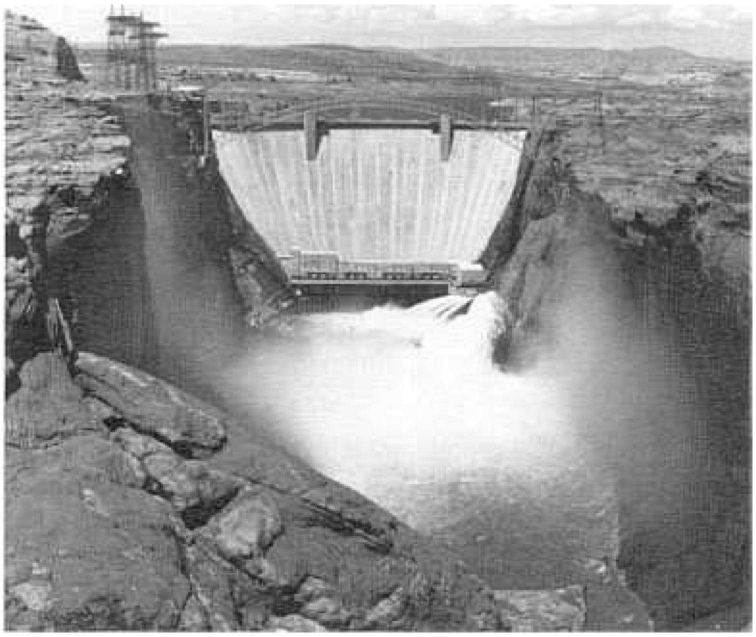

SPILLWAY TESTS AT GLEN CANYON DAM

July 1985
Engineering and Research Center

U. S. Department of the Interior
Bureau of Reclamation

Cover: Colorado River below Glen Canyon Dam. The discharge from the 41-foot-diameter left tunnel spillway is 50,000 ft^3/s and the four 96-inch hollow-jet valves are releasing a combined flow of 4,000 ft^3/s. These flows occurred August 12, 1984, during tests to evaluate the newly constructed aeration slot in the left spillway.

SPILLWAY TESTS AT GLEN CANYON DAM

by

K. Warren Frizell

Hydraulics Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado
July 1985

UNITED STATES DEPARTMENT OF THE INTERIOR ★ **BUREAU OF RECLAMATION**

ACKNOWLEDGMENTS

I would like to thank the following for their involvement in making this a successful test:

Clifford Barrett, Regional Director, and the Upper Colorado Regional Office in Salt Lake City, Utah, for the funding and planning support.

Thomas Gamble and the staff of the Colorado River Storage Project Office in Page, Arizona.

Richard White and the operations staff at Glen Canyon Dam.

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Theodore Whitmoyer, photographer.

G. F. Atkinson Company, spillway repair contractor.

Principal designer, David Hinchliff, and other involved parties from the Division of Dams and Waterway Design, E&R Center.

Hydraulics Branch staff, notably Lee Elgin, who participated in the testing, Division of Research and Laboratory Services, E&R Center.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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FIGURES

INTRODUCTION

Tests were performed on the left spillway tunnel of Glen Canyon Dam August 11 through 17, 1984. The tests were used to evaluate:

1. The effectiveness of the air slot

2. The adequacy of the tunnel lining repair specification

3. The model to prototype conformance

The evaluations were made through a series of measurements and observations. Results showed the newly installed air slot to be operating satisfactorily. Evidence of cavitation damage was not observed.

TEST BACKGROUND

During the summer of 1983, both tunnel spillways at Glen Canyon Dam experienced major cavitation and erosion damage [1].* As part of the tunnel repair, an air slot was constructed in the left and right tunnels. The air slots were designed to reduce the potential for cavitation damage by entraining air into the flow to lower the sonic velocity, and in turn lessen the impact of shock waves caused by the imploding vapor bubbles. Although general flow patterns could be observed in the Bureau's 1:42.8 scale hydraulic model [2], a prototype test was needed to evaluate the air slot's effectiveness for preventing cavitation damage. Previously, two Bureau of Reclamation tunnel spillways had been equipped with air slots; Yellowtail Dam (1968) and Flaming Gorge Dam (1982). However, neither spillway has operated sufficiently to evaluate the designs in detail.

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*Number in brackets refer to the Bibliography.

Glen Canyon Dam provided a unique opportunity for a prototype test. The provisions for instrumentation could be made during the repair at a fraction of the cost of instrumenting one of the previously mentioned existing spillways. In addition, the reservoir was in a surcharge condition providing water for an extended spillway test.

INSTRUMENTATION AND DATA ACQUISITION

An instrumentation scheme was developed in which various measurement locations were provided throughout the spillway tunnel. Eleven instrumentation boxes were installed and connected by electrical conduit to a junction box in the plugged access tunnel. The instrument boxes consist of:

(1) A 15-in length of 6-in-diameter pipe

(2) A removable steel top plate

(3) A 1-1/2-in conduit connection running to the access tunnel

The instrument boxes were installed flush with the tunnel inside surface as the new concrete was placed in the tunnel invert and in the air slot. Details of the instrument boxes and their locations are shown on figure 1. Problems occurred with leakage into these boxes at the connections with the electrical conduit. In addition, scale and rust accumulated on the removable steel plates. Electrical signal cable was pulled into each instrument box and the appropriate instrument connected. A computer-based data acquisition system was configured to poll and record outputs from all tunnel instrumentation.

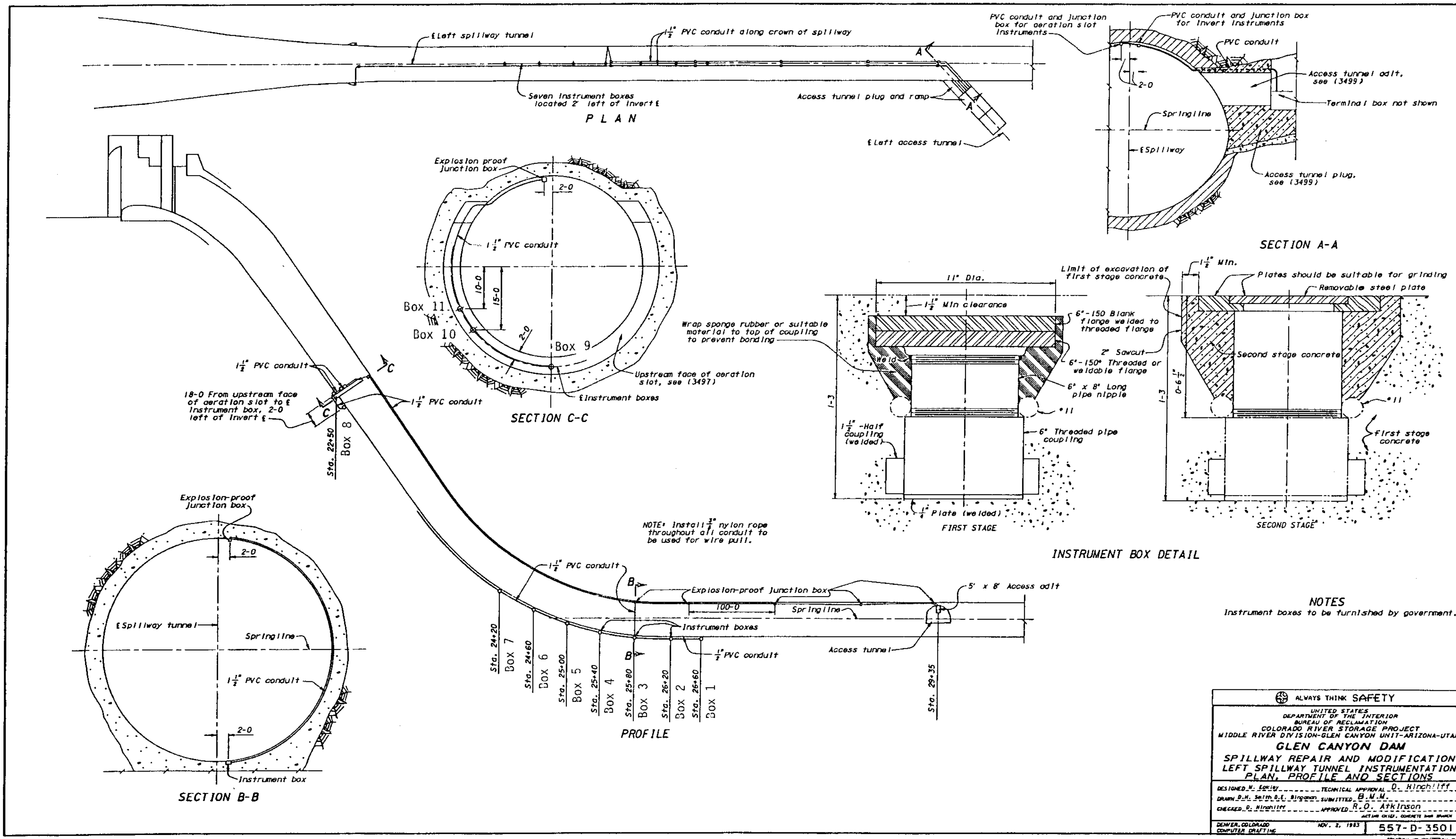

Figure 1. - Glen Canyon Dam - spillway repair.

Instrumentation

All measurements in the spillway tunnel were made with various types of pressure transducers. By operating the transducers using a current loop, it allowed for the use of long cable lengths which were required to connect the transducers with the data acquisition system in the access tunnel.

Pressure measurements (both static and dynamic) were planned for instrument Boxes 1 through 7 in the invert of the spillway tunnel elbow. Sealed, absolute static pressure transducers were installed in Boxes 1, 2, 3, and 6. Dynamic pressure transducers were installed in Boxes 2, 3, 4, 5, and 7. These transducers were mounted flush with the tunnel surface and were of a piezoelectric type.

Four transducers were installed in the air slot area in Boxes 8 through 11. Static LVDT transducers (linear variable differential pressure transducers) were installed in Boxes 8 and 9. One of the differential ports was sealed, the other was vented to the tunnel interior. The same type transducers were used with the air velocity probes in Boxes 10 and 11. Transducers (Nos. 10 and 11) were used to sense the differential on pitot-static type probes. The probes were located at elevations determined from the model study to sense the maximum air velocities for spillway discharges of 20,000- (Box 10) and 50,000-ft^3/s (Box 11). A detailed account of the instrumentation installation is given in the appendix.

Calibration of all pressure transducers was completed prior to installing them. The pitot-static probes were calibrated in the Bureau's E&R Center hydraulic laboratory air test facility.

Data Acquisition

The data acquisition system consisted of:

- System controller (desktop calculator with disk drives)
- Scanner
- High-speed digital voltmeter
- Anti-aliasing analog filters
- Spectrum analyzer

Sampling and recording of the various transducer outputs was controlled by the desktop calculator through a computer program. The scanner performed the switching function between transducers, allowing the high-speed digital voltmeter to measure the different outputs. The analog filters were used as low pass filters to prevent aliasing of digital data taken at fast rates. The spectrum analyzer was used to obtain frequency information about the dynamic pressure fluctuations occurring in the tunnel elbow. All data were recorded on magnetic disks for future analysis. Figure 2 shows the data acquisition equipment used for the test.

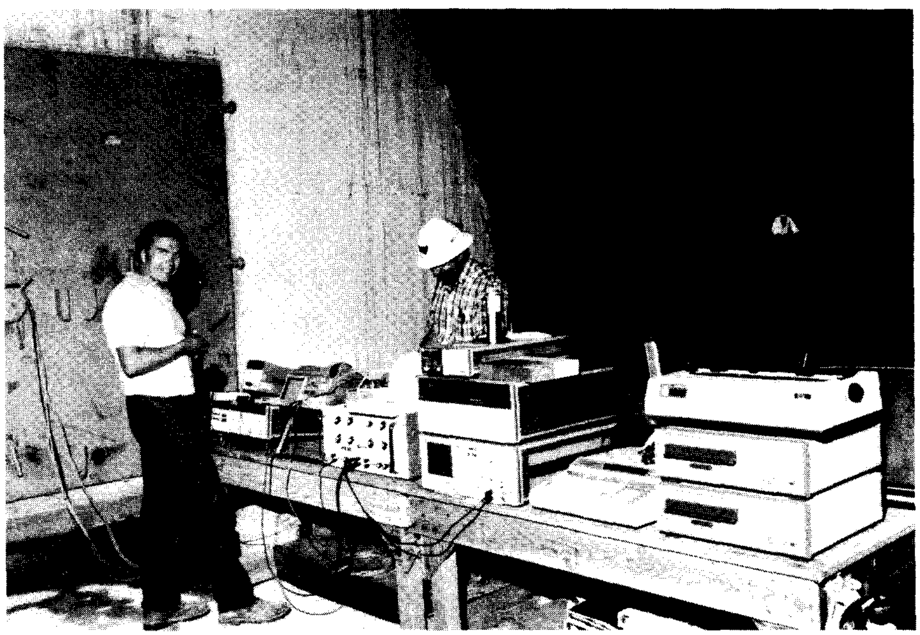

Figure 2. - Data acquisition equipment in the access tunnel. (Note watertight door leading into spillway tunnel.)

PRETEST PREPARATION

Several days before the scheduled test program, the data acquisition system was set up in the access tunnel and the instruments were checked. In the six weeks following the installation of the transducers, water had infiltrated the conduits and instrument boxes. Consequently, only two transducers were operating properly. In most cases, water had created a short circuit in the connector or wire splice. However, in some of the transducers, water had moved up the insulation of the signal wires by capillary action and damaged the internal electronic circuits.

Because a limited time was available to correct the faulty transducers, the most important measurements were identified and test priorities were defined. In the air slot area, all four transducers (Boxes 8-11) were beyond repair. Only two replacement transducers were available and they were installed in Boxes 10 and 11 to measure pressures from the air velocity probes. Boxes 8 and 9 were left open so that water would be free to drain out of the interconnected electrical conduit. In the tunnel elbow, Boxes 1 through 5 were opened. The dynamic transducers were removed and dried in an oven overnight (as suggested by the manufacturer) before being reconnected. All wires and connectors were checked for continuity searching for possible shorts and breaks. Boxes 6 and 7 were left closed since the transducers were operating properly. A check of the repaired instruments showed seven transducers to be operating: static cells in Boxes 3 and 6; dynamic cells in Boxes 2, 3, and 7; and the two differential cells on the air velocity probes in Boxes 10 and 11. Even though several transducers were still inoperative, the test proceeded on schedule with adequate instrumentation operational.

TESTING

The proposed test program consisted of two phases:

Phase 1. - Tests at 5,000-, 10,000-, 20,000-, and 50,000-ft^3/s for about an hour each. These tests were proposed to collect data at a variety of flow conditions.

Phase 2. - A continuous operating test at 20,000 ft^3/s for 48 hours including tunnel inspections after 24 hours and at the end of test. This duration at this flow would provide enough exposure to produce minor cavitation damage if the air slot did not function as expected.

The actual test program was similar to the proposed program. Table 1 shows a synopsis of the spillway operation at Glen Canyon Dam during the test period. Two major differences were implemented: (1) the addition of a test point at a flow of 35,000 ft^3/s during phase 1, to gradually decrease the river flow after the 50,000-ft^3/s test, and (2) an additional sixteen hours of operation at a flow of 20,000 ft^3/s between the 20,000 ft^3/s and 50,000 ft^3/s test points to increase the river water temperature gradually and lessen any shock on the fish downstream.

