Outside Diameter/Length Ratio

An important ratio is cutter outside diameter to length. A proven reasonable figure is 0.67. If the ratio is as high as 1.0, the crown, where much digging occurs, is at such a distance from the suction inlet as to diminish the transport efficiency.

Peripheral Speed

Little or no laboratory data is available on the correct cutting edge speed for various materials since virgin material cannot be transferred to the laboratory. The conventional wisdom and experience recognizes that a variable speed drive is desirable in order to optimize speed for varying materials. For granular, freeflowing materials, almost any speed succeeds. For hard coral or limestone, a high-speed milling action is recommended, coupled with pinned, hardened teeth. For clay, moderate to high speeds as a function of the clay's consistency is recommended, with either a plain or serrated edge, or the pinned tooth cutter. On blasted rock, a slow speed is dictated to avoid repelling the particles. With the variable speed, the operator can experiment on various materials to optimize his cutter operation.

Most cutters have a maximum peripheral speed varying between 300 and 600 feet per minute. The speed variation should be capable of at least a 50 percent reduction, normally with constant torque, and preferably, but not essentially, a smooth, stepless reduction. If the drive is an alternating electric current, it will probably have a stepped reduction, which limits its flexibility, but does not disqualify the drive. For hard materials, a top speed of 600 feet per minute maximum is recommended; for softer, more normal material, a top speed of 400 feet per minute, with both having speed reduction capability to perhaps 200 feet per minute in order to minimize wear, power, and dispersion of bottom materials when the higher speed is unneeded.

Horsepower vs. Torque vs. Cutting Force

Cutter horsepower can be misleading when quoted as a simple number. On most bottom materials, torque or cutting force is the key to successful excavation, not horsepower alone.

$$\text{HP} = \frac{\text{torque} \times \text{RPM}}{5{,}250} \qquad \textit{[Equation 13-1]}$$

$$\text{Torque} = \text{cutting force} \times \text{cutter radius} \qquad \textit{[Equation 13-2]}$$

For a given 3-foot outside diameter cutter, assume there is a choice between two 100-horsepower drives, one with a full-load speed of 50 RPM, and the other 25 RPM. The 50 RPM unit would very likely be cheaper and thus attractive to the buyer, but does it have the same capability as the 25 RPM unit?

In Equation 13-1 above, drop the constant and rearrange to:

$$\text{Torque} \sim \frac{\text{hp}}{\text{RPM}}$$

$$\text{Torque} \sim \frac{100}{25} = 4 \text{ for 25 RPM drive}$$

$$\text{Torque} \sim \frac{100}{50} = 2 \text{ for 50 RPM drive}$$

Equation 13-2 rearranges to:

$$\text{Cutting force} \sim \frac{\text{torque}}{\text{radius}}$$

$$\text{Cutting force} \sim \frac{4}{1.5} = 2.67 \text{ for 25 RPM drive}$$

$$\text{Cutting force} \sim \frac{2}{1.5} = 1.33 \text{ for 50 RPM drive}$$

Therefore, it can be seen that the 50 RPM drive provides only one half the torque and cutting force of the 25 RPM unit.

Cutting force alone is much more indicative of cutter capability than horsepower, but needs to be taken one more step to be definitive. Total cutting force would be sufficiently definitive if all cutters were the same size and geometry, but they are not. Therefore, if one cutter were twice as long as the other, but had the same total cutting force, its force per linear inch of cutter length (pounds/inch) would be only one half as high as the shorter cutter. The operator needs to know pounds/inch of cutter length for a true comparison of cutter options. Successful cutters have varied from 250 pounds/inch to over 2,500 pounds/inch. The requirement is, of course, a function of the material to be dug.

Cutter Drives

The cutter has drive options similar to those of the submerged pump. Variable speed electric drives are impractical to submerge, because of the need to dissipate their heat of inefficiency. Therefore, it is necessary that they use a line shaft. Electrical drives have an advantage over hydraulic in that before stalling, their pullout torque rises dramatically, providing a brief but significant increase in cutting force.

The submerged hydraulic drive has many advantages. It is, undoubtedly, the lowest cost variable speed drive and is relatively simple to submerge. Its speed is easy to change by a simple adjustment to the hydraulic supply pump piston travel. Its torque potential is a constant regardless of speed, providing on demand a constant cutting force which allows a constant relationship to the swing winch line pull. Both electrical and hydraulic cutter drives have their advocates, but hydraulic drives continue to gain on their electrical counterparts in new designs.

