SEISMOLOGICAL SERIES

of the

DOMINION OBSERVATORY

1968-2

Operation and Maintenance
of the
Yellowknife Seismological
Array,
1966-68

E. B. Manchee and
W. D. Cooper

Seismological Service
of Canada

OTTAWA, CANADA

Department of Energy, Mines and Resources

OBSERVATORIES BRANCH

1968

SEISMOLOGICAL SERIES
of the
DOMINION OBSERVATORY

1968-2

OPERATION AND MAINTENANCE of the YELLOWKNIFE SEISMOLOGICAL ARRAY,

1966- 68

E.B. Manchee and W.D. Cooper

Seismological Service

of Canada

OTTAWA, CANADA

Department of Energy, Mines and Resources

OBSERVATORIES BRANCH

1968

THE QUEEN'S PRINTER, OTTAWA, 1969

CONTENTS

OPERATION AND MAINTENANCE OF THE YELLOWKNIFE SEISMOLOGICAL ARRAY, 1966-68

INTRODUCTION

The Yellowknife seismological array was established during August to December 1962, with further expansion and refinement over the next two years, to collect seismic data for research into the detection and identification of underground nuclear explosions. Scientists of the Atomic Weapons Research Establishment (AWRE) of the United Kingdom Atomic Energy Authority had been investigating the problem since 1958 and had designed and built two seismic arrays, one in Scotland and the other in Wyoming, to aid them in their studies. In May 1962, the British Ministry of Defence approached the Canadian Defence Research Board about the possibility of locating another such array in Canada. Officials of the Department of Mines and Technical Surveys (now Energy, Mines and Resources) were called in to provide technical advice, and a cooperative project was quickly arranged. In brief, AWRE would supply and set up all equipment and train Canadian personnel in its use, and Canada would supply the site, do all construction work necessary, supply all personnel required for the continued operation of the array and join with the U.K. in analysis of the array data. A full description of the construction and instrumentation of the array has been given by Manchee and Somers (1966) and readers are directed to that paper for further details.

The purpose of the Yellowknife array is to collect seismological data for research. It is not intended in any sense to be an operational monitoring station. Nevertheless, the performance record of the station during the past few years may provide lessons which will be valuable during future operation of this and similar installations. Therefore, this paper will describe and attempt to analyze the day-to-day operation and maintenance of the station and draw some conclusions regarding future operation.

ROUTINE OPERATION

The reader is referred to Manchee and Somers (1966) for a full description of the construction and instrumentation of the station. The only major change that has been made is that the secondary tape deck, which originally made an edited tape containing only seismic events, now records continuously, as does the primary deck. The tapes fron the second tape deck are sent to Ottawa for processing as described by Weichert, Manchee and Whitham (1967). Selected events are digitized and retained in a library for future research. After a period of about six months, the original analogue tapes are returned to Yellowknife for erasure and reuse. The tapes produced by the primary tape deck continue to be shipped to the U.K. A fourth battery charger has been added to the system to provide for the continuous operation of the second tape deck.

Operation

Except for necessary changes of recording media (magnetic tape, helicorder paper), the operation of the array is entirely automatic. In each of the nineteen vaults there is a Willmore Mk II seismometer, a preamplifier and a tone generator. The seismic signal picked up by the seismometer is amplified and used to amplitude-modulate the tone, which is then transmitted to the central recording laboratory over elevated Spiral-4 cable. Each cable carries the tones from two adjacent vaults (460 Hz and 1220 Hz) and these tones are separated at the laboratory by notch filtering, and demodulated. The resulting seismic signals are amplified, frequency modulated and written onto 24-channel magnetic tape (19 array signals, 2 cluster signals, 2 error correction channels, and a locally-generated timing signal, all in frequency-modulated form). The signals from one vault are supplied to a helicorder visual recorder and one of the cluster channels is also displayed on a helicorder.

The recording proceeds continuously 24 hours a day. Power is supplied by a 4160 V, 3-phase, 60 Hz power line from the town of Yellowknife. A pole transformer drops the voltage to 240/120 V. This power supplies several large 24 V battery chargers, which in turn supply three 240 V, 50 Hz solid-state inverters with floating storage battery banks for smoothing and emergency standby operation of up to 1 1/2 hours. A diesel generator may be switched into the mains supply for longer power failures. The helicorders are supplied by their own 60 Hz inverter.

Power from the inverters is delivered to the various power supplies in the laboratory. Since the entire system was designed and built in the U.K. and delivered in a block, we were initially committed to U.K. power standards (240 V, 50 Hz). Since only the helicorders require 110 V, 60 Hz, it has not seemed worth while to change the entire power system over to North American standards.

As stated previously, the entire operation is automatic and no operator intervention is required except when repairs, preventive maintenance, calibration or recording media changes are necessary.

Recording media changes

Each magnetic tape reel contains 7200 feet of tape and the recording speed is 0.3 in/sec. Thus each tape is allowed to run continuously for 72 hours, after which it is rewound onto its original reel and replaced by a fresh tape. Only eight hours worth of recording time is wasted per tape, and part of this is used in calibration and lead-in on the tape. Both tapes are replaced at the same time so that serial numbers can be kept synchronized. The Canadian tape number carries the prefix YKA and the prefix for the U.K. tape is YKP. A complete tape rewind and replacement cycle takes approximately 10 minutes. The helicorders record continuously for 24 hours between changes. Thus, there are six helicorder sheets corresponding to each roll of magnetic tape. These records are mailed to Ottawa where copies are made and the originals forwarded to the U.K.

Until May 14, 1968, all changes were made at 1800Z, the tapes at three-day and the helicorders at one-day intervals. On that date the changes were moved forward to 1600Z to make two more hours per day available for field work.

Standard vault

In addition to the operation and maintenance of the array, the technicians at Yellowknife are responsible for the operation and maintenance of a standard vault of the Canadian Seismic Network. The vault contains three orthogonal components of both short- and long-period seismometers. There are thus six photographic records to change, develop, fix, wash, dry, label and pick, per day. This routine work requires several man-hours per day and maintenance and adjustment of the instruments normally amounts to only a few man-hours per month. No further reference will be made to the standard station in this paper. Details concerning instrumentation and calibration of the standard instruments will be found in the quarterly bulletins of the Seismology Division.

