UNCLASSIFIED

AD NUMBER
AD836555
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; JUN 1968. Other requests shall be referred to Air Force Technical Application Center, VELA Seismological Center, Washington, DC 20333. This document contains export-controlled technical data.**
AUTHORITY
usaf ltr, 25 jan 1972

THIS PAGE IS UNCLASSIFIED

AD
836555

AD836555

TR 68-29

TECHNICAL REPORT NO. 68-29

DESIGN, INSTALLATION, AND INITIAL OPERATION OF THE LONG-PERIOD SEISMIC ARRAY AT THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

STATEMENT #2 UNCLASSIFIED

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Air Force Technical Applications Center, attn: VSC, Langley AFB, Va 23365

[redacted]

GEOTECH

A TELEDYNE COMPANY

TECHNICAL REPORT NO. 68-29

DESIGN, INSTALLATION, AND INITIAL OPERATION OF THE LONG-PERIOD SEISMIC ARRAY AT THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

GEOTECH
A Teledyne Company
3401 Shiloh Road
Garland, Texas

15 June 1968

IDENTIFICATION

AFTAC Project No:	VELA T/7702
Project Title:	Operation of TFSO
ARPA Order No:	624
ARPA Program Code No:	
Name of Contractor:	Teledyne Industries Incorporated Geotech Division Garland, Texas
Date of Contract:	1 January 1967
Amount of Contract:	$1,090,300
Contract Number:	AF 33(657)-67-C-0091
Contract Expiration Date:	30 April 1968
Program Manager:	B. B. Leichliter, BR1-2561

CONTENTS

	Page
ABSTRACT	
1. INTRODUCTION	1
1.1 Authority	1
1.2 General	1
1.3 Geology	1
2. DESIGN AND INSTALLATION	2
2.1 Array design parameters	2
2.2 Characteristics of the TFSO Noise Field	2
2.3 Selection of sites	5
2.4 Array instrumentation systems	5
2.4.1 Seismometer and amplifiers	5
2.4.2 Data transmission	7
2.4.3 Data conditioning	8
2.4.4 Lightning protection	19
2.4.5 Power	19
2.5 Land acquisition, surveying, and clearance	19
2.5.1 Land permits	19
2.5.2 Archeological survey	23
2.5.3 Geographic survey	23
2.5.4 Site clearance	23
2.6 Installation of field equipment	23
3. INITIAL OPERATION	25
3.1 Operating parameters	25
3.2 Calibration schedule and procedures	32
3.3 Array response	32
3.4 Operational problems	32
3.4.1 Data transmission	32
3.4.2 Amplifiers	32
3.4.3 Power supplies	32
3.4.4 Seismometers	35
3.4.5 Vault Seals	35
4. RECOMMENDATIONS	35

ILLUSTRATIONS

Figure		Page
1	Configuration of recommended TFSO long-period array	3
2	General orientation and spacing of the LRSM portable stations relative to TFSO and Payson, Arizona	4
3	Vault locations of the TFSO long-period array	6
4	View from Diamond Point south to LP5	9
5	The generator and radio equipment building during construction of site LP5 at TFSO	10
6	The equipment building and the diesel oil supply during construction of site LP5 at TFSO	11
7	The open-grid, 6-foot dish antenna on the microwave tower at site LP5 at TFSO	12
8	View from site LP5 north to Diamond Point (in the gap)	13
9	The microwave dish antennas mounted on the Central Recording building at TFSO	15
10	Close-up view of the 10-foot dish antennas mounted on the Central Recording Building at TFSO	16
11	The Diamond Point relay antennas. The two lower dishes are aimed at the Central Recording Building at TFSO, and the two upper dishes are aimed toward LP5. The top vertical antenna is for the base transmitter-receiver used in the TFSO voice communication system	17
12	Amplitude response as a function of period for the long-period seismographs at TFSO	18
13	Portion of the lightning protection system installed at the Hoffman boxes of the 7-element long-period array at TFSO	20
14	Lightning protection system for the Lambda power supplies in the 7-element long-period array at TFSO	21
15	Photograph of the 7-foot diameter hole at the LP4 site at TFSO prior to installation of the steel vault	26

ABSTRACT

During the second half of 1967 and the early part of 1968, a 7-element long-period seismic array was constructed at the Tonto Forest Seismological Observatory (TFSO). Each of the seven elements consists of a vertical long-period seismograph and two mutually-perpendicular horizontal seismographs. The elements are arranged in a hexagonal pattern and are distributed over an area of approximately 800 square miles. This report describes each aspect of the design, installation, and initial operation of the array.

BLANK PAGE

DESIGN, INSTALLATION, AND INITIAL OPERATION OF THE LONG-PERIOD SEISMIC ARRAY AT THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

1. INTRODUCTION

1.1 AUTHORITY

The work described in this report was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, and was monitored by the Air Force Technical Applications Center (AFTAC) under Contract AF 33657-67-C-0091, dated 1 January 1967.

1.2 GENERAL

During the second half of 1967 and the early part of 1968, a 7-element long-period seismic array was constructed at the Tonto Forest Seismological Observatory (TFSO). Each of the seven elements consists of a vertical long-period seismograph and two mutually-perpendicular horizontal seismographs. The elements are arranged in a hexagonal pattern and are distributed over an area of approximately 800 square miles. The installation and operation of this array, extending as it does over such a large, inaccessible area, represents a significant contribution to the state-of-the-art capability in seismic data acquisition. This report describes each aspect of the design, installation, and initial operation of the array.

1.3 GEOLOGY

The long-period array is located in the Basin and Range Province in the area immediately south of the southern boundary of the Colorado Plateau. This boundary is marked by the Mogollon Rim, a 450-meter erosional escarpment of Paleozoic and Mesozoic sediments. The array area is severely dissected by erosional features, faults, and intrusive masses. Either granite or a thin sedimentary section covers the array area. In general, the granite is highly decomposed, and weathering extends to a depth of as much as 30 meters. Its decomposed character supports only subdued topography, but numerous granite and diabasic dikes of a more resistant nature support ridges trending in an east-west direction across the array area. The sedimentary section consists of Cambrian and Devonian sandstones and limestones.

Although the general location of each seismometer was made on a theoretical basis, care was taken to select the final location so that each seismometer could be coupled to competent rock.

2. DESIGN AND INSTALLATION

2.1 ARRAY DESIGN PARAMETERS

The recommended 7-element long-period array, shown in figure 1, was designed so that a simple summation would improve the signal-to-noise ratio for body-wave signals. Because of the space stationarity of long-period body waves over large distances and their high apparent velocity, little signal degradation occurs from a simple sum. Thus, improvement in signal-to-noise ratio is based primarily on noise reduction.

The simple summation of the recommended array theoretically provides a minimum improvement in body wave signal-to-noise ratio of about 9 dB over the period band of 12 to 20 seconds, relative to a single detector.

2.2 CHARACTERISTICS OF THE TFSO NOISE FIELD

To furnish data from which the characteristics of the noise field could be determined, six 3-component long-period seismographs recorded data in the TFSO vicinity between 2 February and 7 April 1967. The array, shown in figure 2, consisted of five portable, long-period seismographs and the TFSO long-period seismographs. The TFSO seismographs were modified to match the response of the portable systems.

Four samples of long-period noise recorded on a vertical seismograph at each station were selected and digitized. The autopower spectra and coherence functions were computed for each of the noise samples. Phase velocities for selected frequencies were computed from the phase angles of the cross-power spectra, using standard tripartite methods. The following conclusions were made regarding the power spectra, phase velocities, and coherence functions:

a. The noise power is concentrated in two frequency bands, 0.04 to 0.082 cps and 0.11 to 0.165 cps.

b. The autopower spectra may be space stationary, but relative variations in spectral level cause some doubt.

c. The autopower spectra are not time stationary.

