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TECHNICAL NOTE N-454

RAPID TUNNELING EQUIPMENT AND TECHNIQUES

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

RAPID TUNNELING EQUIPMENT AND TECHNIQUES

Y-FO15-11-604

Type B Final Report

by

Douglas Taylor

ABSTRACT

A study of existing reports and information for commercial tunneling equipment and methods was conducted to provide information about rapid tunneling, and to determine which equipment can be adopted by naval construction forces at advanced bases to permit underground operations. An outline is given for a manual on rapid tunneling equipment and techniques.

INTRODUCTION

The Bureau of Yards and Docks, in consideration of the possible use of nuclear weapons against naval advanced bases, assigned Task Y-F015-11-604 to the Naval Civil Engineering Laboratory to obtain basic information on rapid tunneling equipment and techniques that can be adopted by naval construction forces to provide underground protective construction at advanced base sites.

The task instructions call for the evaluation of existing reports and literature on the subject, search for and analysis of existing commercial type tunneling equipment, an outline of and plan for the preparation and completion of a manual on equipment and techniques, and recommendation for any necessary additional work.

THE LITERATURE SURVEY

Rapid tunneling records abound because each tunneling effort has been a challenge to the skill and ingenuity of men to tunnel faster than has ever been done before. Often it has been a challenge of teamwork, with face crew pitted against face crew on the same heading, or perhaps on opposing headings racing at snail-like pace toward each other, and trying to outdo one another in terms of footage or rounds completed in each shift. Frequently, the outcome has been determined by some geological inconstancy that has hampered or accelerated the progress of one or the other group. Tunneling contractors can usually point with pride to some constructional aspect that has become a record-breaking event. For this reason most tunneling equipment manufacturers can truthfully claim some outstanding performance of equipment that has contributed to at least one rapid tunneling record. These records are proclaimed in reports and advertising and usually cannot be brought to a common denominator for comparison because of differences in geological conditions and/or tunnel sizes.

Tunneling to provide underground protection against early World War II weapons is history to the Bureau of Yards and Docks and the construction battalions. The Bureau administered work from December 1940 to July 1943 for a six-million-barrel underground fuel storage at Pearl Harbor. Twenty vaults in two parallel rows were excavated. Each vault was 100 feet in diameter and 250 feet high. Over seven miles of tunnels were required for access and piping.¹ From September 1942 to December 1943, 120 tunnels 240 feet long were excavated at Waikale Gulch for underground ammunition storage.²

In September 1942, the 6th Naval Construction Battalion used air spades, air drills, and hand shovels to dig four tunnels at Pagoda Hill, Guadalcanal, to place vital equipment underground as soon as possible to be safe from bombing and shelling.³ Japanese cars were used on Japanese rails to remove the spoil.

Tunneling to provide underground protection against nuclear weapon effects has been used limitedly within the United States for a few key military installations. Notably at some missile launching sites where continuous boring machines have been used to cut underground personnel passages,⁴ and at the granite base of Cheyenne Mountain in Colorado, where, since May 1961, about a third of a million cubic yards is being excavated by the cyclic drill-blast-muck method for the underground headquarters of the North American Air Defense Command. The main rock chamber of this facility will house a three story structural steel building with about 200,000 square feet of floor space.⁵

Tunneling has been practiced extensively for many years throughout Sweden to provide bomb-resistant underground factories, power plants, oil and gasoline storage chambers, and more recently for civilian shelters. One shelter in Stockholm can hold 20,000 people in an emergency, and it doubles as a 600 car garage in peacetime. The shelter chamber is 1000 feet long, 57 feet wide, and 37 feet high.⁶ The cyclic tunneling method prevailed in all Swedish work.

Several studies of underground protection have been sponsored by U. S. Government agencies. The Rand Corporation, in connection with work for Air Force Contract No. AF 49 (368) - 700, held the Second Protective Construction Symposium (Deep Underground Construction) in March 1959 to provide information about the design and construction of underground facilities to resist nuclear weapon effects. (The First Protective Construction Symposium was held in 1957 to determine the state of the art in protective construction, and to show the construction requirements for the survival of vital installations.)⁷ Atomic Defense Engineering Technical Study No. 28 reports on the vulnerability of underground protective construction.⁸

Since tunneling is akin to mining, it is not surprising to find that the Bureau of Mines, under a project assignment from the Army Corps of Engineers, wrote a report in 1951 on the subject of underground excavations for military use in forward and intermediate areas.⁹ Then in 1957, this Bureau prepared a classified engineering manual for the design of underground installations in rock.¹⁰ The 1951 report is particularly important because the basic information fills

some of the requirements of this "rapid tunneling" task.