CALIBRATION

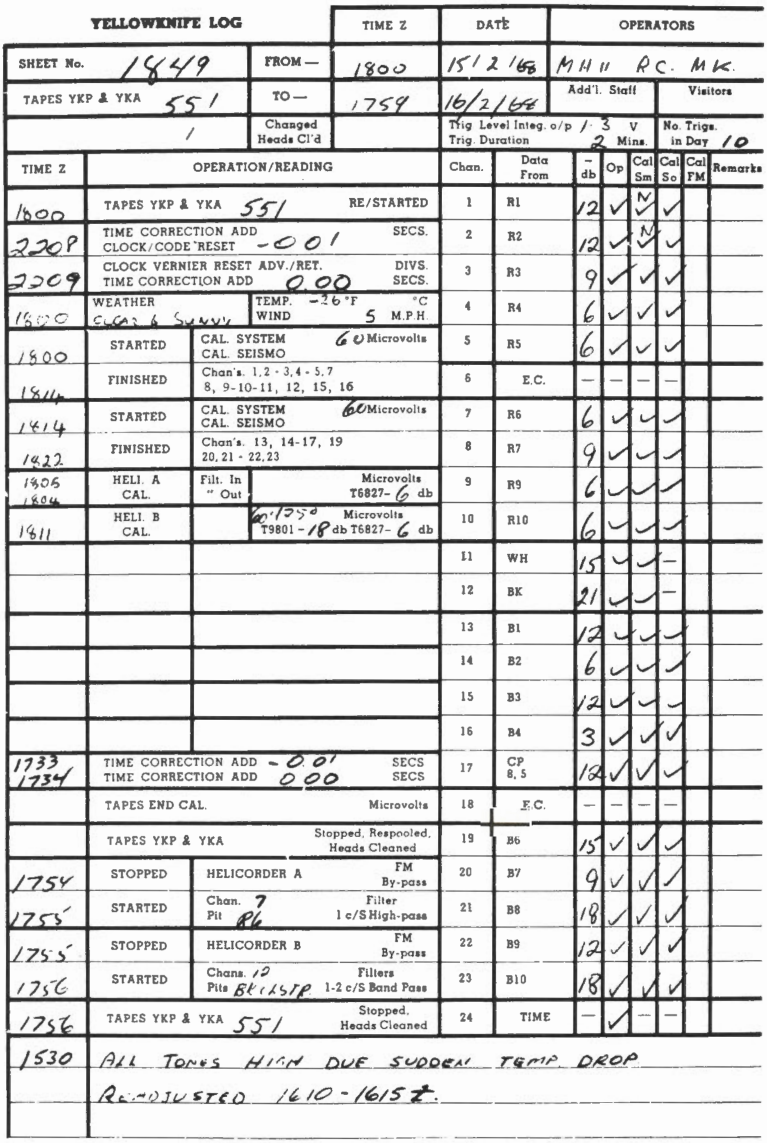
Calibration of all channels is carried out once every day, starting immediately after the recording media change. Each helicorder record thus contains one complete calibration for the particular channel being displayed, and each tape contains three complete calibrations for all channels, once at the start of the tape and twice more at 24-hour intervals thereafter. Just before tape change every three days, a system calibration (see 'System calibration') is carried out on all channels, the calibration pulses appearing on the magnetic tape. The calibration procedure is described as follows (see also Reference 1), and the form illustrated in Figure 1 is filled out as the calibration progresses.

Seismometer calibration

The mass of the Willmore MK II seismometer is lifted by applying 0.5 Vdc across the seismometer coil via a calibration relay, which is activated over the 'calibrate' line of the Spiral-4 cable. A 3-s time delay circuit removes the calibration voltage from the coil and the seismometer mass is allowed to oscillate, virtually undamped. The output voltage, together with the calibrating dc step voltage, is recorded via the normal recording system on the tape and on a 4-channel pen recorder. Each seismometer is calibrated in this manner. Although the actual sensitivity constant is not computed on a daily basis, a visual inspection of the recorded wave form is made. The amplitude of the wave form is usually a reliable indication of the condition of the preamplifier in the vault and very seldom (no case has been recorded in YK) indicates a low-output seismometer. Loss of gain in the preamplifier (60 db nominal) can be compensated for by increasing the gain of the very low frequency (VLF) amplifier in the recording laboratory in 3-db steps. When the range of adjustment falls below 6 db, a field trip is necessary to replace the amplifier at the vault site.

The period of the seismometer, set at 1 s, generally remains constant throughout the year. However, the motion of the mass is occasionally obstructed by

foreign particles. This shows up as a shortening of the response 'trumpet' of the recorded free-swing calibration and a field trip is made to replace the seismometer (see 'Maintenance, Vaults').



YELLOWKNIFE LOG

			TIME Z	DATE	OPERATORS	
SHEET No.	1849	FROM —	1800	15/2/68	MH 11 RC. MK.	
TAPES YKP & YKA	551	TO —	1759	16/2/68	Add'l. Staff	Visitors
	1	Changed Heads Cl'd		Trig Level Integ. o/p 1·3 V Trig. Duration 2 Mins.		No. Trigs. in Day 10

TIME Z	OPERATION/READING		
1800	TAPES YKP & YKA 551 RE/STARTED		
2208	TIME CORRECTION ADD SECS. CLOCK/CODE RESET -001		
2209	CLOCK VERNIER RESET ADV./RET. DIVS. TIME CORRECTION ADD 0.00 SECS.		
1800	WEATHER CLEAR & SUNNY		TEMP. -26 °F °C WIND 5 M.P.H.
1800	STARTED	CAL. SYSTEM 60 Microvolts CAL. SEISMO	
1814	FINISHED	Chan's. 1, 2 - 3, 4 - 5, 7 8, 9-10-11, 12, 15, 16	
1414	STARTED	CAL. SYSTEM 60 Microvolts CAL. SEISMO	
1422	FINISHED	Chan's. 13, 14-17, 19 20, 21 - 22, 23	
1806 1804	HELI. A CAL.	Filt. In " Out	Microvolts T6827- 6 db
1811	HELI. B CAL.		60·1750 Microvolts T9801 - 18 db T6827- 6 db
1733 1734	TIME CORRECTION ADD -0.01 SECS TIME CORRECTION ADD 0.00 SECS		
	TAPES END CAL. Microvolts		
	TAPES YKP & YKA Stopped, Respooled, Heads Cleaned		
1754	STOPPED	HELICORDER A FM By-pass	
1755	STARTED	Chan. 7 Filter Pit R6 1 c/S High-pass	
1755	STOPPED	HELICORDER B FM By-pass	
1756	STARTED	Chans. 12 Filters Pits BK & LSTP 1-2 c/S Band Pass	
1756	TAPES YKP & YKA 551 Stopped, Heads Cleaned		
1530	ALL TONES HIGH DUE SUDDEN TEMP. DROP		
	RE-ADJUSTED 1610-1615 Z.		

