Blasting for Rescue Applications

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Abstract

The use of blasting to rescue entrapped persons has a long history. At the turn of the 20th century, mine collapses were unfortunately common. Major rescue efforts often involved drilling and blasting to reach trapped miners. In recent years, explosives have been used in at least one cave rescue effort in Europe and a successful mine rescue in Australia. Given the risks involved and limitations of high explosives however, blasting to remove obstacles is uncommon today.

Advances in technology have opened up new possibilities for the cave or mine rescue team that should be considered. The wide availability of high-powered, battery-operated rock drills, non-detonating blasting cartridges and even small-scale “micro blasting” kits have opened up new options.

In this paper, we survey the current state of these techniques, including their capabilities, limitations and the logistics of building a deployable capability for a rescue team. We will include an overview of the evaluation and training program we implemented for the San Bernardino Sheriff’s Cave Rescue Team, as well as data and test results.

Background and Need

Caves and mines present a challenging environment for the rescuer. Hazards such as rockfall and restricted access can make it difficult to remove a person who may be trapped. The ability to modify rock features is a unique capability that can simplify many of these complex problems.

After studying the unsuccessful rescue effort at Nutty Putty Cave in Utah in 2009, (Anon, 2021a) the San Bernardino Sheriff's Cave Rescue Team began looking at ways to improve outcomes in underground rescue through the use of rock breaking. The only recent events involving the use of explosives in a rescue we could locate were the Beaconsfield Mine Disaster in Tasmania in 2006 (Anon, 2021b) and a cave rescue in the Tatra Mountains of Poland in 2019 (Anon, 2021c). It is the intent of this paper to show that, due to advances in portable drills and low-impact blasting, explosives are now a viable tool for a modern rescue team.

Applicable Specialties: Cave Rescue, Mine Rescue, Urban Search & Rescue

Enabling Technologies

Four key technologies were identified as enablers for rescue rock breaking:

1. Cordless rotary hammers featuring Lithium battery and brushless motor technology
2. Micro-blasting systems that use small-diameter holes and are largely exempt from licensing and storage issues
3. Class 1.4 blasting cartridges that can rival high explosive performance for many applications while presenting fewer risks
4. Traditional stone quarrying techniques (wedges and shims) combined with modern tools and methods

Considerations

We attempted to view this capability from a holistic standpoint. There is no point in pursuing a rock breaking and blasting program if rescue teams cannot afford the cost and time commitment, or the agency on scene will not allow its use.

To that end, we investigated the following areas:

Logistics - All capabilities discussed here meet the following criteria:

a. Require a minimum of special storage, handling and transportation
b. Are portable in backpacks or parcels under 30lbs/15kg
c. Can operate with zero access to AC power or other utilities

Legal - Since all explosive products are regulated in some way, a variety of rock breaking options should be available to teams, including:

a. Mechanical options that do not use explosives
b. Micro-blasting systems that are regulated similarly to powder-actuated tools and do not require a license to use in most US jurisdictions
c. Class 1.4 rock-breaking cartridges that, while falling under ATF and other regulations, can be transported in a non-placarded vehicle and stored in an inexpensive Type 4 magazine
d. The use of conventional high explosives, typically in coordination with an agency bomb squad or a blasting contractor

Cost - Developing a blasting capability from scratch is expensive. Any new capability must provide a benefit to the public at a reasonable cost. To do this, the following design principles were utilized:

a. Each level of capability builds on the one prior. Higher level capabilities leverage the existing investment in training and equipment.
b. Almost all of the tools needed for each capability level can be sourced from construction and mining suppliers around the world.
c. The micro-blasting systems and 1.4S explosive cartridges described are available from at least two manufacturers and multiple distributors.