The Bureau of Mines conducts research and development in minerals and explosives technology to promote safe and healthful working conditions in the minerals industries, to educate mine personnel in safe practices, and to devise acceptable standards of mining operations.¹¹ This work brings them in close contact with the mining and tunneling industries and the related equipment manufacturers, and gives them first hand knowledge of the operating characteristics and comparative efficiencies of tunneling equipment and techniques.

The Bureau of Mines, in its 1951 report "Underground Excavation Methods and Equipment,"⁹ points out that underground excavating is usually performed with experienced supervision, and with methods and equipment designed for a somewhat specific condition. However, underground conditions vary widely and are difficult to predetermine; therefore, tunneling equipment and practices are usually modified to suit each underground operation as the occasion demands to provide efficient procedures. Further, it would be impractical to describe all the methods and equipment for all underground conditions. The 1951 report is intended to serve as a guide.

The Bureau of Mines selected a tunneling method that, in 45 to 60 days, would be capable of excavating 43,200 cubic yards of rock (about 960 to 720 cubic yards per day) in a single level, room-and-pillar system. This would provide three entries, each 14 feet wide and 12 feet high, and ten standardized rooms, each 35 feet wide, 175 feet long, and 12 feet high, (about 61,000 square feet total floor space), under a minimum 85-foot overhead cover. Speed of excavation was the prime consideration, and standard commercial excavating equipment for the cyclic drill-blast-muck method was selected wherever possible. Special consideration was given to existing standard Army equipment. The tentative tunneling equipment to perform this excavation in hard rock was estimated to be as given in Appendix A. With this equipment, entries could be driven with 11-1/2 degrees maximum incline (20 percent slope). It was stated that the equipment selected may not have been used in this combination in practice although each item had been used successfully in other combinations; therefore, some items would be subject to modification or substitution following trials.

The report described alternate methods for some phases of the tunneling cycle, and in each case one method was selected as the best for rapid excavation. The selected procedures included the following:

1. Compressors placed at the surface and the compressed air piped to the working faces.
2. Electric generators placed at the surface and cables laid to lighting and other circuits.
3. Surface material and rock at the portal sites to be removed as in quarrying to uncover 35-foot faces for the entries.
4. All entries driven simultaneously and each ventilated by a blower and vent pipe. After the first crosscut has been driven to connect the entries, the blowers are moved to the working faces and a ventilating fan is installed in a bypass around a two-door airlock at the center entry. Air circulates in at the center and exhausts at the outer entries.
5. Sump pumps to remove drainage while driving the inclined entries. Sumps to be excavated at the bottom of completed inclines, then the pumps are installed permanently.
6. The standard drilling round in headings to be a modified burn cut in preference to the wedge or pyramid cut. (In a burn cut, several closely spaced holes are drilled straight in. Some of them are loaded and the initial blast breaks from these to the unloaded holes. In a wedge cut, pairs of holes are angled to meet in a vee, several vees form a wedge. In a pyramid cut, four holes are drilled at an angle to meet at a common point. The wedge or pyramid breaks out with the initial blast to provide an opening to break into from delayed blasts in surrounding reliever and trim cut holes.) In the selected modified burn cut, the first reliever holes are angled as a narrow wedge, and the next relievers angled as in a pyramid. Delay electric blasting caps are used, and the number and spacing of the drill holes and amount of explosives are determined from the rock conditions.

7. Wagon drills used for open cut drillings at the entries. Jumbo mounted drifter drills with feed shells for 11-foot steel changes to drill headings and rooms. Jackhammers for secondary drilling to blast large blocks left by the primary rounds. Stoper drills for roof bolt holes.
8. Headings enlarged to room size by slabbing. Blast holes drilled with 11-foot and 20-foot steel.
9. Water tanks on diesel powered trucks to supply water (if it is not readily available at the surface) to pipe to jumbo manifolds for the drills and to wet down the muck while loading.
10. Blasting methods and safety precautions as given in Dupont's "Blaster's Handbook."
11. Thorough scaling (barring down) of all loose rock after each blast with scaling bars and gads from safe ground toward loose ground. (An oft repeated but often violated rule. About 60 percent of all mine fatalities are caused by rock fall, with more than 40 percent occurring within 25 feet of working faces).
12. Mucking by overcast loader at the face area into Koehring "Dumpton" type trucks because this equipment is best suited for forward and reverse travel and end loading in the 14-foot by 12-foot headings. Trucks will enter at the center and leave by an outside entry.
13. A minimum of roof support. It is assumed that the best tunneling ground will be selected. Large areas of bad ground encountered during tunneling will be bypassed, and small areas will be supported by roof bolts or cribbing.
14. General illumination to be supplied by 100-watt lamps at 50-foot intervals, and floodlights at all working areas.

