Thos. Smith & Sons, Limited ; and the Thew Shovel Company. He wishes to thank also the numerous excavator users whose machines are illustrated and who have kindly supplied working information and costs.

The Paper is accompanied by five sheets of drawings and fifty-two photographs, from some of which the Figures in the text and the seven half-tone page-plates have been prepared.

Discussion.

The Author, in introducing his Paper, showed a number of lantern-slides, followed by a cinematograph-film of the "walking" dragline.

Mr. J. R. Davidson observed that the Paper clearly showed that the dragline excavator provided engineers with a convenient and economical means of excavating material of all kinds, and that it possessed, for a great variety of purposes, marked advantages over other types of excavators. As the Author pointed out, one of the main reasons why the dragline had those advantages was that it stood for its work on the original surface of the ground, above the material to be excavated, and thus avoided having to work from the bottom of the excavation. That feature gave the additional advantage that, if the material being dealt with were taken away as spoil in wagons, the wagons themselves moved on undisturbed ground. Another valuable feature was the ability of the dragline, within the limits imposed by the radius of the boom, to transport the material over a considerably greater distance than most other forms of excavator.

Fig. 2 (p. 14) was very interesting. It clearly showed the influence which the class of material being dealt with had on the maximum depth to which excavation could be carried out, but he would suggest to the Author that some information as to the depths for maximum economy of working would be very useful. He would take the case of a standard dragline with a bucket of 1-cubic-yard capacity, working in dry loam or ballast and delivering into wagons, which meant that the tipping-point was, say, 10 feet above the level on which the machine stood. In such a case as that, what was the most economical depth for working, and within what range on either side of that figure would the most economical price apply ?

He agreed with the Author as to the great importance of suiting the

type of bucket to the particular job to be dealt with, and also the necessity of eliminating superfluous weight from the boom and its fittings—in fact, from all the moving parts. At the same time care had to be taken, as he was sure the Author would agree. Some of the welded lattice booms seen on draglines appeared to be extremely light. They were subject to considerable strains and shocks during working, and the tendency to increase the motive power used and the speed of working also emphasized the need for ample strength without undue weight in the boom.

The Paper contained some valuable Tables with regard to working costs, but he would suggest that it would be more convenient if the units of cost could be the same; in Table I (p. 20) the costs were given in pence and in Table II (p. 21) they were given in cents. He realized, of course, that it was not fair to compare the costs in the two Tables, because the work might have been done under totally different conditions.

The illustrations in the Paper showed clearly the ability of the machine to work in ground where there were stratified layers of different materials, and the way in which an expert operator could separate the different classes of material that had to be dealt with was extraordinary. The dragline had another very valuable feature, namely, the ability to make a nearly vertical cut. The Author referred to the advantage of that in getting clay for brick-making, in that a mixture of the different layers was obtained; Mr. Davidson might add that where embankments were being formed from stratified alluvial deposits it was a great advantage at times to be able to get a cut the whole depth, so as to obtain a more or less uniform mixture, instead of getting layers of different classes of material, which would tend to produce a bank which was not so strong as a thorough mixture would give.

He was interested in the question of the maximum size of dragline. The Author said in his Paper, in the section dealing with buckets (pp. 10 *et seq.*), that the largest machine had a 20-cubic-yard bucket, but at the end of the Paper, where details were given of the world's largest dragline, a 15-cubic-yard bucket appeared to be the largest. He believed that the first statement was correct, and that the capacity of the largest bucket was 20 cubic yards.

He wished to refer very briefly to one development of the dragline which was not mentioned in the Paper. It might be held that strictly it was not a dragline, but he thought it was, as it was a single-bucket machine operated with hoisting rope and drag ropes. He referred to the tower-scraper, where the bucket, instead of being suspended from the end of a boom, was suspended from a traveller running on an overhead cable. He had four machines of that type working at present, with which it was possible to excavate over a width up to 800 feet. The cable was slung between two towers, the one at the end where the material was being tipped being, of course, very much higher than the anchor-tower. The two towers travelled on parallel lines of rails and straddled both the

area to be excavated and the area on which the material was being tipped. The largest machines which were working on the two jobs with which he was connected were forming embankments over 50 feet in height, and were electrically operated. Those machines had buckets of $3\frac{1}{2}$ cubic yards capacity, and it took about 2 minutes to complete the cycle of operations. In order to employ the tower-scraper it was clearly necessary to have the work confined within a comparatively small area, as the machines could not be moved a great distance. The amount of material to be moved within that area had to be sufficient to make it worth while to go to the expense of erecting such plant. For certain purposes, however, he believed that that type of machine offered a field for considerable development.

