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"DRAGLINES AND THE DEVELOPMENT OF THE SINGLE BUCKET EXCAVATOR."

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The development of the Dragline Excavator can be traced from the horse-drawn plough and a scoop-bucket known as a dragscraper.

The horse-drawn dragscraper, being a very cheap and simple form of power excavator, was at one time very largely used in America and Canada for road making and shallow excavation.

In 1904, Mr. J. W. Page, an American, used a scoop or dragscraper in conjunction with a steam derrick. It was such a decided success that the designer and excavator manufacturers, seeing its possibilities, not only improved the original design of scoop but designed a special form of full circle machine to operate it. The machine is known as a dragline, the bucket being dragged towards the machine by means of a rope or line and the cut is taken below the level of the machine.

This single bucket excavator is very similar to the revolving shovel. It has the usual motions of digging, slewing and travelling, but the method of regulating the depth of cut is different.

The main engine on a dragline is fitted with two drums, one for digging, or, in other words, dragging the bucket towards the machine; the other for regulating the depth of cut and lifting the bucket out of the excavation.

The digging rope, instead of passing over the jib head as on the revolving shovel or crane navvy and all machines of the shovel type, is taken out at the front, close to the foot of the jib. The lifting or hoisting rope, which is only called upon to take the weight of the bucket and its contents, is carried over the head of the jib to the bucket.

The jib in large machines is of the lattice pattern, much lighter in construction than that of a revolving shovel, owing to the fact that it has only to take the load due to the weight of the bucket and the material, together with the slewing stresses. The jib, however, of a revolving shovel has to be constructed to take the whole, or practically the whole, of the excavating stresses, not only on account of the digging rope passing over the jib head, but because the bucket arms with the resulting slewing and digging stresses are connected to it. Further, as the loading of the jib head is much less than that of a revolving shovel of equal size and weight the jib can be made much longer; this is a great advantage in dragline work as it enables the bucket to be thrown out further to take a deeper and wider cut.

The bucket is very simply constructed, being open both at the front and top. A renewable cutting lip and teeth are fitted, although in soft easily dug material under water it is better to dispense with the latter.

A set of bridle chains lead from the front of the bucket and connect with the drag rope. The hoisting rope from the jib head passes round a pulley block connected to the bale, which is attached to the sides of the bucket by chains behind the centre of gravity. Another short rope for dumping leads from the bucket arch to a small pulley on the pulley block and connects to the drag rope and drag chains.

When a cut has been taken and the bucket hangs free under the jib head and in position for discharging, it will retain a more or less horizontal position and retain the excavated contents providing tension is kept on the drag rope. When, however, the weight of the bucket and its contents are fully held by the hoisting rope and the drag rope is slacked off completely, the bucket tilts forward owing to the centre of gravity being in front of the hoisting bale. The contents are then discharged from the front of the bucket.

The method of working a dragline is as follows :—

The bucket is lowered into the excavation at the extreme working radius, or thereabouts. The digging drum is then put into gear by means of its steam operated clutch and the bucket is dragged into the material and towards the machine, the thickness of the cut being regulated by the tension on the hoisting rope, the bucket being slightly lifted out of the excavation with the hoisting rope if too deep a cut is being taken or the engines show signs of stalling. When the bucket is full the digging clutch is thrown out and the hoisting clutch thrown in to lift the bucket and its contents out of the excavation. The drag rope is then allowed to run out under the control of the brake so as to swing the bucket towards the front of the jib. At the same time the slewing engines are started up and the bucket is swung round over the dumping point and discharged by holding the bucket up on the hoisting line and lowering out the digging line. This allows the bucket to dump, as previously described. The machine is then slewed back to the excavation and the bucket lowered into the cut again in readiness for the next cycle of operations.

If necessary, the bucket can be swung out from eight to twenty feet beyond the jib head radius, depending upon the size of machine and length of jib, by drawing the empty bucket in on the digging line close to the underside of the jib and allowing it to run out as fast as possible beyond the jib head radius and dropping it at its maximum point of swing.

The speed of operation of any machine is practically equal to that of the revolving shovel of the same weight, the size of bucket in proportion to the cutting pressure also being similar.

A feature of the single bucket full circle excavator is its adaptability for use either as a crane, crane navvy, dragline or as a grabbing machine, and it is now possible to purchase excavators which are convertible for use with any of these excavating equipments. Figures 1, 2 and 3 clearly illustrate adaptability of the modern small size full circle excavator. This is very valuable from the general contractor's point of view, as it enables him to work efficiently with less plant. Another advantage is that when the contract is finished, the contractor has a better chance of obtaining work for his plant with its more universal application.

Most of us are acquainted with the uses of the single bucket excavator for railroad and dock construction, but so rapid have been the strides of these machines that very few excavating jobs of any description are without them in some shape or form.

