# SHAFT SINKING AT THE NEVADA TEST SITE

# U1h SHAFT PROJECT

**Authors:**

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## ABSTRACT

The U1h Shaft Project is a design/build subcontract to construct one 6.1 meter (m) (20 feet (ft)) finished diameter shaft to a depth of 321.6 m (1,055 ft.) at the Nevada Test Site. Atkinson Construction was subcontracted by Bechtel Nevada to construct the U1h Shaft for the U.S. Department of Energy. The project consists of furnishing and installing the sinking plant, construction of the 321.6 m (1,055 ft.) of concrete lined shaft, development of a shaft station at a depth of 297.5 m (976 ft.), and construction of a loading pocket at the station. The outfitting of the shaft and installation of a new hoist may be incorporated into the project at a later date.

This paper will describe the design phase, the excavation and lining operation, shaft station construction and the contractual challenges encountered on this project.

## INTRODUCTION

The U1h Shaft is part of an upgrade program to the U1a Complex at the U.S. Department of Energy's (DOE) Nevada Test Site (NTS) which is managed by Bechtel Nevada. The NTS is approximately 105 kilometers (65 miles) northwest of Las Vegas. The U1a Complex is the underground facility (see U1a Complex map, Figure 0) where defense related hazardous experiments are conducted. The upgrades will provide increased and improved ventilation, personnel and materials handling capabilities of the Complex.

Figure 0: U1a Complex Map

Bechtel Nevada

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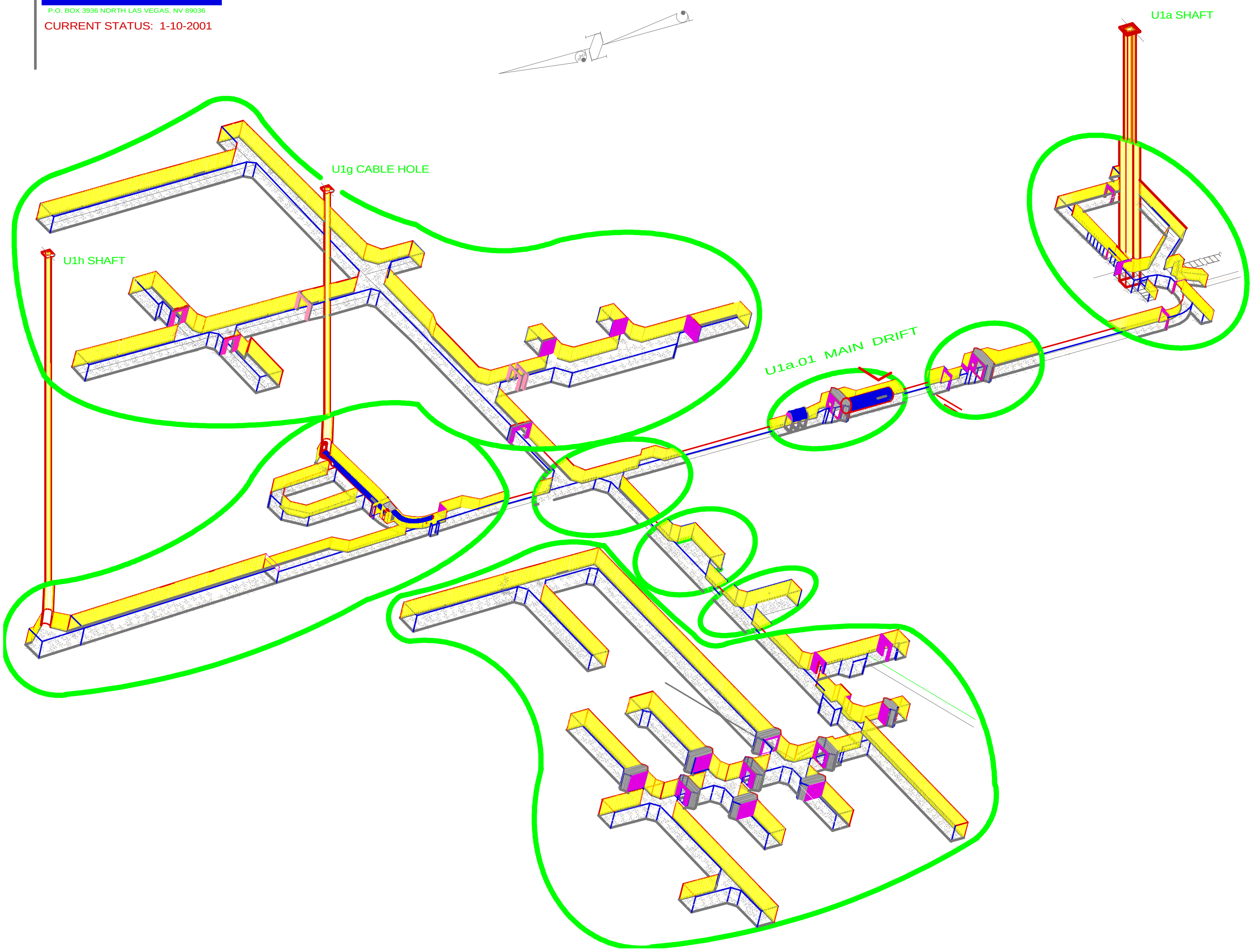
CURRENT STATUS:  1-10-2001