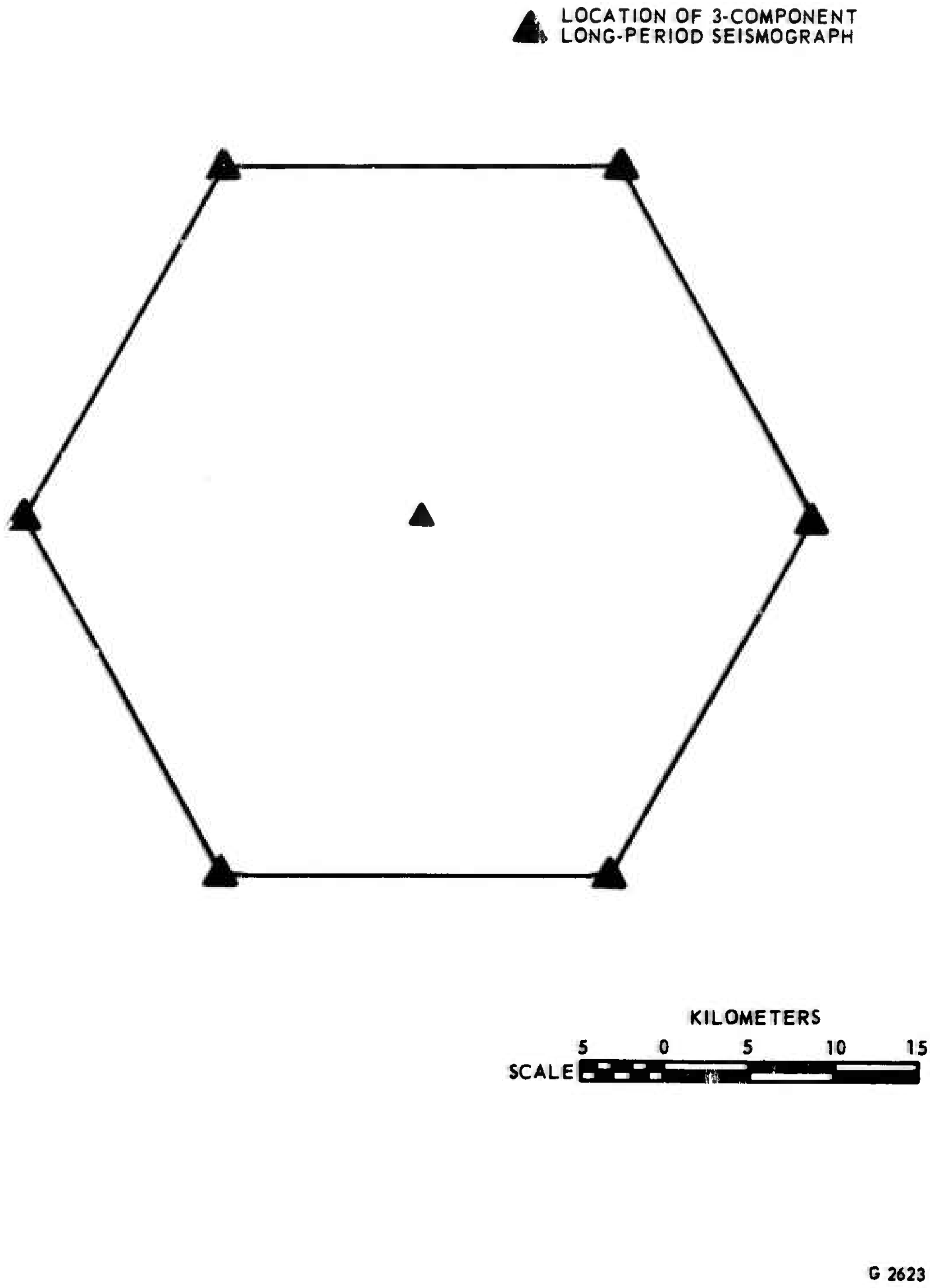


Figure 1. Configuration of recommended TFSO long-period array

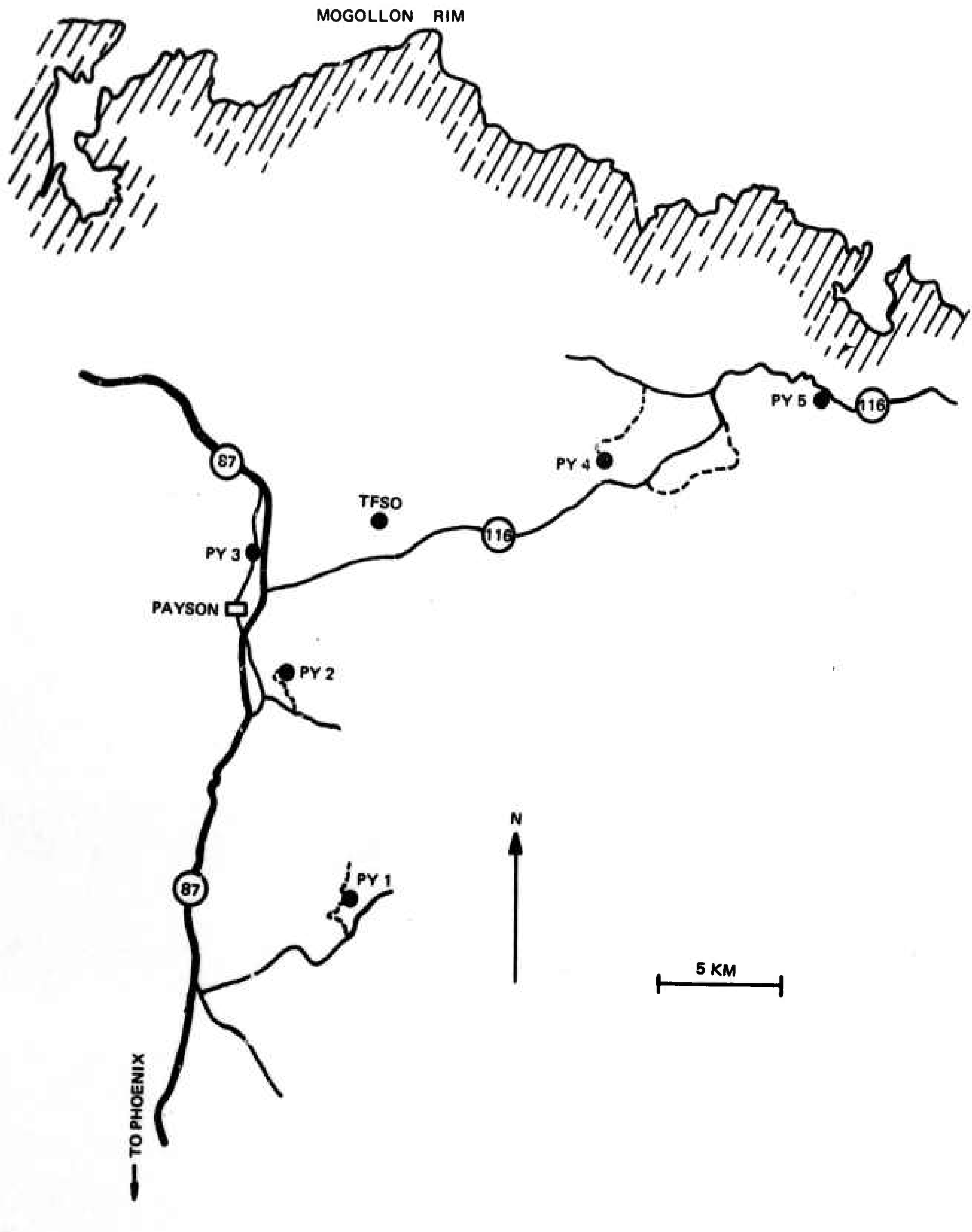


Figure 2. General orientation and spacing of the LRSM portable stations relative to TFSO and Payson, Arizona

d. The experimental phase velocities showed some scatter, but were in basic agreement with a theoretical dispersion curve determined for the TFSO area.

e. The coherence functions are neither time nor space stationary.

f. The noise in the frequency band 0.04 to 0.082 cps shows high coherence for small station separations and tends to decrease with increasing distance between stations.

g. The peak coherence usually occurs near the same frequency as the spectral peak in the frequency band 0.04 to 0.082 cps.

2.3 SELECTION OF SITES

The diameter of the array and the relative positions of the array elements were determined on a theoretical basis. The wave number responses of many different arrangements of 7 elements were computed, and by comparing these results with the wave number structure of the TFSO noise field, we determined that a hexagonal array with a diameter of 46.6 kilometers and seismometer spacing of 23.3 kilometers would give the best body wave signal-to-noise ratio. We also determined that each element could be located anywhere within a radius of 1 kilometer of its theoretically optimum position without significantly degrading the array response.

Many factors other than the theoretically-determined optimum positions had to be considered in making the final vault locations. Topography, legal and physical access to the sites, cultural features, and rock competence were important in making the final selections. All six of the outer elements of the hexagon were located within 1 kilometer of their optimum positions; the central element was not located within the 1-kilometer tolerance because it was considered financially worthwhile to utilize an existing long-period installation even though it was located 10 kilometers northwest of the optimum position. Figure 3 is a map showing the final site locations.

2.4 ARRAY INSTRUMENTATION SYSTEMS

2.4.1 Seismometers and Amplifiers

Each of the seven sites is equipped with one Vertical Advanced Long-Period Seismometer, Geotech Model 7505A and two Horizontal Advanced Long-Period Seismometers, Geotech Model 8700C. Two modifications were performed to improve the operation of the instruments. A second remote leveling foot was added to each seismometer so that the free period could be adjusted from a remote location. Controls for the free period and mass position adjust are located at each site. An extension of the free-period foot was required to

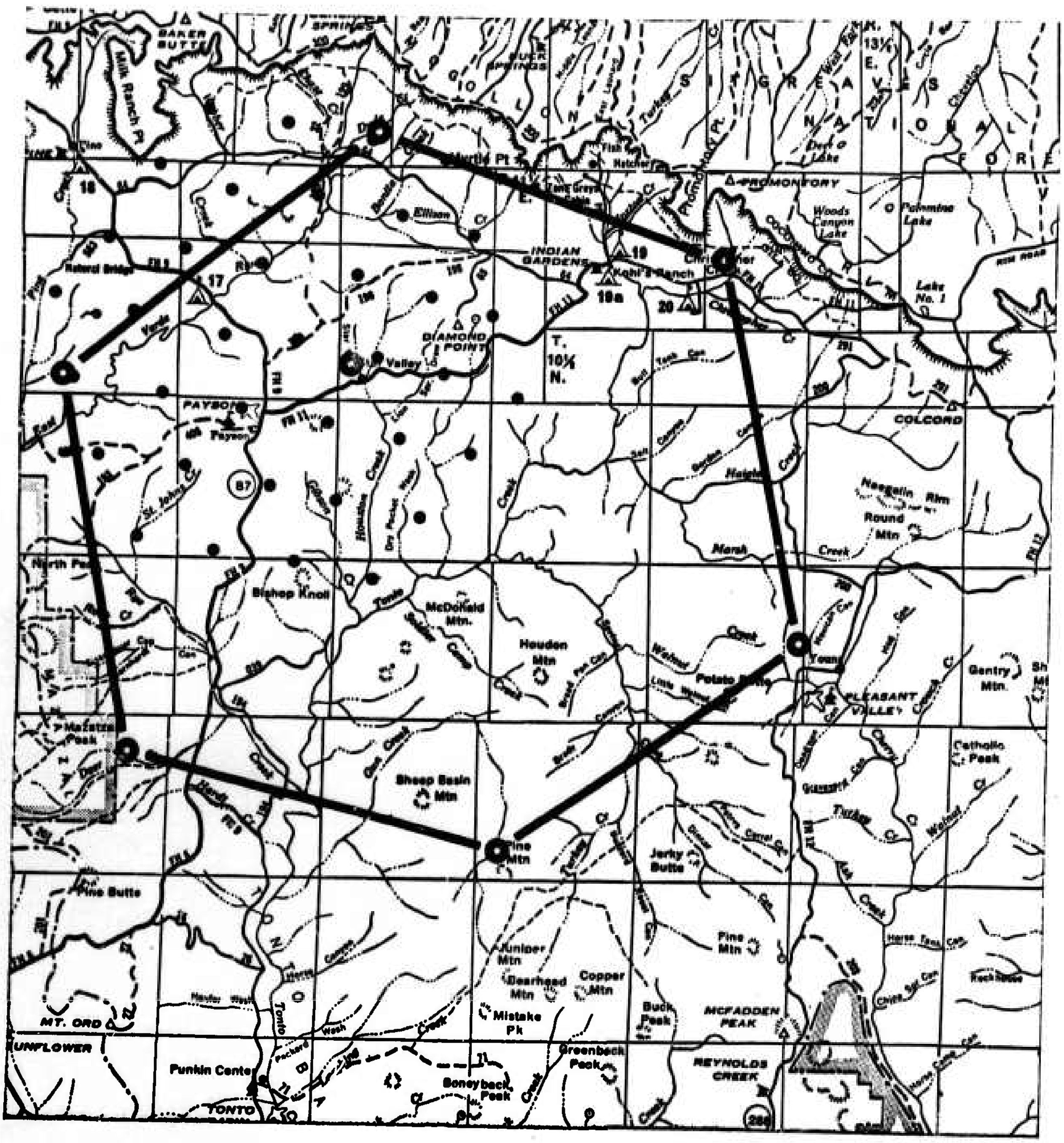


Figure 3. Vault locations of the TFSO long-period array

provide adequate clearance between the motor cover and the data output terminal posts.

The two data coils were connected in series to obtain the optimum source impedance for the solid-state amplifier so that with proper seismometer damping we could obtain the best possible signal-to-noise ratio.

The amplifier being used in the long-period array is the Geotech Solid-State Amplifier, Model 28470. This amplifier replaces the Model 5240A galvanometer-type amplifier that was previously used in the long-period systems at TFSO. The Model 28470 amplifier has the following advantages over the galvanometer-type amplifier:

1. The solid-state amplifier is smaller.

2. No adjustments are necessary when installing the amplifier.

3. There is a low power requirement.

4. There is a capability of multiplexing the three frequency-modulated data outputs to be transmitted over one data line.

5. It is expected to provide a more stable and reliable system.

The data output from the amplifiers is a frequency-modulated carrier with a bandwidth of ±15 percent of the center frequency. The amplifier center frequencies are 560 cps for the east-west horizontal seismographs, 960 cps for the north-south horizontal seismographs, and 1700 cps for the vertical seismographs.

2.4.2 Data Transmission

The data are transmitted from the field sites to the central recording building (CRB) in four different ways:

1. Spiral-4 cable is used to transmit data from sites LP1, LP6, and LP7.

2. A Motorola microwave system is used to transmit data from site LP5.

3. Data from sites LP2 and LP3 are transmitted by telephone company facilities using "panhandle" carriers over open-wire facilities.