The latest and largest dragline, illustrated in fig. 4, has a weight of approximately 300 tons. It has a jib 120 feet long and a bucket of 8 cubic yards capacity. These can, however, be varied to suit any particular working conditions ; for instance, a 10 cubic yard bucket can be used in conjunction with a 100 feet jib, or a 5 cubic yard bucket with a jib 160 feet long. The upper revolving framing upon which the main machinery is mounted might well be termed a power station.

Three sets of double cylinder engines are mounted upon it, one of 300 h. p. for digging and travelling, another of 200 h. p. for slewing, and a small set for hoisting the coal or oil fuel into the coal bunker or oil tanks ; the former has a capacity of four tons, sufficient for 8 hours digging. In addition, two steam cylinders are fitted for operating the hoist and drag drums and two steam operated brakes for controlling the free drag and hoist drums. The boiler is of the locomotive type, weighing 17 tons, with a grate area of 48 square feet. The huge size of the machine can also be gauged from the turntable or slewing path upon which the whole of the superstructure revolves, this being 30 feet diameter. The roller path consists of a live ring of rollers mounted between rails of 175 lbs. section, the rollers being spaced at approximately one per 15 inches of the circumference of the path. In spite of the weight and overall dimensions of the excavator, it is so easily controllable that a complete cycle of operations can be carried out in from 40 to 60 seconds, according to the working radius ; in other words, 8 cubic yards of materials can be excavated and dumped in less than one minute.

The machine is supported upon bogies at the four corners, the travelling power being transmitted through the centre of the machine on to all four wheels of each bogie, 16 in all. Its power and stability is such that a load of 25 tons can be safely lifted at a radius of 125 feet. A few years ago such large machines would have been considered impracticable propositions. They are, however, so useful on account of their large outreach and outputs, that they are becoming increasingly popular for many classes of work.

A good average output from the excavator in question is 8,000 cubic feet per hour when employed on canal excavation of suitable depth and width and dumping direct on to spoil bank. The coal consumption, given coal of average value of say 9,000 B. Th. Us., should not exceed 10 cwts. per working hour. A two hours' continuous test run on a machine of this size and type showed a coal consumption of exactly one ton and a water evaporation of 17,756 lbs., equivalent to 7·9 lbs. of water per lb. of coal actual, or, 9·48 lbs. from and at 212 degrees fah. The dragline referred to was a "Ruston" No. 300 equipped with an 8 yard bucket.

Given the conditions referred to above, the cost of excavation should not exceed Rs. 5-8-0 per 1,000 cubic feet.

One learns only by experience what is to be gained or lost by the employment of mechanical excavators, and although it is obvious, by results obtained in this country, that the dragline can favourably compete with hand labour, the former should not be employed until the purchaser has received expert advice as to the most suitable machine for the job; also he must be certain of constant supplies such as coal, water and general stores.

The size of machine most suitable for various workings is governed chiefly by—

(*a*) The nature of the material.

(*b*) The depth and width of cut.

(*c*) The distance from centre line of cut to centre line of spoil bank.

(*d*) The height of spoil bank.

The former will determine the minimum cutting effort to be used. For example—

4 to 6 tons is suitable for material up to clay of medium hardness.

8 to 10 tons is suitable for stiff clay.

12 to 20 tons is suitable for boulder clay.

20 to 30 tons is suitable for heavier material, such as limestone and heavy iron ore.

The output depends also upon the size of the bucket, which again is governed by the nature of the material to be excavated; thus a machine having 6 tons cutting effort is most efficient with a bucket of ¾ to 1 yard capacity, and if 20 tons from 2½ to 3½ cubic yards, to give approximate examples. With the standard dragline, such as the No. 6 "Ruston" illustrated, and with the length of jib shown as a crane navvy, the machine has sufficient stability for 6 tons cutting effort on the bucket teeth, or, if used as a crane it will lift a load of 6 tons.

Dragline buckets vary in weight according to the material to be excavated ; for instance, a 2 cubic yard bucket designed for excavating sand or loose earth, crushed stone, etc., will weigh approximately 3,000 lbs. These buckets are used without teeth.

For general excavation work the same bucket will weigh approximately 4,900 lbs.

For excavating hard material the 2 cubic yard bucket will weigh approximately 6,000 lbs.

For excavating the hardest material that a dragline will handle, such as boulders and blasted rock, the same size bucket will weigh approximately 7,100 lbs.

If necessary, the dragline machine can use the clam-shell or orange-peel bucket, by having the drag drum and hoist drum the same diameter and running at the same speed, or by re-arrangement of the hoist rope from jib head to bucket. The dragline bucket is, however, more completely under the control of the operator and digs harder material than either the orange peel or clam-shell bucket. It is when the digging is very deep that the dragline bucket is at a disadvantage.

