

PAP-710

**Terror Lake Hydroelectric Project, Falls Creek Diversion Tunnel
Hydraulic Analysis**

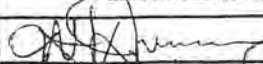
by

Bill McStraw

October 1995

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	Signature Printed Name	
Author initials		PEER REVIEW NOT REQUIRED

OCT 17 1995

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ADM-13.00

Alaska Energy Authority
Attention: Stan Sieczkowski
480 West Tudor
Anchorage AK 99503

Subject: Transmittal of the Hydraulic Analysis and Recommendations for the Repairs to the Terror Lake Hydroelectric Project - Kodiak Electric Association, Inc. - Kodiak Island, Alaska

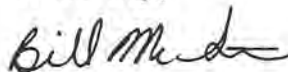
Dear Mr. Sieczkowski:

Transmitted with this letter is a technical report addressing work task 3 as defined in the Memorandum of Agreement between the Alaska Energy Authority and the Bureau of Reclamation, dated July 25, 1995. This task concerns the hydraulic analysis of the Falls Creek Diversion Tunnel inclined shaft to determine if the damaged area was the result of hydraulic characteristics of the flow system. In addition, a recommended method for the repair of Falls Creek Diversion Works based on the findings of the hydraulic analysis is also enclosed.

This transmittal completes Reclamation's scope of work as defined in the above-mentioned Memorandum of Agreement. I would like to express my appreciation for the cooperation and professionalism exhibited by Alaska Energy Authority personnel which greatly facilitated the completion of this Memorandum of Agreement.

Questions you may have regarding the hydraulic analysis or the recommended method of repair for the Falls Creek Diversion Works should be directed to Bill McStraw at (303) 236-8666.

Sincerely,



Bill McStraw
Mechanical Engineer
Hydroelectric Research and
Technical Services Group

Enclosures

cc: Kodiak Electric Association
Attention: Terror Lake Project
515 Marine Way
Kodiak AK 99615
(w/enclosure)

bc: D-8311 (Steighner)
D-8400
D-8420 (Read)
D-8450
D-8450 (Duncan)
D-8450 (McStraw)
D-8610 (Luebke)
D-8560 (Frizell)
(w/encls to each)

WBR:BMcStraw:dbp:10/13/95:236-8666
(WP:TERROR.TRA)

**Terror Lake Hydroelectric Project
Falls Creek Diversion Tunnel
Hydraulic Analysis**

This report addresses work task 3 as defined in the Memorandum of Agreement between the Alaska Energy Authority and the Bureau of Reclamation, dated July 25, 1995. This task concerns the hydraulic analysis of the Falls Creek Diversion Tunnel inclined shaft to determine if the damaged area was the result of any hydraulic characteristics of the flow system. In addition, a recommended method of repair based on the findings of the hydraulic analysis will be presented.

Hydraulic Analysis.-Inspection reports from August 1994 indicated a large cavity in the inclined shaft of the Falls Creek Diversion Tunnel. The cavity was located about 275 feet down from the shaft collar and had an effective scour diameter of 20 feet and its length extended about 30 feet. The inclined shaft was unlined, with shotcrete and rock bolts placed above the springline on the hanging wall. Although the appearance of the damage is not characteristic of cavitation, an analysis was completed to check whether the potential for cavitation exists under normal operating conditions of the diversion tunnel. Characteristics of the open channel flow were arrived at using a computer program which computes the water surface profile by the standard step method (Falvey, 1990). The cavitation index was computed using the following equation and the velocities and piezometric pressures from the program results.

$$\sigma = \frac{P_o - P_v}{\rho V_o^2 / 2}$$

Results of this analysis showed that for a relatively smooth surface (rugosity = 0.002 ft) the cavitation index at the station where the damage has occurred was about 0.35 (figure 1). With a rougher surface, which would be more characteristic of an unlined rock tunnel, the cavitation indices are even higher. However, the velocities at the damage location are on the order of 75 feet/second. Taking into account the highly fractured rock which was discovered in this area during construction, hydraulic mining due to the high velocity jet along the tunnel surface is the probable cause for the existing damage and rock fall. High pressures can be generated in cracks and gaps due to high velocity flow (Hepler and Johnson, 1988). If the pressures are high enough (or the rock blocks small enough), material can easily be lifted from place and removed. Once this process begins, further damage occurs due to the increased hydraulic energy dissipation until an equilibrium is reached based on flow conditions and material properties in the area of concern.