Table 1. - Operation Record - Glen Canyon Dam Left Spillway - August 11-17

August 11	7:00 a.m. - 2:00 p.m.	Inspection of left spillway
	2:00 p.m. - 4:00 p.m.	Removed pumps and access cart
	4:30 p.m.	Phase 1 test began
		Established flip at 15,000 ft^3/s then immediately reduced to 6,500 ft^3/s
		Powerplant discharge 25,000 ft^3/s
	6:00 p.m.	Spillway increased to 10,000 ft^3/s
	7:30 p.m.	Spillway increased to 20,000 ft^3/s
August 12	Noon	Spillway increased to 50,000 ft^3/s, river outlets opened to release 4,000 ft^3/s
		Powerplant reduced from 25,000 ft^3/s to 21,000 ft^3/s
	1:00 p.m.	Spillway decreased to 35,000 ft^3/s Powerplant discharge increased to 25,000 ft^3/s
	1:30 p.m.	Spillway decreased to 20,000 ft^3/s
	2:00 p.m.	Spillway and river outlet closed
	2:15 p.m. - 3:30 p.m.	Rigged in access cart and pumped out tunnel
	3:30 p.m. - 5:00 p.m.	Inspection of left spillway
	5:00 p.m. - 6:00 p.m.	Removed pumps and access cart
	8:15 p.m.	Phase 2 test began
		Opened spillway gates to 10,000 ft^3/s
	9:15 p.m.	Spillway increased to 20,000 ft^3/s
August 13	9:15 p.m.	Spillway closed, pumped out tunnel
August 14	7:00 a.m. - 9:00 a.m.	Rigged in access cart
	9:00 a.m. - 5:00 p.m.	Left spillway inspected
	5:00 p.m. - 7:00 p.m.	Removed pumps and access cart
	7:15 p.m.	Phase 2 test continued
		Opened spillway to 10,000 ft^3/s
	8:15 p.m.	Spillway increased to 20,000 ft^3/s
August 15	8:15 p.m.	Spillway closed, pumped out tunnel
August 16	6:00 a.m. - 8:00 a.m.	Rigged in access cart
	8:00 a.m. - 11:00 a.m.	Removed instruments at left air slot
	10:00 a.m. - 3:00 p.m.	Left spillway inspected
August 17	8:00 a.m. - 11:00 a.m.	Instruments removed from left elbow

RESULTS AND DISCUSSION

Air Slot Instrumentation

The average air velocities were measured with the two pitot-static probes and are shown in table 2.

Table 2. - Average air velocity, V vs. spillway discharge, Q

Discharge Q, ft^3/s	Air Velocity V, ft/s	
	Box 10 - Probe 1	Box 11 - Probe 2
6,500	-*	-
10,000	64.1	-
20,000	124.9	-
35,000	231.8	-
50,000	113.1	247.3

*Denotes a negative differential pressure on the pitot-static probe. Negative values are possible due to positioning the probes to read maximum air velocities at 20,000 ft^3/s and 50,000 ft^3/s.

A comparison of these velocities with scaled model values is shown on figure 3. The single point velocity data can be integrated into a volumetric flowrate by assuming a velocity distribution in the slot. A standard logarithmic distribution was assumed along with symmetric performance of the slot. A comparison of air demand, for model, prototype, and computed data is shown on figure 4. It should be noted that measurements in the model and prototype only reflect air demand passing through the slot. Additional air is entrained through shear drag on the free surfaces of the jet and at flows below 30,000 ft^3/s air may enter beneath the jet downstream from the slot because the sides of the jet are not sealed against the tunnel walls.

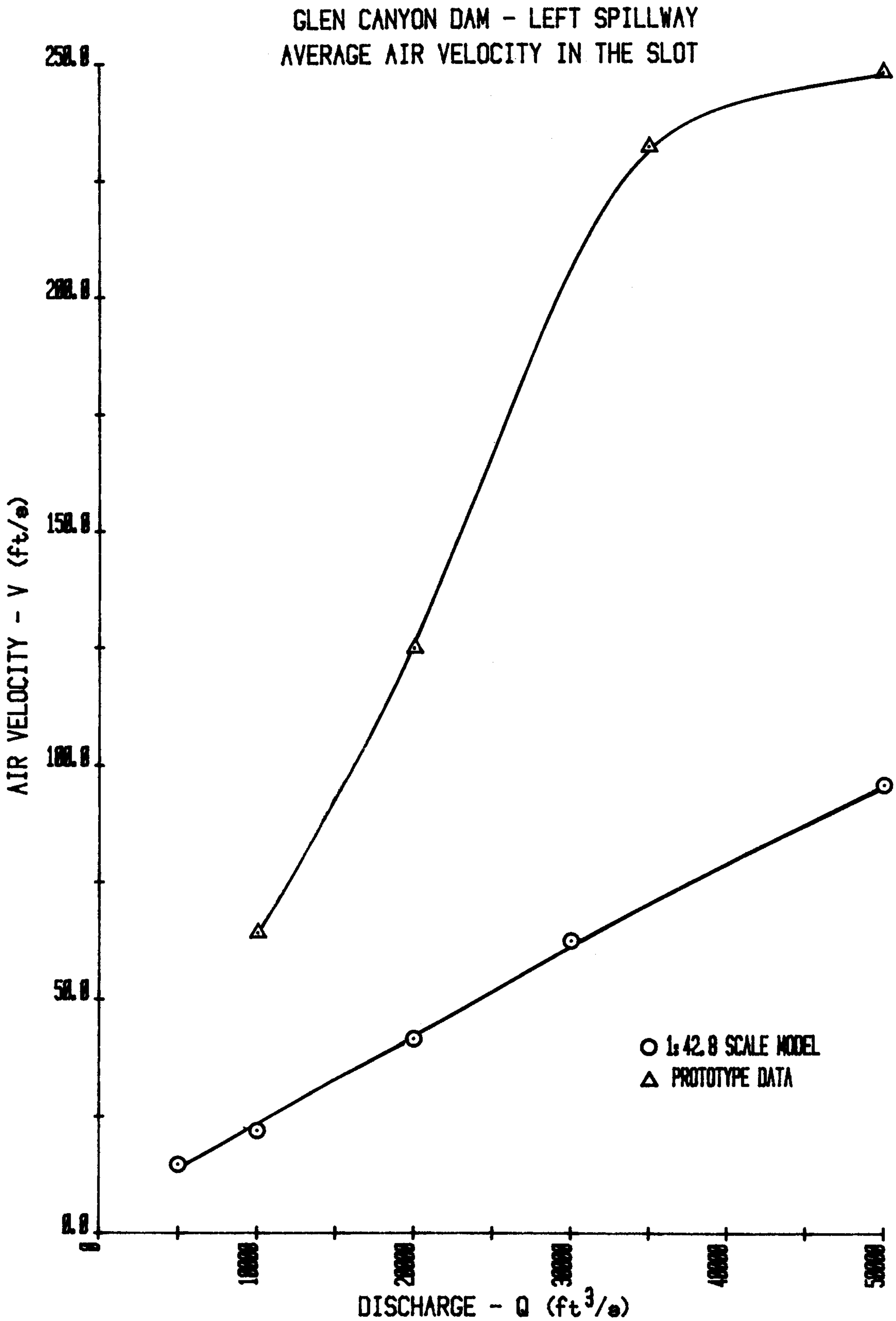

Figure 3. - Air velocity measurements in the air slot.

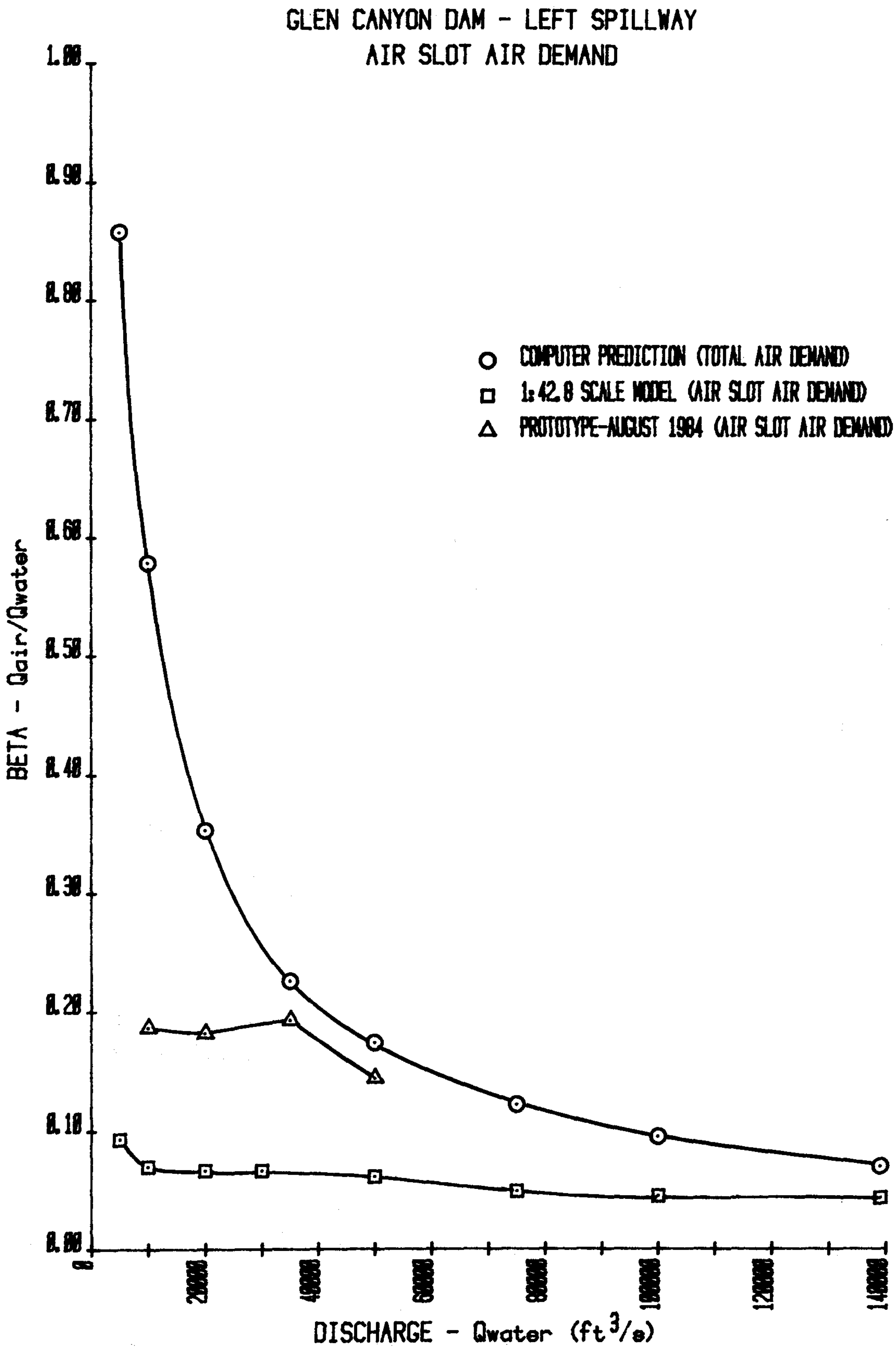

Figure 4. - Air demand comparison - computed-model-prototype.

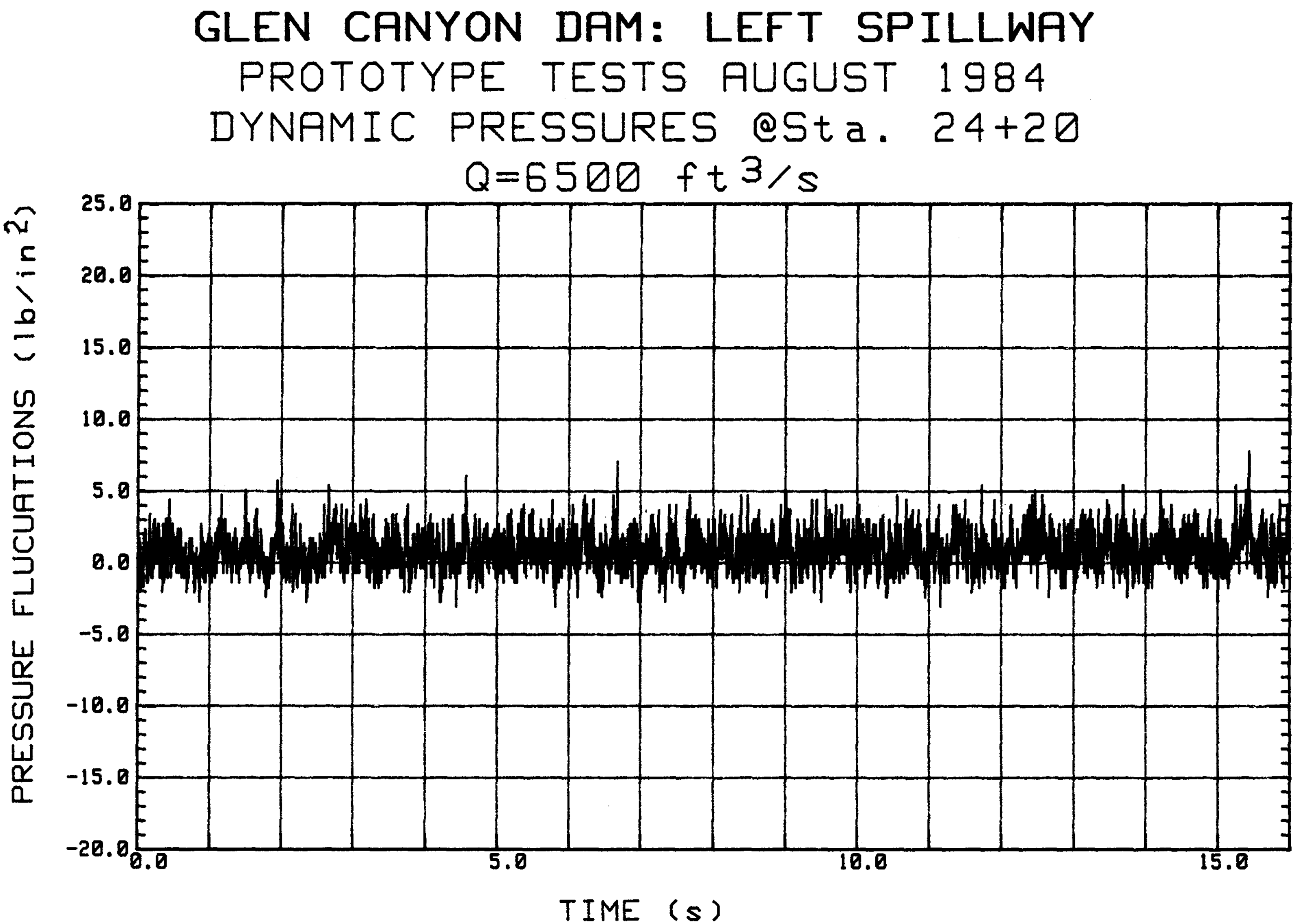

Figure 5. - Dynamic pressure fluctuations, Sta. 24+20 (Box 7), Q = 6,500 ft^3/s.