Draglines are invariably used when the excavated material can be deposited where it is to remain. Should the working radius of the dragline be insufficient to do this, it is obviously advantageous to use the revolving shovel and load wagons for transporting the excavated material away from the machine ; always providing, of course, that the cut is dry. Should it be found necessary to deposit the material, say 200 feet away from the cut, or more, and the dragline is the only machine available, the material is deposited at a convenient distance from the cut and pulled to the required site by a tower excavator or transporter, allowing the dragline to make a second cut over the ground originally occupied by the spoil.

The cost of excavation depends very largely on the lay-out of the job. Any improvements which will reduce the labour required on or around the machine, decrease the fuel or current consumption without lowering the output or increasing other costs, and also incorporate in the machine, design, workmanship or materials that will reduce repairs and upkeep, should be seriously considered.

The most recent improvement is the substitution of self-laying tracks, more usually called caterpillars, for flanged wheels and rails.

Flanged wheels and rails involve much time and labour in laying the necessary sleepers and rails and lev.lling the ground to receive them. Consider, for instance, a machine of medium size which travels forward about twice an hour. The average time taken for each operation is about six minutes, a total loss of twelve minutes per hour or 20 per cent. of the working time. Also about twelve coolies would be employed.

With caterpillar tracks only one or two coolies are required about the machine and travelling time is reduced to two or three minutes per hour.

The caterpillar travelling gear is particularly valuable when the working face is shallow and it may be necessary to travel three or four times in the course of an hour. Also, the machine can be more readily and quickly travelled from one part of the works to another when occasion requires.

Caterpillars add from 20 per cent. to 35 per cent. to the weight and consequently cost and price of a machine, therefore it is of no use adopting them unless more than a corresponding saving is effected in the working costs. Generally speaking the use of caterpillar tracks will save their cost over and over again.

Figs. 1, 2, 3 and 5 show machines fitted with this type of travelling gear.

The tracks are driven from the main engines through the centre post of the machine and thence by means of gearing to the driving wheels of each track.

Each track is separately driven, which enables the machine to be readily steered in any direction. By driving one track only and scotching the idle track it is possible to turn the machine in practically its own length.

The smaller machines are only fitted with one track on each side (see figs. 1, 2, and 3) but the larger machine shown in fig. 5 has two tracks on each side to provide increased flexibility. All four tracks are separately driven and each track is pivoted on the axles.

In addition to the flexibility of each track for travelling over uneven ground, two of the tracks upon this larger machine are fitted to a long equalising beam pivoted at the centre of the framing to obtain a three point suspension.

Adjusting screws are fitted to each end of the beam immediately above the tracks. When the machine is travelling, the screws are slackened off as much as possible so that the beam is free to oscillate. This gives a three point suspension and reduces or altogether prevents twisting stresses in the framing due to travelling over uneven ground. When the machine is in the required position for digging, the adjusting screws are screwed hard up to the framing so as to give rigid support to all four corners.

Electrically operated excavators are becoming increasingly popular for certain classes of work, particularly open-cast mines which have cheap electric power available. Their design involves the use of motors in place of steam engines for the various motions, the provision of an electrically operated air compressor to operate the power clutches by means of compressed air, and in the larger sizes, contactor. gear or jamming relays to control mechanically the current to the various motors. The electrically operated machine is rather more costly than steam, or machines equipped with internal combustion engines in the initial outlay.

Excavators equipped with internal combustion engines are invariably used where the water is unsuitable for boiler feed or the supply is insufficient for steam operated machines.

The output per lb. of fuel from these machines is considerably higher than from the steam and electrically operated machines, and it is safe to assume an average output in average material of 25 cubic feet per lb. of fuel.

The following are fairly representative outputs under average working conditions with various sizes and weights of dragline excavators.

Bucket capacity.	Weight of Machine. Caterpillars.	Output per hour in cubic feet.
$\frac{3}{4}$ cubic feet	25 tons	1,100
$1\frac{1}{4}$,, ...	45 tons	1,850
$1\frac{3}{4}$,, ...	90 tons	2,500
$2\frac{1}{4}$,, ...	100 tons	2,900
$3\frac{1}{2}$,, ...	125 tons	4,300
5 ,, ...	175 tons rail wheels	5,500
8 ,, ...	300 tons rail wheels	8,500

No average cost of excavation can be given as it varies with practically every job, according to the nature of the material, the output obtained or required, the cost of labour on and around the machine, the price of fuel or current and chiefly the general organisation.

Referring to the development of the single bucket excavator, the earliest excavating machines recorded were introduced for removing material from below water level. Descriptions and illustrations of these can be traced back over 300 years, but land excavators are of comparatively recent introduction. Practically all of the under water excavators and a few land machines are of the dredger or endless bucket type, but this paper confines itself to the dragline and the machine commonly known as the crane navvy or revolving shovel.