Mr. Oscar Borer rather joined issue with the Author on the point of the dragline having originated in the United States, because in the office of Messrs. Priestman Brothers there was a sketch made on an envelope by Mr. Philip Priestman and Mr. Crowther when they were dealing with the problems of the Ouse Drainage Board in 1922-1924, and the sketch showed a crane mounted on wheels with something indicating a dragline attachment, with which the scraper scoop was to be used from the base of the jib instead of being lifted from the jib-head, the whole machine being drawn by a tractor. There was a development of that in one of the old machines of the Ouse Drainage Board which had passed to the ownership of the Great Ouse Catchment Board; it had been built in 1926, and had wheels in the front portion and caterpillar tracks behind. That machine was still working. Many of the catchment boards had pressed dragline manufacturers in Great Britain to keep on developing their machines, and had insisted that the machines should be as light as possible. In the last 10 years the $\frac{1}{2}$ -cubic-yard machine had been developed from having a 28-foot jib to having a 50-foot jib, and for ordinary commercial purposes that was the limit, but the catchment boards had insisted that 60-foot jibs should be available.

He was very interested to see in the Paper a reference to the fact that the weight of the bucket and its load should be about two-thirds of the tipping or overturning load. That was a point which catchment boards continually bore in mind, and every time they found they had a little more stability in hand he was afraid that they were guilty of insisting upon the jib on the next machine being increased in length.

He had been trying for some time to get a further development in the way of draglines, and certain of the dragline manufacturers in Great Britain were specializing in meeting the demands of the catchment and drainage boards. It should be noted that the machine had to bring its load within range of the lifting power at the base of the jib, and so the question arose as to why the load needed to be lifted at all. His board had therefore set to work to see whether they could develop such a machine. Their first development had been to use an ordinary $\frac{1}{2}$ -cubic-yard machine, which had a standard jib of 32 feet, and to have that jib increased in length

to 40 feet. Then they had decided to use a scraper scoop, so that instead of lifting $\frac{1}{4}$ cubic yard they would drag $\frac{1}{2}$ cubic yard. That form of development was, however, suitable only for shallow-river conditions.

Mr. Borer then showed three lantern-slides illustrating the machine which his board had developed for doing a deferred maintenance job, where there was no necessity to cut very deeply but where it was mainly silt that had to be pulled out. The machine did that, and also pulled the material to the side. In so far as the scraper scoop was used, it could only be pulled on to the bank in front of the machine. It became necessary for the machine itself to stand some 10 feet back from the bank. That setting back of the machine was offset by the bigger outreach obtained from the 40-foot jib. The scraper scoop was slung right across to the opposite bank and the material dragged back across the river and deposited in front of the machine. The advantage was that $\frac{1}{2}$ cubic yard was handled each time instead of $\frac{1}{4}$ cubic yard. A further development took place in connexion with the high banks along the Tidal River. There a normal 12-cubic-foot machine with a 40-foot jib was all that could be used on account of the weight of the machine itself on the banks, which consisted only of silt. The catchment boards generally had increased the 40-foot jib to 45 feet, but as it was necessary on that job to secure an outreach of from 70 to 75 feet, a special jib 55 feet in length was constructed, making full use of electrically-welded designs. On the low tide a 1-cubic-yard scraper scoop was used which hauled the material by the side of the bank out of range of the high tide; then when the tide rose the scraper scoop was taken off and the bucket put back, and the machine continued to lift the material and to put it on the top of the bank. He did not think that it would be possible to stretch things much further than that, because the position had been reached when it became almost impossible to control the swinging of the machine, due to the great length of jib, except at very low speeds.

The Author referred in his Paper to the use of the dragline afloat. The experience of his board with a dragline afloat had not been a very happy one. Generally speaking, in the operation of a dragline the scoop was loaded by being pulled into the working face, and when it was loaded it was tilted up and lifted. In the case of dredging along a river, however, the machine was dredging from deeper water into shallower water, and therefore there was nothing for the drag scoop to pull against. His board had tried to use the machine afloat, but it was quite useless in the case of soft material, and they had to go back to using it as a grab. In one case on the river Trent it had been used, but there a fairly firm gravel was being handled, and the gravel held until the drag scoop managed to cut through it, but anything softer than that was simply pushed under the pontoon. Therefore when a dragline was used afloat it turned itself into an ordinary grab dredger, and the cost was doubled.