The damaged region in the Falls Creek Diversion inclined shaft is exposed to very high water velocities during operation. Due to this high velocity flow, it seems appropriate to bring the tunnel profile back to its original diameter. Zones of fractured rock downstream from the repaired area should be protected to reduce the chance that future erosion will take place. An analysis and recommended method to repair the damaged area of the Falls Creek inclined shaft is attached.

REFERENCES

- Falvey, Henry T., *Cavitation in Chutes and Spillways*, Bureau of Reclamation, Engineering Monograph No. 42, Denver, CO, April 1990.
- Hepler, Thomas E. and Perry L. Johnson, "Analysis of Spillway Failures by Uplift Pressure," Proceedings of the ASCE National Conference on Hydraulic Engineering, American Society of Civil Engineers, Edited by Steven R. Abt and Johannes Gessler, August 8-12, 1988, Colorado Springs, Colorado, pg. 857-862.

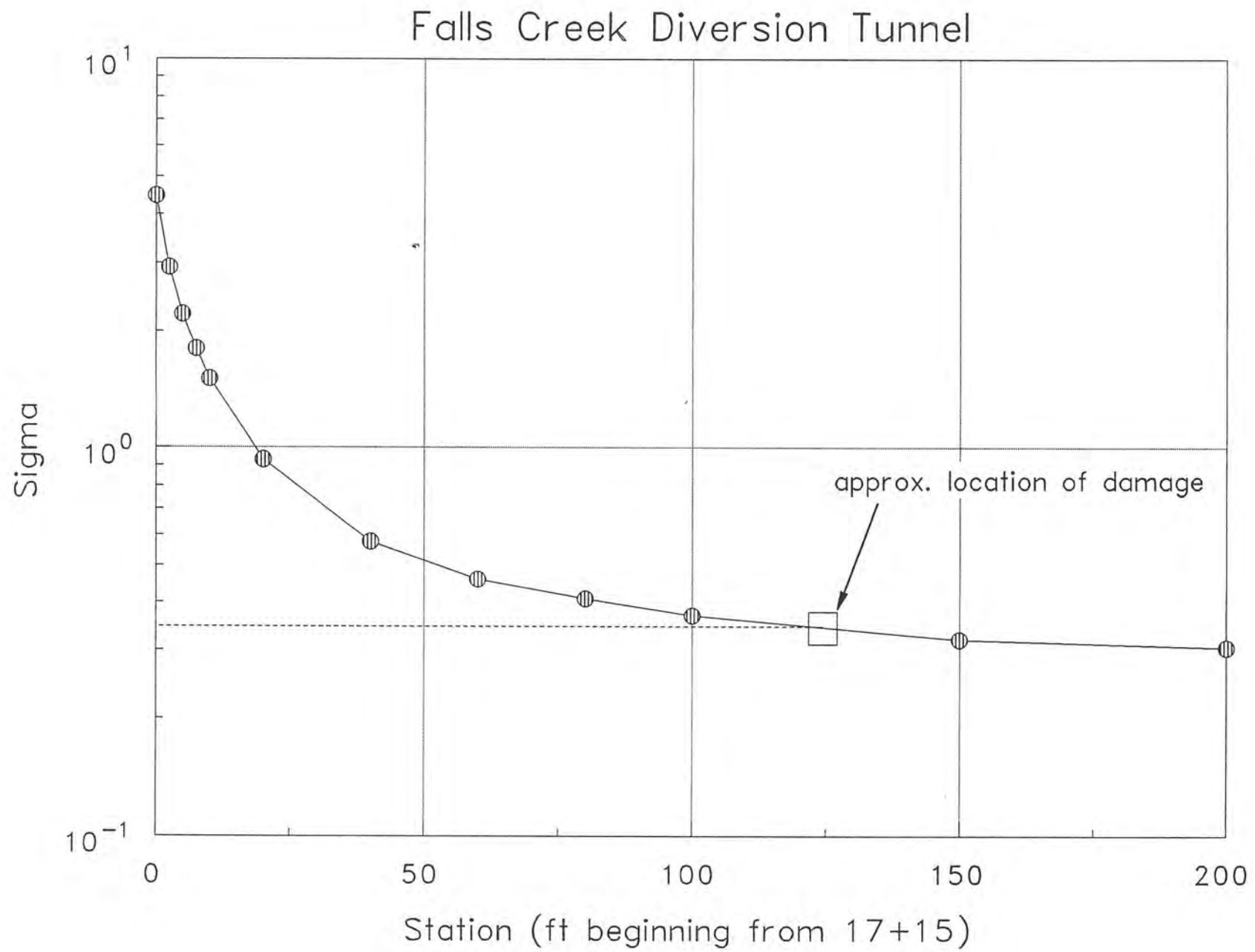


Figure 1

Terror Lake Hydroelectric Project Repair of Falls Creek Diversion Works

prepared for:

**Kodiak Electric Association, Inc.
Kodiak, Alaska**

by:

United States Bureau of Reclamation

October, 1995

author: John Steighner

peer review: Gregg Scott

John Steighner. 10/10/95
Gregg A. Scott 10-10-95

Introduction

Kodiak Electric Association owns and operates the Terror Lake Hydroelectric Project on Kodiak Island, Alaska. This project was recently taken out of service for a thorough maintenance inspection (1). That inspection revealed two potential problem areas:

- 1) a cavity in the inclined shaft portion of the Falls Creek Diversion Tunnel (1, p.C-8) and
- 2) inadequate ground support at the intersection of the Falls Creek Diversion and the Power Tunnel (1, p.C-9).

At the request of the owner we reviewed the text of the inspection report and video tape of the inspection. The review was made to suggest a response to the findings of the maintenance inspection. In this report, we advise the owner of the project to repair the damaged areas of the shaft and suggest a repair method and contract provisions which may be considered during the formulation of a repair plan.

Undoubtedly there are volumes of data on the project which may be pertinent; however, in the interest of beginning the discussion of repair methods the recommendations of this report are based on limited information, primarily the inspection report cited as reference 1.

Data reviewed:

Appendix C of the report titled "Terror Lake Hydroelectric Project, Dewatering, Inspection, and Rewatering of the Power Tunnel, Falls Creek Drop Shaft, and Diversion Tunnels". This report was prepared by R.W. Beck Associates and includes attachments by Mr. David R. Eberle, and Shannon and Wilson Associates.

Drawings	Figure II -11 Conduit System TL-10-002 Project Facilities General Arrangement TL-31-001 Power Tunnel Plan and Profile TL-31-002 Power Tunnel Sections TL-31-003 Power Tunnel Falls Creek Diversion Tunnel TL-31-005 Power Tunnel Outlet General Arrangement TL-24-101 Falls Creek Diversion Works General Arrangement TL-31-009 Power Tunnel Falls Creek Diversion Tunnel Upper Tunnel/Shaft Modifications TL-31-011 Power Tunnel Falls Creek Diversion Tunnel Sections and Details TL-31-004 Power Tunnel Rolling Rock Creek Diversion Tunnel TL-31-008 Power Tunnel Rolling Rock Tunnel Junction and Geometry & Sections
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Data not reviewed:

Basis of Design presumably prepared by the project designer mentioned in (1) p.C-7.

Information showing the reaches of tunnels left unlined, those lined with concrete, and those lined with shotcrete.

Geologic profiles.

Power System Layout

Figure A.1 shows a plan view of the power system.

From Figure II-11 listed above in the section titled "Data Reviewed", the design flows are:

Power Tunnel:	435 cfs to the plant
	415 cfs to Terror Lake
Falls Creek Diversion:	330 cfs
Rolling Rock Creek Diversion:	85 cfs

Figure A.2 shows a profile of the Falls Creek Diversion. Another section of this report includes a hydraulic analysis of the system by the Bureau of Reclamation.

Figure A.3 shows selected typical tunnel sections and notes from drawing TL-31-002. These sections may represent the geometry and support in Falls Creek Diversion Tunnel, but the Power Tunnel was excavated by Tunnel Boring Machine (TBM) so the original sections shown on Figure A.3 do not show the as-built geometry of the Power Tunnel.

Figures A.4 and A.5 show views of Falls Creek Tunnel and Falls Creek Shaft taken from a video tape of the tunnel inspections.