The first steam navvy was designed by William Otis, of Boston, U. S. A., in 1839, and built by John Souther, of the same city. It was a very crude machine compared with those of to-day, but the fundamental principles of our present day single bucket excavator, were embodied in its design and construction. The excavating gear consisted of a jib carrying a bucket on the end of an adjustable radial arm. The digging power was communicated to the bucket by means of a chain leading from the main drum over a pulley at the end of the jib, and the bucket was constructed with an adjustable tie from the bucket to the bucket arm to enable the dip or angle to be varied to suit the material to be excavated. Teeth were also fitted to the cutting edge, and the contents of the bucket were discharged by means of a door fulcrumed at a point forward of the door itself, so that the door mechanically closed and relatched itself, when it was lowered preparatory to taking another cut. Means were also provided for racking the bucket in and out of the point of suspension to vary its cutting and discharging radius. All these movements are included in modern excavators, but are, of course considerably elaborated and improved, and instead of one engine being employed for driving all the motions, as on the Otis and a few later machines, three sets of engines are usually fitted (two on the Dragline), in addition to auxiliary engines and steam cylinders, or compressed air in the case of electric machines, for operating the various clutches, etc.

The next machine was the Dunbar and Ruston Steam Navvy introduced by Ruston Proctor & Co., of Lincoln, England, in 1875. Fundamentally it was similar to the Otis but of sounder design and construction. It was employed in the construction of the Manchester Ship Canal, over seventy of these machines being used in the excavation of this waterway. A proof of the sound construction of the Dunbar and Ruston is found in the fact that some of these machines, over forty years old, are still in use. One of the characteristics of this machine was the fact that the excavating gear could only be slewed or revolved through half a circle. The slewing motion was transmitted from the drum to a turntable at the foot of the jib by means of two chains which led from the drum and passed round the turntable to which they were anchored.

The latest type of limited swing machine is the Railroad Type Shovel. (Fig. 6). Fundamentally it is similar to the one described, but great advances have been made in the design and construction to improve the working speed, mobility, power and ease of handling to make it more efficient.

Railroad type bogies are fitted, complete with oil axle boxes and springs ; these make it possible to travel the machine over most modern main lines without having to dismantle the machinery beyond detaching the excavating gear and lowering the " A " frame.

The limited swing is, however, a disadvantage in that wagons can only be loaded alongside the machine and it is only possible to excavate at the front and to a limited extent at the sides.

The excavator which overcame this difficulty was the revolving shovel or crane navvy. This machine, like a locomotive crane can swing through a complete circle and, consequently, can also dig in any position around its centre, as with the dragline. The machine will cut equally well in any direction about its centre.

The speed of operation varies from one to three complete cycles of operations per minute depending upon the size of machine and length of jib.

The crane navvy is in use on practically all contracts and schemes in which excavation is involved.

About 90 per cent. of the world's iron-ore is being excavated by these machines.

Approximately 95 per cent. of the raw material for the manufacture of cement is being obtained with them in England.

Most of the copper ore in America, Spain and the Belgian Congo is being mined by them.

Different problems are encountered, naturally, where mining work is concerned. Applying equally well to surface as well as underground mining ; many knotty problems have had to be solved.

Air operated shovels are employed for underground mining, the oldest air-operated shovel on the market being the Hoar Shovel, designed and built by the Hoar Shovel Co., Inc., Duluth, Minn., U. S. A. this machine has become very popular throughout the United States of America. It has a marked advantage over its competitors, in that the design follows fairly closely that of the surface steam shovel, and it can be applied to surface as well as underground work when occasion demands. Also, it will handle virgin ground in the original excavation where other types can only cope with loose materials. This adaptability means that the machine can be used by the mine operator or contractor wherever he has materials to move. In this way the full value is obtained from the machine, and it becomes a universal worker.

The designers of this small and compact machine obviously had in mind the idea of completely eliminating hand digging and loading underground, and also lessening the very wide margin between the hand worker and the smallest of the excavating machines for surface work.

This shovel is built to suit any gauge of track, and is light enough to be raised or lowered in any mine cage ; also in a very few minutes it can be stripped to pass through an opening of 42 inches by 42 inches. Dipper capacities range from 4 to 6 cubic feet.

Undoubtedly the smallest mechanical excavator on the market, it is very practical, and operates at a good speed, and performs steady digging and loading at close quarters in the same powerful way that the steam shovel and dragline operates on the surface. The shovel is the outcome of fifty years' experience of mining conditions possessed by its patentee, Captain Hoar.

The operating of this machine differs from that of the standard steam shovel in that there are no brakes or clutches to use, all the mechanism being directly connected through gearing to the engines, these latter being instantly reversible and under constant control through the hand levers.