Horsepower Requirements

Perhaps the most controversial aspect of cutter drives is their horsepower requirement. One chief executive officer of a major dredging company was heard to remark that there was never a cutter with sufficient horsepower. From the viewpoint of being able to overcome any obstacle and afford the maximum feed to the pump at all times, this sounds like a reasonable statement. However, it is somewhat equivalent to stating that there was never an automobile with sufficient horsepower. It is entirely possible that in a tight passing situation, one might wish he had twice the horsepower on even the most powerful automobile, but the cost of such power would be prohibitive. The same is true of the cutter horsepower on a dredge because the cutting force affects the winches, the spuds, the ladder, and even the hull size. Since the dredge is an economic tool, it is not reasonable to pay a great deal of money for a powerful drive whose full capacity is utilized 1 percent of the time while the cost of its size inefficiency continues unabated 100 percent of the time.

The operator can arrive at a reasonable and economic horsepower for the cutter by working with the peripheral speed of 400 to 600 feet per minute and a unit cutting force of 250 to 2,500 pounds/inch, varying as a function of the material to be dug. In the author's experience, only extraordinary conditions justify exceeding the 2,500 pounds/inch figure.

Velocity and unit cutting force are, of course, a function of cutter outside diameter. A reasonable ratio of cutter outside diameter to suction line inside diameter is 3:1. While this ratio can vary, 3:1 is economical and allows for the reasonable arrangement of a "clown's mouth" suction inlet.

Cutter Calculations

Having determined the size of the suction line from the capacity requirements in Chapter 11, the cutter size and horsepower can be calculated from the following ratios using the above information.

Assume an 18-inch suction and a 3:1 ratio of cutter diameter to suction diameter, then:

$$\text{Cutter diameter} = 3 \times 18 = 54 \text{ inches}$$

With cutter length equalling 0.67 of its diameter:

$$\text{Cutter length} = 0.67 \times 54 = 36 \text{ inches}$$

To calculate the mean diameter of the cutter, assume a 15° face angle:

$$\text{Tan } 15^\circ = .268 \times 36 = 9.6 \text{ inches}$$

$$\text{Diameter at crown} = 54 \text{ inches} - 2(9.6) = 35$$

(Say, 36 inches)

$$\text{Mean diameter of cutter} = \frac{54 + 36}{2} = 45 \text{ inches}$$

Assume 500 pounds/inch unit cutting force:

$$\text{Total cutting force} = 500 \times 36 = 18{,}000 \text{ pounds}$$

$$\text{Torque} = \text{R} \times \text{F} = \frac{45 \times 18{,}000}{2 \times 12} = 33{,}750 \text{ foot-pounds}$$

For hard materials, assume 600 feet/minute peripheral speed, and a pinned tooth cutter:

$$\text{RPM} = \frac{600 \times 12}{\pi \times 45} = 50.93$$

$$\text{HP} = \frac{\text{torque} \times \text{RPM}}{5{,}250} = \frac{33{,}750 \times 50.93}{5{,}250} = 327.4$$

For softer, more normal materials, use 400 feet/minute peripheral speed and a plain, serrated, or pinned tooth cutter.

$$\text{RPM} = \frac{400 \times 12}{\pi \times 45} = 33.95$$

$$\text{HP} = \frac{33{,}750 \times 33.95}{5{,}250} = 218.25$$

The latter speed and horsepower are more normal for the industry which is not accustomed to thinking in terms of rock being cut by a moderately sized dredge. In many cases, it is more appropriate to blast, but coral, soft limestone, or incipient rock have been dug with no more power than that calculated above for hard materials. The economics of rock dredging are chancy, and should be considered carefully for each project.

The practical operator will recognize that the dimensions arrived at by the above procedure are approximate, and that he should avail himself of economies offered by available standard cutters and drive components which approximate his calculations.

Cutter Capacity

The cutter functions as an excavator and feeder of the solids to the hydraulic transport system. If the cutter is unable to feed the system at the calculated transport rate, the dredge capacity must be down-rated.

Cutter capability varies broadly between dredges. Even where two cutters have the same HP, the cutting force of one can be twice that of the other. To compare cutters, it is necessary to reduce the analysis to the lowest common denominator, i.e., cutting force expressed in pounds/linear inch of projected blade length. Then, by plotting the Standard Penetration Test (SPT) blow count (the dredge industry's traditional indication of cutting difficulty) against the cutting force in pounds/linear inch, and against observed empirical production rate in cubic yards per hour, we can supply the estimator with a guide for predicting cutter limitations on the production of a dredge.

