UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

Reply to:
301 E. Stewart Ave., #203
Las Vegas, Nevada 89101
Tel: (702) 388-6125
FTS: 598-6125

TO: King Stablein and John Peshel, M/S 4 H 3

FROM: Paul T. Prestholt, Sr. On-Site Licensing Representative

DATE: April 11, 1991

SUBJECT: HOOVER DAM VISITOR FACILITIES
ELEVATOR SHAFT AND APPURTENANT STRUCTURES
BOULDER CANYON PROJECT, NEVADA

Please find enclosed the above-referenced information.

PTP:nan
cc: Joe Holonich, M/S 4 H 3
w/o enc.

Please return ~~[illegible]~~ to KStablein

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FK

PETER M. HANKE
Project Engineer

FRONTIER - KEMPER
CONSTRUCTORS, INC.

Headquarters
P.O. Box 6548
1695 Allen Road
Evansville, IN 47719-0548
812-426-2741
Telex 27-2141

Hoover Dam
Elevator Shaft and Appurtenant Structures
P.O. Box 336
Boulder City, NV 89005
(702) 293-2413
(702) 293-2573 (Fax)

HOOVER DAM VISITOR FACILITIES
ELEVATOR SHAFT AND APPURTENANT STRUCTURES
BOULDER CANYON PROJECT, NEVADA

REVIEW OF PHASE 1 PROJECT SCOPE AND CONSTRUCTION METHODS

CLIENT: UNITED STATES DEPARTMENT OF THE INTERIOR
CONTRACTOR: FRONTIER-KEMPER CONSTRUCTORS, INC.

1. INTRODUCTION

The Hoover Dam, constructed in the 1930's and operated by the United States Department of the Interior's Bureau of Reclamation (USBR), is one of the largest dams in the world and a major tourist attraction in the western United States. Daily public tours of the powerhouse and underground facilities are conducted by the USBR and due to the large number of visitors, the USBR decided in 1989 to expand the visitor facilities on the Nevada side of the dam. Construction began with Phase 1 in 1989 which encompassed the construction of a new bridge to divert the access road to the dam. Frontier-Kemper Constructor's, Inc. (FKCI) began work on Phase 2 of the visitor facilities expansion in August 1990 and expects to complete the new elevator shaft and underground excavations in September 1991. Phase 3 will commence after completion of Phase 2 and all facilities are planned to open to the public in 1992. The following provides a brief overview of the visitor facilities expansion project and outlines the scope of work and construction method used by FKCI to complete Phase 2 construction.

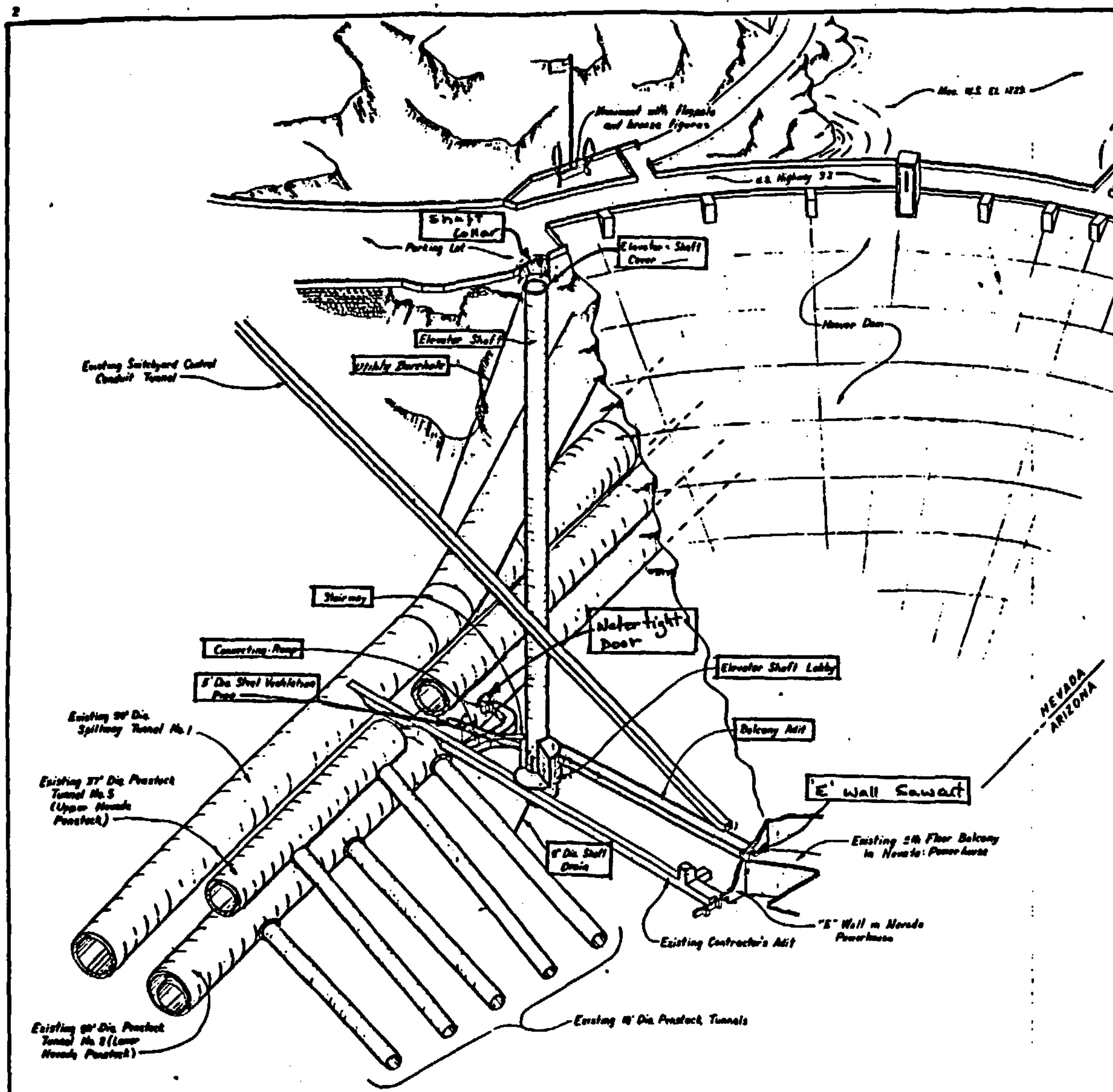
2. SCOPE OF WORK OF PHASE 2

FKCI's scope of work in Phase 2 includes the construction of the new elevator shaft, a station at the bottom of the shaft and several new visitor access tunnels leading from the shaft to the powerhouse and penstock tunnel. Figure 1 shows the scope of work to be completed by FKCI by September 1991. The remainder of this paper describes the construction methods and equipment used by FKCI to complete this phase of the work.

2.1 Elevator Shaft

The new elevator facility extends from the surface near the dam to an existing visitor access tunnel (Figure 1). Total depth from surface to the bottom of the sump is 572 ft. This depth is divided into several excavations:

- The top 52 ft is a large open-cut collar excavation approximately 42 ft by 48 ft to accommodate the future elevator building.
- The shaft excavation starts at the bottom of the collar excavation and extends to the top of the lobby. It has an excavation diameter of 23 ft and will be concrete lined to a diameter of 20 ft. Total depth is 453 ft.



SUMMARY OF PHASE 2 CONSTRUCTION:

Shaft Collar Excavation	-	42' x 48' x 52' deep
Elevator Shaft	-	23' dia. drilled, 20' dia. lined, 453' deep
Elevator Shaft Lobby & Sump	-	±42' dia., 67' high
Shaft Drain Hole	-	10' dia. drilled, 8' dia. lined, ±21' long
Utility Borehole	-	22" dia, 316' long, ±12° from vertical
Balcony Adit	-	9'h x 12'w x 214' long
Concrete 'E'-Wall Sawcut	-	6'4"h x 7'4"w x 7' thick
Connecting Ramp	-	8' x 8' x 107' long
Watertight Steel Door	-	Intersection of Penstock and Connecting Ramp
Stairway	-	8' x 8' x 54' long
Ventilation Tunnel	-	±6' dia. excavated, 5' dia. steel pipe lining with Butterfly Valve

FIGURE 1: PROJECT OVERVIEW

- The lobby is a roughly 42 ft diameter station with three levels and a total height of 52 ft. The lobby intersects the existing visitor tunnel on its lowest level.
- A 15 ft deep sump completes the new elevator shaft facility.