The Bureau of Mines 1951 report was judged to be a satisfactory source of information for the most effective rapid tunneling equipment and techniques at that date. So the literature survey was directed toward finding improvements that have been introduced since the report was issued. Information was examined for cyclic and other methods.

There was a division of opinion among manufacturers contacted by the Laboratory on whether there have been any outstanding developments in the tunneling field in the past several years. However, the annual reviews in mining journals report steady improvement in equipment and methods that have increased the speed and economy of mining and tunneling.

Drilling

The improvement in drilling equipment is toward lightweight airleg drills for short rounds and jumbos with centralized controls for long rounds. Within the last two years, most of the airleg drills have been changed to provide easily reached one-hand controls, increased drill blow frequency and impact, and increased airleg pressure.¹²

The Swedish ladder drilling method, which has been adopted in several countries, uses a retractable airleg drill mounted on a narrow steel ladder. The drill is carried in a cradle which slides along the ladder rails, and the airleg acts against the rungs. It can be easily advanced or withdrawn. The advantages of this method over hand-held drills are a higher drilling rate, better control of position and direction, longer steels can be used, two drills can be operated by one man, and with less operator fatigue.¹³ Several ladders mounted on a jumbo, present a simple low cost arrangement that approaches the efficiency of jumbos with hydraulically controlled drill booms. The hydraulic booms are being used extensively in this country to replace the older hand adjusted jibs. Boom and drill controls on some jumbos have been centralized so that several drills can be operated simultaneously by one man. Cycle time has been reduced because the time-consuming manual labor associated with spotting the drill to the hole pattern has been eliminated.

Rotary percussion drills have been developed that have hydraulic bit rotation and pneumatic bit impact. Torque and feed pressure can be varied separately to suit drilling conditions. The best results are expected with slow bit rotation and heavy bit impact in hard rock, and the opposite in softer deposits. The drills can be jumbo-mounted.¹²

The 13-1/2-foot diameter, 44-mile long, West Delaware tunnel for the New York City Board of Water Supply, which was holed through in January 1960, was a proving ground for some new tunneling methods and equipment. The two principal

contractors for this tunnel made the first extensive drilling with large burn-cut holes in the drill pattern. One contractor used two 5-inch holes, close together vertically, and drilled by a Gardner-Denver Model 143 unit. The other contractor drilled a single 8-inch hole with an Ingersoll-Rand modified Model DHD-400 down-hole drill. With the large unloaded burn-cut holes, all other holes could be drilled parallel and 11-foot rounds were pulled without steel changes. This drilling arrangement eliminated the difficult and more precisely drilled short angled holes required for the wedge-cut and pyramid-cut patterns. It is believed that tunnels can be driven 20 to 30 percent faster with the large burn-cut holes, and with less overbreak, more muck per round, and more concentrated muck with less fly-rock.^{14, 15, 16} The latter contractor also used an Ingersoll-Rand Fog Eliminator, a device which preheats the drill air so that the air temperature will be above dewpoint when it is exhausted from the drill and expands. This improved visibility at the working face and increased the drillers' efficiency.¹⁶

The American Mining Congress Underground Drilling Committee, in a 1959 survey of the drilling practices of over 60 companies,¹⁷ found that alloy drill steels were used by 49 percent and carbon steel by 22 percent, the rest used both types. Most frequent failures were at the shanks and metallurgical notches, and from thread wear. However, drill steels are being improved constantly to increase the total footage drilled per steel. Some alloy drill steels are carburized and shot peened, and connection thread forms have been changed to give longer wear and to make coupling and uncoupling easier. Another development to eliminate stresses at drill-steel collars that are introduced during forging, upsetting, and heat treatment is a rubber-lined collar that is bonded to the steel shanks with epoxy cement. One company reports triple increase in footage for steels with this collar.¹² These improvements have increased cycle speed by reducing the frequency of steel breakage.

The shock resistance of drill bits has been improved in recent years by better heat treatment of bit bodies, and better bonding of carbide inserts to the bodies. One manufacturer notes that hole footage per bit has increased about 70 percent in the last five years and bits cost less.

