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8 April 2009

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FOIA Officer

Enclosures

MISCELLANEOUS PAPER E-74-5

USE OF THE SUBTERRENE FOR MILITARY DRILLING APPLICATIONS

Major Lynn C. Webster

October 1974

U. S. Army Engineer Waterways Experiment Station

Explosive Excavation Research Laboratory

Livermore, California

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The subterrene melts holes through soil and rock by means of a high temperature penetrator. Its capabilities include precision drilling, simple operation, a natural casing of the drill hole (in the form of a glass lining produced during penetration), long life of the penetrator (the life of the subterrene penetrator far exceeds that of the rock bit), and environmental advantages (the loud noise and dust produced by rotary and percussion drills do not exist at a subterrene site). On the other hand, the cost of subterrene operations is a definite limitation; it is very high compared with that of conventional drilling.

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It is concluded that, in its present configuration and even with its projected capabilities, the subterrene does not meet a significant number of the drilling requirements of the Army.

MISCELLANEOUS PAPER E-74-5

USE OF THE SUBTERRENE FOR MILITARY DRILLING APPLICATIONS

Major Lynn C. Webster

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
EXPLOSIVE EXCAVATION RESEARCH LABORATORY
LIVERMORE, CALIFORNIA

MS. date, October 1974

PREFACE

The U. S. Army Engineer Waterways Experiment Station (USAEWES) Explosive Excavation Research Laboratory (EERL) evolved from the organization originally known as the USAE Nuclear Cratering Group (NCG), which was established in 1962. The period between 1 August 1971 and 21 April 1972 was a transition period during which the laboratory was known as the Explosive Excavation Research Office (EERO).

EERL conducts research in the areas of nuclear and high explosive effects with emphasis on the use of explosives for creation of military barriers to armor movement and large scale construction excavation. Closely related to this explosive excavation work is a concern with the ability of Corps of Engineers personnel to optimally place explosives for specific applications. Thus, there exists an extensive interest in improving the capability to drill large-diameter holes to reasonable depths. This work was performed as a result of this interest and funding supplied by the Inhouse Laboratory Independent Research Program of the Waterways Experiment Station.

The Director of WES during the preparation of this report was COL G. H. Hilt and the Director of EERL was LTC R. R. Mills, Jr.

ABSTRACT

The subterrene melts holes through soil and rock by means of a high temperature penetrator. Its capabilities include precision drilling, simple operation, a natural casing of the drill hole (in the form of a glass lining produced during penetration), long life of the penetrator (the life of the subterrene penetrator far exceeds that of the rock bit), and environmental advantages (the loud noise and dust produced by rotary and percussion drills do not exist at a subterrene site). On the other hand, the cost of subterrene operations is a definite limitation; it is very high compared with that of conventional drilling. An analysis of military drilling requirements reveals that additional serious limitations arise when the subterrene is considered for military applications.

It is concluded that, in its present configuration and even with its projected capabilities, the subterrene does not meet a significant number of the drilling requirements of the Army.

ACKNOWLEDGMENTS

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CONTENTS

USE OF THE SUBTERRENE FOR MILITARY DRILLING APPLICATIONS

I. INTRODUCTION

A. Background. U. S. Army Engineers, like their counterparts in industry, are continuously seeking new ways to increase their capability to excavate soil and rock. Unlike his civilian counterpart, the Army Engineer has as his main purpose for this search the improvement of the quality of the support he is able to give to the fighting soldier. The types of missions included in this support vary from the excavation of individual fighting positions to the creation of effective obstacles and beyond. Construction is also included in these missions; however, responsiveness to the front-line soldier's needs is of primary importance. The Army Engineer has been severely restricted in efforts to improve his capabilities by the absence of a truly effective method for rapidly drilling holes in soil and rock. Therefore, he is vitally interested in new drilling techniques.

One such technique now being developed at the Los Alamos Scientific Laboratory (LASL) employs a tool called the subterrene. The subterrene melts holes through soil or rock with a high temperature penetrator. Tests have demonstrated that the concept is workable and may well prove to be an extremely effective drilling method.

B. Scope. This report will review current and anticipated military drilling requirements, briefly describe the subterrene, and evaluate the apparent suitability of the subterrene for meeting these requirements. Since subterrene development is still in the active stage, the evaluation of its capabilities must, by necessity, reflect the anticipations of its developers. In some cases, these concepts have not yet been proven.