Controlled drill-and-blast methods are used to excavate the collar, lobby and sump. Strict control of the blasting parameter is required due to the proximity of the dam and its associated facilities.

The shaft excavation passes within 15 ft of one of the existing penstock tunnels and FKCI is therefore using a shaft boring machine to excavate the shaft. This system is described in more detail below.

2.2 Underground Facilities

Figure 1 shows the new underground excavations extending from the existing visitor tunnel and elevator shaft lobby. A total of about 480 ft of tunnel will be excavated. The structural integrity of the tuff formations allow all tunnel excavations to remain essentially unlined to preserve the natural appearance of the facility. Only the floors of the tunnels will be concreted and spot rockbolting, handrails and several doors are the only other installations. The excavations include the following:

- the balcony adit
- the connecting ramp
- the stairway
- the ventilation tunnel.

All underground excavations were completed in February 1991 with the exception of the lobby. The lobby will be excavated when shaft construction is complete to the bottom of the lobby.

2.3 Utility Borehole

The elevator surface installations will be serviced from an existing conduit tunnel (Figure 1). FKCI drilled an inclined borehole from the shaft collar parking lot area to intercept the inclined tunnel. Drilling was carried out in several passes beginning with directional drilling of a 3.65" diameter diamond drill hole to the vicinity of the conduit tunnel. The hole was then reamed out in several passes using a raise bore machine to its final 22" diameter. Eleven conduits with diameters up to 6" will be cemented into the hole for future utilities. After installation of the utilities, an excavation from the conduit tunnel will intercept the bottom of the borehole to expose the conduits.

A new hoist and cable car will also be installed in the conduit tunnel to replace the existing, outdated installation.

3. SHAFT CONSTRUCTION

The location of the elevator shaft is such that there is only about 15 ft distance from the shaft to the upper penstock tunnel. USBR specifications require compliance with very stringent blasting procedures, especially with respect to movement of the tunnel lining. If only one-fourth inch movement is detected, blasting may be suspended, causing delays and added costs in having to possibly change fundamental construction methods.

After evaluation of many different excavation methods including pilot-and-slash and blind shaft drilling, FKCI selected to use a Vertical Mole (V-Mole) to excavated the shaft. This method is similar to the Pilot-and-Slash method, but substitutes a proven mechanical excavator, the V-Mole, for the drilling and blasting part of the operation. The V-Mole method is outlined in this section and has the following advantages:

- When the V-Mole is used for shaft excavation, there is no blasting and none of the risks that are associated with it, therefore no blast-induced rock fracturing and no blast-induced vibration are suffered.
- The excavated shaft walls are comparatively very smooth allowing uniform thickness of shotcrete and improved quality of installation of the drainage system.
- Initial rock support can be concurrently installed near to the face as a routine operation, and very close to the face under special circumstances. Because the shaft walls are not disturbed by blasting, the likelihood that rock support will become critical is reduced.
- Once the V-Mole is installed in the shaft, the exposure of workmen to falling down the pilot hole is eliminated.
- After the very short section of shaft needed to erect the V-Mole is conventionally excavated, there is no further risk of blasting dislodging rocks from the cliff face, and no further risk or disruption to other parties because of blasting.
- Ground water inflows, if present, are not accelerated or increased, and may be grouted off in an orderly way as downreaming proceeds.
- Because while reaming, muck will fall down the pilot raise at a constant rate and in more-or-less uniform fragments, the bore-and-slash method piston effect of suddenly falling muck masses does not occur, and the air movement induced is predictable and controllable. This can be a problem in bore-and-slash operations that is difficult to predict and control.
- Shaft excavation proceeds continuously, except for routine maintenance and cutter servicing.
- The overall V-Mole operation is more intrinsically safe than methods involving blasting in the shaft.
- The equipment and the method is proven, and has been utilized in coal mine shaft construction on one past project domestically and very frequently in the Ruhr coal mining region of West Germany.

A prerequisite to the use of the V-Mole is the existence of a 5 to 8 ft diameter borehole from the shaft top to the bottom elevation for cutting removal and a system to remove the cuttings from the bottom of the borehole. The following sections describe the preparatory work for the V-Mole and outlines the main features and operation of the V-Mole itself.

3.1 Pilot Hole Drilling

The elevator shaft construction process began with the drilling of an 8 ft diameter pilot hole on the shaft center line. The hole was drilled from the surface to intersect a small opening excavated off the existing visitor adit for muck removal during V-Mole operation (The underground construction methods and installation used during construction are described in Section 4). FKCI used a Robbins raise bore machine to drill an initial 13 7/8" diameter pilot hole on the shaft center line. After breakthrough in the bottom, the raise borer pulled an 8 ft diameter reaming head back to surface. After completion of the reaming operation, the raise borer was removed from the shaft and excavation of the shaft collar commenced.

3.2 Shaft Collar and Foreshaft Excavation

The shaft collar excavation will accommodate the future elevator building and consists of an excavation roughly 42 ft by 48 ft with a depth of 52 ft. The collar was excavated using controlled drill-and-blast methods. Extra precautions were required throughout to control fly rock due to the proximity of the canyon, at base of which was the Nevada powerhouse. Excavated rock was removed both via the pilot borehole/underground muck removal system and by hoisting to a truck on the surface for haulage to the disposal areas. The walls of the collar excavation were lined with rock bolts and wiremesh and shotcrete. After completion of the collar, the first 30 ft of shaft were excavated using similar drill-and-blast methods. The diameter is 24 ft and this foreshaft served as the assembly shaft for the V-Mole.

3.3 Shaft Construction

Actual shaft construction begins with the installation of the V-Mole followed by installation of the shaft collar steel, headframe, winches, hoists, and shaft services. Once all these installations are complete, shaft excavation proceeds with the V-Mole to the bottom of the shaft. As the V-Mole drills down the shaft, drill cuttings falling to the bottom of the pilot hole are removed with a muck removal system installed for that purpose under the borehole. The top deck of the V-Mole serves as a work deck and installation of the preliminary shaft lining of rock bolts, wiremesh and shotcrete takes place there. Air, water, communication, shotcrete and power lines are clamped to a messenger cable and are continually lowered as excavation proceeds.

V-Mole Operation

The V-Mole shaft boring system was developed for use in the German coal mine industry to excavate ventilation shafts and several generations of machines with a range of drill diameters have been in use since 1971. The V-Moles are vertical shaft reamers and can enlarge pilot holes from 5 to 8 ft in diameter to a final diameter ranging from 16 to 28 ft (depending on machine model) in one pass. The cutter head has a conical shape and thus facilitates transfer of the cuttings to the borehole. A muck removal system at the bottom of the borehole continually removes cuttings during drilling. Two requirements for the application of the V-Mole are therefore the construction of the foreshaft for assembly and access to the bottom of the pilot for cutting removal.

The V-Mole in use by FKCI is shown in Figure 2. Its full designation is VSB VI - 580/750 E/Sch and is capable of drilling shafts with diameters from 19 to 24.6 ft. The drill diameter of the elevator shaft is 23 ft.

The V-Mole was assembled in pieces starting at the cutter head and proceeding up to the work deck at the top of the machine. During assembly the machine was supported on three legs which were removed once the machine could support itself using the gripper pads. The machine consists of two basic components:

1) The cutter head and inner kelly column which consists of:

- the star-shaped cutter head with six arms carrying the disc cutters
- the main bearing and drive gear, gear boxes and motors
- the inner kelly extensions.