4. Data from site LP4 are transmitted by telephone company microwave circuits except for a short length of spiral-4 cable at the site end and telephone cable from Payson to TFSO

Data at each site are multiplexed with a summing amplifier; the amplifier is also used as a line driver to increase the signal level before it is transmitted over the data lines. It has an adjustable gain so that the signal level can be reduced when operating into the telephone company circuits.

The Motorola microwave equipment was available from a previous program and was utilized to microwave data from the remote LP5 site. Spiral-4 cable is used to link the amplified data at the seismometer site to the microwave site. The seismic signals are fed into the transmitter and directed to Diamond Point from a 6-foot open-grid antenna. It is microwaved at a carrier frequency of 959.7 megacycles, 20.5 miles at approximately "N. 5°W." to one of the 42-inch closed-face antennas at the Diamond Point relay site. Figure 4 is a view from Diamond Point south to LP5. Data is then transmitted at a center carrier-frequency of 956.1 megacycles from a 42-inch closed-face antenna "S. 70° W." for six miles to a 10-foot open-face antenna, to the CRB roof.

The antennas were aligned by Canyon States Communications Company during the period 24 through 26 April 1968. Figures 5, 6, 7, and 8 show the LP5 installation. All of the radio equipment requires 117 volts ac at 60 cps as the primary power. Table 1 itemizes the radio equipment in the basic unit. Four of these units were needed with two antennas for each unit.

Utilization of the antennas previously used with the system proved adequate. These are mounted on towers and on the CRB roof. They were purchased for the original microwave link. Figures 9 and 10 show the two 10-foot open-grid antennas which are mounted on the roof of the CRB. Three 42-inch solid antennas, along with one 6-foot open-grid antenna, are mounted on the relay tower at Diamond Point. Two 6-foot open-grid antennas are tower-mounted at LP5. All the open-grid antennas have heaters. Line-of-site was maintained between broadcasting and receiving antennas.

The towers used at both LP5 and Diamond Point are Model 25G, manufactured by the Rohn Company. The towers are triangular in shape and are 12 inches across each side of the triangle. They may be installed in 10-foot sections. The tower at Diamond Point, shown in figure 11, has 4 antennas and 6 guy wires. It has been constructed to withstand a 100-mile-per-hour wind with iced antennas.

2.4.3 Data Conditioning

Data conditioning of the long-period system is accomplished by the Solid-State Telemetry Amplifier, Geotech Model 28470, the FM Discriminator, Geotech Model XD 410, and the Signal Control Center, Geotech Model 22602. The three units amplify and filter the data signal to form the relative amplitude response shown in figure 12.

G 4237

Figure 4. View from Diamond Point south to LP5

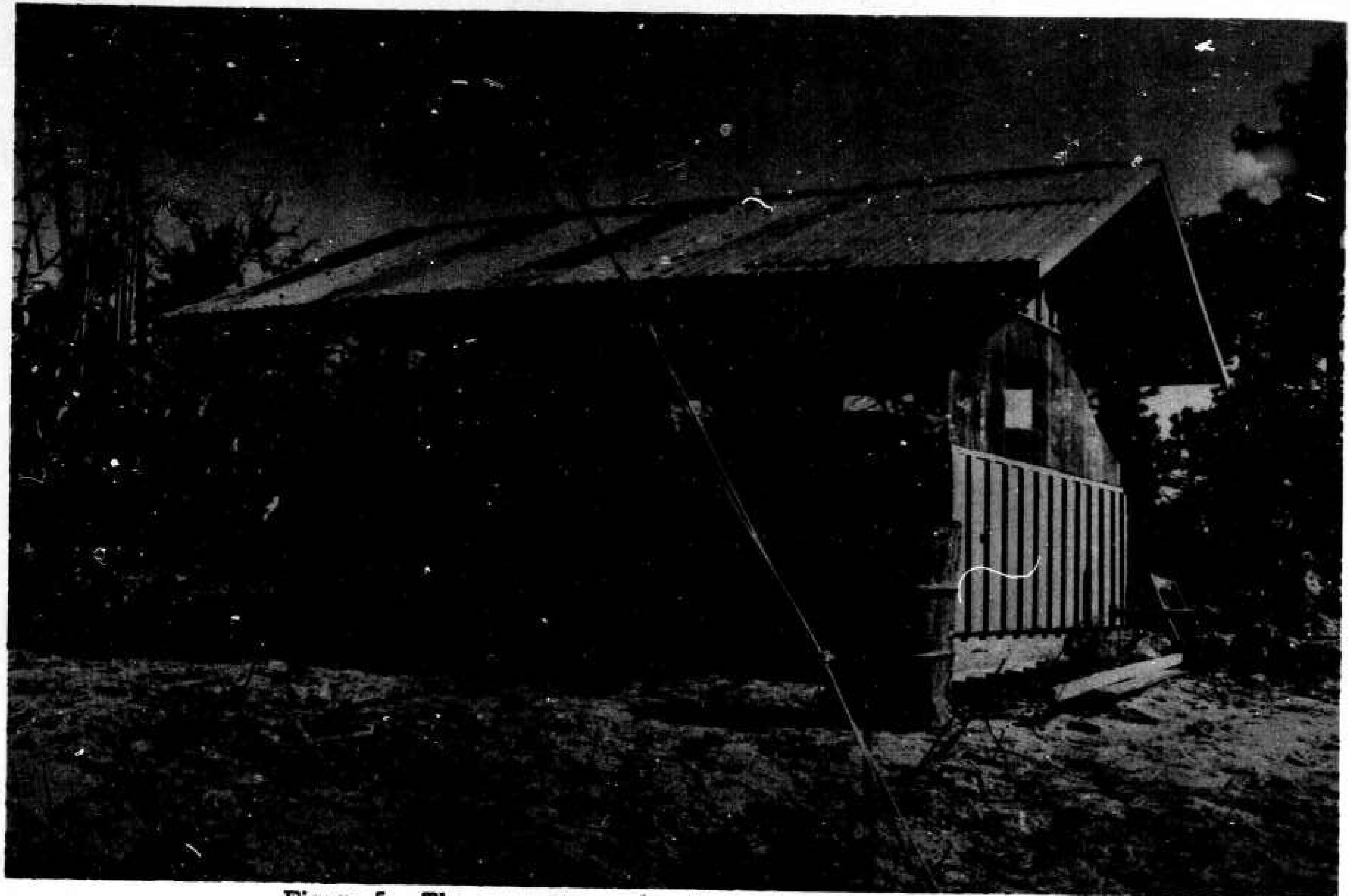


Figure 5. The generator and radio equipment building during construction of site LP5 at TFSO

G 4238

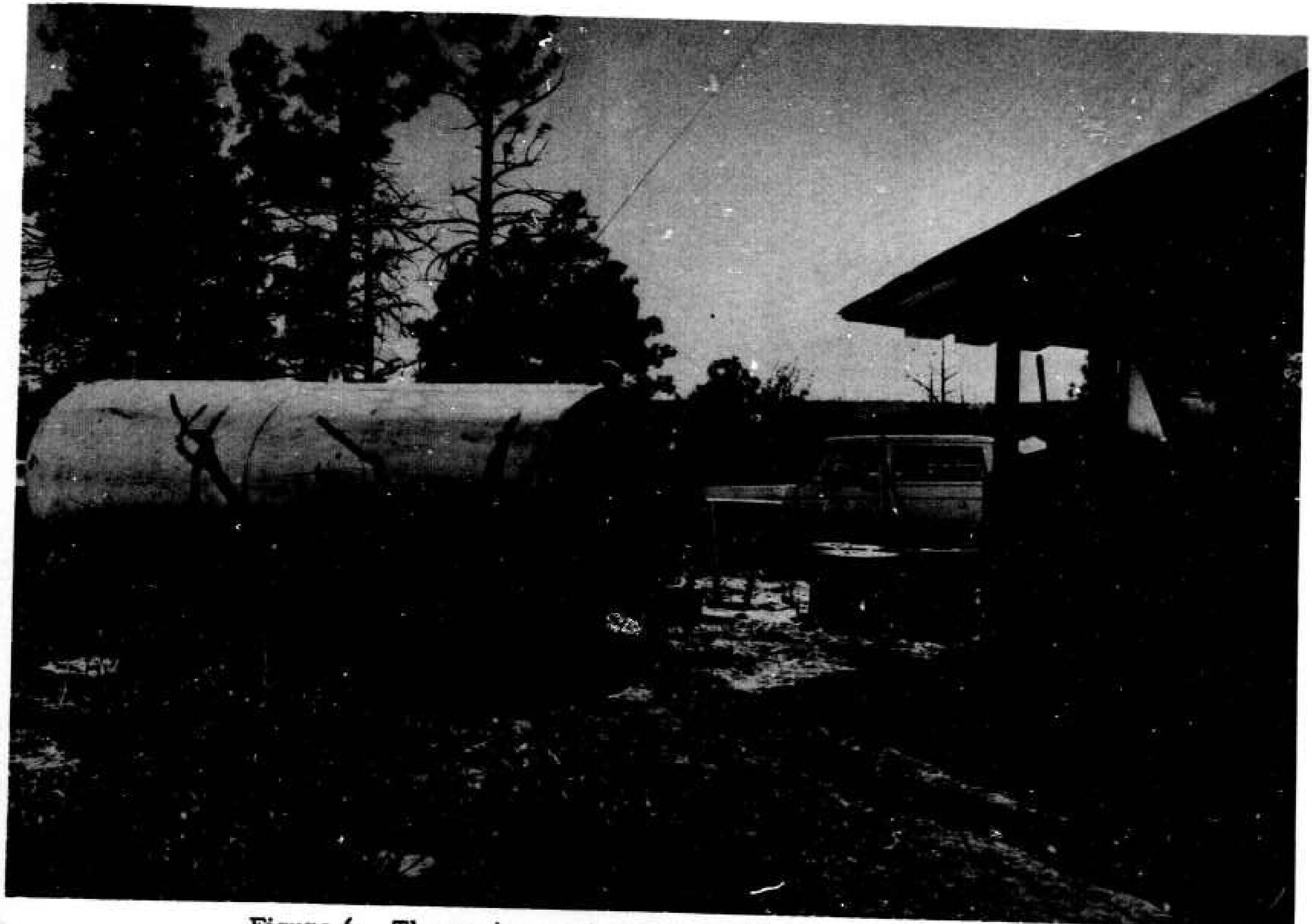
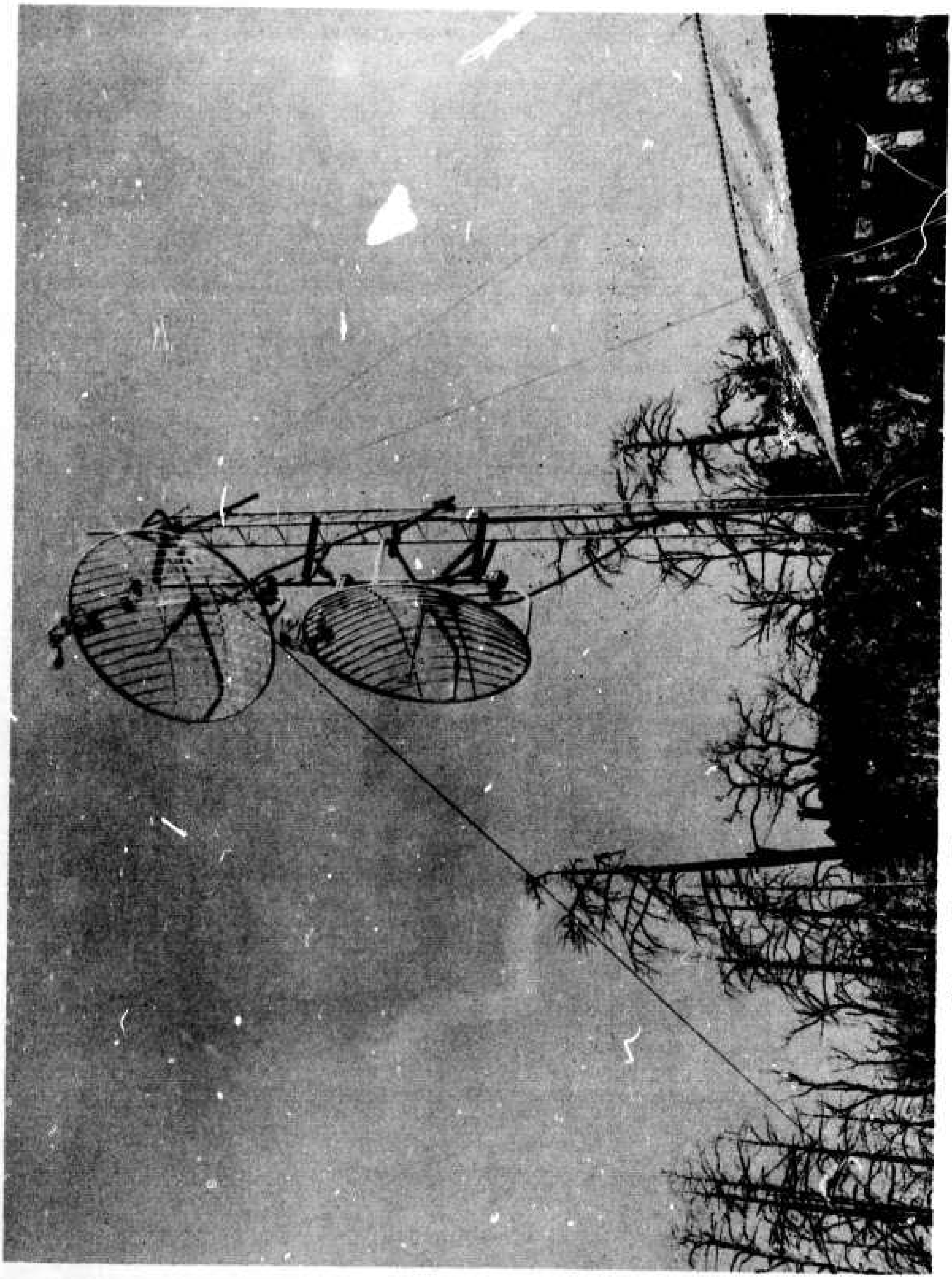


