The Helms Pumped Storage Project

by Wes Bender

In the mid to late 1950s, Pacific Gas & Electric (PG&E) built two dams in the Sierra east of Fresno. The upper dam, on Helms Creek at an elevation of 8200 feet, impounded Courtright Reservoir. The lower dam, on the North Fork of the Kings River, at an elevation of approximately 6550 feet, impounded Wishon Reservoir. Courtright has a capacity of 123,000 acre feet and Wishon a capacity of 129,000 acre feet. These two dams were to eventually make possible the Helms Creek Pumped Storage Project, part of PG&E's Kings River Project.

A pumped storage project acts as a hydroelectric storage unit that is capable of reusing the same water over and over again. During peak electricity demand times, water flows from the higher reservoir down through the powerhouse and into the lower reservoir, generating the needed additional power. When demand for power is reduced and electricity is less expensive, the system is reversed and water is pumped back up to the upper reservoir. The Helms Project uses three Francis Pump/Turbine-Generators to accomplish this. Nuclear power plants are most efficient when they are operating at or near capacity. Diablo Canyon Nuclear Power Plant can be used more efficiently because it can power Helms for pumping when other demands are low. Pumped Storage plants are net users of power, consuming more power than they generate because of friction losses. Total generating capacity at Helms is a little over 1200 megawatts, enough to power nearly 900,000 average homes.

In 1977, after all the engineering had been accomplished and the necessary permits obtained, PG&E put the main part of the project out to bid. The project consisted of putting inlet/outlet works in Courtright and Wishon reservoirs, excavating a powerhouse deep within Lost Peak, excavating and lining the connecting tunnels, sinking shafts, and constructing and/or improving the access roads required for the project.

Viewed from above, Lost Peak is a teardrop shaped mountain that trends roughly north and south (see Figure 1). It is bounded on the east by Helms Creek Canyon (and partially by the North Fork of the Kings River) and on the west by Lost Canyon. Courtright Reservoir is at the north end of the mountain while Wishon Reservoir is at the south end, some 3.6 horizontal miles from Courtright. All but the inlet/outlet works, the Lost Canyon viaduct, the switchyard and some peripheral structures are contained within the mountain.

Near its northernmost end, Lost Canyon narrows and turns to the northeast slightly toward Helms Creek. In doing so, it cuts across the path of the tunnel route from Courtright to the powerhouse penstock, necessitating a viaduct (a large diameter pipe) to carry the water across the floor of the canyon.

