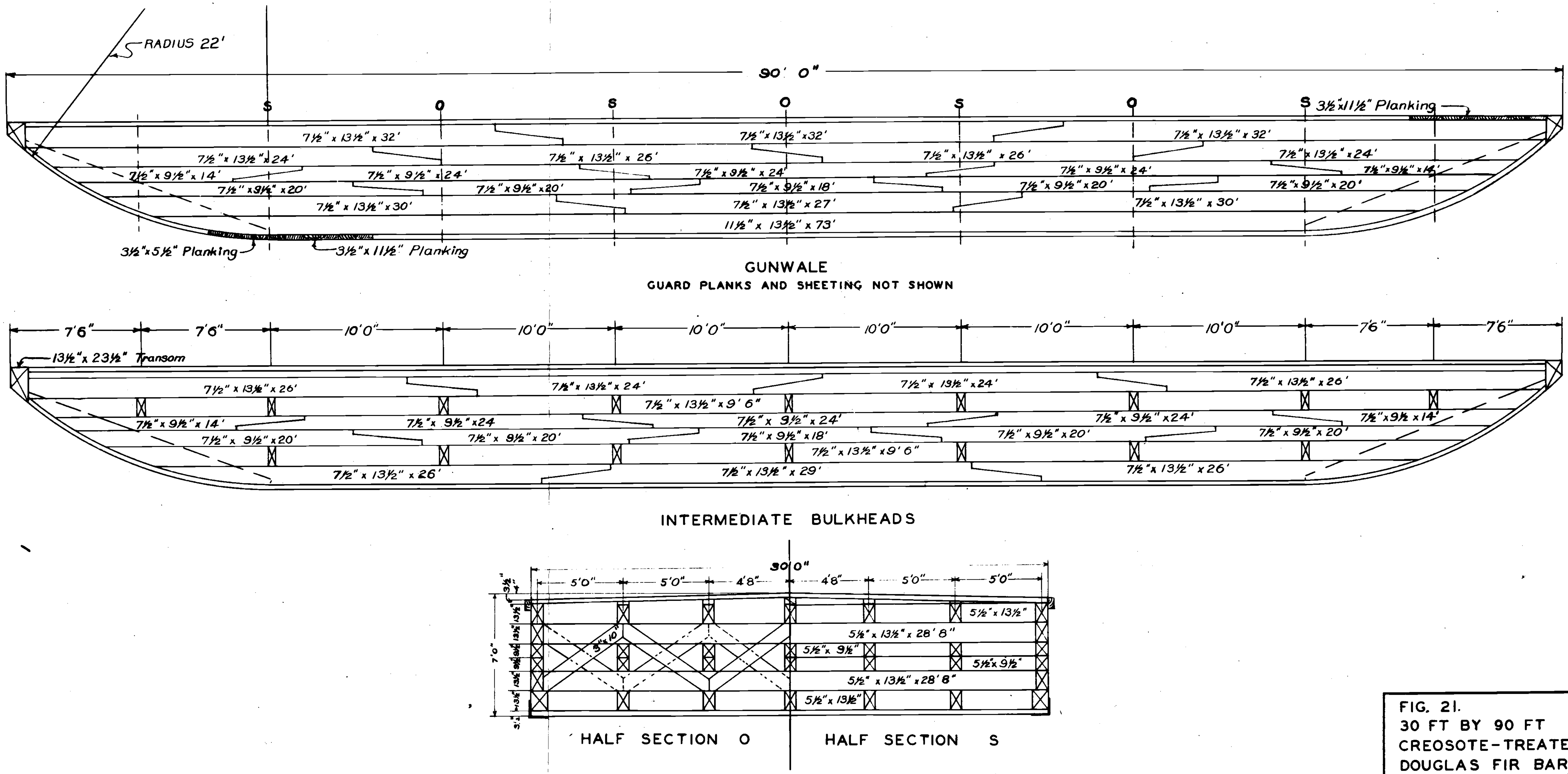



FIG. 21.
30 FT BY 90 FT
CREOSOTE-TREATED
DOUGLAS FIR BARGE

side elevation, a longitudinal section, and two half cross-sections. The solid bulkheads serve to stiffen the barge as well as to divide it into water tight compartments which alleviate the danger of sinking in the event of an accident. This barge has not been designed upon a basis of the computed stresses but its features have been borrowed from the many scows used successfully in the northwest. The U. S. Engineers have a small sweeping barge of lighter construction on the river at present, which has proved to be quite stable when moored in fast water. A barge smaller than the proposed one would be preferable from the standpoint of ease in maneuvering, but the machinery cannot be designed proportionately smaller, therefore the draught would be increased. The least possible draught is one of the chief objectives in this design. A further discussion of this important feature will be found accompanied by calculations at the conclusion of this section. The long rake on the hull reduces the horizontal force of the current.

THE LINES. The six lines employed to move this barge and to hold it in position during the drilling operation are satisfactorily operated by single drum units placed as shown in Fig. 22. Plow steel wire rope composed of six strands with nineteen wires to the strand and a wire center is particularly adaptable, since it possesses a high strength and will resist severe abrasion. Its stiffness is not a liability because it is in a stationary position most of the time, and the direct feed eliminates all bending except at the drums.

The diameter of rope to use on this barge is determined on a basis of the following considerations. The barge should always be parallel to the direction of flow of the current, but a mistake or an accident might permit the boat to swing until it receives the force of the current full on its beam. Assuming these conditions and a maximum current of fifteen feet per second, the force would be

$$F = \frac{WV}{g} = 15 \times \frac{62.5}{32.2} \times 15 = 437 \text{ pounds per square foot of area.} \quad (1)$$

Assume the draught to be 3 feet, then

$$\text{Area} = \frac{60 + 75}{2} \times 3 = 203 \text{ square feet.}$$

$$\text{Total Force} = 203 \times 437 = 88{,}500 \text{ pounds}$$

It is apparent that a combination of any two lines must withstand this force, depending upon the direction in which the boat swings. To employ a safety factor of three under these conditions the rope must have a breaking strength of

$$\frac{88500}{2} \times 3 = 132{,}500 \text{ pounds.}$$

A wire rope $1\frac{1}{4}$ inches in diameter will withstand about 135,000 pounds and should be used for all lines. Under normal conditions the stress in the lines will be comparatively small with a resulting safety factor of approximately ten.

A convenient length would be at least twelve hundred feet for each bow line and seven hundred fifty feet for each of the four breast lines. This permits the boat to move over a large area without changing the lines, an operation which consumes much time. In moving these lines it is impossible to avoid impact. A long bite is always desirable since the weight, the elongation and the force of the current on the cable all tend to absorb the energy load.

Anchors have been found unsatisfactory in this formation and their use should be avoided if possible. They hold temporarily but when sufficient force is applied they release suddenly and drag along with no resistance other than their weight until they strike an obstruction. This is not a dependable method of mooring an expensive plant in the current. It is sometimes necessary to use anchors when the boat is operating out of range of the ring-bolts. In this case anchors weighing five thousand pounds should be placed carefully.