2) The outer kelly or gripper ring:

- four pieces bolted together to form a circle containing two levels of gripper pads with four pad per level at 90^0.

The two components are connected by four thrust cylinders and four, near horizontal, steering cylinders. A steering frame fits over the top, square, inner kelly extension and bolts to the outer kelly. This stabilizes the top of the inner kelly during drilling. The operator deck is mounted on top of the outer kelly and contains the operator stand, transformer, hydraulic pumps, motors, and switch boxes powering the machine. All functions are contained on the V-Mole and the only connection to the surface is a 5,000 volt power cable continually lowered during drilling. A work deck completes the top of the machine. USBR safety regulations also required installation of an additional protective canopy over the V-Mole work deck.

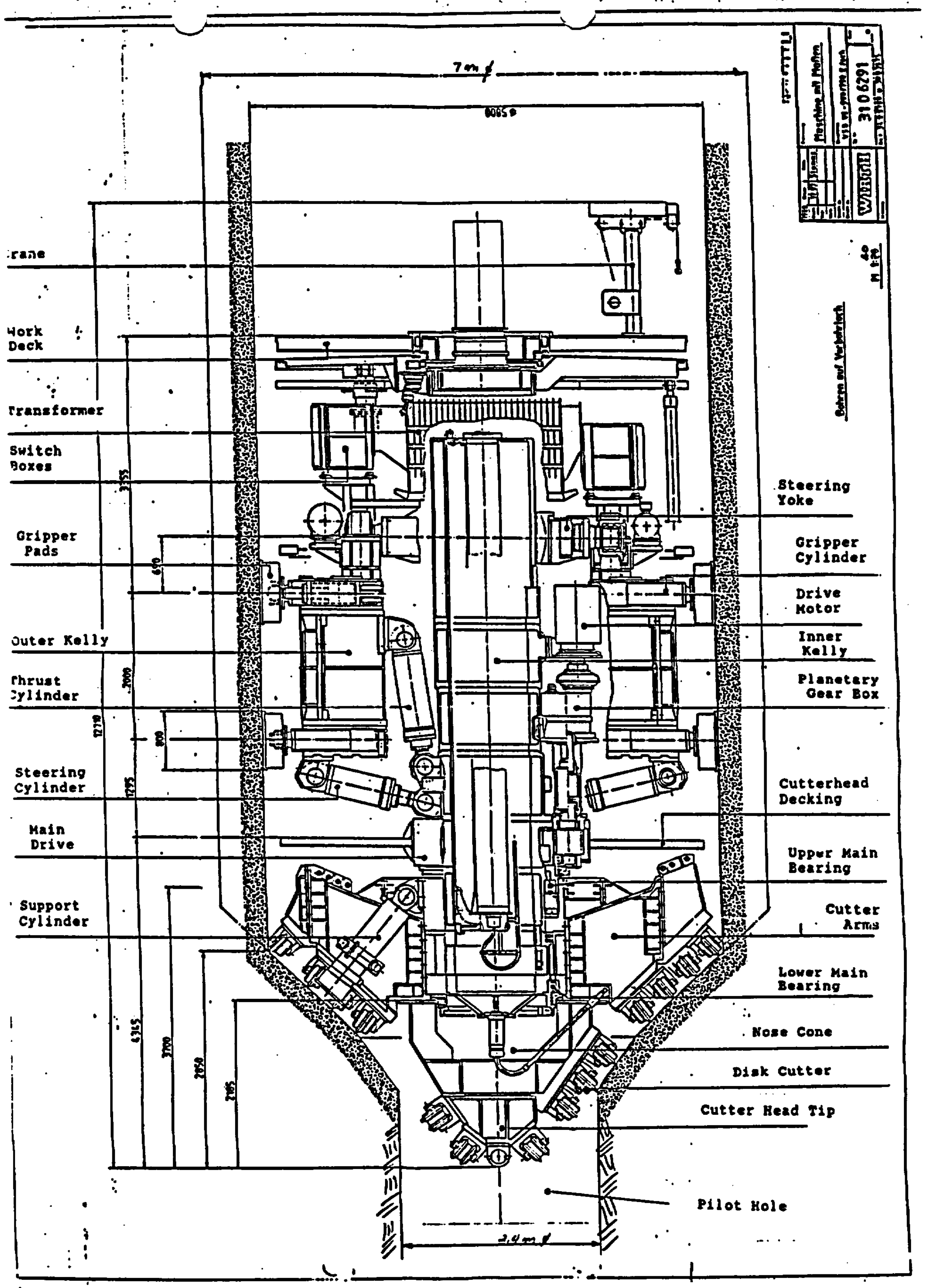


FIGURE 2: V-MOLE VSB VI-580/750E/Sch

Operation of the V-Mole is similar to a tunnel boring machine and requires only one operator. To commence drilling, the grippers are pressurized against the shaft wall to lock the outer kelly in the shaft. This provides the reaction point for the trust and steering forces during drilling. Cutter head rotation is started and the thrust cylinders slowly force the rotating cutter into the rock face. The disc cutters cut concentric grooves spaced about 3" apart in the cutting face and continually chip the rock between the grooves to advance the cutter head. Cuttings migrate to the pilot hole and fall to the bottom. A vertical laser beam mounted on the shaft axis near the shaft top provides the alignment target during drilling. An array of photoelectric cells in the cutter head center continually transmit to the operator stand the location of the cutter head relative to the laser beam. The operator can pressurize each steering cylinder individually and continually maintain accurate alignment of the cutter head during drilling. Using this system, the drilled shaft alignment can be therefore maintained on the shaft centerline despite deviations of the pilot hole. The construction of the steering frame at the top of the inner kelly allows 360^0 horizontal movement of the cutter head relative to the outer kelly to achieve facilitate this continual correction during drilling. Deviations up to 1/2 the pilot hole diameter can be corrected in this manner. At the end of the thrust cylinder stroke (about 2 1/2 ft), cutter head rotation is stopped and the head is seated on the cutting face. The gripper cylinders are then retracted followed by retraction of the thrust cylinders also lowering the whole outer kelly and work decks by 2 1/2 ft. After repressurizing the grippers, the next cutting stroke commences. Some of the major statistics of the V-Mole are summarized in the attached table.

As the V-Mole proceeds down the shaft, a crew of miners installs the preliminary support of rock bolts, wiremesh and shotcrete from the V-Mole work deck.

When the V-Mole reaches the bottom of the shaft in the lobby area, dismantling will commence using the hoisting system. Components will be hoisted to the surface starting at the top of the machine, basically in reverse order to dismantling.

3.4 Shaft Lining

After completion of the shaft excavation, V-Mole dismantling, and lobby construction, shaft lining operations begin. The shaft lining will consist of a drainage element, watertight PVC liner, and cast-in-place concrete to give a watertight, 20 ft finished diameter lined shaft.

Installation of the lining will begin at the lobby and proceed to the shaft collar. The first 30 ft of lining above the lobby will included extra reinforcement and a drain ring. Before placing the concrete, the drain ring will be installed about 20

V-Mole VSB VI - 580/750E/SCH

Machine weight	330 tons
Total machine height	42 ft
Drill diameter	23 ft
Machine Drive	Electric
Thrust	± 700 tons
Stroke	2 1/2 ft
Penetration rate	0 - 10 ft/hr
Gripper	8 (total 1,500 tons)
Thrust cylinders	4
Steering cylinders	4
Hydraulic pressure	2,500 psi
Total installed horsepower	± 800 HP
Drive motors	4 @ 175 HP ea.
Cutter head rpm	4.7

Work deck can be raise 6 ft to accommodate lining installation ft above the top of the lobby. Two discharge pipe will connect the drain ring to the bottom of the shaft sump where the collected water is diverted to one of the penstock tunnels via a shaft drain hole. The drainage element and PVC liner will then be installed from the drain ring to within 80 ft of the shaft top. The drainage element will be nailed to the profile shotcrete installed during the V-Mole operation. The watertight PVC liner will be heat-welded to the drainage element with special fasteners. This drainage system will divert all water from behind the PVC liner via the drainage element to the drain ring and from there to the shaft drain. All components just described will be cast into the concrete lining and thereby provide dry shaft interior. The concrete lining will be placed from the lobby to the shaft top using the slipforming system to give a smooth, unblemished shaft finish.