His experience had been that, whereas a diesel-operated machine

might be used for dragline work, it was extremely doubtful whether it was an economical machine to use for grabbing. For grabbing work, where there was really hard work to do, his experience was that the steam machine could not be beaten. It was true that three men had to be in attendance instead of two, but that was of no consequence, because when there was a pontoon afloat there had to be a deck-hand to look after it, and he might just as well assist in keeping up steam. With good steam coal no difficulty was experienced in keeping the steam dredgers working well. He was surprised to see the statement in the Paper that the net working time, with steam as the motive power, averaged only from 65 to 75 per cent. of the gross working hours. His board had had no difficulty whatever in keeping steam machines working continuously, and when hard digging was in progress steam machines had every advantage over diesel machines: when it was necessary to use the full purchasing power that could possibly be obtained for closing the grabs, a steam-driven machine stood up to the work better than a diesel-driven one.

The Author referred to the increase in working radius; the increase of the boom radius had helped his board to solve one of their problems. The old practice in fen drainage was to work by hand and to deposit half the spoil on one bank and half on the other; it had been regarded from time immemorial as the right of drainage boards to do that, and they paid no compensation. The dragline had originally introduced a complication, in that all the material had to be deposited on one side, and the owner of the land on that side naturally objected. The increase of boom radius made it possible for a skilled driver to deposit part of the spoil on the other side of the stream or ditch, although it was only now and again that an operator was sufficiently skilled to swing his machine out and to dump half the material on the opposite side.

Mr. H. A. Henry observed that the Author and the previous speakers in the discussion had rightly viewed the subject of the dragline in its broadest aspects, but to a British contractor's engineer one of the principal points of interest about the dragline was the way in which it had revolutionized excavation work in Great Britain. Previous to 1920 or thereabouts, mechanical excavation work had been more or less limited to the steam-shovel or to the crane grab, and, owing to the limited use of the steam-navvy, only the larger firms of contractors owned such plant. Since the evolution of the dragline, and particularly of the smaller types, not only had the large contractors found it essential to operate draglines, but even the very smallest contracting and building firms would find it impossible to compete without making use of the dragline and of its offshoot, the skimmer. If they had still been limited to the shovel, even in its up-to-date form, a tremendous amount of excavation work would still be carried out by hand instead of by machine. For instance, previous to 1924 his own firm owned one or two steam-shovels, but they were em-

ployed only on big works of a heavy engineering nature. Now they operated approximately fifty draglines as compared with only six shovels, and the great majority of the draglines were in use, not on real constructional engineering works, but on small road, drainage, and building-foundation contracts, which previously would have been carried out by hand.

Mr. Davidson had already spoken of the cableway-draglines. Those tools were, of course, limited in their application ; in other words, it was necessary to have a job to suit them, but where there was not less than, say, 200,000 cubic yards to be shifted a distance within their span, which might be about 800 feet or so, there were no better machines for the job than cableway-draglines. The cost of laying the very heavy tracks necessary for the machines, together with the cost of erecting and dismantling the towers, necessitated a fairly large amount of excavation in order to absorb the initial charges. It was interesting to note that the rope renewals cost considerably more on cableway-draglines than on ordinary draglines, the reason for that being that the ropes were dragged along the ground much more than was the case with orthodox machines. The cost of rope renewals varied greatly, depending on the nature of the soil being dug ; it might range from $\frac{1}{4}d.$ per cubic yard in normal conditions to $1d.$ per cubic yard where the soil was of an abrasive character.

The Author had mentioned how the dragline could be used with efficiency for rehandling excavated material. A further example of its use in that way was when a soft material, such as mud, was delivered at a tip in rail or road vehicles. It was then found very difficult to maintain a road or a railway on the soft material in order to tip direct on to the bank. The dragline, standing on firm ground alongside the tip, made a small gullet adjacent to the road or railway, into which the vehicles tipped their load, and the dragline then dug the soft material and threw it up on to the tip. That method of forming a bank or tip with soft material saved a great amount of money, which would otherwise be spent on platelaying or on the maintenance of roads.

Mr. F. W. Ireland observed that the development of the dragline in the last few years had been wonderful ; it was now extremely efficient, and its users tended to take it for granted. The Paper, however, tended to make them consider whether they were utilizing the plant with the greatest efficiency, particularly, he thought, in regard to changing the bucket. The bucket was a part of the dragline which had been developed considerably, due mainly, he thought, to welding having been utilized a good deal in recent years, but he still felt that there was room for improvement. When a dragline was digging gravel, for instance, it did not appear to fill the bucket to the advertised capacity, but only to the extent of about 60 or 70 per cent. of that capacity. It was possible that buckets made to better design would hold more material in proportion to the advertised capacity, and it might also be possible to design a bucket in

which sticky clay would not accumulate and require the attention of the banksman.