RING-BOLTS. During low water ring-bolts may be placed in projecting rocks and on the banks of the river at strategic points. This work may be performed by installing a small portable compressor and a jackhammer on a work boat which can navigate in the shoal water. These ring-bolts, equipped with a split shank and a wedge, should be inserted at least two feet in the rock and grouted in place with cement or sulphur. If the location of the bolt is such that it will be under water at a higher stage of the river, a short rope with a thimble and a buoy should be attached. When it is to be used the line from the barge may be hooked into the thimble of the attachment.

THE ANCHOR ENGINES. The single drum units operating the lines should have diameters of at least forty inches to obtain most economical rope service. A wire center rope requires a larger diameter drum than an ordinary hemp center of equal size. These drums should be back geared in order to develop a pulling force of approximately 20,000 pounds with an air pressure of one hundred pounds per square inch. In order to obtain this line tension the engines must either be very large or must operate slowly, sacrificing speed for force. Due to the fact that a minimum draught is an objective the smaller units are preferable, since most of the moves are short.

The breast line engines are installed with their axes of rotation about twenty-five degrees from parallel to the side of the barge and the fair leads are placed at the gunwales in such a position that the lines are guided directly to the drums. The bow-line engines are placed on the center line of the barge with the lines running through fair leads at the center of the transoms.

From the plan view of Fig. 22 it is seen that the anchor engines are placed at different distances from the point of intersection of the three lines on each end of the barge. These are installed in such positions in order that the lines will not be in contact when drawn up. The variable distances result in unequal slopes from a common plane at the deck of the barge, consequently the elevation of each line at the point of crossing is different.

The fair leads are a very important part of the line mechanism and should conform to the specifications required for a line of this size. Although they are very expensive in large sizes, the proper diameters and shapes will preserve the life of the rope.

A centralized control for all drums is placed amidships above the shops where the leverman may observe in all directions and may receive orders from the bridge. This small house includes the controls for the anchor engines and the spud hoists.

THE ANCHOR SPUDS. The anchor spuds are designed to resist column action due to the weight of the boat. These are not of sufficient dimensions to withstand the bending moment caused by lateral force of the current upon the hull and consequently they are much smaller than the spuds commonly used on a barge of this size. The overall length of these columns is thirty-five feet with only twenty-three feet of effective length below the water surface. In some locations on the river it will not be possible to reach bottom at all four corners of the boat with legs twenty-three feet long. In this event the spuds which are effective will be employed and the others withdrawn.

Small spuds have been chosen for two definite reasons; the elimination of excessive weight, and the desirability of maintaining the center of gravity of the barge as low as possible when the spuds are up. The latter consideration will be discussed more fully upon the completion of the design.

It is assumed that an elevation of one foot above the normal buoyancy line will suffice to hold the barge stable, granted that the lines are being utilized to maintain it in a lateral position. The unsupported length of the 14 inch x 12 inch--78 pound H-section, which has been chosen to serve as spuds, is approximately 21 feet when dropped to its lowest limit. The area of this section is 22.94 square inches and its ratio of slenderness becomes

$$l/r = \frac{21x12}{3} = 84$$

to employ the American Institute of Steel Construction formula,

$$f = \frac{18000}{1 + \frac{1}{18000} \times \left(\frac{l}{r}\right)^2}$$

the allowable unit stress will be

$$f = \frac{18000}{1 + \frac{1}{18000}(84)^2} = \frac{18000}{1.392} = 12950 \text{ pounds per square inch.}$$

The total allowable stress will then be

22.94 x 12950 = 297,000 pounds on each spud.

The force necessary to lift the barge one foot may be determined from the fact that the barge is approximately 75 feet long at a point 1/2 foot below the water line and is 30 feet wide, thus displacing 75 x 30 = 2250 cubic feet of water for one foot of depth. This is equivalent to a weight of 62.5 x 2250 = 141,000 pounds. In order to raise the barge one foot each of the four spuds would support a weight of

141,000 ÷ 4 = 35,000

or approximately one eighth of the allowable load.

Considering the column as a cantilever beam, the maximum allowable bending moment would be

$$M = \frac{sI}{c} = 18,000 \times 121.1 = 2,180,000 \text{ inch pounds.}$$

The maximum force caused by the water impinging upon a vertical surface was previously calculated to be 437 pounds per square foot. This will create a bending moment of

$$M = \frac{Wl}{2} = 437 \times 21 \times \frac{21}{2} \times 12 = 1,160,000 \text{ inch pounds}$$

or approximately one half of the allowable moment. The total weight of each spud, including the sheaves, will be about 78 x 35 = 2730 + 270 = 3000 pounds.

THE SPUD ENGINES. The engines employed to operate the legs are much smaller than those maneuvering the lines. Reversible drums twenty-four inches in diameter with a pull of seventy-five hundred pounds will suffice for this purpose. The lines are arranged over the spud in a four to one ratio thus producing the necessary vertical force to raise the boat. The line ratio is the same on the bottom of the spud for purposes of withdrawing it from the bottom. It is obvious that this is not necessary in order to lift a three thousand pound spud, but in order to operate the spud in both directions with one winch the line must run out from the drum at the same rate that it feeds in. The alternative of employing a small hoist to raise the spud and a larger engine to force it downward is quite feasible. a 5/8-inch wire rope of the same construction as those described above will operate the spud with a sufficient margin of safety. The sheaves at the top of the column are eighteen inches in diameter and those at the bottom are twelve.

The spud well is composed of three structural steel yokes connected and braced with angles as shown in the drawing. The two sheaves are placed in the yokes in such a way that the lower lines will always be close to the web and thus protected by the flanges of the column, while the upper lines passing over the eighteen inch sheaves are outside of the upper yoke.

THE POWER PLANT. The power plant mounted on the barge is composed of two diesel-driven two-stage portable compressors each capable of furnishing 315 cubic feet per minute of actual air. The portable compressors are chosen in preference to the stationary type because of their greater salvage value upon the completion of the job. Portable compressors are used extensively in many types of construction, while the stationary machine is adaptable only to those activities where it may remain in one place for a protracted length of time. With the current improvements and increased capacity of the portable machine it has supplanted its more cumbersome colleague on many operations.

The wheels are removed from the two units and they are placed as shown in Fig. 22. Both machines are connected in parallel and maintain a pressure of 100 pounds per square inch in the 2000 gallon receiver and the distribution system. The small tanks on each unit plus the receiver and the piping system form the reservoir necessary for the operating machinery.

A study of this arrangement discloses the fact that the compressors perform three major functions. They furnish power to the anchor engines, to the spud hoists and to the drill towers resulting in continuous operation. The barge is not encumbered with machinery which is idle a great part of the time, as would be true if separate power units were employed for each operation. The above functions take place independently and one at a time, therefore the compressors have a distributed load which never exceeds that of the largest air consumer. The drill towers and the spud hoists will not over-tax these units, but the line winches are of large capacity. Not more than two winches will be operating simultaneously while moving the boat. When one winch is subjected to the maximum load of 20,000 pounds the two compressors will develop a line of speed of approximately fifty feet per minute, or twenty-five feet per minute when two engines are running. The normal load will be approximately one-fourth of this, therefore, the speed developed would ordinarily be much greater. From this standpoint a third compressor would be desirable, but in view of the additional weight and the infrequent use it is not justified. It is apparent that the entire drill boat is dependent upon the satisfactory operation of the compressor units. These machines should be the best quality available and should be maintained in perfect condtion at all times.

