Lawrence Livermore Laboratory

MEASURED AIR OVERPRESSURES, SOIL-PARTICLE PRESSURES, AND SLUMPS DURING THE
PRE-ASIAGO U2Ar STEMMING EXPERIMENT

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SL MPS DURING THE PRE-ASIAGO U2Ar STEMMING EXPERIMENT

ABSTRACT

On November 15, 1976, Lawrence Livermore Laboratory completed its first comprehensive stemming experiment for measuring downhole parameters while varying fill material and rate. A computer code is being developed for stemming operations, and this experiment was designed to measure parameters under different stemming conditions so the code could be verified and modified. The experiment was conducted in the lower half of a steel-cased, 4-ft-diam, 2000-ft-deep hole at Nevada Test Site. The two stemming materials used in the experiment, Overton sand and LLL II mix, were tested at three fill rates. Significant results of this experiment included successful measurement of downhole air overpressures, vertical and horizontal soil-particle pressures, and temperature. Vertical soil-particle pressures were higher than expected. All surface measurements were valid. The slump-displacement measurements system provided a timing mark to indicate the occurrence of a slump. A major slump occurred on the third day of stemming; a minor slump occurred on the fourth day.

INTRODUCTION

A computer code being developed by S. C. Cowin was the basis for Lawrence Livermore Laboratory's (LLL's) first comprehensive stemming experiment in hole U2Ar at the Nevada Test Site (NTS).¹ This experiment was defined on September 20, 1976, and was completed 8 wk later on November 15. It was designed to measure various parameters using different stemming materials and fill rates so the code could be verified and modified.

Stemming can be defined as backfilling a hole in which a device has been placed to prevent leakage of radioactive materials or gases to the surface. Current LLL stemming philosophy and procedures are thoroughly detailed in a recent report.²

STEMMING EXPERIMENT

The U2Ar stemming experiment was performed in the lower half of a steel-cased, 4-ft-diam, 2000-ft-deep hole (U2Ar) at NTS. Six instrumentation canisters were placed downhole at various intervals on a wire rope to measure air overpressure, vertical and horizontal soil-particle pressures, temperature, and slump displacement (Fig. 1). The transducers measured overpressure and soil-particle pressures independent of each other so that measurements of air overpressure did not include soil-particle pressures, and measurements of soil-particle pressures did not include atmospheric pressure or air overpressure.

Two stemming materials, Overton sand and LLL II mix, were tested at three fill rates. Each day for five consecutive days hole U2Ar was filled with either of the stemming materials at one of the fill rates.

The stemming experiment produced some significant results. Downhole air overpressures, vertical and horizontal soil-particle pressures, and temperature were successfully measured. Vertical soil-particle pressures were higher than expected. Two of the three vertical soil gauges bottomed out against their 7- to 9-psi-range overload stops. All surface measurements were valid. These included measurements of air and hopper sand temperature, air pressure, force on the wire rope, and the D-cable height and total weight of the fill materials in the hole. The slump-displacement measurements system provided no useful data other than a timing mark to indicate the occurrence of a slump. A major slump occurred at 4157 min on the evening of the third day of stemming; this was almost 7 h after stemming ended for the day. D-cable measurements indicated a 16-ft slump. A 2-ft minor slump occurred at 5260 min at 3:40 PM on the fourth day of stemming, or 16 min after stemming had ended.

The experiment matrix of Table 1 details by channel number the depths, stemming materials and rates, canister locations, and parameters measured at each canister location.

DOWNHOLE CANISTER DESIGN

The standard stemming release canister³ was modified into a backfill measurement canister (Fig. 2). The principal change in canister design was the incorporation of a large diameter midsection to house the transducers.

Table 1. Experiment matrix for U2Ar stemming experiment.^a

Stemming material	Depth of stemming material, ft	Stemming rate, ton/h (fpm)	Stemming day, 1976	Location and depth, ft	D-cable depth when Holec cutter fired, ft	Canister channel number				
						Air over-pressure, psi	Horizontal particle pressure, psi	Vertical particle pressure, psi	Temperature, °F	Slump displacement, ft
Overton sand	1134-1234	25 (0.7)	Friday, November 12	Canister 6 1184	1179	232	233	234	—	235
LLL II mix	1234-1464	25 (0.7)	Thursday, November 11	Canister 5 1349	1344	228	229	—	230	231
	1464-1694	50 (1.4)	Wednesday, November 10	Canister 4 1579	1574	224	225	226	—	227
	1694-1924	100 (2.9)	Tuesday, November 9	Canister 3 1809	1805	220	221	—	222	223
Overton sand	1924-2007	100 (2.9)	Monday, November 8	Canister 2 1970	1965	216	217	218	—	219
				Canister 1 1997	—	213	214	—	215	—

^aCanisters are arranged in descending order according to their relative positions on the wire rope.

The nickel temperature sensor and the air overpressure, horizontal soil-particle pressure, and slump-displacement transducers were mounted in this midsection; they will be discussed in detail later in this report. Canister 4 (Fig. 3) was representative of the modified design.

Six standoff fins were attached to the top plate of the midsection. These fins were added to keep the horizontal soil gauge at least 6 in. from the 4-ft-diam hole liner. The first sandpile calibration test indicated the 6-in. distance was probably inadequate. As a result, extensions were bolted on the fins to keep the horizontal soil gauge at least 12 in. from the liner (Figs. 2 and 3).

An explosive cable cutter (Holex Model 2802 Guillotine) was used to cut a wire cable. This released the slump-displacement transducer anchor (Fig. 3) shortly after fill material had just covered the canister.

A vertical soil-particle pressure transducer (Fig. 3) was mounted on a plate bolted to the wire rope from which the canister hung. The plate was designed so that the soil gauge was aligned to measure almost perfectly vertical despite the large moment on the rope due to canister weight.

MEASUREMENTS SYSTEM

The measurements system (Fig. 4) consisted of downhole canister and surface transducers, cables from the canisters and surface transducers to Trailer T-920, and the B & F signal-conditioning and digital-data-acquisition system. The downhole canister transducers included those used to measure air overpressure, vertical and horizontal soil-particle pressure (soil gauges), temperature, and slump displacement. Surface transducers included EG&G and LLL air and hopper sand temperature, LLL air pressure, force on the wire rope, D-cable height of the top of the fill, and the total weight of fill materials in the hole.

Measurements system parameters are summarized in Table 2. Note the error band listed is for the transducer only; it does not include temperature and other extraneous effects on the transducer or errors from the rest of the measurements system. A more detailed examination of the measurements system can be found in the error analysis section.

Suppliers rarely stock transducers; most are fabricated after receipt of order. Delivery normally takes 8 to 16 wk. Only 3 wk were available between the first design meeting for the U2Ar experiment and the start of

Fig. 3. View of Canister 4 just before it was sent downhole.

Fig. 4. Block diagram of measurements system.

Table 2. Instrumentation summary.