The tower-scraper had already been mentioned. Except under very favourable conditions, it struck him as being a rather expensive machine to use for excavating. It was, he thought, very expensive in first cost, it took a long time to erect, and the track was expensive. He thought a comparison of costs as between a tower-scraper and a diesel-engine dragline would be of interest. A disadvantage of the tower-scraper seemed to be that it did not travel very quickly as compared with its digging powers, and that meant that there was a tendency to get a large accumulation of spoil in one spot, which was not required in a bank. He thought also that when men were paid on the bonus system there was a tendency for spoil to accumulate still more, because with more travelling there was less digging !

There were other forms of excavators which were to some extent superseding draglines nowadays, where the conditions were suitable, and possibly at some future date comparisons of costs with those might be available.

Draglines were now being much used on big irrigation works. The Author mentioned in his Paper the Sukkur barrage in India, which gave a tremendous scope for the use of draglines. As far as he remembered, in that area there was a rather light soil and the conditions were very dry, and the Author quite rightly said that steam could not compete there with diesel drive. He had not had actual experience of the Sukkur Barrage scheme, but he had had some experience of works on a canal in south India, and it was found that coal could not very well be used there. It had to come about 1,000 miles and was of extremely poor calorific value, and water was sometimes difficult to obtain. Another factor to be taken into consideration was that coal and petrol tended to disappear, as they had a marketable value in the bazaar, whereas diesel fuel had not much marketable value there. In the case of the canal in south India to which he had referred, he thought that about 90,000,000 cubic yards of soil had been shifted. Two diesel-electric machines were used, with caterpillar tracks, one working down each side of the canal, and they did very good work. The cost was a little high, but in a country like India there were difficulties which added to costs. An interesting point was that until 1918, although the machines were obtainable, they could not compete with coolie labour ; after the war, however, coolie wages were increased and then the position was altered. Excavating work in India could be compared with coal mining in Great Britain ; it was a staple industry, and when draglines were adopted a great many coolies were thrown out of work.

He did not think that there was in the Paper any comparison of the output and costs of diesel draglines and steam draglines in Great Britain. It was possible that under present conditions a return might have to be

made to steam if diesel fuel were difficult to obtain. Some years ago he had had the opportunity of seeing steam and diesel draglines working side by side, and the diesel dragline gave about 20-25 per cent. greater output in a shift. He did not remember how the costs compared, but it would appear that the diesel machine would be better in that respect.

Mr. H. C. Erith said that 4 years ago he had seen the 6-cubic-yard dragline shown in *Fig. 11* (facing p. 26), and he had been interested to see that the Albert canal in Belgium had been mainly excavated by a very large continuous-bucket excavator. Such machines were very largely used throughout the Continent, and, whilst there were very large excavating jobs in the United States, it was well-known that the brown-coal industry in Germany was greater than any other excavating job in existence. One concern alone had thirty-six different machines, the average weight being 700 tons, and they were excavating a prodigious quantity of material, both very dense overburden and the brown coal or lignite itself. For that class of work the continuous-bucket land-dredging machine was absolutely universal, and he was very much impressed with the land-dredger in various other types of work. Curiously enough, however, it had never been generally adopted in the United States. The leading Continental firms made dragline excavators, but they all supplied multi-bucket excavators for the brown-coal industry.

He was very interested in the "walking" dragline, which he knew had been made in America for 27 years, from the small sizes such as those of $\frac{3}{4}$ -cubic-yard bucket capacity, up to the 15-cubic-yard machine. The lifting and tilting motion known as "walking traction" was very ingenious, but he could not help thinking that that variation of the tractor motion was a somewhat similar case to the fluid flywheel for motor-cars, in that it was an ingenious and useful talking point for a salesman, but was not really of great importance. It was shown throughout the Paper that even the largest machine could be furnished with the ordinary crawler or caterpillar tractor.

He wished to draw attention to a Lecture delivered to the Students of The Institution by the late Sir Henry Japp, M. Inst. C.E., in December 1934*, which was prepared from the impartial standpoint of the user and covered the whole range of excavators of every kind. It would be within the memory of most of the members, but it was a Lecture which was very well worth referring to. There were, of course, many cases in which draglines had to be used, as, for instance, the ironstone deposits mentioned in the Paper, where the surfaces were undulating and in pronounced steps, so that the earth cover could be removed by draglines without disturbing the ironstone underlying it.

Fig. 20 (facing p. 34) showed a crawler dragline working an irregular and very steep face of Fletton clay at Peterborough, but in the same area

* The Institution Lecture to Students, 1934-35. "Modern Methods and Plant for Excavations." The Inst. C.E., 1935.

a multi-bucket excavator had worked most successfully for 10 years. It cut a smooth face on an angle of 45 degrees, which prevented landslides—a very important matter—while its series of small buckets allowed a perfect mixture of the successive strata, which was hardly obtainable with a single-bucket machine; and when boulders were encountered, as they very often were, they were easily dislodged and rolled down the slope and could not be carried on to the grinding mills.