THE JET PUMP. The pump which furnishes water to the drills is of the reciprocating piston type, either duplex or triplex. The water is used only when the drills are operating and may be controlled at each drill tower. It is therefore necessary to equip this pump with a by-pass which diverts the water when a pressure of 250 pounds per square inch is exceeded. In order to equalize the flow a small compensating chamber is installed in the line. A flow of 75 gallons per minute to each drill would require the power imput show below.

$$P \text{ in ft. lbs.} = \frac{\text{gal/min.}}{\text{gal/cu.ft.}} \times \text{lbs/cu.ft.} \times \text{head in ft.}$$

$$P = \frac{150}{7.48} \times 62.5 \times 250 \times 2.3 = 722{,}000 \text{ ft. lbs.}$$

Assuming the pump to be 50% efficient, the necessary imput in horse power would be

$$\frac{722{,}000}{33000 \times .50} = 43.8 \text{ or } 45 \text{ H. P.}$$

THE SAFETY PUMP. A safety pump with a capacity of 5000 gallons per minute is placed amidships and equipped to pump water from the bilge. This is a centrifugal type, powered in the samemanner as the piston pump described above. Assuming that this pump operates against a twenty foot head with an efficient of 80% the required power imput would be

$$\frac{5000 \times 62.5 \times 20}{7.48 \times 33000 \quad .80} = 31.6 \text{ or } 35 \text{ H. P.}$$

This pump is connected by a small pipe with a valve to the piston pump for the purpose of priming. A suggested emergency measure would be to prime this pump every few hours in order that it may be of immediate service in the event of an accident. The motor should be in perfect condition so that it could be started with the least difficulty. A ten kilowatt lighting plant is installed to furnish illumination to all parts of the boat during the night operations.

THE SHOP. The shop should be adequately equipped with all the machines necessary to perform the ordinary repairs. This should include a work bench with a full set of tools and a full stock of spare parts, which embodies one complete drill and most of the moving parts comprising a second drill. Detachable bits are recommended for this work in order to eliminate the weight of a forge and sharpener and to preclude the necessity of handling long steel in a confined area. In this case a bit sharpener becomes one of the most important tools in the shop.

THE FUEL TANKS. The fuel tanks are placed below decks on the opposite side of the barge from the drill towers as shown in Fig. 22. In each of two compartments a 750 gallon tank may be placed with the intakes on the deck of the barge outside of the covered area. This makes it possible for the work boat to deliver oil to the tanks through a hose without hindering the drilling operation. A total of 1500 gallons is sufficient to supply the plant for a period of a week of constant operation. The 500 gallon gasoline tank

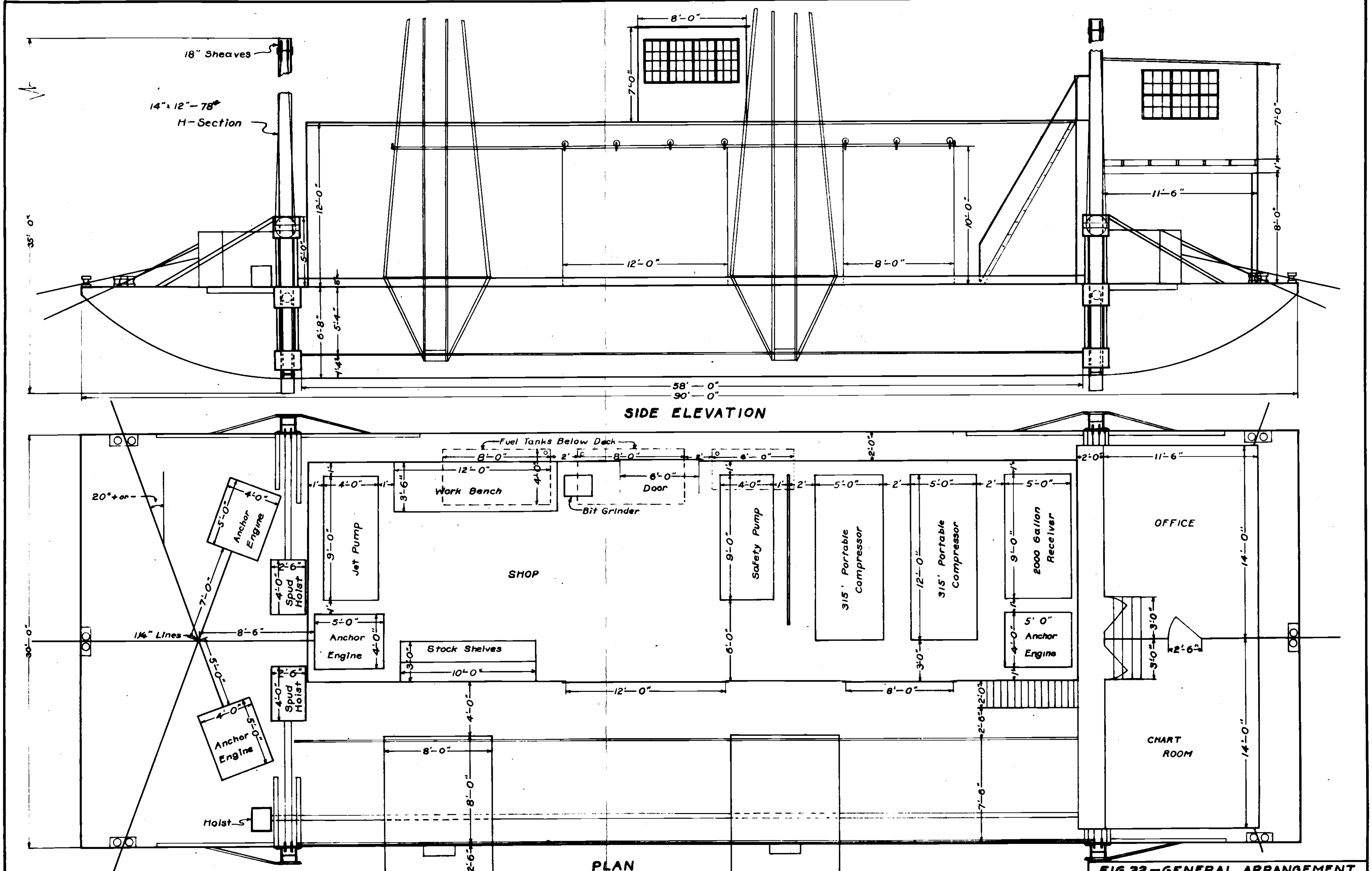



FIG. 22—GENERAL ARRANGEMENT OF DRILL BOAT

for the engines running the pumps may be placed in a third compartment under the bit grinder. A small fuel pump powered by air is utilized to convey the oil from the tanks below deck to the small tanks at the compressors.

