SUBSURFACE LASER DRILLING APPLICATIONS

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ABSTRACT

This state-of-the-art paper covers subsurface laser drilling from its early beginnings as proposed by the authors in the 1980s to our current understanding. The number of activities to which laser drilling technology can be applied is tremendous, including foundation studies, long distance tunneling and much of the environmental tasks related to subsurface releases and plumes. The laser assembly has the potential to interrogate and explode unexploded ordinances. The ability to rapidly evaluate building and bridge structures relative to earthquake damage and rehabilitation is enormous. The ability to drill through the earth, often at speeds many times that of mechanical drills, with complete control of the direction and, therefore, placement of the bottom of the hole has tremendous breakthrough potential.

Previously Unattainable Control

Laser drilling tools, as envisioned by the research team at SLAI, will give the environmental industry full control of the characterization, monitoring and remediation process of hazardous material plumes. Since the drill string does not have to exert pressure on the cutting head, flexible, lightweight composites can be used and the surface equipment will be smaller and lighter weight as well. The direction of the hole will be controllable, with short radius turns possible. Real-time sensing of the direction and angle of the bottom hole assembly will give positive, accurate readings of the cutting head position at all times and allow precise placement of the sensors within a target zone.

Faster Drilling Through All Types of Rock

Hard rocks or layers, such as gravel or soil caliche, will not stop the laser drilling process. The laser parameters can be changed from surface controls to facilitate penetration. Different rocks require different irradiances. For example, limestone requires irradiance levels three times that of sandstone, while shale requires only half as much.

Other Advantages to Laser Drilling

Since the cutting head is connected optically and electrically to the surface, real-time characterization while drilling is possible with the correct sensors. The most efficient cutting of hard rock is done by spalling, rather than melting or vaporizing the rock. However, through soft or weak materials, having surface control of the power sent to the cutting head means that the material around the cutting head can be melted and then cooled to stabilize the hole, if desired.

Once the hole is in place, the drilling string can be left in place to be used as data conveyance or, if the hole has been stabilized, the drill string can be removed and the stable hole can be re-entered with more sophisticated instrumentation

Project Needs

There is significant work left to be done. In the lab, the work done on hard rocks needs to be adapted to facilitate and optimize penetration of soils and sediments. The project needs to be taken out of the lab and prototypes constructed for both bench and field testing. The research team has ideas about the best configuration of the drill string and cutting head, but the concepts need to be proven by tests on real materials under natural conditions.

INTRODUCTION

The laser-drilling project has been pursued in two venues, oil and gas drilling for the energy industry and environmental uses. The bridge between the two efforts has been Dr. Richard Parker, as contract manager turned technical lead of the energy industry effort and a partner in the company formed to create technology for use in treatment of environmentally hazardous wastes, Subsurface Laser Applications, Inc. The energy industry work has had the opportunity to perform more testing in the laboratory, since 1998, but the environmental group has been thinking about the possibilities and performing small-scale tests for much longer.

The oil and gas drilling work has focused on hard rocks, trying the determine the most efficient way to create a hole in the earth through the three most common rock types encountered during normal drilling, sandstone, limestone and shale. Environmental drilling, staying closer to the surface of the earth, is primarily concerned with penetrating soils and sediments, with occasional need to penetrate hard boulders or outcrops to get to where the hole needs to go. Several examples of the breakthroughs that have been accomplished and their applications for both hard rock and soft soils will be summarized and discussed in this paper.

Both efforts are excellent examples of the cooperation of industry, government (including the military), academia and an institute of research.

UNBELIEVABLE POWER

Solid State Lasers	
Nd:YAG	15 kW
Fiber Diode	5+ kW
Chemical Lasers	
Chemical Oxygen Iodine Laser (COIL)	7+ kW
Mid-InfraRed Advanced Chemical Laser (MIRACL)	>1,000 kW
Gas Lasers	
CO_2	200+ kW

POTENTIAL UNLIMITED

Environmental Drilling

The environmental industry drills a tremendous number of monitoring and remediation wells each year. With the control and sensing capabilities available through the laser system, fewer wells that provide more information from more meaningful locations within or around a plume are possible.

Subsurface Tunneling

The laser-drilling system provides the potential to assist boring speed and accuracy, either through a hybrid laser/mechanical excavation machine or a totally laser-drilled, laser-guided system.

Unexploded Ordinance Removal

Lasers are being used to explode buried ordinance, but the success is measured in feet of fiber optic cable lost after setting off the explosives. With the sensing devices possible today, it should be possible to find and remove or explode buried ordinance without endangering personnel or equipment.

Structural Foundation Examinations

Small diameter laser-drilling tools could be used to visually check foundations through video links, or to place sensors along the foundations to have continuous monitoring capability.