Channel	Transducer location	Measured parameter	Manufacturer/model/serial number	Full-scale range	Error band, % full scale ^a
207	Surface	Air temperature	Micro-Measurements/STG-50	100°F	0.3°F
208		Air pressure	Taber/2215/761073	15 psia	0.03 psi
209		Temperature of fill	RdF/21-A-11-D-6-A-180-B	100°F	0.3°F
210		Total weight of fill	—	—	—
211	Downhole	Weight of fill (D-cable)	—	—	—
212	Surface	Force on wire rope	—	—	—
232	Canister 6 ^b	Air overpressure	Tyco/AB/51446	25 psia	0.085 psi
233		Horizontal particle pressure	Lebow/3397/1197	5.3 psi	0.002 psi
234		Vertical particle pressure	Lebow/3108-100/536	5.3 psi	0.002 psi
235		Slump displacement	Celeco/PT-101-250A/964755	20 ft	0.03 ft
228	Canister 5	Air overpressure	Tyco/AB/51407	25 psia	0.103 psi
229		Horizontal particle pressure	Lebow/3108/503	5.3 psi	0.002 psi
230		Temperature	Micro-Measurements/STG-50	100°F	0.3°F
231		Slump displacement	Celeco/PT-101-250A/964757	20 ft	0.02 ft
224	Canister 4	Air overpressure	Tyco/AB/51431	25 psia	0.088 psi
225		Horizontal particle pressure	Lebow/3397/1199	5.3 psi	0.002 psi
226		Vertical particle pressure	Lebow/3397/916	5.3 psi	0.002 psi
227		Slump displacement	Celeco/PT-101-250A/964753	20 ft	0.02 ft
220	Canister 3	Air overpressure	Tyco/AB/51434	25 psia	0.063 psi
221		Horizontal particle pressure	Lebow/3108-50/1732-2	2.65 psi	0.002 psi
222		Temperature	Micro-Measurements/STG-50	100°F	0.3°F
223		Slump displacement	Celeco/PT-101-250A/964754	20 ft	0.02 ft
216	Canister 2	Air overpressure	Tyco/AB/51433	25 psia	0.1 psi
217		Horizontal particle pressure	Lebow/3108-50/920	2.65 psi	0.002 psi
218		Vertical particle pressure	Lebow/3108/530	5.3 psi	0.002 psi
219		Slump displacement	Celeco/PT-101-250A/964756	20 ft	0.02 ft
213	Canister 1	Air overpressure	Tyco/AB/51427	25 psia	0.11 psi
214		Horizontal particle pressure	Lebow/3108-101/337	2.65 psi	0.002 psi
215		Temperature	Micro-Measurements/STG-50	100°F	0.3°F

^aThis error band excludes temperature effects and is for the transducer only.

^bCanisters are arranged in descending order according to their relative positions on the wire rope.

canister assembly. This limited transducer selection to those transducers in stock at LLL and EG&G. The only exceptions were the displacement potentiometers and hopper sand thermometer delivered 2 wk after our order was placed.

DOWNHOLE CANISTER TRANSDUCERS

Air Overpressures

Tyco Model A3 absolute-pressure transducers were used to measure air overpressure at each canister location. These semiconductor, strain-gauge based transducers were selected because LLL and EG&G stock them specifically for air overpressure measurements during stemming. The 25-psia full-range transducers were referenced to 0 psia. The pretest estimate of air overpressure was about 7 psi. The absolute pressure to the transducers consisted of the 12-psia atmospheric pressure at WFS plus the 7-psi overpressure for a total of 19 psia, which is within the range of the Tyco transducers.

Metal-screen and open-celled foam rubber filters kept sand and fly ash out of the diaphragm area of the pressure transducers, but allowed air to pass. The metal-screen filter is shown on the midsection wall in Fig. 5. A foam rubber filter was bonded over the metal-screen filter (Fig. 6). Bonding was done along the outside edge of the foam rubber.

The back of a Tyco air overpressure transducer adaptor is shown in Fig. 7.

Soil-Particle Pressures

The most likely vertical soil-particle pressures were predicted to be 3 psi, with a maximum of 15 psi possible. Horizontal soil-particle pressures were predicted to be 1-1/2 psi, with a maximum of 7 psi possible.

A 4.9-in.-diam metal collector plate converted soil pressure into a force on the force transducer (Figs. 7-9). The rubber diaphragm over the collector plate and tubular housing kept sand from getting between them and interfering with the free motion of the collector plate (Fig. 10).

Metal-screen filters and small-pore, open-celled filters of foam rubber (Fig. 11) kept sand and fly ash out of the housing, but allowed pressure to equalize on both sides of the collector plate so particle pressures independent of air overpressures could be measured. Metal-screen filters alone

Fig. 5. Metal-screen filter for air
overpressure transducer.

Fig. 6. Foam rubber air filter for
air overpressure transducer in Can-
ister 5.

Fig. 7. View of canister midsection showing particle pressure transducer on front wall and air over-pressure transducer on rear wall.

Fig. 8. Detail of particle pressure transducer (soil gauge). Source: EG&G.

Fig. 9. Particle pressure transducer overload stops being adjusted.

Fig. 10. View of canister midsection showing particle pressure transducer on front wall and slump-displacement potentiometer (#2) on center bottom.

Fig. 11. Foam rubber air filters for horizontal soil-particle pressure transducer in Canister 2.

were not adequate to screen out fill material; Overton sand dribbled through these filters in preliminary tests.

The conventional 50- and 100-lb Lebow force transducers used in the U2Ar experiment were from stock. They are designed so that forces up to 150% of full scale do not affect their performance. These transducers use metal-foil strain gauges as sensing elements. Soil gauges using 50- and 100-lb load cells have full-scale pressure ranges of 2.65 and 5.3 psi, respectively.

Full-scale displacement of the Lebow force transducers is about 0.003 in. Stops were placed under the collector plate to limit its permissible displacement to about 0.004 to 0.005 in., as measured by feeler gauges. This allowed the soil gauges to measure pressures up to the limit of the stops, or approximately 133 to 167% of full scale. The purpose of these stops was to protect the load cell from unexpectedly high soil pressures.

The soil gauges used in the experiment were field-calibrated with a 42-lb lead brick after assembly and again just before going downhole.

Canister Temperature

Nickel temperature sensors (Micro-Measurements STG-50) were mounted on an aluminum plate. A equal-arm completion bridge of the nickel sensor was completed on this plate and was trimmed so there was no output from the bridge at 75°F. This plate was then screwed to the top plate of the canister mid-section (Fig. 12) using silicone grease to increase thermal coupling between the two plates. Response time was on the order of minutes.

Slump Displacement

A Celesco rotary potentiometer, Model PT-101-250A, with a 250-in. range was selected as the basic sensor in the slump-displacement measurements system (Fig. 13). This potentiometer was firmly attached to the canister; the base plate of the potentiometer is marked #2 in Fig. 10. The potentiometer cable was affixed to a sand anchor that was detached from the canister at the appropriate time by firing a Horex cutter. If a slump occurred, the anchor would drop with the fill material; this would pull the cable and rotate the potentiometer to measure total drop.

A special teflon brake was fabricated to prevent the potentiometer reel from overrunning and snarling should the anchor suddenly stop. This brake was tested at EG&C North Las Vegas by dropping the anchor from various heights up

Fig. 12. Nickel temperature sensor and equal-arm completion bridge.