II. ARMY DRILLING REQUIREMENTS AND CAPABILITIES

A. Drilling Requirements. For discussion purposes, Army drilling requirements have been divided into three distinct categories:

1. Combat Support. Combat support represents those operations specifically oriented toward assisting the front-line combat soldiers in performance of their fighting mission.

Although several techniques have been developed to assist the soldier in preparing fighting positions, none has proven entirely adequate. Most require excessive installation time or are at least partly restricted by certain geologic conditions. A workable large-hole drilling capability could do much toward improving this situation. Such a capability would be especially effective in rapidly preparing secondary or alternate positions during defensive and retrograde operations. The reduction in manpower required to perform such work would greatly increase the forces available to the combat commander.

One of the most useful combat support tools available is the barrier or obstacle to enemy armor movement. Many natural obstacles exist in most terrains; however, the combat engineer is called upon to tie these natural obstacles together with artificial obstacles created at selected locations and selected times. An effective obstacle of this type is the explosively produced crater. Both nuclear and high explosive sources can be used to produce such craters. At present, only nuclear cratering detonations are available for producing large obstacles. High explosive cratering is generally limited to production of small road craters that will certainly slow and harass enemy armored forces but will not present a serious obstacle to their movement. An active research program is evaluating the possible military use of bulk explosives commonly used in the commercial mining and quarrying industries. These explosives would allow the combat engineer to produce large craters using large quantities of explosives. In order to gain optimum use of both nuclear devices and these new bulk explosives, a capability for drilling large, relatively deep emplacement holes must be provided. Only then can cratering charges be placed at sufficient depth to optimize crater production.

2. Construction Support. The construction support capabilities of combat and construction engineers can be greatly improved by expanding the ability to drill holes more effectively in soil and rock. Exploratory drilling can do much toward improving construction designs. Current capabilities are seriously limited. Larger hole size, both diameter and depth, is needed to allow expansion of foundation construction. In many locations, the ability to install large concrete caissons would ease the construction of large structures, such as petroleum storage tanks.

The state-of-the-art in explosive excavation has been significantly advanced in recent years. With the potential for using large quantities of explosives in such applications, a capability to drill large holes is essential if this new tool is to be fully utilized. It was learned in Vietnam,that in certain locations, massive quantities of crushed rock must be produced in order to build and to maintain effective lines of communication. Current capabilities proved inadequate for the needs in this particular situation. As mentioned earlier, the quarrying industry is now using large quantities of bulk explosives to increase production. This same capability is required if the Army is to be prepared for all types of combat situations. In addition to a bulk explosive, rock drilling equipment is required to produce rapidly emplaced, larger, deeper holes for production blasting.

3. Utilities. In the area of utilities construction, an improved capability to install water wells and utility poles is required to enhance base development operations.

B. Drilling Capabilities. In view of the current capabilities of commercial drilling equipment, Army drilling equipment might be considered quite antiquated. Rock drilling equipment includes a hand-held pneumatic percussion drill capable of drilling a 51-mm (2-in)-diameter hole to a depth of 3 m (10 ft), wagon- and crawler-mounted drifters capable of drilling up to 0.1-m (4-in)-diameter holes to a depth of 7.3 m (24 ft), and a well-drill capable of drilling 0.2 m (8-in.)-diameter holes to a depth of 305 m (1000 ft). The only earth drilling equipment available is a skid-mounted earth auger, which can drill holes up to 0.5 m (20 in.)in diameter to a depth of only 2.7 m (9 ft).[1]

C. <u>Proposed Procurement.</u> An effort is being made to gain approval for procurement of a commercial-type drilling machine for military use. A Requirement Operational Capability (ROC) is being evaluated and, if it is approved, evaluation of existing commercial equipment will begin. The specifications included in the ROC call for a drilling machine capable of drilling a 0.9-m (3-ft)-diameter hole to a depth of 18.3 m (60 ft) in a maximum of 2 h. The material to be excavated includes soil and very soft rock. The machine must also have a capability for underreaming the bottom of the hole to a diameter of 1.8 m (6 ft). If this proposed capability is approved and a suitable drilling machine is procured, a major step toward satisfying the requirements described above will have been taken. Yet to be met is the requirement to drill larger holes more quickly in medium and hard rock.