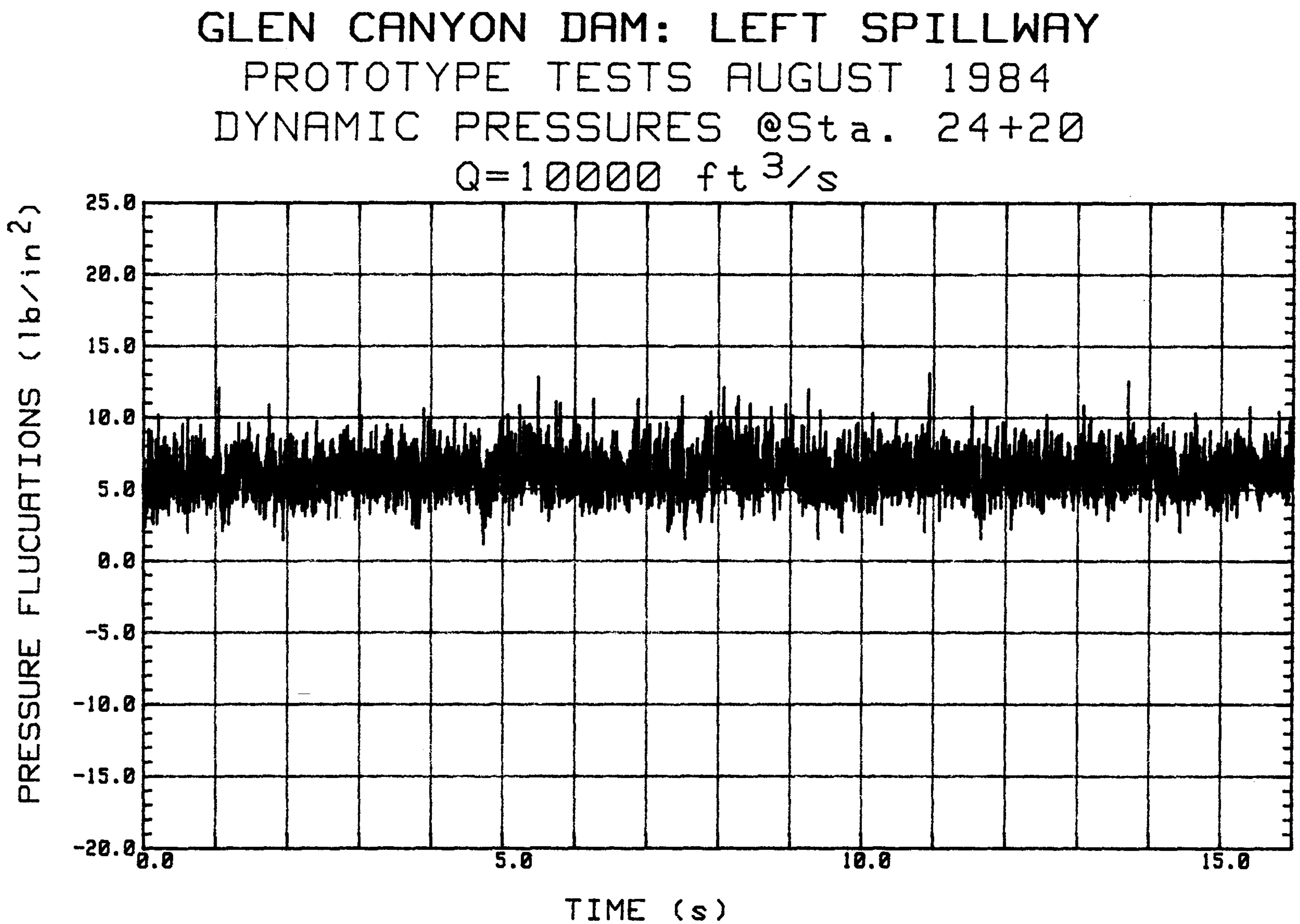

Figure 6. - Dynamic pressure fluctuations, Sta. 24+20 (Box 7), Q = 10,000 ft^3/s

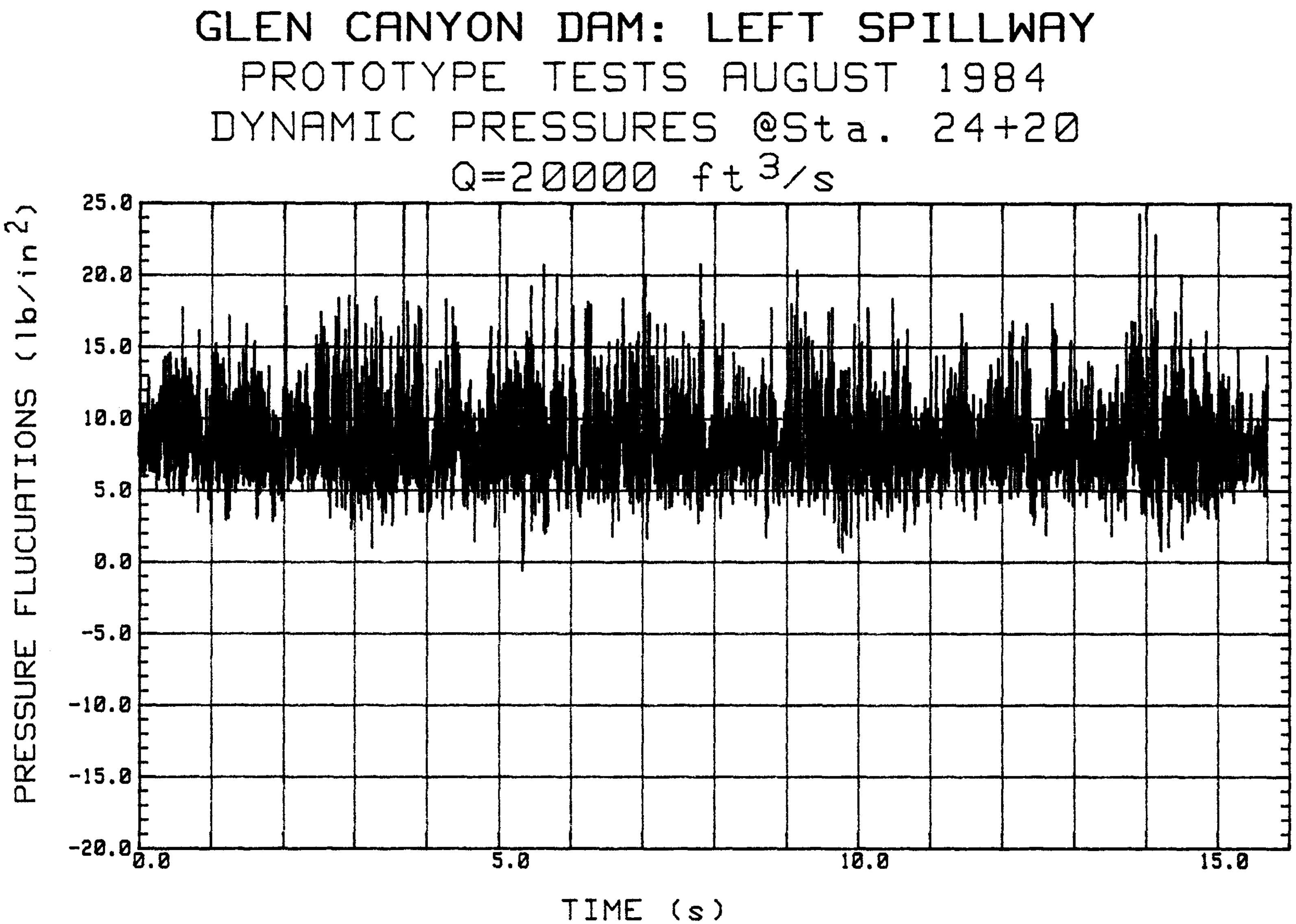

Figure 7. - Dynamic pressure fluctuations, Sta. 24+20 (Box 7), Q = 20,000 ft^3/s.

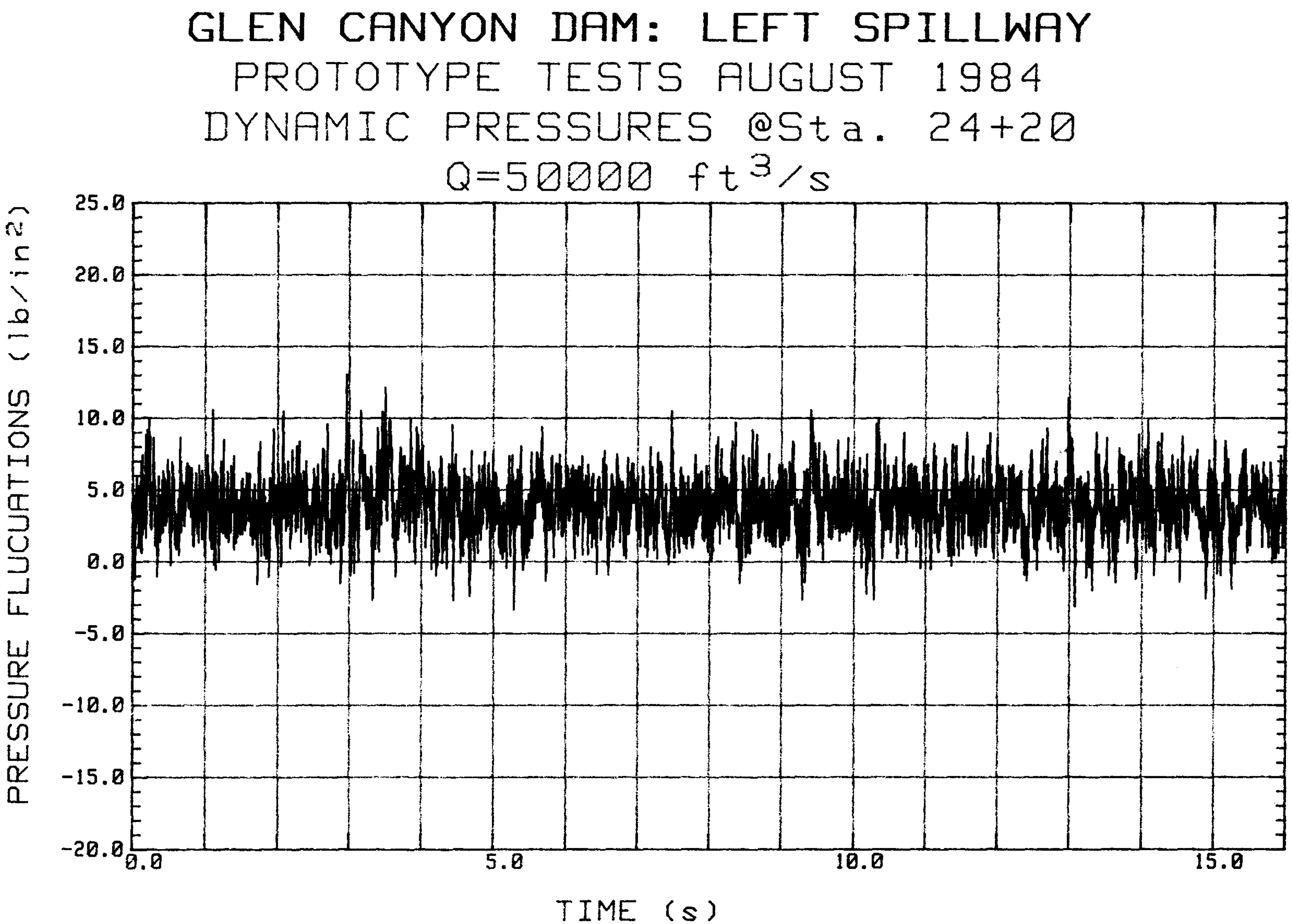

Figure 8. - Dynamic pressure fluctuations, Sta. 24+20 (Box 7), Q = 50,000 ft^3/s.

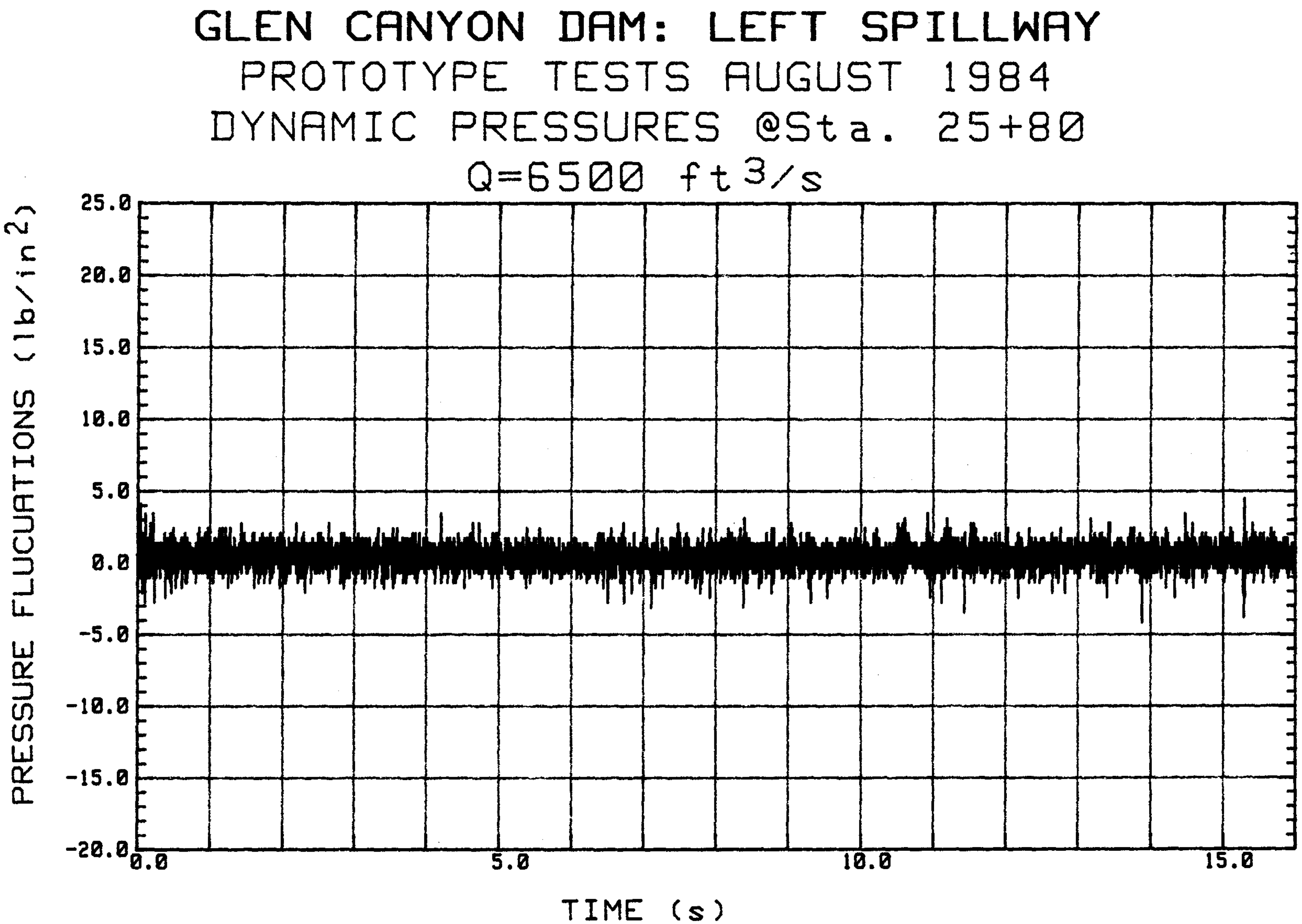

Figure 9. - Dynamic pressure fluctuations, Sta. 25+80 (Box 3), Q = 6,500 ft^3/s.

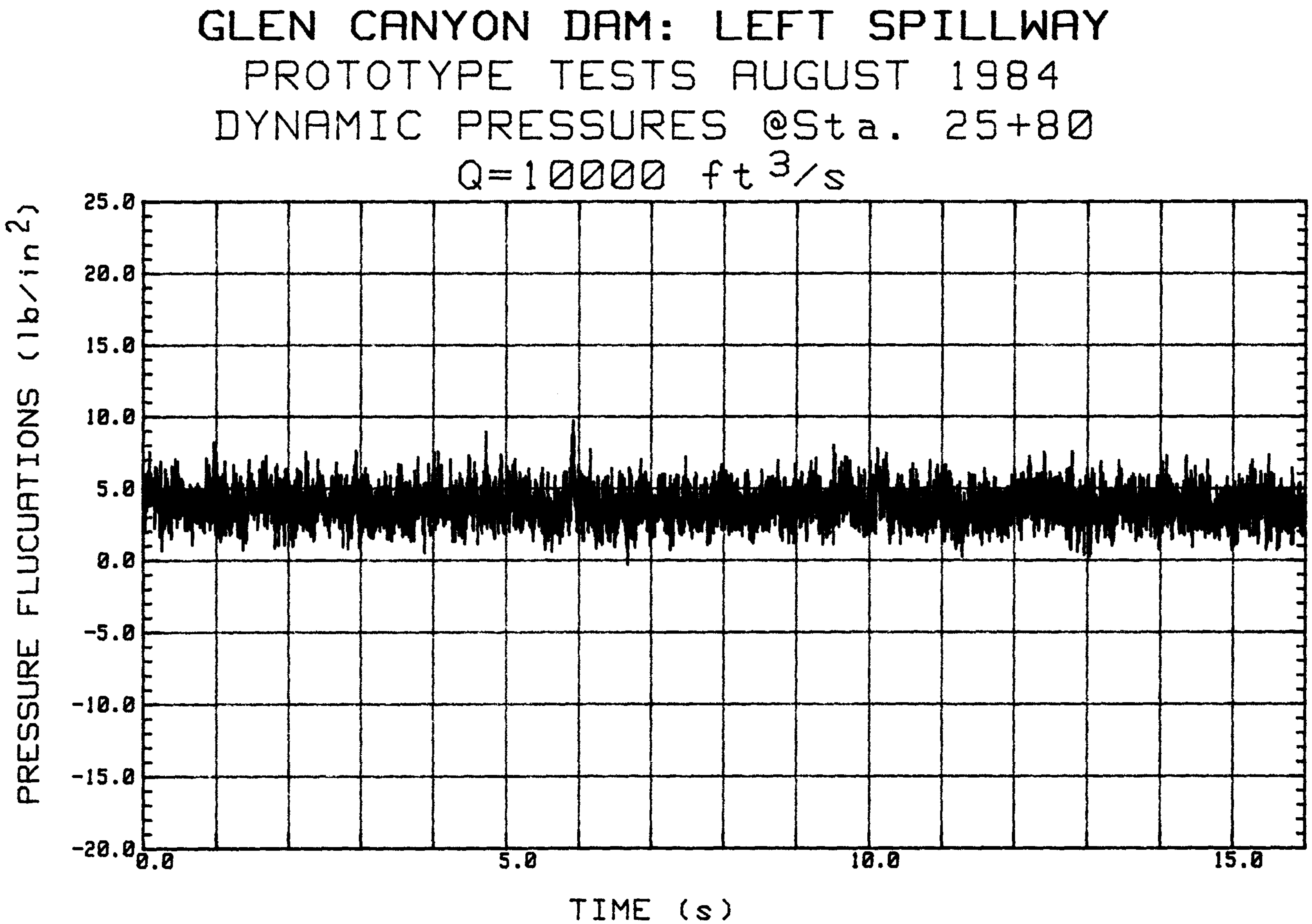

Figure 10. - Dynamic pressure fluctuations, Sta. 25+80 (Box 3), Q = 10,000 ft^3/s.