Chan.	Data From	– db	Op	Cal Sm	Cal So	Cal FM	Remarks
1	R1	12	✓	N ✓	✓		
2	R2	12	✓	N ✓	✓		
3	R3	9	✓	✓	✓		
4	R4	6	✓	✓	✓		
5	R5	6	✓	✓	✓		
6	E.C.	—	—	—	—		
7	R6	6	✓	✓	✓		
8	R7	9	✓	✓	✓		
9	R9	6	✓	✓	✓		
10	R10	6	✓	✓	✓		
11	WH	15	✓	✓	—		
12	BK	21	✓	✓	—		
13	B1	12	✓	✓	✓		
14	B2	6	✓	✓	✓		
15	B3	12	✓	✓	✓		
16	B4	3	✓	✓	✓		
17	CP 8, 5	12	✓	✓	✓		
18	E.C.	—	—	—	—		
19	B6	15	✓	✓	✓		
20	B7	9	✓	✓	✓		
21	B8	18	✓	✓	✓		
22	B9	12	✓	✓	✓		
23	B10	18	✓	✓	✓		
24	TIME	—	✓	—	—		

Figure 1. Specimen daily log of operating and calibrating conditions on the Yellowknife array.

System calibration

A second relay at the remote site can be activated over the calibration line of the Spiral-4 cable, removing the seismometer coil from the preamplifier input terminals and inserting an input attenuator in its place. This attenuator is capacitively coupled to the calibration lines and allows the operator in the recording laboratory to superimpose a calibrated dc voltage step (usually 60 μ V) on the relay control voltage. The differentiated dc voltage step is then applied to the preamplifier and recovered in the laboratory where it is recorded on magnetic tape through the normal recording system and on a 4-channel pen recorder for visual inspection. Each remote site is treated in this manner.

The operator in the laboratory monitors the output of each seismic channel and adjusts its attenuation in 3-db steps for equal pulse heights (3.3 mm) on the 4-channel pen recorder. Low-gain preamplifiers in the field, requiring high amplification in the laboratory, are replaced when necessary. Common difficulties with field amplifiers, detected by studying the recorded calibration pulses, are loss of gain and imbalance in the matched pair of low-noise input transistors.

As well as the seismometer and system calibrations which are actually recorded on magnetic tape, other routine calibrations are carried out daily as described in the following section.

Recording system calibration

The recording system consists of 2 FM tape decks operating in parallel to produce two simultaneous recordings. Each tape deck records 21 channels of seismic information, one timing channel and two error correction channels. Two helicorder single-channel pen recorders are used to provide a continuous visual record of two selected channels.

Daily calibration of the FM tape system is carried out. The FM modulators are checked for correct centre frequency (270 Hz) and percentage deviation (25% high and 23% low) by applying calibrated dc voltages of +3.79, -3.48 and 0 V corresponding to frequencies of 337.5, 208 and 270 Hz. Lissajous figures are produced on an oscilloscope, comparing the modulation output to crystal-controlled standard frequencies (337.5, 208, 270 Hz). The FM demodulators are checked by the same standard frequencies and the output of each demodulator is measured with a voltmeter. Adjustments of centre frequency, gain and deviation are made when necessary. The 4-channel pen recorder detects any malfunctioning of the FM system by monitoring the replay of calibration signals from the tape. Any faulty modulator or demodulator is replaced or repaired when indicated by the testing program.

The FM tape decks are driven by synchronous motors; hence the frequency of the driving voltage supplied by the inverters must be closely controlled. This has been achieved by synchronizing the inverters to the crystal clock as explained in 'Maintenance, Power'.

The gains of the helicorder amplifiers are usually set to a level which allows the array noise background of the channel being monitored to be just visible. These settings may change from day to day and are recorded in the station log.

Timing system calibration

The timing system essentially consists of a frequency standard and time-code generator with provision for monitoring WWV or CHU standard time broadcasts. Daily calibration procedures consist of comparing the output of the time-code generator at the start of its time frame to the time pulses received from the WWV broadcast at 15 MHz. The generated time code is advanced or retarded by the amount indicated by the calibrated time base of an oscilloscope used to make the time comparison. The time difference usually does not exceed 10 ms over any 24-hour period. Errors greater than 10 ms are corrected and any correction is entered in the station log.

Maintenance of the timing system has been excessive during 1967, sometimes resulting in a complete collapse of reliable record timing. A new time-code generator and associated equipment was installed in the YK array in July 1968. The new system incorporates a precision frequency standard (drift rate $< 1 \times 10^{-9}$ s per day) and a built-in CRT comparator for WWV time checks, and delivers a VELA-uniform time code for recording on magnetic tape. A slow-code timing program providing relay closures at minute intervals, plus additional half-hour, hour and 24-hour identification, records on the helicorders and the standard seismic station records. In addition, the timing system synchronously drives the helicorder motors (60 Hz, 110 V) and also provides 50 Hz synchronization for the three inverters. The installation of this updated timing system is expected to provide a reliable and accurately synchronized time code.

MAINTENANCE

Apart from a few preventive maintenance jobs, most of the maintenance of the array equipment is carried out as a result of faults discovered during daily calibration. There are certain standards that must be maintained in the calibration. If these are not reached, trouble-shooting is immediately started. This section starts with a brief description of the preventive maintenance schedule of the station and then gives a more detailed account of the types of faults that have occurred and the measures that have been taken to deal with them.

