Blasting and Vibration Recording at Kartchner Caverns

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In 1974, two cavers from Tucson discovered a cave in the Whetstone Mountains south of Benson, Arizona. Rather than an ordinary cave, this was a "living" series of caverns where stalactites, stalagmites, helictites and other features were still being formed by water filtering down through limestone. In addition, bats had been using the caverns to raise their young during the summer months. Analysis of the bat guano indicates that they have been returning to the Big Room for at least the past 10,000 years and, although they no longer use it, were in the Throne Room approximately 50,000 years ago. Until 1974, no human had set foot in the main portion of the caverns and, even now that they have been carefully explored, mapped and opened to controlled entrance by the public, over three-fourths of the caverns' floors have not experienced a human footprint.

The existence of the caverns was kept a secret from all but a few persons until 1988, when the state of Arizona purchased the land from the Kartchner family. The discoverers (and later, the Kartchner family) wanted to protect the fragile caverns from the vandalism and wear that would result from its location being generally known. They even went so far as to plant a "mole" in a Tucson cave club to keep track of any field trips that might have found it. One such trip was cut short when three of the Kartchner boys, having been pre-warned, rode out on horseback and intercepted the club members, took their names and advised them that they were trespassing on private property.

Paradoxically, they eventually came to the realization that the only way to provide adequate protection was to develop the caverns commercially. The Kartchners did not have the estimated $28,000,000 to do it, but the state of Arizona did.

The caverns consist of two large rooms, the Big Room and the Throne Room, and several smaller rooms, all connected by passages of varying lengths and diameters, totaling approximately 2-1/2 miles. While the height of the large rooms approaches 100 feet, the vertical height of some passages is so low that one must remove one's belt and lamp battery and push it ahead in order to crawl through. Some of these passages are flooded during the summer monsoon season. The temperature inside is a constant 68 degrees and the humidity hovers between 99 to 100%.

Extensive studies were done to determine how best to open the caverns to the public, while at the same time protecting their fragile nature. If either the temperature or humidity were to be changed appreciably, the structure growing mechanisms could be slowed or even stopped. Too much or the wrong type of light could also start unwanted growth of organisms.

Because the original entrance was too small (and really only useful to the bat population), a 4 foot diameter, 41 foot deep construction access shaft was drilled just off the Big Room, lined with concrete and an airlock was installed at the bottom. This was used during the research and mapping phase, and provided access for instrumentation and monitoring of construction effects. Underground, trails and walk areas were flagged and no one was permitted to enter without an official escort.

A plan was laid out to provide access tunnels (declines) into several locations of the caverns so that the public might view the spectacular formations. Initially, blasting was precluded and excavation was to have been accomplished by mechanical means. After trying several means, including high pressure water jets, it became apparent that no tunnels were going to be excavated without explosives. The Arizona Parks Department had three criteria: Do it quickly, do it cheaply, and don't damage anything. It was pointed out to the state that a certain number of soda straws (the most delicate of the stalactites) would probably break and fall. Some had broken from their own weight and several in place were noted to already have lateral cracking. Many areas had soda straw remnants lying on the floor. It was also noted that, after the initial falls, it would not be expected that additional soda straws would break without elevated vibration levels. You can understand the state's concern. Experts have estimated that these soda straws are growing at a rate of only one inch every hundred years.

In September 1994, ten test shots (individual holes) were detonated in order to determine blast vibration regression rates in this particular rock and to evaluate the adverse effect on the more sensitive structures. Charge weights ranged from 0.5 lbs to 5.0 lbs. Particle velocities ranged from 0.4 in/sec to 2.1 in/sec. As expected, some soda straws cracked and fell, and several other overhanging loose fragments fell from the roof. The overall effects, however, were not too severe and it was determined that blasting could proceed. Although initial tests caused several soda straws to break at 0.6 in/sec, it was felt that these were probably ready to fall anyway. Later tests, with velocities up to 2.0 in/sec did not result in significant fall of any formations. Several vibration limits were considered. A vibration limit of 1.0 in/sec true vector sum (or resultant) was established, although a "target" vibration limit of 0.5 in/sec was used at the most critical locations. It was not possible to establish a frequency-dependent limit for two reasons: (1) Because of the size and shape of the various formations, the range of natural frequencies was quite wide, and (2) The use of LP delays precludes fine tuning the vibration frequencies. Following the test shots, some changes in tunnel design and location were made, based upon the need to keep production blasting away from some of the most critical locations.

Prior to the commencement of production blasting, two seismographs were deployed. We were not allowed to drill any holes into or inside the caverns. For ease in retrieving data, the instruments themselves were located on the surface at the construction office, while the geophones were located underground.