Training - A rescue team cannot commit to learning a new skill without understanding the training commitment needed. Based on our team's experience, the following principles were developed:

a. Teams should first focus on proficiency at breaking and moving small rocks. Since explosives fundamentally turn very large rocks into smaller ones, small, close-quarters rock breaking and removal is a foundational skill.
b. For a team to be proficient in a skill, it is recommended that they not only train regularly on that particular skill (i.e. mechanical breaking) but also seek out "awareness level" training at the next higher level (i.e. micro-blasting or commercial blasting).
c. Rock breaking should become an adjunct to other skills the team already practices, such as bolting, mechanical advantage systems or USAR skills.

Safety and Risk Management - Any new capability introduces new risks. Since everyone involved in rescue operations has to answer to some type of risk management, we have included some general concepts to guide the rescuer:

a. In most cases, there is a rock-breaking option that is safe to use even in direct proximity to a live subject.
b. The capabilities described can mean the difference between life and death for a trapped subject. They may be the only viable option for saving someone facing imminent death due to hypothermia or crush injury.
c. The risk to rescuers can be reduced by modifying the rock environment with explosives. Hazards such as rockfall and squeezes can be greatly mitigated.
d. The class 1.4S cartridges and micro-blaster charges described will not detonate unless confined inside rock. They also produce a minimum of fumes and are safe to use in non-ventilated areas.

Capability Level Model

We have developed a 4-tier model of team capability. The levels defined below can be met within a single team or by utilizing a composite team such as Search & Rescue (SAR), Fire/USAR and private contractors working together.

A recommended set of equipment and techniques for each level is outlined in Appendix 2. They are designed to work without access to utilities such as mains power or compressed air.

These capability levels assume that a team undertaking rock breaking is already proficient in some type of underground or confined-space rescue. We do not consider other non-explosive methods of rock breaking, such as the use of expanding grout, as these are usually too slow for practical rescue applications. Methods of hauling out the broken rock are also outside the scope of this paper.

Level 1: Can use mechanical rock breaking techniques such as "feathers and wedges," (Anon, 2021d) chisels, and sledgehammers. Can crack and remove rock flakes or modify openings with power and hand tools. Able to utilize technical rescue techniques such as bolting and rope systems to move rock. A level 1 team should also have awareness-level training on micro-blasting.

Level 2: Adds proficiency with a commercial micro-blasting system. This complements mechanical splitting and prying techniques with the ability to break up boulders or rock one (1) cubic yard/meter or less in size using 1-5g explosive charges. The team should have awareness-level training on explosives and blasting and ideally, should have one person working towards becoming a licensed blaster.

Level 3: Includes class 1.4 blasting with commercial cartridges ranging in size from 5-120g net explosive weight (NEW). A level 3 team has the ability to break multiple tons of rock quickly and manage moderate air blast and fly rock hazards. The team should have at least one licensed blaster and all team members need support-level training on explosives use. This capability may be in conjunction with a public safety agency bomb squad or outside contractor who manages product inventory and oversees the program.

Level 4: The team is fully integrated with a bomb squad or blasting contractor. A level 4 team can utilize detonating cord, shaped charges and other high explosives in conjunction with level 1-3 techniques. A full level 4 team is capable of actually mining 3 feet/1m or more into unbroken rock, shattering blocks over 3 cubic yards/meters in size safely and can operate in difficult rock conditions. Multiple licensed blasters should be able to deploy with the team. In addition, engineers, experienced miners, or other professionals must be available for help with technical issues.

Overview of Technologies

Micro Blasting is a small-scale rock-breaking process that has become widely available in the last 20 years. The general idea is that a small diameter hole is drilled, cartridges containing nitrocellulose or similar propellant are inserted, and the hole is stemmed up with a metal tool and fired. Rock is broken via the hole pressurizing, causing it to fail in tension. No significant shock wave is generated.

A variation on this, variously called "capping" or "Tic-boum" in Europe utilizes widely available .22-.27 caliber blank cartridges made for nail guns that are fired with a slide hammer or similar tool that can both stem the hole and strike the cartridge's primer.