In December 1998, Bechtel Nevada began a best value, design/build procurement of services for the shaft sinking subcontract with a Commerce Business Daily announcement. This was followed by a Request for Proposal in March and Proposals in June 1999. The scope of work included furnishing and installing the sinking plant, construction of a 321.6 m (1,055 ft.) of concrete lined shaft, development of a shaft station at a depth of 297.5 m (976 ft.), construction of a loading pocket at the station and providing a 10 ton personnel and materials hoisting system.

Challenging customer requirements of limited resources, site security requirements and infrastructure availability required creative options to be developed that allowed the project to be broke up and awarded as small options. Each option had the ability of the customer to authorize work in segments and with schedule constraints and restrictions of one or two shifts.

On September 9, 1999, Atkinson Construction was awarded the U1h Shaft Project design build subcontract from Bechtel Nevada. The award included the design of the shaft and the first option of construction activities. This option included mobilization, excavation of the collar and shaft to a depth of 33.5 m (110 ft.), construction of the shaft collar and subcollar, installation of the concrete shaft liner and installation of the sinking plant for the remaining shaft construction activities. Design activities commenced on October 4, 1999, followed by construction beginning on October 29, 1999.

The following options included the sinking and lining of the shaft to its final depth of 321.6 m (1,055 ft.), excavation and support of the shaft station and loading pocket, and loading pocket equipment and utilities. The last set of options was to include the procurement and installation of a permanent hoist, headframe, installation of the shaft steel, guides, and the installation of the surface utilities and support structures. Customer requirements drove options to be released in several work packages allowing the work to proceed incrementally. The subcontract will be completed with the installation of the station level and loading pocket steel and equipment. The permanent hoist system procurement and installation will be delayed a year requiring modification of the sinking plant to function with the permanent station equipment. Bechtel Nevada will operate in this mode to complete development construction of the complex until the permanent system is completed.

## DESIGN PHASE

Atkinson Construction subcontracted the design of the U1h Shaft to Luarentian Engineering Group in Duluth, Minnesota. As with most design build contracts, the final design could not be completed prior to the start of construction activities resulting in partial segments of the design and specifications being initially released to facilitate construction activities of the collar. At the U1h shaft, the initial option design activities were fast tracked and resulted in no appreciable delays to the construction activities. The communications between Bechtel Nevada, Atkinson Construction, and Luarentian Engineering were critical during this period. Open communications and cooperation between all parties resulted in the project starting on schedule and continuing without delay.

Several design progress meetings were held to refine the detail of the criteria from the original Bechtel Nevada conceptual design and functional requirements. The first formal review of the design drawings and specifications was made at the 75 percent complete stage. The 75 percent design was submitted on December 1, 1999, with the design review meeting taking place on December 12, 1999. Final design was completed March 30, 2000, with formal sign-off and transmittal of design deliverables on April 17, 2000. Although the design phase exceeded the original schedule, no delays were incurred to the construction activities and no modifications to previously constructed items were required.

The geology at the U1h Shaft did create some challenges during the design. The entire shaft is constructed in a moderately to loosely consolidated Alluvium deposit with varying degrees of calcium carbonate cementation. The alluvium lies in near horizontal bedding planes with the water table located approximately 304.8 m (1,000 ft.) below the bottom of the shaft. The opening for the shaft station was modeled in both 2D and 3D computer modeling programs to analyze the ground support requirements.

The problems encountered during the modeling revolved around uncertainties of material characteristics and behavior in the calculations.  The varying characteristics of the alluvium layers encountered at other excavations in the U1a Complex required the use of very conservative estimates of the alluvium's structural properties in the model.  After several iterations and analyses, a rock bolt and shotcrete support system along with a 30-degree brow leading into the station arched back as shown in Figure 1 was settled upon.