After completion of the shaft lining and underground work, all temporary hoisting facilities and other equipment will be removed, a shaft cover placed on top of the shaft and the facility turned over to the USBR.

4. UNDERGROUND CONSTRUCTION

A major portion of FKCI's work involved the construction of new underground facilities for the visitor complex. This work involved construction of several tunnels and a large shaft station or lobby. The scope of the underground work is outlined in this section.

4.1 Tunnel Construction

The tunnel excavations in order of excavation consist of the following (see Figure 1):

1) The connecting ramp is an 8 ft by 8 ft arched roof tunnel about 107 ft long. It connects the exiting visitor adit with a new visitor platform (Phase 3 construction) in the 50 ft diameter penstock tunnel. This ramp will provide wheelchair access to the new platform.

2) The stairway is an 8 ft by 8 ft arched roof inclined tunnel with a length of about 54 ft. It connects the new balcony adit and upper lobby level with the connecting ramp.

3) The balcony adit is a 9 ft high by 12 ft wide, 214 ft long tunnel connecting the lobby to the existing powerhouse visitor balcony. The additional width was provided to allow two-way pedestrian tour traffic. Excavation includes saw cutting through the 7 ft thick powerhouse concrete wall to access the balcony.

4) The ventilation tunnel is a 6 ft by 6 ft long tunnel about 104 ft long. It connects the penstock tunnel to the shaft lobby to provide fresh air to the shaft area.

5) The shaft drain hole will be a 10" diameter hole about 21 ft long drilled from the bottom of the shaft sump to the penstock tunnel. All water from the shaft drain ring and lobby areas will be diverted via this drain hole to the penstock drainage system.

Due to the proximity of the penstock tunnels and their obvious vulnerability special excavation methods had to be employed during all underground excavation. Drill-and-blast excavation was carried out under the following conditions:

- Stringent vibration and air blast controls (limited to 2 in/sec peak particle velocity)
- Smooth-wall controlled blasting and line drilling methods
- Non-electric detonation of blast rounds
- Detonator timing through the use of millisecond surface delays and isolated series of detonator chord circuits to limit blasts to one hole per delay
- Trim powder and high energy phlegmatized dynamite
- Drilling with jackleg drills.

Within 10 ft of the penstock tunnel, all excavation had to be carried using non-blasting techniques. The techniques used to excavate the connecting ramp and ventilation tunnel breakthrough were:

- Pre-drilling with jackleg drills and cracking rock with Darda splitters
- Penstock lining was saw cut about 6" deep around excavation perimeter
- Balcony adit excavation through concrete wall will be by plunge-type, 2 ft diameter concrete saw.

<u>Rock Support</u>

To expose the natural appearance of the host rock and due to the self-supporting nature of the rock only spot rock bolting with 6 ft long rock bolts was used. Pressure grouting will also be used to divert any water from the tunnel roof to the sides.

<u>Muck Removal</u>

Due to the small dimensions of the new and existing tunnels, several muck removal systems are employed for the excavation. A 36" conveyor extending from the near the start of the connecting ramp through the penstock tunnel to the spillway tunnel (about 240 ft) removed all excavated material from the tunnel and shaft excavations. The connecting ramp was mucked out using a 1 CY LHD loading onto the conveyor. The stairway and ventilation tunnels were mucked out using a slusher and the 1 CY LHD loading onto the conveyor. A draw point and surge bin was establish in the lobby at the existing visitor adit level for removal of the V-Mole drill cuttings and balcony adit muck. A small opening was excavated at the upper lobby level to allow a Bobcat loader to discharge muck from the balcony adit excavation into the top of the surge bin. A 1 CY LHD draws from the bottom of the surge bin and transfers the muck to the conveyor belt about 75 ft away. The conveyor discharges into the spillway tunnel. Before any excavation began, a bulkhead was installed at the discharge end of the spillway tunnel, the tunnel dewatered and a small hoisting system installed at the bulkhead. A 966 LHD loader hauls the muck from the discharge point of the conveyor down the spillway tunnel to the hoisting system at the bulkhead. The hoisting systems feeds truck which carries the muck to the disposal areas. Figure 3 shows the underground mucking system installed by FKCI.

All mine water produced underground is collected and pumped to a water treatment plant at the spillway bulkhead for clarification before discharge into the Colorado river.

Tunnel Furnishings

Only the tunnel and stairway floors will be concreted with a smooth floor and side curbs and gutters. A 60" diameter steel pipe and valve will be cemented into the ventilation tunnel.

Protection of the powerhouse against the possibility of water ingress from the penstock tunnel is provided by:

- Installation of a watertight door at the connecting ramp intersection with the penstock tunnel. The door automatically closes when high water sensors are activated. The door is designed for a water head of 600 ft.
- Installation of a 60" diameter butterfly valve in the ventilation pipe activated by high water sensors.

4.2 Lobby Construction

The lobby is basically a 42 ft rectangular station surrounding the inner 20 ft diameter shaft. The top of the lobby is tapered to form a cone shaped roof. The lobby will have three floors. The balcony adit level at El. 700, the mechanical room elevation at El. 687.5 and the contractor adit/visitor tunnel at El. 675.16. The sump extends to El. 660.66 below the contractor adit.

Excavation

The lobby excavation will total ±1,900 CY. Excavation will be split between the V-Mole excavation and conventional drill-and-blast excavation. Controlled blasting techniques will be used as described in the tunnelling section above.