The cables ran down the construction shaft and then to the respective geophones. One geophone was located at Kartchner Tower in the Big Room at the end of a 600 ft cable. A second was located in the Cul-De-Sac at the end of a 1000 ft cable. Later, another seismograph was added with a geophone that was located in the Throne Room at the end of a 2330 ft cable. At the time that this was accomplished, it was (and maybe still is) the longest geophone cable used with conventional blasting seismographs. This last was the most difficult to install because it involved crawling through very limited passageways while feeding cable segments out through the bottom of a stuff sack. Portions of these passages were expected to flood, hence the connection points had to be carefully selected to be dry and the cable lengths designed and constructed accordingly. The geophones were clamped to the cavern roof through the use of 4 x 4 wood posts and shims. Once the wood started to absorb moisture and swell, the geophones were locked tightly in place. No major problems were encountered with the monitoring system. One cable was cut inadvertently, but luckily the cut was in the vicinity of the construction shaft. False-triggering was encountered occasionally, usually caused by RF energy from walkie-talkies. Although it was considered, no attempt was made to record airblast in the caverns. A microphone could have easily been lowered through a hole drilled in the roof of the caverns, but this was not allowed. A ringing sound that resulted from some of the blasts was thought to originate from some of the formations being put into motion (similar to a tuning fork), however it did not appear that airblast caused any damage. Blasting was conducted during the time of year when most of the bat population was absent, so the noise did not affect them.

The portal was located over a portion of the caverns near the Big Room and the 420 foot tunnel progressed in a northwesterly direction toward the Throne Room. This tunnel was intended to provide access to both the Throne Room and The Rotunda and later the Cul-De-Sac. The location was selected to keep the tunnel, at least at the outset, away from the most fragile formations.

The contractor used conventional patterns and loading as he started driving the decline, which was excavated to a height of 9'6" and a width of 8'. He used 10' LP Nonels, in delays zero through fourteen. Most rounds consisted of 35 each 1-1/2" diameter holes drilled 6' deep, with two larger non-loaded burn holes. Explosive loading was approximately 2.8 lbs/hole. Total explosive per round was just less than 100 lbs. At the outset, he was able to shoot up to 4 holes on a delay. As he approached and passed critical areas, he had to either reduce the number of holes per delay or shorten up the round (or both).

Although the state's consultant had envisioned rounds as shallow as 2 feet, it would not have been practical to attempt to blast less than 3 feet because the holes would either rifle or crater well short of full depth. For efficiency, the contractor naturally wished to pull as deep a round as possible.

As the tunnel drew closer to the cavern and vibration approached levels that caused anxiety among state representatives, a revision to the pattern was made to further subdivide the detonation times. The actual detonation times of the holes were analyzed using the seismic tapes. The detonation times were well within the manufacturer's spec. (A slight variation in times would have been acceptable, even desirable, given the need for subdividing the detonations, as long as they didn't approach an overlap.) To introduce a controlled variation in times, rounds were tried where the initiation trunk line was separated into two halves, with the right half being detonated 100 ms before the left. This resulted in fewer holes detonating simultaneously and reduced the vibration levels somewhat. It was found however, that the crossing of the decline through fault zones and changes in the nature of the rock possibly had a greater impact on vibration levels than a 2-3 lb decrease in explosive.

Obviously it was not possible to blast all the way into the caverns and when blasting had reached a point where there was imminent danger of damaging cavern features, blasting ceased and the short breach into the cavern was accomplished mechanically and by hand. After the rough tunnels were complete and lined and air locks installed, work on the concrete pathways inside was started. All concrete had to be mixed on the surface and carried by buckets and placed by hand. While all of this was going on, a visitor center and other park facilities were being constructed on the surface. While inside work was progressing numerous fossils were uncovered. Because this area had been underwater at one time in the ancient past, it was not surprising to find shells. At the time of this writing, findings of an 80,000 year old sloth; an extinct form of horse (in excess of 11,000 years old) and a very large bear have occurred. The bear is far larger than any previously known to have existed in the southwest.

On final analysis, blast vibration caused no appreciable damage to cave features. There were numerous instances where vibration in excess of 0.7 in/sec was recorded, however it must be remembered that these were at selected permanent recording points. It is likely that blast vibration at cavern locations nearer the tunnel rounds experienced vibration at and above 2.0 in/sec for these same blasts. The largest soda straw, 21 feet long (second largest in the world), was not damaged nor were other major cavern features.

Dealing with the environmentally-oriented state park personnel was quite an experience. At the outset, they were absolutely positive that blasting would destroy the caverns. They eventually came to realize otherwise, but were still opposed to most blast-related operations. On the other hand, their tunnel consultants and some imported management people never doubted that the blasting could be accomplished without major adverse effects.

One rather humorous incident occurred well into the project. The tunnel contractor's project manager had a habit of referring to the decline as "the mine". This totally upset one Park official on site and he would always correct him, "IT'S NOT A MINE" he would insist. One day, this same Park official, after observing the growing pile of tunnel muck outside the portal, commented, "I wonder if we could sell that rock?" I responded, "Now you're talking about operating a mine!"

Plans are currently in the works (as of 2003) to open additional rooms to public access. There are major concerns, however, that more people and more light will degrade the environment within the cavern. There were some people alarmed by the fact that humidity levels seemed to be dropping in the cave, but it was pointed out that the drought conditions in the southwest were having the same effect on all the caves throughout the region.

It is likely that a number of studies will be necessary and precautions taken before more of this precious resource is made available to the public. I feel specially privileged to have been able to see many of the features (both currently exposed and proposed for the future) even though I had to crawl on my hands and knees through 10,000 year old bat guano to do it.

(Side note: If you get the chance and are traveling through southern Arizona, it would be well worth your time to visit Kartchner Caverns. Best to call ahead for reservations though. There is a daily limit on the number of persons allowed to visit the cave.)