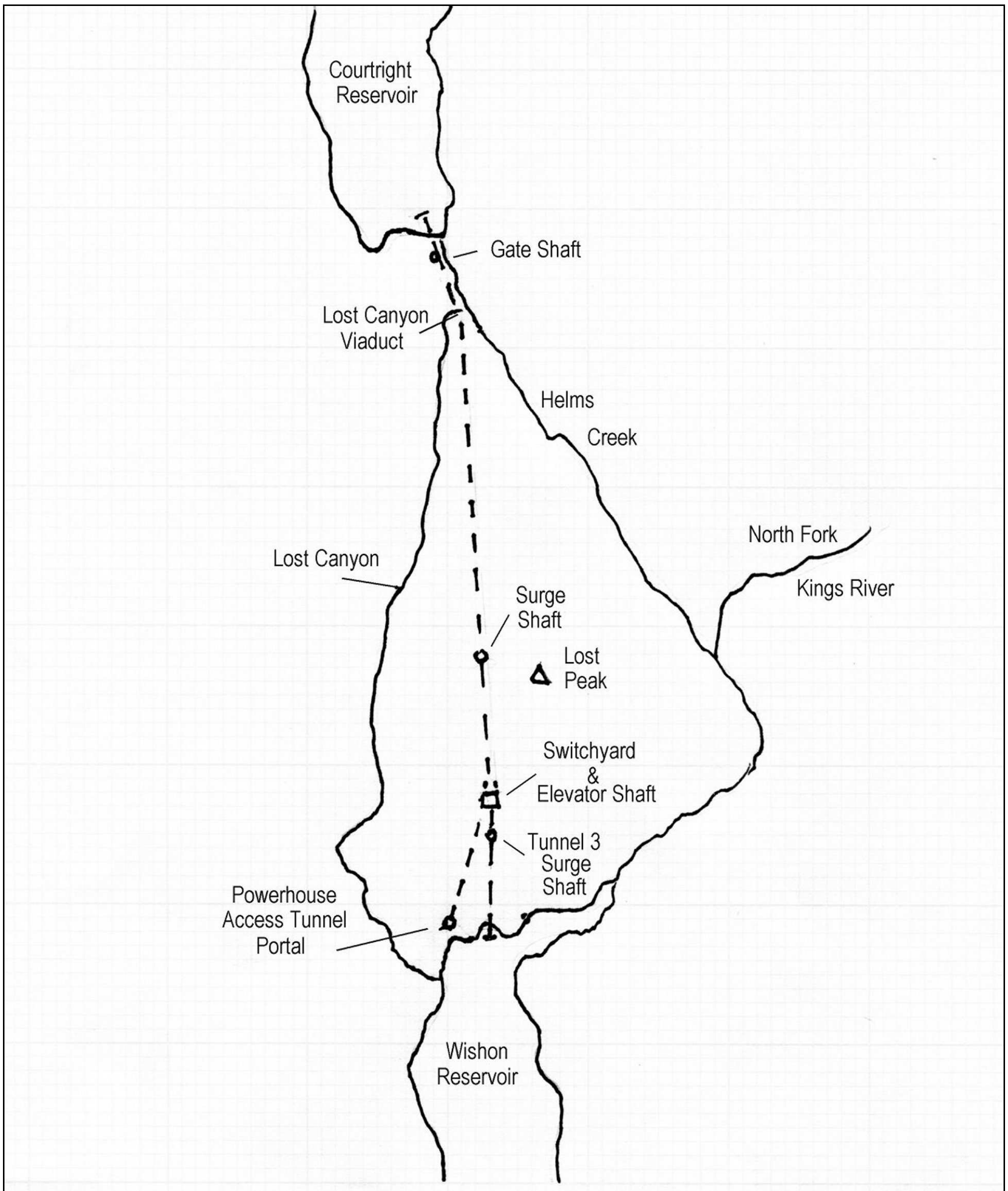

Figure 1 - Helms Project location

Because of the size of the project, it wasn't likely that any one major contractor had the ability to bid the project alone. The winning bid was submitted by the consortium, Granite-Ball-Groves. This consortium consisted of Granite Construction Co. the managing partner, Gordon H. Ball and S. J. Groves Construction Co.

Well in excess of a million cubic yards of rock would need to be blasted; much of it at powder factors in excess of 5 pounds per cubic yard, so competition for supplying the explosives was quite fierce. The three major powder companies at the time, Atlas, DuPont and Hercules, in conjunction with their distributors, put together very competitive bids.

Hercules and Alpha Explosives had worked to assist Granite with formulating their proposal. Dale Johnson and Tom Beck from Hercules and Charlie Strohm and I (representing Alpha) attended the project award unveiling in Fresno. We couldn't be certain that we would be awarded the explosives business but we were hopeful for a positive outcome. As the evening wore on, Joe Luco, Granite's Helms Project Superintendent, was getting quite a bit of pressure from our main competitor to use their products. Eventually Joe came over to Charlie and suggested that we all go to dinner. Apparently we had obtained the explosives business. Not long after that Charlie went to Algeria to assist a contractor building a natural gas plant, and I became Alpha's main representative at the Helms project.

The first order of business was to set up magazines on the project site. Portable magazines were set in place at Wishon Reservoir for explosives for the inlet/outlet works there and for road building. Initially, the access tunnel also used explosives from this location, but after the access tunnel had been driven a short way into the mountain, an underground chamber was blasted out of the granite and used for storage of explosives for the access tunnel and powerhouse excavation. Additional magazines were set in place at the upper end of Lost Canyon for explosives for the driving of tunnels at that location and for the inlet/outlet works at Courtright.

Early delivery of explosives was mostly from Alpha's location at Lincoln and consisted mainly of Unigel dynamite in 2 x 16 and 1-1/4 x 8 sizes. Some of the very early blasting was done electrically, but eventually all initiation was accomplished with Ensign-Bickford's Nonels. In addition to being safer, they were much faster to hook up, thus improving cycle time in the tunnel driving.