Preventive maintenance

There is no rigid schedule for preventive maintenance, since instrumental problems vary with the season. Generally, the winter season (from November to April) is characterized by reliable operation of field instruments. During this period, replacement seismometers are prepared for the field season. Because of earlier experience, special attention is paid to waterproofing all seals. The seismometers are inspected for mechanical damage such as rusty screws and bent spokes, which are replaced when necessary. Period adjustments are made and the sensitivity factor of each seismometer is determined by a mass-lift method suggested by AWRE (J.R. Truscott, technical note). Spare tone-modulated senders are checked and calibrated. Particular attention is paid to balancing the front end of the preamplifier and transistor pairs are closely matched before they are soldered into the circuit. Linearity and gain measurements are made, first under normal room temperature conditions and again after the instrument has been cooled for several hours to approximately 30°F. The frequency and amplitude of the tone oscillator output is checked and adjusted when necessary. Thus, at the start of the field season, the entire stock of spare seismometers and senders is available to replace any inoperative or substandard components in the vaults.

Laboratory instrumentation is maintained per manufacturers' instructions in a regular year-round schedule. Normal maintenance includes mechanical adjustments to the tape decks, adjustment and calibration of the various electronic elements and maintenance of the power supply system.

From time to time, as field trips have to be made, the technicians make a practice of 'meggering' selected cables (see 'Cables'). This test exposes any low resistance paths that exist in the cables or Scotchcast joints, enabling repairs to be made before a fault shows up.

Cables

There are approximately 100 miles of Spiral-4 cable connecting the field instruments to the recording laboratory. All field cables are supported on wooden tripods at a nominal spacing of 100 to 130 feet, the individual cables being tensioned every third or fourth tripod. All of the regular plugs and sockets that were on the 1/4-mile lengths of Spiral-4 cable when it was delivered have been removed and replaced by alternating Scotchcast joints and junction boxes. Thus there is one easily accessible junction box with test points every one-half mile on every cable. When a cable fault occurs, it is possible to isolate it rapidly by carrying out the indicated test procedure at successive junction boxes. In the same way large sections of cable can be shown to contain no faults.

Cable faults may take one of two forms: low resistance leakage between conductors or conductors and shield; and open circuits, i.e., a clear break in any conductor. A leakage fault usually produces noise on the signal lines or the calibration lines, especially when the moisture conditions are high. The fault may not be detected in the winter season when the humidity is very low, but usually causes concern in the spring and fall when the humidity is high. An open-circuit fault causes loss of signal or loss of calibration, is easily detected and requires immediate attention. Both faults are generally caused by lightning damage to the cable, the junction boxes or the Scotchcast joints, but a poorly made Scotchcast joint may allow water to enter and give rise to the first condition. A direct lightning strike on the cable may burn and break it, causing the second condition. A direct lightning strike on a Scotchcast joint may explode the joint or cause arcing between the connectors inside the joint, resulting in a low resistance path. This fault is quite common and is the major cause of cable noise.

When a suspected cable fault is detected during the daily calibration procedure, a field check must be made. The procedure for checking a noisy cable consists of first disconnecting the suspected cable at the laboratory. A junction box is then opened at some convenient point along the cable line and a resistance measurement is made toward the open-ended conductors at the laboratory end using a megger, which produces a high enough voltage to break down any low resistance path and so expose the fault. Repeating these measurements at successive points along the line quickly isolates the fault and the Scotchcast joint or the quarter-mile section of cable is replaced. If the fault is an open circuit, an ohmmeter may be used in either direction from a junction box, the cable pair to be checked having first been shorted at the laboratory end.

When the Scotchcasts were originally installed, the conductors were clamped in pairs in dual Scotchlok connectors. We have determined that many of our noise and attenuation faults have been caused by leakage within an individual dual Scotchlok and have, therefore, used only single Scotchloks in our repair and maintenance program since October 1967. It may be significant that we have not had to replace any of the single Scotchloks to date.

Vaults

The nineteen individual vaults each consist of two hemicylindrical steel sections which are bolted together along flanges on either side of the section to form a vertical cylinder 40 inches in diameter and 20 inches high. A convex steel lid with neoprene gasket is bolted on. The vault itself is set into a pit blasted in the rock, the steel cylinder originally being set in a ring of mastic set into the concrete floor of the pit. The mastic was later cemented over, since it did not prevent leaks as had been intended. Leaks also developed along the vertical bolted seams, most of which have now been welded. The steel lids have always allowed some runoff water and moisture to enter the vaults, since the extreme temperature variations encountered, coupled with the seam welding, have caused some distortion in the cylinders. In fact, vault leakage has been a persistent problem and has caused a certain amount of instrument damage and lost recording time over the years. Originally, the vault electronics were not in sealed containers and frequent repairs were necessary to replace water-damaged components. All electronics packages in all vaults are now contained in sealed and pressurized containers and we have had no major trouble with these. Although the Willmore Mk II seismometer is designed to withstand a 100-foot head of water, imperfect sealing of the rubber O-ring gaskets has occasionally allowed moisture to seep into the seismometer case, resulting in some rusting of screws and spokes, and also peeling of the painted surfaces. It is now standard practice during overhaul of seismometers to apply silicone grease to all gaskets. In addition, screws and spokes are being replaced with noncorroding parts.

On a number of occasions we have opened a vault in May or June for the spring checkup and found a solid block of ice filling the entire vault. The instruments, completely encased in ice, have on some occasions continued to function normally. However, in May of 1967, a total of 54 vault-days of recording were lost because of vault flooding. This rather high outage has been typical of operation during May each year and has necessitated the action described as follows.

Welding of seams and cementing of the bottoms of the vaults have greatly alleviated the seepage problem. However, the accumulation of spring runoff over the vaults and consequent filling of the vaults through the poorly fitting lids have continued to give trouble. Two lines of attack have been taken against this problem: drainage channels were blasted at twelve vault sites in October 1967, in the hope that these would keep runoff from accumulating over the vaults; and a simple 45-gallon oil drum with a tightly fitting lid was cemented inside the R3 vault to see whether it will make an adequate vault, since its extra height will certainly exclude any normal runoff.