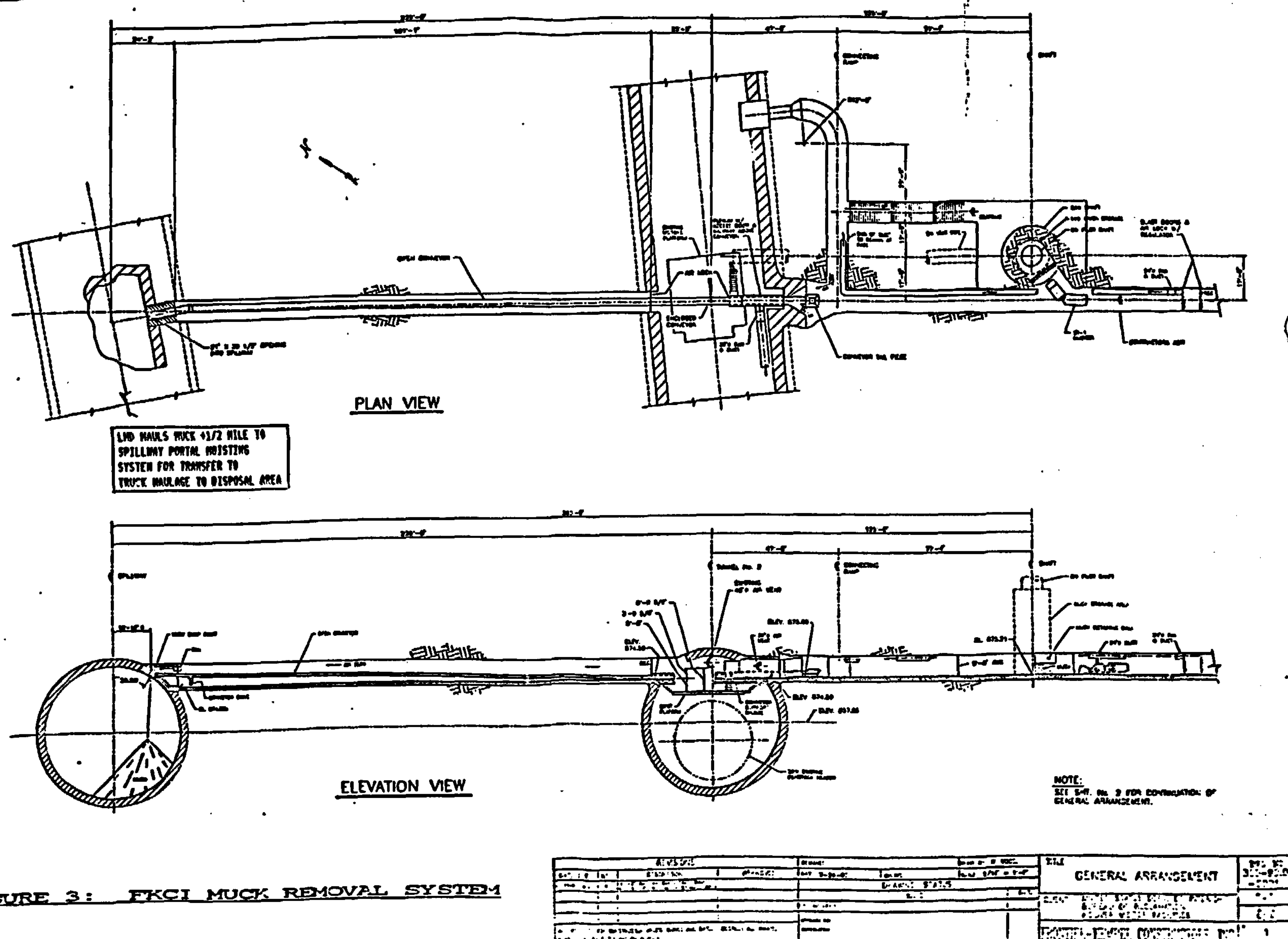


FIGURE 3: FKCI MUCK REMOVAL SYSTEM

Ground Support

The outside walls of the lobby will be self-supporting. The lobby roof will be heavily reinforced with rockbolts up to 20 ft long. Shotcrete will also be place in critical zones. Several cantilever floors will be installed and epoxy-coated dowels will anchor these to the walls. Any ground water will be pressure grouted.

Muck Removal

Muck will be removed via the draw point and LHD/conveyor systems described above. An Eimco 630 or similar loading into a muck bucket will be used to excavate the sump.

Lobby Furnishings

The shaft lining will start at the sump and continue through the lobby to the actual shaft. The lobby shaft wall will be about 1.25 ft thick. Floors will be placed at the three levels and will connect with the shaft lining. Openings will be provided in the shaft lining for future doors and windows. Dowels will connect the floors with the shaft lining.

5. PHASE 3 CONSTRUCTION

Following completion of the shaft and underground construction by FKCI, Phase 3 construction will include the following to complete the new visitor facility:

- A new visitor platform in the penstock tunnel at the end of the connecting ramp
- Two elevators in the shaft
- An elevator building at the top of the shaft
- A visitor facility adjacent to the elevator shaft building
- A five-story parking garage in an existing canyon on the Nevada side near the elevator shaft
- A new pedestrian access, including an escalator under Highway 93 near the end to the new bridge, to the new visitor facility.

The complete facility is expected to be open to the public at the end of 1992.

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Reply to:
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Las Vegas, Nevada 89101
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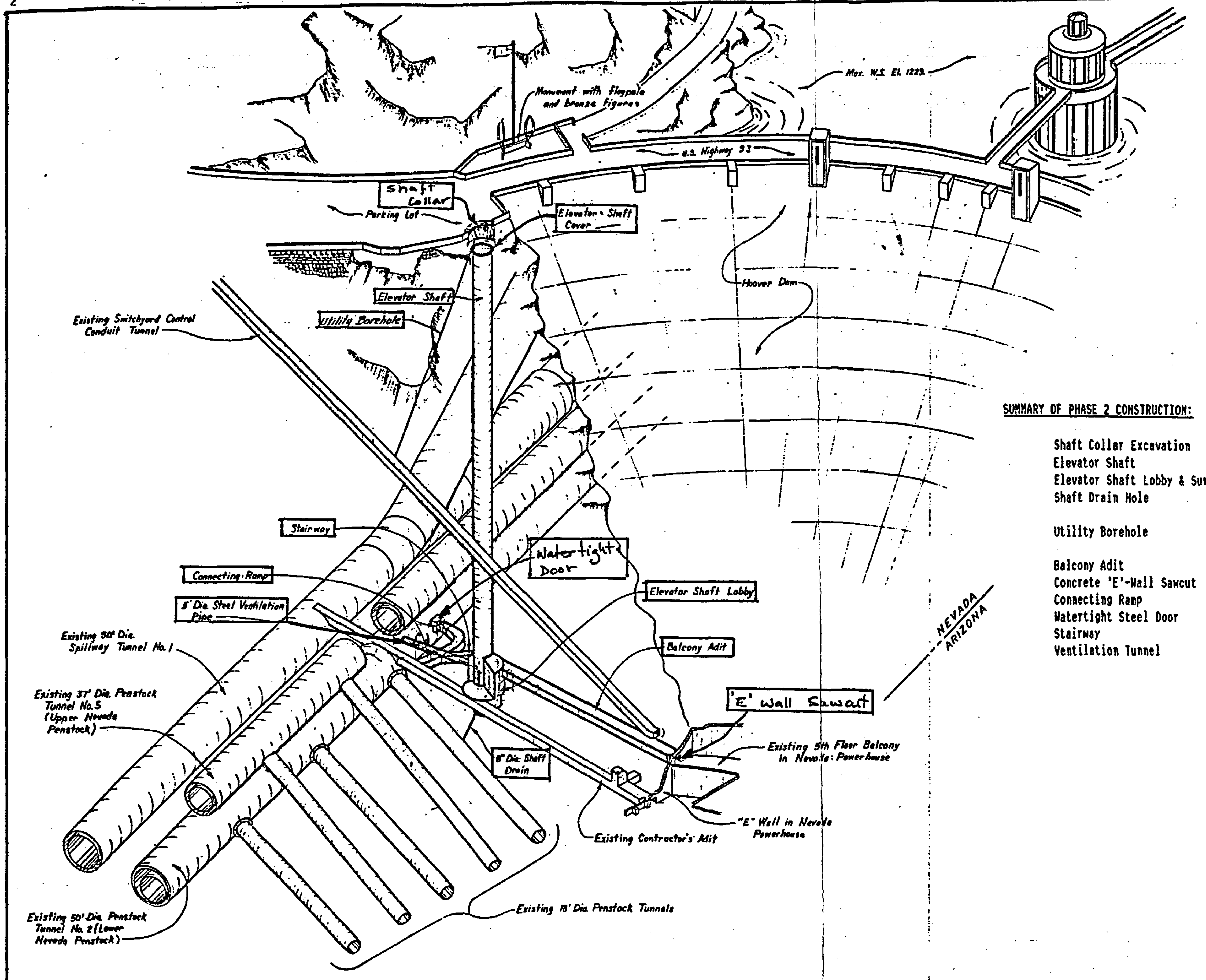

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FIGURE 1: PROJECT OVERVIEW

- The lobby is a roughly 42 ft diameter station with three levels and a total height of 52 ft. The lobby intersects the existing visitor tunnel on its lowest level.
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A new hoist and cable car will also be installed in the conduit tunnel to replace the existing, outdated installation.

3. SHAFT CONST CTION

The location of the elevator shaft is such that there is only about 15 ft distance from the shaft to the upper penstock tunnel. USBR specifications require compliance with very stringent blasting procedures, especially with respect to movement of the tunnel lining. If only one-fourth inch movement is detected, blasting may be suspended, causing delays and added costs in having to possibly change fundamental construction methods.