There was one other point which he wished to mention. The price paid for excavating sand and silt with “walking” draglines for the irrigation canal in California referred to in the Paper, namely, 6d. per cubic yard, seemed enormously high in comparison with prices paid for similar work in Europe carried out with multi-bucket excavators.

Mr. Norman Brocklebank said that he had the privilege of attending the meeting as a deputy for Mr. Philip D. Priestman, who could not be present himself. The Author's Paper, and the lantern-slides and cinematograph-film which he had shown, displayed a highly-specialized knowledge of a field of excavators in which the firm with which Mr. Brocklebank was associated had no part; consequently his great interest in the subject was very largely academic. The firm that he was very glad to be representing that evening were specialists in the manufacture of excavators for the smaller jobs. The firm had been connected actively with excavation work since 1876, when the first grab was built for the salvage of treasure from a sunken Spanish galleon. The idea was originally conceived by Mr. William Dent Priestman. The grab built was a very primitive affair, but, although the treasure did not materialize, the grab certainly came to stay, and it was the original predecessor of the thousands of sizes which were in use to-day. From that time until the year 1921, when the first British all-purpose excavators were built, and later up to 1932, when his firm were building the smaller excavators of the 7½-ton type, they had always been directly connected with land-drainage problems and had now accumulated a very large number of statistics, not only on fen work and general river work, but also on excavation jobs, in Cumberland, Westmoreland, and North Wales, of a very rough and heavy character, which previously would have been unsuitable for small machines.

With regard to the slack-line cableway, which had been referred to in the course of the discussion, his firm had found it possible on several occasions to adapt the ordinary standard type of dragline for that work by fitting very long hoisting and dragging ropes and by forming the anchor on the opposite side of the waterway on a mobile tractor. They had thus been able to work without the normal restrictions which were imposed by the length of boom as a slack-line cableway, and still to preserve the mobility of the land dragline and the nature of the dragline as an all-purpose general-utility tool.

Another point mentioned in the course of the discussion was the difficulty encountered occasionally by clay sticking in the dragline buckets.

In that connexion he might mention that his firm had experimented with timber-lined buckets, following the example of drainage engineers, who used wooden sludging spades because of their ability to discharge the mud, and also buckets of special taper design, which had to some extent overcome the difficulty, except in the case of the most adhesive materials.

Finally, there were a few very minor points arising out of the Paper which he wished to mention. The first related to *Figs. 19* (p. 33), which illustrated the method by which the dragline could be employed to augment the use of the shovel, when the latter was not able to top the limit of the face. It appeared to him from the diagram that the dragline was having to work on the finished level and thus to rake down the material from the higher level to the lower bench, and it was his feeling that the dragline should have been standing on the top of the excavation, and should therefore be shown ahead of the shovel.

His second point was in connexion with the already-discussed item of working costs, which were given in Table II (p. 21) for various sizes and types of excavators. It appeared that the $\frac{3}{4}$ -cubic-yard diesel dragline showed lower costs of excavation than the 2-cubic-yard diesel machine. Probably that was an isolated case, but he would be glad to have the Author's comments upon it, because his firm had found in almost every case that they could not avoid a rise in costs with a reduction in the size of the machine, owing to the fact that output was bound to go down at a greater rate than capital cost and running expenses.

The last point he wished to mention was with regard to the "walking" dragline. He failed to see why the "walking" dragline was so much more capable of travelling on bad ground than the caterpillar type. Admittedly, when the machine was stationary and working it was standing on a base of very large area, and consequently gave a considerably reduced ground-pressure per square foot, but during the actual movement it appeared that the side shoes in contact with the ground gave approximately only the same ground-pressure as would be obtained by the equivalent size of caterpillar crawler.

The Author, in reply, referred first to Mr. Davidson's question regarding the maximum economical depth to which excavation could be carried out in the case of a machine with a 1-cubic-yard bucket excavating dry loam or ballast. Irrespective of the size of machine, the most economical digging depth would depend upon the length of cut necessary to fill the bucket efficiently at the normal digging speed, so as to reduce the digging time in a cycle of operations to a minimum. The thickness of cut should be controlled so that the normal digging effort was exerted on the teeth at the maximum normal digging speed; in other words, the thickness of cut taken should not be so thick as to slow down the digging speed nor be so thin that the bucket was not filled at the end of the cut. The thickness of cut depended on two factors: the nature of the material,