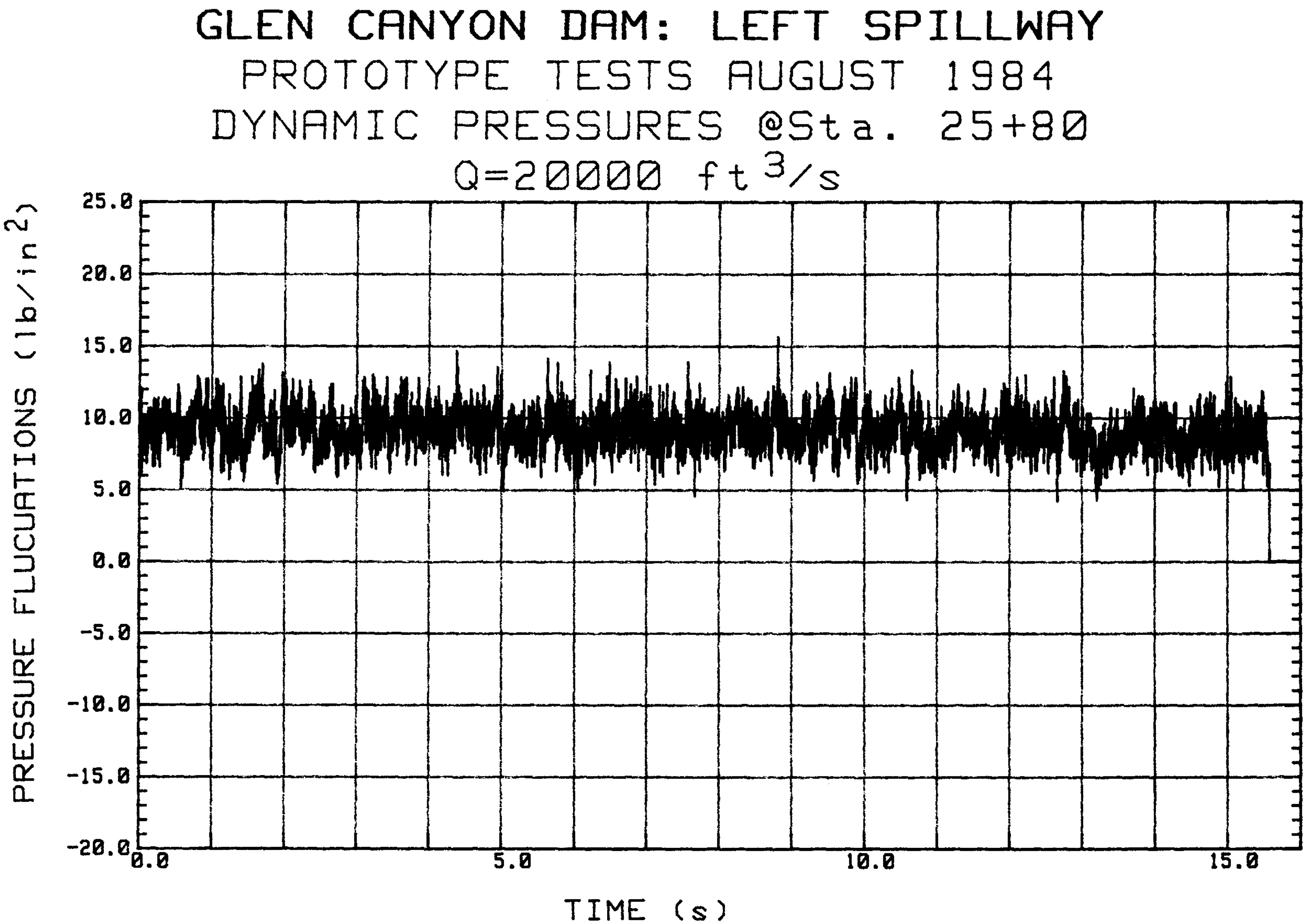

Figure 11. - Dynamic pressure fluctuations, Sta. 25+80 (Box 3), Q = 20,000 ft^3/s.

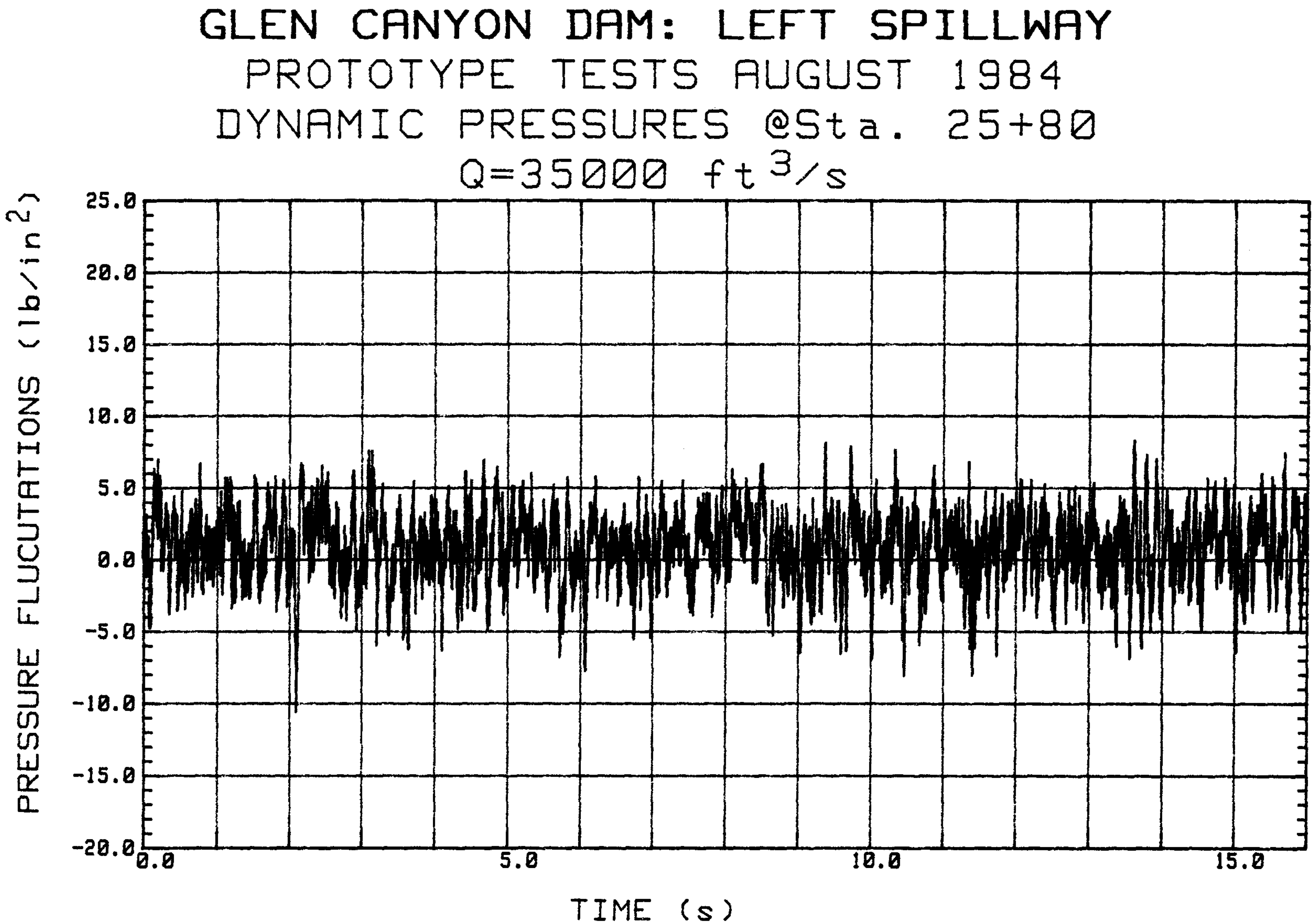

Figure 12. - Dynamic pressure fluctuations, Sta. 25+80 (Box 3), Q = 35,000 ft^3/s.

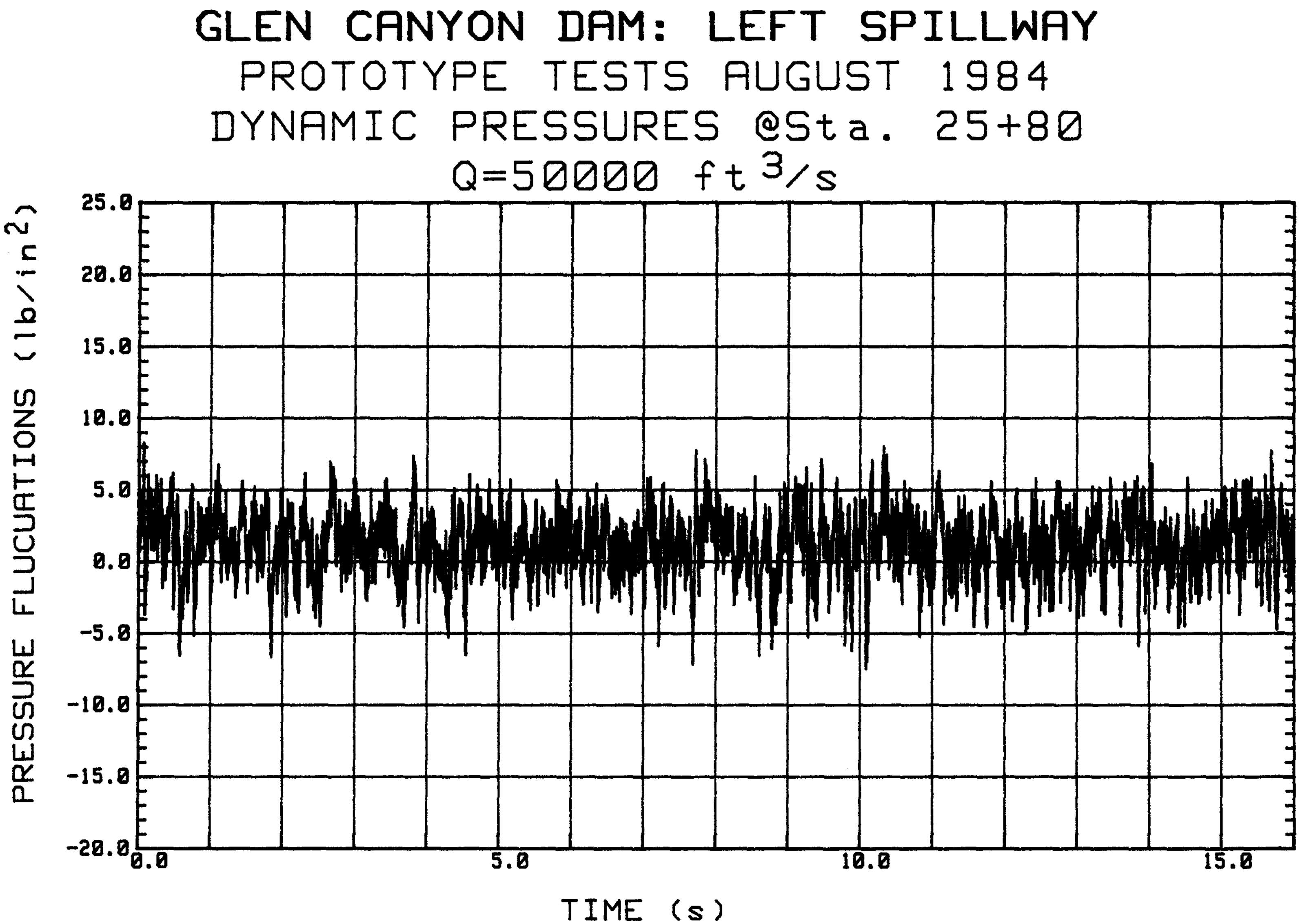

Figure 13. - Dynamic pressure fluctuations, Sta. 25+80 (Box 3), Q = 50,000 ft^3/s.

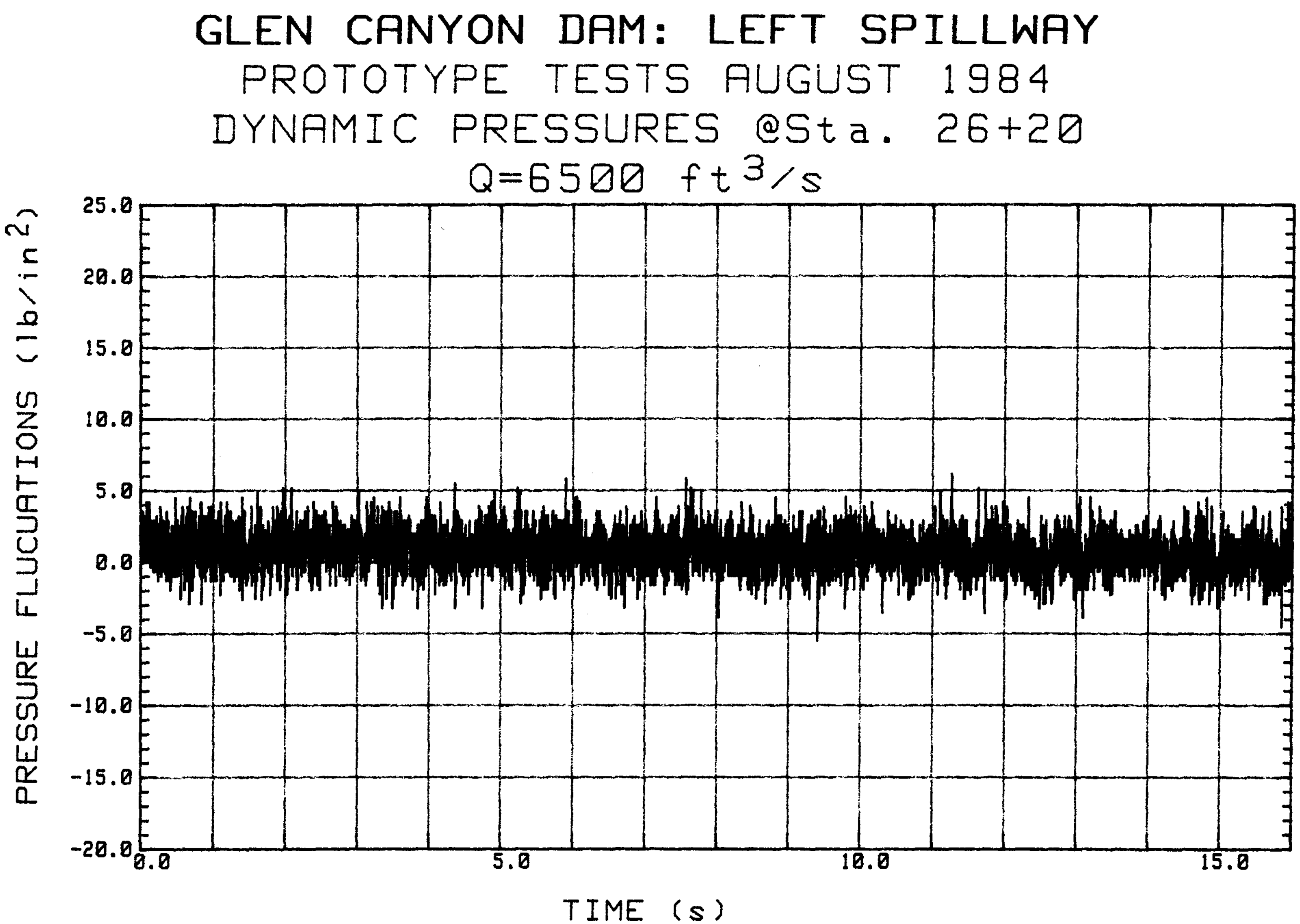

Figure 14. - Dynamic pressure fluctuations, Sta. 26+20 (Box 2), Q = 6,500 ft^3/s.

