DEVELOPMENT OF A MECHANICAL ALCOVE EXCAVATOR FOR THE YUCCA MOUNTAIN EXPLORATORY STUDY FACILITY

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ABSTRACT

A 25 ft (7.6 m) diameter tunnel, bored nearly 26,000 ft (8 km) long, is planned as the initial opening into a rather thick strata of welded tuff rock, known as Topopah Springs (TSw2). The near term purpose of the tunnel is to examine the geology to determine if the selected formation is suitable to be used as a nuclear waste repository. In addition to the tunnel, some 30 to 40 alcoves are envisioned along the tunnel which will serve as rooms in and from which the various scientists can conduct their analytical experiments. In addition, a series of rooms and hallways are planned in an area set aside as "the main test facility".

The overall site is known as The Exploratory Studies Facilities (ESF).

The entire construction is governed by a series of ESF DRs; a set of rules, regulations and limitations which are direct descendants of the Congressional Empowering Act. One of these, ESF DR 3.2.2.4 states, "*Ground should be excavated by mechanical means. When mechanical means are not feasible, controlled drilling and blasting methods shall be used*". Other sub tier orders limit blast damage to 300 mm outside the true line of the excavation. Based on results of controlled blasting experiments in other areas where the welded tuff formation was accessible, containing blast damage to within 300 mm of the excavation line appears unlikely.

The mission of this study program was to determine if a mechanical means of constructing the alcoves, rooms and hallways was feasible. Of particular interest were the alcoves which exit directly off of the main tunnel because:

a. Drill and blast work in these intersections would interrupt any work further down the tunnel including the Tunnel Boring Machine (TBM).

b. Structurally, blast damage at an underground intersection is the most deleterious.

c. Although a Determination of Importance Evaluation (DIE) has not yet been completed, the water injected, plus fumes injected plus fracture damage due to drill and blast operations may be found to radio nuclide movement.

The work for this study included determining a somewhat standard size for the initial alcove, determining whether existing equipment and/or technology was available, and determining if such equipment could be transported and launched from the main tunnel with minimum to no interruption to the main TBM operation.

The study determined that no off the shelf equipment was both capable of effectively cutting welded tuff, and sufficiently mobile to meet the minimum interruption requirements. The study did determine that suitable technology was available, and that a special purpose machine was feasible.

This paper describes the trade off studies conducted on various excavation methods, the system selected for conceptual design and the potential performance of a mobile alcove excavator.

I. INTRODUCTION

The main 5 mile (8 km) long tunnel planned for the ESF at the proposed nuclear waste repository at Yucca Mountain in Nevada, USA, will be the first opportunity to closely inspect the geology of the proposed repository horizon. In addition to the vast amount of in-situ information to be gained from this tunnel, a number of alcoves are planned to permit more detailed scientific studies. It would be desirable to excavate these openings mechanically since blasting would not only damage the rock but would also require the dismounting of utilities and interfere with any activity further down the tunnel. This paper presents and discusses the feasibility study and performance evaluation of the Alcove Excavator.

II. BACKGROUND

At the time that this study was funded, April 1993, the then current 50% review drawings included alcoves at some 38 locations varying greatly in size and depth. The decision was made to focus on an 11.5 ft (3.5 m) high by 21.3 ft (6.5 m) wide by 40 ft (12.2 m) deep alcove. This provided for many of the requirements including being large enough to serve as a starter tunnel for the excavation of larger openings utilizing the biggest, most powerful, roadheader type machines on the market.

The requirements of the Mechanical Alcove Excavator included the following:

a. Small overall size to permit transport within the 12 by 12 ft (3.6 by 3.6 m) tunnel cross section dedicated to the transport vehicles.

b. Highly efficient cutting of the rock so that power and thrust requirements are kept to a minimum.

c. Minimum interference with tunnel utility lines.

d. Minimize time required to clear the tunnel sufficiently to facilitate single lane traffic.

e. Utilize proven technologies.

f. Incorporate the same fluid mitigation restraints as the Tunnel Boring Machine to be used for boring the main tunnel.

The overall objective of the project was to determine if a machine meeting all these objectives was feasible.