and the angle of the working face. If the latter were too steep the digging efficiency of the bucket due to its weight would be affected, as referred to at the top of p. 15; the easier the material the thicker the cut, and the shorter the digging length that would be necessary to fill the bucket. Bearing those facts in mind and assuming a modern dragline fitted with a standard medium-weight bucket, the Author considered that the most economical digging depth in easily-excavated loam or loose ballast would be 6-7 feet. That meant a digging slope of about 20 degrees and a cut from 6 to 7 inches thick over a length of about 16 feet, to fill the bucket. With regard to the ranges above and below that figure, it was unlikely that any differences in output would be noticeable between depths of 3 feet and 8 feet. It had to be remembered that the deeper the face the longer it took to hoist and lower the bucket into and out of the excavation, but that did not matter so much providing that the hoisting speed was such that the bucket reached its dumping height at or before the end of the swing, which meant skilfully co-ordinating the two motions. It was also assumed that the material, loam or ballast, was uniform throughout the digging depth, as frequently material was heavier and more compact at lower depths, and in consequence was more difficult to excavate.

With reference to Mr. Davidson's comments regarding light welded booms, it might be of interest to know that the latest development to combine strength with lightness on long welded booms for large machines was to include steel tubing in their construction.

It was difficult to make the units of costs in Tables I (p. 20) and II (p. 21) the same, as Table II was extracted from Mr. B. J. Huntsman's Paper on the Salonika Plain Reclamation Scheme¹ and the Author had no information regarding the value of the cent. In any case the alteration would be of no real value as the Author had carefully pointed out that the cost figures were only given to compare the costs of different types of dragline on the same job.

In regard to the maximum size of draglines, the Author had mentioned, when introducing his Paper, that since the information about the world's largest dragline shown on p. 38 had been printed the latest model of that machine carried a 20-cubic-yard bucket on a boom 200 feet long. That brought that particular machine into line with the statement on p. 13.

The tower-scraper which Mr. Davidson referred to was not strictly the type of dragline excavator dealt with in the Paper. It was manufactured under various names, such as the "Tower Excavator," the "Slack Line Cableway Excavator", and the "Power Drag Scraper." At one time very large machines of that type were used on the Mississippi Levee Construction Schemes. Some of those machines had their towers mounted on caterpillar tracks. They weighed up to 300 tons, each with scraper-type buckets of 10 cubic yards capacity and with working spans of up to

¹ Journal Inst. C.E., vol. 5 (1936-37), p. 243 (March 1937).

1,000 feet. Within recent years, however, they had been superseded to a large extent on those schemes by large "walking" draglines and tractor-drawn scrapers. It was of interest to note that Mr. Borer applied the scraper principle to the machine he referred to for dragging material up on to the bank in front of a dragline. That principle was frequently carried out in one form or another on drainage jobs. One firm, in particular, in Great Britain used a rotary form of scraper or scoop which was hauled backwards and forwards across a river or drain by means of traction-engines of the cultivator type.

In reply to Mr. Borer, the Author's statement that the dragline was developed in America was quite correct. The development, commencing in 1904, was illustrated and described in the Author's book, "Excavating Machinery"¹. The first draglines to be used in Great Britain were Bucyrus machines imported from America in 1914-16. Messrs. Sir Robert McAlpine and Sons were the pioneers in their use, and they ordered two machines in 1914; the first, mounted on rail wheels, was used on a railway contract at Cuffley, and the second, on caterpillar tracks, on a new works near Derby. Two were also ordered by Messrs. S. Pearson & Sons in 1916 for use at Gretna. Another was purchased by Messrs. Sir William Baird & Company in 1916 for stripping iron-ore on the island of Raasay. The first dragline to be constructed in Great Britain was made by Rustons in 1918, and was originally intended for use on the coprolite workings near Cambridge. Before it was completed, however, the armistice was signed and it was sold to Mr. Harry Fairclough of Warrington, and was used by him for throwing up retaining banks alongside the Manchester Ship Canal. That machine, as well as several of the early American machines, was still in active service in Great Britain.

The Author agreed with Mr. Borer that the catchment boards had been largely responsible for "stretching" the boom lengths on certain sizes of machines, but he thought that the safety limit had been reached, at any rate as far as standard machines were concerned. He believed, however, that the longer and wider caterpillar tracks, which were now available on many sizes of machines, could, with advantage, be used on drainage work to a greater extent than they were at present, to provide greater stability on soft ground.

With reference to Mr. Borer's contention that steam power was better than diesel power for grabbing work, there was no reason why that should be, provided that the diesel engines were of ample power—that was of great importance—and that the clutches were correctly designed for easy operation to transmit easily the requisite power.