After evaluation of many different excavation methods including pilot-and-slash and blind shaft drilling, FKCI selected to use a Vertical Mole (V-Mole) to excavated the shaft. This method is similar to the Pilot-and-Slash method, but substitutes a proven mechanical excavator, the V-Mole, for the drilling and blasting part of the operation. The V-Mole method is outlined in this section and has the following advantages:

- When the V-Mole is used for shaft excavation, there is no blasting and none of the risks that are associated with it, therefore no blast-induced rock fracturing and no blast-induced vibration are suffered.
- The excavated shaft walls are comparatively very smooth allowing uniform thickness of shotcrete and improved quality of installation of the drainage system.
- Initial rock support can be concurrently installed near to the face as a routine operation, and very close to the face under special circumstances. Because the shaft walls are not disturbed by blasting, the likelihood that rock support will become critical is reduced.
- Once the V-Mole is installed in the shaft, the exposure of workmen to falling down the pilot hole is eliminated.
- After the very short section of shaft needed to erect the V-Mole is conventionally excavated, there is no further risk of blasting dislodging rocks from the cliff face, and no further risk or disruption to other parties because of blasting.
- Ground water inflows, if present, are not accelerated or increased, and may be grouted off in an orderly way as downreaming proceeds.
- Because while reaming, muck will fall down the pilot raise at a constant rate and in more-or-less uniform fragments, the bore-and-slash method piston effect of suddenly falling muck masses does not occur, and the air movement induced is predictable and controllable. This can be a problem in bore-and-slash operations that is difficult to predict and control.
- Shaft excavation proceeds continuously, except for routine maintenance and cutter servicing.
- The overall V-Mole operation is more intrinsically safe than methods involving blasting in the shaft.
- The equipment and the method is proven, and has been utilized in coal mine shaft construction on one past project domestically and very frequently in the Ruhr coal mining region of West Germany.

A prerequisite to the use of the V-Mole is the existence of a 5 to 8 ft diameter borehole from the shaft top to the bottom elevation for cutting removal and a system to remove the cuttings from the bottom of the borehole. The following sections describe the preparatory work for the V-Mole and outlines the main features and operation of the V-Mole itself.

3.1 Pilot Hole Drilling

The elevator shaft construction process began with the drilling of an 8 ft diameter pilot hole on the shaft center line. The hole was drilled from the surface to intersect a small opening excavated off the existing visitor adit for muck removal during V-Mole operation (The underground construction methods and installation used during construction are described in Section 4). FKCI used a Robbins raise bore machine to drill an initial 13 7/8" diameter pilot hole on the shaft center line. After breakthrough in the bottom, the raise borer pulled an 8 ft diameter reaming head back to surface. After completion of the reaming operation, the raise borer was removed from the shaft and excavation of the shaft collar commenced.

3.2 Shaft Collar and Foreshaft Excavation

The shaft collar excavation will accommodate the future elevator building and consists of an excavation roughly 42 ft by 48 ft with a depth of 52 ft. The collar was excavated using controlled drill-and-blast methods. Extra precautions were required throughout to control fly rock due to the proximity of the canyon, at base of which was the Nevada powerhouse. Excavated rock was removed both via the pilot borehole/underground muck removal system and by hoisting to a truck on the surface for haulage to the disposal areas. The walls of the collar excavation were lined with rock bolts and wiremesh and shotcrete. After completion of the collar, the first 30 ft of shaft were excavated using similar drill-and-blast methods. The diameter is 24 ft and this foreshaft served as the assembly shaft for the V-Mole.

3.3 Shaft Construction

Actual shaft construction begins with the installation of the V-Mole followed by installation of the shaft collar steel, headframe, winches, hoists, and shaft services. Once all these installations are complete, shaft excavation proceeds with the V-Mole to the bottom of the shaft. As the V-Mole drills down the shaft, drill cuttings falling to the bottom of the pilot hole are removed with a muck removal system installed for that purpose under the borehole. The top deck of the V-Mole serves as a work deck and installation of the preliminary shaft lining of rock bolts, wiremesh and shotcrete takes place there. Air, water, communication, shotcrete and power lines are clamped to a messenger cable and are continually lowered as excavation proceeds.

The V-Mole shaft boring system was developed for use in the German coal mine industry to excavate ventilation shafts and several generations of machines with a range of drill diameters have been in use since 1971. The V-Moles are vertical shaft reamers and can enlarge pilot holes from 5 to 8 ft in diameter to a final diameter ranging from 16 to 28 ft (depending on machine model) in one pass. The cutter head has a conical shape and thus facilitates transfer of the cuttings to the borehole. A muck removal system at the bottom of the borehole continually removes cuttings during drilling. Two requirements for the application of the V-Mole are therefore the construction of the foreshaft for assembly and access to the bottom of the pilot for cutting removal.

The V-Mole in use by FKCI is shown in Figure 2. Its full designation is VSB VI - 580/750 E/Sch and is capable of drilling shafts with diameters from 19 to 24.6 ft. The drill diameter of the elevator shaft is 23 ft.

The V-Mole was assembled in pieces starting at the cutter head and proceeding up to the work deck at the top of the machine. During assembly the machine was supported on three legs which were removed once the machine could support itself using the gripper pads. The machine consists of two basic components:

1) The cutter head and inner kelly column which consists of:

- the star-shaped cutter head with six arms carrying the disc cutters
- the main bearing and drive gear, gear boxes and motors
- the inner kelly extensions.

2) The outer kelly or gripper ring:

- four pieces bolted together to form a circle containing two levels of gripper pads with four pad per level at 90°.

The two components are connected by four thrust cylinders and four, near horizontal, steering cylinders. A steering frame fits over the top, square, inner kelly extension and bolts to the outer kelly. This stabilizes the top of the inner kelly during drilling. The operator deck is mounted on top of the outer kelly and contains the operator stand, transformer, hydraulic pumps, motors, and switch boxes powering the machine. All functions are contained on the V-Mole and the only connection to the surface is a 5,000 volt power cable continually lowered during drilling. A work deck completes the top of the machine. USBR safety regulations also required installation of an additional protective canopy over the V-Mole work deck.

