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PERMEABILITY OF A NUCLEAR CHIMNEY AND SURFACE ALLUVIUM, AREA 2, ERDA NTS

R. Rozsa
D. Snoeberger
J. Baker

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ABSTRACT

We have conducted permeability tests at a fifth nuclear chimney site in alluvium and tuffs at the ERDA Nevada Test Site (NTS). Permeability results were obtained by fitting calculated and measured underground pressure response generated by atmospheric pressure changes at the surface. Calculations were made using an analytic solution for Darcy flow in a semi-infinite slab with stepwise, time-varying surface pressure (superposition). The calculated values of pressure diffusivity for the chimney is 0.64 m^2/s and 1.1 m^2/s for the undisturbed surface layer.

INTRODUCTION

This report gives the results of field permeability tests made at a fifth nuclear chimney site in Area 2 at the ERDA Nevada Test Site (NTS). The purposes of this program of field permeability testing are to obtain a permeability data base for test areas at NTS and to develop efficient testing techniques for determining flow characteristics of underground media.

We used previously described experimental[1,2] and calculational[2,3] methods. Pressure measurements were made at the surface and below ground by means of tubes or hoses. Data were transmitted to Livermore and recorded using a computer system and leased telephone lines. Data were taken at intermittent intervals from July to October 1974. Permeability results were obtained by fitting calculated and measured underground pressure response generated by atmospheric pressure changes at the surface. Calculations were made using an analytic solution for Darcy flow in a semi-infinite slab geometry with stepwise, time-varying surface pressure (superposition).

DESCRIPTION OF SITE

The experiment was conducted in Area 2 of the Nevada Test Site. To avoid classification difficulties, we will call this location CB-5 and label the chimney DH-9 and the surface alluvium hole DH-10. The immediate region consists of alluvium to a depth of 300 m (985 ft) underlaid by tuff to a depth of about 457 m (1500 ft). Figure 1 shows a schematic of the experimental set up.

The uncased postshot drill hole enters the chimney (DH-9) at an estimated vertical depth of 260 m (853 ft). A gas sampling tube, 7.3 cm (2-7/8 in.) in diam, was placed to a measured (slant) depth of 285 m (934 ft). An external casing packer was