Concerning the net working time of steam machines, the figures given were from actual experience on many jobs in many countries. The loss of time included getting up steam before starting work in the morning,

¹ Published by Ernest Benn, Ltd., London, in 1928.

shortage of steam due to bad firing, waiting for supplies of coal or water, or both, and frequently the use of unsuitable coal and water, and in winter time the freezing of water-supplies.

The Author thanked Mr. Borer for his very interesting contribution to the discussion from a catchment engineer's point of view.

The Author thanked Mr. Henry for the information that out of fifty-six excavators that his firm were operating, fifty of them were draglines, which was an excellent proof of the general utility of the dragline excavator. Mr. Henry's reference to steam machines recalled the fact that great prejudice existed at one time amongst contractors in favour of steam machines. It was granted that steam was the ideal power for easy control and flexibility, but the loss of time and the difficulty often of obtaining ample and suitable supplies of coal and water more than outweighed those advantages.

With regard to the economical loading of a dragline bucket in gravel, referred to by Mr. Ireland, that was always an annoying point, especially if the material were waterlogged, or excavated from under water, as a percentage of the material was almost always washed out of the bucket. Special buckets had been designed and patented from time to time, fitted with hinged doors which fell down over the mouth of the bucket to prevent the material from being washed out, but they had not met with much success. It was, however, fairly common practice to supply specially deep buckets for those conditions, or for users to fit standard buckets with collars to increase the carrying depth, especially at the back, but probably the easiest solution was to fit a larger-capacity bucket to make up for the smaller loading of the usual standard bucket.

It was difficult to cater for sticky clay and to avoid it accumulating in the bucket. One of the features of the modern bucket was, however, the fact that it dumped cleaner than the older types. That had been effected by well rounding the corners, and by the use of welding, which dispensed with rivet-heads and resulted in generally smoother construction inside.

A tapered bucket did not, unfortunately, overcome the difficulty, as, unlike the bucket of a shovel, a dragline bucket was discharged from the open end or mouth, so that if it were tapered to assist dumping, the material would wedge in the back or tapered end when filling. If the clay were very sticky it was useful, when water was available, occasionally to swill the bucket out with water, as the Author had seen contractors swill out shovel buckets when dealing with "bungum." Occasionally he had seen dragline drivers drop the dragline bucket into a pool of water when one was within reach.

Mr. Ireland was correct in thinking that most of the excavation on the Sukkur barrage had been in rather light soil, although there was, in some places, a proportion of hard clay, and in others sand almost as fine as pepper, which enveloped the draglines in a smoke-like cloud.

Regarding the comparison of the output and costs of diesel draglines

and steam draglines in Great Britain, the Author had no comparisons similar to those given in Table I (p. 20), which were taken from Indian reports. The outputs from diesel draglines were usually greater over a period than those from steam draglines, chiefly because the average net working hours were greater on the diesel machines, although the time taken to complete a cycle of operations was approximately the same.

It could be confidently stated, however, that working costs were lower with diesel machines, because the fireman on a steam machine was dispensed with on a diesel machine, and the cost of diesel oil at £5 per ton was from one-quarter to one-fifth the cost of coal on a steam machine with coal at 30s. per ton. Depreciation and maintenance charges were rather higher on a diesel machine than on a steam one. Taking everything into consideration, the cost per cubic yard using a diesel dragline would probably be from 25 to 30 per cent. less than with a steam machine.

Referring to Mr. Erith's comments, the Author thought that his enthusiasm for endless-bucket excavators, or land-dredgers, as they were sometimes called, was not consistent with the real facts. There was no better nor more economical type of excavator when the working conditions were suitable—such as, for instance, when it was working in reasonably dry uniform material, similar to that in the German brown-coal mines referred to by Mr. Erith. The endless-bucket excavator was not so popular on the Continent as it had been. It was not, of course, a novelty in Great Britain, as several machines had been used on the Manchester Ship Canal 50 years ago, and their good and bad features were fairly well recognized by most engineers. The Author knew, however, of more failures of that type of excavator than of all the other types added together. Some of those failures were worth recording. It should also be noted that all the failures mentioned were with large machines that had been purchased either by engineers after a conducted tour of Germany, or as a result of the engineers' recommendations following such a tour.

Before draglines were used upon Indian irrigation schemes a number of large endless-bucket excavators had been purchased and discarded after a short experience with them in sun-baked clay. That costly experience had made it difficult, for a time, to convince some of the engineers in India that it was the type of machine that was at fault and not the principle of excavating machines, for conditions in India.

A large endless-bucket excavator purchased for excavating chalk was another failure owing to the unsuitability of the material.