Spools of wire rope, extra sheaves and other cumbersome equipment may be stowed in hatches near the ends of the barge. A rack for auxiliary drill steel may be installed at a convenient point on the deck of the barge near one end of the tracks. Other minor details which are necessary in the complete design of a barge will be omitted in this discussion.

THE DRILL TOWERS. Two drill towers have been adopted for this boat. The areas to be drilled in this project are for the most part small and irregular in shape, composed of small ledges, rocks and pinnacles, consequently it would often be impossible for more than two drills to operate simultaneously. In a few instances only one drill may operate at one time while the other stands idle over deep water. Some proposals favor a smaller boat with one drill tower, but this method would be more expensive because the capacity of the plant would be reduced more than the boat and crew. The two towers are identical, therefore an examination of one will automatically include the details pertaining to both.

A discussion of the drill tower resolves itself into an explanation of Fig. 23. In all of the diagrams the line of the water surface is drawn at a point two and one half feet above the bottom of the barge. This is assumed to be the average position of the water line when the boat is spudded up and in drilling position. The drill tower is bolted to shoes which fit around the upper flanges of two 8-inch I-beams thus forming a skid mounting which will not permit the tower to leave the tracks. The towers are moved along the tracks by means of an endless cable passing from a reversible air hoist shown in Fig. 22 behind the spud, to a sheave at the other end and back to the drum of the hoist. The cable is equipped with one or more hooks which may be attached to a ring in the base of the tower when it is desired to move it. When not in use the rope rests on the deck between the tracks. As shown in the figure, the hoist employed to move the towers is in an inconvenient position to operate. This condition may be improved by extending the throttle so that it can be handled from the end of the tracks.

The tower is eight feet wide and the clear distance between the spuds is fifty-eight feet permitting a working range of fifty feet. It extends thirty feet above its base or 30 feet 8 inches above the deck of the barge. The base of the tower is used as the point from which all measurements are taken and will serve as the datum in this discussion. The guides extend six feet four inches below the base where another shoe slides along a vertical strap on the side of the hull. Fig. 23 A is a front view of the tower showing the guides and the position of the sand pipe and drill when operating in a minimum depth of water. Three and one half feet is only six inches more water than necessary to float the barge and will be encountered very rarely.

The sand pipe, which serves to exclude overburden, and actsas a guide for the drill steel, and in loading the holes, is a high carbon steel casing with an inside diameter of four inches. The walls of this casing are ½ of an inch thick in order that it may withstand the abuse it receives in service. It is a single piece with an over all length of ten feet from the bottom of the shoe to the top of the collar. It is clamped securely in the upper crosshead which is heavily weighted and designed to slide freely in the guides. The bracket at the bottom of the guides is equipped with a sleeve through which the pipe may slide. This yoke is also movable in the guides but rests at the bottom unless the shoe on the casing picks it up when the pipe is withdrawn. The sleeve mentioned above is large enough to permit the pipe to slide through it, but it will not pass over the shoe.

An analysis of the dimensions shown on the figure discloses the fact that the pipe has a range of five feet ten inches between the minimum and maximum depth to the surface of the rock. The maximum depth is, therefore, nine feet four inches below the surface of the water, or to grade when the water is 2.33 feet above low datum. When the water level exceeds this a longer pipe may be substituted. Figure 23B shows the position of the mechanism when operating at a maximum depth. To the upper crosshead is attached a line which passes over a sheave at the top of the tower and down to a small hoist mounted on its base. This is used only when the pipe is being withdrawn or lowered. While drilling, the pipe rests on the surface of the rock and slides freely in the guides with the slight motion of the boat. The dotted lines in each of the two drawings indicate the position of the drill and casing when fully withdrawn.

The drill is mounted in a frame commonly called a "slab-back" which also moves freely in the guides. The slab-back is heavily weighted in order to absorb the recoil from the hammering action of the drill and to keep the steel in contact with the bottom of the hole. The limits of the range through which the slab-back may travel are the collar on top of the sand pipe and the top of the guides. In order to keep the drill aligned over the top of the steel and in the direction of the hole the full length of the slab-back is five feet.

A drill steel twenty-two feet in length is shown in the drawing. When it is necessary to remove the steel to change bits or load the hole, a minimum clearance of four inches exists between the collar of the pipe and the bit. In this way it is possible to change the bit, or draw the steel to one side and load the hole without removing it from the chuck of the drill. A strap with a hook may be placed outside of one guide to hold the steel away from the casing. When drilling in deeper water the clearance between the bit and casing is increased. With this length of steel it is possible to drill a hole eleven feet deep, before the slab-back is resting on the collar of the sand pipe.

The guides are equipped with safety catches upon which the slab-back and the crosshead rest when withdrawn. These are designed to work automatically when the mechanism is raised above them, removing the hazard of dropping the pipe or the drill if one of the hoists should let go. These safety catches may be released by lifting the weight and withdrawing them with hemp ropes attached and extending down to the deck.

The common land type hammer drill or the small submarine drill would be satisfactory for this shallow work. Since the water is not deep enough to demand a submerged hammer or extremely long steel the large drill would not be practicable. Its comparative cost and air consumption is justified only where the work is of such a nature that no other drill would be satisfactory. It is not the purpose of this paper to discuss the comparative merits of the drills which are manufactured. Many different makes are available and sold by reputable companies. The fact that they are continuously on the market indicates that they are capable of withstanding the competition of others. Any one of many drills would be satisfactory for this appointment.

The drill steel should be $1\frac{1}{4}$-inch hollow round, ranging in lengths from twenty-two to thirty feet. This steel is readily available and should be prepared with lugs and upset threads before it is delivered to the job. Much breakage should be anticipated in connection with this work due to the very hard rock that is encountered. For this reason most of the steel should be longer than twenty-two feet because broken pieces may often be salvaged and made into shorter steels without welding. Welded steel has not been thoroughly satisfactory in hard rock, since the ordinary blacksmith finds it difficult to properly heat treat this alloy steel subsequent to the welding. A chrome vanadium sleeve has been used to connect two sections of steel, but this too has been unsatisfactory and is coupled with a great cost. Nevertheless one must resort to one of these methods when steels longer than thirty feet are necessary.

Detachable bits are recommended for this work, not because they are unquestionably superior but because of the convenience and the elimination of the forge and sharpener on the boat. Bits three inches in diameter and equipped with a side or center hole would be satisfactory for this purpose. In using these bits much time is saved in handling the steel, changes being necessary only when it breaks or when an unusually deep hole is being drilled and an increased length is demanded.

A side view of the drill tower, Fig. 23 C, discloses the arrangement back of the drill guides. One large single drum air hoist is employed to handle the drill, and a smaller one operates the sand pipe. A small capstan hoist is also convenient as an auxiliary to handle drill steel and the charging tube. The throttles and the brakes on the hoists, together with the air and water controls should all be in such a position that the driller may sit comfortably and operate the entire mechanism. The hoist attached to the drill should have a very sensitive throttle in order that the drill may be fed accurately and withdrawn quickly, a feature of much importance in the drilling operation. The charging tube, Fig. 23 D, is employed in loading the holes. The barrel is loaded with the powder with the wires from the primer extending out of the side through the slot which is cut for the purpose. The tube is lowered into the hole and then withdrawn as the tamping rod passing through the pipe handle holds the charge in place.