The International Nickel Company in its mines near Sudbury, Ontario, drills over 16,000,000 linear feet annually. They maintain a Drilling Research Department to study drilling practices with an eye to increasing efficiency and reducing cost.

Drills, steels, and bits are tested for acceptance, and operating and maintenance procedures are developed to extend the useful life of this equipment. One important finding was that bit insert life could be increased 80 percent when the insert was sharpened from maximum dullness to half sharpness rather than to full sharpness, and loss of drilling speed was only 6 percent.¹⁸ A choice must be made by the bit user for speed or economy.

A method for jet drilling blast holes has been used for several years in open pit drilling of taconite. The jet is a rotating burner head which uses oxygen and kerosene to heat the rock to 4200F. Water is fed through the jet stem to the hot surface where it spalls the rock and generates steam to eject the chips. It produces a large irregular hole varying from 6-1/2 inches up to an occasional 18-inch diameter; average about 9 inches. Piercing rate averages about 17 feet per hour and burner life is about 10,000 hours. This compares with churn drill speed in taconite of 1 foot per hour and bit life of 100 minutes.^{19, 20} This method of drilling is not suitable for underground work.

Blasting

Ammonium nitrate-fuel oil (AN-FO) has been used for about five years as an explosive for open pit mining and quarrying. Procedures are gradually being developed for extensive use underground. Ammonium nitrate is sold as prills, pellets and granules. It is not considered to be an explosive until a sensitizer is added, usually 5 percent by weight of fuel oil, and this can be mixed at the site. AN-FO is highly soluble in water, but it can be loaded in thin polyethylene tubing when holes are wet. Pneumatic loading devices are available that force AN prills from a storage tank through a loading tube to the blast holes. Loading time is less than for dynamite, but static electricity, caused by movement of the prills through the tube, is a hazard. AN-FO blasting costs are about 50 percent less than for other explosives.^{12, 21}

Some blasters are experimenting with ammonium nitrate slurries which have high detonation velocities suitable for hard rock blasting. The most common is 65 percent AN, 20 percent TNT, and 15 percent water. It is unaffected by water in the blast hole. The slurries may permit a reduction in the size and number of blast holes in a round, and thus decrease cycle time. Fume characteristics of AN-FO and the slurries, when compounded properly, are comparable to standard dynamite.
12, 21

The Airdox system of blasting with 10,000 psi air, which is used in some coal mines, eliminates explosives and the attendant fumes and danger.²² The system would be adequate for some rock conditions, but it is not believed suitable for general use in unpredictable formations.

An electrothermal method for secondary breaking of rocks has been reported by Russians, and experiments with this method are under way at the Montana School of Mines. Physical break is caused by thermal breakthrough along the path of water trapped in the crystalline structure of rock when point electrodes are applied and an electric current is passed through. The current frequency and voltage varies for different types of rock. The method is dustless, cheaper, and safer than blasting, but is still in the developmental phase.^{12, 23} Similarly, the British are experimenting with high-frequency radar waves which can produce a wedge of heat to split rocks. It is almost noiseless, and the rock crumbles at hair-line cracks. For tunneling, wave-guides would be inserted in drill holes at the working face then the energy would be applied.²⁴

Loading and Hauling

The size of the loading and hauling equipment will probably determine the tunnel cross-section dimensions (except where larger items would be transported through or be stored in the completed underground facility); therefore, they should be selected for minimum size consistent with the objective of excavating useful underground space efficiently, speedily, and safely. The minimum tunnel height would be determined by the height of the hauling vehicle cab, or by the maximum working height of the loader, which in turn would depend upon the dump body height of the hauling vehicle. If a loader is selected that can load and unload without turning around, such as the rocker or overcast type, the minimum tunnel width will probably depend upon the hauler. The EIMCO Model 630 Tractor-Excavator loads 3 tons per minute in about 11-foot headroom and 6-foot width, and the EIMCO Model 635 Continuous Loader is rated at 4 tons per minute in about 9-foot headroom and 6-foot width. Both can be obtained with air or electric drives.

Several available diesel powered carriers can be made suitable for underground hauling by the addition of exhaust scrubbers. The 10-ton capacity Koehring WD 60 Dumptor and Euclid LUD have 7-foot 4-inch dump body height, about 9-foot 10-inch cab height, and about 8-foot 3-inch over-all width. Lake Shore, Incorporated,

manufactures 10, 15, and 24 ton, four-wheel-drive shuttle trucks that can negotiate 40 percent grades, 30 percent side slopes, and make sharp turns. They have no cab, and dump body height is about 6 feet. The Sanford-Day S-D Transloaders are versatile transports that self-load, haul, and dump using a single operator. The Model TL-45 has 4.5 cubic yard capacity, is 7-feet 10-inches wide and has 6-foot operating height. The Model TL-55 has 5.5 cubic yard capacity, is 7-feet 9-inches wide and has 8-foot operating height. Both have exhaust scrubbers.