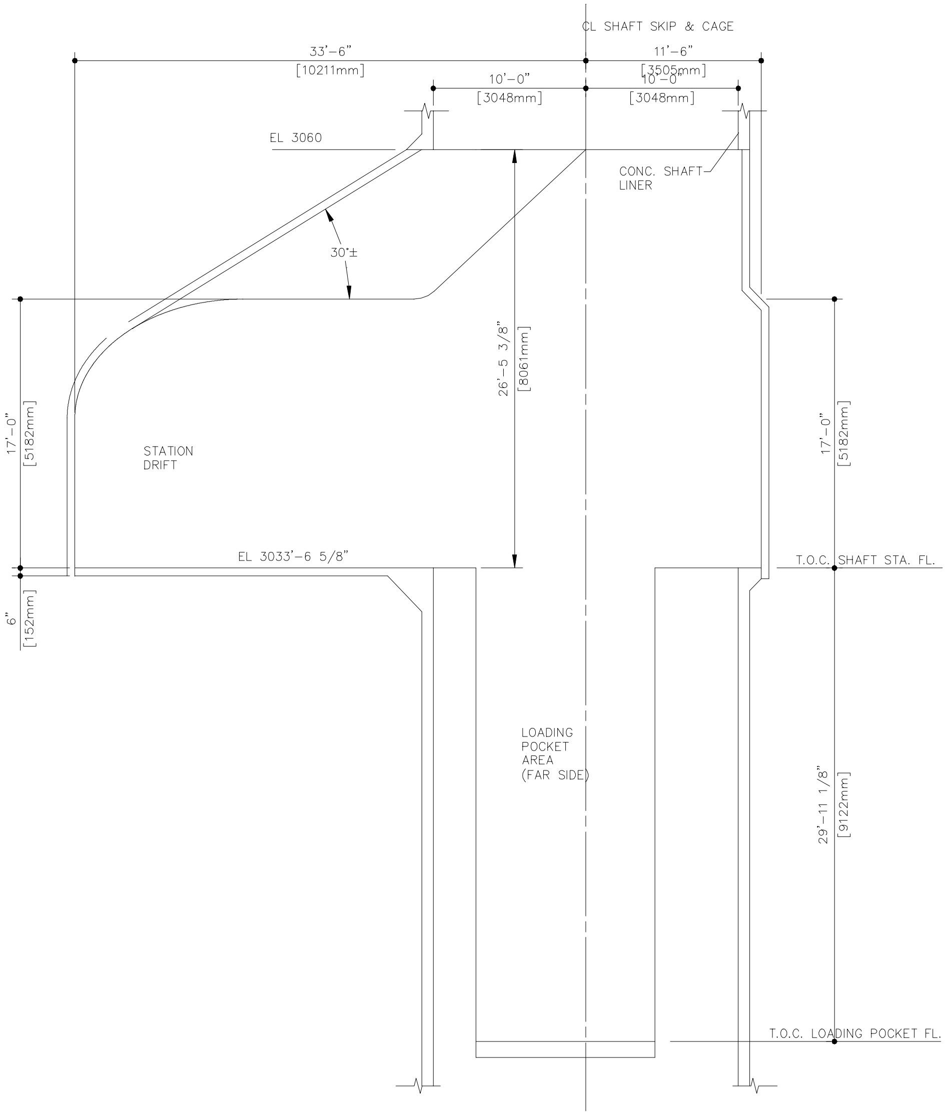



Figure 1: U1h Shaft Station Section View

## COLLAR CONSTRUCTION

### Equipment Selection

As with any project, the equipment selection at the beginning of the project was critical. The sinking hoist selected was a 750 hp, 1,524 mm (60 inch) diameter single drum hoist (Figure 2). The hoist is equipped with dual post brakes, dynamic braking ,and secondary parking brakes. The hoist production speed is approximately 228.6 m/minute(min) (750 ft/min) with a line pull of approximately 30,000 lbs. A matched pair of deck winches (Figure 3) was selected to hoist the work deck and shaft form. The work deck and shaft form were designed specifically for the U1h shaft. Atkinson designed and procured a 3.05 m (10 ft.) long blastproof form. The form included a curb ring, with 3 additional form rings and a pour ring. Atkinson also designed and procured a two stage work deck for the project. The work deck winch cables also served as the rope guides for the crosshead of the main hoist (Figure 4).

After observing excavation operations at the complex, Atkinson decided to employ a steel tracked 40 hp mini-excavator (Figure 5) as the primary means of excavation of the shaft. The excavator was equipped with a quick connect hydraulic hammer to be used in areas that could not be simply dug by the bucket. The mini-excavator was a change from Atkinson's original proposal to use a roadheader and cyderman shaft mucker as the primary means of excavation. The main operational benefit realized by the change was the reduction of dust generation at the excavation face. The purchase of two excavators allowed for one excavator to be working while the other was receiving preventive maintenance. This resulted in almost zero downtime due to equipment break down.