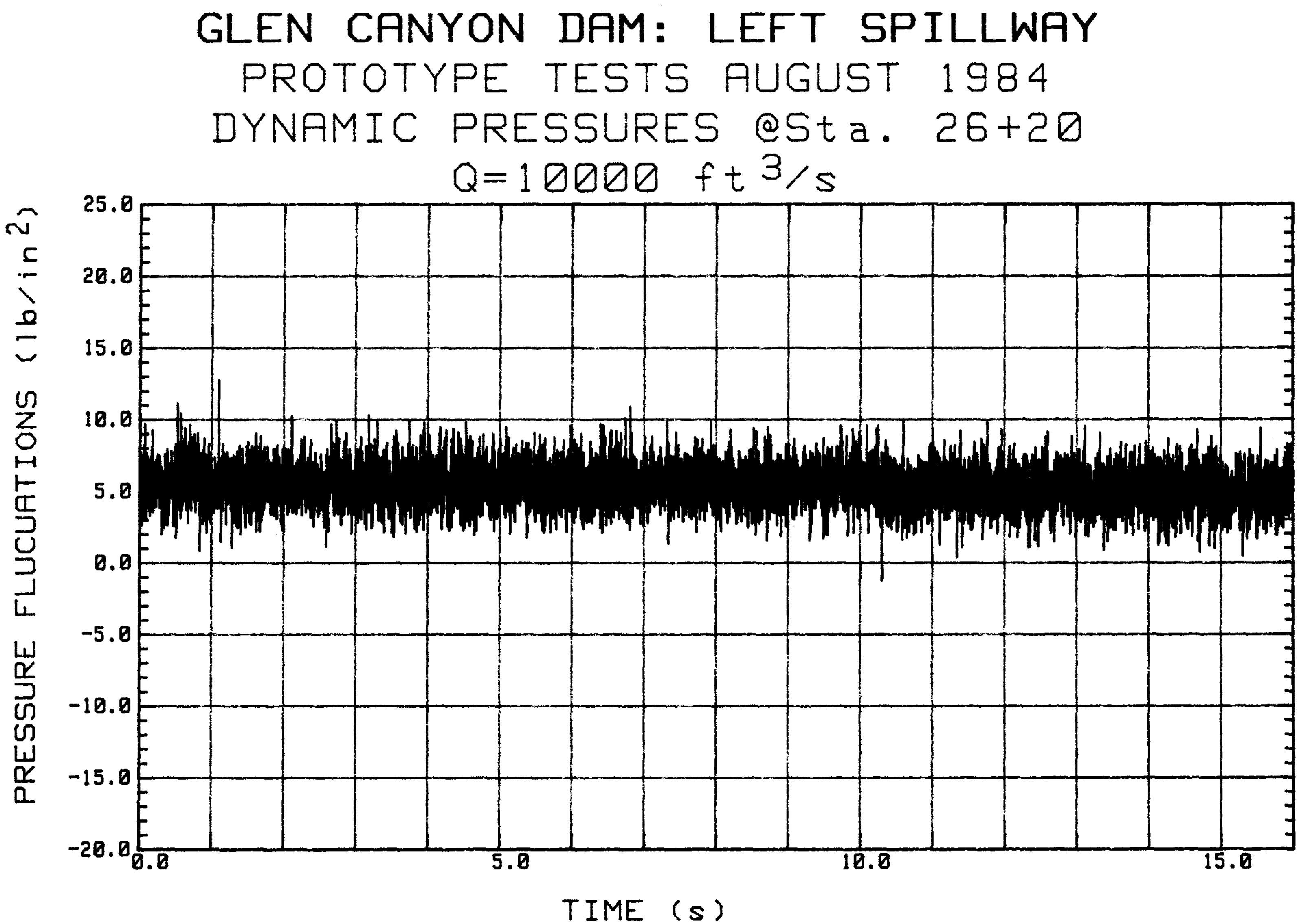

Figure 15. - Dynamic pressure fluctuations, Sta. 26+20 (Box 2), Q = 10,000 ft^3/s.

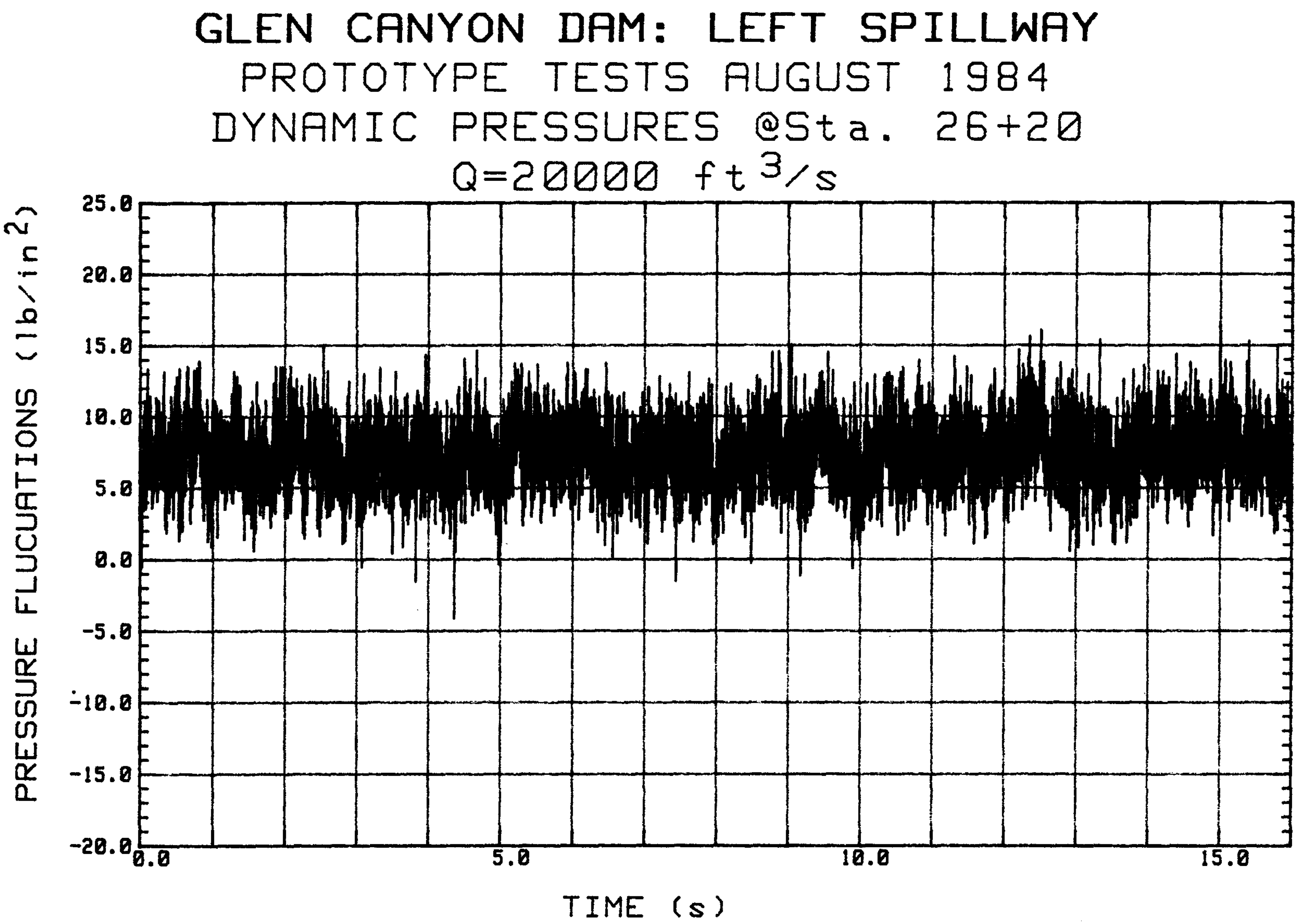

Figure 16. - Dynamic pressure fluctuations, Sta. 26+20 (Box 2), Q = 20,000 ft^3/s.

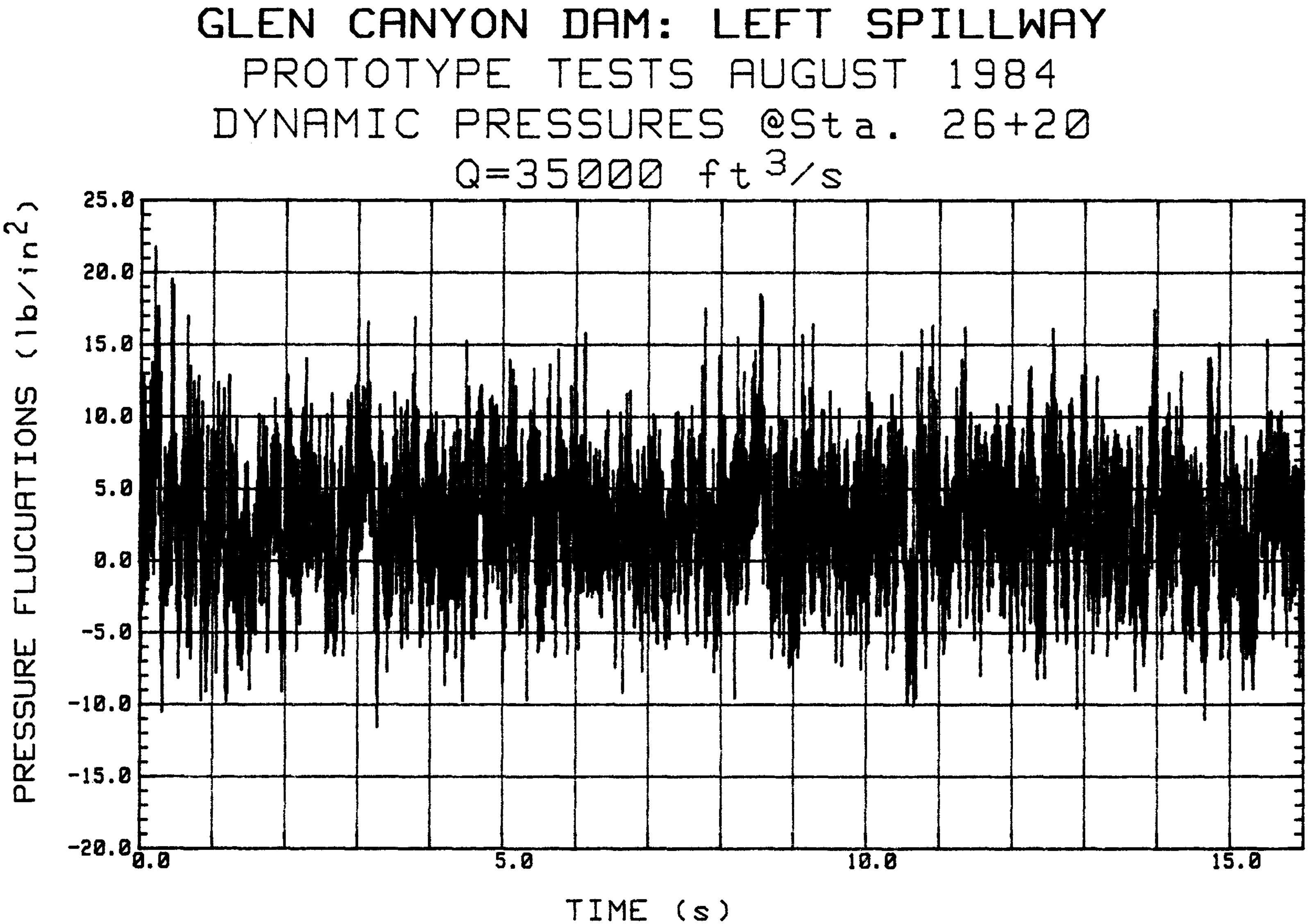

Figure 17. - Dynamic pressure fluctuations, Sta. 26+20 (Box 2), Q = 35,000 ft^3/s.

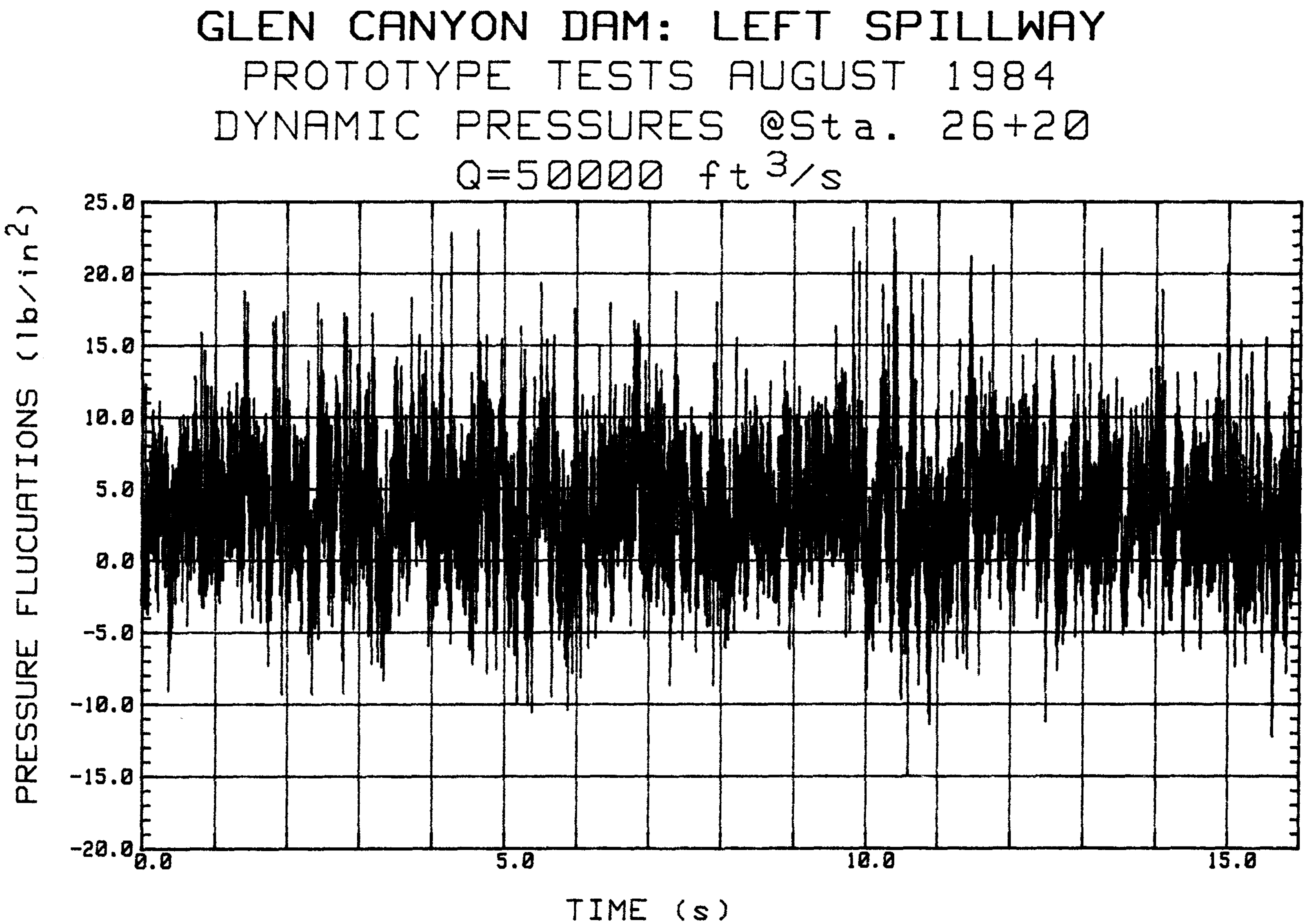

Figure 18. - Dynamic pressure fluctuations, Sta. 26+20 (Box 2), Q = 50,000 ft^3/s.