III. APPROACH

The basic excavation technology used in this study was based on data accumulated from commercial tests at the CSM Laboratory while testing a small disc cutter, 5 in. (127 mm) in diameter (Figure 1). This mini-disc was tested extensively at EMI both individually, in a linear cutting machine (LCM), and in a full scale 32 in. (0.8 m) cutterhead. These tests utilized Topopah Spring welded tuff unit #2 and Tiva Canyon rock samples. The attractiveness of this cutter was its exceptional penetration at low thrusts compared to other disc cutters being marketed. For example, the mini-disc achieved at 11,000 lbs. (49 kN) of thrust the same penetration as a conventional 17 in. (432 mm) cutter at over 40,000 lbs. (178 kN) of thrust. It is key to mobile excavator design that a suitable penetration be achieved with low power and thrust hence allowing the machine structure to be held to a minimum.

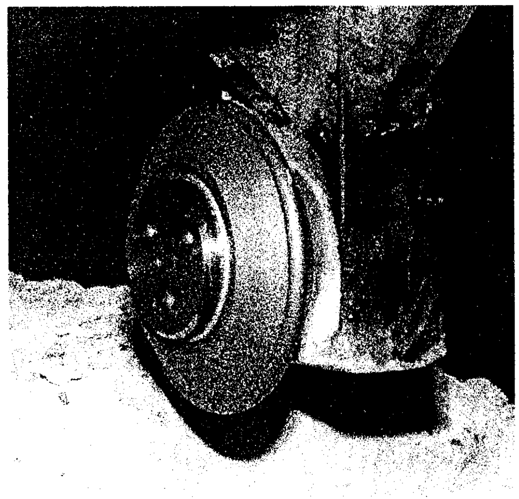

Figure 1. Mini-disc cutter

A computation based on the mini-cutter test data indicated that a sufficient excavation rate could be achieved while limiting the power to about 120 hp (90 kW), and thrust forces to about 100,000 lbs. (445 kN).

IV. METHODS OF CUTTING ROCK

Techniques of attacking the 11.5 by 21.3 ft (3.5 by 6.5 m) opening were studied from the standpoint of which cutting method utilized the cutters most effectively. Effective cutting of the rock is defined here as the proportion of the rock cut by disc cutters running repetitively in properly spaced parallel (or concentric) kerfs, as compared to the total volume of rock cut.

Four methods of cutting the alcoves were investigated:

a. Multiple plunging of a 4 ft (1.2 m) diameter drum cutter head.

b. A single 2 ft (0.6 m) plunge of the 4 ft (1.2 m) drum cutter head, followed by slewing the drum. Similar concept to Figure 2, the 6 ft (1.8 m) drum cutter head.

c. A single 2 ft (0.6 m) plunge of the 6 ft (1.8 m) drum cutter head, followed by slewing the drum (Figure 2).

d. A cutter wheel 6 ft (1.8 m) in diameter which plunges and slews over the face (Figure 3).

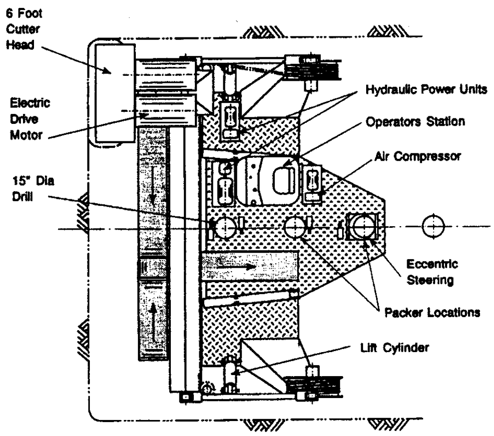

Figure 2. 6 ft (1.8 m) drum cutter head concept.

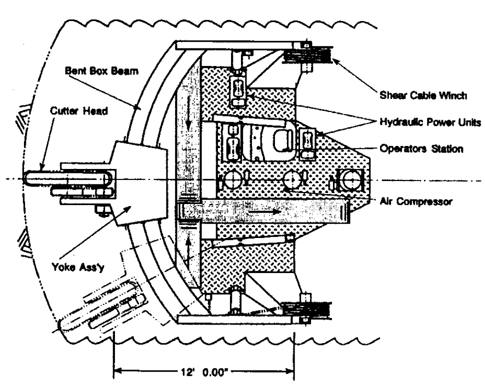

Figure 3. 6 ft (1.8 m) wheel cutterhead concept.

The percentage of rock cut efficiently by the different methods is shown in Table 1.

Concept	Type	Diameter	% cut efficiently
1	Plunging holes	4 ft (1.2 m) drum	53 %
2	Plunge and slew	4 ft (1.2 m) drum	58 %
3	Plunge and slew	6 ft (1.8 m) drum	60 %
4	Plunge and slew	6 ft (1.8 m) wheel	53 %

Table 1. Percent of rock cut in an effective manor.