Commercial systems include a pneumatically-activated system called the "EZ Break" that utilizes 5/16" (8mm) diameter holes up to 18" (45cm) deep and an electrically-fired system called the "Sierra Blaster" that uses 10mm drill holes and waterproof cartridges. The net explosive weight of a cartridge for both systems is around 1g. Both systems can break up and remove 1-3 cubic feet (.03-0.1m^3) of rock at a time and typically do not require licensing nor magazines in most cases.

1.4 Cartridge Blasting is a process similar process to micro-blasting. The products are larger and instead of a metal stemming tool, a clay/sand/aggregate mixture is typically used to seal up the hole.

High-pressure gas (up to 140,000psi) is generated in a deflagration process. The cartridges are typically oxygen-balanced and do not produce significant quantities of toxic fumes if initiated within a well-stemmed borehole. They are available in weights from 3g to over 1kg and diameters from 9mm to

90mm, depending on brand and include electric or NONEL initiators. The NXBurst products from NXCO Mining tested ranged from 10-60g and were cable of breaking very large boulders and even in-situ rock. In the US, they are classed as class 1.4S material and can be stored in a simple type 4 magazine. They do not represent a significant hazard when not confined in a borehole.

Investigation

In order to develop this idea into a real capability, several questions needed to be answered about these technologies. We interviewed professionals in the quarrying and trail building professions, solicited samples of the materials and tools involved and performed hands-on testing. The goal was to determine if the methods outlined would actually be useful to a rescue team. The study methods used were as follows:

1. Using manufacturers' catalogs and datasheets, we identified tools and drill bit sizes available in the US commercial trade that would be useful for portable rock breaking.

2. We performed field tests to determine if suitable blast holes could be drilled by rescuers using only cordless equipment. Test drilling took place using brushless SDS+ and SDS MAX drills and fully-charged Lithium Ion battery packs.

A series of holes were drilled, with drill bits cooled off after each 45cm/18" of progress. Drilling continued until a drill battery pack was no longer capable of powering the drill. Both hard and medium rock types were tested. Drill test results are summarized in Table 1.

3. Using interviews and data supplied by manufacturers, we determined that 1.4S products ranging in size from 10-60g would be best suited for rescue applications and we procured samples for testing.

4. A variety of high explosive shaped charge configurations from 100-400g were tested for their potential to break boulders or create holes into in-situ rock. Orica Powerditch 1000 dynamite was used.

5. Rock splitting with 50grain/foot (10.2g/m) PETN detonating cord and small diameter holes was tested as a rescue blasting technique.

5. Qualitative results and simple "rules of thumb" models uncovered during testing were documented and prepared as findings.

6. The micro-blaster and full-size 1.4S cartridges were safety-tested by initiating them in open air to determine if they represent a significant storage/transport hazard. All products were initiated using a BTS-50 Handi-Blaster machine.

Trade Size	Rock Type	Metric (mm)	Area (cm^2)	Drilling Effort	CM of holes per 72W/H (measured)	CM of holes per 72W/H (predicted)	CM of holes per 320W/H (measured)	CM of holes per 320W/H (predicted)	Standard Blast Hole (cm)	Blast holes per battery	Product Type	Applicable Techniques
5/16		7.94	0.49	0.39		332.80			45	7.40	EZ Break (4x1gm)	1,2,4
10mm		10.00	0.79	0.62		209.68			60	3.49	Sierra Blaster (3x1gm)	1,2,4
7/16		11.11	0.97	0.77		169.80			60	2.83	Autostem 9mm x 10gm	
½	Hard	12.70	1.27	1.00	130	130.00			60	2.17	Autostem 9mm x 10gm	1,3,4
14mm		14.00	1.54	1.22		106.98			60	1.78	NXCO (13mmx10gm)	1,3,4
9/16		14.29	1.60	1.27		102.72			60	1.71	NXCO (13mmx10gm)	1,3,4
5/8	Medium	15.88	1.98	1.56	140	140.00			65	2.15	Autostem 17mmx20gm	1,3,4
5/8	Hard	15.88	1.98	1.56		83.20			65	1.28	Autostem 17mmx20gm	1,3,4
¾		19.05	2.85	0.36				388.89	80	4.86	Autostem 17mmx40gm	1,3,4
7/8		22.23	3.88	0.49				285.71	40	7.14		1,3,4
1		25.40	5.07	0.64				218.75	65	3.37		1,3,4,5
1 ¼	Medium	31.75	7.92	1.00			140.00	140.00	65	2.15	NXCO 28mmx20gm	1,3,4,5
1 ¼		31.75	7.92	1.00				140.00	65	2.15	NXCO 28mmx40gm	1,3,4,5
1 3/8		34.93	9.58	1.21				115.70	65	1.78	NXCO 34mmx40gm	1,3,4,5
1 ½		38.10	11.40	1.44				97.22	65	1.50	NXCO 34mmx60gm	1,3,4,5