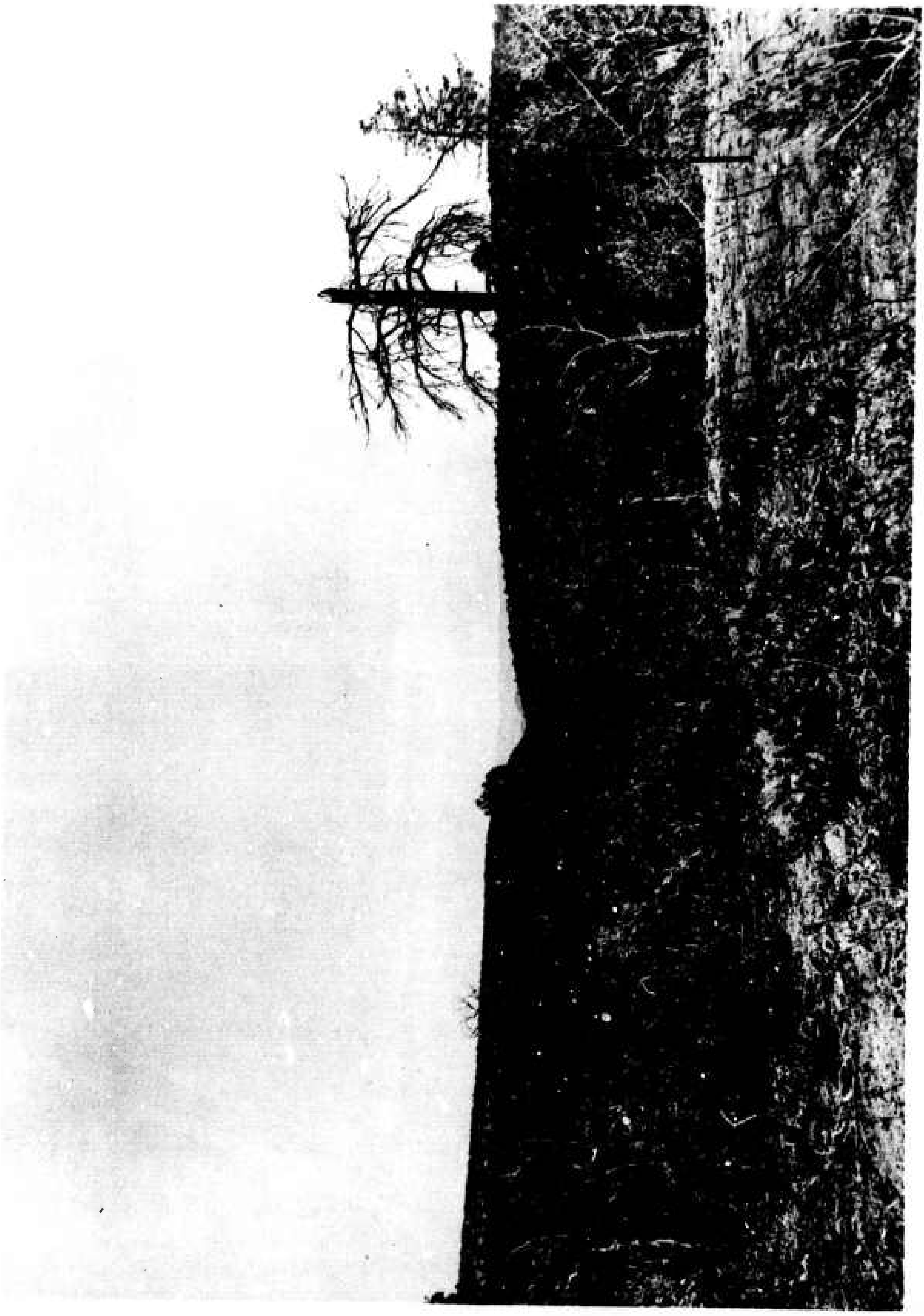
Figure 6. The equipment building and the diesel oil supply during construction of site LP5 at TFSO

G 4239



G 4240

Figure 7. The open-grid, 6-foot dish antenna on the microwave tower at site LP5 at TFSO



G 4241

Figure 8. View from site LP5 north to Diamond Point (in the gap)

Table 1. Items included in the Basic Microwave Unit, Motorola Model J35AAB-1000A

Model Number	Description
TTF1000AA	Single frequency, 5 watt transmitter
TRF1000AA	Single frequency Sensicon receiver with TU344 "Permakay" filter
TPN6036A	117 V ac power supply (terminal stations)
TLN6317A	Filament voltage regulator kit
TU388	Termination and fuse panel
TU139A	Universal metering kit
TK592	Cabinet kit
TLN6332A	Cabinet accessory kit (outdoor)
TK355	Blower and filter panel
TK356	Receiver shield and filter panel (terminal stations)
TKN6091A	Cable kit
Type RN20	Transmitter crystal
Type AM18-SP	Receiver control crystal
Type AN-SP	Receiver IF crystal (13.540 megacycles)
TK578	Alignment tool kit
DS96654A*	Open grid, parabolic, 6-foot antenna with heaters
DS9655A*	Open grid, parabolic, 10-foot antenna with heaters
DS9667A*	Closed face, parabolic 42-inch antenna

*Antennas are not included in basic unit. Two antennas are used for each unit.

Figure 9. The microwave dish antennas mounted on the Central Recording building at TFSO

G 4242

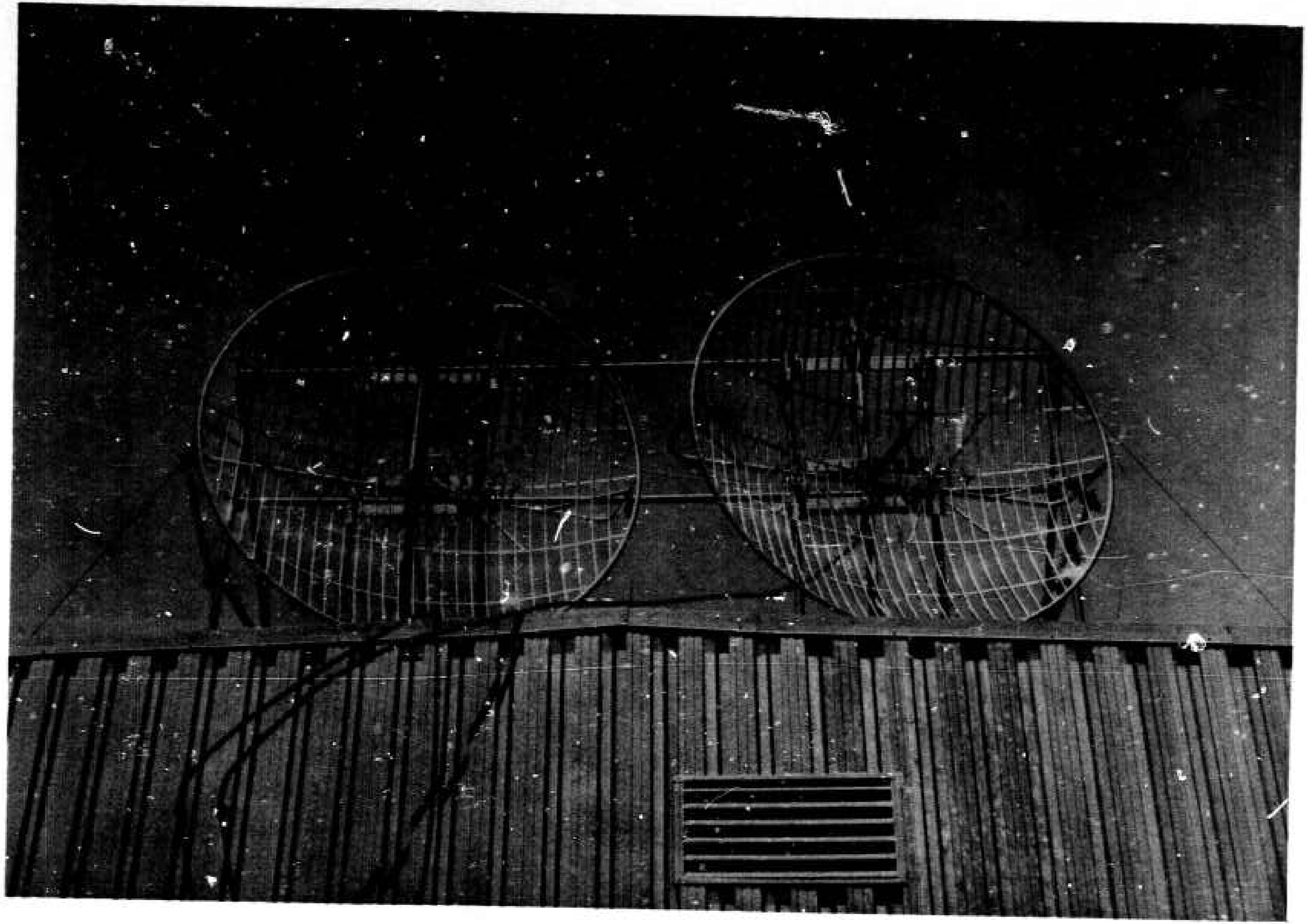


Figure 10. Close-up view of the 10-foot dish antennas mounted on the Central Recording Building at TFSO