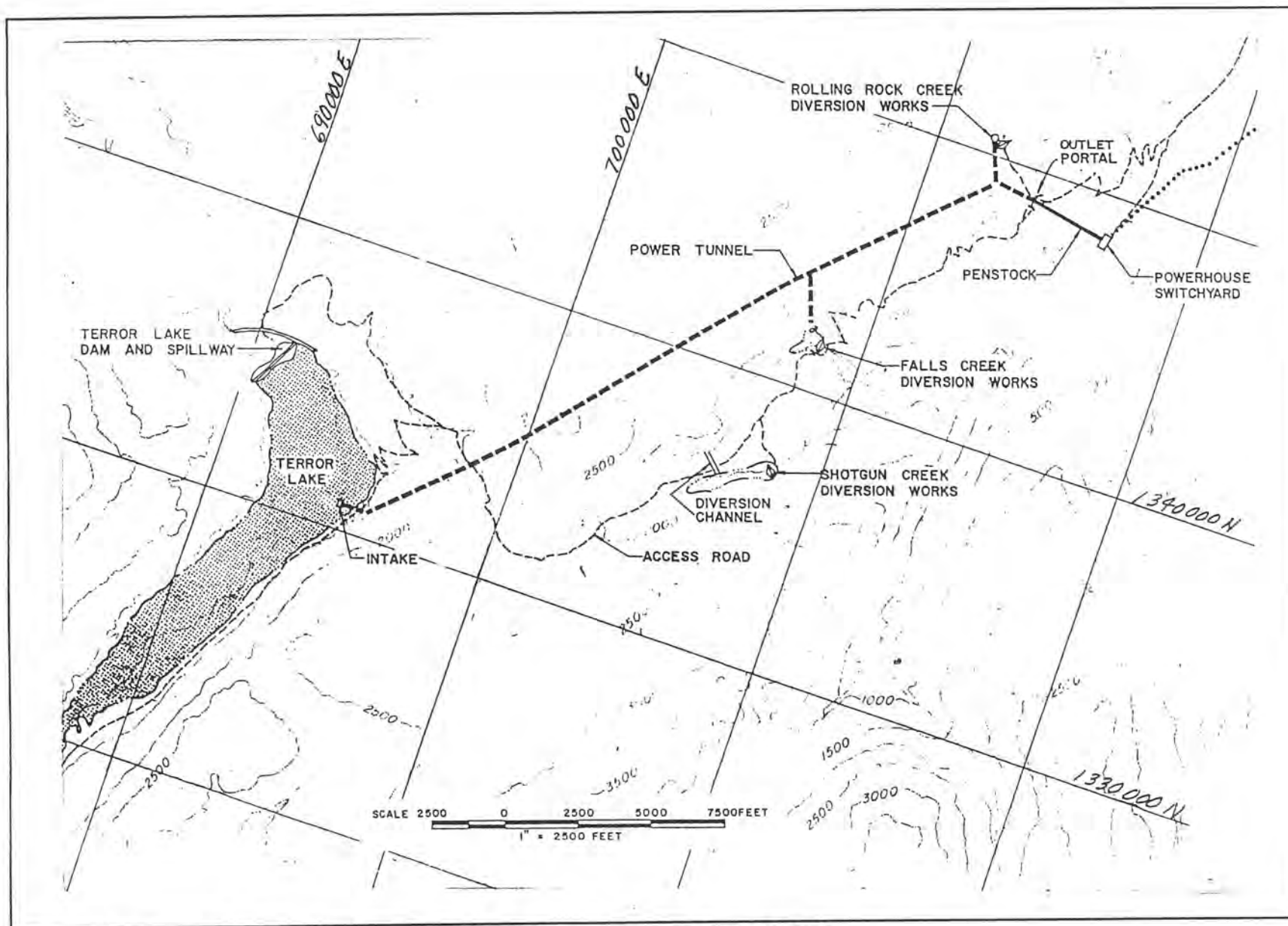


Figure A.1 General Plan (from Kodiak Electric Association, Inc. drawing TL-10-002)