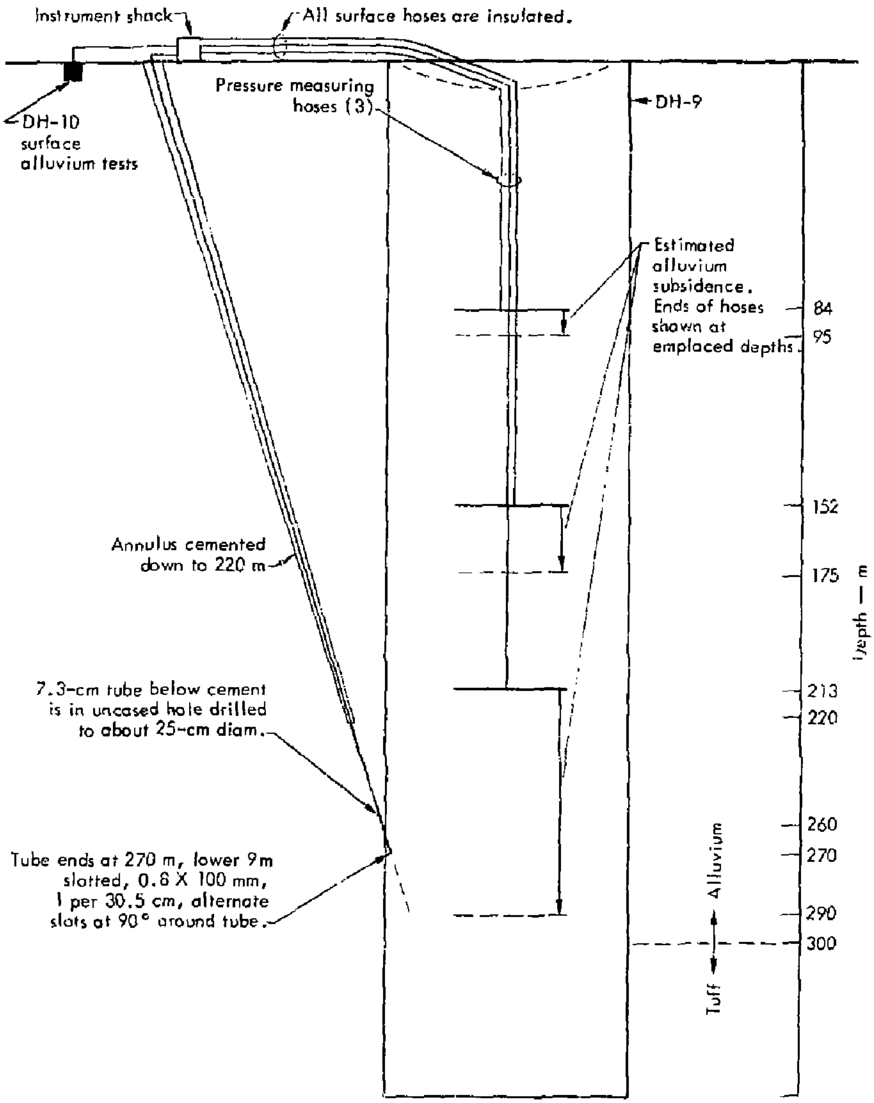

Fig. 1. Schematic of arrangements underground for tests in nuclear chimney, DH-9, and in surface alluvium, DH-10.

set at 233 m (763 ft). The annulus above the packer was filled to the surface with cement. In drilling this hole, fluid circulation was maintained to the surface at a measured depth of 272 m (893 ft).

The surface alluvium test hole (DH-10) was drilled to 30 m (100 ft) with air and, when necessary, foam additives to lift gravel. The hole was about 229 m (750 ft) to the east-south-east of DH-9 at a location judged not to intersect fractures that were visible postshot and closer to the subsidence crater. However, the hole was relocated once after an apparent fracture was encountered during drilling. Two pressure-transmitting tubes 1.3 cm (1/2 in.) i. d. with screened ends were placed in the hole: one at a depth of 30 m (100 ft) and the other at 15 m (50 ft). The hole was back-filled with 1.5-m gravel sections at the tube ends and with low-permeability LLL stemming mix,[4] in the balance of the hole.

An installation of three hose-on-wire rope assembiles was made preshot for an attempt to measure barometric pressures as a function of depth in the chimney after collapse. The hose was 1.9 cm (3/4 in.) i. d., and had a 15.5-MPa (2250-psi) working pressure; the wire rope was 1.4 cm (9/16 in.) o. d. Rupture discs of 6.9-MPa (1000-psi) burst rating were installed in each hose at 38 m (125 ft) depths for gas containment during the shot. Rupture discs of 10.3-MPa (1500-psi) burst rating were installed at the lower end of each hose to permit pressure testing for leaks before postshot pressure measurements were begun through the hoses. Connecting hoses on the surface were 1.6 cm (5/8 in.) i. d. and 91 m (300 ft) long. Leaks were observed in all three between the upper and lower rupture discs after the upper discs were ruptured postshot. We believe the damage occurred during subsidence, thus sharply limiting their usefulness for pressure response measurements.

The surface connection for the tube in the postshot drill hole was a 2.54-cm (1-in.) hose, 76 m (250 ft) long. The same type hose, 46 m (150 ft) long, was used to connect the two tubes in the surface alluvium test hole. The latter hoses were replaced by 6-mm (1/4 in.) copper tubing part way through testing to test the effect of reduced gas volume in these surface lines. Surface lines to the tubes in the postshot hole and the surface alluvium test hole were insulated. Lines to the chimney hoses were not.

EQUIPMENT, SOFTWARE, AND PERFORMANCE

The instrumentation and data acquisition systems have been described in previous reports.[1,2] For this experiment, a special manifolding and solenoid-operated valving system were used to allow sequential sampling of the surface pressure and each of the six underground hoses (four in the chimney region, two in the nearby surface alluvium layer). We set the transducer systems to give an output of 0 to 10 V for the range of 85.3 to 89.3 kPa (640 to 670 mm Hg). Accuracy and precition are ±67 Pa and ±13 Pa (±0.5 mm Hg and ±0.1 mm Hg), respectively. In prior testing, pressure comparisons were made with a precision mercury barometer in the instrument shack. From this, we estimate instrument drift over a 14-day period to be ±40 Pa (±0.3 mm Hg).

As in previous tests, thermistors were used to monitor the temperatures in the hose, the instrument shack, and the thermostatted pressure-transducer enclosure.

An ALPHA-16[*] computer at Livermore transmits valve-control and data-request commands to the PDP-16 computer (at the test location), which digitizes and returns data.[5,6] The two are linked by Prentice data couplers and a dedicated Bell System telephone line. Data were recorded on punched paper tape and as teletypewriter printout.

We experienced signal transmission problems during operation for extended periods of time. Several times data were lost for one to two days, necessitating a restart of the data recording and analysis process. Nevertheless, several 8-day test periods and one 11-day test period were recorded successfully in Livermore. Development tests were made of an on-site tape recording system, but software bugs delayed successful operation until it was too late in the test schedule for use as a data source for analysis.