Fig. 13. Slump-displacement potentiometer.

to the full 250 in. onto a concrete floor. In all cases, the brake stopped the potentiometer reel within 1 in. after the anchor stopped.

The potentiometer cable exited the canister through a nylon alignment bushing. This bushing was sealed with a small amount of silicone rubber before the canisters were sent downhole. The sealer kept sand and fly ash out of the potentiometer until a slump occurred.

Figure 14 is a bottom view of the canister. It shows the threaded cable to the Holec cutter and the potentiometer cable connection; Fig. 3 shows the anchor attached to the Holec cutter.

SURFACE TRANSDUCERS

EG&G Air and Hopper Sand Temperature

Both the EG&G air and hopper sand temperature systems measured temperature using a thermistor and an EG&G conditioning circuit. Their nonlinear output was converted to temperature by use of a table. The air thermometer was mounted in the shade under Trailer T-920. The thermometer in the hopper was a sheathed unit that protruded into the sand flow.

LLL Air Temperature

Air temperature was measured by a nickel sensor (Micro-Measurements STG-50). This sensor was mounted on an aluminum block and suspended in the shade midway between the floor of Trailer T-920 and the ground. Its design features were identical to those of the nickel sensors in the canisters. The EG&G and LLL air thermometers agreed to within 1°F.

LLL Hopper Sand Temperature

Hopper sand temperature was measured with a sheathed platinum resistance thermometer, RdF Model 21-A-11-D-6-A-180-B. This 1/4-in.-diam sensor protruded about 3 in. into the hopper. It had a resistance of 100 Ω at 32°F. An equal-arm completion bridge, prebalanced to zero output at 75°F, was mounted on the hopper framework. The EG&G and LLL hopper sand thermometers agreed to within 1°F.

LLL Air Pressure

A Taber Model 2215 absolute-pressure transducer with a 15-psia range measured air pressure. This transducer was suspended midway between the floor of Trailer T-920 and the ground.

Fig. 14. Bottom view of backfill measurement canister with anchor removed.

Force on the Wire Rope

A BLH 20 000-lb force transducer measured force on the wire rope. The force data enabled monitoring and adjustment of tension during stemming. A sudden increase in wire rope tension during a slump is a sensitive indicator of such a slump.

The BLH force transducer was powered by a constant voltage source. Output from the force transducer was recorded on the B & F recording system.

D-Cable Height of Stemming Material

The D-cable system used time-domain reflectometry to measure distance between the top of the fill material in the hole and the surface. Calibration markers were placed along the D-cable at selected depths to calibrate the system. Depth measured by the D-cable was accurate to within ± 1 ft. The D-cable data in feet were transmitted to the B & F system as an analog voltage; this number was updated about every foot of depth change.

Total Weight of Fill Material in the Hole

Fill material going into the hole was weighed by a load cell under the conveyor belt. The total weight of the fill material was calculated in the stemming trailer and was transmitted to the B & F recording system as an analog voltage.

CABLES

The cables from each canister to Trailer T-920 were nine-pair cables with pair shields (16-1230-6201). In most cases, the canister transducers required seven pairs of cables and one shield to complete all necessary circuits. The remaining two pairs of cables were used to fire and monitor the Halex cutters.

B & F SIGNAL-CONDITIONING AND DIGITAL-DATA-ACQUISITION SYSTEM

Signal conditioning for most channels was done by the B & F system. Exceptions were the channels for EG&G air and hopper sand temperature, total weight, D-cable height, and force on the wire rope. These channels were externally powered, and only their outputs were transmitted to the B & F system.

The 100-channel B & F system is a pulsed-current excitation system. It uses one constant current power supply that is sequentially switched through all channels at the rate of 10 channels/s. A 10-mA current was supplied to all transducers powered by the B & F system.

Voltage output is measured and digitized on an integrating digital voltmeter and is recorded on an incremental magnetic tape recorder. Switching is done by a crossbar scanner. Quick-look, unscaled voltage data are available on a fast printer output.

The B & F system on its most sensitive range of 100.000 mV has a basic inaccuracy of $3\mu\text{V} \pm 0.015\%$ of reading, if reading is less than 30 mV; it also has a 1- μV resolution. The inaccuracy of the entire measurements system (including transducers) is greater.

The B & F system was selected because it requires less than one day (1 d) to set up in the field, is easy to use, and very reliable. Its constant-current excitation eliminates most concerns about voltage drops in excitation leads to the transducers, and it has high accuracy and resolution. The data acquisition rate of the B & F system was more than adequate for this experiment.

A number of check channels were used to verify B & F system condition and performance during the 7 d of testing. These check channels included shorted inputs, zero-output bridges, full-scale output bridges that simulated air overpressure transducers and soil gauges, and a dummy potentiometer.

About 4 s was required to complete one scan of 40 channels at a 10-channel/s rate. All data channels were scanned at 1-min intervals except when fill material was going downhole. During stemming, the channels were scanned at various rates from continuous (each channel scanned every 4 s) to 1-min-interval scans. Continuous scans were used when fill material was covering up any canister, when the Holec cutter was being fired, and at the start and end of all fills except during fill stop on the first day.

CALIBRATION OF SOIL-PARTICLE PRESSURE TRANSDUCERS

Two calibration tests were performed before the canisters were lowered downhole. No adequate sketches of relative canister location, soil gauges, pipe walls, or sandpile geometry are available.

Test 1

The six canisters were placed on the ground with the horizontal soil-particle pressure transducers faced horizontally and the three vertical soil gauges faced directly upward. A 9-ft-diam, hollow corrugated pipe that was 8-ft high was placed to enclose all canisters. This pipe is visible in the background of Fig. 15. There was at least a 6-in. clearance between any soil-particle pressure transducer and adjoining structure, such as the pipe wall or another canister.

Overton sand was poured into the pipe, and measurements were made at sand heights of 0, 1, 2, 5, and 6.7 ft above the soil gauges' nominal center-line (see Table 3). Variations in measured pressure were rather high, and one possible conclusion is that the 6-in. clearance between the soil gauges and nearby structures was inadequate.

Sand was left at the 6.7-ft height overnight. Data taken 16 h later indicated several soil gauge readings had changed; however, these changes were not due to temperature effects on the gauges. All soil gauges returned to their initial zero pressure outputs when sand was cleared from the rubber diaphragm covering the collector plates.

Table 3. First calibration test of soil-particle pressure transducers inside a 9-ft-diam pipe.

Transducer orientation	Channel	Elapsed time, h: Sand height, ft:	Soil-particle pressure, psi				
			0	0.22	0.40	0.57	0.70 16.75 6.7 6.7
Horizontal	214	0	0.26	0.54	0.83	0.99	0.88
	217	0	0.58	0.86	1.28	1.46	1.90
	221	0	0.63	0.96	1.44	1.61	1.59
	225	0	0.33	0.64	1.34	1.69	1.22
	229	0	0.49	0.82	1.67	1.93	2.12
	233	0	0.57	1.06	1.64	1.85	1.69
Vertical	218	0	0.73	1.36	1.95	2.18	2.21
	226	0	1.24	2.07	3.09	3.43	3.33
	234	0	1.01	1.75	2.61	2.91	2.90

Fig. 15. Calibration test 2 showing 2-ft-high pile of Overton sand.

