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Construction Methods and Management

Stephens W. Nunnally

Eighth Edition

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FIGURE 14. Hydraulic demolition hammer. (Courtesy of Allied Construction Products, Inc.)

larger hydraulically powered units that may be attached to backhoes or other machines. *Hydraulic hammers* such as that shown in Figure 14 are increasingly popular for use in all types of demolition. Mechanical methods of rock breaking eliminate the safety hazards and liability problems associated with blasting.

Controlled blasting is utilized to reduce disturbance to nearby structures, to reduce rock throw, to obtain a desired fracture line, or to reduce the cost of overbreak (fracture of rock beyond the line required for excavation). The principal controlled blasting technique is called *presplitting.* Presplitting involves drilling a line of closely spaced holes, loading the holes with light charges evenly distributed along the hole depth, and exploding these charges before loading and shooting the main blast. Typical presplitting procedures involve $2\frac{1}{2}$- to 3-in. (5.4- to 7.6-cm)—diameter holes spaced 18–30 in. (45.7–76.2 cm) apart. Detonation of the presplitting charges results in a narrow fracture line that serves to reflect shock waves from the main blast and leaves a relatively smooth surface for the final excavation.

A related technique for producing a smooth fracture line is called *line drilling.* In this technique, a single row of closely spaced unloaded holes [4–12 in. (10–30 cm) on center] is drilled along the desired fracture line. In preparing the main blast, blastholes adjacent to the line drilling holes are moved close together and loaded lighter than usual. The line drilling technique normally produces less disturbance to adjacent structures than does presplitting. However, drilling costs for line drilling are high and the results can be unpredictable except in very homogeneous rock formations.

Blasting Safety

Blasting is a dangerous procedure that is controlled by a number of governmental regulations. Following are a few of the major safety precautions that should be observed:

- Storage magazines for explosives should be located in isolated areas, properly marked, sturdily constructed, and resistant to theft. Detonators (caps) must be stored in separate containers and magazines from other explosives.
- Electrical blasting circuits should not be connected to the power source and should be kept short-circuited (except for testing) until ready to fire.
- Permit no radio transmission in the vicinity of electric blasting circuits, and discontinue work if there is evidence of an approaching electrical storm.
- Protect detonators and primed charges in the work area from all physical harm.
- Check blastholes before loading, because hot rock or a piece of hot drill steel in the hole can cause an explosion.
- Do not drop or tamp primed charges or drop other charges directly on them.
- Use only nonmetallic tools for tamping.
- Employ simple, clear signals for blasting, and ensure that all persons in the work area are familiar with the signals.
- Make sure that the blasting area is clear before a blast is fired.
- Misfires are particularly dangerous. Wait at least 1 h before investigating a misfire. Allow only well-trained personnel to investigate and dispose of misfires.

4 ROCK RIPPING

Employment of Rippers

Rippers have been utilized since ancient times to break up hard soils. However, only since the advent of the heavy-duty tractor-mounted ripper has it become feasible to rip rock. The availability of powerful heavy tractors such as the one shown in Figure 15 now makes it possible to rip all but the toughest rock. Where ripping can be satisfactorily employed, it is usually cheaper than drilling and blasting. Additional advantages of ripping over drilling and blasting include increased production, fewer safety hazards, and reduced insurance cost.

Ripping Equipment

Although other types of rippers are available, most modern rippers are of the adjustable parallelogram type, shown in Figure 16. This type of ripper maintains a constant angle

FIGURE 15. Heavy-duty crawler-mounted ripper. (Reprinted Courtesy of Caterpillar Inc.)