Continuous Tunneling Machines

A survey of tunneling records shows that the continuous method using tunneling machines is faster than the cyclic method in some geological conditions; notably in clay and shale where rates up to 2,600 cubic feet per hour have been found. The machines are generally expensive. One machine for a 30-foot diameter tunnel cost over \$500,000.²⁵ Because these machines are used in soft materials, they are usually designed with a means to line the tunnel with poured concrete or with precast concrete or metal segments.

Some continuous mining machines can excavate underground space faster than tunneling machines. A 7-foot diameter auger has bored horizontally into coal seams at about 4,200 cubic feet per hour,²⁶ and the Joy Push Button Miner of the Peabody Coal Company was designed to mine 4-feet high by 9-feet 9-inches wide to about 1,000-foot distance at about 6,400 cubic feet per hour.²⁷

The Alkirk Corporation has developed the Alkirk Cycle Miner, a self-anchoring, pilot-pull, trepanning-type boring machine which is claimed to have a mining rate in sub-bituminous coal of 225 to 375 cubic feet per minute (13,500 to 22,500 cubic feet per hour). This rate cannot be maintained because of the limited capacity of present loading and hauling equipment to remove the loose coal from the working face.²⁸

There is need for a continuous hard rock tunneling machine that can economically match or surpass excavation rates of about 500 cubic feet per hour achieved by the cyclic tunneling method. At least two hard rock tunneling machines are being planned.

Lake Shore, Incorporated, Iron Mountain, Michigan, has a company-confidential program for the development of what is believed will be the fastest tunnel driving machine. The manufacturer's literature will be available after the prototype has been fully tested.

The Alkirk Corporation has made preliminary studies toward the design of a hard rock tunneler which show that an effective machine could be built around the Alkirk Pilot-pull Principle using rolling cutting tools similar to those for oil well drills. The company is currently studying torque requirements and other aspects of the design.²⁸

These developments should be watched although it is believed that tunneling machines would be too expensive and would restrict tunnel configuration. They should not be considered for tunneling at advanced bases except in an emergency and where geological conditions would permit the use of existing tunneling machines (which are sometimes stored by contractors for potential modification for future tunnel work.) This equipment would complement cyclic tunneling equipment to provide maximum underground space in minimum time.

CUT-AND-COVER TUNNELS

The cut-and-cover method of tunneling, where a trench is dug and the underground tube is placed then covered with the excavated material, is commonly used for the construction of drainage structures, sewers, and many subway tunnels. The same construction techniques and equipment could be used for the installation of underground protective structures such as cattle-pass shelters. Similar work has been regular practice for Mobile Construction Battalions in the construction of military bases.

The U. S. Army Engineer Research and Development Laboratories are considering a concept for a combat emplacement excavator which can excavate about 400 cubic yards per hour. It is capable of cross-country travel at speeds up to 25 mph, and can be airlifted.²⁹ If this unit proves practical, it would be a valuable asset to cut-and-cover construction work.

ADVANCED BASE TUNNELING COMPONENT

The Bureau of Yards and Docks publication NAVDOCKS P103,³⁰ Detailed Catalog of Yards and Docks Material for Advanced Base Functional Components, has several components and assemblies with rock drilling and blasting capability.

Components P-1, Construction Battalion Large; P-5, Construction Battalion Maintenance Unit; P-8, Port Development Equipment; and P-21, Harbor Clearance Component; all contain assemblies of rock drilling equipment and rock blasting consumables. These assemblies were recently revised to provide new equipment and materials. Assembly 7052, Rock Drilling Equipment - 75 TPH replaces Assemblies 7053, Rock Drilling Equipment - 30 CY-HR and 7054, Rock Drilling Consumables for 1 Wagondrill, 6 sinkers. Assembly 7055, Rock Blasting Consumables for 22,000 CY Rock has been revised to 45,000 tons. The P-4B Rock Drilling and Blasting Component supplements the combined P-1 and P-4 components on a large rock job. It is capable of producing about 200,000 tons of medium hardness quarry rock at 200 tons per hour.³¹ This component was revised recently to equip it with modern drilling machines. The components and assemblies might be revised further to include the economical ammonium nitrate-fuel oil explosives.