RECORD OF SPRING VAULT FLOODING CONDITIONS FOR 1965 to 1968
AT THE YELLOWKNIFE ARRAY

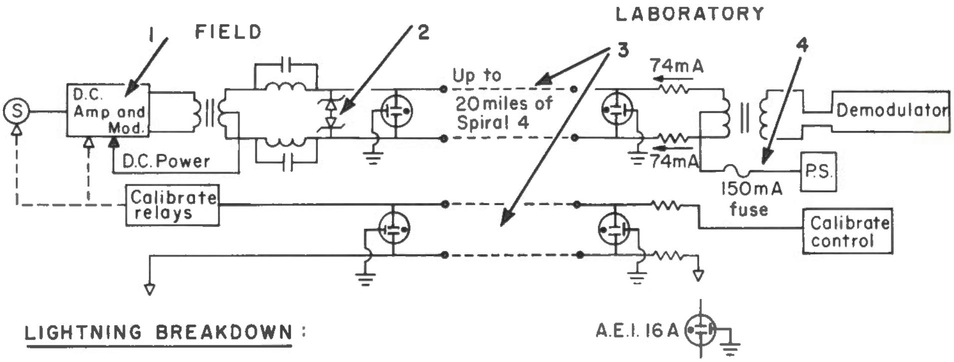
Vault	Spring 1965	Spring 1966	Spring 1967	Channel Blasted	Spring 1968
	(inches)	(inches)	(inches)		(inches)
B1	no record	dry	damp		6 (not welded)
B2	no record	dry	4	x	6 (not welded)
B3	damp	dry	full	x	2 (not welded)
B4	dry	dry	dry		2
B5, R8	damp	full	full	x	2
B6	full	damp	full	x	2
B7	damp	full	full	x	2
B8	no record	full	dry		2 (not welded)
B9	dry	2	2		2
B10	dry	dry	dry		dry
R1	dry	2	dry		2
R2	4	2	full	x	2
R3	1	full	full	x	dry (1/2 in drum)
R4	full	dry	full	x	2
R5	dry	1	dry		2
R6	1	full	full	x	2
R7	dry	full	full	x	2
R9	dry	dry	3	x	2
R10	damp	2	3	x	2

Inspection of the twelve vaults for which drainage channels were blasted indicates that eleven of them are virtually dry (May 1968), the twelfth being one of those with unwelded (therefore leaky) seams. In contrast, nine were full of water or ice in the spring of 1967 and the other three had 3 or 4 inches of water in them. Also, the oil drum in R3 came through the winter in very good shape and was almost completely dry inside. When we have evaluated the effects of spring and summer climatic conditions on the R3 installation, we will be in a better position to decide whether or not the remaining leaky vaults should be treated similarly.

The flooding history of the vaults since 1965 is given in the accompanying table. The 2-inch measurement apparently is an irreducible minimum for most vaults. It is believed to be due to frost accumulating on the inside of the vaults during the winter and melting in the spring. This condensation can be prevented only by heating or sealing the vaults, but the problem is not considered sufficiently serious at this time to warrant such action.

Instruments

Maintenance of instruments may be divided into two parts: routine maintenance and repair. The former has been discussed at the beginning of this section. The types of instrument failure that occur in both the laboratory and the field remain to be considered.



LIGHTNING BREAKDOWN:

1. Any transistor in the D.C. amplifier or modulator.
2. Zener diodes across signal pair.
3. Cable and junctions.
4. Fuse in D.C. power supply — 148 mA normal supply current - 150 mA fuses. Any damage demanding > 150 mA total blows fuse.

Figure 2. Areas of lightning damage in the Yellowknife array cables and electronics.

Perhaps the most extensive (and expensive in terms of recording time) type of breakdown that has occurred has been that caused by lightning strikes. Whereas direct lightning strikes on the cables may damage the conductors or Scotchcasts as well as the electronics, even a near strike may cause induced currents in the lines which can damage the electronics. In each vault there are two AEI-16A three-electrode sparkgaps, placed across the signal and calibration lines as shown in Figure 2. The breakdown voltage of the AEI-16A is 150 V. No damage from lightning strikes has occurred in the calibration circuitry since the lines are connected only to fairly rugged relays. However, the signal lines are connected directly to the output transformer of the vault electronics package and, to provide additional protection for these electronics, back-to-back Zener diodes are placed across the signal lines. In spite of these measures, the protection circuitry has often failed to perform adequately.

Lightning surges may destroy the Zener diodes and may also be transmitted through the output transformer to the vault electronics, destroying the matched transistors or, in some cases, all the transistors in the preamplifier. In either case, a trip to the vault in question is necessary, usually with a replacement electronics package.

At the laboratory end, a pair of AEI-16A's is connected across the Spiral-4 conductors as in the vaults to protect the laboratory equipment from lightning damage. During severe thunderstorms, these sparkgaps sometimes fail to protect the signal circuitry, but the most common fault is then a blown fuse in the dc supply feeding the vault electronics via the signal lines. Here again the AEI-16A has provided adequate protection to the calibration circuitry as there have been no breakdowns.

Station log sheets for 1966 and 1967 record an average loss of 89 vault-days per year due to lightning damage. This includes both cable and instrument damage and occurred from June to August each year. Several large storms each year account for most of the damage, with most of the array being put out of action at once.

During June, July and August of 1966, a grounded skywire was erected over the cable bundle on the Blue line south of the Mackenzie Highway, i.e., from B1 to midway between B3 and B4. At the same time, wooden insulators were inserted into the guywires that have been used on the tripods in various areas (such as rounding a corner). It was hoped that these measures would enable us to assess the feasibility of protecting the entire array while providing a measure of protection to the south end of the Blue line. The technicians are of the opinion that damage has been definitely decreased over this portion of the array; however, due to lack of detail in reporting, it has not been possible to separate the statistics on lightning damage for this part of the array from the statistics for the array as a whole. Also, a lightning strike on an unprotected part of the array could cause damage in a protected part. At any rate, the guywire insulators and skywire have not adversely affected this part of the array in any noticeable way.