DATA

Pressure data in this report and as recorded during measurement are in volts, dc. From calibrations at atmospheric pressure, the range of 0 to 10 V represents 85.22 to 89.22 kPa (639.2 to 669.2 mm Hg). Output is linear. We did not convert values from volts to absolute pressure units. For purposes of curve fitting, either unit is appropriate.

Figures 2 and 3 are graphs of the measured atmospheric and underground pressure versus time for the main chimney hose and surface alluvium experiments, respectively. The chimney data interval was taken between August 7 and August 18, 1974, and the surface alluvium data between October 15 and October 23, 1974.

Pressure response measured in the three intermediate-depth hoses in the chimney was apparently dominated by leaks near the surface, and further analysis was therefore not made.

CALCULATIONS AND MATHEMATICAL MODEL

The simplest mathematical model to describe the pressure response at depth in a homogeneous medium is that for linearized, one-dimensional, isothermal, compressible gas flow in a uniform, porous medium[7]:

$$\frac{\partial P}{\partial t} = \alpha \frac{\partial^2 P}{\partial x^2} ,$$

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[*] Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Energy Research and Development Administration to the exclusion of others that may be suitable.

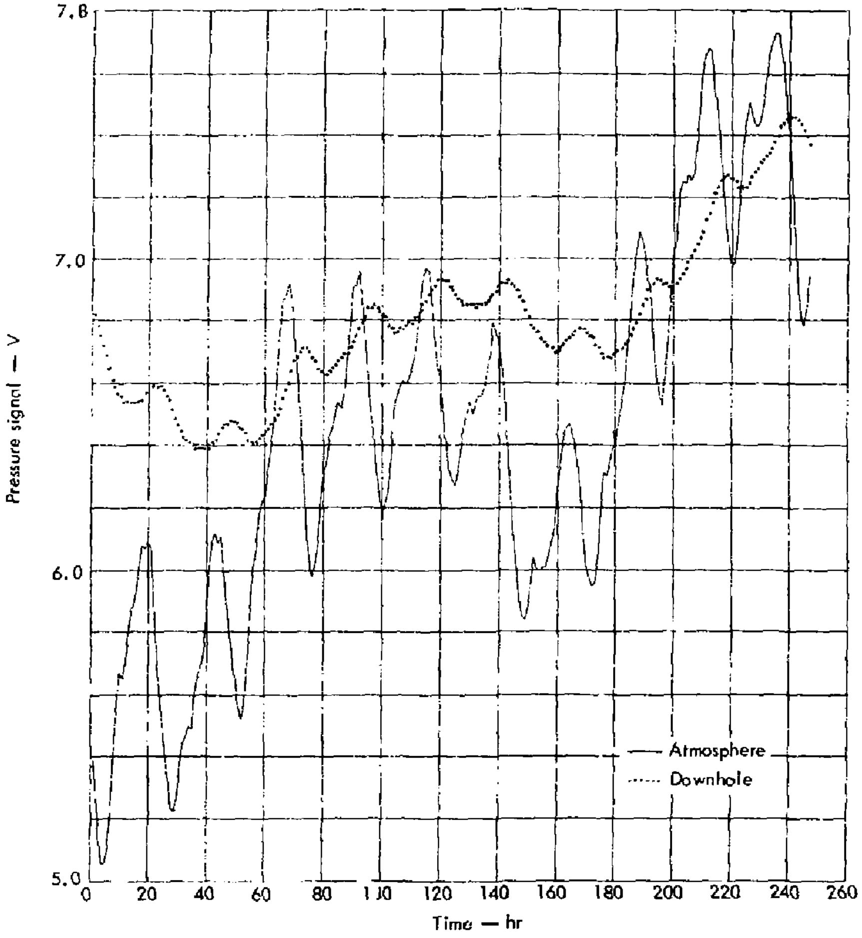

Fig. 2. Measured surface and downhole pressure vs time, chimney experiment (DH-9).