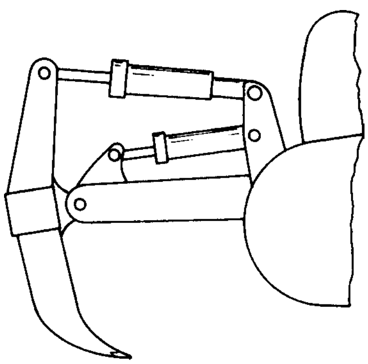

FIGURE 16. Adjustable parallelogram ripper.

with the ground as it is raised and lowered. However, the upper hydraulic cylinder permits the tip angle to be varied as desired to obtain optimum results. The tip angle that produces the best surface penetration is usually different from the tip angle that produces optimum rock breakage after penetration. Automatic ripper control systems are available that control ripping depth and automatically vary tip angle as the ripper is raised or lowered.

Impact rippers utilize a hydraulic mechanism to impart a hammering action to a single shank ripper. As a result, impact rippers are able to effectively rip tougher rock than can conventional rippers and usually produce a significant increase in ripper production. Some typical values for the increased performance provided by impact rippers include a 5–15% increase in the maximum seismic velocity for rippability and a 10–45% increase in hourly ripper production.

Ripper shanks and tips are available in several different styles and in a variety of lengths for use in different types of material. Shank protectors, which fit on the front of the ripper shank immediately above the tip, are used to reduce wear on the shank itself. Both tips and shank protectors are designed to be easily replaced when necessary.

Ripper Production

The seismic velocity of a rock formation (Section 1) provides a good indication of the rock's rippability. Charts such as the one shown in Figure 17 have been prepared to provide a guide to the ripping ability of a particular tractor/ripper combination in various types of rock over a range of seismic velocities. When ripping conditions are marginal, the use of two tractors to power the ripper (tandem ripping) will often produce a substantial increase in production and reduce unit excavation cost.

Equation 6 may be used to predict ripper production when effective ripping width, depth, and speed can be established. Trial operations are usually required to accurately estimate these values unless such data are available from previous operations under similar conditions.

$$\text{Production (BCY/h)} = \frac{2.22 \times D \times W \times L \times E}{T} \qquad \textbf{(6}\boldsymbol{A}\textbf{)}$$

$$\text{Production (BCM/h)} = \frac{60 \times D \times W \times L \times E}{T} \qquad \textbf{(6}\boldsymbol{B}\textbf{)}$$

where D = average penetration (ft or m)
W = average width loosened (ft or m)