Table 4. Second calibration test of soil-particle pressure transducers in sandpile without 9-ft-diam pipe.

Channel	Vertical soil-particle pressure, psi, at three sand heights		
	0 ft	1 ft	2 ft
214	0	1.17	2.42
217	0	0.59	1.68
221	0	0.96	1.84
225	0	0.82	1.95
229	0	0.93	2.06
233	0	0.92	1.71
218	0	0.78	1.77
226	0	0.94	1.78
234	0	0.78	1.46

Test 2

A second calibration test was performed to minimize interference from adjacent structures. This test was performed without the 9-ft-diam pipe. All vertical and horizontal soil gauges faced directly upward, and all were aligned at the same height (Fig. 16).

Overton sand was poured over the canisters and leveled with a board. Measurements were made at sand heights of 0, 1, and 2 ft above the nominal soil gauge centerline (Table 4). Figure 15 shows a 2-ft-high sandpile. The sand flat did not extend over Channel 217 when the sand was 1 ft high.

The second calibration test was imperfect for at least two reasons. The large fins standing out from the canisters (Fig. 16) probably interfered with the free settling of the sand above the soil-particle pressure transducers and introduced discontinuities into the uniform sand-pressure field above these transducers. And, the limited volume of available Overton sand prevented horizontal extension of the sandpile beyond the soil gauges to a two or more sand-depth approximation of a semi-infinite sandpile.

RESULTS

The timing of events is detailed in Table 5. All times were referenced to 1976 Julian Day 313-00-00-00, which is midnight on Monday morning of November 8, 1976.

Fig. 16. All nine soil-particle pressure transducers were aligned vertically before calibration test 2.

Table 5. Timing of events.^a

Stemming day	November 1976 date	Fill start	Holox cutter fired	Fill stop
1 - Monday	8	824	841.7	855
2 - Tuesday	9	2078	2123.6	2160
3 - Wednesday	10	3590	3674.4	3749
4 - Thursday	11	4906	5093.2	5244
5 - Friday	12	6322	6404.2	6468

^aAll times are shown in minutes.

Figure 17 shows measured fill start and stop times and corresponding measured fill material heights relative to canister location, fill material, and fill rate.

The metal-screen and open-celled foam rubber air filters worked well. There was no indication that filters were either plugged or transmitting fill material.

INDEX TO DATA FIGURES

The index to data figures that follows is a detailed listing of parameters measured during the U2Ar experiment and their corresponding data plots (Figs. 18-61). Canisters are listed in order of their relative positions on the wire rope.

DOWNHOLE MEASUREMENTS

Air Overpressure Transducers

Air overpressures were calculated for plotting by subtracting initial absolute pressures at 819 min, or 5 min before the start of stemming on the first day, from all later data. Figures 18 through 32 show overpressure data from the six canister locations plotted for different time intervals.

Plots for air overpressure at the six canisters for the 5 d of stemming and the following weekend are shown in Fig. 18. The 16-ft major slump that occurred at about 4157 min is indicated by S₁ on each plot. It is also visible

Fig. 17. Pictorial of U2Ar stemming experiment showing measured fill start and stop times and corresponding measured fill material heights relative to canister location, fill material, and fill rate.

Index to data figures,^{a,b}

Channel	Location	Parameter	7 d or 5 d	Figures					16-ft slump (S ₁)	2-ft slump (S ₂)
				Stemming days						
				1	2	3	4	5		
207	Surface	Air temperature	47	—	—	—	—	—	—	—
208		Air pressure	49	—	—	—	—	—	—	—
209		Temperature of fill material	48	—	—	—	—	—	—	—
210		Total weight of fill material	52(a)	52(b)	52(c)	52(d)	52(e)	52(f)	—	—
211	Downhole	Height of fill material (D-cable)	51(a)	51(b)	51(c)	51(d)	51(e)	51(f)	—	—
212	Surface	Force on wire rope	50(a)	—	—	—	50(b)	—	50(a) 53	50(a) 50(b)
232	Canister 6	Air overpressure	18(f)	19(f) 20(f) 21(d)	22(f) 23(d) 24(c)	25(d) 26(c) 27(b)	28(c) 29(b) 30	31 32	18(e) 61	—
233		Horizontal soil gauge	42(a)	—	—	—	—	42(b)	—	—
234		Vertical soil gauge	36(a)	—	—	—	—	36(b)	—	—
235		Slump displacement	—	—	—	—	—	—	—	—
228	Canister 5	Air overpressure	18(e)	19(e) 20(e) 21(c)	22(e) 23(c) 24(b)	25(c) 26(b) 27(a)	28(b) 29(a)	—	18(e) 61(a)	18(e) 28(b)
229		Horizontal soil gauge	41(a)	—	—	—	41(b)	—	—	41(a) 41(b)
230		Temperature	45(a)	45(b)	45(c)	45(d)	—	—	—	—
231		Slump displacement	—	—	—	—	—	—	—	—
224	Canister 4	Air overpressure	18(d)	19(d) 20(d) 21(b)	22(d) 23(b) 24(a)	25(b) 26(a)	28(a)	—	18(d) 57(b)	—
225		Horizontal soil gauge	40(a)	—	—	40(b)	—	—	40(a) 59(b)	—
226		Vertical soil gauge	35(a)	—	—	35(b)	—	—	35(a) 58	—
227		Slump displacement	46(b)	—	—	—	—	—	46(b) 60(b)	—
220	Canister 3	Air overpressure	18(i)	19(c) 20(c) 21(a)	22(c) 23(a)	25(a)	—	—	18(c) 57(a)	—
221		Horizontal soil gauge	39(a)	—	39(b)	—	—	—	39(a) 59(a)	—
222		Temperature	44(a)	44(b)	44(c)	—	—	—	—	—
223		Slump displacement	46(a)	—	—	—	—	—	46(a) 60(a)	—
216	Canister 2	Air overpressure	18(b)	19(b) 20(b)	22(b)	—	—	—	18(b) 54(b)	—
217		Horizontal soil gauge	38(a)	38(b)	—	—	—	—	38(a) 55(b)	—
218		Vertical soil gauge	34(a)	34(b)	—	—	—	—	34(a) 56	—
219		Slump displacement	—	—	—	—	—	—	—	—
213	Canister 1	Air overpressure	18(a)	19(a) 20(a)	22(a)	—	—	—	18(a) 54(a)	—
214		Horizontal soil gauge	37(a)	37(b)	—	—	—	—	37(a) 55(a)	—
215		Temperature	43(a)	43(b)	—	—	—	—	—	—

^aData figures include Figs. 18-61.

^bCanisters are listed in descending order according to their relative positions on the wire rope.

Fig. 18. Plots of air overpressure at Canisters (a) 1 through (f) 6 for the 5 d of stemming and the following weekend.

in the air overpressure at the two canisters that were unburied at the time [Fig. 18(e) and (f)]. This slump will be discussed in detail in a later section.