The enormous progress that has been made in the development, and the amount of labour put into the development and perfection of the mechanical excavator during recent years, from the time of the old "Tower" Navvy down to the design of the latest Draglines and Steam Revolving Shovels, can hardly be realized except by those who have had the actual handling of these machines. Perfection, however, has not been attained, and there is still room for progress. No doubt civil engineers in this country, who are engaged in moving large quantities of earth, trust that that progress will be made in their lifetime, in order that they may benefit from it.

The requirements of civil engineers, in all parts of the world are studied very closely by British and American mechanical engineers who associate themselves with every movement for progress. To the mechanical engineer, the present day machine appears to be as near perfection as possible, but the civil engineer will not admit that this is so, consequently progressive mechanical engineers do not remain still under present conditions.

There is still the idea abroad that excavating machinery means throwing men out of employment. Sometimes it does, for short periods, but in practically all cases it means a larger output from the contract and diverting the displaced labour on to other and more congenial work. With regard to Irrigation for instance, machinery will enable the work to be carried out in probably half the time and result in putting the land into cultivation several years earlier.

In conclusion, the author hopes the paper will prove instrumental in increasing the knowledge of the general design and capabilities of an increasingly popular and useful machine for almost all classes of excavation.

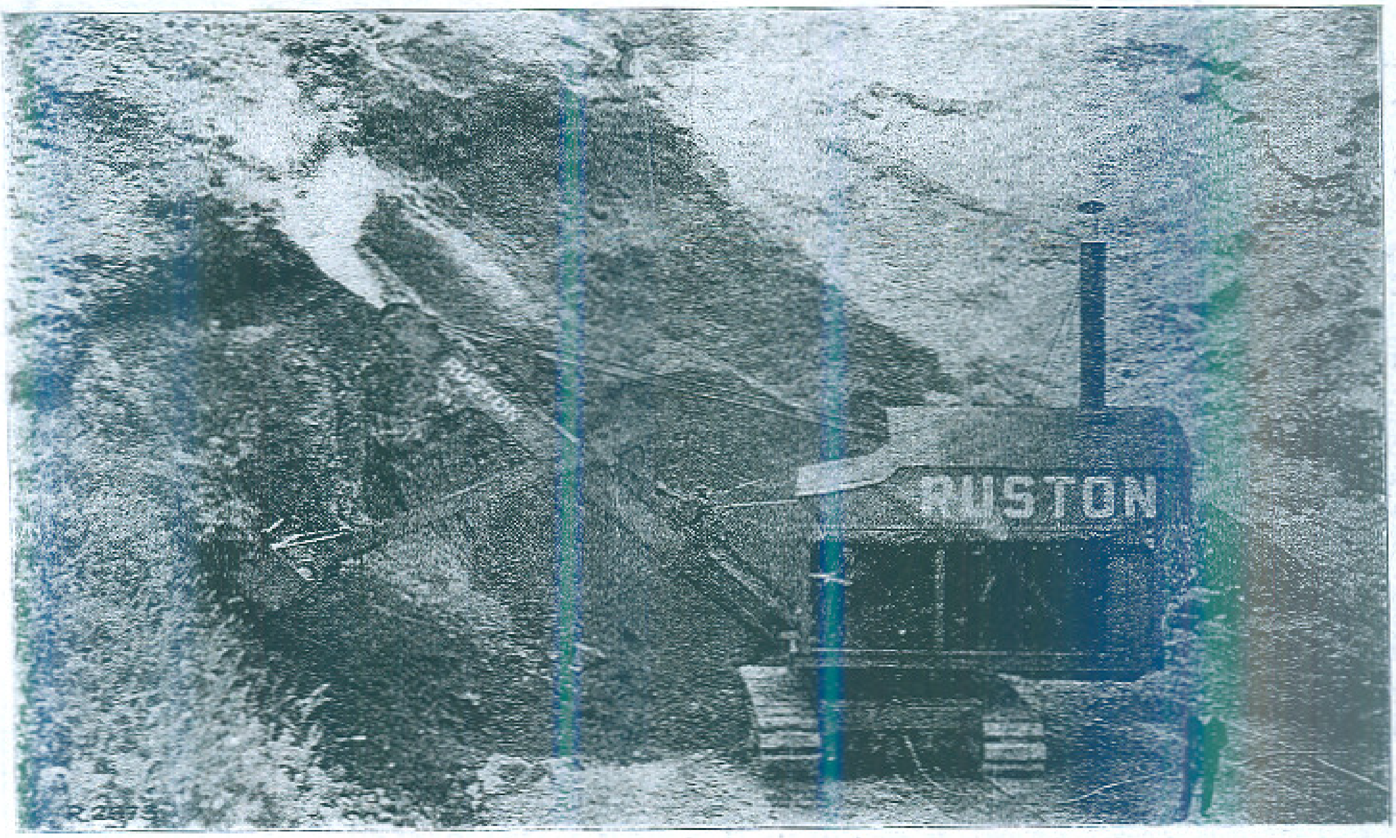

Fig. 1. AS A REVOLVING SHOVEL.