Figure 2:  Sinking Hoist

Figure 3:  Deck Winch

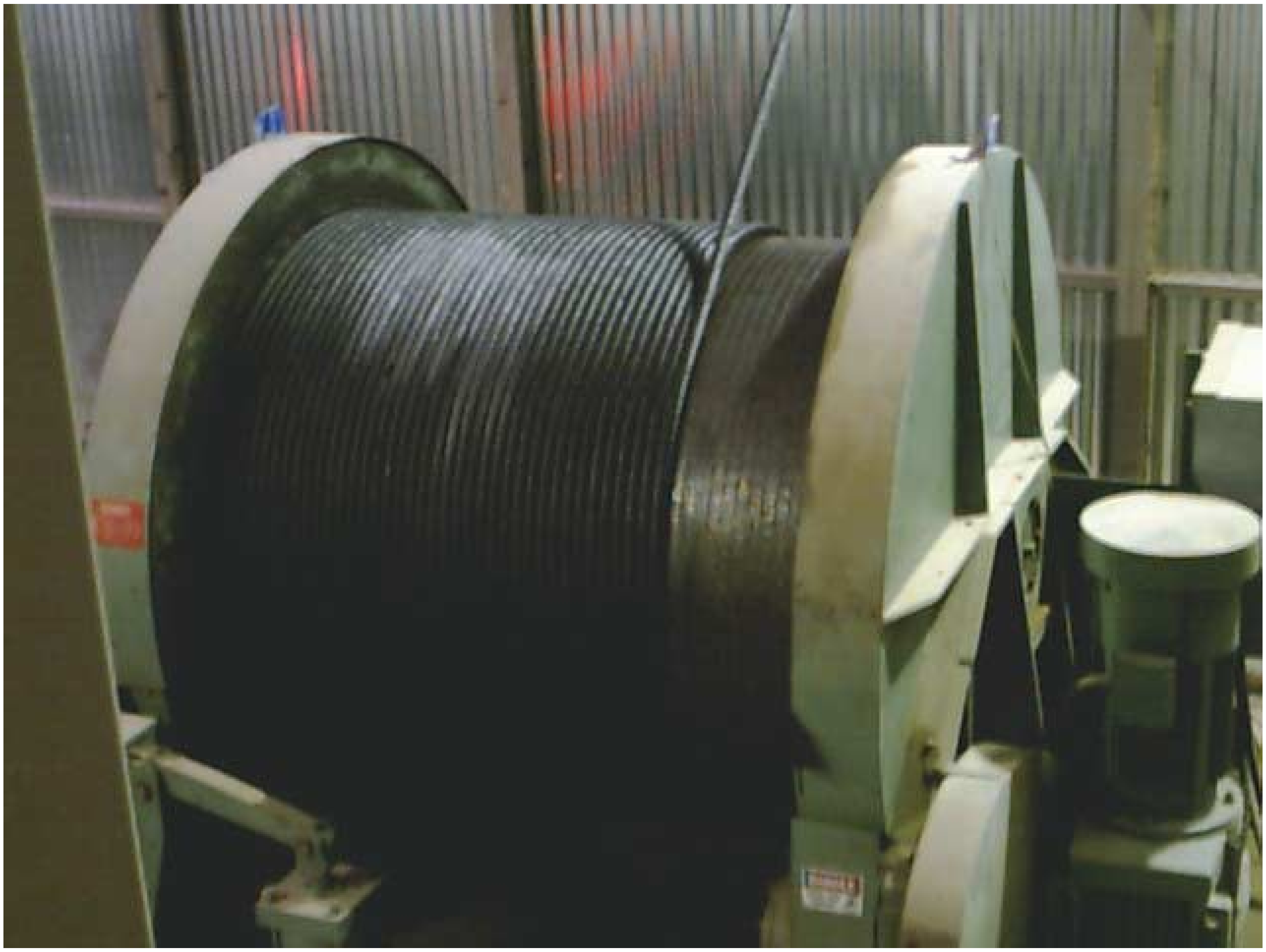


Figure 4:  Muck Bucket and Crosshead at Collar Deck

Figure 5:  40 hp Mini-Excavator

**Construction**

Mobilization to the project site began on November 15, 1999. After establishing the utilities for sinking operations (electrical, compressed air, water) and the surface support facilities (site office, dry house, shop, storage containers), the shaft collar excavation began on November 29, 1999. The initial 6.1 m (20 ft.) of excavation was performed by a surface excavator with the walls sloped backed for stability. Once at depth, a 7.6 m (25 ft.) section of liner plate was placed into the open cut to establish the shaft collar. Steel ring beams on 1.2 m (4ft.) centers were installed to support the liner plate. A concrete ring was placed (1 m (3 ft) x 1 m (3 ft) x 7 m (24 ft) diameter) and backfilled establishing the "sinking collar".

Figure 6 shows the configuration of the collar and foreshaft with the bearing hitch at 30.43m (100 ft). Excavation to the 33.5 m (110 ft.) depth was performed by the mini-excavator and utilizing a 100 ton crane and 3.06 m^3 (4 cubic yard (CY)) muck buckets to remove the excavated material. During the initial excavation, the mini-excavators proved themselves as an efficient means of excavating the shaft. The shaft collar was supported with liner plate and ring beams to a depth of 27.4m (90 ft.) and the hanging walls of the hitch were supported with split sets and wire mesh. The contact between the excavated collar walls and the liner plate were backfilled with lean mix concrete and grout. Excavation of the shaft collar to a depth of a 33.5 m (110 ft.) and the bearing hitch were completed on January 18, 2000.