As production blasting ramped up, Alpha ordered explosives to be delivered directly to the project magazines from the Hercules plant at Carthage, MO. Once the tunnel portals had been established at Wishon, Courtright, Lost Canyon and the access tunnel, five tunnel headings were driven simultaneously. Tunnel 1 was driven from both Lost Canyon and from Courtright. Tunnel 2 was driven from Lost Canyon south toward the top of the penstock. Tunnel 3 was driven from the Wishon inlet/outlet works toward the powerhouse location and the access tunnel was being driven from its portal a few hundred feet to the west.

While these five tunnels were being driven, every Monday morning two 40,000 lb truckloads of Unigel dynamite were delivered to the site. In addition, every Thursday morning another 40,000 lb truckload of Unigel arrived.

As the project was using a lot of Nonel detonators, every 60 days Alpha would order a two month supply and Ensign-Bickford would send a truck out from their Simsbury CT plant. Half would be dropped off at the project and the other half would be unloaded at Alpha's Lincoln facility. Alpha would then deliver these to the project the following month.

Four vertical shafts were eventually opened. None of the shafts could be excavated until the tunnel beneath them was open. The smallest was for the gate structure just south of the inlet/outlet works at Courtright. The main surge shaft for tunnel 2, the elevator shaft over the powerhouse and the surge shaft for tunnel 3 were all raise bored. To sink such a shaft, a raise bore machine is set up on top of the ground surface directly over the tunnel or underground excavation. A special large diameter drill steel and a 12" drill bit are used to drill down into the tunnel below. The bit is removed and an 8 ft diameter cutting head is brought into the tunnel and mounted on the end of the drill steel. The machine then rotates the cutting head while at the same time exerting a lifting force. The cuttings fall down into the tunnel through slots in the cutting head. If the diameter of the finished shaft needs to be larger than the cutting head, drilling and blasting is then used to slash rock to enlarge the shaft. This rock falls down the shaft and is mucked out through the tunnel or excavation below.

The profile of the Helms Project is shown in Figure 2. It should be noted that, because the project was a little over 10 times longer than it was tall, I've taken some literary license in drawing the profile.

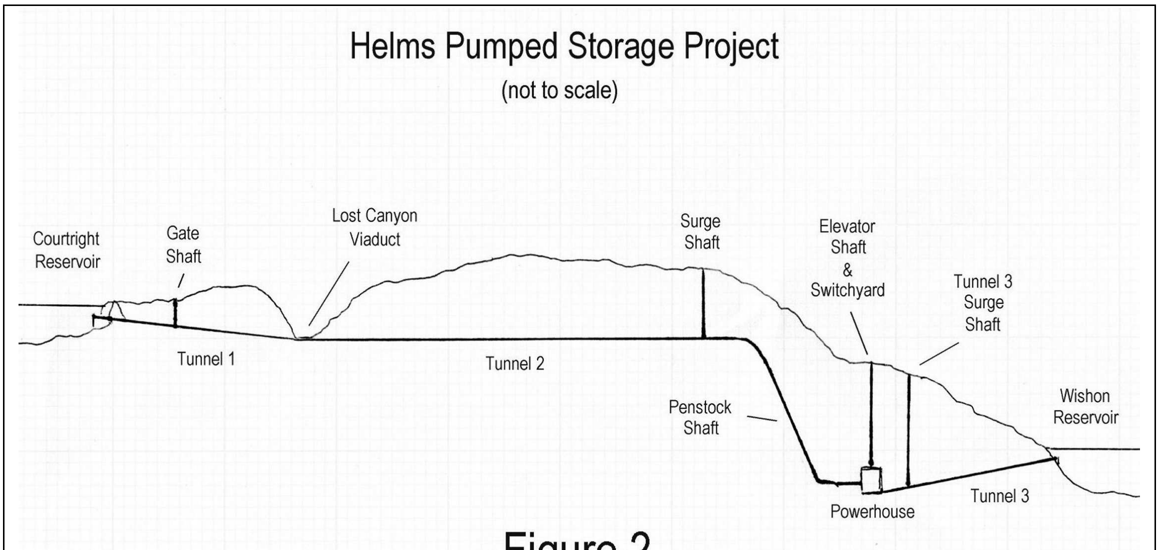

Figure 2

All tunnels were 38 foot diameter horseshoe shaped tunnels. The penstock decline was circular and also 38 feet in diameter. Tunnel 1 was approximately 3350 feet in length. Tunnel 2 was approximately 8300 feet long from Lost Canyon to the top of the penstock decline. The penstock decline (See Photo below) was approximately 1625 feet long, sloped at 55º from horizontal and branched into three smaller tunnels before it entered the powerhouse. Tunnel 3 was approximately 3900 feet long. The Access Tunnel was approximately 3600 feet long. All of the above water transporting tunnels except the penstock were lined with concrete to a 27 foot diameter. The penstock had a steel liner because of the increased pressures anticipated.