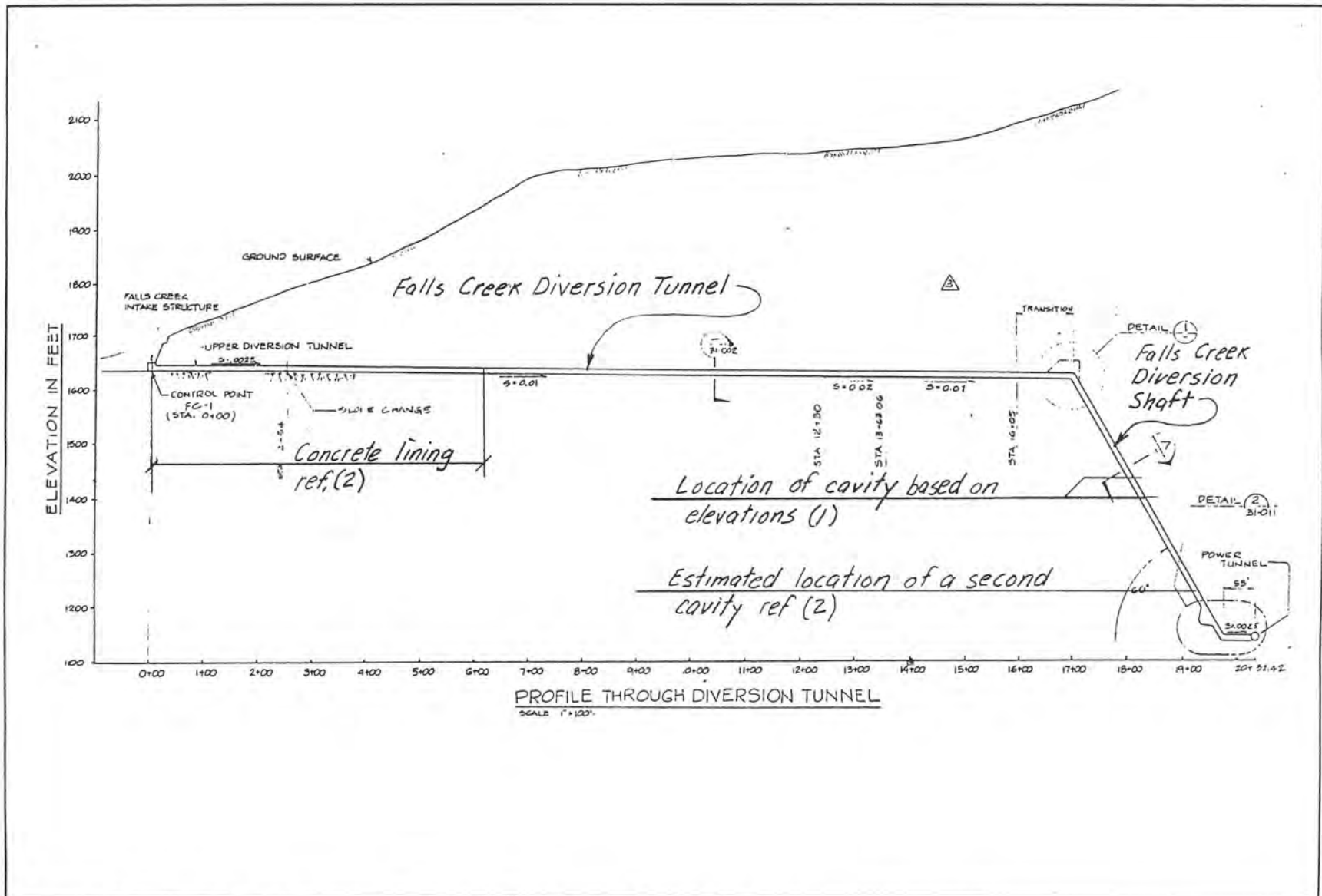


Figure A.2 Profile Falls Creek Diversion (from Kodiak Electric Association, Inc. drawing TL-31-003)