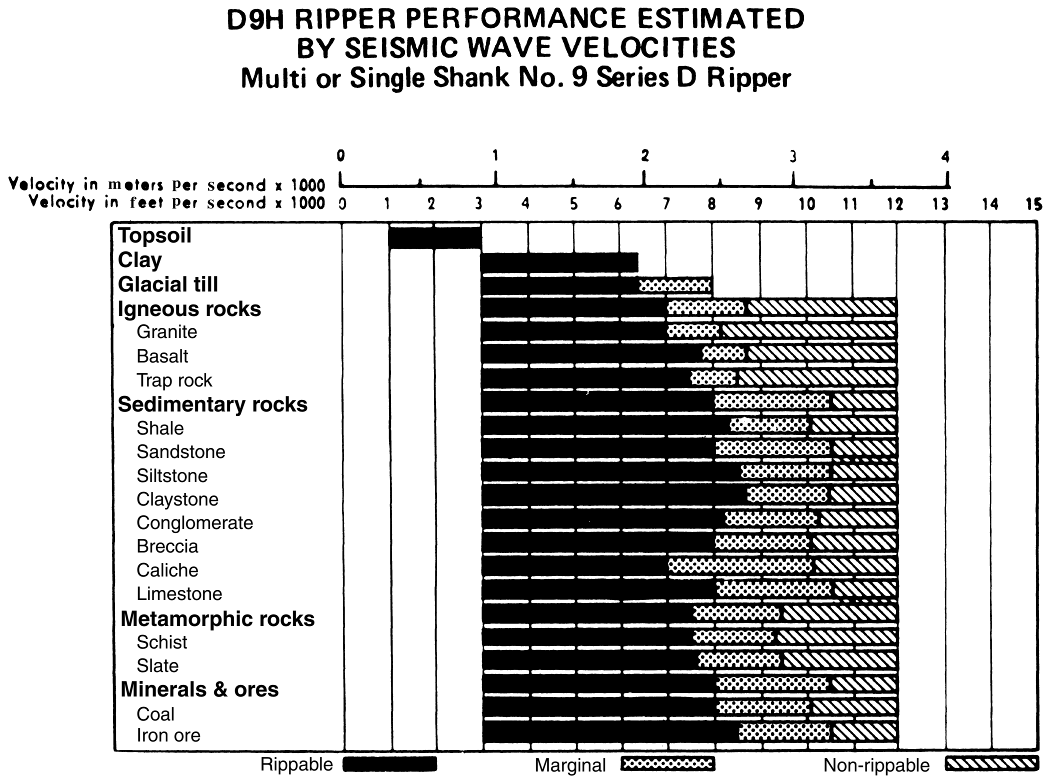

FIGURE 17. Ripper performance vs. seismic velocity. (Reprinted Courtesy of Caterpillar Inc.)

L = length of pass (ft or m)

E = job efficiency factor

T = time for one ripper pass, including turn (min)

Considerations in Ripping

Ripping speed and depth, spacing of ripper passes, and the number of shanks to be used for maximum ripper production depend on rock type and soundness, and tractor power. The presence and inclination of laminations will also affect ripping procedures. In general, rip downhill to take advantage of gravity. However, when ripping laminated material, it may be necessary to rip uphill to enable the ripper teeth to penetrate under the layers. The number of shanks to be used in a ripper should be the number that yields the desired penetration without straining the tractor. Depth of ripping will depend on the number of shanks used and the tractor power. In stratified material, try to match ripping depth to layer thickness. Ripping speed should be kept low to reduce wear on ripper teeth and shanks. First gear is usually used when ripping tough materials. The spacing of ripper passes will depend on rock hardness and the degree of fracture desired.

When loading ripped material, always leave a thin layer of material on the surface to provide a good working surface for the tractor. When ripping extremely hard rock, production may be increased and unit cost lowered if the rock is loosened by light blasting before ripping.

5 ESTIMATING PRODUCTION AND COST

The procedure for estimating rock excavation production and cost for a typical project is illustrated by Examples 4 and 5. Example 4 employs conventional drilling and blasting procedures for rock loosening, while Example 5 employs a tractor-mounted ripper.

Example 4 Estimate the hourly production and the unit cost of the rock excavation involved in preparing an industrial building site by drilling and blasting. The site is 300 ft (91.4 m) by 400 ft (121.9 m) and must be excavated to an average depth of 12 ft (3.658 m). The material to be excavated is a thinly laminated shale with a sonic velocity of 4000 ft/s (1220 m/s). The drilling equipment to be used will consist of an air-powered track drill and air compressor. The average drilling rate, including steel changes, moves, and delays, is estimated at 100 ft/h (30.5 m/h).

Trial blasting indicates that 3-in. (7.6-cm) holes drilled in a 12-ft (3.658-m) rectangular pattern will provide adequate fracturing. A hole depth of 13.5 ft (4.115 m) must be drilled to yield a 12-ft (3.658-m) effective depth. The blasting agent is ANFO. One-half pound (0.23 kg) of primer with an electric blasting cap will be used in each hole. The powder factor is 0.5 lb/BCY (0.297 kg/BCM).

A labor force of one drill operator and one compressor operator will be used for drilling. One blaster and one helper will be employed in blasting.

Cost information:

Labor:	Blaster	= $18.00/h
	Helper	= $15.00/h
	Drill operator	= $17.50/h
	Compressor operator	= $18.00/h
Equipment:	Track drill and compressor	= $63.00/h
Material:	ANFO	= $0.32/lb ($0.705/kg)
	Primer, cap, and stemming	= $3.00/hole