The plunging head, Concept 1, was dropped at this point in the study and the latter three concepts were developed further. Two types of machine chassis were studied for each concept. One was based on a small chassied machine referred to as "partial cut machine". And the other on a full cut width machine, which could cut the entire face from one stance, referred to as a "full cut machine". The partial cut machines cut an alcove in several steps, six steps for the 4 ft (1.2 m) machine and four steps for the 6 ft (1.8 m) machine.

Performance, thrust variation and cutter head balance were investigated by creating a computer program based on the CSM data from prior mini-cutter tests. One important goal of the performance and balance program that was developed was to study the balancing of the cutter head during the slewing cutting action. In this cutting mode the cutters are moving in and out of the rock and during certain cutting actions have a constantly changing penetration depth. By simulating this with a computer program it was possible to design the cutter head to minimize the variation in resulting forces and therefore to create a stable cutting action which gives both a good performance and minimizes the structural requirements of the chassis.

At the same time the chassis layout of the units began. These took into consideration the restrictions imposed by the allocated transport space within the tunnel, an approximate cross section of 12 by 12 ft (3.6 by 3.6 m).

V. PREFERRED CONFIGURATION

As study commenced in the three areas of performance, thrust variation and physical layout, the 6 ft (1.8 m) drum plunge and slew cutterhead began to appear more and more promising.

The drum plunges into the face a depth of 2.0 ft (0.61 m), it then slews across the top, moves downward, and slews across the bottom, covering the entire 11.5 by 21.3 ft (3.5 by 6.5 m) face. Upon completion of this action, an estimated 92 minutes, the plunge and slew procedure is repeated a second time. The machine is then "re-gripped". This is done using a hole drilled in the floor and set with hydraulic packers, rather than using bulky hydraulic grippers. After advancing the sliding platform 4.0 ft (1.2 m), two plunges can again be made. Total time for a complete cycle is estimated at 189 minutes (1.27 ft/hr, 0.39 m/hr).

Other interesting features of the machine include:

a. A hollow drum cutterhead which both cuts the rock and picks up the cuttings, transferring them by a short screw conveyor onto a 12 in. (0.30 m) transverse conveyor belt.

b. A 120 hp (90 kW) A.C. electric drive composed of two 60 hp (45 kW) motors.

c. Slewing by means of a 1.375 in. (35 mm) diameter cable powered by two winches.

d. A pantex lifting arrangement which maintains the axis of the cutterhead parallel to the axis of the tunnel.

e. A gripping technique consisting of a drill and two packer units.

f. Fluid spill mitigation incorporated in the design; electric drive, dry cutters, low oil volume, short hoses, catch trays, etc.

g. The roof, floor and ribs of the tunnel are smooth. Because of the slewing and pantex beam lifting device, no scallops are cut into the tunnel ribs (unlike a swinging action). Also the face is vertical, the most favored configuration for broken or highly fractured rock.

The performance model output indicates that the force and power requirements will be as in Table 2 below. A range is provided corresponding to the range of actual performance experienced in Welded Tuff during testing of the mini-disc.

Sumping mode	Calculated requirements	Balance during cutting
Sumping Thrust	112,900-131,900 lbs. 502-587 kN	Constant
Sumping Torque	26,300 - 28,400 ft-lbs 35.7 - 38.5 kNm	Constant
Sumping Power	70 - 80 hp 52.2 - 59.7 kW	

Slewing mode	Calculated requirements	Balance during cutting
Slewing Thrust	52,900 - 71,000 lbs 235 - 316 kN	± 3,200 lbs ± 14 kN
Slewing Torque	27,600 - 37,500 ft-lbs 37.4 - 50.8 kNm	± 1,450 ft-lbs ± 2.0 kNm
Slewing Power	80 - 110 hp 59.7 - 82.0 kW	

Table 2. Calculated thrust, torque and power requirements for the Alcove Excavator.

VI. GRIPPING MECHANISM

The light weight and small size of the alcove machine compared with Tunnel Boring Machines, roadheaders or the Robbins Mobile Miner dictates that the machine must in some way be fastened down. Grippers in the form of hydraulic shoes which brace against the tunnel walls are undesirable in the case of the full cut machine and impossible for the partial cut machine types. Shoe grippers are bulky, use large volumes of hydraulic fluid and in the case of a partial cut machine would have to reach unreasonably large distances to contact a wall.

Instead, drilling a hole in the tunnel floor and then inserting a packer into the hole was investigated. This technique would appear to be feasible and from an operational standpoint more acceptable. Packer components are standard parts.