In an emergency, some useful tunneling work could be accomplished with the equipment and consumables in the components mentioned above, but a tunneling component should be planned if the excavation of underground space is to become standard practice. The component should be based on Appendix A except where it can be improved by greater detail, or where the items can be replaced by more efficient equipment that has been introduced since the Bureau of Mines issued its 1951 report, "Underground Excavation Methods and Equipment."

The Laboratory's review of tunneling equipment indicates that consideration should be given to a jumbo-mounted Swedish ladder drilling arrangement which would use lightweight retractable airleg drills and a large burn-hole drill for an economical and efficient arrangement, or jumbo-mounted rotary percussion drills on hydraulically-controlled drill booms for versatility and speed in mixed geological formations. The use of ammonium nitrate-fuel oil explosives should also be considered.

MANUAL FOR RAPID TUNNELING

Equipment alone will not generate rapid tunneling. It also requires skilled manpower, teamwork, and knowledge of the problems that are apt to be encountered in tunneling.

The basic Navy Mobile Construction Battalion, within its A-company, has a platoon, A-1, that is trained to do the drilling, blasting, loading, and hauling associated with quarry operations using the P-4B Rock Drilling and Blasting Component. The P-4B has a rated output of 150 cubic yards of rock per hour of a size that can be handled by 1-1/2 to 2-1/2 cubic-yard shovels.³² Although the A-1 Platoon training covers operations similar to those used for tunneling, it does not include the techniques and safety requirements that are peculiar to the underground work. If tunneling is to become standard practice for the Mobile Construction Battalions, the techniques and safety requirements would need to be added to training courses and should be included in a manual on tunneling.

The Bureau has indicated a need for a manual on rapid tunneling equipment and techniques. Seemingly, it would exclude such things as the desirability, design, or economy of underground protection as related to fallout or blast protection; the size and shape of rooms except as these affect tunneling techniques and safety; or the living or storage arrangements in the completed underground spaces.

The manual should present all factors that will lead to the rapid excavation of underground space, such as standardization of entries, crosscuts, and rooms; development of the maximum number of headings simultaneously; and the most efficient scheduling of equipment.

It is believed that the manual should be written along the lines of the Bureau of Mines 1951 report, "Underground Excavation Methods and Equipment."⁹ It should contain a condensed version of Part I of that report to instruct Mobile Construction Battalion personnel in the identification of rocks and other geological conditions pertinent to excavating competent underground structures. Part II should be rewritten to Bureau of Yards and Docks standards, and updated in regard to the speedier and more efficient equipment selected for the advanced base tunneling component and for the techniques introduced since 1951. Part III could be eliminated except, perhaps, for the glossary. A suggested outline is given in Appendix B.

CONCLUSIONS

If the excavation of protective underground space becomes standard practice for the Construction Battalions, it will be necessary to provide (1) an advanced base functional component for tunneling, (2) a manual for tunneling equipment and techniques and (3) revision of the existing Construction Battalion training courses in drilling and blasting to cover the equipment, techniques, and safety requirements that are peculiar to underground work.

The Bureau of Mines 1951 report, "Underground Excavation Methods and Equipment,"⁹ provides an excellent basis for (1) an advanced base tunneling component, and (2) a manual for tunneling equipment and techniques, but it should be updated in respect to improvements that have been introduced since 1951, particularly in drilling and blasting.

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Appendix A

BUREAU OF MINES TENTATIVE TUNNELING EQUIPMENT TO EXCAVATE 43,200 CUBIC YARDS OF HARD ROCK IN 45 TO 60 DAYS.⁹

<u>Item</u>	<u>Quantity</u>	<u>Drilling Equipment and Supplies</u>
1.	4(1)*	Jumbo. A medium size crawler type diesel [±] tractor with mounted framework and platform for 5 pedestals, hydraulic controlled booms, and 11-foot feed shells; water and air manifolds with automatic line oilers for drifter drills; racks for drill steel, spare hose, blow pipes, bits, and small tools; and floodlights with cable and a 200-foot capacity reel.
2.	20(8)	Drifter drill, 3-inch, pneumatic, automatic feed, chucked for 1-1/4-inch hollow round lugged drill steel. To be mounted on jumbo with necessary hose and fittings.
3.	6	Jackhammer drill, 55-pound, chucked for 1-inch hollow hexagonal steel. (Army standard equipment.)
4.	2(1)	Stoper drill, 2-3/4-inch, self rotating, 3-foot feed, chucked for 1-inch hollow hexagonal steel.
5.	6(1)	Wagon drill, 4-inch, 6-foot feed, chucked for 1-1/4-inch hollow round lugged steel. (Army standard equipment.)
6.	5(2)	Compressor, 600 cfm, rotary, diesel [±] driven, portable.
7.	1(1)	Water pump, 100 gpm at 60 psi water pressure at the drills.
8.	4(1)	Water truck, diesel [±] powered, 1000 gallon tank. (Alternate source for water when it is not available for pumping from surface.)