In the design of a drill boat it must be remembered that the efficiency of the entire plant is dependent upon the mechanism utilized to drill the holes and place the powder. Therefore, particular attention should be devoted to the careful and accurate construction of a tower which will perform under all working conditions.

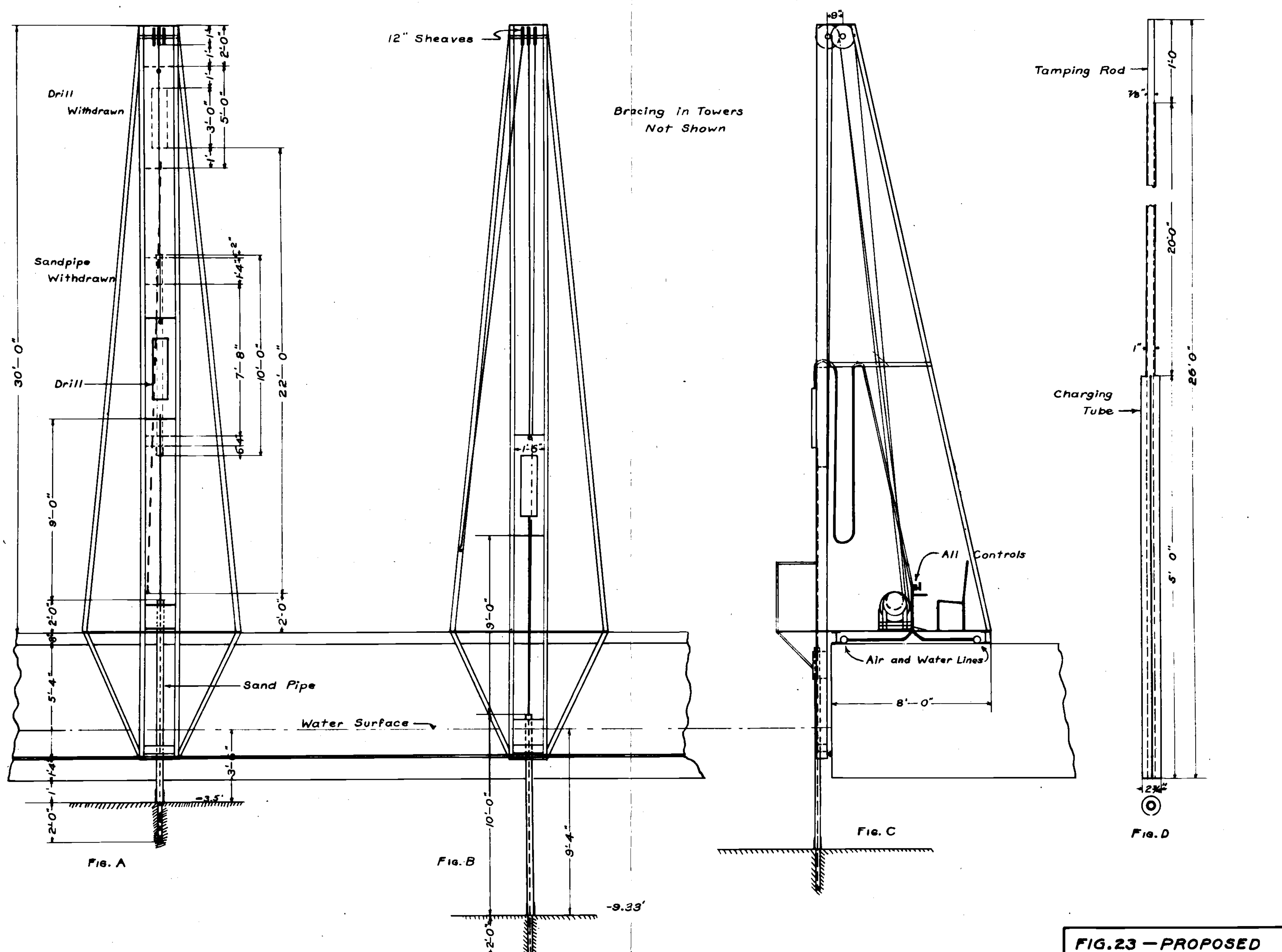



FIG. 23 — PROPOSED DRILL TOWER

THE BRIDGE. Extending between the two spuds at one end of the boat is a bridge, the floor of which is twelve feet above the deck of the barge. This is of sufficient height to permit visibility in all directions and is the point from which observations are made to determine the location of the boat in the river. At the end of the bridge closest to shore is mounted a reel carrying a graduated aircraft strand. This extends to a known point on shore, making possible the determination of the position of the boat in one direction. A double row of markers at intervals of fifty feet will serve to indicate the other coordinate. When operating within thirty feet of the center line of the channel it is possible to supplant the graduated cable, utilizing the channel ranges. This could be effected by graduating the railing of the bridge and placing vertical rods at intervals of five feet along the other end of the barge.

DISTRIBUTION OF WEIGHT. The equipment has been placed upon the hull with two objectives; convenience and a proper distribution of weight so that the center of gravity of the equipment will coincide with the geometrical center of the hull. It has not been mentioned previously, but all equipment is placed as low as possible. Through proper bracing below the deck all heavy machinery may be bolted directly to the deck without supplementary mountings. It is for the same reason that light anchor spuds were chosen to stabilize the barge. The drill towers were designed as short as possible in order to keep the center of gravity below the deck.

To create a hypothetical situation, assume that the boat was equipped with heavy spuds about sixty feet long and operating in a fast current. The barge has just moved into position on a ledge adjacent to deep water and all of the spuds are up. Ring bolts are inaccessible and anchors are being used on some of the lines. Just as the anchor spud over deep water at the bow is dropped the bow line anchor slips causing the inshore breast line anchor to give way also. The head of the barge would swing into the current and start down stream broadside. The offshore breast line at the bow would slack and drop down under the barge. If the lowered spud should strike a rock or a submerged ledge in all probability the boat would tip over with all the crew. In a similar situation utilizing the small spuds, the center of gravity would be lower and the submerged column would not furnish as long a lever arm. When it struck bottom the 14-inch H section would probably crumple up leaving the barge in an upright position. In any event, this would be a very dangerous predicament and every effort should be made to avoid such an accident.

DRAUGHT. A calculation of the weight of this boat in order to determine the draught and the approximate position of the center of gravity in a vertical plan is computable at this point. Below is a table of approximate weights.