Solution

(a) Production

$$\text{Total volume} = \frac{300 \times 400 \times 12}{27} = 53{,}333 \text{ BCY}$$

$$[= 91.4 \times 121.9 \times 3.66 = 40{,}778 \text{ BCM}]$$

$$\text{Yield} = \frac{12^2 \times 12}{27} = 64.0 \text{ BCY/hole}$$

$$[= (3.658)^2 \times 3.658 = 48.9 \text{ BCM/hole}]$$

$$\text{Drilling yield} = \frac{64.0}{13.5} = 4.74 \text{ BCY/ft}$$

$$\left[= \frac{48.9}{4.115} = 11.88 \text{ BCM/m}\right]$$

$$\text{Production} = 4.74 \text{ BCY/ft} \times 100 \text{ ft/h} = 474 \text{ BCY/h}$$

$$[= 11.88 \times 30.5 = 362.3 \text{ BCM/h}]$$

$$\text{Time required} = \frac{53{,}333 \text{ BCY}}{474 \text{ BCY/h}} = 112.5 \text{ h}$$

$$\left[= \frac{40{,}778}{362.3} = 112.5 \text{ h}\right]$$

(b) Drilling cost

$$\text{Labor} = \$35.50/\text{h}$$

$$\text{Equipment} = \$63.00/\text{h}$$

$$\text{Drilling cost/volume} = \frac{\$98.50/\text{h}}{474 \text{ BCY/h}} = \$0.208/\text{BCY}$$

$$\left[= \frac{\$98.50}{362.3} = \$0.272/\text{BCM}\right]$$

(c) Blasting cost Material:

$$\text{ANFO} = 0.5 \text{ lb/BCY} \times 64 \text{ BCY} \times \$0.32/\text{lb}$$

$$= \$10.24/\text{hole}$$

$$[= 0.297 \times 48.9 \times 0.705 = \$10.24/\text{hole}]$$

$$\text{Prime, cap, and stemming} = \$3.00/\text{hole}$$

$$\frac{\$13.24}{64 \text{ BCY}} = \$0.207/\text{BCY}$$

$$\left[\frac{\$13.24}{48.9} = \$0.271/\text{BCM}\right]$$

Labor:

$$\text{Unit cost} = \frac{\$33.00/\text{h}}{474 \text{ BCY/h}} = \$0.070/\text{BCY}$$

$$\left[= \frac{\$33.00}{362.3} = \$0.091/\text{BCM}\right]$$

$$\text{Total blasting} = \$0.207 + \$0.070 = \$0.277/\text{BCY}$$

$$[= \$0.271 + \$0.091 = \$0.362/\text{BCM}]$$

(d) $$\text{Total cost} = \$0.208 + \$0.277 = \$0.485/\text{BCY}$$

$$[= \$0.272 + \$0.362 = \$0.634/\text{BCM}]$$

Example 5 Estimate the hourly production and the unit cost of rock excavation by ripping for the problem of Example 4. Field tests indicate that a D7G dozer with ripper can obtain satisfactory rock fracturing to a depth of 27 in. (0.686 m) with two passes of a single ripper shank at 3-ft (0.914-m) intervals. Average speed, including turns, is estimated at 82 ft/min (25 m/min).

Cost information:

Labor (operator)	= $20.00/h
Equipment (D7G with ripper, including ripper tips, shanks, and shank protectors)	= $75.00/h

Solution

(a) Production

$$\text{Volume} = 53{,}333 \text{ BCY } (40{,}778 \text{ BCM})$$

$$\text{Production} = \frac{2.22 \times 2.25 \times 3 \times L \times 50/60}{2 \times L/82} \quad \text{(Eq 6)}$$

$$= 512 \text{ BCY/h}$$

$$\left[= \frac{60 \times 0.686 \times 0.914 \times L \times 50/60}{2 \times L/25} = 392 \text{ BCM/h}\right]$$

$$\text{Time required} = \frac{53{,}333 \text{ BCY}}{512 \text{ BCY/h}} = 104 \text{ h}$$

$$\left[= \frac{40{,}778}{392} = 104 \text{ h}\right]$$

(b) Cost

$$\text{Labor} = 20.00/\text{h}$$

$$\text{Equipment} = 75.00/\text{h}$$

$$\text{Unit cost} = \frac{95.00/\text{h}}{512 \text{ BCY/h}} = 0.186/\text{BCY}$$