9. 3,000 feet Pipe, 4-inch light weight, 20-foot lengths. Include quick-connect couplings such as Dresser, Victaulic, or wedge lock. (For compressed air.)
10. 3,000 feet Pipe, 2-inch standard, 20-foot lengths. Include quick-connect couplings similar to those on air lines. (For water.)
11. 1,000 feet Air hose, 4-inch, 50-foot lengths. (To connect main air line to jumbo.)
12. 1,000 feet Air hose, 1-inch, 50-foot lengths. (For jackhammers and stopers.)
13. 1850 Rock bits, 1-5/8-inch, tungsten carbide inserts. (For drifter drills.)
14. 150 Rock bits, 1-1/2-inch, tungsten carbide inserts. (For jackhammers and stopers, and as follower bits in drifters.)
15. 1100 Drill steel, 1-1/4-inch hollow round lugged, 11-foot lengths.
16. 265 Drill steel, 1-1/4-inch hollow round lugged, 20-foot lengths.
17. 30 Drill steel, 1-inch hollow hexagonal shanked, 2-foot lengths.
18. 30 Drill steel, 1-inch hollow hexagonal shanked, 4-foot lengths.
19. 30 Drill steel, 1-inch hollow hexagonal shanked, 6-foot lengths.
20. 20 Drill steel, 1-inch hollow hexagonal unshanked, 3-foot lengths.
21. 20 Drill steel, 1-inch hollow hexagonal unshanked, 6-foot lengths.

Blasting Equipment and Supplies

- | | | |
|-----|----------------------------|--|
| 22. | 71.5 tons | Explosives, 60 percent ammonia gelatin, 1-1/4 by 8-inch sticks, packed in 50-pound cases. |
| 23. | 9,500 | Electric blasting caps, No. 6 strength, milli-second delays 0 through 10, 16-foot leg wires. |
| 24. | 9,500 | Electric blasting caps, No. 6 strength, milli-second delays 0 through 10, 24-foot leg wires. |
| 25. | 8,200 | Electric blasting caps, No. 6 strength, milli-second delays 11 through 16, 16-foot leg wires. |
| 26. | 1(1) | Blasting switch, safety type, 200 volt, 60 amp. (Main line.) |
| 27. | 6(2) | Blasting switch, safety type, 220 volt, 60 amp. (Branch lines.) |
| 28. | 5,000 feet
(5,000 feet) | Wire, No. 8 B & S gage, single conductor, rubber covered, double braided, waterproof. (For main blasting circuit.) |
| 29. | 35,000 feet | Wire, No. 14 B & S gage, single conductor, rubber covered, double braided, waterproof. (For lead and bus wires.) |
| 30. | 30,000 feet | Wire, No. 20 B & S gage, single conductor, rubber covered, double braided, waterproof. (For connecting wires.) |
| 31. | 50,000 | Stemming bags, paper, 1-1/4-inch diameter, 18-inch long. |
| 32. | 3(1) | Blasting wagon, 4 wheel rubber-tired trailer with 6-foot high loading platform, capacity for 250 pounds of explosives. |

33. 30 tons Sand for stemming bags.
34. 4(4) Tamping stick, 1-1/4-inch diameter, 14-foot long.
35. 4(4) Tamping stick, 1-1/4-inch diameter, 24-foot long.
- Loading Equipment and Supplies
36. 4(2) Overcast type shovel, 1-yard capacity, mounted on a crawler type diesel[±] tractor.
37. 3(1) Bulldozer.
- Hauling Equipment and Supplies
38. 12(4) Trucks, 10 ton, diesel[±] powered, preferably similar to Koehring "Dumpton."
- Ventilation Equipment and Supplies
39. 1 Main ventilating fan, 100,000 cfm at 0.5 inch water gage pressure, axial flow propeller, driven by a 20 hp electric motor.
40. 3(2) Auxiliary blower, 26,000 cfm at 3.5 inches water gage pressure, axial flow propeller, driven by a 40 hp electric motor.
41. 1,500 feet Ventilating pipe, 36-inch diameter, light-weight, rigid or semi-rigid, equipped with (1,000 feet) easily made connections.
42. 2(1) Ventilating doors, double swing, equipped with a mechanical opening device. (To fit air lock opening.)
43. 200 square yards Brattice cloth.