G 4243

Figure 11. The Diamond Point relay antennas. The two lower dishes are aimed at the Central Recording Building at TFSO, and the two upper dishes are aimed toward LP5. The top vertical antenna is for the base transmitter-receiver used in the TFSO voice communication system

G 4244

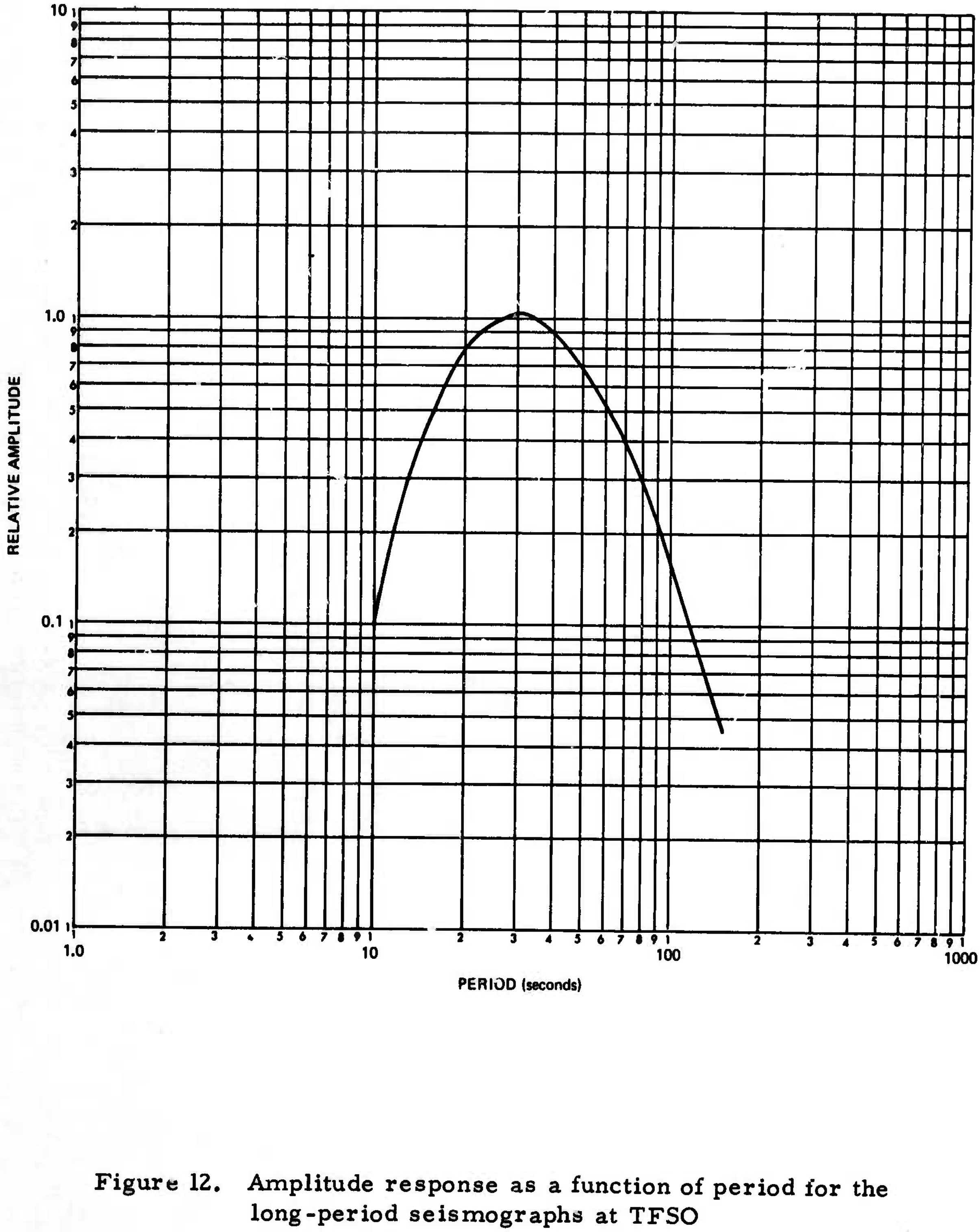


Figure 12. Amplitude response as a function of period for the long-period seismographs at TFSO

G 4245

Seismometer calibration is achieved by the electromagnetic method. The calibration signal is generated at the CRB and converted to a frequency-modulated signal. The signal is then transmitted to the vault over spiral-4 cable, telephone company facilities, or microwave facilities, depending on the particular site location. The calibration signal is then discriminated and converted to an analog input.

The calibration system is adjusted so that the current through the seismometer coil is equal to the amount of current fed into the system at the CRB.

2.4.4 Lightning Protection

The long-period array lightning protection is similar to the standard short-period protection, except for an additional protective arrangement for the Lambda power supplies. Figure 13 shows the portion of the lightning protection system installed in the Hoffman box near the vault sites. Figure 14 shows the portion of the system protecting the power supplies.

2.4.5 Power

At the sites where 110 volts ac commercial power is available (sites LP1, LP2, LP3, and LP4), a Lambda Power Supply, Model LH127 supplies 24 volts dc to the vault equipment. The power supply is mounted on a pole or tree, and dc power is transmitted to the vault over spiral-4 cable. The length of cable required for each site varies up to a maximum of 2-1/4 miles at site LP4.

Thermoelectric generators, General Instrument Type U2P, provide 24 volts dc power to sites LP6 and LP7.

Site LP5 is powered by a 9.0 kilowatt Witte generator operated on diesel oil fuel. The requirement for 110 volts ac power was necessitated by the decision to use the Motorola tube-type microwave equipment to transmit the data to TFSO. A Lambda power supply supplies the required 24 volts dc for the vault equipment.

Table 2 summarizes the types of vault construction, the methods of data transmission, and the sources of power used in the long-period array.

2.5 LAND ACQUISITION, SURVEYING, AND CLEARANCE

2.5.1 Land Permits

The Phoenix real estate office of the United States Corps of Engineers received the Air Force request-for-use permits for the long-period sites on 28 August 1967. A meeting was held between personnel of the Corps of Engineers and TFSO personnel shortly thereafter. On 6 September 1967,

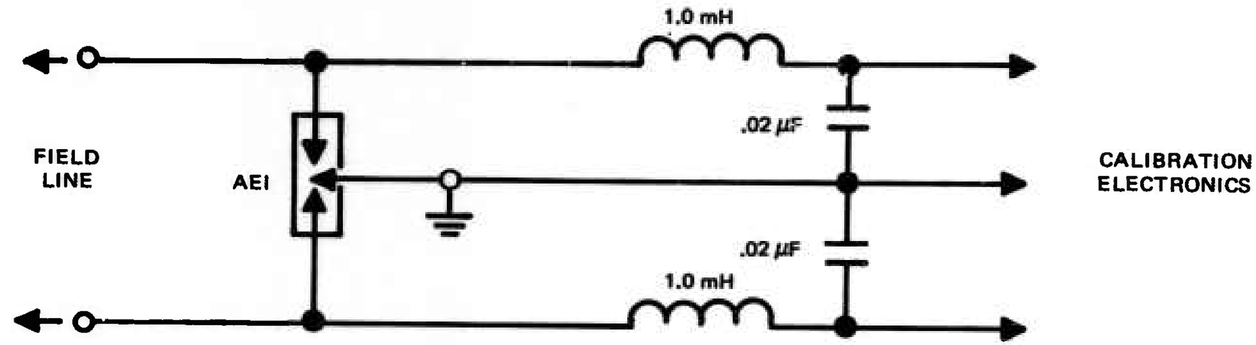


Figure 13. Portion of the lightning protection system installed at the Hoffman boxes of the 7-element long-period array at TFSO

G 4246

LIGHTNING PROTECTION LAMBDA SUPPLY

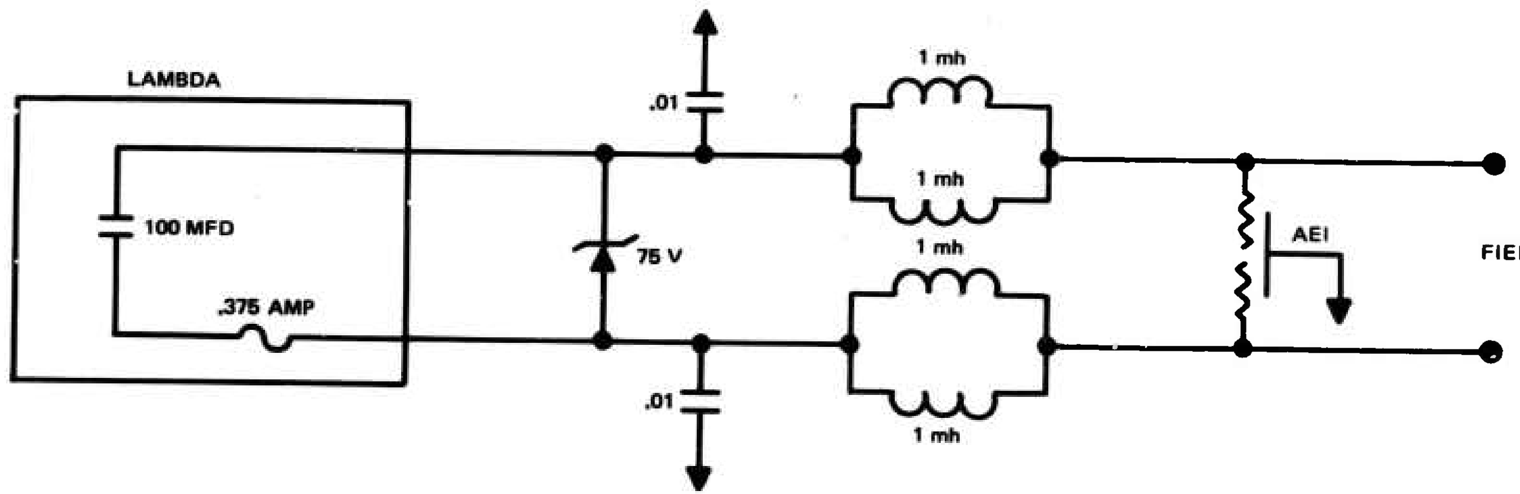


Figure 14. Lightning protection system for the Lambda power supplies in the 7-element long-period array at TFSO

G 4247

Table 2. Summary of the types of vault construction, the methods of data transmission, and the sources of power used in the long-period array at TFSO

Station	Vault Type	Data Transmission	Source of Power
LP1	Walk-in	Spiral-4 cable	Commercial
LP2	3 tank vaults	Telephone	Commercial
LP3	3 tank vaults	Telephone	Commercial
LP4	26-foot-deep steel cylinder	Telephone, microwave, Spiral-4 cable	Commercial
LP5	3 tank vaults	Motorola microwave	Witte Generator
LP6	3 tank vaults	Spiral-4 cable	Thermoelectric generator
LP7	3 tank vaults	Spiral-4 cable	Thermoelectric generator

all maps, specifications, and updated information for the long-period array were forwarded to the Corps of Engineers, so that an application for a special-use permit could be submitted to the Forest Service. The Corps of Engineers sent the application to the Forest Service on 6 October 1967. Verbal approval to proceed with sites LP2, LP3, LP5, LP6, and LP7 was received from the Forest Service on 2 November 1967. Verbal approval to proceed with site LP4 was received on 5 November 1967. Site LP1 is located in an area for which a use permit had been previously obtained.