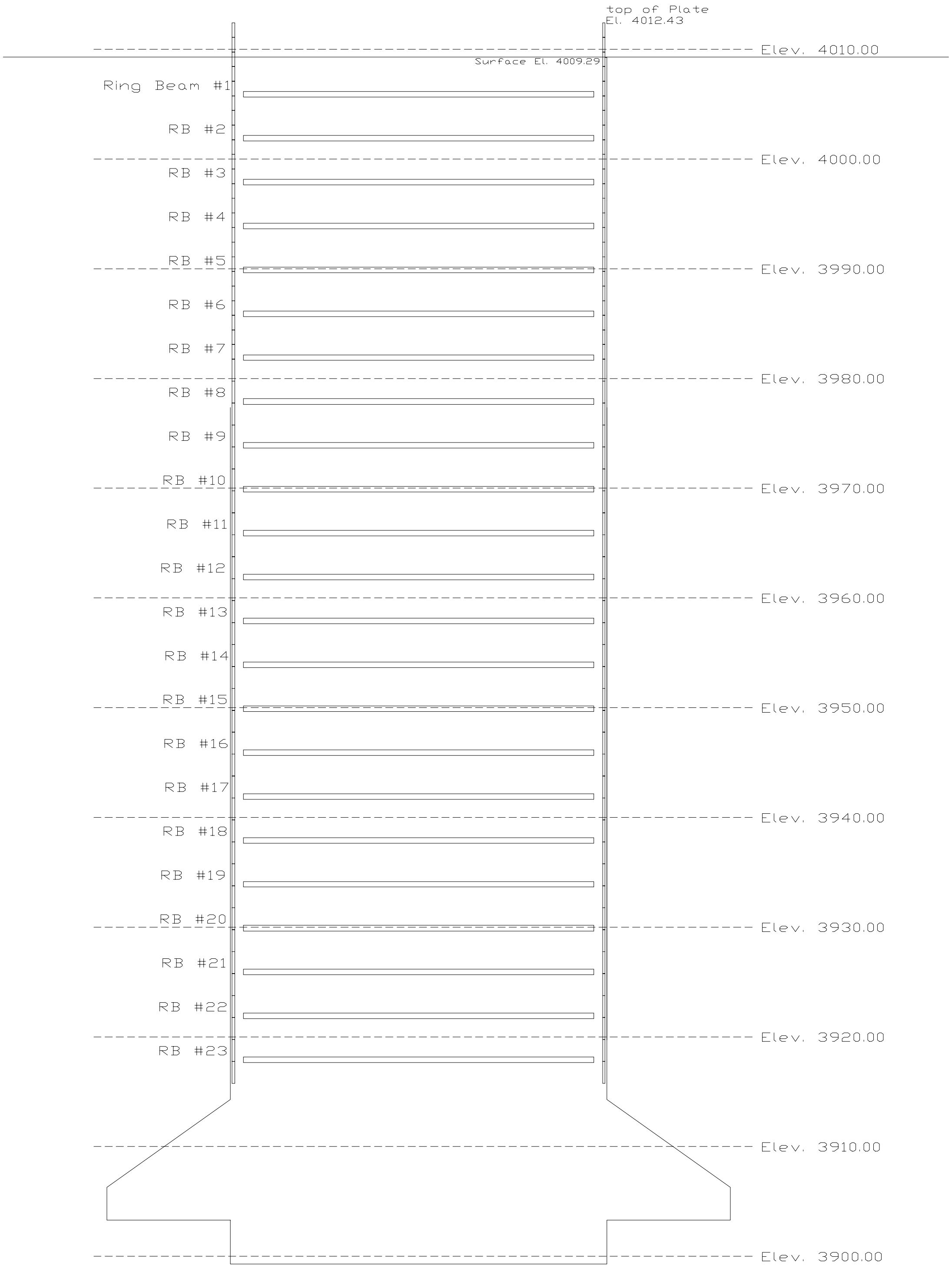



Figure 6: Shaft Collar and Bearing Hitch Section View

A nominal 609 mm (24 inch) thick concrete liner was installed from the 33.5 m (110 ft.) bottom elevation to the collar in 11 each 3.0 m (10 ft.) lifts. The shaft form was installed for the concrete placements with the curb ring being removed after the initial placement. Anchor bolts inserts were installed in the top portion of each placement to support the form as it was raised up the shaft. The surface collar/slab placement included beam pockets and anchor bolts for the sinking headframe as well as the permanent headframe.