The air overpressure transducers used measured absolute pressure. For all plots, air overpressure was defined as zero just before the start of stemming on the first day. Thereafter, it varied between 0 and -0.2 psi at the unburied canisters whenever stemming material was not going downhole. Figure 18(f) shows this zero variation for the 7 d. The variation in zero was largely due to variations in atmospheric pressure with minor contributions from temperature zeroshift of the air overpressure transducers. For optimum accuracy during analyses, air overpressure for unburied canisters should be calculated relative to atmospheric zero just before fill start on a specific stemming day.

A 2-ft minor slump (labeled S_2) occurred at 5260 min. It is discussed in a later section of this report.

Figures 19 through 21 show air overpressures measured at the six canister locations on the first day of stemming. Measured overpressures were highest near the bottom of the hole. Canisters 1 and 2 were buried in Overton sand during this fill. Pressure decayed slowly [Fig. 19(a) and (b)] because it had to diffuse through the column of sand. Data plotted in Fig. 21 were measured at 1-min intervals.

Air pressures measured at the six canister locations on the second day of stemming are shown in Figs. 22-24. The air overpressure during stemming diffused into the vicinity of Canisters 1 and 2 [Fig. 22(a) and (b)]. Canister 3 [Fig. 22(c)] was buried during this fill.

For the only time during this entire experiment, air overpressures in the open hole jumped about 0.7 psi when the stemming run was about 60% complete [Fig. 22(d)-(f)]. Data signatures in the three canisters were nearly identical. Canister 3 was buried under 25 or more feet of LLL II mix at this time, and the open-hole pressure jump was seen as only a slight pressure increase.

The digital listing of the total weight signal transmitted from the stemming trailer indicated a steady fill during this pressure jump. And, the digital listing of D-cable height indicated a steady increase in height before and during the jump.

Fig. 19. Plots of air overpressure at Canisters (a) 1 through (f) 6 on the first day of stemming.

Fig. 20. Air overpressure buildup after fill start at Canisters (a) 1 through (f) 6 on the first day of stemming.

Fig. 21. Air overpressure decay after fill stop at Canisters (a) 3 through (d) 6 on the first day of stemming.

Fig. 22. Air overpressure at Canisters (a) 1 through (f) 6 on the second day of stemming.

Fig. 23. Air overpressure buildup after fill start at Canisters (a) 3 through (d) 6 on the second day of stemming.

Fig. 24. Air overpressure decay after fill stop at Canisters (a) 4 through (c) 6 on the second day of stemming.

B & F check channels did not indicate any anomaly in the recording system, and none of the other downhole or surface channels indicated any unusual behavior. Therefore, these data were valid, and the transducers were measuring actual air pressure in the open hole.

An explanation for this behavior might be found in the mechanism of fly-ash transfer to the hole. The weight fill rate of fly ash was not measured during the stemming experiment. It is possible the fly-ash fill rate could have changed partway through the fill.

Figures 25-27 show air overpressures at the four highest canisters during the third day of stemming. There was only a slight increase in air overpressure at the previously buried canister [Fig. 25(a)]. Canister 4 [Fig. 25(b)] was buried during this fill.

Air overpressures at the three highest canisters during the fourth day of stemming are shown in Figs. 28-30. There was no significant increase in air overpressure at the previously buried canister [Fig. 28(a)]. Canister 5 [Fig. 28(b)] was buried during this fill. The 2-ft slump occurred at 5260 min.

Figures 31-32 show air overpressures at Canister 6, which was buried on the fifth day of stemming.

Air overpressures measured at the unburied canisters after the start of each day's stemming are listed versus stemming day, fill material, and fill rate in Table 6. A plot of steady-state air overpressures (Table 6) shortly after the start of stemming on the first day is shown in Fig. 33. Overton sand was used as the fill material at a 100-ton/h fill rate. The straight line joining the zero depth with the six data points shows a good fit to the data.

Vertical Soil-Particle Pressure Transducers

The vertical soil-particle pressure transducers or soil gauges were designed for full-scale pressures of 5.3 psi; they were independent of air overpressure. Stops were set to protect the force transducers when soil pressures increased to a 7.1- to 8.8-psi range.

Figure 34 shows vertical particle pressure for the vertical soil gauges at Canister 2 for the (a) 7 d and (b) first day of stemming. Measured pressure peaked to 4.94 psi at 842 min as the canister was buried. This pressure flattened out to about 1.1 psi 18 min later when fill material was about 52 ft above the soil gauge.

Fig. 25. Air overpressure at Canisters (a) 3 through (d) 6 on the third day of stemming.

Fig. 26. Air overpressure buildup after fill start at Canisters (a) 4 through (c) 6 on the third day of stemming.

Fig. 27. Air overpressure decay after fill stop at Canisters (a) 5 and (b) 6 on the third day of stemming.

Fig. 28. Air overpressure at Canisters (a) 4 through (c) 6 on the fourth day of stemming.

Fig. 29. Air overpressure buildup after fill start at Canisters (a) 5 and (b) 6 on the fourth day of stemming.

Fig. 30. Air overpressure decay after fill stop at Canister 6 on the fourth day of stemming.

Fig. 31. Air overpressure at Canister 6 on the fifth day of stemming.

Fig. 32. Air overpressure buildup after fill start at Canister 6 on the fifth day of stemming.

Fig. 33. Steady-state air overpressures at the six canister locations shortly after start of stemming on the first day. Overton sand fill rate 100 ton/h.

Fig. 34. Vertical particle pressure at Canister 2 for the (a) 7 d and (b) first day of stemming.

Fig. 35. Vertical particle pressure at Canister 4 for the (a) 7 d and (b) third day of stemming.

Table 6. Air overpressures at the unburied canisters after the start of stemming each day.^a

Day	Canister	Fill material	Fill rate, ton/h	Figure	Channel	Air overpressure, psi
1	6	Overton sand	100	19(f)	232	2.4
1	5			19(e)	228	2.75
1	4			19(d)	224	3.25
1	3			19(c)	220	3.70
1	2			19(b)	216	4.1
1	1			19(a)	213	4.1
2	6	LLL II mix	100	22(f)	232	2.35
2	5			22(e)	228	2.7
2	4			22(d)	224	3.25
2	3			22(c)	220	3.8
3	6	LLL II mix	50	25(d)	232	1.55
3	5			25(c)	228	1.8
3	4			25(b)	224	2.15
4	6	LLL II mix	25	28(c)	232	0.9
4	5			28(b)	228	1.1
5	6	Overton sand	25	31	232	1.0

^aCanisters are arranged in descending order according to their relative positions on the wire rope.

The data show no evidence of bottoming against the stops. The 4.94-psi peak pressure was below the full-scale pressure of 5.3 psi and considerably below the lowest stop setting of 7.1 psi. Pressure variations were smooth, and there was no evidence of flattening out at some maximum pressure value.