Power

Power for the Yellowknife area is generated at two hydroelectric stations of the Northern Canada Power Commission on the Snare River some 90 miles northwest of the town. A 115 KV, 3-phase, 60 Hz line carries the power to the Northern Canada terminal, some 5 miles outside the town, where it is turned over to the 34 KV lines of the Consolidated Mining and Smelting Co., Ltd., for further transmission to Yellowknife. There the Plains Western Natural Gas Company assumes responsibility for power distribution to the town and surrounding area. The array building receives its power from a 4160 V 3-phase line which runs to the Department of Transport installations at and near the airport. Obviously the array can be affected by a variety of breakdowns between the generating plants and the final entry to the building. With a few notable exceptions, these power failures have been very short, from a few minutes to perhaps half an hour. When a major breakdown occurs, or any situation involving a longer shutdown, the technicians are notified by the power company and start up the standby diesel power plant.

Another problem which has arisen occasionally has been the presence of large voltage surges on the mains. On several occasions this has caused the destruction of a series of large capacitors connected across the input to the inverters to protect against this very situation. There are also frequent frequency shifts in the input power, down to 58 or up to 62 Hz, but these are, of course, removed by the synchronization of the inverters.

As well as loss of mains power, we have experienced some difficulties with the power conversion system in the control centre. The power supplied to the tape decks must be constant in frequency so that they may be driven at constant speed. An internal oscillator in the inverters supplies a synchronizing pulse to the switching silicon control rectifiers (SCRs), but the resultant 50 Hz output has not been reliable enough for our purposes. Since provision is made for an external synchronizing pulse to be used, we have built circuitry to make use of the 50 Hz output of the crystal-controlled clock in the laboratory. Another reason for requiring such close frequency control is that, if the switching of the SCR power rectifiers is not done in synchronism for each half cycle of delivered output power, an overload can develop which will destroy one or all of the SCRs. This has been one of our most vexing problems, but since our synchronization efforts have now succeeded, our tape deck speeds are stable and no SCR breakdowns are occurring.

Travel

The area in which the array is situated is composed of Precambrian granite with a scattering of diabase dykes and joints. Locally, the dykes have eroded away, leaving small valleys, some with nearly vertical walls. The jointing system also contributes to the general roughness of the terrain. Drainage is very poor, and muskeg interspersed with small lakes covers from 30% (in the north) to 50% (in the south) of the surface. The rest is mainly bare rock with a good deal of scrub growth. During the winter, travel by tracked vehicle is easy since the lakes and muskeg are frozen and the rocks are covered by snow. The only problems are the often extreme cold, the short days and the possibility of vehicle breakdown in a remote location. However, from May to November travel must be mainly over the bare rock areas, often necessitating detours of considerable length to avoid lakes or very wet muskeg. The Mackenzie Highway crosses the south and west arms of the array, providing convenient access to approximately 60% of the vaults, although off-highway travel must still be by tracked vehicle. The north arm extends some 10 miles north of the highway and the terrain is so difficult that a full work-day is required in most seasons just to make the return trip in the tracked vehicle. If work is to be done only at or near one of the farthest north vaults, a charter trip by float plane to a nearby lake is usually made. If cable or instrument work must be done between B6 and B10, two men make the trip in a tracked vehicle. Several trips on successive days may be necessary; we have made a general practice of not staying overnight in the bush. In this case the tracked vehicle is usually left in the bush overnight and the technicians travel back and forth by chartered float plane.

From April 1963 to April 1968, the principal means of transportation on the array lines was a Bombardier Muskeg Tractor. This tracked vehicle performed yeoman service, but the heavy demands made on it, especially the pounding it received when operating in the bare rock areas, had rendered it unsuitable for further service by the end of 1967. During that winter, we were virtually without transport: the few maintenance trips that had to be made out to remote vaults were made in rented vehicles.

In April 1968, we took delivery of a new FlexTrack Model 676. This vehicle possesses several features which are missing from the Bombardier and which we expect will add to its life and utility on the array. These include a walking-beam track suspension, hydraulically assisted steering and a wide, flat, uncluttered rear deck. We have been very pleased with the first few months of operation but have no idea yet how it will stand up to varying conditions throughout the year, or what the maintenance costs will be.

From what has been said, it is apparent that a great deal of the time involved in field maintenance is actually spent on travel. Hence, good tracked vehicle transportation must always be available.

ANALYSIS OF BREAKDOWN TIME

All of the various types of breakdown that we have encountered during the first 5 1/2 years of operation of the Yellowknife array have been described and discussed in the preceding paragraphs. This section will present actual numerical data concerning breakdown time and a following section will attempt to derive conclusions which may be applicable to future operations. Figures 3 and 4 present a month-by-month summary, respectively, of noisy conditions and lost data. In two typical years, operate and calibrate conditions were noisy for 11.6% of the time. In addition, the average data loss suffered was 4.0% during the 8-month period, September to April inclusive, and 10.9% during the four difficult months, May to August, for an average annual date loss of 6.3%.

Lightning damage

Station log sheets record an average loss of 89 vault-days per year due to lightning damage, for a data loss of 1.3%. Virtually all of this damage occurred during the months of June, July and August, with the preponderance being in July. All types of damage, including cables and instruments, are included in these figures, since it has not been possible to separate them. Station logs now being kept will enable the separation of these elements. In addition to lost data (Figure 4, i.e., no signal being received or the signal entirely obscured by noise spikes) many cases of noisy or missing calibration (Figure 3) are also reported in the lightning season. While the noisy calibrations are usually due to moisture somewhere in the system, or subsequent lightning damage, most of the dead calibration lines during the lightning season probably are caused by lightning damage alone. Damage due to lightning has never extended to all nineteen channels at once, so that the array cannot be said to have been put completely out of action. However, there have been occasions lasting a day or two when 70 to 80% of the array has been out.