VII. TRANSPORT VEHICLE

Figure 4 shows the Alcove Machine in its transport mode, and illustrates the fact that the machine fits within a few inches of the transport envelope. In the present configuration, the rear (sliding) platform is carried above the machine. Attachment of the sliding platform is the only mobilization assembly required.

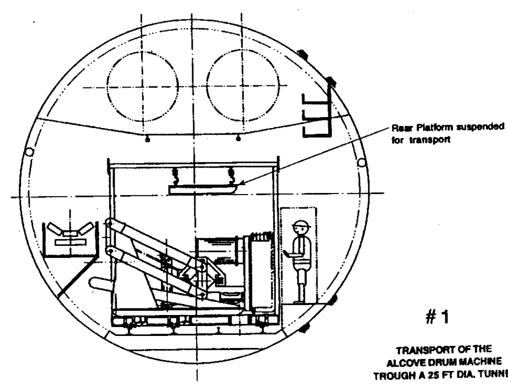

Figure 4. The Alcove Excavator in its Transport Mode

The complete transport train, consisting of two ramp-switch cars, the launch car and a support car is illustrated in Figure 5. The transport train rides on the outside rails of the dual track invert and is kept extremely low by using rollers on the rails. The platform contains a set of rails so that as soon as the Alcove Machine bores 6.0 ft (1.8 m) into the rock one way traffic through the tunnel is restored. The mobilization train functions as bridge and switches. This setup is shown in the plan view of the train, Figure 5.

To mobilize, the launch car is locked into the tunnel with jacks. The launch car also contains built-in "gripping" holes which provide the required stability for the initial cuts.

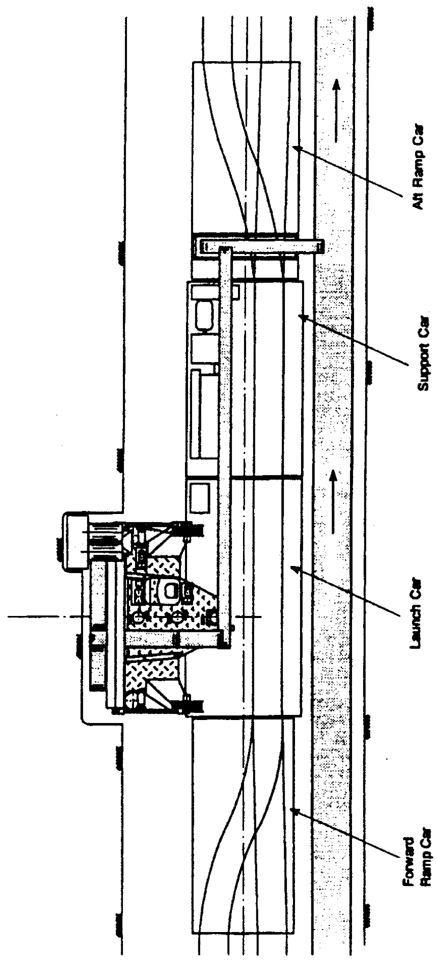

Figure 5. The Complete Transport Train

The support car contains a transformer, electrical controls, cable tray, drop box and a filter system. To control dust, a lower than ambient pressure is maintained in the cutterhead. Air is drawn through the muck pickup slots into the drop box and then through the filters. The same system is used to remove the cuttings generated by the drill which drills the holes in the tunnel floor for the packers.

CONCLUSIONS

The primary conclusion of this study is that a compact, relatively light weight, rail transportable alcove excavator machine is feasible.

A number of minor improvements to the design have been advanced since Figure 6 was conceptualized. However, the 6.0 ft (1.8 m) diameter drum machine design is still feasible. Establishment of a standard alcove size would allow a final decision on the optimal machine width.

The configuration and performance of the Alcove Excavator make it suitable for excavating other side drifts and tunnels as may be required for the Exploratory Study Facility at Yucca Mountain. In the main test area a large number of tunnels will be excavated. By installing more power on this machine the test areas can be excavated quickly and a high production rate can be achieved. More power can be installed on the machine due to the fact that there will not be the same limitation on the size of the machine structure. One of the potential repository layouts suggests alcoves for storage of high-level radioactive waste and this excavator would be suitable for that purpose.

The estimated performance output of the Alcove Excavator is presented in Table 3 below. The time requirements of maintenance, roof support, etc. were not taken into consideration in the estimated time requirements.