TABLE OF WEIGHTS

| Item | Number | Unit Weight | Total Pounds |
|---|---|---|---|
| Hull | | | |
| Creosote treated Douglas Fir | 4750 cu. ft. | 50 lbs. | 237,500 |
| Bolts, sheeting, bracing, etc. | | | 15,000 |
| | | * | 252,500 |
| Machinery | | | |
| Anchor Engines | 6 | 3000 | 18,000 |
| Wire rope 1¼" | 5400 ft. | 2.5 | 13,500 |
| Fair leads | 6 | 400 | 2,400 |
| Anchor Spuds | 4 | 3000 | 12,000 |
| Spud Wells | 4 | 1500 | 6,000 |
| Spud engines | 4 | 1500 | 6,000 |
| Compressors | 2 | 7000 | 14,000 |
| Drill towers | 2 | 7500 | 15,000 |
| Pumps | 2 | 2500 | 5,000 |
| Tanks, Fuel | 3 | 500 | 1,500 |
| Tank, Air receiver | 1 | 1000 | 1,000 |
| Generator & Grinder | 1 | 1000 | 1,000 |
| Stock & Parts | | 10000 | 10,000 |
| Piping system | | 5000 | 5,000 |
| Wood super-structure | | 5000 | 5,000 |
| Miscellaneous | | 10000 | 10,000 |
| | | | 125,400 |
| | | | 252,500 |
| | | Total Weight of boat | 377,900 |

At a point three feet above the bottom the hull is approximately 78 feet long. Treating a section of the barge as a trapezoid the following calculations will approximate the depth to which the barge will settle in still water.

$$\text{Total Displacement} = \frac{377900}{62.5} = 6045 \text{ cubic feet.}$$

Average cubic feet per foot of depth =

$$\left(\frac{78 + 60}{2}\right) \times 30 = 2070 \text{ cu. ft.}$$

Draught = $\frac{6045}{2070}$ = 2.92 or approximately 3 feet.

CENTER OF GRAVITY. From the table above the weight of the hull is approximately twice that of the machinery. When the spuds are elevated so that the points are even with the bottom of the barge, the center of gravity of all the equipment is about four feet above the deck. The center of gravity of all the hull is three feet below the same datum, therefore, the highest limit in the locus of the center of gravity of the boat is approximately eight inches below the deck, or three feet above the water surface. This may be considered comparatively safe with a thirty foot beam.

In all previous discussions the draught has been considered only in still water. When moored in shoal water traveling at a high velocity the barge will squat or "suck down". The extent to which this phenomenon will become effective cannot be accurately determined, but observations on a smaller barge under similar conditions indicate the maximum to be about one foot on the downstream end and no change at the bow. An opposing force exists here, since moving water impinging upon the rake possesses a vertical component of force which tends to raise the upstream end of the boat.

CONCLUSION. In conclusion, a few general statements concerning the capacity and the limitations of the drill boat are in order. It is designed to operate under the normal conditions encountered on the Columbia River in water ranging in depth from four to about seventeen feet, the distance to grade when the river is at a ten foot stage. To drill in deeper water would be possible but a long sand pipe and drill steel made up in sections would be necessary. By removing the steel from the chuck of the drill and employing the auxiliary capstan hoist to make changes, holes of great depth could be drilled, but the efficiency of the short tower would decrease proportionately. During extremely high winds, which normally occur about twenty days each year, it might be necessary to suspend operations because of the surge. An attempt to work during the ice period would be foolhardy with any type of craft. Nevertheless, it is thought that the plant described above will operate as economically as any thus far proposed.

## AUXILIARY EQUIPMENT

The importance of tugboats and auxiliary equipment for this work must be stressed. A detailed analysis of the proper design of boats is beyond the scope of this treatise, but an outline of the essential features which this type of plant should possess to operate satisfactorily will be mentioned.

THE TUG. The first consideration is a tugboat of sufficient power to maneuver the drill barge in swift water. Because of the hydrography encountered it should be a minimum draught in order to navigate safely through the rapids. A boat which does not have a cruising speed much greater than the velocity of the water would be of no value.

The twin screw type with propellors approximately twenty-four inches in diameter and a power plant capable of developing at least 400 B. H. P. is worthy of consideration. It is necessary that these be high speed motors in order to develop the required power, but large wheels cannot be used conveniently in this section of the river. Either high speed diesels or gasoline engines would be satisfactory for the purpose. The approximate length of this boat should range between forty-five and fifty-five feet, with a draught of not more than four feet. In some places it would still be necessary to resort to the use of lines in order to take the barge upstream, but the tug would be adequate under most conditions. The United States Army boat "John Day" is of this design but smaller, using two 185 H. P. gasoline engines. It is used satisfactorily to maneuver a 75-foot sweeping barge weighing approximately one hundred tons, and is considered one of the best boats of its size on the river.

The functions of this tugboat would be rather diversified covering a wide range of duties. It could be employed to carry fuel to the drill boat from a convenient loading point on the river. With a small anchor barge tied alongside it may serve to move the anchors or carry the lines to the ring-bolts. When the dredging operation is being carried on, it would serve to maneuver the dredge in the same way.

Unfortunately very few boats possessing these features are available. The cost of building such a craft would be prohibitive for a project of this size unless future work is in the offing or the builder can be assured that it would be marketable at a fair price upon the completion of the job. For this reason one must resort to a diligent search for a boat which measures up fairly well to the desirable specifications. To rent a tug to operate in this section of the river is a very expensive enterprise also. Therefore, in any event the cost of a tugboat should be carefully considered.

WORK BOAT. In addition, two smaller work boats would be necessary to carry supplies and perform miscellaneous duties. One of these should be about thirty feet overall and should be equipped to carry the crew to and from the drill barge. It may also be used to carry powder and other expendable items which are constantly transported to the barge. A twenty-foot open boat powered with an out-board motor would suffice for other purposes.

THE DREDGE

A limited discussion of proposed dredges and dredging methods on this project will be presented to complete the picture. From the general outline of the commonly used dredges described in Part I of this paper it is seen that three types of plant may be considered. The ladder dredge, the dipper dredge and the dragline excavator are all capable of removing blasted rock. The dipper dredge has been the most widely used of this group.

To retain the assumptions made at the beginning of this hypothetical project and to add a few more, let it be supposed that the rock is to be disposed of in deep water or out of the channel where it will not return to form a shoal. The hydrography of the river is such that it is not uncommon in many locations to find deep holes adjacent to the ledge or pinnacle to be removed. Few places are close enough to the shore so that the broken rock may be deposited above the water. It is to be remembered that this formation is diced basalt and most of it will break up into small fragments when blasted.

The quantity of material is very small when considering a dredging operation. This situation automatically eliminates a large and expensive plant, unless provision has been made to remove additional loose material. The ladder dredge is considered too cumbersome for this particular work, and its capacity is not warranted in the removal of small quantities. The dipper dredge may be used to remove the blasted rock, but it too is a difficult craft to handle in swift water and its short boom confines its operation from one position to a small area.

The dragline excavator mounted on a barge should be the most satisfactory plant to employ. Since the rock is finely broken a small capacity but heavy bucket may be placed on a long boom. This would permit the dredge to side cast into deep water in many instances. A haul-back line could also be used employing a sheave attached to an anchor or a ring-bolt beyond the area to be excavated. In this manner the barge could be moored in deep water and the bucket could be dragged out to a distance much greater than the length of the boom over the area of blasted rock. On its return the bucket would load and then be picked up with the hoist line when it reached a point under the end of the boom.