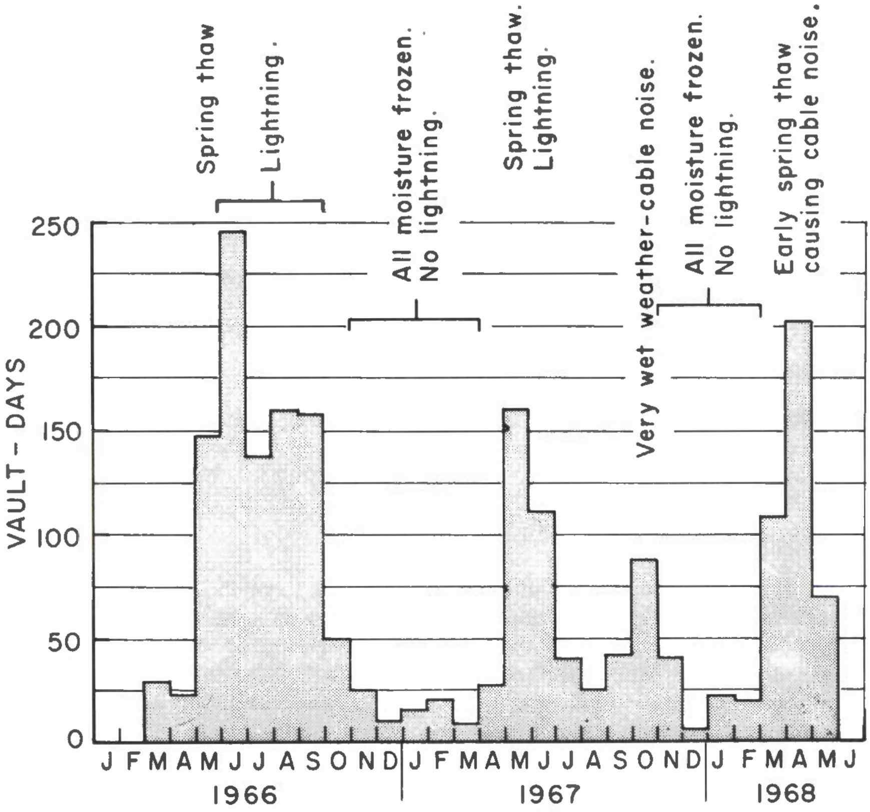


Figure 3. Noisy operating and calibrating conditions at the Yellowknife array, March 1966 to May 1968.

Flooding of vaults

A total of 54 vault-days (9.5%) were lost in the month of May 1967 due to flooding of vaults during spring breakup. No exact data for 1966 are available, but the situation apparently was not quite as bad, since only 2/3 as many vaults as in 1967 were found to be flooded when they were first opened in May. Thus the loss of data due to this cause has been prorated in Figure 4. The high calibration noise levels that began in May and persisted throughout June were probably due to dampness in Scotchcast joints rather than in the vault electronics. The flooding of vaults is completely limited to the month of May each year, although minor amounts of water have been taken from the odd vault later in the summer, especially after a heavy rainstorm. Since the seams were welded and extra concrete poured around selected vaults, this problem has virtually disappeared. Furthermore, the blasting of drainage channels has ensured that no further leakage can occur around the vault lids.

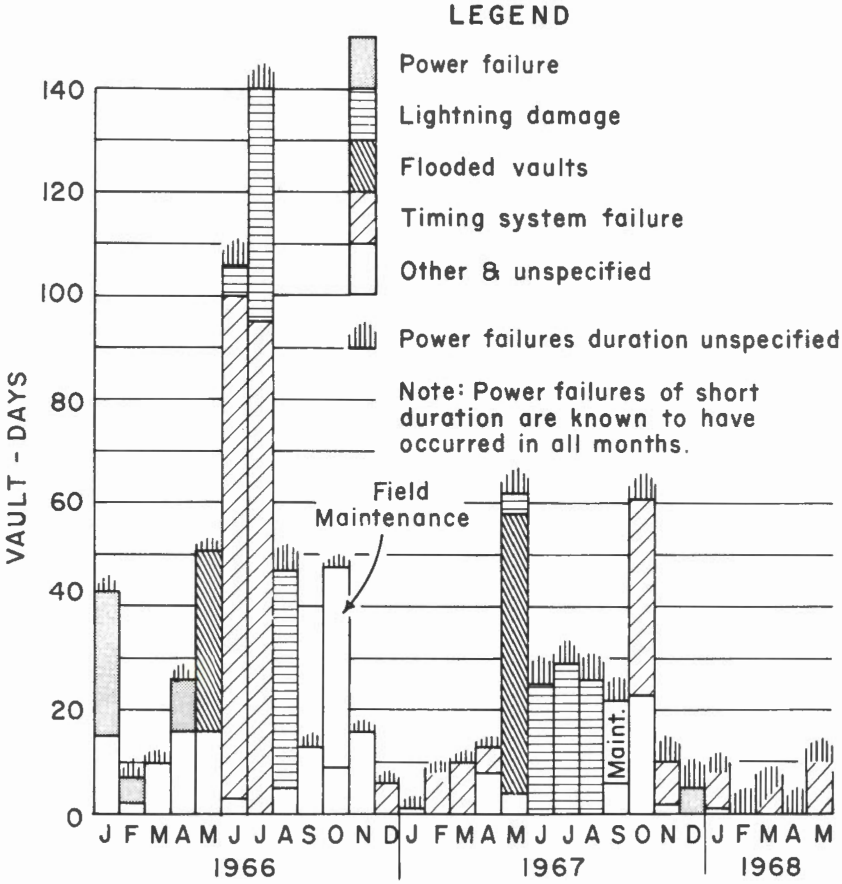


Figure 4. Loss of data at the Yellowknife array in vault-days, January 1966 to May 1968.

A record of spring flooding conditions in the vaults is given in the table on page 9 for years 1965 to 1968. Once more it may be said that the array has never been entirely out of action because of vault flooding.

Time coding system

The entire system was effectively out of operation for approximately 16 days (1.8%) in the 29 months for which detailed records are available, due to the failure of the time code system. The details of failure have varied somewhat; the most persistent has been trouble in the time code generator itself, which consists of a series of binary counting networks which convert the basic 10-Hz signal from the primary clock into the coded 1-second and 30-second marks of the fast and slow time codes (Keen, et al., 1965). The other major source of trouble has been the master clock. This is driven by a temperature-controlled crystal (153.6 KHz) and the oven, thermistors and other circuitry involved have given a good deal of trouble. A third and somewhat minor source of trouble has been the binary readout circuitry.

As mentioned previously, a completely new off-the-shelf timing system was installed in July 1968.

Power failures

In the 5 1/2 years of operation of the Yellowknife array, no month has been completely free of power failures. In most cases short-duration power failures have not been recorded on the station log sheets, since the battery banks have been able to maintain continuous operation. In some longer power interruptions, it has been possible to switch to standby diesel operation with no loss of data, and these instances are also not recorded. Figure 4, then, reflects only the power failures that actually caused data loss because they occurred when the station was unattended, continued beyond the capacity of the battery banks or caused some equipment damage.