1. Feather & Wedges 2 – Micro-blasting, 3- 1.4 Blasting 4 – Pre-splitting 5 – Conventional Blasting

Note: 1/2" holes tested with Ryobi SDS+ drill, 3AH high-output Lithium battery, med & hard rock. 1.25" holes tested with Hilti TE-60A36 in medium rock.

Table 1: Cordless Drilling Test Results.

Qualitative Findings

1. All forms of small-scale rock breaking work best in hard rock that is free of major flaws. Both testing and interviews with experts confirmed that soft or fractured rock often requires more energy to split than competent rock. This is true with feather and wedge breakage, detonating cord pre-splitting, and 1.4S blasting.
2. With micro-blasting and 1.4S cartridges, a good gas seal is critical to performance. The stemming material or tool must be tightly-fitted in the hole. Holes should be drilled perpendicular to any obvious cracks. Holes should be cleaned of drill dust before loading, as the cartridges are often a tight fit.
3. Detonating cord is extremely reliable at splitting even low-quality rock. More explosive weight or a closer pattern of holes may be required in fractured or soft rock, but it will reliably split rock linearly or shatter small boulders under almost any conditions.
4. Water is an efficient coupler of explosive energy. It’s often possible to achieve a rock split with lower-weight detonating cord if water can be introduced into the hole.
5. Small-diameter drill bits (i.e. less than ¾” or 19mm) do not dissipate heat well and should be swapped out frequently during drilling. In hot conditions, batteries and drills may also overheat.
6. Battery consumption appears to scale linearly with hole volume. Rock type can vary the energy requirement for a give hole by up to a factor of 2.
7. SDS+ style drills should be used for holes < 19mm or ¾” and SDS Max systems should be used for larger holes. SDS Max machines turn slower and deliver fewer blows per minute. Small-diameter holes can actually be drilled faster with the lighter SDS+ drill. Energy consumption per volume of hole is similar between SDS+ and Max systems.
8. In all cases, rock with multiple free faces is much easier to break. Free-standing boulders or flakes are easiest to break while in-situ rock is the most difficult. Creating relief through digging, drilling relief holes or making a wedge cut is the key to removing embedded boulders or bedrock.
9. 1.4S cartridges require accurate, straight drilling. Hole depth must be at least 3X the length of the cartridge and holes should be situated to allow a predictable burden to a free face. Small holes should be stemmed with a mix of very small aggregate, clay, and water and larger holes with sized, sharp gravel.

10. When initiated in open air, both the 1g micro-blaster cartridges and the 60g 1.4S product do little more than blow the ends off of the cartridge. They do not represent an explosion hazard until confined.
11. Shaped charges over 220g (½lb) are effective at breaking small and medium-sized boulders, They must be large (1kg+) and utilize a high-density liner to achieve significant penetration in bedrock. Air blast is a significant hazard.

Figure 1: Drilling a wedge cut to lower the floor in a cave passage.

Figure 2: A two-head Micro-blaster system prepared for use.

Conclusion and General Notes

Rock removal with explosives is a viable technique for underground rescue teams, thanks to modern cordless tools and precision blasting products. In particular, micro-blasting, 1.4S blasting and detonating cord pre-splitting were shown to be very effective while keeping air blast and flyrock hazards to a manageable level. Future work could include studying more advanced 1.4 hole and delay patterns, developing high-efficiency shaped charges specifically for rock and developing a rescue blasting manual.