Within the last few years three endless-bucket excavators near Bedford, two for digging brick clay and one for stripping, had proved costly failures. All three of those machines were successfully replaced by draglines. In one works the output of bricks was increased by 30 per cent. within a week of the installation of the dragline, because the clay excavated by the dragline was drier and there were fewer stoppages due to wet clay and bad weather.

Mr. Erith was quite correct in his statement that an endless-bucket type of excavator had been digging brick clay successfully in the Peterborough area for 10 years. It was equally true that since that excavator had been installed the engineer responsible for purchasing and using the machine had purchased two draglines for two new clay pits, not, however, because the endless-bucket machine in his first pit was a failure, but because the working conditions, including a bed of stone in the clay, were not suitable for endless-bucket excavators. One of those engaged in deep digging had been illustrated during the introduction of the Paper at the meeting.

It was far from correct to state that the big Albert Canal was mainly excavated by a very large endless-bucket machine, as only a very small percentage of nearly 3,000,000 cubic yards was excavated by that machine. Over fifty excavators of various types were used on the Albert Canal, of which three were endless-bucket machines and the remainder shovels, draglines, and grabbing cranes.

Referring to Mr. Erith's statement that the leading Continental firms made dragline excavators as well as endless-bucket machines, the Author had no knowledge that Messrs. Krupps, Siemens-Schuckert, and Lübecker manufactured draglines.

The Author could not confirm Mr. Erith's contention that "walking" draglines had been made in America for 27 years with capacities as small as $\frac{3}{4}$ cubic yard. Although small machines, having a capacity as low as 1 cubic yard, had formerly been listed, very few were made. The smallest size listed at present had a capacity of 2 cubic yards. The Author did not think that the "walking" device would be available on machines smaller than that, as caterpillar tracks provided greater mobility.

Mr. Erith suggested that the "walking" device was not of really great importance and was only an ingenious and useful talking point for a salesman. It was worth pointing out, however, that the low bearing-pressure which it exerted on the ground was only one of its advantages, for it was clear that longer booms or larger buckets, or both, could be fitted to a walking dragline than was the case with a caterpillar machine of the same weight. Alternatively, if certain ranges and bucket capacities were specified, a caterpillar-mounted machine would necessarily be larger and heavier, and usually more expensive. Its ability to "sidestep" on certain jobs such as levee construction was also useful. The main point was, however, that the "walking" dragline had advantages for certain jobs, just as the endless-bucket machine had for others.

Finally, the Author did not think that any contractor would consider 6*d.* per cubic yard to be "an enormously high price" with any plant, especially when it was borne in mind that the price of 6*d.* not only included digging the material but putting it into the banks. It should also be borne in mind that costs, generally speaking, were higher in the United States than in Europe.

Mr. Brocklebank suggested that the Paper and the lantern-slides shown at the meeting dealt with excavators in which his firm had no part, but the Author pointed out that two of the illustrations used by him, including one of the lantern-slides showing a dragline in the Malayan jungle, were of machines made by Mr. Brocklebank's firm. The $\frac{1}{4}$ -cubic-yard dragline mentioned in connexion with the working costs given in Table III (p. 22) referred to another machine made by Mr. Brocklebank's firm.

The Author thanked Mr. Brocklebank for drawing his attention to an error in *Figs. 19* (p. 33). The dragline shown in the plan should have been shown at the bottom of excavation B, and its position would then have coincided approximately with the dimension 45'. Working thus the dragline followed the shovel as shown, but dragged down the material B in a similar manner to the dragline in *Fig. 18* (facing p. 33), which was dragging down the upper portion of the overburden or cover.

The Author regretted that he was unable to explain the reason for the low working cost of the $\frac{3}{4}$ -cubic-yard diesel dragline given in Table II (p. 21), as compared with the larger diesel draglines, as the figures were taken, as stated, from a Paper by Mr. B. J. Huntsman, and the Author did not know the conditions under which the machines worked. Those conditions would probably account for the unusual difference in cost, because, as Mr. Brocklebank correctly pointed out, the excavation costs of small machines were almost always greater than those for larger machines.

Regarding the "walking" dragline, the Author did not know of any claims that the machine was so much more capable of travelling on bad ground than a machine of the caterpillar type. It had, however, a definite advantage when working on soft ground, as it was then that a machine tended to sink in; that was because the vibration and the movable varying loads upon the base or caterpillar tracks, acting for some considerable time, caused the ground to give way. A machine could frequently travel safely over ground into which it would sink if it were excavating.

Referring to the probable pressure on the walking-shoes when the machine was travelling, the fact that about half the weight of the machine was taken on the trailing edge of the base should be taken into consideration.

* * The Correspondence on the foregoing Paper will be published in the Institution Journal for October 1940.—SEC. INST. C.E.