2.5.2 Archeological Survey

The long-period array is situated in an area of considerable archeological interest, and the Federal Government requires that a qualified team of archeologists inspect a site before any excavating is done. Accordingly, site LP5 was inspected and approved for construction by Mr. Roger Kelley of Arizona Northern University during September 1967. Messrs. P. J. Pilles, Jr., and W. Barrera, Jr., of the Museum of Northern Arizona, inspected and approved sites LP2, LP3, LP4, LP6, and LP7 during November 1967.

2.5.3 Geographic Survey

The 1381st Geodetic Survey Squadron determined the geographic positions and elevations of the long-period sites. Table 3 lists the results.

2.5.4 Site Clearance

All vegetation within 100 feet of the vaults was removed to reduce the effects of wind-generated noise.

2.6 INSTALLATION OF FIELD EQUIPMENT

The installation of field equipment varied at the different long-period sites due to the difference in vaults.

At LP1, the previously constructed walk-in long-period vault was used. A standard Emcor "half-rack" was used to mount a panel containing the amplifier-multiplexer, lightning protection, and other peripheral equipment. At site LP4, it was decided to drill a large-bore hole to bedrock and to install the 3-component system in a single steel cylindrical vault, which is 6 feet in diameter and 26 feet deep. Prior to commencing to drill the large-bore hole, it was necessary to determine the depth to competent rock and the type of overburden. Some difficulties were encountered in this preliminary task.

TFSO personnel drilled several preliminary test holes with a hand-operated drill. The drill proved satisfactory until what was thought was competent rock was encountered. Samples taken from the test holes were intermixed with wet clay as water had to be used to help keep the clay stuck to the auger,

Table 3. Final geographic positions and elevations of the long-period array sites

Site	Latitude (N)	Longitude (W)	Elevation	
			Meters	Feet
LP1	34° 16' 03.760"	111° 16' 12.972"	1491.7	4894
LP2	34° 23' 36.48"	111° 15' 13.000"	1752.8	5750.6
LP3	34° 19' 23.249"	111° 01' 01.673"	1852.9	6079.06
LP4	34° 07' 23.8"	111° 57' 44.1"	1651.8	5422*
LP5	33° 58' 53.495"	111° 09' 59.875"	1634.9	5355
LP6	34° 03' 11.521"	111° 24' 08.340"	1151.2	3776.90
LP7	34° 15' 28.296"	111° 26' 47.18"	1223.5	4014

*Seismometer depth is 26 feet below surface elevation shown above so a sample could be recovered. In conjunction with the test holes, a vacuum type core drill was tried but proved unsatisfactory. The vacuum pump would not lift any sample that was slightly damp from the test hole. This method of recovering a core was abandoned.

Mr. Gordon K. Grimes, the owner of a Chicago-Pneumatic core drill and Jaeger Air Plus Roto compressor, was contracted to drill some test holes and, if possible, recover a core. Drilling of the test holes proved unsatisfactory due to gravel from the gravel stringers plugging the core barrel and preventing recovery of a core.

The size, angularity, and mineral content of the cuttings washed from the test hole indicated that the bedrock being drilled was granite. The 7-foot diameter hole was drilled into the granite and the metal vault was installed. Figure 15 shows the 7-foot diameter hole, and figure 16 shows the steel vault prior to insertion in the hole. A concrete pier was poured and isolated from the concrete floor. Concrete was poured around the sides and over the top except for the entry.

At the other locations, each of the three seismometers is housed in a separate vault. A Hoffman box, which houses lightning protection, calibration distribution, and mass-position monitoring circuits, is installed in the vicinity of the vaults. The amplifier and junction assembly are mounted on a panel which is welded to the inside of the vault. Metal tanks are set in concrete to provide good coupling to the competent, near-surface rock, and a multiconductor cable completes the circuits between the Hoffman box and the vault through a flexible plastic conduit. Figure 17 shows a schematic plan view of the 3-vault long-period installations, and figure 18 shows a cross-sectional view of one of the three vaults.

At each location, the vaults were filled with an insulating material to reduce the effects of convection currents. The vaults were then sealed and covered with several feet of sawdust. The areas surrounding each vault were leveled to reduce the effects of wind on surface irregularities.

3. INITIAL OPERATION

3.1 OPERATING PARAMETERS

The frequency response and tolerances for each of the seven 3-component long-period seismograph systems are shown in table 4. Other operating parameters are shown in table 5. The relative phase shift, within the frequency band of interest, between any two seismograph systems will be maintained at less than 20 degrees.

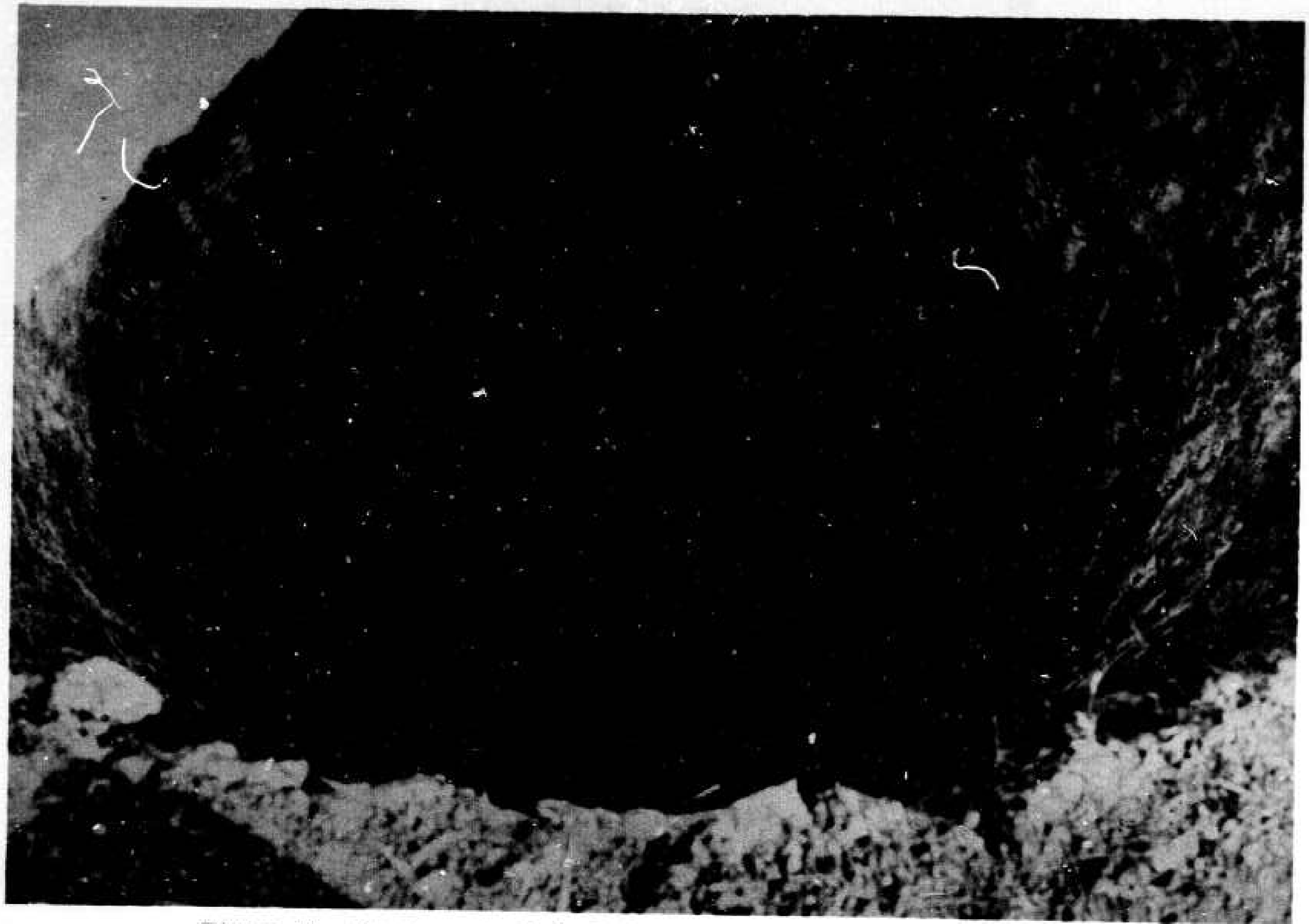


Figure 15. Photograph of the 7-foot diameter hole at the LP4 site at TFSO prior to installation of the steel vault