Performance	Results (US)	Results (SI)
Volumetric output	16.2 - 11.4 yd^3/hr	12.4 - 8.7 m^3/hr
Efficiency	2.9-5.7 hp-hr/ton	2.4-4.7 kW-hr/t
Advance rate	1.8 - 1.3 ft/hr	0.55 - 0.40 m/hr
Time to clear tracks (6 ft, 1.8 m)	3.3 - 4.7 hrs	3.3 - 4.7 hrs
Time to cut a 40 ft (12.2 m) deep alcove	22.2 - 31.1 hrs	22.2 - 31.1 hrs

Table 3. Estimated performance of the Alcove Excavator.

Condensed specifications for the machine are as follows (Table 4).

	US units	SI units
Alcove Face	11'6" high by 21'4" wide	3.50 m high by 6.50 m wide
Motors (2)	60 hp TEFC, NEMA 364T	44.7 kW TEFC, NEMA 364T
Slewing:		
force	75,000 lbs.	333.6 kN
rate	6.25 in/min @ 30 ton/hr	$2.65x10^{-3}$m/s @27.2 ton/hr
wire rope	1-3/8" 6x37	35 mm 6x37
Thrust		
force	132,000 lbs.	587.2 kN
cylinders (2)	8" dia @ 1,400 psig	203 mm dia @ 9.65 MPa
Cutter Head		
diameter	6'-0"	1.83 m
revolutions	14 rpm	14 rpm
No of cutters	35 ea. 5 in. diameter	35 ea. 127 mm diameter
gear reduction	11.7 : 1	11.7 : 1
guide rollers	VLRY 6-1/2	VLRY 6-1/2
Conveyors		
width	12"	304 mm
speed	200 ft/min	1.02 m/s
idlers	22°	22°
capacity	44 ton/hr	40 tonnes/hr
max. slope	15°	15°
Stroke	4'-0"	1.22 m
Overall Weight (estimated)	25 tons	22.7 tonnes

Table 4. Condensed specifications for the Alcove Excavator.

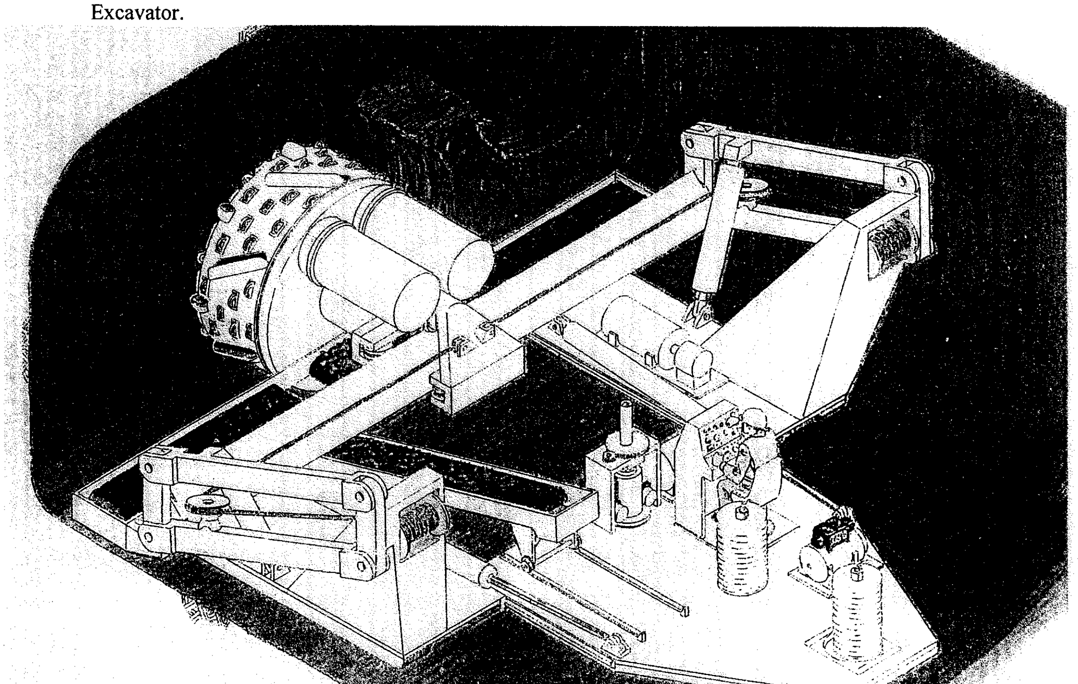

Figure 6. 6 ft Drum Alcove Excavator, (Conceptualized Drawing)

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