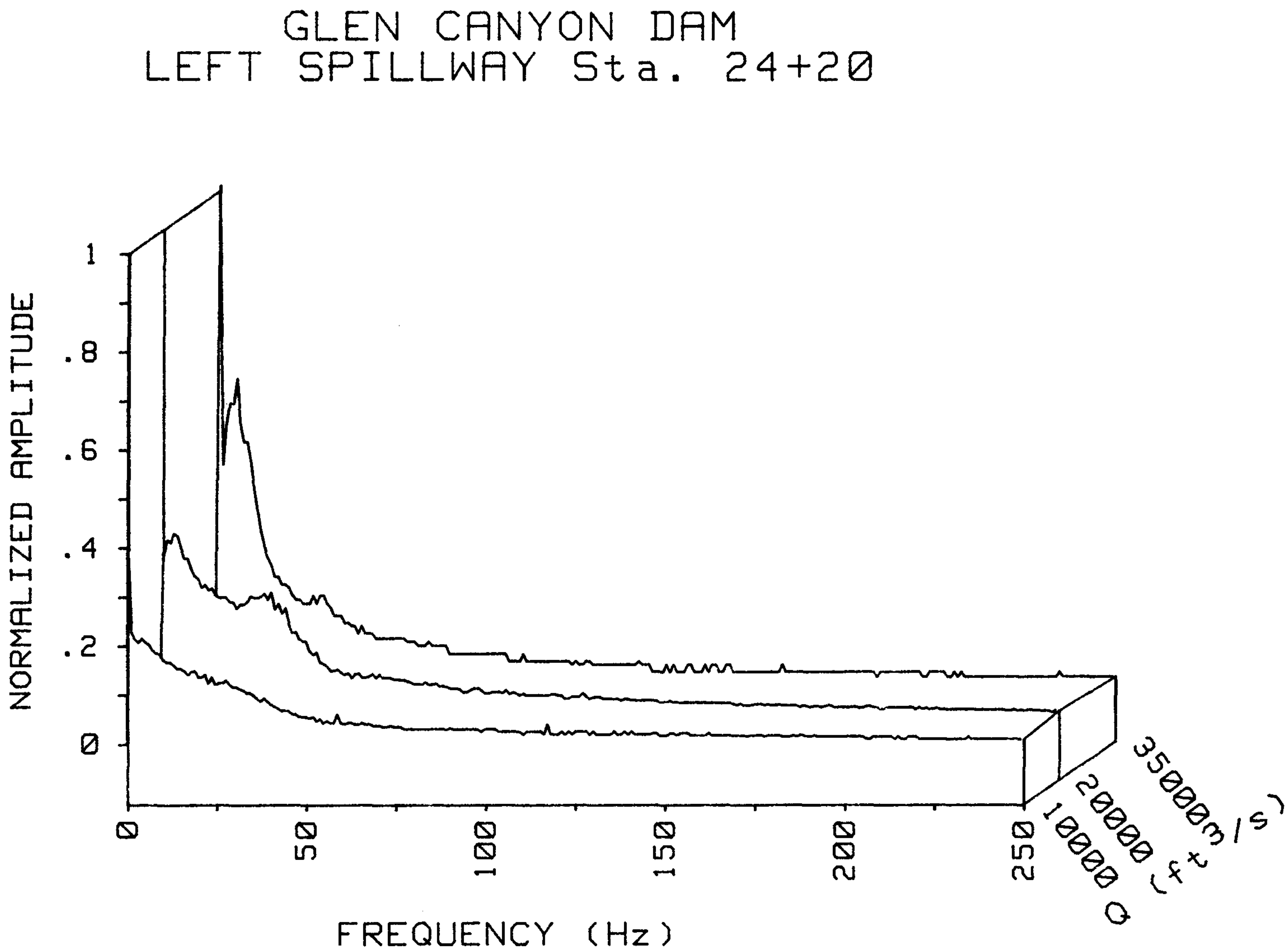

Figure 19. - Energy spectrums of dynamic pressure fluctuations at Sta. 25+80 (Box 7), for flows of 10,000, 20,000, and 35,000 ft^3/s.

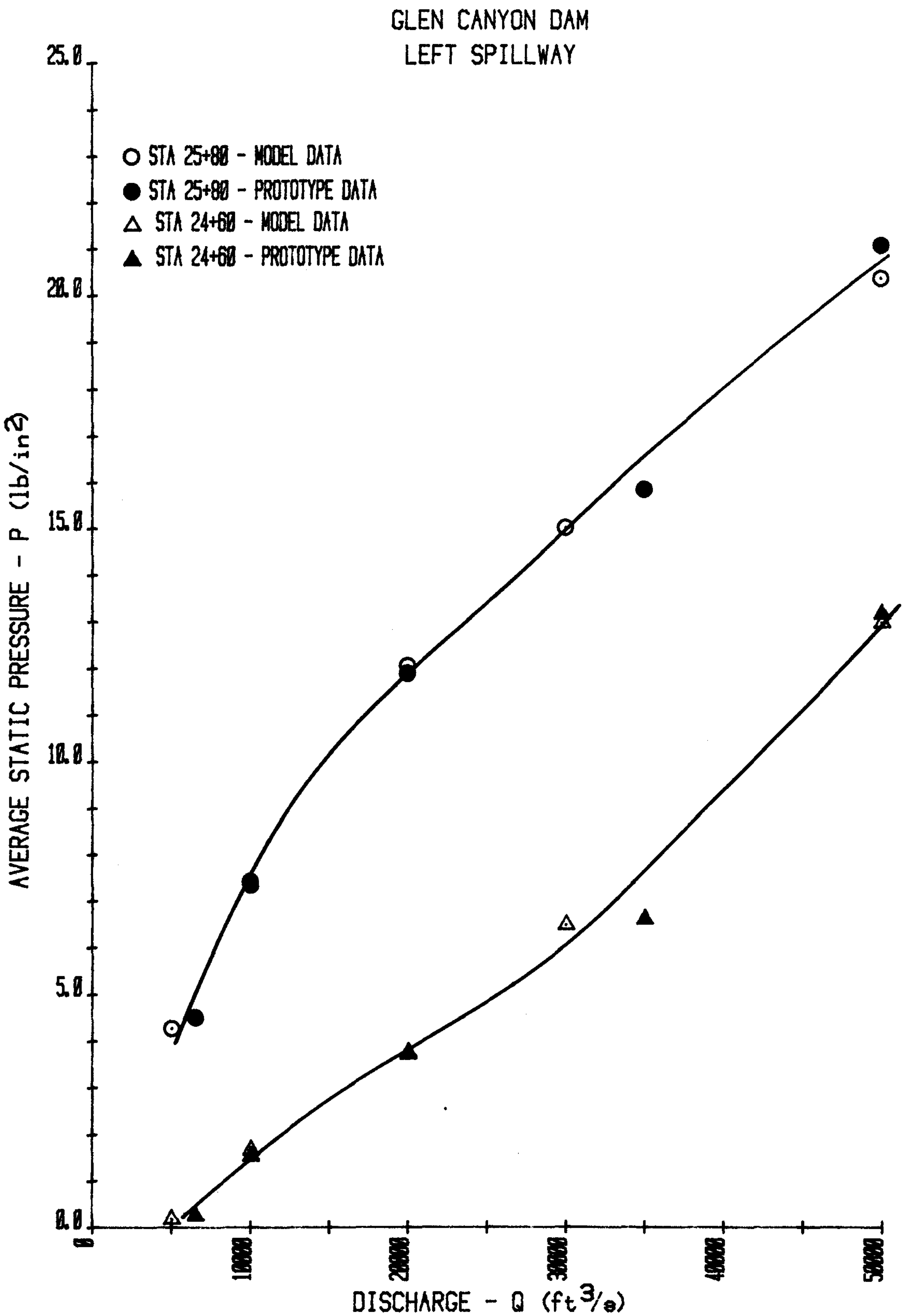

Figure 20. - Model-prototype comparison of static pressures at sta. 24+60 (Box 6), and Sta. 25+80 (Box 3).

Both methods yielded similar results. The spectrum analyzer was capable of covering a frequency range up to 25 kHz, while the digital data allowed frequency analysis only up to 250 Hz. The major energy in the frequency spectrum occurred below 100 Hz as shown on figure 21; this is FFT data from digital recordings (Refer to figure 19 for a similar plot of spectrum analyzer data.). Correlation between model and prototype dynamic pressure fluctuations was not found. Frequency appears to function as a dependant variable; therefore, it does not allow separate scaling of the fluctuation amplitudes. The model spectrums show major spectral power caused by bubble noise which does not show up in the prototype.

OBSERVATIONS

A great deal also was learned from observing the flow and inspecting the tunnel surfaces. Flow observations tend to be subjective, but in comparison with the left spillway flows during 1983 many observers agreed that the tunnel outflow appeared to have much more air. The test flows entrained more air and did not flip into the river as far as similar spills prior to air slot construction. However, the main observations used to evaluate the air slots' effectiveness were the tunnel inspections performed throughout the test sequence. These observations did not show cavitation damage. Construction techniques resulted in some concrete "popouts" and minor surface damage. However, these did not grow appreciably during extended operation, indicating that with known offsets into and away from the flow, cavitation damage did not occur. Past experience shows cavitation damage can be expressed in terms of a cavitation damage index [4]. The following is a comparison of cavitation damage indexes caused by previous flows in the Glen Canyon Dam left spillway to those during this test (1984):

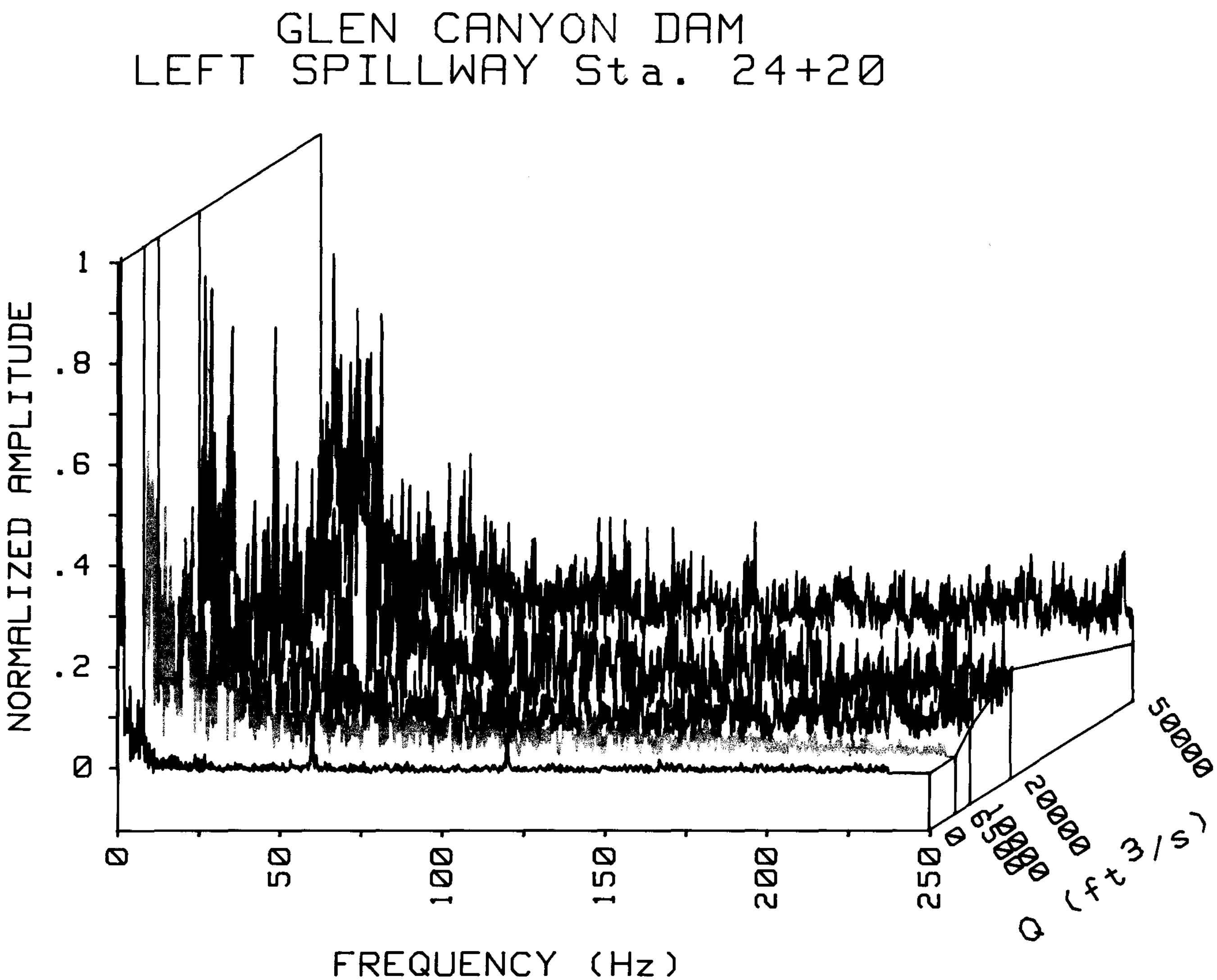

Figure 21. - Prototype frequency spectrums (by FFT) of dynamic pressure fluctuations at Sta. 24+20 (Box 7).

1981 - 1/2-in high offsets at Sta. 24+25 caused 1/2-in deep holes
Damage index 13,100

1983 - 1/2-in high offsets at Sta. 24 + 12 caused 3-ft deep holes
Damage index 21,500

1984 - 1/2-in high offsets at Sta. 24+50 did not cause damage
Damage index 17,800

- 1/2-in high offsets at Sta. 26+25 did not cause damage
Damage index 23,500

The air slot addition was the only modification to the spillway structure in 1984. The fact that cavitation damage did not occur during the 1984 test can be tied directly to the new air slot.

CONCLUSIONS

Evaluation of all prototype data indicates that the air slot operates satisfactorily. Cavitation damage was not observed and measurements of air demand and pressures (static and dynamic) support this finding.

Many parameters are still under investigation in the Bureau's E&R Center Hydraulics Branch which will provide additional information about the air slot design. Both model and prototype data from Glen Canyon Dam are being used, as well as model data from Blue Mesa Dam and Hoover Dam. Items currently under study are:

1. Further analysis of dynamic pressure fluctuations. USBR Program Related Engineering and Scientific Studies Project No. DR-458 - Scaling of Dynamic Pressures.

2. Measurement of the model velocity distribution in the air slot with the laser-doppler velocimeter.

3. Testing in the Bureau's low ambient pressure chamber of offsets which were cast from "popouts" and joint misalignments in the Glen Canyon left spillway during the testing. These tests will show if damage could have been incurred without the addition of air through the slot.

4. Development of an air concentration probe for future use in model and prototype tests.

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[4] Falvey, H. T., "Monograph on Cavitation," Bureau of Reclamation, Denver, Colo., unpublished.