During the writing of this paper, the SBSD Cave Team was deployed to an actual mission requiring level 2 rock breaking skills. The outcome was successful, as described below in “Appendix 1.”

Figure 3: 40g, 20g and 10g class 1.4 blasting cartridges

Figure 4: A 50-cap blasting machine and 25m firing line for 1.4 product

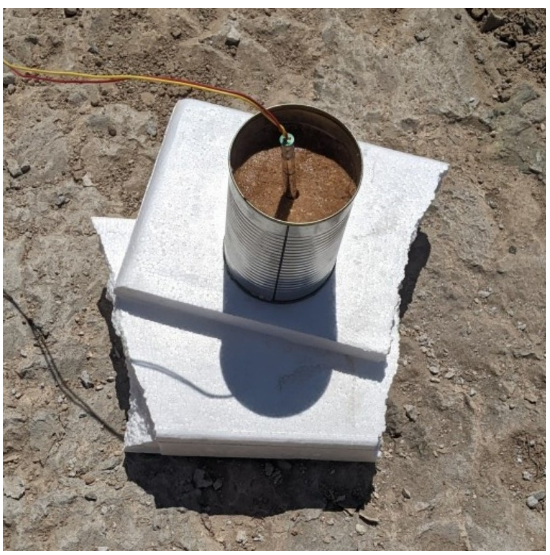

Figure 5: A ~225g (½lb) lined shaped charge set up in test configuration

Figure 5: Typical shaped charge results on bedrock. 10-22cm penetration and a shallow crater left behind.

Appendix 1: Case Study: Joshua Tree Mission

In July 2021, the SBSD Cave Team was requested to help with recovering a deceased subject in a remote area of the Mojave Desert. A County Fire team had previously been unable to extract this body by conventional means. An evaluation on-scene revealed an adult male pinned on their back inside a deep, narrow cave formed from granite boulders. Only the subject's hand was visible from above. Team members packed up equipment including PPE, a cordless rotary hammer, pry bars, chisels, micro-blasting equipment and rope rescue gear and began the mission.

The plan was for one team to begin removing rock from the bottom, with a goal of enlarging the opening enough to slide the deceased out for packaging. The other team would survey the top and watch for rock movement. Work began by drilling into the largest rock to the left of victim's legs and placement of (3) 1g EZ Break charges and the micro-blasting tool into the hole. After clearing personnel away, the hole was detonated. A rock flake weighing approximately 100lbs/45kg was broken off and removed with scaling bars. More holes were drilled and fired. After 3 such blasts, it was apparent that the rock was quite fractured and did not blast well.

Work shifted to freeing the subject from the top. With 30 minutes of work with hammers and chisels, we were able to visualize victim's head, torso and left arm. The arms were secured at the wrists with webbing and tied off to a 6'/2m miner's scaling bar, to prevent subject from sliding away.

At this point, it appeared that the right arm and torso had swollen and were stuck tightly in the cave opening. Our best chance at recovery seemed to be removing the ring of rock around the cave opening. Team members drilled 3 holes approximately 12"/30cm deep and spaced 6"/15cm apart. The rock was blasted with one cartridge loaded in the center hole. The ledge rock cracked but did not break apart.

Using a hammer and tapered pin, the crack was enlarged enough to insert a pry bar. About 50lbs/20kg of rock were freed and removed. Another 8"/20cm deep hole was drilled lower and to the right and loaded. This was a particularly unpleasant task, as it involved working inches from the decomposing body. On firing, the last remaining rock entrapment fractured off. Team members were able to manipulate the rock piece and lift it free. The victim was lifted out of the hole using a 100' rope and pulley system without incident.