G 4248

G 4249

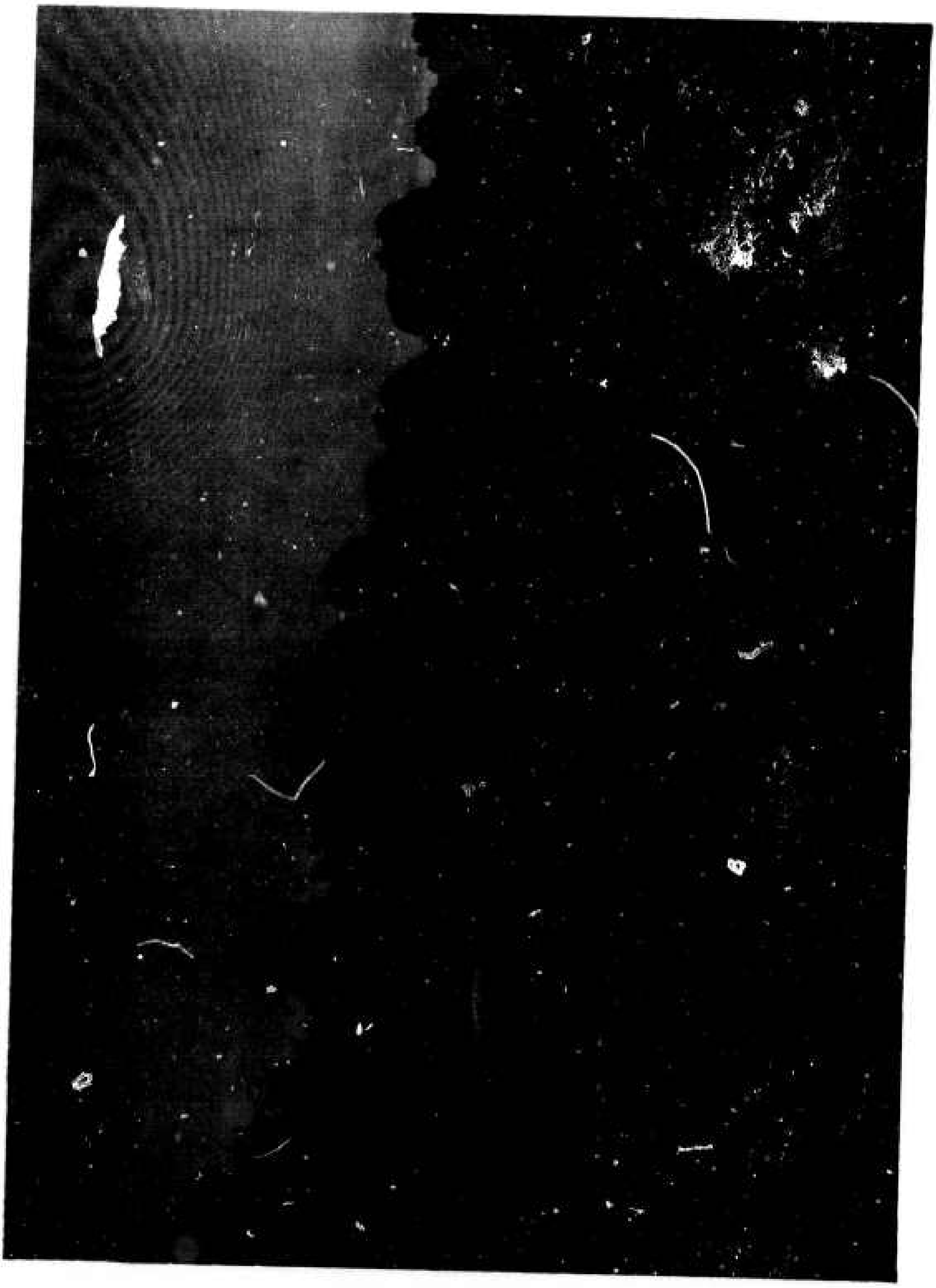


Figure 16. Photograph of the 26-foot long steel vault prior to installation at site LP4 at TFSO

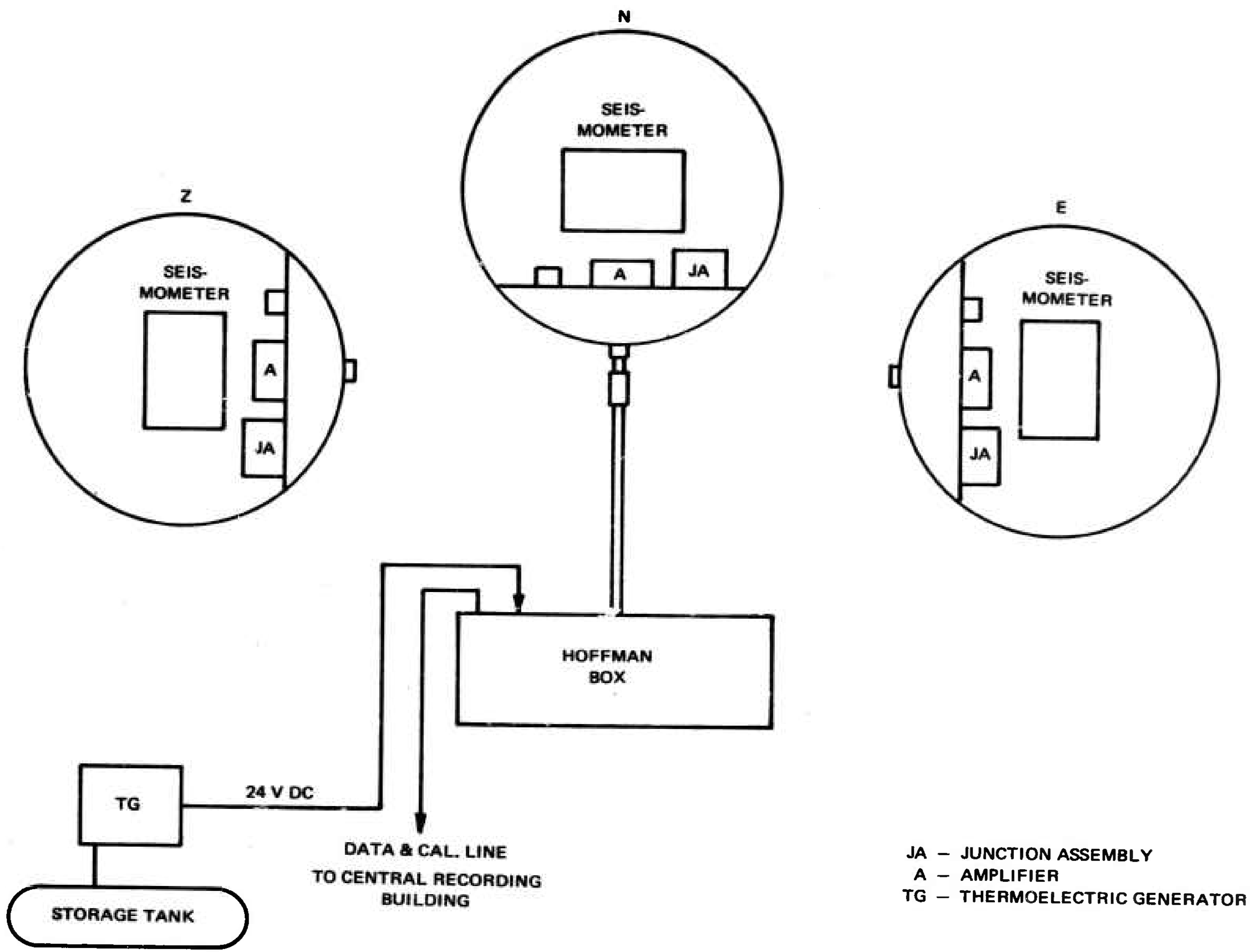


Figure 17. Plan view of a typical long-period installation

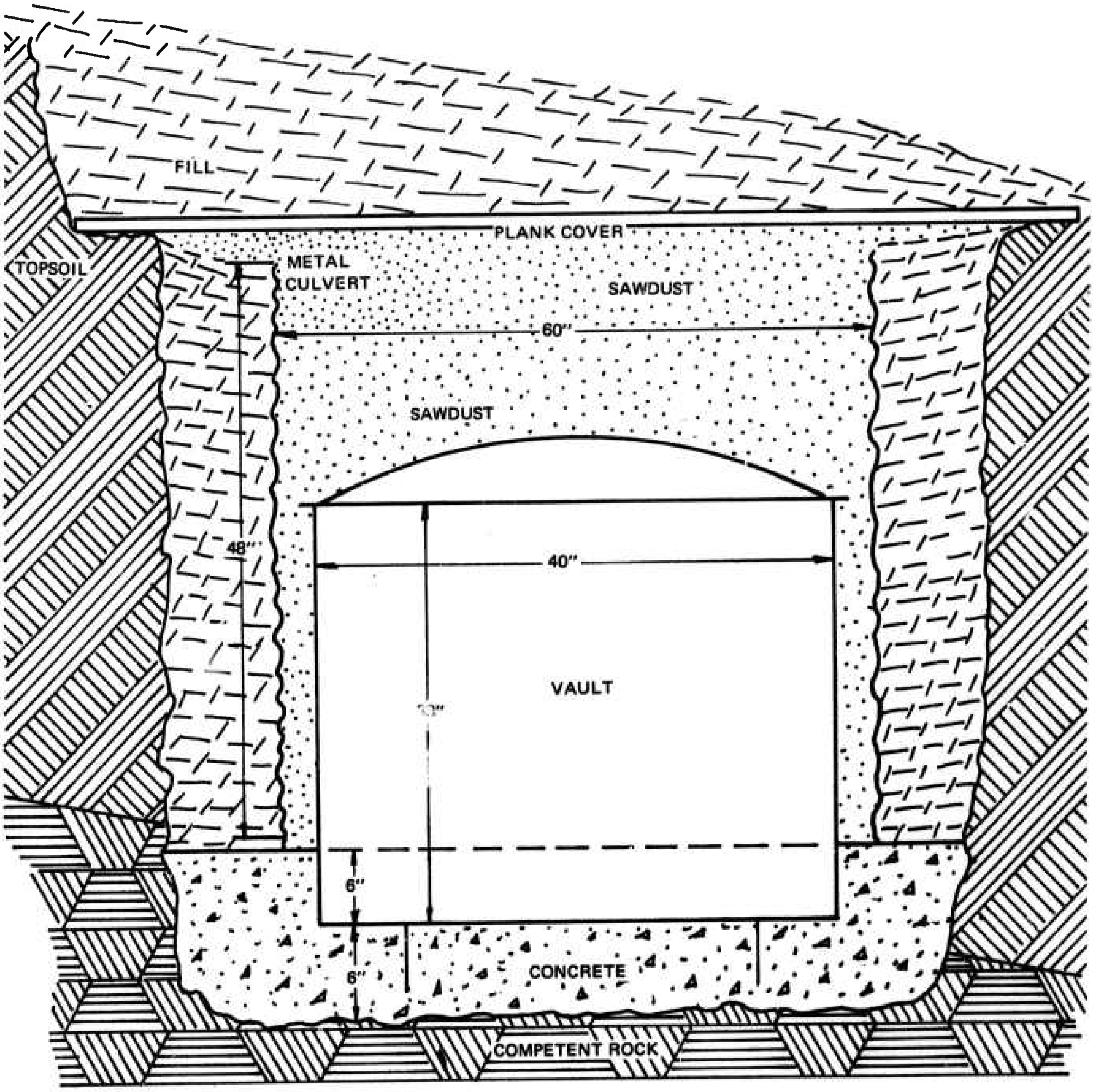


Figure 18. Cross-section of a typical vault installation at sites LP2, LP3, LP5, LP6, and LP7 in the long-period array at TFSO

Table 4. Normalized frequency response and tolerance for the long-period seismographs at TFSO

Frequency (cps)	Normalized Response	Tolerance (percent)
0.01	0.135	±20
0.0125	0.278	20
0.0167	0.485	15
0.02	0.644	15
0.025	0.874	10
0.033	1.03	5
0.04	1.00	0
0.05	0.825	5
0.0667	0.470	10
0.100	0.110	20

Table 5. Operational parameters for the 7-element long-period array at TFSO

Seismometer free period (seconds)	20.0
Set-up tolerance (percent)	±2.0
Operate tolerance (percent)	±5.0
Seismometer damping	0.77
Voltage-controlled oscillator center frequencies (cps)	560, 960, and 1700
Set-up tolerance (percent)	±0.1
Operating tolerance (percent)	±0.8
Calibrator motor constant (newtons/ampere)	0.028
Set-up tolerance (percent)	±2.0
Operating tolerance (percent)	±3.0
Effective mass (kilograms)	10.5

3.2 CALIBRATION SCHEDULE AND PROCEDURES

Each of the 21 long-period seismograph systems is calibrated daily with a 0.04 cps sine wave. A calibration current of 0.024 milliamperes is used to produce an equivalent ground motion of 1000 millimicrons. The duration of the 0.04 cps calibration is no less than 3 minutes.

Amplitude and phase response as a function of frequency is checked monthly. Motor constants are checked semi-annually.

3.3 ARRAY RESPONSE

The wave-number response of the array is shown in figure 19. Due to the fact that the interior element is offset from the center, the response along northwest-southeast wave-number vectors is down only about 15 dB. This makes the response inferior to the wave-number response of the recommended array shown in figure 20. In comparing the two responses, the theoretical response should be rotated about 8 degrees counter-clockwise.