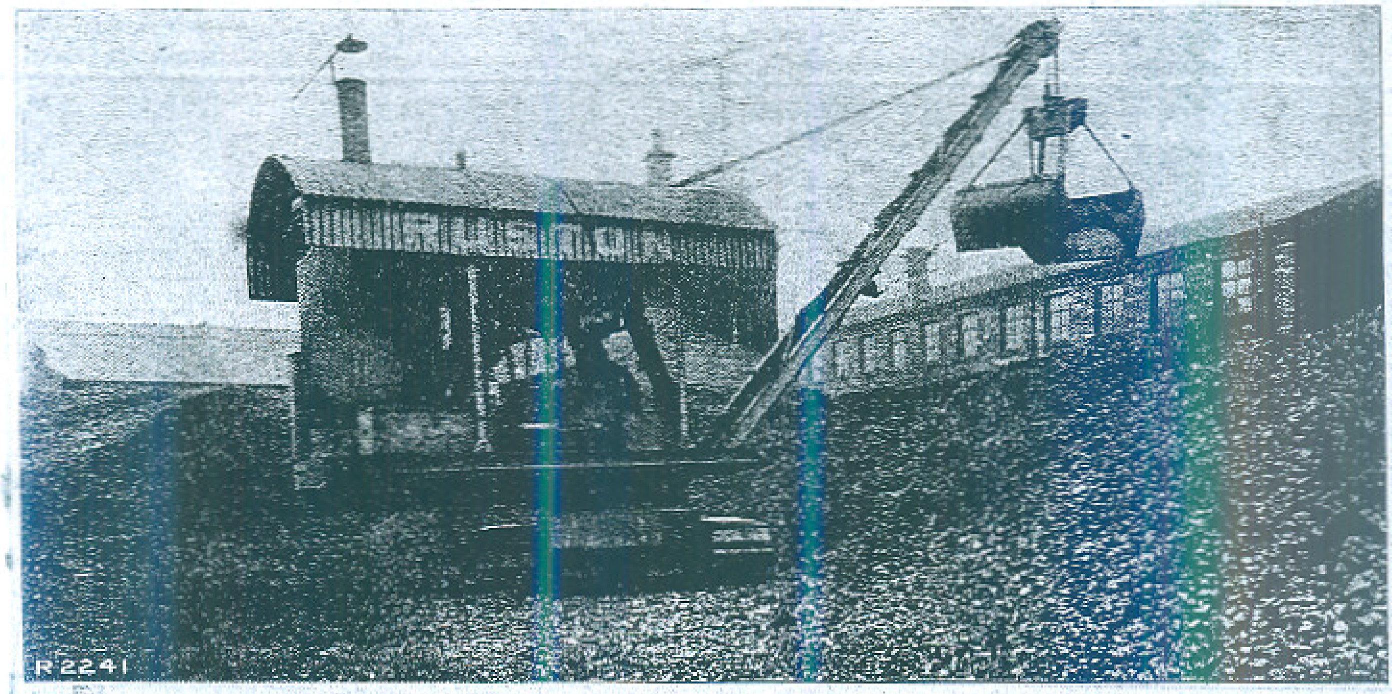

Fig. 2. AS A GRAB.