The data shown in Fig. 35 are for the vertical soil gauge at Canister 4 for the (a) 7 d and (b) third day of stemming. The data near 3680 min show the pressure as the canister was buried. There was a 7-min interval between the time fill material began to cover the soil gauge and the pressure peak. This 7-min interval corresponded to about 10 ft of fill material over the soil gauge at peak pressure.

The 8.14-psi peak pressure recorded at 3681 min was within the range of the stops. This pressure peak stayed nearly constant for 2 min, and the soil gauge bottomed against the stops.

Measured peak pressure was very close to actual peak pressure. The slope of the curve before and after the peak was very gradual, and there was no sudden slope change in the data listing to indicate abrupt bottoming of the gauge.

The 8.14-psi peak pressure decreased and flattened out at about 5.5 psi about 38 min after the peak. This corresponded to 53 ft of fill material above the soil gauge. The change in level at 4157 min was caused by the 16-ft major slump.

Figure 36 shows data for the vertical soil gauge at Canister 6 for the (a) 7 d and (b) fifth day of stemming. The pressure at 6400 min was recorded as the canister was buried. Twenty minutes elapsed between the time fill material began to cover the soil gauge and the 7.7-psi pressure peak. This 20 min corresponded to about 14 ft of fill material over the soil gauge at peak pressure.

The data listing indicates the soil gauge bottomed out against the stops. It is difficult to estimate how much higher true peak pressure might have been.

Horizontal Soil-Particle Pressure Transducers

The horizontal soil-particle pressure transducers or soil gauges had a full-scale range of 2.65 psi at Canisters 1-3 and of 5.3 psi in Canisters 4-6. These horizontal soil gauges measured particle pressure independent of air overpressure, and all were partially shadowed by the standoff fins above them. The following figures show horizontal particle pressure data for the stemming experiment. The S_1 on all figures indicates the 16-ft major slump.

Fig.

- 37: Shown are horizontal soil gauge data from Canister 1 for the (a) 7 d and (b) first day of stemming.
- 38: This figure shows data from the horizontal soil gauge at Canister 2 for the (a) 7 d and (b) first day of stemming.
- 39: Data from the horizontal soil gauge at Canister 3 are shown for the (a) 7 d and (b) second day of stemming.
- 40: Horizontal soil gauge data from Canister 4 are shown for the (a) 7 d and (b) third day of stemming. The data beginning near 3670 min were measured as the canister was buried.

Fig. 36. Vertical particle pressure at Canister 6 for the (a) 7 d and (b) fifth day of stemming.

Fig. 37. Horizontal particle pressure at Canister 1 for the (a) 7 d and (b) first day of stemming.

Fig. 38. Horizontal particle pressure at Canister 2 for the (a) 7 d and (b) first day of stemming.

Fig. 39. Horizontal particle pressure at Canister 3 for the (a) 7 d and (b) second day of stemming.

Fig. 40. Horizontal particle pressure at Canister 4 for the (a) 7 d and (b) third day of stemming.

- 41: Canister 5 soil gauge data are shown from the (a) 7 d and (b) fourth day of stemming. The data, measured as the canister was buried, began at 5080 min. The S marking at 5260 min indicates the 2-ft. minor slur.
- 42: Data from the horizontal soil gauge at Canister 6 are shown for the (a) 7 d and (b) fifth day of stemming.

Canister Temperature Transducers

The following figures show temperature data from the canister locations during the stemming experiment.

Fig.

- 43: Temperature data from Canister 1 are shown for the (a) 7 d and (b) first day of stemming.
- 44: Canister 3 temperature data are shown for the (a) 7 d, and for the (b) first and (c) second day of stemming.
- 45: Temperature data from Canister 5 are shown for the (a) 7 d and (b) first to (d) third day of stemming.

Slump-Displacement Transducers

Data from the slump-displacement transducers are shown in Fig. 46. Listed data indicate a slump occurred sometime between the scans at 4156.3 and 4157.3 min about 9:17 PM on the third day of stemming (Wednesday, November 10, 1976). This major slump will be discussed in a later section.

The size of the slump is not indicated on either plot. The slump-displacement measurements system indicated no slump activity at 4156.3 min. One minute later, a -0.46-ft displacement was noted for Canisters 3 and 4. These data would be consistent with the anchor separating from the potentiometer and the cable reeling back into the potentiometer housing until halted by internal stops.

No visible displacement was noted when Hoxley cutters were fired to release the anchors after the canisters were covered with about 5 ft of fill material. These data at firing time were studied on expanded-scale plots and on the corresponding data listing.

Hoxley cutters fired in all canisters, and this firing was observed on the horizontal particle pressure transducers in each canister [Fig. 38(b)]. These cutters cut cable so reliably that lack of visible displacement might

Fig. 41. Horizontal particle pressure at Canister 5 for the (a) 7 d and (b) fourth day of stemming.

Fig. 42. Horizontal particle pressure at Canister 6 for the (a) 7 d and (b) fifth day of stemming.

Fig. 43. Temperature at Canister 1 for the (a) 7 d and (b) first day of stemming.

Fig. 44. Temperature at Canister 3 for the (a) 7 d and (b) first and (c) second days of stemming.

Fig. 45. Temperature at Canister 5 for the (a) 7 d and the (b) first through (d) third days of stemming.

Fig. 46. Slump displacement at Canisters (a) 3 and (b) 4 for the 7 d of the stemming experiment.

Fig. 47. LLL surface air temperature for the 7 d of the stemming experiment.

simply indicate that fill material surrounded the anchor and kept it from moving.

We concluded from the above data that the design of the slump-displacement transducer was unsatisfactory. Suggested design improvements are discussed in another section of this report.

SURFACE MEASUREMENTS

LLL Air Temperature

Surface air temperatures for the 7 d of the stemming experiment are shown in Fig. 47. These data agreed with EG&G measurements to within 1°F.

LLL Hopper Sand Temperature

Figure 48 shows hopper sand temperatures for the 5-d stemming experiment. Note the data end at 6500 min shortly after the fifth day of stemming. These data agreed with EG&G measurements to within 2°F.

LLL Air Pressure

Surface air pressure for the 7 d is shown in Fig. 49. These pressure data agreed closely with those from the Yucca Flat weather station after correction was made for altitude differences between Yucca Flat and Trailer T-920.

Force on the Wire Rope

Figure 50 shows force data for the wire rope for the (a) 7 d and (b) fourth day of stemming.

D-Cable Height

Figure 51 shows D-cable height data for the (a) 7 d and (b) first through (f) fifth day of stemming.

D-cable data for the 5-d stemming experiment varied nearly linearly with time. Spikes and glitches noted on these data were not real data, but range changes on the voltage supply that transmitted a voltage proportional to D-cable height to the B & F recording system. However, real data were transmitted the morning after the 16-ft major slump when new D-cable height was recorded at about 4800 min [Fig. 51(a)].

Fig. 48. LLL hopper sand temperature for the 5 day of stemming.

Fig. 49. LLL surface air pressure for the 7 d of the stemming experiment.

Fig. 50. Force on the wire rope for the (a) 7 d and (b) fourth day of stemming.

Fig. 51. D-cable height for the (a) 7 d and (b) first through (f) fifth day of stemming.