During the shaft collar construction activities, work was being performed concurrently on the surface. The surface work included the construction of the hoist and deck winch foundation, installation of the hoist and winches, installation of the hoist electrical trailer, assembly of headframe sections, construction of backleg foundations, and construction of the service entry in the subcollar. The installation of the collar formwork, reinforcing steel and embeds were coordinated with the shaft concrete to allow the final shaft placement to occur concurrently with the collar foundation placement. The initial concrete operations were completed on February 23, 2000.

The final portion of this option was the installation of the sinking plant and headframe and completing the setup for production shaft sinking. The installation of the headframe, commissioning of the hoist and winches, and installation of the two stage work deck were completed on the scheduled completion date of March 17, 2000.

## SHAFT CONSTRUCTION

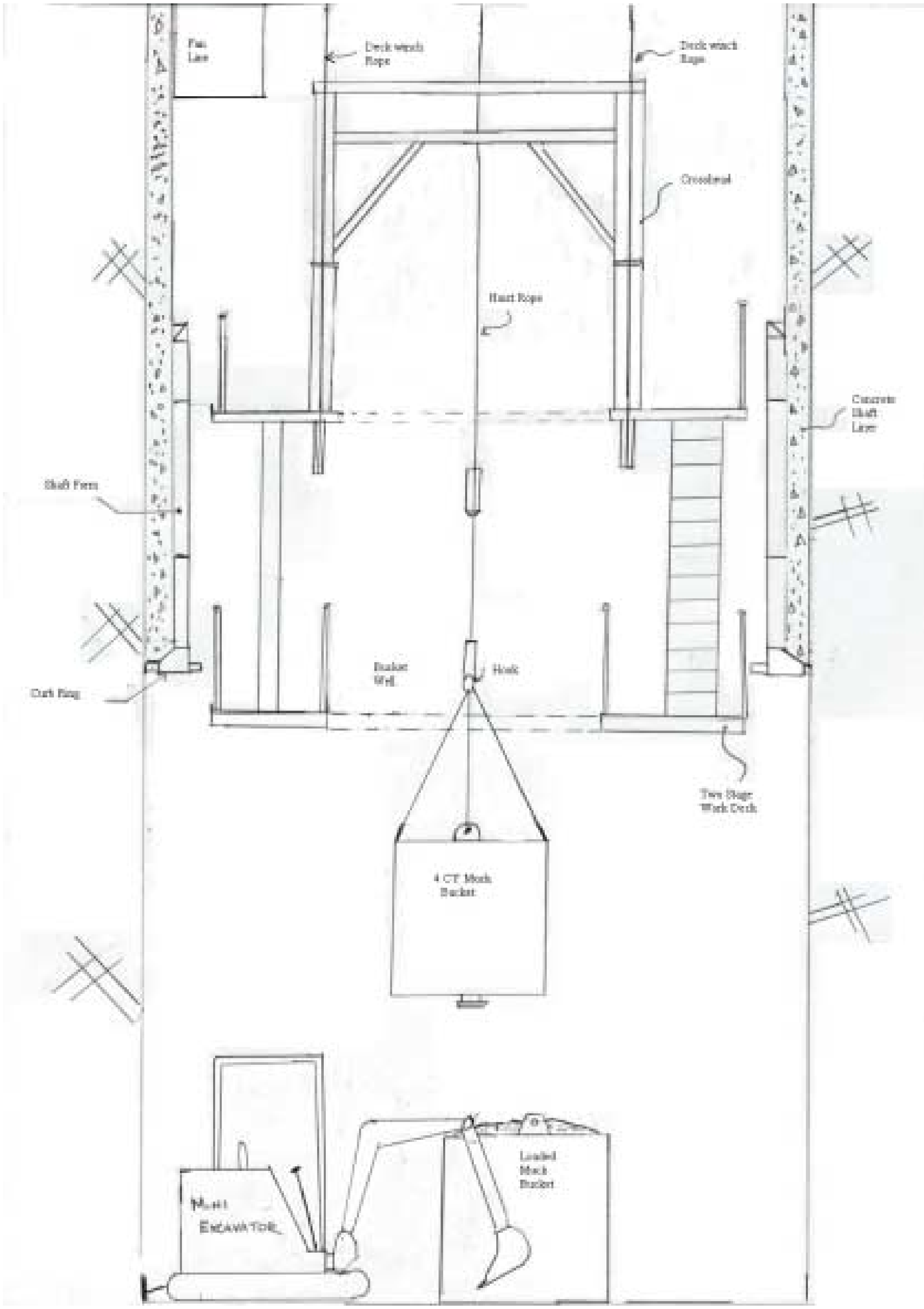
### Subcontract Restructuring

In December of 1999, DOE reprogramming required restructuring the remaining work on the subcontract. Negotiations between Bechtel Nevada and Atkinson Construction commenced to restructure the subcontract  to allow Bechtel Nevada to release work packages in smaller portions and in either 1 shift per day or 2 shift per day segments as constraints dictated.  Provisions were also made for placing the job on standby or to halt production and purchase of the sinking plant by Bechtel Nevada in the event program requirements dictated that the project be terminated prior to completion.