Where the disposal area is a great distance from the point of excavation, small scows could be loaded by the dragline and transported to the disposal area with the tug-boat. Here they may be unloaded with a small bulldozer caterpillar or the dragline may follow and unload. In general the disposal areas are downstream from the excavation, so it would often be possible for the dredge to drop down using her own lines, unload and return.

The dredge could remove the rock much more rapidly than the drill boat could prepare it for dredging. Fortunately the construction of a channel in the Columbia River would include the excavation of many yards of loose material in addition to the blasted rock. In this case it would be possible to operate the dredge a majority of the time at a nominal unit cost.

## ORGANIZATION AND OPERATION

The organization of a competent crew to handle a drill boat on the Columbia River requires as careful study as the design of the plant. An efficient and safe operation is more dependent upon the personnel and the organization than upon the equipment which is employed to do the work. The training of each member must be such that he is fully capable of performing his duty accurately and in a manner which inspires the confidence of the crew working under the hazardous conditions. The greatest burden in this respect falls upon the captain of the boat.

THE CREW. The proposed crew is composed of nine members, five of which may be considered skilled laborers, while the remaining four belong to the semi-skilled group. Each drill requires a drill operator who controls the entire mechanism, and a helper who performs all the duties out near the drill under the direction of the operator. One powderman and a helper prepare the charges and load the holes drilled by both drills. A leverman, who operates the spud and anchor engines during the moving operation is responsible for the condition of all machinery except the drill towers. Since he is employed only a small percentage of the time in the control house, his duties are ordinarily those of mechanic and general-service man. Subordinate to him, one deck hand is employed to sharpen bits in the shop and perform miscellaneous work about the plant. The foreman or captain completes the crew. His duties are those of general supervision, which include all calculations and determinations necessary to perform the prescribed work.

NORMAL PROCEDURE. To treat the method of operation generally, an outline of the normal procedure will first be presented, then certain modifications will be suggested to meet specific situations. Unlike many operations of this type, each small area to be removed will require variations in order to perform the work efficiently.

The barge is moved into position, all lines are drawn up, and the spuds are forced down. The position of the boat is checked by making soundings with a pole to be sure that the drills are over the ledge or pinnacle. The depth and spacing of the holes have previously been determined and the drillers are instructed to set the movable pointers, which are installed on a graduated board, along the side of the drill guides. Another system of tags is placed on hooks on the side of the house to direct the spacing of the holes.

When a range of holes is to be drilled, it is usually more satisfactory to place one tower at each end of the tracks and permit them both to progress toward the center. In this way the operation of both towers is continuous until the last hole is drilled. When another arrangement is employed, one drill may be idle while the other is finishing the drilling near one end of the barge. Identical speed for both towers is only true in theory; in actual practice one unit is always delayed due to various conditions of the rock.

When a tower is in position to drill a hole, the operator lowers the sand pipe to the surface of the rock. If overburden is encountered, which is very rare, the loose material must be washed out of the casing with the water jet from the drill. This is accomplished by lowering the drill simultaneously with a sand pipe and with the bit a few inches below the shoe of the pipe. The water is turned on and the steel is rotated slowly, if a separate rotation motor is employed. When the sand pipe reaches the surface of the rock and the loose material has all been removed, the hammer is put in action. The drill is operated slowly at first, and then the speed increased as the hole is started. During the drilling operation, the hammering action, the rotation of the steel, and the flow of water exist simultaneously. The water issuing from the bottom of the drill hole is one of the most important features of the operation.

Frequent bit changes are necessary when drilling this hard rock, and it is probable that at least two bits will be necessary for each hole. Nothing is gained in the attempt to use a dull bit, and when the drill begins to slow up it should be withdrawn and the bit replaced. If employed too long, the gage is worn off the bit, and it is ruined for future use. It cannot be sharpened without a great decrease in diameter which leads to serious trouble. A 3-inch bit is the smallest which can be used satisfactorily in this work, and the gage should be preserved. If the bits are used properly, they may be sharpened at least twice before they are discarded. All drill holes taper slightly due to the wear of the bit. For this reason, the sharpened bits should be graded and placed in separate compartments on the base of the drill tower, so that the drill helper will not attempt to use a new bit at the bottom of a hole which has been drilled by a slightly smaller one.

When the hole is completed, the drill is withdrawn and the steel pulled to one side of the casing. During the drilling operation, the powderman and his assistant should prepare the charge and place it in the charging tube. Upon the removal of the drill steel, the tube is inserted to the bottom of the hole, where the powder is held firmly in position with the tamping rod, while the tube is withdrawn. The wires which are inside of the sand pipe are carried up to a stage in the tower and held in position while the pipe is raised. When the shoe is high enough so that the wires can be grasped below it, the upper ends are dropped through the pipe and carried to a point on the edge of the barge where they are tied temporarily. The tower is then moved to the next position and the cycle is repeated. In this work where the drilling is slow, the powderman and helper can handle both units satisfactorily.

Upon the completion of a range of holes, the barge is moved a distance normal to the range equal to the desired spacing and the operation is repeated. When this move is effected, care must be exercised to leave sufficient slack in the wires so that they will not be broken. The barge may be moved over the previously drilled holes, or it may be backed away from them depending upon the method in which the area is being drilled. In the event that it is backed away, the wires may be attached to the two bus wires, which are equipped with small, wooden blocks as floats, and the entire system, except the ends of the bus wires, may be thrown overboard. In this way the drill towers may be moved freely without continuously changing the wires. This method is not satisfactory when the barge is moved over the holes, because they may become entangled around the spuds or the drill casings.

When a number of ranges have been drilled, the barge is then backed off a safe distance, using a reel to let out the two lead wires. The wires are then connected to a circuit from the generator and the powder is detonated. The safe distance is variable, depending upon the size of the shot and the depth of the water. In general, the boat should be farther away from the blast in this work than most submarine blasting because of the shallow water. When the boat is in position to fire a shot, a check should be made to be sure that one of the maneuvering lines is not too near the area to be blasted where it will be injured or broken.

VARIOUS METHODS OF ATTACK. In general, the areas to be removed are small and irregular in shape. Some may require two or three thousand drill holes while others are merely pinnacles. Obviously these variations require many methods of attack. The charts of the areas should be carefully studied and a plan outlined previous to the work. The shape of the area to be drilled may be such that it would be more practicable to place the boat at an angle with the flow of the current. This practice should be employd within limits, so that the force of the water on the side of the barge will not be excessive, placing too much strain in the lines. The boat may be placed in any position by employing a protractor on the charts and a sextant on the bridge. The desired angle may be determined from a known point on shore, and the barge brought into position, utilizing the sextant by superimposing a rod at the other end of the boat upon the known point.

The position of the boat, the direction of advancement, and the number of holes to be blasted at one time are all subject to variations. Likewise the spacing and depth of the holes and the size of the charge in each hole will be peculiar to each area. The answers to many of these problems could never be determined without employing the trial and error method.