It is obvious from Figure 4 that no number can be presented to cover total data loss resulting from power failures. However, a reasonable estimate may be made, based partly on incomplete written reports and partly on current experience.

1. A total of 44 vault-days were lost in January, February and April 1966, according to reports.

2. Current experience suggests that the mention of 'numerous short power failures', or words to that effect, in reports means that an average of approximately 5 vault-days were lost during the month for this reason.

3. Current experience also suggests that where no mention has been made of power failures, an average of approximately 2 vault-days were lost during the month for this reason.

Using these figures, the total data loss for the 29-month period comes to 129 vault-days, or 4.4 vault-days per month. This figure is probably on the low side; rounding it up to 5 vault-days per month would mean that the array was completely out of action for an average of approximately 12 to 15 minutes per day during the period under review because of line power failures. This figure is considered to be correct, at least within a factor of 2, and gives some indication of the reliability of the power supply at this remote location. With any requirement for continuous monitoring, such a data loss would be unacceptable.

CONCLUSIONS

As a result of the preparation of this report, certain changes are being made in reporting format and procedure. The format used in the past has not permitted types of failure to be analyzed in sufficient depth for detailed recommendations to be made on instrumental and operational changes. The following general statements will, therefore, outline steps that have been proposed or are actually being implemented to deal with the various problems.

1. The problems of lightning damage to cables and noise caused by moisture in Scotchloks, etc., can all be solved by doing away with cable data transmission altogether and installing a complete FM telemetering network. The only problems which would then exist, outside of routine maintenance of the extra electronic equipment, would be the power supply to the field electronics and lightning protection for the transmitting and receiving equipment. Lightning protection would be much simpler than at present, since it would involve only a few whip antennas instead of many miles of overhead cables. Power could be supplied by batteries in the individual vaults, by thermoelectric generators or, as at present, by transmitting power from the laboratory on the existing Spiral-4 cables.

Equipment has been ordered and a special vault has been constructed near R 4 to test the telemetering concept. The new vault will contain one long- and one short-period seismometer (Geotech S-11 and Willmore Mk II) and power will be supplied at least initially by a thermoelectric generator. The data will be transmitted in FM form and will be recorded in the laboratory on a 7-channel IRIG FM tape deck. The entire system is expected to be ready for operation by December 1968, and a direct comparison of the quality of the data obtained via the telemetry link and via cables from the adjacent array vaults will then begin. The new vault has been blasted into the side of a 30-foot granite cliff at mile 12 west of the laboratory on the Mackenzie Highway and will be equipped with a double weatherproof door. As well as testing the telemetering of short-period data, the installation will enable us to move toward assessing the feasibility of a long-period array, since we will also record on the same tape data from a long-period seismometer in the standard network vault near the laboratory.

2. The problem of vault flooding is believed to have been solved by welding the vertical seams of the metal liners, by pouring extra concrete around the bases of certain liners, and by providing proper drainage channels to take care of the heavy spring runoff. It is anticipated that B1 and B2 will be welded, or otherwise made waterproof, during the 1968 summer season. The authors believe that a better solution to the leaking vault problem, in a new installation, would be to use a section of concrete sewer pipe, set in concrete, and firmly grouted into the surrounding wall rock of the pit. A tightly fitting lid of light-weight material with a circular clamp to hold it in place would complete the installation, the whole being covered with bags of wood shavings, as at present, for thermal insulation.

3. The serious problem of power failures can be met only by setting up a self-contained power generating station. For the present Yellowknife Array System, this would involve the acquisition of two 15-KVA diesel generators, preferably with a complete switchover to North American power standards (60 Hz, 110/220 V). One member of the station staff would also have to be an expert in diesel-electric maintenance. As long as the Yellowknife array is considered to be only part of an experiment, there is little point in going to the expense and considerable inconvenience of making the change.

4. Due to the physical size of the Yellowknife array and the very difficult terrain on which it is built, access to some of the more distant vaults has sometimes been denied to us for as much as a month at a time during spring breakup. For assurance of year-round access to all vaults on the present array, a helicopter would be necessary, at least from the end of March to mid-June each year. Alternatively, a limited-access road building program and the relocation of some vaults could render all vaults accessible at all times, but the expense of this is not justified at the present time. In any case, reliable transportation is of prime importance on the Yellowknife array.

5. The other problems that we have had during the past 5 1/2 years have been concerned almost entirely with instrumentation. The solution for this type of problem is to have sufficient stores on hand so that any particular unit can be replaced immediately a malfunction is detected, and repairs made off-line. This is, in fact, the situation at present with the exception of a very few units, such as the inverters. When a breakdown occurs at some point remote from the laboratory, however, there is also the problem of getting at the fault, as mentioned in paragraph 4.

To conclude, flooding and time generation problems either can be, or have been, cured. These measures should reduce lost data to about 8% in the worst four months (May to August) and to about 2% in the remaining eight months. Further appreciable reduction seems impossible without expensive road building, conversion to telemetering and local power generation.

ACKNOWLEDGMENTS

The authors wish to thank Mr. M.M. Kuntz, the present O.I.C. of the Yellowknife Seismic Station, for supplying and clarifying many of the technical details that made this paper possible, and for his helpful comments after reading the first draft; and Dr. K. Whitham, Chief of the Division of Seismology, for permission to publish this paper.

The cooperation of AWRE staff members in this project is gratefully acknowledged, particularly that of J. Montgomery, D.C. Platt and W.M.H. Mowat.

REFERENCES

Keen, C.G., J. Montgomery, W.M.H. Mowat, J.E. Mullard and D.C. Platt, 1965 British Seismometer Array Recording Systems. Radio and Electronic Engineer, 30(5):297-306.

Manchee, E.B., and H. Somers, 1966. The Yellowknife Seismological Array, Pub. Dom. Obs. Ottawa, 32:69-84.

Weichert, D.H., E.B. Manchee, and K. Whitham, 1967. Digital Experiments at Twice Real Time Speed on the Capabilities of the Yellowknife Seismic Array, Geophys. J.R. Astr. Soc., 13:277-295.