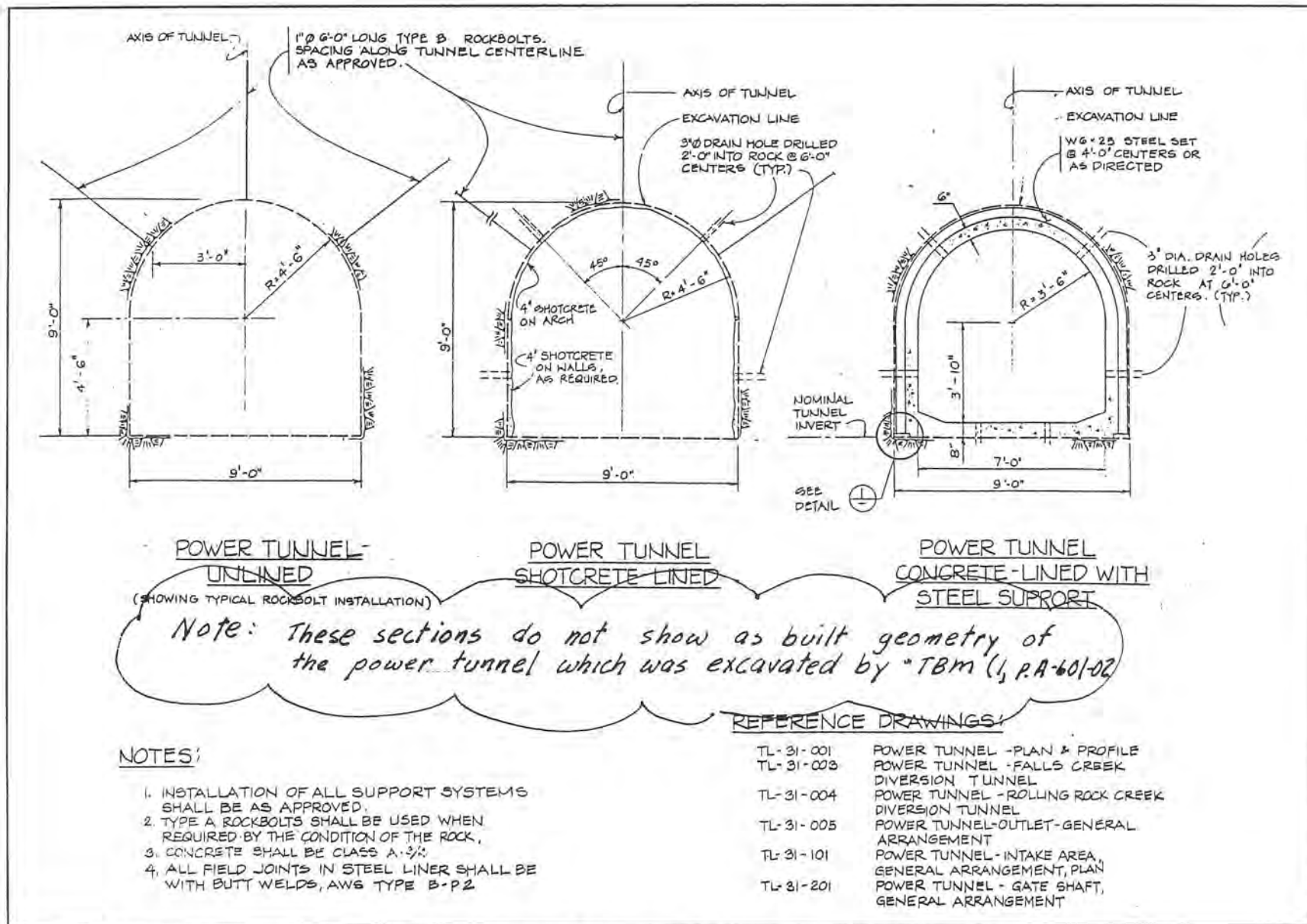


Figure A.3 Typical Sections Falls Creek Diversion (from Kodiak Electric Association, Inc. drawing TL-31-002)

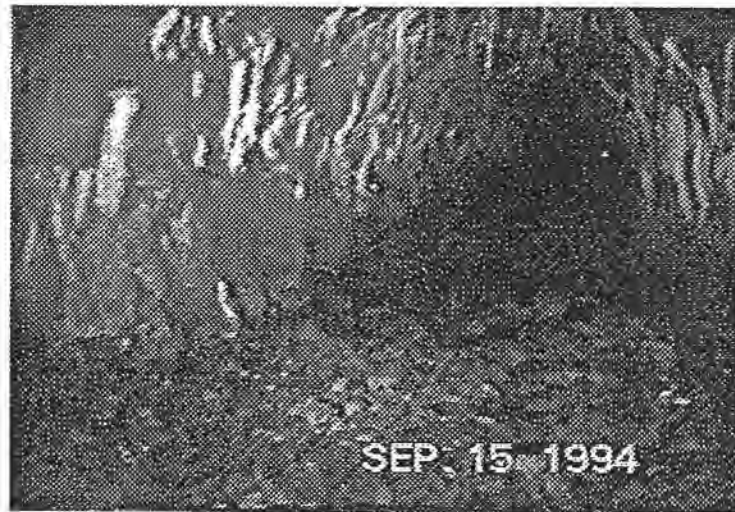


Figure A.4 View captured from video (2) showing Falls Creek Diversion Tunnel.

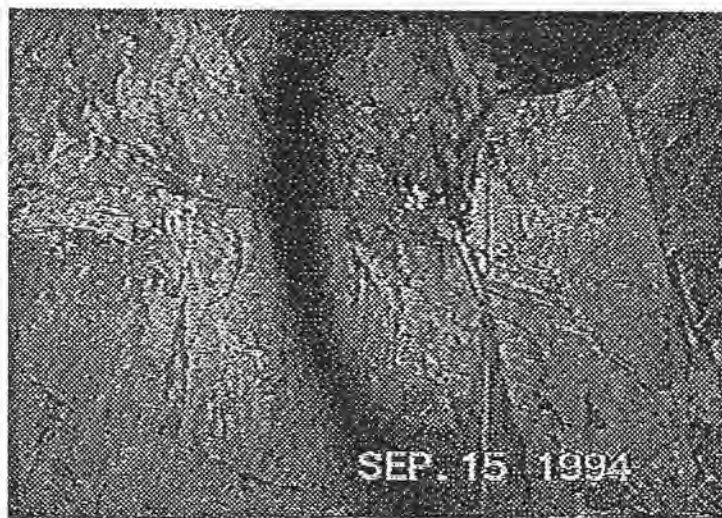


Figure A.5 View captured from video (2) showing Falls Creek Diversion Shaft near elevation 1400 to 1435 feet.