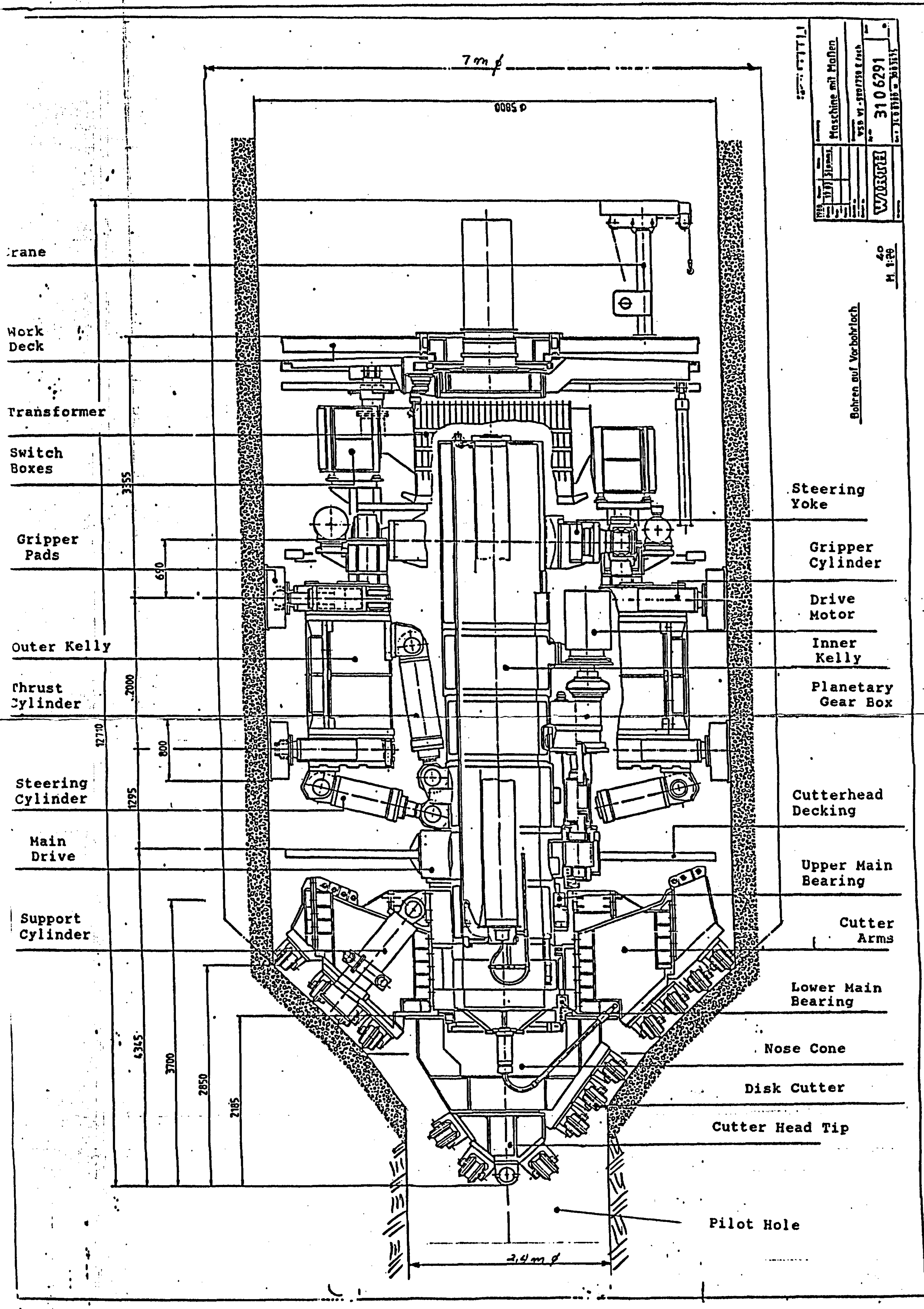

FIGURE 2: V-MOLE VSB VI-580/750E/Sch

Operation the V-Mole is similar to tunnel boring machine and requires only one operator. To commence drilling, the grippers are pressurized against the shaft wall to lock the outer kelly in the shaft. This provides the reaction point for the trust and steering forces during drilling. Cutter head rotation is started and the thrust cylinders slowly force the rotating cutter into the rock face. The disc cutters cut concentric grooves spaced about 3" apart in the cutting face and continually chip the rock between the grooves to advance the cutter head. Cuttings migrate to the pilot hole and fall to the bottom. A vertical laser beam mounted on the shaft axis near the shaft top provides the alignment target during drilling. An array of photoelectric cells in the cutter head center continually transmit to the operator stand the location of the cutter head relative to the laser beam. The operator can pressurize each steering cylinder individually and continually maintain accurate alignment of the cutter head during drilling. Using this system, the drilled shaft alignment can be therefore maintained on the shaft centerline despite deviations of the pilot hole. The construction of the steering frame at the top of the inner kelly allows 360^0 horizontal movement of the cutter head relative to the outer kelly to achieve facilitate this continual correction during drilling. Deviations up to 1/2 the pilot hole diameter can be corrected in this manner. At the end of the thrust cylinder stroke (about 2 1/2 ft), cutter head rotation is stopped and the head is seated on the cutting face. The gripper cylinders are then retracted followed by retraction of the thrust cylinders also lowering the whole outer kelly and work decks by 2 1/2 ft. After repressurizing the grippers, the next cutting stroke commences. Some of the major statistics of the V-Mole are summarized in the attached table.

As the V-Mole proceeds down the shaft, a crew of miners installs the preliminary support of rock bolts, wiremesh and shotcrete from the V-Mole work deck.

When the V-Mole reaches the bottom of the shaft in the lobby area, dismantling will commence using the hoisting system. Components will be hoisted to the surface starting at the top of the machine, basically in reverse order to dismantling.

3.4 Shaft Lining

After completion of the shaft excavation, V-Mole dismantling, and lobby construction, shaft lining operations begin. The shaft lining will consist of a drainage element, watertight PVC liner, and cast-in-place concrete to give a watertight, 20 ft finished diameter lined shaft.

Installation of the lining will begin at the lobby and proceed to the shaft collar. The first 30 ft of lining above the lobby will included extra reinforcement and a drain ring. Before placing the concrete, the drain ring will be installed about 20

V-Mole VSB VI - 580/750 /SCH

Machine weight	330 tons
Total machine height	42 ft
Drill diameter	23 ft
Machine Drive	Electric
Thrust	± 700 tons
Stroke	2 1/2 ft
Penetration rate	0 - 10 ft/hr
Gripper	8 (total 1,500 tons)
Thrust cylinders	4
Steering cylinders	4
Hydraulic pressure	2,500 psi
Total installed horsepower	± 800 HP
Drive motors	4 @ 175 HP ea.
Cutter head rpm	4.7

Work deck can be raise 6 ft to accommodate lining installation ft above the of the lobby. Two disch ge pipe will connect the drain ring to the bottom of the shaft sump where the collected water is diverted to one of the penstock tunnels via a shaft drain hole. The drainage element and PVC liner will then be installed from the drain ring to within 80 ft of the shaft top. The drainage element will be nailed to the profile shotcrete installed during the V-Mole operation. The watertight PVC liner will be heat-welded to the drainage element with special fasteners. This drainage system will divert all water from behind the PVC liner via the drainage element to the drain ring and from there to the shaft drain. All components just described will be cast into the concrete lining and thereby provide dry shaft interior. The concrete lining will be placed from the lobby to the shaft top using the slipforming system to give a smooth, unblemished shaft finish.

After completion of the shaft lining and underground work, all temporary hoisting facilities and other equipment will be removed, a shaft cover placed on top of the shaft and the facility turned over to the USBR.

4. UNDERGROUND CONSTRUCTION

A major portion of FKCI's work involved the construction of new underground facilities for the visitor complex. This work involved construction of several tunnels and a large shaft station or lobby. The scope of the underground work is outlined in this section.

4.1 Tunnel Construction

The tunnel excavations in order of excavation consist of the following (see Figure 1):

1) The connecting ramp is an 8 ft by 8 ft arched roof tunnel about 107 ft long. It connects the exiting visitor adit with a new visitor platform (Phase 3 construction) in the 50 ft diameter penstock tunnel. This ramp will provide wheelchair access to the new platform.

2) The stairway is an 8 ft by 8 ft arched roof inclined tunnel with a length of about 54 ft. It connects the new balcony adit and upper lobby level with the connecting ramp.

3) The balcony adit is a 9 ft high by 12 ft wide, 214 ft long tunnel connecting the lobby to the existing powerhouse visitor balcony. The additional width was provided to allow two-way pedestrian tour traffic. Excavation includes saw cutting through the 7 ft thick powerhouse concrete wall to access the balcony.

4) The ventilation tunnel is a 6 ft by 6 ft long tunnel about 104 ft long. It connects the penstock tunnel to the shaft lobby to provide fresh air to the shaft area.

5) The shaft drain hole will be a 10" diameter hole about 21 ft long drilled from the bottom of the shaft sump to the penstock tunnel. All water from the shaft drain ring and lobby areas will be diverted via this drain hole to the penstock drainage system.

Due to the proximity of the penstock tunnels and their obvious vulnerability special excavation methods had to be employed during all underground excavation. Drill-and-blast excavation was carried out under the following conditions:

- Stringent vibration and air blast controls (limited to 2 in/sec peak particle velocity)
- Smooth-wall controlled blasting and line drilling methods
- Non-electric detonation of blast rounds
- Detonator timing through the use of millisecond surface delays and isolated series of detonator chord circuits to limit blasts to one hole per delay
- Trim powder and high energy phlegmatized dynamite
- Drilling with jackleg drills.

Within 10 ft of the penstock tunnel, all excavation had to be carried using non-blasting techniques. The techniques used to excavate the connecting ramp and ventilation tunnel breakthrough were:

- Pre-drilling with jackleg drills and cracking rock with Darda splitters
- Penstock lining was saw cut about 6" deep around excavation perimeter
- Balcony adit excavation through concrete wall will be by plunge-type, 2 ft diameter concrete saw.