III. DEVELOPMENT OF THE SUBTERRENE CONCEPT

A. History. The subterrene (rock melting) concept was first generated over a decade ago at LASL. Unfortunately, insufficient interest in its development prevented funding for immediate research. Thus, the concept lay essentially dormant until recent years. In the early 1970's, LASL revived the concept and was able to obtain development support funds from the National Science Foundation (NSF).

The initial basis for this support was the desire to develop an improved tunnelling capability. Development research began with tunnelling as its initial goal. Midway through this first-year effort, the emphasis was changed by the sponsor. LASL was asked to concentrate its efforts on developing a subterrene capable of drilling deeply into rock. In deep holes where rock temperatures rise to a significant level, conventional drilling techniques encounter serious problems. The subterrene was viewed as a device the effectiveness of which might be enhanced by these rising temperatures. When NSF was unable to continue its support of the subterrene development during the following year, the Atomic Energy Commission (AEC) provided for its continued development. The goal of the AEC gave another new direction for the developers. It called for the development of a working subterrene capable of drilling nonlinear exploration holes through granular materials. LASL is working toward this goal and plans to begin on-site field testing soon.[2]

B. Concept and Devices. The subterrene concept is based on the fact that most rocks melt at about 1200°C (2200°F), and that materials are available that can be heated to this temperature without nearing their melting points.[3] Thus, a penetrator manufactured from some such material, heated to a temperature in excess of 1200°C, and pressed against rock by an external load should melt a path through the rock.

The initial device developed to test the concept consists of an electric heating element encased in a bullet-shaped metal penetrator (see Fig. 1). A series of hydraulic jacks provide a controlled loading to push the penetrator forward as the rock melts. The molten rock is

Fig. 1. Prototype of consolidating-penetrator subterrene.

forced into rock fractures, pores in the rock, and back alongside the penetrator as the penetrator advances. When properly adjusted for temperature and advance rate, this subterrene can leave a relatively impervious glass-lined hole. Although rock drilling was the primary goal, the glass lining prompted the testing of the device in granular soil in which hole casing is normally a necessity in conventional drilling. Tests performed in these soils showed that the glass lining was again formed and served as an effective casing.

Problems encountered in penetrating dense, unfractured rock, coupled with a desire to increase hole sizes led to the search for a technique for evaluating at least part of the molten rock. Whereas the original device consolidated the melted materials, the new device would be required to extrude the material. Thus, the subterrene technique was expanded to include two types of operation, consolidation and extrusion.

The extrusion penetrator still leaves a glass-lined drill hole; however, the bulk of the melted material is removed to the surface. The technique used for this removal includes the use of forced gaseous coolant circulating through the device. As the coolant returns to the surface, it cools the melt and carries it out of the hole through the center of the penetrator stem. The rock-melt debris can be extruded as glass rods, glass pellets, or rock wool. The system for removing the debris is not unlike that used in conventional rotary rock drills.[4]

C. Support Equipment. The total system for the current subterrene devices is somewhat complex. Both extrusion and consolidation devices require precision monitoring and control equipment to ensure maintenance of optimum penetrator temperatures and advance rates. Both also require an electrical power source, a load application structure, and a supply of compressed coolant to cool the penetrator and in extrusion to cool and remove debris.

D. Evaluations. The subterrene prototypes have been extensively evaluated in both laboratory and field environments. They have successfully drilled small-diameter holes in various types of soils and rock, including tuff, granite, and basalt (Fig. 2). Use in an actual field application has been accomplished, and another field application