Total Weight of Fill Material

The 5-d data for total fill material weight are shown in Fig. 52(a). Data for the first through fifth day of stemming are shown in Fig. 52(b) through (f). These data were continuous and nearly linear with time. Spikes and glitches were not real data, but range changes on the analog voltage supply to the B & F recording system.

MAJOR SLUMP

A 16-ft major slump occurred at 9:17 PM on Wednesday, November 10, 1976. This slump took place 6.8 h after stemming ended on the third day sometime in the 1-min interval between data scans at 4156.3 and 4157.3 min. Canister 4 was buried on the third day of stemming (Table 1).

Data were recorded at 1-min intervals the night slump occurred; however, the first evidence of a slump was noted the following morning by increased tension on the wire rope (Fig. 53). This slump was confirmed by the D-cable, which indicated the height of fill material in the hole had dropped 16 ft during the night. Table 7 is a listing of major changes during the slump.

The slump probably did not extend into the Overton sand. Air overpressures measured at Canisters 1 and 2 increased very slowly after slump time [Figs. 18(a) and (b) and 54]. This pressure rise was probably produced by pressure diffusing slowly through the Overton sand. These slump data were similar to those measured at 2200 min on the second day of stemming when LLL II mix was poured downhole on the Overton sand that contained Canisters 1 and 2.

The slump event could be seen on the horizontal and vertical soil gauges in Canisters 1 and 2 [Figs. 34(a), 37(a), 38(a), 55, and 56], but magnitudes were only on the order of 0.1 psi. These small changes may have been due to the downward slumping of sand in the vicinity of Canisters 3 and 4 or to shock transmitted by the 4-ft-diam steel pipe from the uphole slump event to the Overton sand surrounding Canisters 1 and 2.

Canisters 3 and 4 were clearly affected by the slump. Air overpressures increased suddenly at both canisters [Figs. 18(c) and (d) and 57].

The vertical soil gauges at Canister 4 indicated a pressure increase from 4.7 to 23.7 psi [Figs. 35(a) and 58]. Protective stops should have limited pressure in this soil gauge to a maximum of about 9 psi. The severe

Fig. 52. Total weight of stemming material for the (a) 5 d and (b) first through (f) fifth day of stemming.

Fig. 53. Force on the wire rope during the 16-ft slump.

Fig. 54. Air overpressure at Canisters (a) 1 and (b) 2 during the 16-ft slump.

Fig. 55. Horizontal particle pressures at Canisters (a) 1 and (b) 2 during the 16-ft slump.

Fig. 56. Vertical particle pressure at Canister 1 during the 16-ft slump.

Fig. 57. Air overpressure at Canisters (a) 3 and (b) 4 during the 16-ft slump.

Fig. 58. Vertical particle pressure at Canister 4 during the 16-ft slump.

Table 7. Measured changes in parameters during the 16-ft major slump.

Canister	Channel	<u>Measured data</u>			Remarks
		Before	After	Change	
<u>Air overpressure, psi</u>					
1	213	1.85	2.65	+0.8	25 h required for total change
2	216	1.85	2.65	+0.8	25 h required for total change
3	220	1.80	3.05	+1.25	
4	224	1.65	3.65	+2.0	
5	228	-0.05	0	+0.05	Unburied canister
6	232	-0.05	0	+0.05	Unburied canister
<u>Horizontal particle pressure, psi</u>					
1	214	1.24	1.32	+0.08	
2	217	1.27	1.38	+0.11	
3	221	1.94	0.88	-1.06	
4	225	1.20	0.12	-1.08	
<u>Vertical particle pressure, psi</u>					
2	218	0.8	0.9	+0.1	
4	226	4.7	23.7	+19	Overranged. Probably damaged.
<u>Slump displacement, ft</u>					
3	223	0	-0.46	-0.46	Anchor cable parted?
4	227	0	-0.45	-0.45	Anchor cable parted?

overrange indicates the stops were yielded or the soil gauge housing was physically deformed during the slump. A large slug of fill material could have slammed down on Canister 4 with enough force to damage the vertical soil gauge.

The horizontal soil gauges in Canisters 3 and 4 both indicated about a 1-psi reduction in particle pressure during the slump [Figs. 39(a), 40(a), and 59].

The slump-displacement transducers in Canisters 3 and 4 provided no data. Both transducers indicated a -0.45-ft step change at slump time (Figs. 46 and 60). This was consistent with the potentiometer cable reeling

Fig. 59. Horizontal particle pressures at Canisters (a) 3 and (b) 4 during the 16-ft slump.

Fig. 60. Slump displacement at Canisters (a) 3 and (b) 4 during 16-ft slump.

back into the canister. Sometime during the 1-min interval between scans, the cable that connected the anchor to the potentiometer parted in both canisters. We don't know if the anchors deployed partially, completely, or at all before the cables parted.

Data measured at Canisters 3 and 4 indicated fill material slumped along at least the 230 vertical feet between the canisters and probably more. The slump was even observed as a slight pressure increase in the unfilled hole at Canisters 5 and 6 (Fig. 61).

MINOR SLUMP

A 2-ft minor slump (labeled S_2 on the figures) occurred at 5260 min, or 16 min after stemming ended on the fourth day. The slump was only observed at Canister 5, which was covered.

Air overpressure increased about 0.25 psi [Figs. 18(e) and 28(b)]. Horizontal soil pressure increased 0.45 psi (Fig. 41), and force on the wire rope increased as shown in Fig. 50. The slump-displacement transducer in Canister 5 indicated no change.

D-cable measurements the following morning indicated a 2-ft slump had occurred.

ERROR ANALYSIS

Air Overpressure Transducers

Tyco AB absolute-pressure transducers with a 25-psia full-scale range were used to measure air overpressure in the U2Ar experiment. The manufacturer's specifications for these transducers included:

- Accuracy: 1% or less deviation from best-fit straight line including nonlinearity, repeatability, and hysteresis.
- Output signal at rated pressure: 100 mV at 5-V excitation.
- Excitation voltage recommended: 5 V.
- Bridge resistances: input $150 \pm 50 \Omega$.
output $115 \pm 25 \Omega$.
- Compensated temperature range: 30 to 130°F.
- Thermal effect on zero: less than 5% of reading over compensated range.

Fig. 61. Air overpressure at Canisters (a) 5 and (b) 6 during the 16-ft slump.

- Thermal effect on sensitivity: less than 2% of reading over compensated range.

These specifications were based on constant voltage excitation. A pulsed, constant current of 10 mA was used in the stemming experiment. The thermal effect on zero and sensitivity was not measured under constant current excitation. We therefore assumed that the thermal effect for constant current excitation was the same as for constant voltage excitation.

The Tyco AB transducers were calibrated at a laboratory temperature of about 75°F. Measured temperatures in the downhole canisters ranged from 73 to 83°F; thus, transducer temperature in the worst case was 8°F higher than calibration temperature. The thermal effects for this 8°F difference were probably small, and constant voltage thermal effects were probably a good approximation to constant current thermal effects. If we assume a maximum absolute pressure of 17 psia and an 8°F maximum temperature above calibration temperature, the thermal effects on zero and sensitivity are approximately 0.06 and 0.03 psi, respectively.