Inferences from Data Reviewed

Generally, the power system appears to be in good condition. Falls Creek Diversion Tunnel and Falls Creek Diversion Shaft exhibit the most severe deterioration. Before local repairs in the shaft are initiated, the question of systematic deficiencies should be considered. Are there geologic conditions or other system conditions which imply continued even accelerating deterioration of the power conduits? As discussed below, the available information indicates the deterioration of the tunnel and shaft may be due to flow velocities in the shaft and flow velocities combined with drill and blast construction damage to the rock in the tunnel. Since the flow velocities are fixed by the system layout, there is a potential for continued erosion in the tunnel and shaft.

The reported condition of Falls Creek Diversion Tunnel indicates greater erosion and deterioration of the excavation than that encountered in the Power Tunnel. The inspection report (1) describes the Power Tunnel as: "... in very good condition with only minor rockfalls.." and "Invert erosion was minimal or absent." (1, p. C-6). Figure A.4 shows erosion and deterioration of Falls Creek Diversion Tunnel. Geologic differences between Falls Creek Diversion Tunnel and the Power Tunnel were not noted in the inspection report and geologic profiles were not available, so it is possible Falls Creek Diversion Tunnel was excavated in more fractured rock. The two tunnels were excavated differently; drill and blast excavation was used in Falls Creek Diversion Tunnel. The combination of blast damage to the rock and flow velocities on the order of 10 feet per second, probably explains the erosion in Falls Creek Diversion Tunnel. Erosion will probably continue perhaps at a reduced rate until sound rock is encountered throughout the tunnel and the tunnel cross section reaches a stable shape. Previous erosion was not identified as a problem, so continued erosion may be equally tolerable.

Falls Creek Diversion Shaft is in poor condition compared to Rolling Rock Shaft. This difference is explained by operational patterns. The inspection report indicated Rolling Rock Diversion operated for only two years 1989-90 and 1990-91 (1, p. C-5). The limited use of Rolling Rock Shaft explains the excellent condition of the shaft. While there may be geologic differences between the two shaft locations, nine years of operation explains the deterioration at Falls Creek.

The hydraulic analysis of the system attributes the damage in Falls Creek Diversion Shaft near elevation 1400 to 1435 to hydraulic mining. Figure A.5 shows the cavity with the shaft in the upper right of the photograph. Highly fractured rock conditions were mentioned in the inspection report with the implication that erosion at that location could be due to a fault. The combination of high velocity flows and fractured rock allowed initial erosion of the rock which continued to the current shape. Based on the results of the USBR hydraulic analysis, we recommend restoration of the shaft cross section to the original diameter. Possible repair methods are discussed in the following section.

Another area of erosion in the shaft was described in the video narrative but was not photographed. If the damage is similar to that shown in Figure A.5, this area should also be repaired. This location is shown approximately on Figure A.2.

In the area of the intersection of the shaft and Power Tunnel, the report (1) suggested additional rock reinforcement. Information on the intersection is not sufficient to make a recommendation.

Repair Methods

Three potential repair methods are described in the following paragraphs.

Reinforced or fiber reinforced shotcrete could be used to fill the cavity and return the section to its original diameter. This method is not recommended due to the demonstrated erosion potential of the flow. If the Terror Lake water surface is near elevation 1420, the damaged area in the shaft will be subject to very high energy dissipation forces. Shotcrete is considered to be less erosion resistant than cast in place reinforced concrete or steel and is therefore not recommended.

Reinforced cast in place concrete is a possible repair method having greater resistance to erosion than shotcrete; however, the cost of this repair is anticipated to be nearly equal that of using a steel liner so this method is not recommended.

A steel liner placed through the damaged area and backfilled with concrete will provide the maximum resistance to erosion and will be cost effective in the long term.

Recommendations

We recommend repair of Falls Creek Diversion Shaft near elevation 1400 using a steel liner with erosion resistant lining. The steel liner should be backfilled with concrete and backfill grouted near the top of the installation. Figure A.6 shows the recommended repair.