View Down the Penstock Decline – 1980 photo courtesy of PG&E

The powerhouse excavation (located within the mountain directly below the switchyard) was 325 feet long, 140 feet high and 85 feet wide. The adjacent transformer vault was 41 feet wide, 41 feet tall and 300 feet long. The drainage gallery was 10 feet wide, 41 feet tall and 260 feet in length.

The T-3 surge shaft was 27 feet in diameter at the bottom, 44 feet in diameter at the upper end and the vertical length was 970 feet. The T-2 surge shaft was also 27 feet in diameter at the bottom, 60 feet in diameter at the upper end and was 580 feet in length. The T-1 gate shaft was oblong, 26.5 feet by 12.5 feet and was 270 feet in depth.

There are several interesting items on the internet that pertain to the Helms Project. If you have access to Google Earth or Google Earth Pro, you can search for “Lost Peak, California” and look down on the entire project area.

One can easily see Courtright and Wishon Reservoirs and the switchyard that is located directly above the underground powerhouse. If you zoom in you can also find the top of the tunnel 2 surge shaft. It is approximately 450 meters (1475 feet) west of Lost Peak. At the north end of the mountain, the viaduct that carries water across the floor of Lost Canyon is readily visible, as is the gate structure near the dam. At the south end, Wishon reservoir appears to be quite low and would indicate that water has been pumped up to Courtright in preparation for the next power need. At the time of this space photo, the top of the intake/outlet structure at Wishon is visible. The portal for the access tunnel is also visible a few hundred feet west and slightly north of the Wishon intake structure.

In Figure 2, for simplicity’s sake, the powerhouse excavation is shown as a simple rectangular void in the interior of the mountain. In actuality, it was quite a bit more complex. In order to have the powerhouse access tunnel enter the powerhouse at the floor elevation and to also be able to excavate the powerhouse from the top using a top heading and bench method, an inclined construction tunnel had to be driven to the top of the powerhouse and the transformer vault. This tunnel branched off of the main Powerhouse Access Tunnel as indicated on Figure 3.

It was also necessary to branch off of the Powerhouse Access Tunnel with a penstock access tunnel. From this access tunnel it was possible to drive the smaller individual penstock tunnels and to drive an incline up the main penstock while the powerhouse was being excavated. When the penstock access tunnel was no longer needed, it was sealed with a concrete plug.

Additional excavation was done (as indicated in Figure 3) for a drainage gallery, a tunnel bypassing the powerhouse and a tunnel that would provide access to the upper end of Tunnel 3. Three smaller draft tubes (tailrace tunnels) were also driven to connect the generator outflows to Tunnel 3.   As you can see, there was quite a bit of critical underground surveying and blasting in this area.