A feature which should be mentioned because of its importance in connection with the cost of the work is the position of the area with respect to deep water. It is often true that a ledge or pinnacle is adjacent to deep water on one or more sides. If the ledge is properly blasted, it is possible to employ the flow of the current and place much of the broken rock in the disposal area without using the dredge. This may be accomplished in many ways depending upon the position of the ledge. The holes adjacent to deep water may be drilled a number of feet below grade, then each successive range of holes may be shallower, thus producing a slope, from which, with the aid of the current, the loose rock may slide.

When a small pinnacle with steep sides is encountered in deep water, its removal may be effected economically by drilling one or two deep holes. Larger bits may be necessary in order to insert sufficient powder to shatter and lose it. Although the quantity of rock removed and the powder used would be much greater than necessary, the time consumed may be sufficient to more than offset the other cost. Because this rock is hard and brittle, a high velocity powder is desirable.

CONCLUSION. In conclusion, a fewgeneral rules of operation may be of value in excavating rock from the Columbia River. An ample quantity of powder should be used to break the rock into small fragments so that it can be dredged easily. Where the current will carry the rock to deep water sufficient powder should be employed to break and lift the rock from the ledge. A careful study of each area should be made and the natural forces employed to aid in the work rather than to hinder it. A well-trained and competent crew should be on board the drill boat. This is a very difficult type of work, every phase of which should be approached intelligently.

## A COST ANALYSIS

Little data are available upon which an estimate of probable costs can be made. Records of similar work may be used to a limited extent but these figures are subject to so many variables that an approximation should be viewed caution. The cost of operation of the proposed plant for a unit length of time may be computed with a fair degree of accuracy, but the speed of operation of the drill boat is difficult to determine prior to actual test.

The outline of probable costs presented herein will include only the direct costs encountered in operating the drill boat. These do not include the indirect costs which are extensive in this type of work, or the cost of dredging the rock subsequent to drilling and blasting. The proposed list should not be considered accurate to a degree comparable with an estimate upon many construction projects.

SPEED OF OPERATION. The first assumption pertains to the speed of operation of the drills. It will be assumed that the drills are capable of averaging fifteen linear feet of drill hole per hour during operation. Representatives of drill manufacturers will cite many instances where their drills have far exceeded this figure, but in actual practice under conditions where very hard rock is encountered a conservative estimate for the drifter type drill using a 3-inch bit will approximate fifteen feet per hour.

Observations over a period of years indicate that a drill is in operation about forty percent of the time. Modern improvements have increased this figure slightly, but the extreme conditions on the Columbia River will cause a greater loss of time than on many projects, consequently the "40%" will be used without change.

An ideal situation would be to remove all the rock to the overdepth level, but this is not realized in actual practice, so the estimate will be on a basis of receiving pay for fifty percent of the rock between grade and one foot overdepth. It was previously stated that half the entire quantity was between these limits, therefore the basis of estimate will be

75% of 50,000 = 37,500 cubic yards.

The average depth of the existing surface of the rock is about 5½ feet below low water or 1½ feet above grade. With a drill hole spacing of five feet the necessary depth to drill the holes would be 6½ feet, apprximately.

A summary of these assumptions will lead to the following figures.

TABLE PERTAINING TO SPEED OF OPERATION

To adopt one 24 hour day as a unit the linear feet per day will be

15 x 24 = 360 x 40% = 144 ft/drill/day.

144 x 2 = 288 feet per day.

With a spacing of 5 feet in both directions and the rock removed to 5/10 ft. below grade the total cubic content of pay rock per hole would be

5 x 5 x 2 = 50 ÷ 27 = 1.85 cubic yards/hole

1.85 ÷ 6.5 = .285 cubic yards per foot of hole

or

1 ÷ .285 = 3.5 ft. of hole per cubic yard

The number of cubic yards per day equals

.285 x 288 = 82 cubic yards per day.

The time necessary to complete the project would be

37500 ÷ 82 = 457 days

500 - 457 = 43 days margin.

COSTS PER DAY. An estimate of the direct costs of operating the drill boat for a period of one twenty-four hour day would involve the following considerations.

| Labor | Number | hours | Total |
|---|---|---|---|
| Captain(supervision) | 1 | 24 | 24 man hrs. |
| Skilled | | | |
| Drill operators | 2 | 24 | 48 " " |
| Leverman | 1 | 24 | 24 " " |
| Powderman | 1 | 24 | 24 " " |
| | | | 96 |
| Semi-skilled | | | |
| Drill helpers | 2 | 24 | 48 |
| Powder monkey | 1 | 24 | 24 |
| Deck hand | 1 | 24 | 24 |
| | | | 96 |

Materials and Supplies. The engines driving the compressors will each burn approximately six gallons of oil per hour. The gasoline engine driving the jet pump will burn about two and one half gallons per hour.

| | Gal/hr | | hours | |
|---|---|---|---|---|
| Diesel oil | 2 x 6 | x | 24 | 288 gallons |
| Gasoline | 3 | x | 24 | 72 " |

Powder and Caps. It is assumed that this work will consume five pounds of 80% nitro-gelatin per cubic yard of pay rock.

| | | |
|---|---|---|
| Nitro-gelatin | 5 x 82 | 410 pounds |
| Caps (1 per hole) | 288 ÷ 6.5 | 45 |

Bits. The estimated life of each bit is three linear feet each time that it is used. It may be sharpened at least twice if carefully handled.

$$\frac{288}{3x3} = 32 \text{ bits/day}$$

Miscellaneous. Large quantities of grease are used for lubricating the hoists, drills, and winches. Steel breakage is an expensive item. Drill parts, hose couplings, shooting wire, and hemp rope should be considered.

Plant. As previously stated, it is assumed that the entire cost of the plant is absorbed by the job. To this cost should be added twenty per cent to include replacing the maneuvering lines, major repairs, and contingencies.

The cost per day would be

Total initial cost x 1.20 ÷ 457 = .262% initial cost daily.

Below is a summary of the items upon which a cost estimate for a period of one working day may be derived.

| | |
|---|---|
| Labor | |
| Supervision | 24 man hours |
| Skilled labor | 96 man hours |
| Semiskilled Labor | 96 man hours |
| Materials and supplies | |
| Diesel oil | 288 gallons |
| Gasoline | 72 gallons |
| Powder | 410 pounds |
| Caps | 45 |
| Bits | 32 |
| Steel, grease, oil, wire parts | --- |
| Plant (initial cost) | .232% |

The items have been presented in units of man hours and quantities in order that the unit costs which are existing at any time may be applied. The unit costs have been subject to many variations recently and will probably continue to change rapidly in the future. It should be cautioned that the summary above is not an estimate of the entire cost of removing the rock, but includes only the direct costs of operating the drill boat. These costs apply only to a plant of the proposed size and are not adaptable to all types of craft.

Removing solid rock from below the water surface in the Columbia River is an extremely expensive operation. The nature of the work is such that an adequate plant and careful organization are imperative in order to effect the work economically. The cost of operation is continuous and practically constant whether the rock is satisfactorily broken or not, therefore the unit cost is controlled largely by the speed of operation.

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