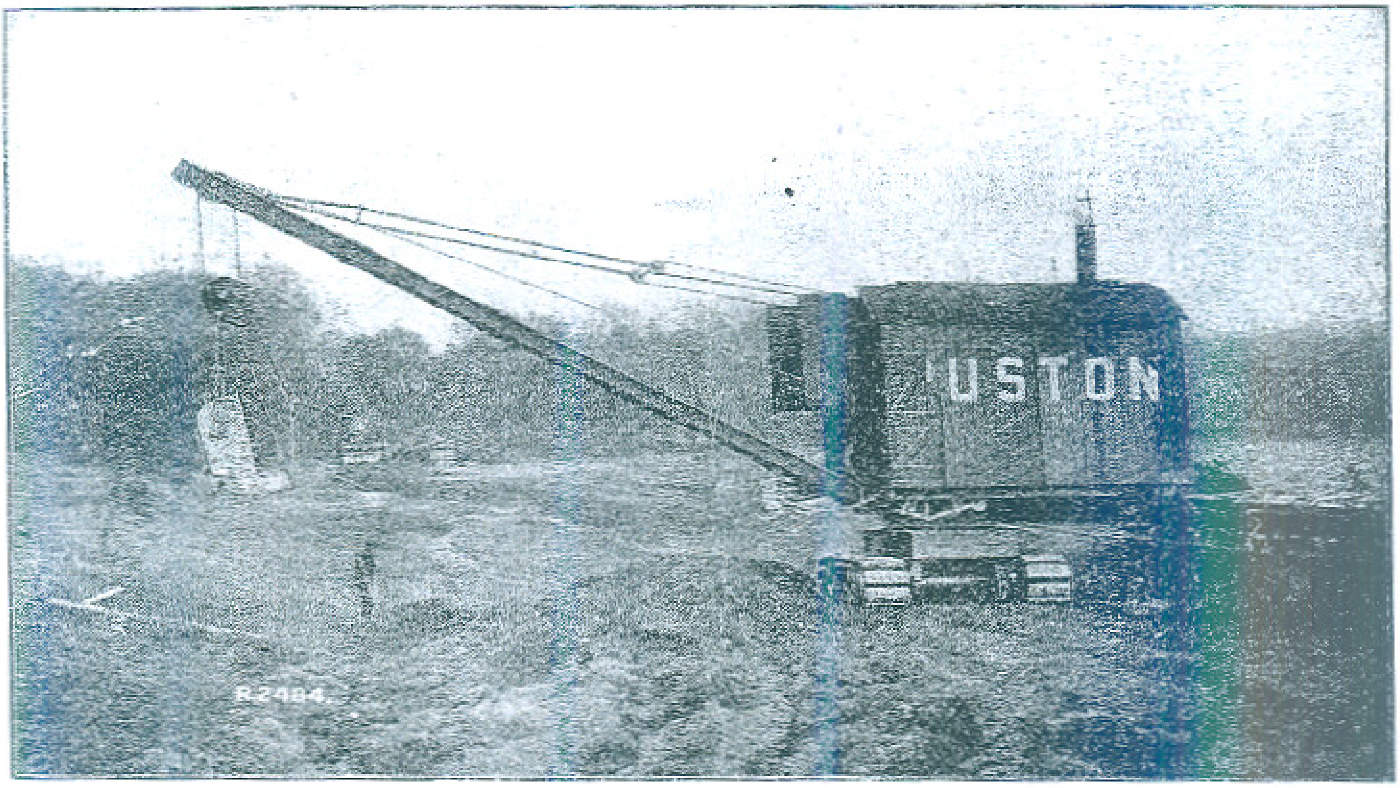

Fig. 3. AS A DRAGLINE.