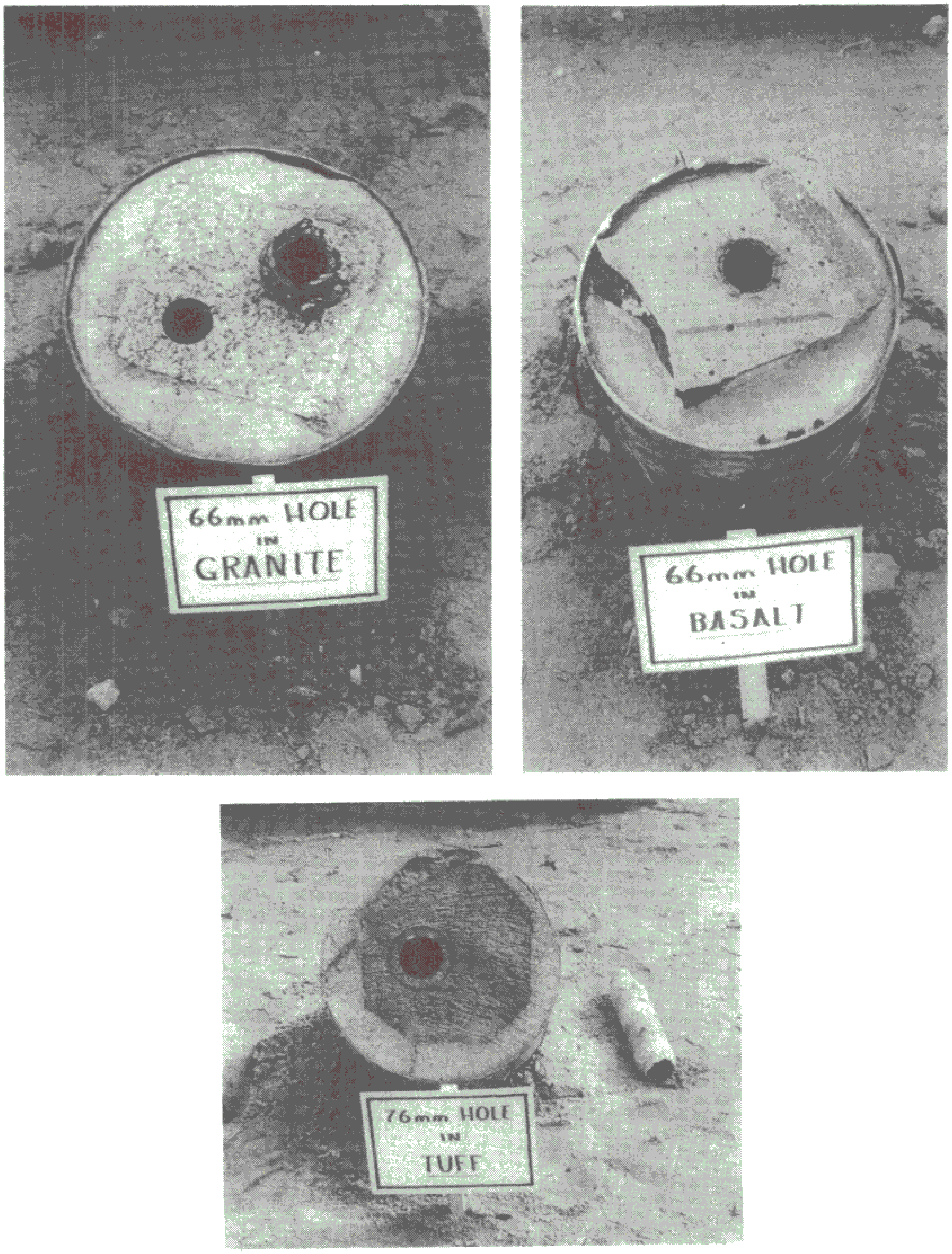

Fig. 2. Holes drilled in rock samples by consolidating-penetrator subterrene.

is planned for the near future.

E. <u>Future Plans</u>. LASL developers envision expansion of the subterrene's capability to include the drilling of much larger holes. It is expected that such a device will consist of a series of small penetrators mounted together in a circular configuration (or some other shape if desired). On very large holes, such as tunnels, the subterrene would probably be used to excavate and to line the extremities of the hole; some other method, possibly conventional, would be used to fracture and remove the core material. Another extension being considered is the development of a device that will leave intact a glass-coated center core removable for exploratory examination. The ultimate subterrene is a tunnelling machine with a self-contained nuclear power source to support its operation.[5,6]