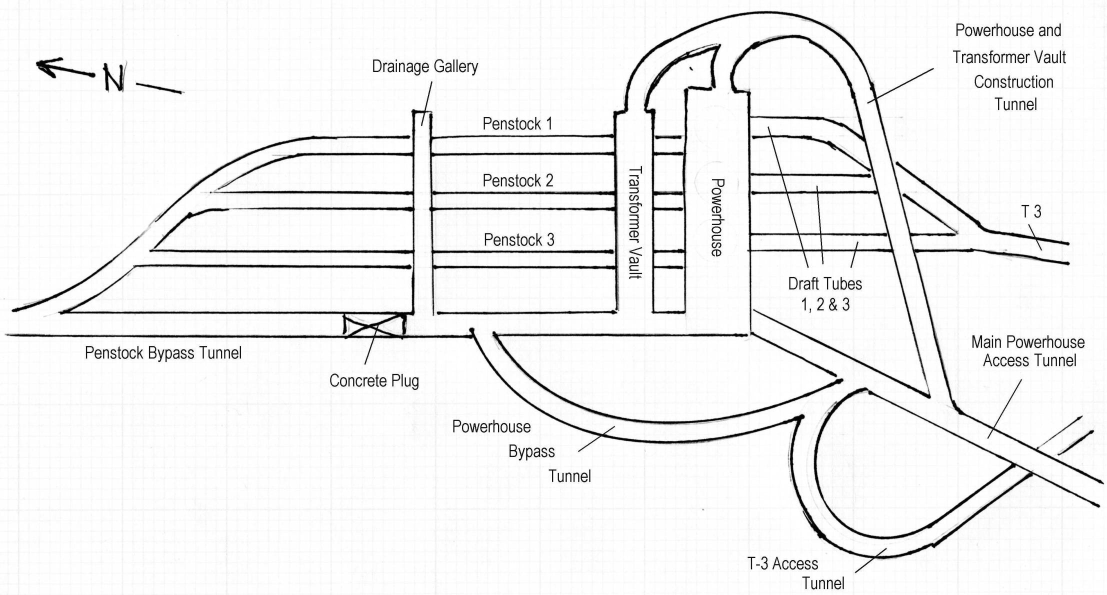

Figure 3 - Powerhouse Plan View

Most of the excavation was accomplished in good, solid Sierra granite, but as the Powerhouse Access Tunnel approached the location of the powerhouse, several shear zones were encountered in the rock. Portions of these shear zones intersected the penstock access tunnel and the lower part of the penstock and the powerhouse itself. Extensive grouting was done in the vicinity of these shear zones. In spite of the grouting, when pressure testing was first started in September of 1982, there was considerable leakage in these areas, including at the location of the concrete plug.

On September 29, 1982, during testing of the system, the viaduct that crossed the upper end of Lost Canyon ruptured sending a large quantity of water and debris down Lost Canyon. PG&E elected to work through the winter replacing the viaduct and doing other restoration work. They took advantage of this down time to do additional grouting in the areas where leakage had occurred in the shear zones. This grouting program was only marginally effective and, in 2009 they shut the system down and conducted a major grouting program to stop the leakage. As far as I know, this later grouting program has been successful.

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Although Hercules and Ensign-Bickford, through Alpha Explosives, were the primary explosives suppliers to the Helms Project and sold most of the 4,000,000 lbs used, Dupont was able to obtain a test of their water-gels in the T-3 surge shaft. This isn't unusual in the explosives business. Many times explosives companies continue their sales efforts after a competitor has been awarded the business. The products that made up a large percentage of the explosives consumed at Helms, however, was Hercules' Unigel dynamite and Ensign-Bickford Nonels, and they performed very well.

As one might expect on any large project, there were problems that could crop up from time to time. At that time, in the early days of their development, all Nonels had clear plastic tubing as opposed to the color-coded tubing that they use today. The coating of HMX and powdered aluminum on the inside of the tubing caused it to appear silver. After the tubing had been activated (fired), it would appear to be black. If a mis-fire occurred, it was customary to refer to it as either a silver tube failure or a black tube failure. If the retrieved detonator had a silver tube it usually indicated a user-caused mis-fire or bad connection and if it had a black tube it indicated a possible product problem. In one tunnel, and on one shift, they were experiencing a fair number of misfired holes. The other tunnel headings were not. Almost without fail, these were silver tube failures. It was unlikely that primer make-up was the cause. All the primers for the various tunnel headings were made up in the primer make up magazine by the same well-trained individuals for all shifts.

I met with Tom Treleaven from Ensign-Bickford and we went to the project to investigate the problem of the misfires. All of the tunnels were bunch blasting, a procedure that Tom had developed earlier. In bunch blasting, the Nonel tubes extending from the holes are gathered into bunches, or bundles, taped and then tied with a detonating cord pigtail and initiated with a detonator. In a smaller tunnel, where all the tubes could reach, one bunch was sufficient, but the larger tunnel headings at Helms required that the Nonel tubes be gathered into multiple bunches and the bunches then connected with detonating cord.