The dredge cutter capacity chart is shown as Fig. 13-10. Note the abscissa between 10 and 100 is the SPT blow count, and the ordinate is cu yd/hr, plotted against various cutting forces ranging from 250–3,000 pounds/linear inch. Using the chart requires no multiplier; rather, if the cu yd/hr of the cutter equals or exceeds the hydraulic transport capability of the dredge, no adjustment is required. If the cutter capability is less, then the dredge capability becomes that of the cutter.

As examples of the use of the cutter plot, note that the capacity of a 10-foot diameter, 250 pound/linear inch cutter on 60 blow count materials is $(10)^2 \times 1.05 = 105$ cu yd/hr; a 500 pound/linear inch cutter would achieve $(10)^2 \times 8 = 800$ cu yd/hr; and a 1,000 pound/linear inch cutter would excavate $(10)^2 \times 100 = 10{,}000$ cu yd/hr.

It is commonly acknowledged in the industry that there is an advantage of electrical cutter drives over hydraulic drives. This advantage is derived from the "pull-out" or stalling torque characteristics of the electric motor. As the resistance of the soil increases beyond the cutter drive's full load torque, the drive slows down, increasing the amperage and torque substantially before stalling. The stalling torque may be 4–6 times the full load torque, so this temporary torque (obviously it cannot be maintained for a protracted period) adds an estimated 50 percent more effective cutting force than is available with hydraulic power. The HP formulas, which reflect the lower electrical HP requirement for a given cutter service, are shown below.

The HP required for the 1,000 pound/linear inch cutter at 20 RPM where F equals cutting force in pounds/linear inch would be:

$$\text{Electric HP} = FD^2N/1{,}970 = 1{,}000 \times (10)^2 \times 20/1{,}970 = 1{,}015$$

$$\text{Hydraulic HP} = FD^2N/1{,}313 = 1{,}000 \times (10)^2 \times 20/1{,}313 = 1{,}523$$

The cutter chart is included with the caveat that the data is the best currently available, but *is not sufficient to constitute proof of the widely extrapolated curves as shown.* There are many shortcomings of the somewhat crude SPT procedure, one of which is its lack of linearity. At times it can make a firmly packed, low porosity sand give the impression of incipient rock; upon excavation, however, such sand disintegrates readily and transports freely if not cemented.

Many geotechnical engineers consider the SPT of dubious value above 100 blow count. The dredgeman needful of the maximum available soil data will extrapolate "refusal" blow count of 75 blows for 3″ penetration to an SPT result of 300. These results are nonlinear and questionable, but in the mind of the dredgeman, they are better than blind guesses. There is general agreement that above 100 blow count, a different method of testing is required.

One promising test method sometimes used is the unconfined compressive strength test (UCST). This test is inappropriate for non-cohesive or non-cemented materials since an undisturbed sample cannot be obtained for testing. It is likely that the SPT gives better results on soils with less than 100 blow count, whereas the UCST gives better results on cemented material above 100; modern dredges with powerful cutters have dug lenses of rock with compressive strengths as high as 15,000–20,000 psi. The cutter chart attached has been developed using field data and could prove helpful to the dredge estimator, but should be used with caution.

A clear correlation between SPT and UCST in the range of 10–300 SPT is not clearly established; however the chart allows the use of either SPT or UCST data, as available.

It is possible that a combination of the SPT and UCST will become standard on future projects. Most projects have used the SPT only, necessitating the characterization of some areas as "refusal." This leaves such areas undefined, and the soil data incomplete.

It may prove possible in the future to develop one test for the entire range of soil, such as unconfined shear strength. This may more closely approximate the action of the cutter and give better results. This is an area of research that sorely needs the attention of the dredging industry.

Materials of Construction

It is impractical to harden a one-piece cast steel cutter to a high Brinnell value for better wear since it would fail in shock. Likewise, there is a limit to the hardness and carbon content of cutting edges welded to the softer base blade since the weld would fail if the material were too hard. An advantageous arrangement is the pinned tooth cutter. Here, the teeth which carry the brunt of the excavation can be 350 to 500 Brinnell, while the base blade can be a casting of perhaps 150 Brinnell. A further modification can provide a replaceable cutting edge, possibly 250 Brinnell, which is tack welded to the base blade. The edge can be plain, serrated, or equipped with adaptors to receive the pinned teeth, providing a