IV. CAPABILITIES AND LIMITATIONS OF THE SUBTERRENE FOR DRILLING APPLICATIONS

A. Penetration Rate. The penetration rate of the subterrene varies considerably with the mode of operation (i.e., consolidation or extrusion) and the medium being penetrated. These rates can be predicted with reasonable accuracy based on the medium properties, penetrator design, and melting power (melting power is that portion of the total power input applied to melting the rock). Essentially, the penetration rate is proportional to the melting power with the proportionality constant being dependent upon the media properties and penetrator design.[7] The 90-mm (3.5-in) consolidation prototype has demonstrated penetration rates ranging from 1.4 m/h (4.5 ft/h) in hard soil to 6.1 m/h (20 ft/h) in soft soil. The extrusion prototype has drilled 30-mm (1.2-in.)-diameter holes through rock at rates of 0.6 m/h (2 ft/h) in hard material and 1.5 m/h (5 ft/h) in soft rock.[2] Although these rates appear to be quite low, it must be remembered that refinements of the subterrene are continuing, and one of the foremost goals is to improve these rates significantly. Analysis (by developers) of what might be considered a typical military requirement, drilling of 0.6-m (2-ft)-diameter shafts in hard rock or soil, has led to the conclusion that equipment with the following specifications can be developed:[8]

Hole Diameter	0.6 m (2 ft)
Hole Depth	20 m (100 ft)
Penetration Rate	1.0 mm/s (10 ft/h)
Power	200 kW
Coolant Type	Air
Hydraulic Thrust Force	20 to 50 x 10^3 lb

B. Support Requirements. The presently working subterrene prototype is supported by two major mobile items of equipment. The first, a flat-bed semitrailer, consists of a derrick-type mast mounted on the rear, a power supply for the hydraulic jacking system, and a rectifier to convert an external AC power supply to DC for heating the penetrator.[8] The second item of equipment is a control van semitrailer, which houses the monitoring and control equipment. The compressed coolant supply, like the electrical power, is furnished by an outside source. It is anticipated that the design of a single self-contained unit could be accomplished if such a design is desired. A single power source mounted on the semitrailer could be tailored to meet the electrical, compressed coolant, and hydraulic needs of the system. A compact control unit could also be mounted on the same semitrailer.

Operation of the subterrene prototypes in remote locations requires both electrical generation equipment and an air compressor. A 10-kW gasoline engine generator is adequate to meet electrical needs, and a 105 ft^3/min compressor (actual use = 35 ft^3/min) will provide the coolant flow to support the cooling and debris evacuation functions. The general rule-of-thumb used in estimating power requirements for future larger-scale equipment is that the power needed increases as the square of the penetrator diameter. The fuel consumption of the generator and compressor is approximately 4 gal/h during subterrene operation. Theoretically, the subterrene, after set-up has been accomplished, can be operated by one person; however, it is expected that additional personnel will be required for set-up and maintenance and repair operations.

C. Costs. The cost of operating the subterrene is quite high when compared with conventional drilling. Early cost analyses for the consolidating penetrator revealed that total operating costs ranged from \$8.04/m (\$2.45/ft) to \$26.74/m (\$8.15/ft) depending upon the type of penetrator used and the temperature of operation. The analysis addressed penetration of unconsolidated material. These figures are based upon the cost of construction of prototype one-of-a-kind penetrators and probably represent the upper limits for this type of operation.[9] Despite this fact, the lowest cost operation does not favorably compare with a conventional percussion drill operation costing on the order of \$3.30/m (\$1.00/ft) in hard limestone. In cases in which granular materials are encountered, this variance may be significantly reduced if casing of the conventional hole is required, since the subterrene produces its own glass-like casing. Efforts are continuing to reduce subterrene operating costs to a point at which the costs become competitive with those of conventional equipment. At present, however, only in very special applications involving serious drilling problems can the subterrene hope to compete on an economic basis.

D. Special Advantages. The subterrene offers several special advantages over conventional drilling equipment in certain cases. Although some of these have been mentioned earlier, it is appropriate to review them. The subterrene lends itself to precision drilling. Since the rock or soil material is melted during penetration, the concern for misalignment of the penetrator upon encountering perturbations in the medium is minimized. Such is not the case for conventional drilling. Conventional drills are easily pushed off-course by hard rocks in soil or fault planes in rock. Thus, the subterrene offers a major advantage when hole alignment is a critical issue.

Casing of drill holes becomes a serious problem in conventional drilling. It is both time-consuming and often only marginally successful. The subterrene creates a natural casing in the form of the glass lining produced during penetration.