We went underground in the tunnel where the problem was occurring and as soon as we saw how the blaster was tying each bunch, the cause of the misfires was apparent. The factory recommendation (per Tom's procedure) was to tie one double-wrap clove hitch of detonating cord around each bunch. This particular blaster was putting numerous wraps of detonating cord around each one. In effect he was creating a detonating cord "bomb" at each bunch. When these "bombs" went off, they sent shockwaves out that would blow apart some of the Nonel tubes ahead of where the internal signal had reached, thus interrupting the initiation process. In the blaster's thinking, he was increasing the reliability of the ignition system with his extra wraps, but in reality his efforts had just the opposite effect. It was a prime example of, "If a little is good, a lot must be better."

Tom patiently explained to the blaster that you really only needed one double-wrap clove hitch of cord around the bundle and that his adding additional wraps were causing the misfires. He also indicated to him that Ensign-Bickford had tested the system carefully and had successfully initiated more than twice the number of tubes that the blaster was using, while still tying only one hitch around the bundle. Eventually, the blaster came to understand that his efforts to make the system more reliable were detrimental to his own success and he was willing to change. He never did subscribe to the "one hitch is enough" policy though, and insisted on tying two double-wrap clove hitches around each bundle. Although that was more than necessary, two hitches weren't causing a problem so he was allowed to continue.

As previously mentioned, a temporary powerhouse and transformer vault access tunnel was driven on an incline so that it could access the top of both chambers at the east end. Once inside the upper reaches of each, blasting switched from conventional tunnel rounds to a top heading and bench method of excavation. The perimeter walls of the powerhouse were pre-split. The specifications required "competent walls" to remain after the blasting. At some point, PG&E's inspectors decided that this meant that the walls had to be perfectly flat. Most who have done any pre-splitting or smooth blasting understand that it is very difficult to obtain a perfectly flat wall. Overall it will be reasonably flat, but will usually have some deviation or saw tooth along the surface. Experienced people know that the characteristics of the rock will have a greater effect on the success of pre-splitting than the explosive or procedure.

In the case of the powerhouse walls at Helms, the joint system in the granite was oriented almost 45 degrees to the walls. Explosive energy and rock fractures take the path of least resistance and the pre-split cracks were breaking to the nearest rock joint rather than cracking from hole to hole. The inspectors reasoned that, by decreasing the distance between holes, a nice flat wall would eventually result. The contractor tried tightening up the hole spacing somewhat, but the problem persisted. The additional drilling was increasing his costs and eventually a meeting was called to address the problem. After we looked at what was being done and the wall that resulted, we concluded that the finished walls indeed met the intent of a "competent" wall. The inspectors insisted that, if the holes were drilled on tighter and tighter centers, possibly not loading some of the intervening "pilot" holes, eventually a flat wall would result and that's what they wanted.

We pointed out to them that such a procedure, if eventually successful, would result in a wall that had many vertical rock wedges that were just waiting for the chance to fall out. Elastic rebound would almost guarantee that the cracks behind them would open. At some point in the future, possibly during an earthquake, these slabs would fall out and could damage equipment and/or injure employees. The safety argument eventually won out and normal pre-splitting of the walls was resumed.

There is an older YouTube video that provides an interesting look at the overall construction at the Helms Project. It can be found on the internet at:

https://www.youtube.com/watch?v=i1yfCdsrMdA

From the beginning of construction in 1977 until late 1981 when most of the excavation was complete, I usually visited the project about three times per month, or more often if the situation dictated. I was pleased to have been able to play a very small part in the Helms Project. It was a very interesting experience. Of course, the business aspect was also good for Hercules, Ensign-Bickford and for Alpha Explosives.

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But…… there is still one more interesting story related to the project. Let's fast forward a few years to 1993, some nine years after the Helms Project had been completed and brought on line. Claudia and I had driven over to New Mexico Tech at Socorro. We had gone to the campus to visit with Cathy Aimone-Martin who at the time was Chair of the Mining Engineering department at New Mexico Tech. Cathy and I had known each other through the International Society of Explosives Engineers for quite a few years. She had asked me to come and conduct a lecture on blast monitoring for a couple of her mining classes. She and her husband James had previously been to our cabin in Alpine and Cathy and I had fly-fished some of the streams in the White Mountains of Arizona together. Lecturing her classes was a good excuse to go over to Socorro and socialize.