$$\left[= \frac{95.00}{392} = 0.242/\text{BCM}\right]$$

Problems

1. A parallel series electric blasting circuit consists of five branches of six caps each. Holes are spaced 10 ft (3.1 m) apart in a rectangular pattern. Cap legwire length is 24 ft (7.3 m). Each side of the cap circuit is connected by a No. 16 gauge buswire 40 ft (12.2 m) long. The lead wires are No. 12 gauge 1200 ft (336 m) long. Find the minimum current and voltage required to safely fire this blast under normal conditions.
2. List five safety precautions that should be observed in storing and handling blasting agents.
3. You measure a seismic velocity of 9000 ft/s (2743 m/s) in limestone. Would you expect this rock to be rippable by a D9H tractor equipped with a ripper (Figure 17)? If so, would you recommend using a single or tandem ripper in this situation? Why?
4. Estimate the hourly production and unit cost of rock excavation by drilling and blasting. The rock is a limestone having a seismic velocity of 6000 ft/s (1830 m/s). Trial blasting indicates that $3\frac{1}{2}$-in. (8.9-cm) holes drilled in an 8-ft (2.44-m) rectangular pattern will provide the desired fracturing. A hole depth of 20 ft (6.1 m) yields an effective depth of 18 ft (5.5 m). The average drilling rate is estimated to be 70 ft/h (21.4 m/h). A powder factor of 1 lb/BCY (0.59 kg/BCM) of ANFO will be used.

Cost Information:

Labor:	Drilling crew	$40.00/h
	Blasting crew	$42.00/h
Drilling equipment		$70.00/h
Material:	ANFO	$0.40/lb ($0.88/kg)
	Primer, caps, & stemming	$4.00/hole

5. A tractor-mounted ripper will be used for excavating a limestone having a seismic velocity of 6000 ft/s (1830 m/s). Field tests indicate that the ripper can obtain satisfactory rock fracturing to a depth of 2 ft (0.61 m) with one pass of a single ripper shank at 3-ft (0.91-m) intervals. Average ripping speed for each 400-ft (122-m) pass is 1.5 mph (2.4 km/h). Maneuver and turn time at the end of each pass averages 0.3 min. Job efficiency is estimated at 0.70. Machine cost including the operator is $130/h. Estimate the hourly production and unit cost of excavation.
6. What effect does increased air pressure at the drill have on drill production? What limitations must be observed in using increased air pressure and what are the disadvantages of using increased air pressure?
7. A parallel series electric blasting circuit consists of six branches of eight caps each. Holes are spaced 10 ft (3.1 m) apart in a rectangular pattern. Cap legwire length is 28 ft (8.5 m). Each side of the cap circuit is connected by a No. 16 gauge buswire 50 ft (15.3 m) long. The lead wires are No. 14 gauge 1000 ft (305 m) long one-way. Find the minimum dc current and voltage required to safely fire this blast under current leakage conditions.
8. Using the seismograph test data in the table, find the seismic wave velocity in each layer and the depth of the upper layer.

Distance (ft)	Distance (m)	Time (ms)
10	3.05	5.0
20	6.10	10.0
30	9.15	15.0
40	12.20	20.0
50	15.25	21.0
60	18.3	22.0
70	21.25	23.0
80	24.4	24.0

9. Trial blasting operations indicate that a rectangular pattern with holes 21-ft (6.4-m) deep spaced on 10-ft (3.05-m) centers will yield a satisfactory rock break with an effective depth of 19 ft (5.8 m). Determine the rock volume produced per foot (meter) of drilling.
10. Develop a computer program to estimate hourly production and unit cost of rock excavation by ripping. Input should include length of each pass, average ripper speed, effective depth of ripping, spacing of passes, turning time at the end of each pass, job efficiency, hourly operator cost, and hourly machine cost including ripper tips, shanks, and shank protectors. Solve Problem 5 using your computer program.

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