Pumping Equipment and Supplies

- 44. 3(3) Centrifugal pump, submersible, 200 gpm against 125 foot head, electric driven.
- 45. 3(1) Sump pump, compressed-air driven.
- 46. 1,500 feet Pipe, 4-inch, lightweight, 20-foot lengths.
(500 feet) Include quick-connect couplings such as Dresser, Victaulic, or wedge lock. (For compressed air.)
- 47. 1,000 feet Fire hose, 2-inch. (To be used with sump pumps.)

Miscellaneous Equipment and Supplies

- 48. 2(1) Generator, 100 kw, 220 v, 3 phase, 60 cycle, diesel driven, truck mounted. (Army standard equipment.)
- 49. 1,500 feet Power cable, 3 wire, neoprene covered, water-
(500 feet) proof. (For 200 volt circuit.)
- 50. 4,000 feet Power cable, 2 wire, neoprene covered, water-
(1,000 feet) proof. (For 110 volt lighting circuit.)
- 51. 70(10) Light sockets, waterproof.
- 52. 70(70) 100-watt lamps.
- 53. 1 Transformer.
- 54. 50(50) Electric hand lamps powered by dry cells.
- 55. Miscellany: roof bolts or timber cribs, blowpipes, scaling bars, gads.
- 56. Engineering Equipment: transits, levels, tapes, rods.

57. Basic machine shop (Army standard mobile field shop repair unit housed in a semitrailer.)

Shop equipment (minimum): cutting and welding equipment; lathe; drill press; pipe threading machine; pedestal and bench grinders; rock bit grinder; chain blocks; wheel pullers; blacksmith equipment; electrician's tools, meters, and equipment; truck and tractor repair tools; hand tools.

58. Protective clothing for 150 men.

Notes: * Numbers in parentheses are additional items for spares.

± Diesel equipment must have electric starters and exhaust gas scrubbers.

Appendix B

RECOMMENDED OUTLINE FOR A MANUAL ON RAPID TUNNELING EQUIPMENT AND TECHNIQUES

- I. INTRODUCTION
 - A. The Value of Rapid Tunneling
 - B. Purpose of the Manual
 - C. Scope of the Manual
- II. GENERAL GEOLOGICAL CONDITIONS
 - A. Character and Identification of Rock Types
 - B. Modes of Occurrence of Competent Rock
 - C. Structural Features of Competent Rock
 - D. Site Selection for Tunnel Entries
- III. GENERAL DESCRIPTION OF TUNNELING METHODS
 - A. Engineering Surveys and Records
 - B. Preparation of Entry Site
 1. Surface earth and rock excavation
 2. Drainage.
 - C. Entry Tunnels
 1. Horizontal
 2. Inclined
 - D. Crosscuts
 - E. Rooms

F. Sumps

IV. DRILLING

A. Equipment

1. Drilling machines
2. Drill steel
3. Drill bits
4. Drill mountings and jumbos

B. Techniques

1. Drill round patterns
2. Drifting
3. Slashing
4. Benching

V. BLASTING

A. Equipment

1. Explosives and caps
2. Wires and switches
3. Stemming and tampers
4. Scaling tools

B. Techniques (including precautions)

1. Loading
2. Delay cap sequences
3. Wiring

- 4. Firing
- 5. Scaling down
- VI. LOADING
 - A. Equipment
 - B. Techniques
- VII. HAULING
 - A. Equipment
 - B. Techniques
- VIII. ROOF SUPPORT
 - A. Bolting
 - B. Cribbing
- IX. DRAINAGE
 - A. Pumps
 - B. Sumps
- X. UTILITIES
 - A. Compressed air
 - 1. Compressors
 - 2. Piping
 - B. Electric Power
 - 1. Generators
 - 2. Wiring
 - 3. Illumination

C. Water supply

1. Equipment
2. Installation

D. Ventilation

1. Auxiliary fans
2. Main fan
3. Fan room and Air Lock
4. Piping

X1. MISCELLANEOUS EQUIPMENT

X11. SAFETY MEASURES

APPENDIX A

Tunneling Component

Personnel

Equipment

APPENDIX B

Glossary