A second cavity mentioned in (2) should be investigated for possible repair.

The intersection at the bottom of the shaft should be investigated for erosion damage as well as structural deterioration.

Access to the work and mobilization costs will be more significant than material costs. We recommend solicitation provisions which will permit the owner to review potential contractor's approach to the work before award of a contract.

Recommended Repair.

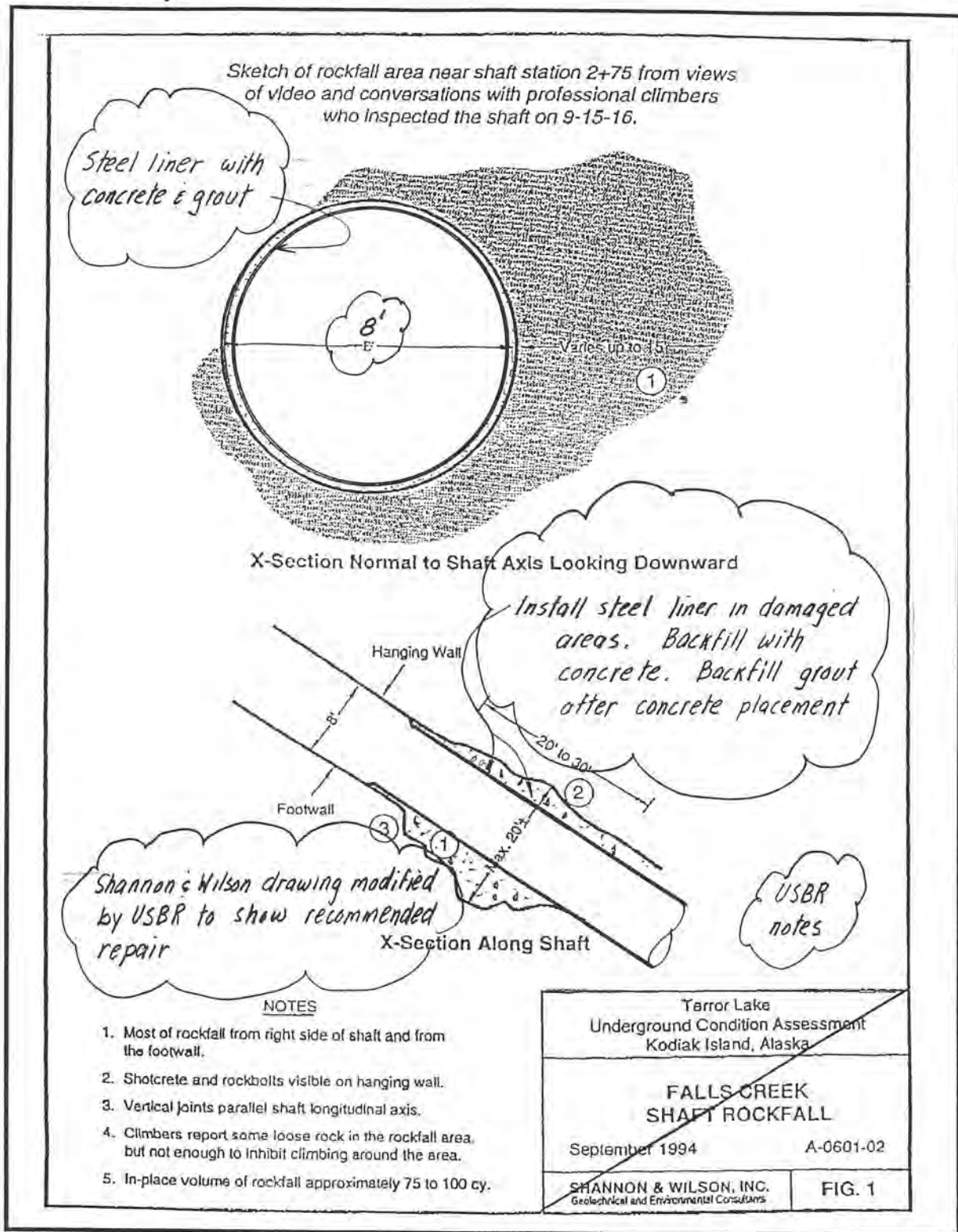


Figure A.6 Recommended Repair

References

1. Appendix C Terror Lake Hydroelectric Project, Dewatering, Inspection, and Rewatering of the Power Tunnel, Falls Creek Drop Shaft, and Diversion Tunnels, R.W. Beck and Associates.
2. Video Tape of inspections made in August and September 1994.