3.4 OPERATIONAL PROBLEMS

3.4.1 Data Transmission

Although lightning protection devices have been installed, several periods of data loss have been caused by lightning, and considerable damage has been done to power supplies, amplifiers, and cable.

The telephone company's "hard wire" circuit has experienced several problems with cross-feed between the data and calibration lines and dropping of the carrier levels. These problems have now been remedied.

3.4.2 Amplifiers

During the early months of operation, noisy amplifiers caused the data to be unreliable. The amplifiers were modified by removal of the diodes across the base-to-emitter junction of the input transistor and by changing the damping circuit from active to passive. The diodes had been added previously for lightning protection. The modifications were successful in eliminating most of the amplifier noise.

3.4.3 Power Supplies

The thermoelectric generator at LP7 has caused some outages. It is now being repaired and an alternate generator is being used. The Witte generator at LP5 had a voltage regulator malfunction, and a new regulator has been installed.

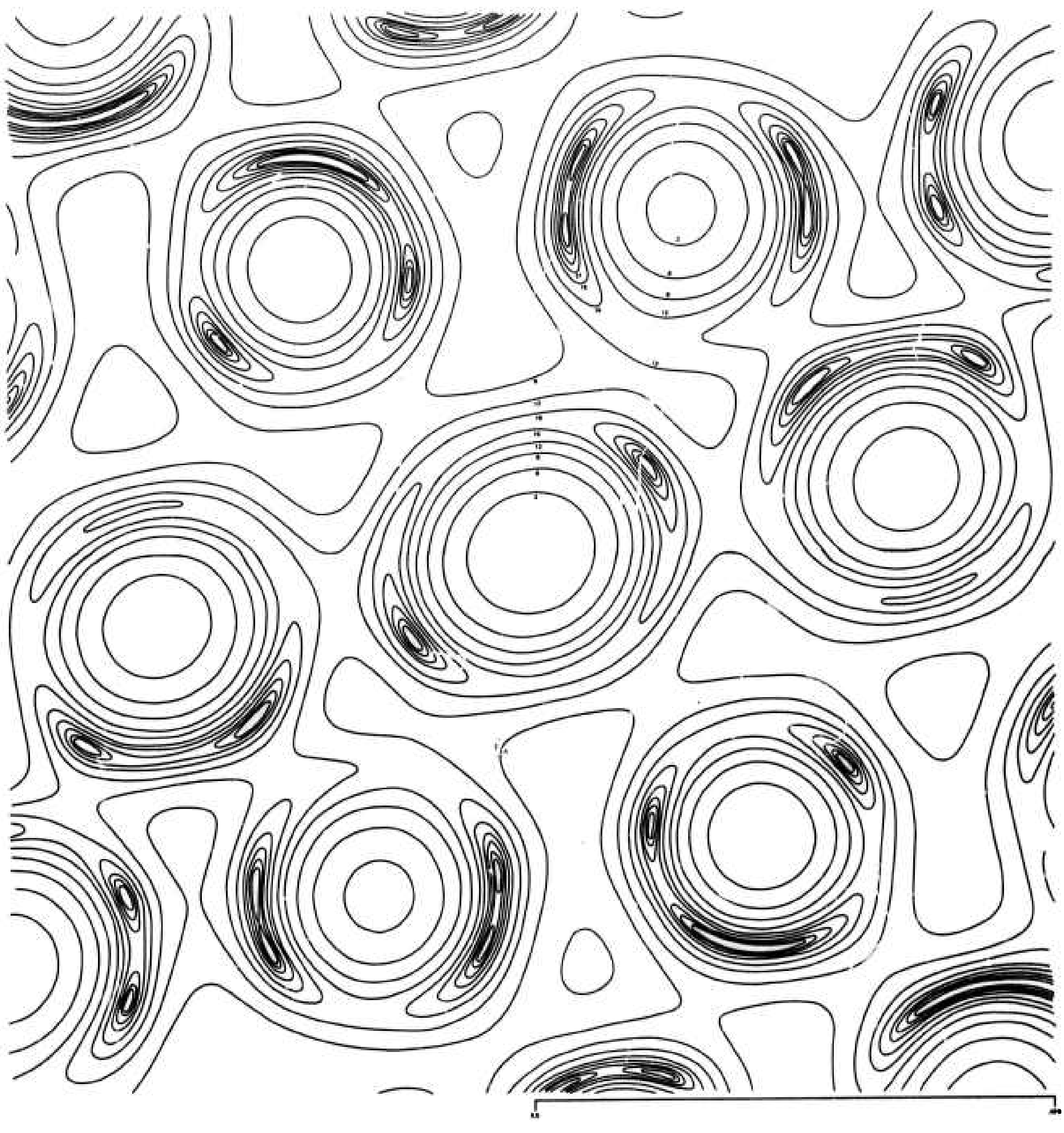


Figure 19. Wave number response of the 7-element, long-period array at TFSO

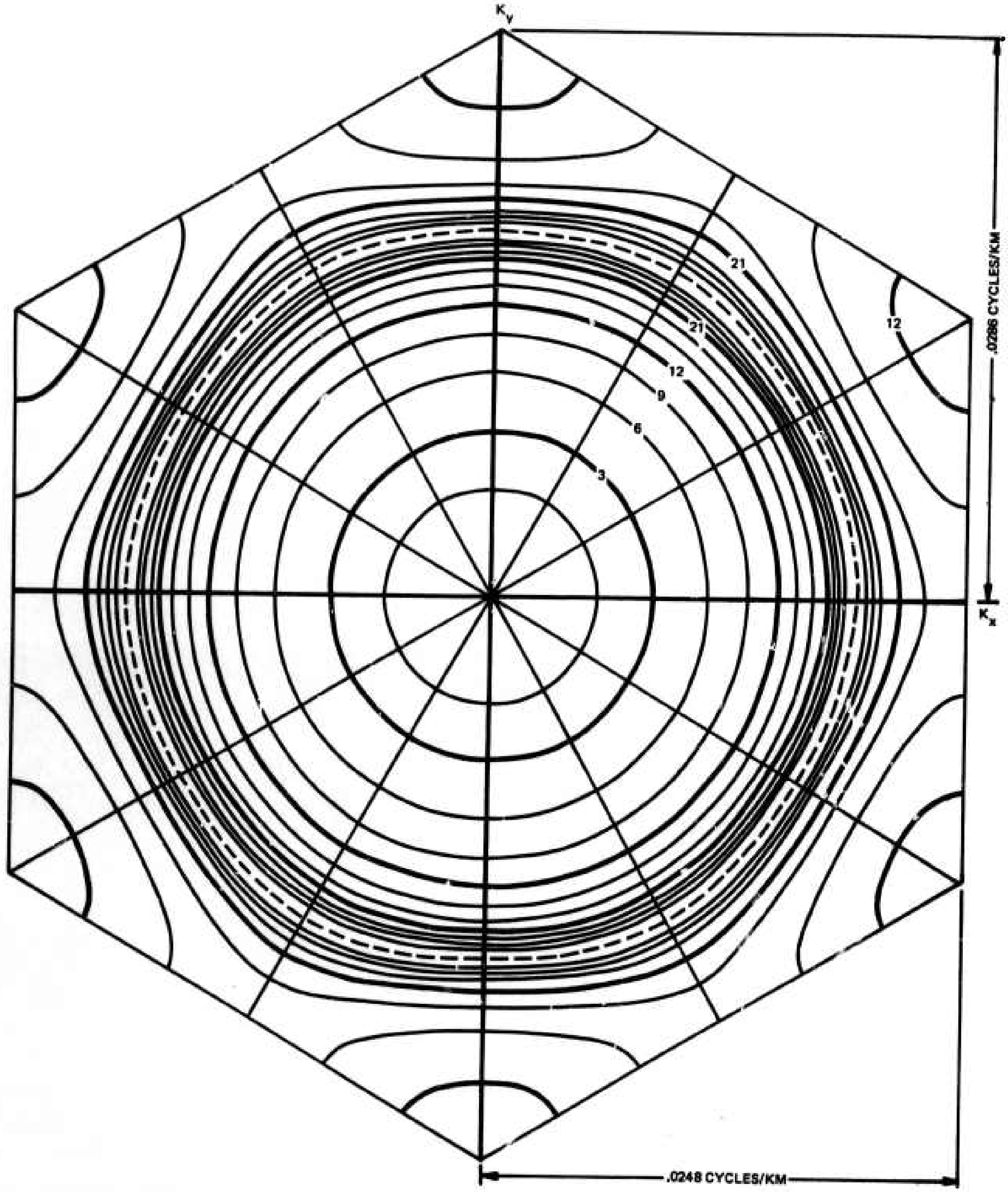


Figure 20. Predicted wave number response of the recommended long-period array at TFSO

3.4.4 Seismometers

Flexure hinges have caused spiking on LP1. The hinges were changed, and the spiking has stopped.

3.4.5 Vault Seals

Lack of optimum sealing has limited the operating magnifications of some of the instruments. The time constants are currently being determined for all of the vaults.

4. RECOMMENDATIONS

The primary task remaining to be accomplished to achieve optimum performance of the array is to complete the sealing of the vaults so that consistently high operating magnifications can be maintained. Upon completion of the time constant determinations, which will furnish a quantitative measure of vault leakage, we recommend that improvements in the vault seals be made such that no vault has a time constant less than two hours. We expect that improving or replacing the gaskets, sealing the vaults to the lids, and eliminating any leaks between the vaults and the cement bases will assure that the time constants are at least two hours.

It is our opinion that another factor limiting the operational magnification of the long-period instruments is noise generated by heating of the electrical components in the Hoffman boxes and by noise generated by convection currents in LP4, due to heat absorption. The grey coloring of the Hoffman boxes and the black lid of LP4 are especially receptive to heating during the daylight hours. We plan to paint these surfaces white to reduce heat absorption.

The outputs of all 21 long-period seismographs are currently being recorded on 16-millimeter film and on FM magnetic tape; the 3 components of LP1 are being digitally recorded on the Astrodata system. We plan to record the 6 other vertical outputs on the available Astrodata channels.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Teledyne Industries, Incorporated Geotech Division, 3401 Shiloh Road Garland, Texas	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Design, Installation, and Initial Operation of the Long-Period Seismic Array at the Tonto Forest Seismological Observatory

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Installation report, 46-kilometer long-period array

5. AUTHOR(S) (First name, middle initial, last name)

Geotech staff

6. REPORT DATE 15 June 1968	7a. TOTAL NO. OF PAGES 44	7b. NO. OF REFS None

8a. CONTRACT OR GRANT NO. AF 33(657)-67-C-0091	9a. ORIGINATOR'S REPORT NUMBER(S) TR 68-29
b. PROJECT NO. VELA T/7702	
c. ARPA Order No. 624	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. ARPA Code No.	

10. DISTRIBUTION STATEMENT

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Chief of AFTAC

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Projects Research Agency Nuclear Test Detection Office Washington, D. C.

13. ABSTRACT

During the second half of 1967 and the early part of 1968, a 7-element long-period seismic array was constructed at the Tonto Forest Seismological Observatory (TFSO). Each of the seven elements consists of a vertical long-period seismograph and two mutually-perpendicular horizontal seismographs. The elements are arranged in a hexagonal pattern and are distributed over an area of approximately 800 square miles. This report describes each aspect of the design, installation, and initial operation of the array. (U)

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Array design parameters						
Noise field characteristics						
Array instrumentation system						
Microwave transmission						
Operating parameters						