The transducers were calibrated to a 25-psia, full-scale range at 10-mA constant current excitation. The measured deviations from the best-fit straight line (for linearity and hysteresis only) are shown below.

Channel	Canister	Error, % of full-scale range	Equivalent pressure, psi
213	1	0.44	0.11
216	2	0.40	0.1
220	3	0.25	0.063
224	4	0.35	0.088
228	5	0.41	0.103
232	6	0.34	0.085

The B & F signal conditioning and digital data-acquisition system had a 0.005-psi inaccuracy when used with the Tyco AB transducer. B & F system performance was monitored by eight check channels, including shorted inputs, balanced bridges, and unbalanced bridges. The pulsed constant current supplied by the B & F system was measured before each scan of the 40 channels.

The various error sources for the worst-case air overpressure transducer included: (a) thermal effects on zero and sensitivity of 0.06 and 0.03 psi, (b) linearity and hysteresis of 0.11 psi, and (c) a B & F system inaccuracy of 0.005 psi. The root sum of the squares of these various error sources produced a likely error of ± 0.13 psi.

Frequency response of the Tyco AB transducers was not measured, but was several orders of magnitude higher than that necessary to measure air overpressure. The frequency response was limited only by the B & F scanning rate.

Soil-Particle Pressure Transducers

The basic measuring element in all soil gauges was a Lebow force transducer (load cell). Some minor error sources of this transducer included: (a) thermal effects of 0.0008 psi on zero and sensitivity (constant voltage), (b) linearity and hysteresis of 0.002 psi (constant current), and (c) B & F system inaccuracy of 0.002 psi.

Thermal effects on zero and sensitivity were not measured for constant current excitation. Had these effects been 10 times larger than constant voltage values, the error would have only been 0.008 psi. The root sum of the squares of these error sources was 0.003 psi.

It was difficult to quantify the effect of partial shielding of the horizontal soil gauges by the standoff fins above them (Fig. 3). A similar error source was partial shielding of the vertical soil gauges by adjacent wire rope and instrumentation cables.

The frequency response of the soil gauge was high enough to faithfully follow all particle pressure transients within the limitation of the B & F scanning rate.

All the above error sources are insignificant compared to the major unknown of how this soil gauge measures *in situ* soil-particle pressure. Some basic questions are:

- (a) What is the soil particle pressure in a given direction at some point in a sandpile? What is the scatter in measured particle pressure at the same location for 10 "identical" sandpiles?
- (b) What is the time history of soil particle pressure as this pressure is correspondingly increased and decreased with the height of the sandpile?
- (c) Is there an existing soil gauge that can accurately measure soil-particle pressure?

- (d) Is the U2Ar soil gauge of optimum design? If not, is the optimum design smaller? Stiffer?
- (e) What is the soil-particle pressure at the soil gauge location? How can we determine true soil-particle pressure and compare it to measured particle pressure? What standard will tell us how well the U2Ar soil gauge is measuring particle pressure?

Without answers to these questions, it is impossible to quantify soil gauge performance and the accuracy of measurement.

Other Transducers

If slump-displacement transducers had functioned as they were designed to, the error band would have been about ± 0.08 ft. The canister temperature transducers had an error band of about $\pm 0.3^{\circ}\text{F}$ and a time constant on the order of minutes. Surface air and hopper sand temperature transducers had error bands of about $\pm 0.3^{\circ}\text{F}$, and surface air pressure transducers had error bands of about ± 0.03 psi. Force on the wire rope had an error band of 0.5% full scale or about 100 lb, and the error band for D-cable height was about ± 1 ft.⁴ The error band for the total weight of stemming was $\pm 1.2\%$ of indicated total weight.

IMPROVEMENTS TO CONSIDER FOR THE NEXT STEMMING EXPERIMENT

The U2Ar experiment was LLL's first comprehensive stemming experiment for measuring downhole parameters while varying fill material and rate. This experience pointed out the need to consider various design and procedural improvements to be incorporated in planning our next stemming experiment. One of the first considerations should be advanced planning to allow for maximum design flexibility. If possible, 8 to 16 wk should be allotted for fabrication and delivery of the various transducers. Another consideration is weighing fly ash when it is going downhole. We should also consider improvements in the design and use of the transducers and recording systems; these are detailed below.

Air Overpressure Transducers

Some improvements in the design of the Tyco AB air overpressure transducers should be considered. Although adequate for our purposes, they

have a relatively high zeroshift with temperature compared to metal-foil, strain-gauge-based transducers. This feature prevented the use of the Tyco transducers for measuring ambient atmospheric pressure but did not interfere with the measurement of air overpressures in the U2Ar experiment.

Soil-Particle Pressure Transducers

Several improvements in the design and use of soil-particle pressure transducers should be considered for future experiments. These include:

- Making design changes to increase the pressure range vertically.
- Optimizing soil gauge design.
- Evaluating soil gauge performance by controlled testing both vertically and horizontally.
- Including vertical soil gauges at all canister locations.
- Avoiding shadowing by standoff fins or instrumentation cable.
- Loading soil gauges against their stops before sending canisters down-hole by use of sand and a heavy metal plate so bottoming of the stops can be identified on the data.

Surface Air Pressure Transducers

Two procedural changes should be considered for the next stemming experiment using surface air pressure transducers. Temperature compensation should be checked from 50 to 125°F, and transducers should be mounted inside a trailer where temperature extremes are reduced. Outside pressures could be measured by a tube protruding below the trailer.

Slump-Displacement Transducers

The slump-displacement transducers used in the U2Ar experiment were unsatisfactory and provided no useful information other than a timing mark to indicate a slump had occurred. Significant improvements in the design and use of this transducer are needed before the next stemming experiment. These include:

- Replacing the complicated anchor design with a simple steel or lead ball.
- Using an antireturn mechanism on the slump-displacement potentiometer to prevent the cable from retracting should it break; this would enable one to read the displacement whenever another data scan is performed.

- Redesigning or replacing the present transducer with one that requires no cable between the anchor and potentiometer.
- Using a four-wire circuit with the potentiometer to eliminate constant zero offset due to line resistance.
- Testing the anchor release mechanism before freezing the design.
- Using a tubular shield over the anchor to permit about a 6-in. free drop after the Horex cutter is fired to confirm anchor release.
- Designing a low-inertia displacement measuring system that can survive and measure despite sudden large loads on the anchor.

Signal Conditioning and Recording System

The basic B & F system used in the U2Ar stemming experiment was very reliable; however, it offered no quick-look listing of scaled data. This feature is available on Materials Engineering Division's NLS system, which is identical to the B & F system except that it includes a minicomputer to do the scaling. Quick-look printouts of scaled data are available on a teletypewriter, but the printing rate is relatively slow. It would be a significant advantage if one system could provide the reliability of the B & F system, minicomputer scaling of data, and a printing rate of 10 to 15 channels/s.

A continuous recording capability might also be desirable for the slump-displacement transducers. A tape recorder with a 10-Hz frequency response and a low recording speed would probably be adequate for recording a slump.

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