**Production Sinking Operation**

The shaft sinking options commenced on March 20, 2000, on a two- ten hour shift per day, four day per week schedule.  The production sinking setup is shown on figure 7.  Six to seven meters (20 to 25 ft.) of open ground was left open at any time.  This open span allowed the shaft forms to be lowered into place for the subsequent concrete placement while leaving approximately 3.0 m (10 ft.) between the curb ring and the shaft bottom.  The 3.0 m (10 ft.) span allowed the mini excavator enough room to maneuver without damaging the shaft form or freshly placed concrete.

Figure 7:  Production Sinking Schematic


Fan Line
Deck winch Rope
Deck winch Rope
Crosshead
Hoist Rope
Concrete Shaft Liner
Shaft Form
Bucket Well
Hook
Curb Ring
Two Stage Work Deck
4 CY Muck Bucket
Loaded Muck Bucket
MINI EXCAVATOR

Within the first week of production sinking a standard cycle was developed. The standard cycle had day shift making the 3.048 m (10 ft.), 19.9 m^3 (26 CY) concrete placement in the morning. Concrete was delivered to the placement by the main hoist in a 2.29 m^3 (3 CY) concrete bucket. The curb ring concrete was placed first to secure its alignment in the shaft. The remainder of the 3.048 m (10 ft.) form was then lowered into to place, set, and the placement was completed. The remaining duration of the shift was used to excavate the shaft, patch the previous concrete placement, and install utilities down the shaft. The swing shift would complete the excavation required to maintain the open span and lower the curb ring into alignment at the end of shift. The early standardization of the cycle greatly reduced the “learning curve” on the job and allowed for full production almost immediately.

At the onset of production sinking, the strength of the alluvium was a concern to maintaining full production. In the first 33.5 m (110 ft.), several thick lenses of highly cemented alluvium were encountered. These hard lenses required extensive use of the hydraulic hammer to excavate. As a result, the anticipated excavation rates were conservative estimates based upon the conditions encountered in the first 33.5 m (110 ft.) and the geotechnical data which stated the calcium carbonate was to increase with depth. Therefore, the scheduled production rate for shaft excavation was set at 991 mm (3.25 ft.) per calendar day for the 2 shift operation. The actual production rate for the initial 118.9 m (390 ft.) of production sinking was 1801 mm (5.91 ft.) per calendar day which equated to 2972 mm (9.75 ft.) per work day as shown on Table 1.

Phase 2 - Production Shaft Sinking Summary

| Date Start | Date Finish | Vertical Ft. (VF) Of Shaft | No. of Shift per day | No. of Work Days (WD) | No. of Calendar Days(CD) | VF/WD | VF/CD | VF/Shift |
|---|---|---|---|---|---|---|---|---|
| 3/20/2000 | 5/25/2000 | 390 | 2 | 40 | 66 | 9.75 | 5.91 | 4.88 |
| 5/30/2000 | 6/29/2000 | 110 | 1 | 19 | 30 | 5.79 | 3.67 | 5.79 |
| 6/30/2000 | 8/06/2000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8/07/2000 | 11/2/2000 | 240 | 1 | 51 | 87 | 4.71 | 2.76 | 4.71 |
| 11/6/2000 | 11/27/2000 | 100 | 2 | 12 | 21 | 8.33 | 4.76 | 4.17 |
| | | | | | | | | |
| Summary | | 840 | | 122 | 204 | 6.89 | 4.12 | 4.83 |

Table 1

With the production exceeding the projected advance rate by a factor of 1.8, the project was slowed down due to the previously discussed program constraints. The job was reduced to a one shift operation on May 30th, 2000. During this period, excavation conditions proved to be extremely favorable and Atkinson achieved its highest advance per shift at 1765 mm/shift (5.79 ft/shift). The continual high production forced the suspension of work on June 30, 2000, due to the program constraints.