APPENDIX

BUREAU OF RECLAMATION
Engineering and Research Center
Denver, Colorado

TRAVEL REPORT

Code : D-1532 Date: July 12, 1984

To : Chief, Division of Research and Laboratory Services

From : K. Warren Frizell and Lee E. Elgin

Subject: Instrumentation Installation in the Left Spillway of Glen Canyon Dam

1. Travel period (dated): June 14, 1984 - June 27, 1984.

2. Places or offices visited: Glen Canyon Dam, Page Arizona.

3. Purpose of trip: To install pressure transducers and air velocity probes in the modified left spillway of Glen Canyon Dam for future testing.

4. Synopsis of trip: We departed the Denver Federal Center in a Government van and arrived at Glen Canyon Dam on June 15, 1984. We carried down the equipment necessary to install instrumentation in the left spillway and also took all our computerized data acquisition equipment. After talking with Jack Tyler, the Construction Engineer, and finding out that the tests would not be run until mid-July at the earliest, we stored our data acquisition equipment in the Bureau warehouse in Page and proceeded to get on with the installation of the instrumentation. We discussed our plans with Art Graff, the Field Engineer, and with Dave Deacon and Jim Landreath of Newberry Industrial, the electrical subcontractor. We took a look at instrument boxes 1-7, and talked about the pulling of the signal wires and what type of water diversion we would need for the installation.

On June 16, the electricians pulled the signal wires into instrument boxes 1-7. Two wires were pulled into each box; a RG59 coaxial cable, and a 4-conductor shielded cable. Water diverters had been installed upstream of each box, and small grout dams were placed around the boxes as well. This system kept the boxes and conduit from filling with water while the pulling of wire and instrument installation took place. Before the electrical connections of the transducers were made, each wire was rung out with voice powered telephones to check on continuity and make proper identification. The transducers had been mounted onto their appropriate cover plates so installation simply required soldering the electrical connections, covering the connections with heat shrink material, and then putting the cover plate back into place. Before the plates were screwed down into their frames, new O-rings greased with No. 2 permatex were installed and duct tape was placed over the exposed transducer diaphragms. The installations started at box 7 and proceeded downstream to box 1.

Travelers: K. Warren Frizell and Lee E. Elgin Date: July 12, 1984

On June 18, we contacted Richard Fehr, a mechanical engineer out of the O&M office about possibly using a barometer during the upcoming tests. He said we could use the one in his office any time we needed it. We also spoke to him about making some vibration measurements on the hollow-jet conduits. He said it would be fine and he would be interested in any results we might come up with. Later that day we picked up Dave Maytum, D-254, and Randy Brammer, D-1543, at the Page airport. They had come down to install strain gages on the radial gate arms so they can evaluate the pin moment as the gates are raised.

We took vibration measurements on the hollow-jet conduits on June 19. Several positions for taking measurements had been located on each of the four conduits. The measurements were made with a Dymac portable vibration meter and a spectrum analyzer. As the accelerometer was held onto the conduits at each of the predetermined locations, displacement and acceleration readings from the Dymac meter were recorded and the major frequencies of the vibration was noted from the spectrum analyzer. The noise caused by the vibration lead us to think that conduits 1 and 2 were vibrating more than conduits 3 and 4; however, this difference in noise level appears to be only a function of the size of the vaults that each pair of conduits run through.

On June 20, the electricians pulled four, 4-conductor shielded cables up to the air slot and into box 11. Box 9, located on the tunnel centerline was inaccessible (underneath the man-car ramp) so the wire pull could not be completed The jumbo was then moved back down the tunnel into the elbow to allow workers to dress some epoxy patches which were unacceptable.

Tom Friedman of the Upper Colorado Public Affairs Office was down on June 21 and took some movie footage of our instrument boxes in the lower tunnel. He said he would make arrangements to get some more footage of our equipment at the time of the test.

On June 23, while still waiting for the jumbo to return up to the air slot area, we talked with Jack Tyler about installation of the air velocity probes. He had concerns that they were not sturdy enough to hold up throughout the test and asked us to investigate possible methods to strengthen the installation. We talked with one of the contractor's mechanics and had a new anchor plate and connecting arrangement made for both probes. However, after talking to Cliff Pugh, D-1531, it was decided not to add any further structure to the probes as it would tend to bring the natural frequency of the probes closer to the vortex shedding frequency that is expected. The idea is to separate these two frequencies as far as possible to prevent lockin at the resonant frequency and sure destruction of the probes.

On June 25, we installed the remaining four instruments into the air slot area. The wires were pulled just ahead of each installation. The area was very wet, but the water control around our instrument boxes was adequate

Travelers: K. Warren Frizell and Lee E. Elgin Date: July 12, 1984

considering these conditions. We began installing at box 11. Air probe II was located in this box, and we experienced some problems with alinement of the probe. The anchor plate had to be relocated to remove stress from the turnbuckle connection. The installation of air probe I in box 10 went smoother, and no problems were experienced. The jumbo was lowered down to box 8 to aid installation. A static pressure transducer was installed in this location. Then the jumbo was moved back up and a static pressure transducer was installed in box 9. All connections and fastening down of the cover plates was done in the same manner as with boxes 1-7, discussed previously.

We departed Glen Canyon Dam on June 26 in a Government van and returned to the Denver Federal Center June 27.

5. Conclusions:

a. Installation of all instruments was completed successfully.

b. At least 3 days will be required prior to testing to set up data acquisition equipment and connect instruments.

c. Arrangements were made for associated items we will need during testings; tables, chairs, power, lighting, etc.

d. Photographs of instrumentation and installation are included in the appendix.

e. Vibration measurements taken on the hollow-jet conduits are being analyzed and a memorandum summarizing the results will follow.

f. We appreciate the support and coordination offered to us by the Glen Canyon Spillway Repair Construction Office and the help of G. F. Atkinson and Newberry Industrial personnel.

K. Warren Frizell
Lee E. Elgin

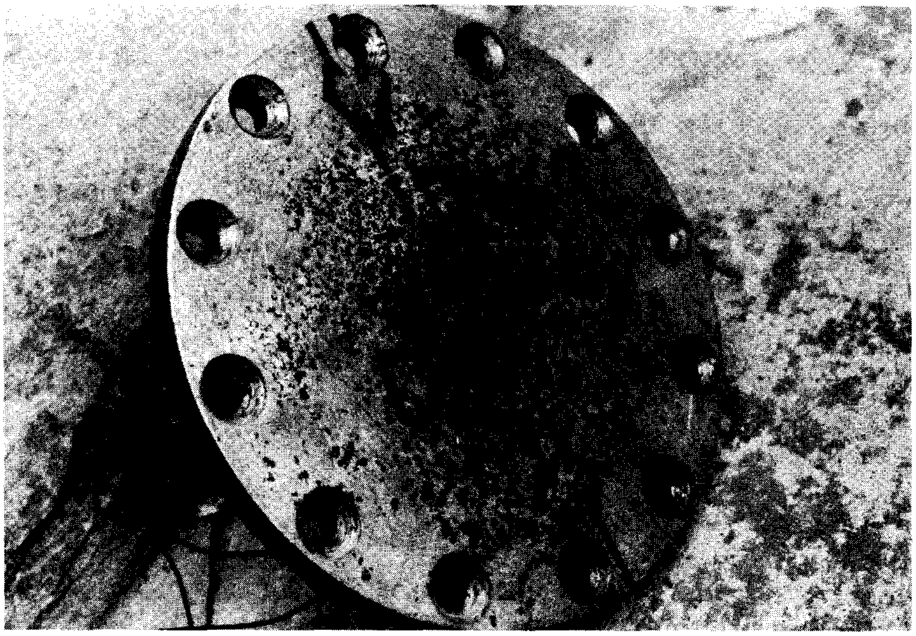
Enclosures

Copy to: Regional Director, Salt Lake City, Utah, Attention: UC-100
Construction Engineer, Page, Arizona
Power Operations Manager, Page, Arizona

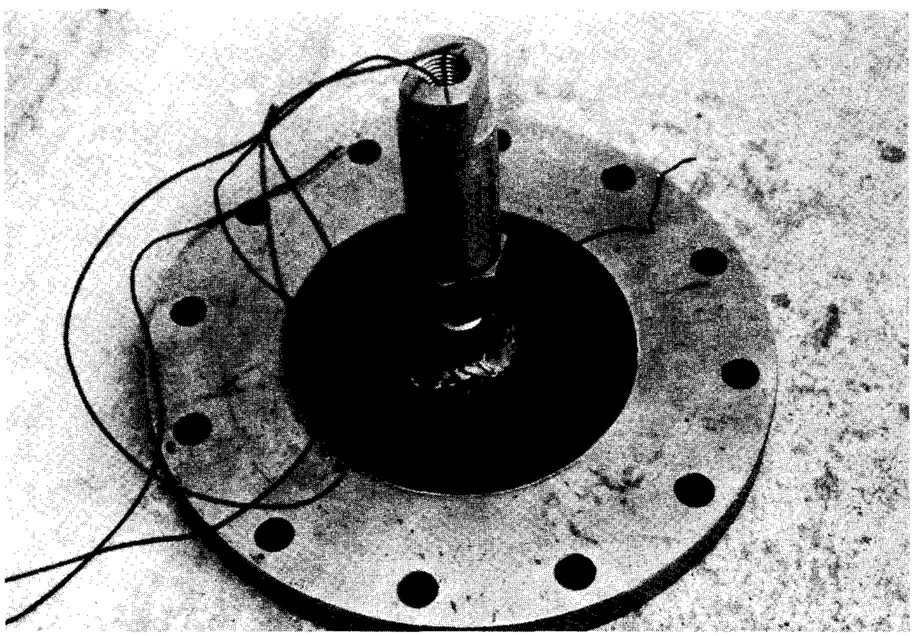
Blind to: D-200
D-210
D-220
D-1500
D-1530
D-1531 (file)
D-1532

Noted: JUL 20 1984
H. Walter Anderson
ACTING Chief, Division of Research and Laboratory Services

KWFrizell:flh

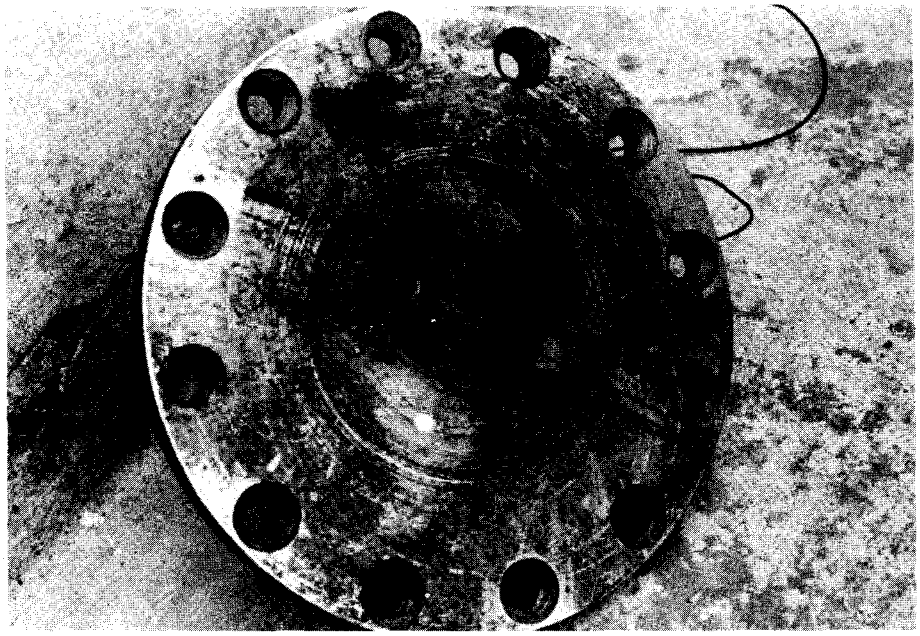


(a) Front face with tap.

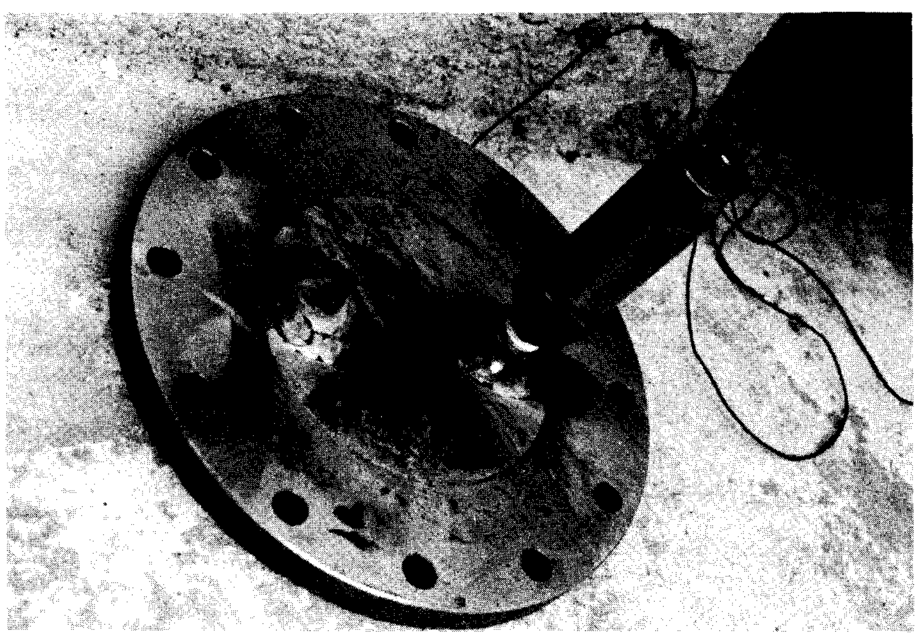


(b) Rear face with transducer and wiring.

Figure 1. - Kulite absolute pressure cell, installed in boxes 1 and 6.

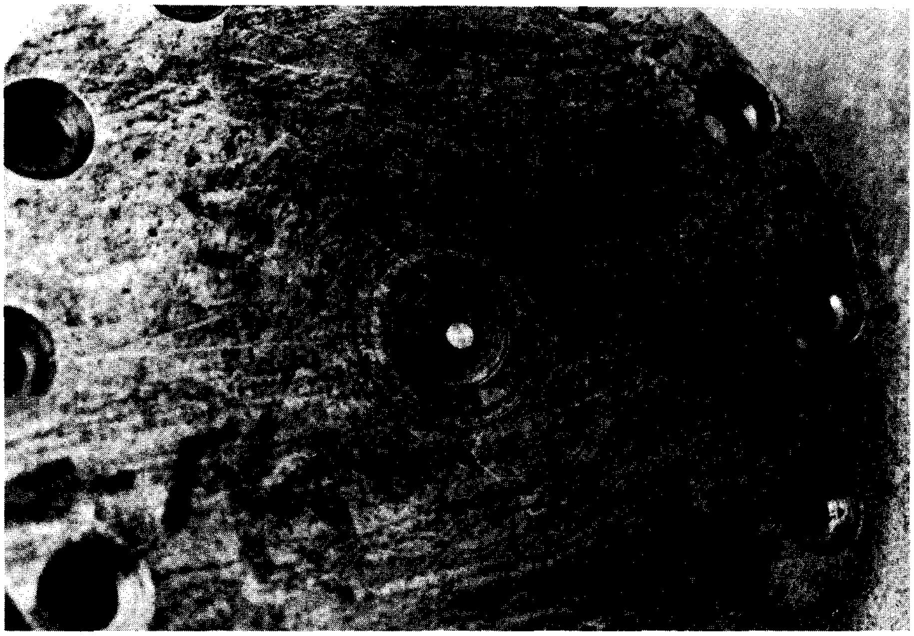


(a) Front face with static tap and dynamic flushmount.