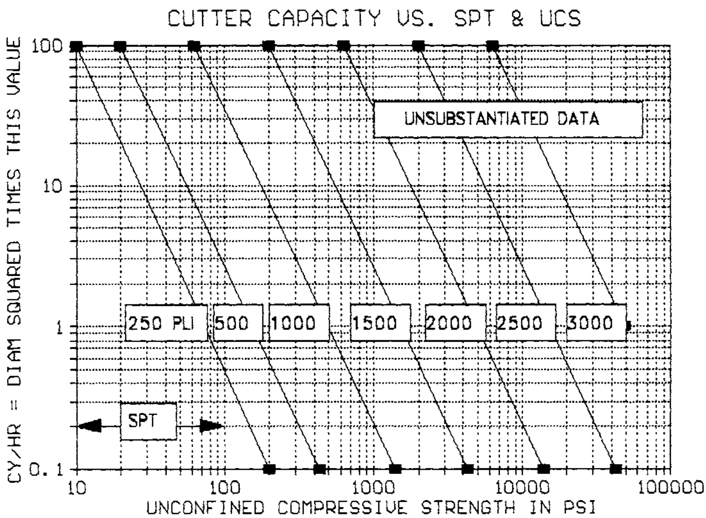

Fig. 13-10. Cutter capacity vs. SPT and UCST.

highly versatile unit. This relatively new configuration is recommended for consideration as a general-purpose cutter. Figs. 13-2 (f) and (g) are examples.

Particle Passage

Surprisingly little coordination between the cutter and the dredge pump regarding particle passage seems to have been attempted in the industry. With the cost in downtime involved in removing oversized particles from the stone box, it would seem some coordination would be justified, but most operators have settled for trash bars welded into the cutter. See Fig. 13-3B. Such trash bars can severely limit the intake of some materials and reduce production; however, if the opening in the cutter would limit the particle size to that which would pass the pump without limiting intake of smaller particles, it would be a boon to the operator. Frequently the sources of the cutter and pump are different manufacturers, and coordination is achieved only by the operator.

THE BUCKET WHEEL

The bucket wheel excavator is a rotating wheel of bottomless buckets mounted on a lateral shaft as shown in Fig. 13-11. The

Fig. 13-11. Rennison Goldfield's 1,340 HP bucketwheel. Courtesy: IHC.

material enters an inner chamber in slurry form, and proceeds to the dredge pump via the suction line.

The bucket wheel was introduced to the dredging industry in the 1970s by an American manufacturer, and since then, has been followed by European and Australian manufacturers. It has numerous advantages which seem to assure it a permanent role in the industry, but it has disadvantages which also assure the role of competitive type cutters.

The conventional basket cutter is, in the vast majority of cases, sold as a separate component. The more complex bucket wheel excavation is normally sold as a complete excavating module, including structure and drive, and the range of size and horsepower offered is more limited than for the basket. No effort will be made in this text to delineate the design aspects of the bucket wheel as was done with the basket shape since it is strongly recommended that only proven proprietary designs of this relatively new excavator be utilized.

Because the excavating element of the bucket wheel is the relatively short length of the bucket projection, each advance of the dredge is much shorter than for the basket cutter. Therefore, the conventional walking spud mechanism is not satisfactory for the bucket wheel since the spud diameter may be equal to the advance, and the spud would fall back in the old bottom hole. The bucket wheel must have a spud carriage arrangement, explained in Chapter 17.

Advantages

The bucket wheel type addresses many of the shortcomings of the basket cutter. The advantages and disadvantages of the bucket wheel over the basket cutter are summarized below.

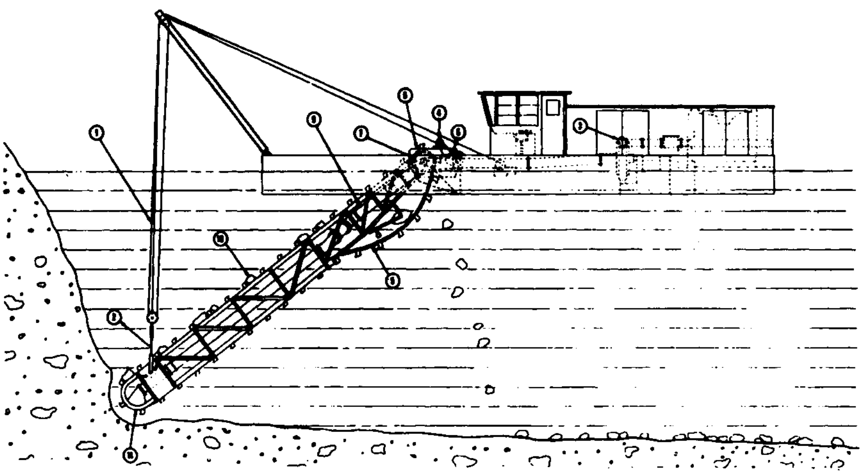

Fig. 13.12. Endless chain cutter. Courtesy: Eagle Iron Works.