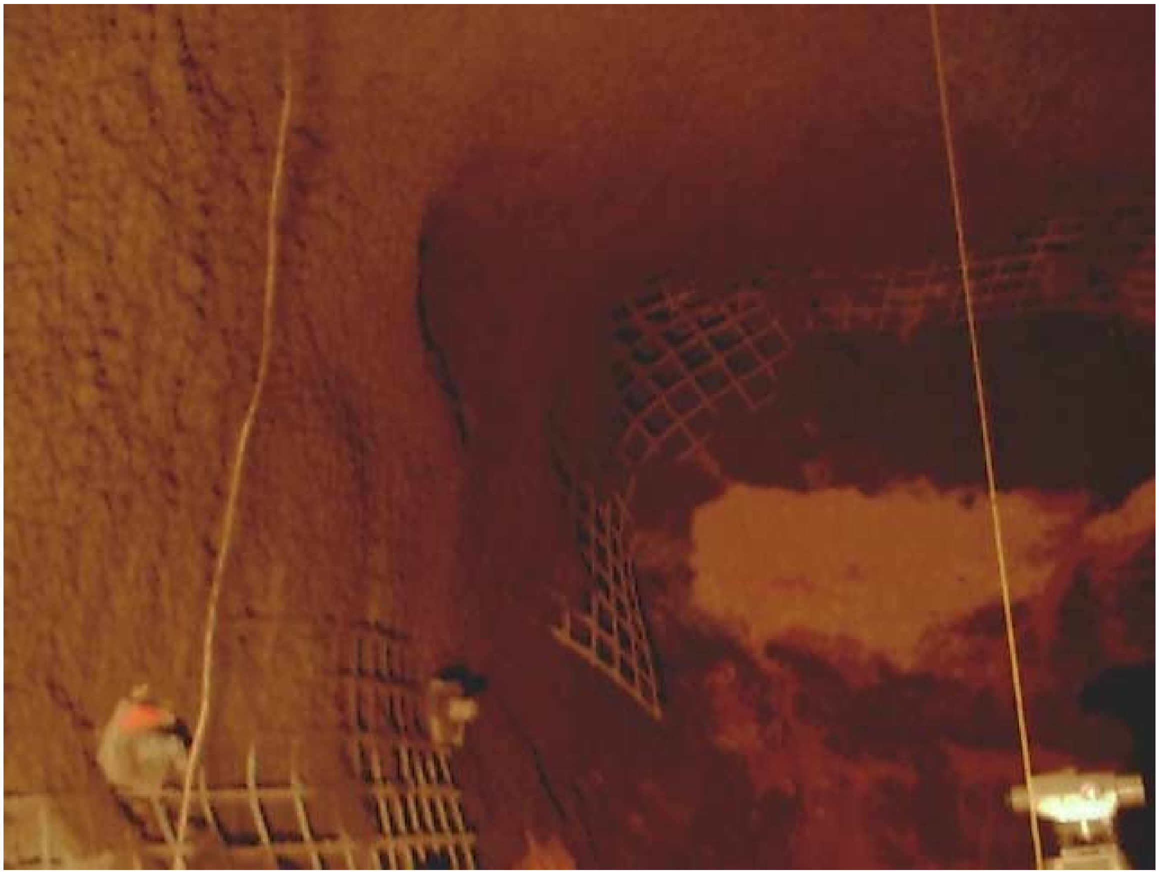
Work resumed on August 7, 2000. The next 73.2 m (240 ft.) of shaft was excavated on a single shift basis until the final 30.48 m (100 ft) of production was released and the two shift operation recommenced on November 6, 2000, this work was completed on November 27 2000.

The production rates achieved on the (103.6 m) 340 ft. of shaft following the shut down were slightly below previous rates achieved. The slower rates are primarily attributed to the increased calcium carbonate cementation encountered at the deeper elevations.

## Station Construction

The shaft station excavation began at a depth of 289.6 m (950 ft) on November 28, 2000. The station design (figure 1) represents a fairly large opening for alluvium. Consequently, Atkinson Construction elected to use sequential excavation techniques for its construction. As the ground was opened, Atkinson would rapidly support it with resin grouted rock bolts, welded wire fabric. Split set rock bolts where utilized to stabilize the ground when needed. Figure 8 shows the station during construction. The station construction is currently proceeding on schedule. At the completion of the station and loading pocket, the tail shaft will be sunk to a final depth of 322.2m (1,057 ft.) The scheduled completion date for the tail shaft is February 5, 2001. At that time the station steel and equipment will be installed and currently authorized options completed by late March 2001. Final authorization of the permanent hoist system is pending at the writing of this paper.

Figure 8:  Photo of Shaft Station During Construction



### Safety

The establishment of a strong safety program from the onset of the project helped to reduce the hazards normally associated with shaft sinking. This program included formal hazard analysis and mitigation and implementation of DOE Integrated Safety Management Initiatives. Input for the safety program, from Atkinson Construction, Bechtel Nevada and U.S. Department of Energy safety personnel, was integrated into the field operations. As a result, at the time of the writing of this paper, the U1h Shaft Project has had zero lost time accidents.

## CONCLUSIONS

Clearly defined objectives and strong communication between the principal parties in a design build contract is paramount for achieving a successful project for all involved. This point is aptly supported by the ability of Atkinson Construction and Bechtel Nevada to have successfully modified the original approach of the subcontract to provide a functioning shaft at the U1h site. The open lines of communications created during the design phase of the project and the flexibility demonstrated by both sides allowed the project to proceed ahead of schedule despite the obstacles encountered. This project will be featured as a DOE Project of the month during 2001.