Appendix 2: Recommended Equipment List

Level 1 Equipment List

Qty.	Description
1	Hearing & eye protection for each team member
1	Fitted P100 half-face respirator or PAPR for each team member
1	SDS+ hammer drill
4	Large (72WH equivalent) batteries.
1	Group charger for above batteries
12	Wedges and shims in ½ or ⅝” sizes.
6	SDS+ drill bit sized for W&S set above, 150mm-300mm length
2	SDS+ moil/jackhammer bit for above drill
2	Pinch Point Bar, 4’/1.2m
2	Single jack hammer, 1-2kg/2-5lb
2	Sledgehammer, 4-5kg
1	1m/30" Jimmy Bar
1	2m/6’ scaling bar
2	Cold Chisels, 1”/25mm width
12	Hardwood wedges, 4”/100mm wide x 8-12”/200-300m length
12	Hardwood blocks, 4x4x12”/100x100mm 300mm length
2	Car jacks, scissor type, 1.4ton capacity
1	Canvas tarp for flyrock protection

Optional:

Qty.	Description
1	SDS MAX hammer drill
4	Large (200WH+ equivalent) batteries.
12	Wedges and shims in 3/4 or 7/8" sizes
4	SDS+ drill bit sized for W&S set above, 200,300mm length
2	SDS+ moil/jackhammer bit for above drill

Level 2 Equipment List

Qty.	Description
1	Micro-Blasting Kit w/2+ heads
1	Sandbag for each head, theatrical type
1	Air blower for hole clean-out, pump type

Equipment for Sierra Blaster System

Qty.	Description
50	Electric cartridges
50	Booster cartridges
8	10mm SDS+ drill bit for above system, 150-600mm length
1	Blasting machine, 50 cap/3.0J capacity
1	10m firing wire per head
2	Spare 9V batteries

Equipment for EZ-Break system

Qty.	Description
100	Non-electric cartridges
2	5/16" SDS+ drill bit for above system, 150mm length
2	5/16"SDS+ drill bit for above system, 300mm length
2	5/16"SDS+ drill bit for above system, 450mm length
1	Spare CO2 inflator or bulk tank w/regulator and manifold
1	Spare CO2 tank or box of cartridges
1	Spare CO2 hose

Level 3 Equipment List		Level 4 Equipment List	
Qty.	Description	Qty.	Description
1	Blasting machine, 50 cap or 3.0J+ capacity	1	100m Detonating cord, 25-100gr/ft
1	25m firing wire on small reel	1	Case, Kinepak or other high-VOD stick explosive product
1	Wire cutter/strippers	12	Wooden stakes or breaching supports for shaped charges
1	Blaster's circuit tester	50	Electric or non-electric detonators
5	Rolls, electrical tape	2	Type 3 day boxes
1	Small type 4 portable magazine w/ATF approved locks	2	Type 2 portable magazines
1	Air blower for hole clean-out, hand pump or cordless		Assorted blasting equipment as appropriate for products in use.
2	Wooden tamping rods, 10,20mm		Equipment as required if using generator or compressed air drilling
100	~10g Electric blasting cartridges		
25	20-60g Electric blasting cartridges		
12	Unfilled sandbags for stemming		
5	Assorted heavy canvas mats for fly rock protection		
3	SDS+ drill bit for above 10g cartridge, 450-600mm length		
1	SDS MAX hammer drill		
4	Large (200WH+ equivalent) batteries.		
4	SDS MAX drill bit for above 20-120g cartridge, 450-600mm length		
12	Wedges and shims in 3/4 or 7/8" or sized for largest blasting cartridge		
2	SDS+ moil/jackhammer bit for above drill		

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Additional Resources

NPS Blaster's Handbook
https://www.nps.gov/parkhistory/online_books/npsg/explosives/Table_of_Contents.pdf

NXCO Training Manual 21/8/19
https://www.nxburst.co.nz/wp-content/uploads/2020/05/nz_NxbursT_manual_full.pdf

Capping:
https://www.braemoor.co.uk/caving/capping.shtml
http://mdemierre.speleologie.ch/?p=1560
http://www.souterrain.ch/michel/speleo/ticboum.htm