Rock Support

To expose the natural appearance of the host rock and due to the self-supporting nature of the rock only spot rock bolting with 6 ft long rock bolts was used. Pressure grouting will also be used to divert any water from the tunnel roof to the sides.

Muck Removal

Due to the small dimensions of the new and existing tunnels, several muck removal systems are employed for the excavation. A 36" conveyor extending from the near the start of the connecting ramp through the penstock tunnel to the spillway tunnel (about 240 ft) removed all excavated material from the tunnel and shaft excavations. The connecting ramp was mucked out using a 1 CY LHD loading onto the conveyor. The stairway and ventilation tunnels were mucked out using a slusher and the 1 CY LHD loading onto the conveyor. A draw point and surge bin was establish in the lobby at the existing visitor adit level for removal of the V-Mole drill cuttings and balcony adit muck. A small opening was excavated at the upper lobby level to allow a Bobcat loader to discharge muck from the balcony adit excavation into the top of the surge bin. A 1 CY LHD draws from the bottom of the surge bin and transfers the muck to the conveyor belt about 75 ft away. The conveyor discharges into the spillway tunnel. Before any excavation began, a bulkhead was installed at the discharge end of the spillway tunnel, the tunnel dewatered and a small hoisting system installed at the bulkhead. A 966 LHD loader hauls the muck from the discharge point of the conveyor down the spillway tunnel to the hoisting system at the bulkhead. The hoisting systems feeds truck which carries the muck to the disposal areas. Figure 3 shows the underground mucking system installed by FKCI.

All mine water produced underground is collected and pumped to a water treatment plant at the spillway bulkhead for clarification before discharge into the Colorado river.

Tunnel Furnishings

Only the tunnel and stairway floors will be concreted with a smooth floor and side curbs and gutters. A 60" diameter steel pipe and valve will be cemented into the ventilation tunnel.

Protection of the powerhouse against the possibility of water ingress from the penstock tunnel is provided by:

- Installation of a watertight door at the connecting ramp intersection with the penstock tunnel. The door automatically closes when high water sensors are activated. The door is designed for a water head of 600 ft.
- Installation of a 60" diameter butterfly valve in the ventilation pipe activated by high water sensors.

4.2 Lobby Construction

The lobby is basically a 42 ft rectangular station surrounding the inner 20 ft diameter shaft. The top of the lobby is tapered to form a cone shaped roof. The lobby will have three floors. The balcony adit level at El. 700, the mechanical room elevation at El. 687.5 and the contractor adit/visitor tunnel at El. 675.16. The sump extends to El. 660.66 below the contractor adit.

Excavation

The lobby excavation will total ±1,900 CY. Excavation will be split between the V-Mole excavation and conventional drill-and-blast excavation. Controlled blasting techniques will be used as described in the tunnelling section above.

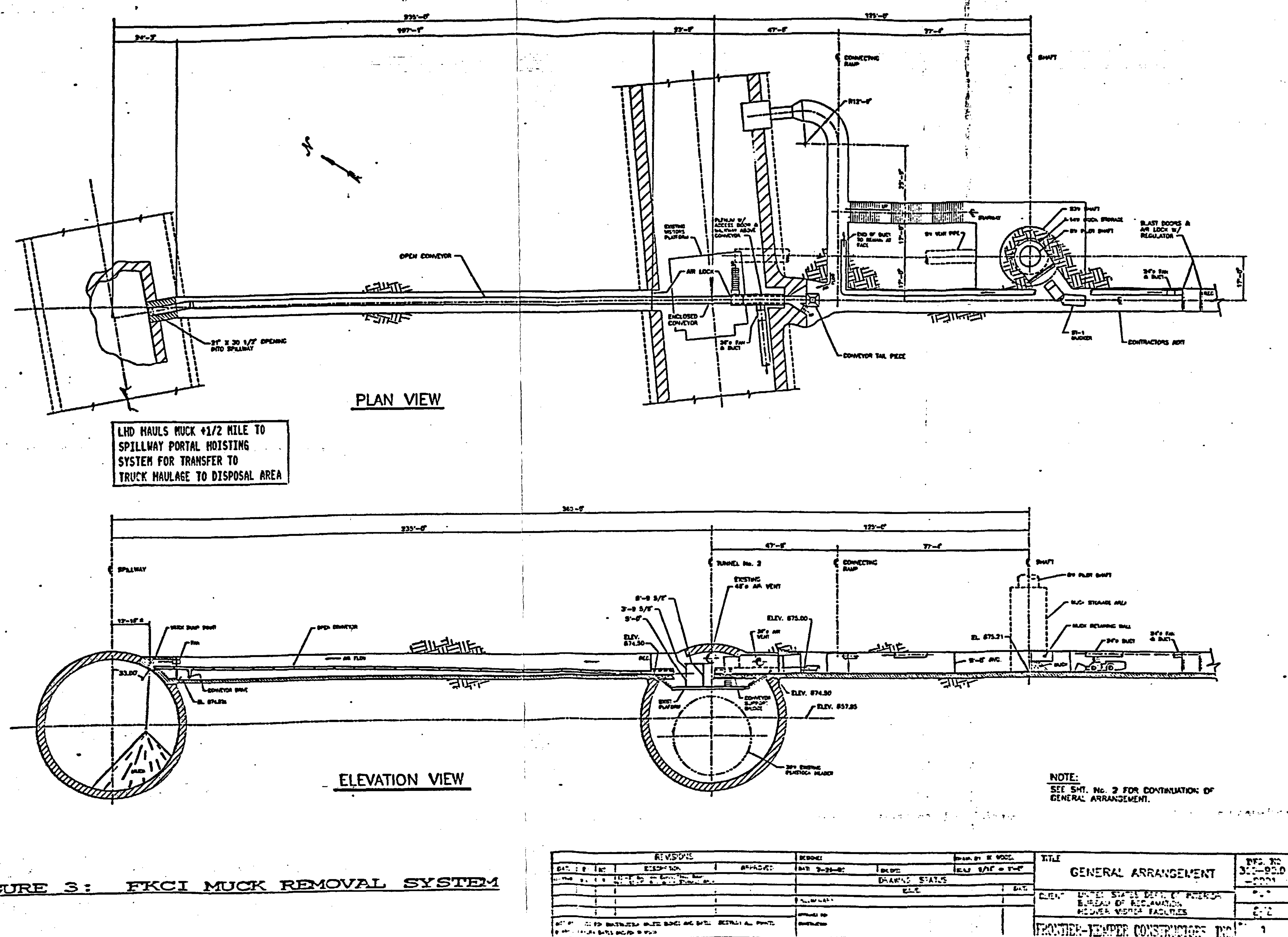

FIGURE 3: FKCI MUCK REMOVAL SYSTEM

Ground Support

The outside walls of the lobby will be self-supporting. The lobby roof will be heavily reinforced with rockbolts up to 20 ft long. Shotcrete will also be place in critical zones. Several cantilever floors will be installed and epoxy-coated dowels will anchor these to the walls. Any ground water will be pressure grouted.

Muck Removal

Muck will be removed via the draw point and LHD/conveyor systems described above. An Eimco 630 or similar loading into a muck bucket will be used to excavate the sump.

Lobby Furnishings

The shaft lining will start at the sump and continue through the lobby to the actual shaft. The lobby shaft wall will be about 1.25 ft thick. Floors will be placed at the three levels and will connect with the shaft lining. Openings will be provided in the shaft lining for future doors and windows. Dowels will connect the floors with the shaft lining.

5. PHASE 3 CONSTRUCTION

Following completion of the shaft and underground construction by FKCI, Phase 3 construction will include the following to complete the new visitor facility:

- A new visitor platform in the penstock tunnel at the end of the connecting ramp
- Two elevators in the shaft
- An elevator building at the top of the shaft
- A visitor facility adjacent to the elevator shaft building
- A five-story parking garage in an existing canyon on the Nevada side near the elevator shaft
- A new pedestrian access, including an escalator under Highway 93 near the end to the new bridge, to the new visitor facility.

The complete facility is expected to be open to the public at the end of 1992.