While we were there, the late Per Anders Persson, another fellow member of the ISEE (and the inventor of Nonels) who was then head of the Energetic Materials Research and Testing Center located on the NMT campus, invited Claudia and me to stay over an extra day and attend a Bomb Squad Seminar that was being conducted for the ATFE and several state agencies. Per Anders was going to chair the seminar and give the attendees some insight into how explosives function. Claudia and I were quite happy to stay the extra day. The lodging was free (we were staying with Cathy and Jim) and it gave us an opportunity to have another good Mexican dinner at one of their local restaurants.

The next morning, after all of the seminar attendees had arrived, each person was asked to stand and introduce themselves and indicate what they did. There were representatives from the NM Highway Patrol, ATF Agents, members of Bomb Disposal Squads from several NM counties, along with a few lab technicians from the research center.

When it was my turn, I got up and told them who I was, that I was a blasting consultant from Nevada City California and that my sole claim to fame was that I had sold the explosives that blew up Harvey's Casino in South Lake Tahoe. As you can imagine, that nearly brought the house down. It also began a short but very interesting discussion on the pros and cons of how the FBI handled/mishandled the situation at Harvey's.

Of course, as some may be aware, the explosives used in the bomb at Harvey's were stolen in June of 1980 from the Wishon magazine site at the Helms Project.

I won't attempt to relate the whole story of the bombing of Harvey's. I wasn't privy to all of the details of the investigation, most of which have been well covered in a very interesting documentary by Adam Higginbotham titled, *1000 Pounds of Dynamite*.

The complete article is contained on the Atavist Magazine website at:

https://magazine.atavist.com/a-thousand-pounds-of-dynamite

It's an excellent and very entertaining article and you should read it. Unfortunately a couple of the minor details of the explosives are incorrect, but his piece is mostly accurate and is an engaging article and well worth the read.

The first dynamite that was stolen, Hercules Unigel, was actually in 2 x 16 inch cartridges rather than the 2 x 18 in the story. Hercules didn't manufacture dynamite cartridges in 18" lengths. The case size listed, 1 ft by 2 ft, doesn't exist but it's close enough. Each case contained 22 cartridges of Unigel 2 x 16. (The 2" powder was used at the Wishon Reservoir site to load 3" diameter holes to blast out the area where the inlet/outflow works would be and also to blast rock when building some of the access roads. After turning underground, all of the tunnels at the Helms project were driven with Hercules Unigel in 1-1/4" diameter cartridges.)

The 18 cases of dynamite that were stolen would only contain a total of 900 lbs, rather than the 1000 lbs indicated in the story. However, the perceived difference in blast effect between 900 lbs and 1000 lbs probably wouldn't have been noticeable to witnesses of the blast.

It's true that a Fresno newspaper reported that the dynamite and caps that were stolen were worth $50,000. I don't know where the newspaper got those numbers. I only wish we could have gotten that kind of money for the 900 lbs of explosive and some detonators! At the contract prices, the goods stolen were only worth between $250 and $350, depending upon how many detonators were included in the theft. They also would have had to break into two entirely separate magazines to obtain the dynamite and the detonators at the Wishon site, but that isn’t indicated in the story.

In spite of those minor items, the story is interesting and I enjoyed it.

It took a total of 7 years to complete the entire Helms Project and bring it on line, not all of which involved blasting. While we were supplying the explosives I visited the project fairly often. And, yes, I took my trout fishing gear with me......

As Paul Harvey used to say, “Now you know the rest of the story.”

2020 Epilogue: There have been many folks critical of PG&E and of the Helms Project. They question the need and complain about the exorbitant cost. Many are from the environmental community who didn’t want the project built in the first place. I’m not trying to defend PG&E and any of its decisions, but I do have a couple of opinions in the matter of the pumped storage concept in general anfd the Helms Creek project in particular. The need for additional power at peak demand times is a given. It is far better to have that capability than for PG&E’s customers to suffer rolling blackouts, even if the project is a net user of power. As far as the cost of the project, most of the additional expense was caused by the U. S. Forest Service’s insistence (at the prompting of environmental interests) that no, or as few as possible, facilities were to be visible on the surface. If a powerhouse/pumping facility and penstock could have been constructed on the surface at the head of Wishon Reservoir, much of the very expensive underground excavation could have been avoided.