LASER TESTS – HARD ROCK

GRI Funded work at Colorado School of Mines

Work on this project started with a 1996 proposal to GRI from Dr. Ramona Graves at the Colorado School of Mines. The project was able to get access to the military's megawatt lasers.

The Colorado School of Mines feasibility study was qualitative in nature, and answered these questions:

1. Do today's lasers have enough power to cut rock?
2. How do the various lithologies behave when exposed to laser energy?

   The lithologies behave similarly, not depending on hardness, all the way from soft shales to granites.
3. How do they differ from each other?

Conclusion There is as much variability within lithologies as between them

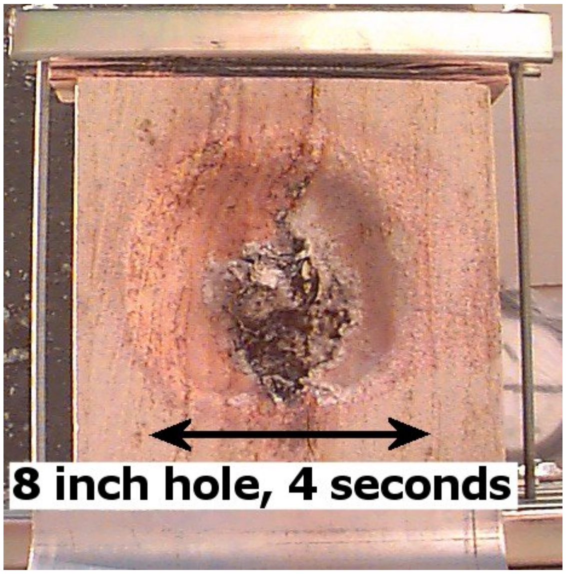

Figure 1. This picture shows a 12X12 in. (31X31 cm) block where an 8 in. area was removed in 4 seconds by a 6 inch beam of energy.

DOE-funded work at Argonne National Lab

After the GRI funding period expired, the team was expanded, adding a Laser Applications Laboratory at Argonne National Lab, and approaching the Department of Energy National Energy Technology Laboratory to continue the work. This team remains together today.

In contrast to the GRI-funded tests, the 2001 continuation study was intended to be more quantitative. The experiment design was changed to reduce beam absorption and other energy wasting occurrences; what we called secondary effects. The goal was to answer the following questions:

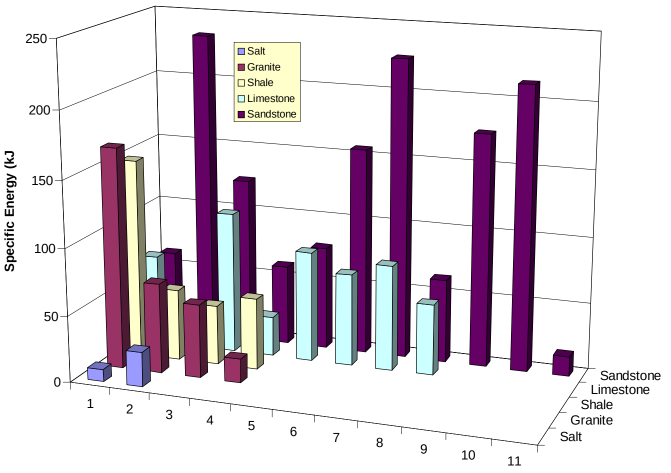

Figure 2. Graph showing how early tests indicated that there was as much variation in the amount of energy required to cut rock within rock ypes as between them.

1. What is the minimum amount of energy required to cut rock?
2. As secondary effects are minimized, do lithologic differences become more apparent?
3. Is breaking the rock, called spalling, more efficient than melting?

Conclusion. The modification of the experiments were very successful, as can be seen in Figure 3 and in Table 1.

Definition. Specific Energy, the amount of energy required to remove a unit volume of rock, was calculated using the equation:

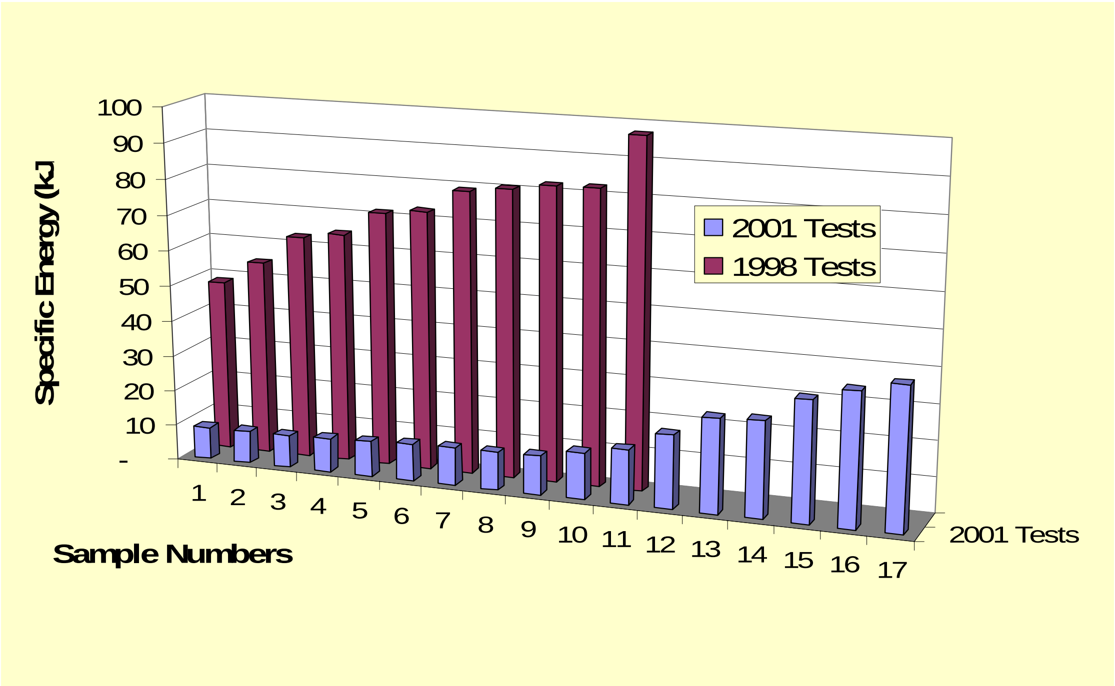

Figure 3. The new experiment design resulted in a much closer approximation of the energy required to remove a unit amount of rock, called the Specific Energy. The values obtained in 2001 on the Nd:YAG laser were, at times, an order of magnitude less than the results of the first tests using the COIL laser.

S.E. = P*t/v
P = power, in watts
t = time in seconds
v = volume of rock removed

Power is the measured power, regardless of whether the laser is pulsed or continuous wave. Time is the total time the beam is on, whether there are off cycles in the pulse train or not. Volume was calculated by weighing the sample before and after irradiation and using its density to calculate the volume removed.

Table 1. Comparison of early, small hole tests (1998-2000) with shallow, wide hole tests (2001).

	1998-2000 Test Series		2001 Test Series	
Lithology	**S.E. Values (J)**	**Standard Deviation**	**S.E. Values (J)**	**Standard Deviations**
Granite	76,000	63,000		
Limestone	73,000	30,000	23,230	6,924
Salt	13,000	9,000		
Sandstone	128,000	78,000	23,103	14,533
Shale	101,000	68,000	2,987	1,563

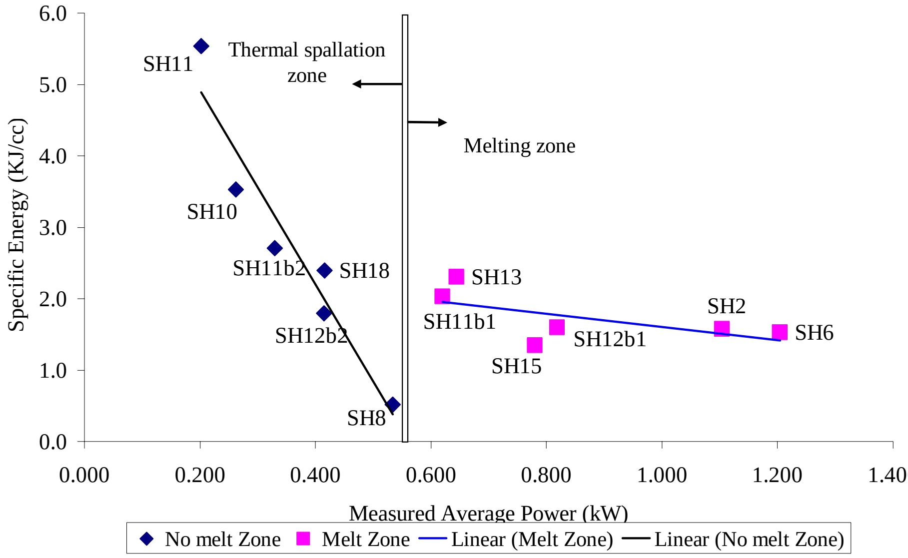

Figure 4. The energy required to melt rock is more than to spall, or break it, even in a non-granular rock like shale. There is also a fine line between the power that is very efficient and the power that causes melting.