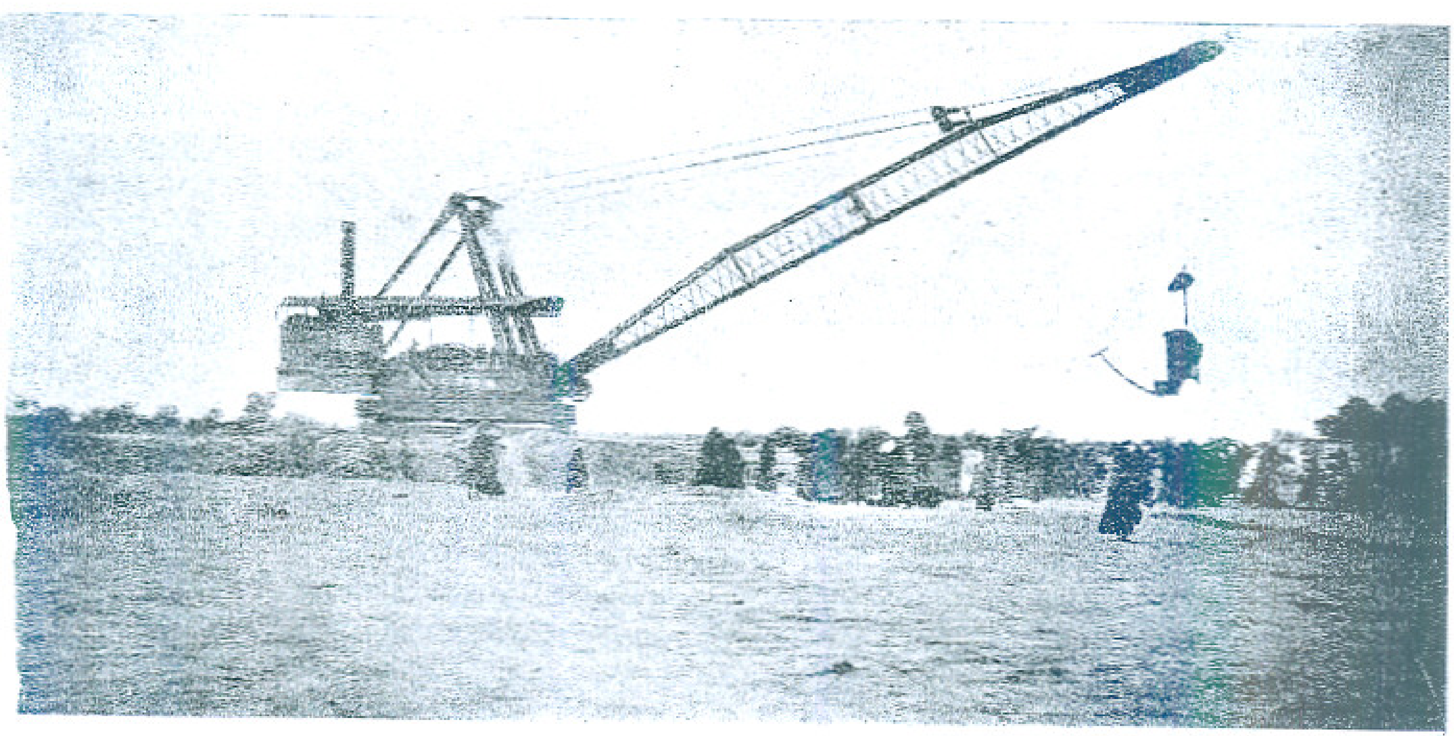

Fig. 4. A 300 TON DRAGLINE EQUIPPED WITH 8 CUB. YD. BUCKET AND 120′ 0″ BOOM.

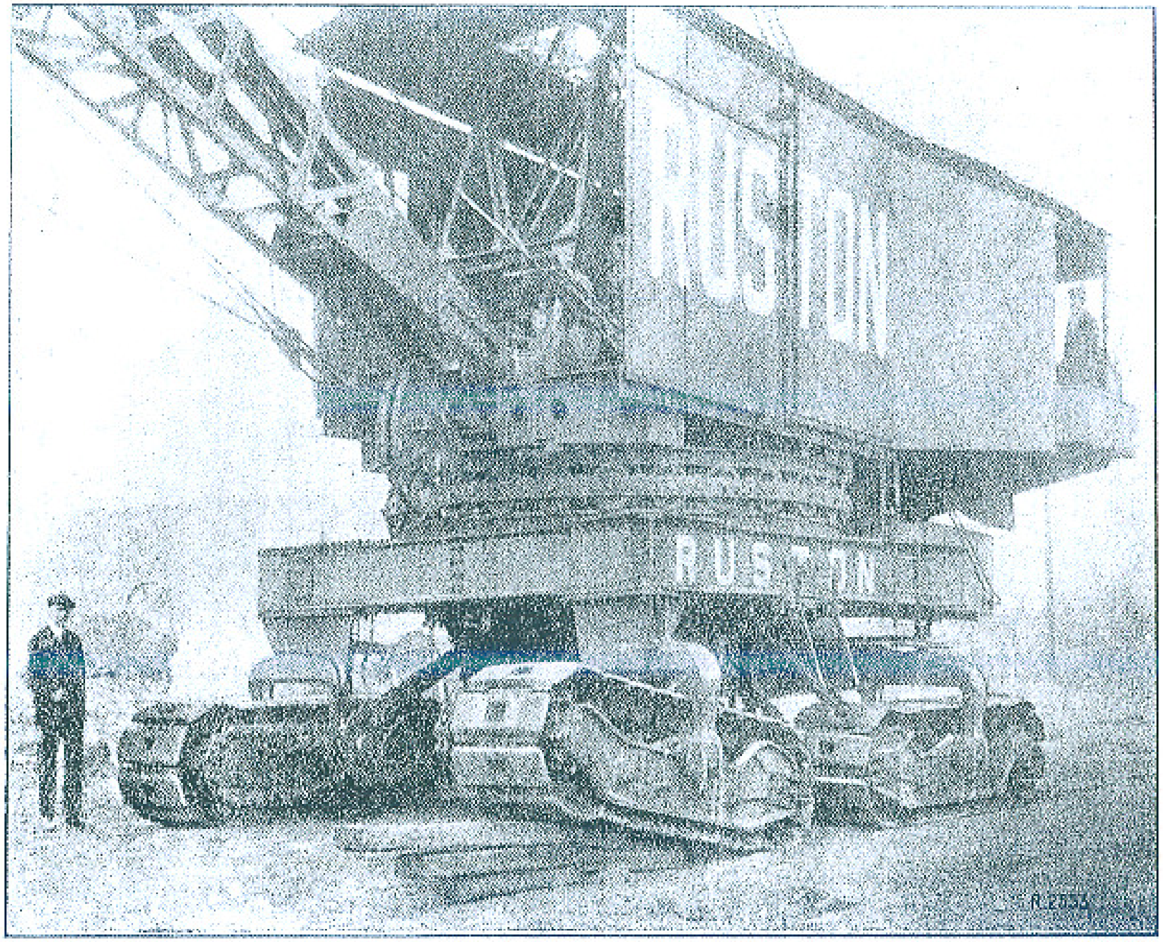

Fig. 5. THE LARGER SIZE DRAGLINE MOUNTED ON DOUBLE CATERPILLAR TRACKS.