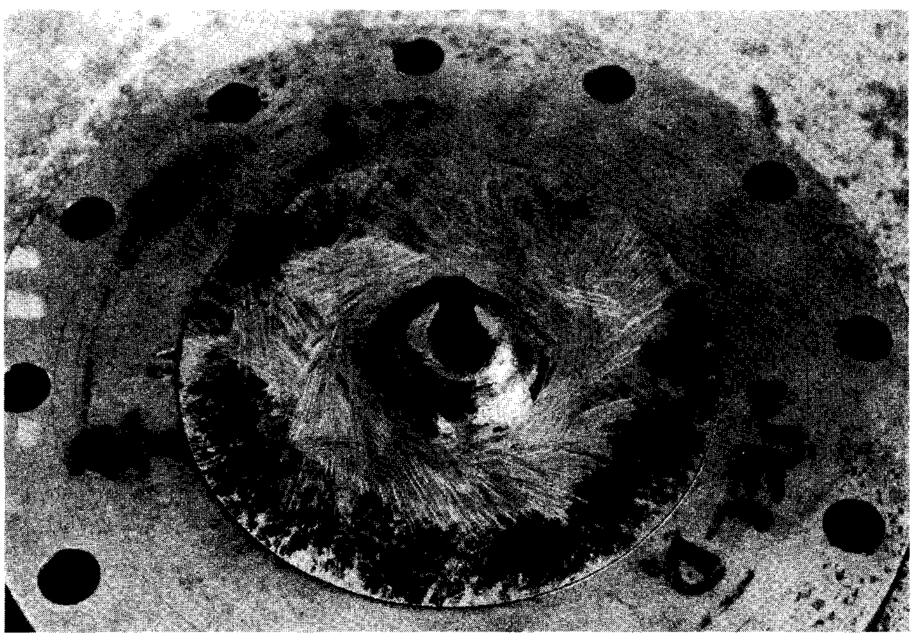


(b) Rear face with transducer connections.

Figure 2. - Kistler dynamic pressure cells and Kulite static cells mounted side by side, installed in boxes 2 and 3.

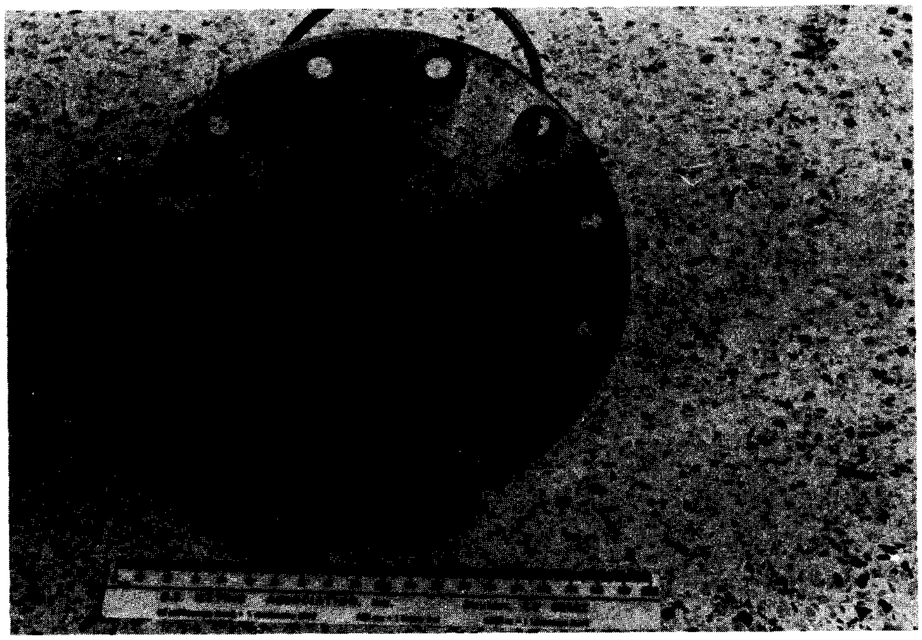


(a) Kistler flushmount dynamic cell, front face.

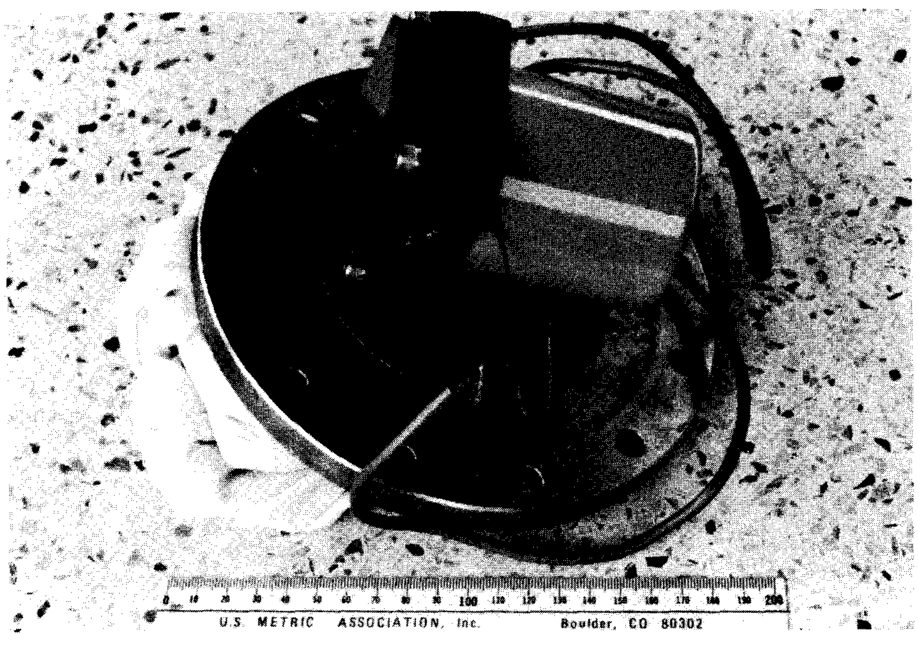


(b) Transducer mounting and body.

Figure 3. - Kistler dynamic pressure cell, installed in boxes 4, 5, and 7.



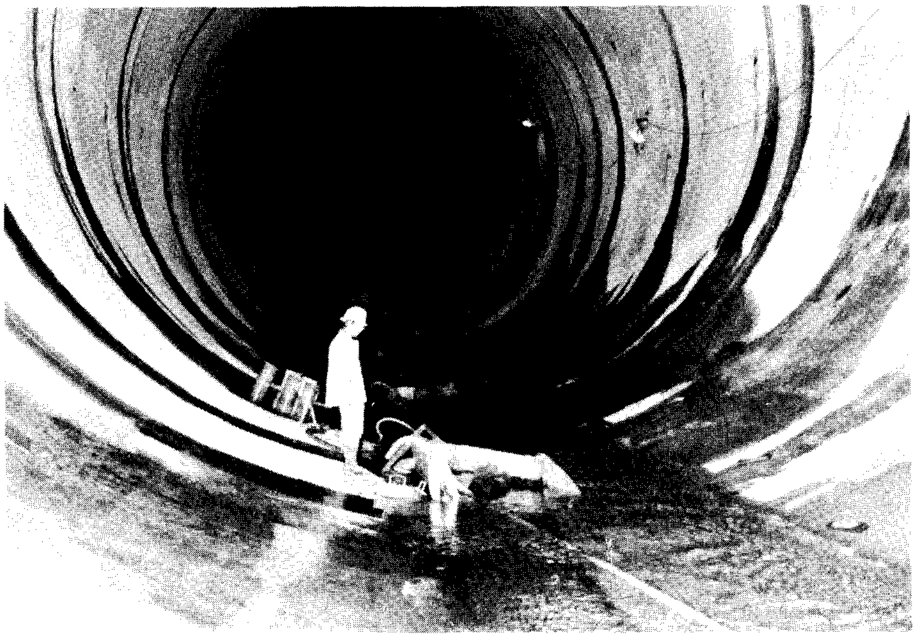
(a) Front face, air pressure transducer tap.



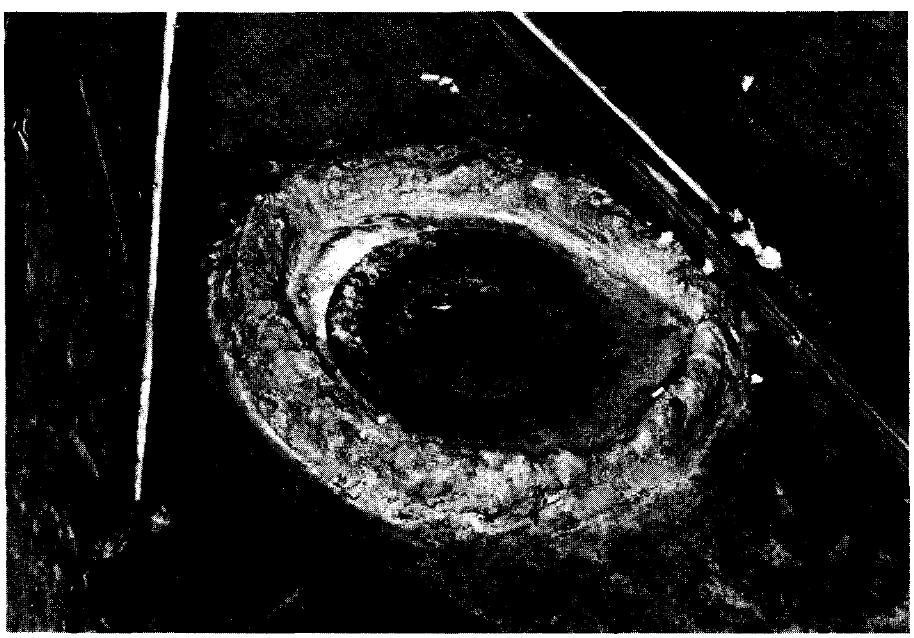
(b) Shaevitz differential pressure cell body and wiring.

Figure 4. - Schaevitz differential pressure transducer, installed in boxes 8 and 9.

Figure 5. - Air velocity probe using Schaevitz differential pressure cell, mounted in boxes 10 and 11.



(a) Boxes 1-7 with water diversion structures in place.



(b) Typical installation.

Figure 6. - Boxes 1-7 in lower elbow and horizontal tunnel section of left spillway.

(a) Air slot and probe locations from jumbo deck.

(b) Installing air probe II in box 11.

Figure 7. - Air velocity probe installation.

(c) Drilling for anchoring of probes.

(d) View of two probes, installation complete.

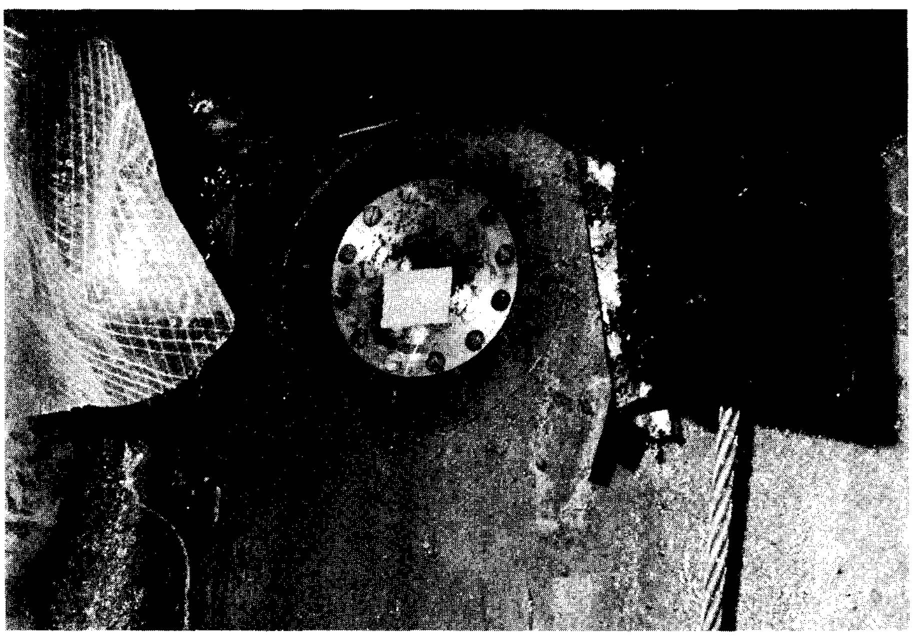
Figure 7. - (continued.)

(a) Water diverter being placed for installation of box 8.

(b) Signal wire being connected to transducer, box 8.

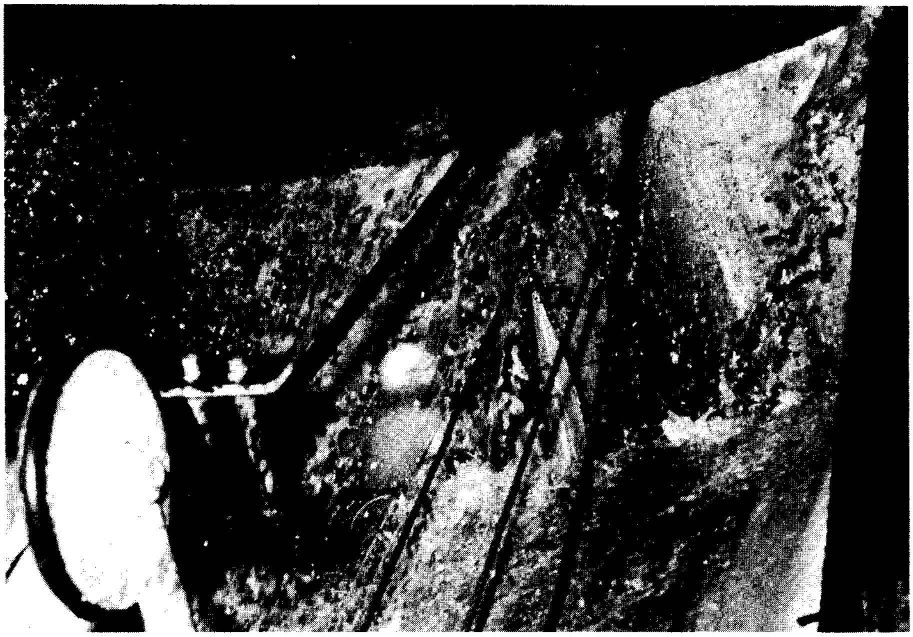
Figure 8. - Installation of static pressure transducer in box 8.

(c) Tightening cover plate to box frame.

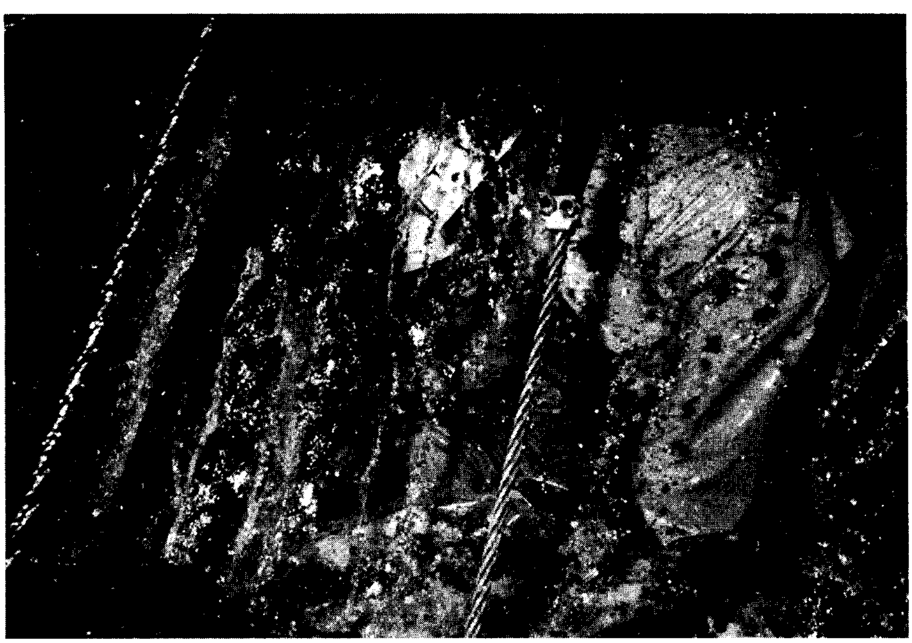


(d) View on finished installation, box 8.

Figure 8. - (continued)



(a) Pulling signal wire into box 9.



(b) Wiring and installing pressure transducer.

Figure 9. - Installation of static pressure transducer in box 9, air slot.

GPO 846-977

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled, "Publications for Sale". It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.