Other Results

When secondary effects were reduced, more subtle, but very meaningful results, were quantified. Figure 4 shows the change in the Specific Energy value when power is increased until melting occurs. This shows the value in controlling power to achieve the most efficient result.

FOCUS ON ENVIRONMENTAL DRILLING

Hazard Characterization

Laser drilling has enormous potential associated with characterizing and remediation of hazardous subsurface groundwater plumes. For example, the fiber cable associated with high-energy lasers is approximately 1” in diameter. These 1” tubes can be transported through a coil arrangement. Thus, bringing the fiber optic head to the drill site could be as simple as walking over with a garden hose that is unraveling from a portable reel. Thus, access in buildings, structurally constrained outside areas, hazardous conditions, etc. can easily be accessed using this technology. When drilling under subsurface tanks or subsurface landfills, the accuracy of laser drilling will allow for a substantial safety of margin when angled drilling or directionally drilling underneath areas of high risk. Current drilling technologies will obtain a soil sample every five feet as part of the drilling process. Laser drilling not only allows continuous information to be gathered over a subsurface profile but also allows for a continuous understanding of the subsurface distribution of contamination. When drilling with micro-holes, numerous advantages are achieved. For example, minimal contaminated soil cuttings are brought to the surface and the hole can be easily imploded upon itself thus sealing it up to preclude any migration once the drilling interrogation has been completed. One of the most common problems associated with groundwater contamination is the potential for subsurface drilling to create conduits for the contaminated groundwater to move even deeper in the system through confining layers. Because of the micro-holes created and the drilling speed, the ability to very accurately determine the depth of the contamination without jeopardizing deeper drinking water aquifers is enhanced.

Monitoring

Groundwater monitoring is the single largest expense associated with long-term stewardship of radioactive and hazardous waste sites. The potential for lasers to be used to drill to multiple depths with multiple analyses has huge potential cost savings. Further, the potential for lasers to be used to analyze groundwater in real time as part of a groundwater monitoring strategy has enormous potential. Since current groundwater monitoring strategies rely almost completely on the use of groundwater wells, a laser-drilling approach could satisfy an early alert criteria wherein soils directly below a contamination site could be monitored in real time to alert an operator that contamination has began to migrate long before it ever reaches the groundwater table.

Remediation

Current remediation strategies associated with groundwater focus on the horizontal and vertical distribution of the contaminated groundwater plume. The remediation strategy not only ensures that the plume does not expand vertically and horizontally but also includes a monitoring requirement to demonstrate that the remediation has successfully taken place and that the groundwater plume is reducing in size. Since all groundwater remediation strategies are very dynamic, the use of conventional drilling technologies results in a pincushion effect related to the contamination area. The potential to use micro-wells to track the contamination as the groundwater plume shrinks has substantial time and cost advantages. Furthermore, since most of the remediation strategies result in a source reduction and a distribution of remediation efficiency within a plume, having many more micro wells to provide a clear understanding of the remediation efficiencies is highly desirable.

Other Advantages to Laser Drilling

Roadways and Other Structures. Many areas of the world use multi-level roadways to enhance vehicular transport ease. Along the same line, many countries use bridges to support rapid transfer on rail systems. The majority of these transportation-support structures rely on concrete and rebar for their structural integrity. As part of an earthquake rehabilitation program it will be possible to use laser-drilling technologies to not only interrogate the concrete for potential failure but also to create access holes wherein rebar can be introduced to reinforce the concrete structures. Clearly, if one can envision a multiple level roadway exchange that requires an earthquake rehabilitation, it is inconceivable to think that a drill rig could allow access to the vertical columns wherein it is highly reasonable to think that one could lower cages down with a coil released laser-drill to create rebar access holes at various locations in vertical concrete support columns.

Unexploded Ordinance: With respect to applications for unexploded ordinance; once new UXO locations have been identified using surface or remote scanning technologies, a confirmation approach is required. That confirmation approach typically involves either excavation or a surface conventional drilling technology. Using micro-laser-drills, a micro-hole can be very accurately created down to the ordinance of interest. Once the ordinance has been located, the laser drill parameters can be changed to either interrogate the kind of ordinance casing or to atomize the material around the ordinance so that one can visually look at the kind of ordinance. If the nature of the ordinance is such that it is unstable or can be exploded in place, the laser-drill parameters can be re-configured to detonate the explosive. The notion of using conventional drilling technologies to drill down to most UXO is simply unreasonable.

PROJECT NEEDS

The project team is anxious to move on to the next steps in developing a laser drilling system, which include engineering design and modeling work for bench and field prototypes

The speed that we can move to prototype development depends on funding levels.

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