Tests indicate that the quality, thickness, and continuity can be influenced by the operator to meet the needs of each particular situation. The life of a conventional rock bit is relatively short when the drilling is in hard rock. The need to change these bits regularly reduces the effectiveness of the drilling operation, especially when very deep holes are to be drilled. The subterrene penetrator life is not nearly so restricted and far exceeds that of the rock bit. This penetrator life enhances the subterrene's capability for providing continuous operation for an extended period -- especially true when very deep drilling is involved.

Whereas the rotary drill begins to encounter severe problems at depths at which rock temperatures become very high, the subterrene takes full advantage of this increased temperature and is able to increase productivity.

The subterrene demonstrates environmental advantages over conventional equipment when rock is being drilled; for example, the loud noise and dust produced by rotary and percussion drills do not exist at a subterrene site. The noise level is limited to that caused by the operation of a generator and a compressor, and these may be remotely located to reduce their effects further. No dust is produced by the subterrene; thus, this nuisance and health hazard normally encountered in rock drilling is eliminated.

V. EVALUATION OF THE SUBTERRENE FOR MILITARY DRILLING APPLICATIONS

In evaluating the suitability of the subterrene for military drilling applications, a typical combat support mission will be used. An analysis of the potential for using the subterrene to support this mission should provide insight into the subterrene's applicability.

The emplacement of an explosively produced crater to close a barrier system would be an extremely high priority combat support mission. Such an obstacle, to be effective, must be on the order of 30 m (100 ft) wide. To produce a crater of this size, the explosive charge would probably range between 4,500 and 9,000 kg (5 and 10 tons). To optimize placement, a vertical shaft with a diameter of 0.5 to 1 m (1.6 to 3.4 ft) to a depth of 6 to 12 m (20 to 40 ft) must be drilled. Since closure of a barrier is normally done in the face of advancing enemy forces, the ability to drill the emplacement hole and place the explosives within a very short time (3 to 4 h at most) must exist. Can the subterrene effectively support such a task?

Although developers predict that a penetrator system could be developed to drill a hole with a diameter on the order of that required, such a design is still highly theoretical. A multiple penetrator head system would be required to attain such hole sizes, and, although a subterrene of this type can probably be developed, development costs will be high and there is no assurance of success.

If the required diameters could be provided, it is anticipated that other requirements might still not be met. Hole depths of 12 m (40 ft) should present no serious problem; however, penetration rates as high as those required to meet the time limits seem impossible with the present, and even projected, state-of-the-art for the subterrene. Penetration rates of 3 to 6 m/h (10 to 20 ft/h) are needed to produce an emplacement hole quickly. Such rates can be achieved with current drills and augers in soil. To create a similar capability for rock presents a most difficult challenge.

Assuming all of the above problems could be overcome, two other difficulties would still exist for the combat engineer. To expedite crater production, explosives must be placed into the drill hole as soon as drilling is completed. This would be extremely dangerous and possibly prohibitive with the subterrene since the material surrounding the hole will remain quite hot for some time. In addition, the maneuverability of a large semitrailer-mounted drill rig will greatly reduce the rapidity with which the site can be reached and the subterrene placed in operation. In some cases, it would be necessary to select a less-than-optimum location due to the inability of the unit to reach the best emplacement location. The degree to which the drilling unit can be decreased in size is extremely limited when one considers the data presented in paragraph IV A for a 0.6-m (2-ft) hole.

The subterrene shows promise for improving the overall drilling capability of the U. S. In its present configurations it is best-suited for special applications in which particular problems are encountered that cannot easily be solved by conventional methods. The most promising future uses appear to be in the areas of deep drilling for geothermal energy recovery and rapid drilling of tunnels through hard rock. The unique capabilities of the subterrene may even be required for special military engineering tasks; however, it is expected that the number of such cases would be limited.

VI. CONCLUSIONS

The subterrene, in its present configuration and with its projected capabilities, does not meet a significant number of the drilling requirements of the Army. The subterrene developers are continuing their attempts to improve its performance. The short-term development goals for the subterrene do not promise to improve significantly its applicability to military requirements.

At some later date, if significant improvements in the subterrene have been achieved, the above conclusion should be reevaluated.

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