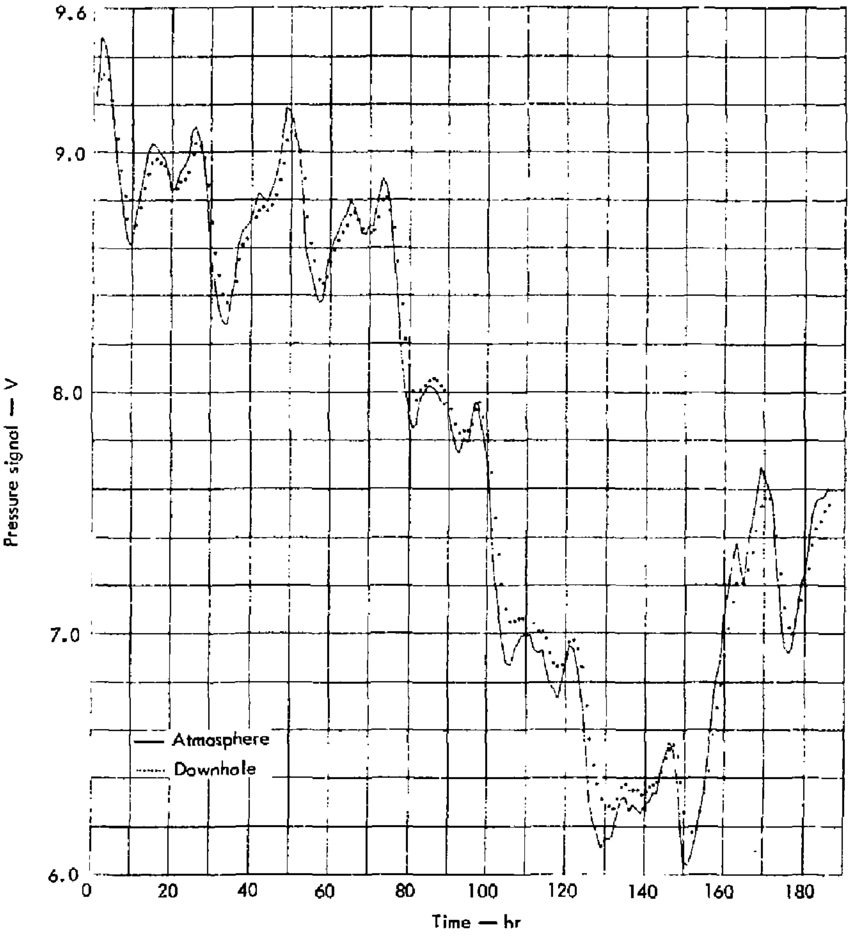

Fig. 3. Measured surface and downhole pressure vs time, surface alluvium (100 ft depth) (DH-10).

where

P = pressure
t = time
x = distance
α = pressure diffusivity.

The pressure diffusivity is the analog of thermal diffusivity in the transient-heat-conduction equation, and is related to the permeability and porosity of the porous or fractured media by

$$\alpha = \frac{K\overline{P}}{\epsilon\mu},$$

where

K = permeability of the medium
ϵ = porosity of the medium
μ = viscosity of the gas
$\overline{P}$ = *mean pressure of the gas.*

As described by Carslaw and Jaeger,[8] a solution to the heat-conduction equation for a semi-infinite slab with zero initial temperature and varying surface temperature can be generated from the solution for the case with constant surface temperature. The method is known as superposition.[9] The resulting expression for P(L, t) is

$$P_\ell = \sum_{n=0}^{\ell-1} (P_{n+1} - P_n) \times \mathrm{ERFC}\left[\left(\frac{L^2}{4\alpha\Delta t(\ell - n)}\right)^{1/2}\right],$$

where

P_ℓ = pressure at ℓth time interval
L = depth in medium
Δt time interval
ERFC complimentary error function.

A computer program,[3] ERFC, written to apply to the above solution, was used with the chimney (DH-9) and surface-alluvium (DH-10) data to predict the downhole response. The predicted and measured downhole pressure histories are plotted with the average values of the data points matched. Since the initial conditions used in the calculations do not match the true condition, the first 100 hr of chimney data and first 48 hr of surface alluvium data are ignored in the averaging process. The averaging takes care of any systematic bias in the measurement such as temperature or density difference between hose and earth, or any offset due to initial conditions or stepwise approximation of the time-varying surface pressure. In most cases, the difference between the averaging process and raw data is less than 27 Pa (0.2 mm Hg).

CALCULATED RESULTS

The results are shown in Figs. 4 and 5. The best or optimum value of $(L^2/4\alpha\Delta t)$ is determined by using the criterion of minimum sum of squared deviations for all data points for $t > 100$ hr for the chimney data and $t > 48$ hr for the surface data.

Using the optimum value of 7.3 for $L^2/4\alpha\Delta t$ and L of 260 m and a Δt between data samples of 1 hr, α for the chimney is calculated to be 0.64 m^2/s. Using an average pressure of 85 kPa (646 mm Hg) and an air viscosity of 0.018 mPa · s (0.018 centipoise), K/ϵ is calculated to be about 136 μm^2 (darcies). This agrees with other chimney experiments. For the surface alluvium, the calculated value of α is 1.0 m^2/s and K/ϵ is about 214 μm^2. The surface values are higher by a factor of about 5 to 10 compared to previous experiments. We do not have any firm explanation for the high surface values, but both the 15 m and 30 m surface alluvium hose measurements agreed, indicating internal consistency.

Table 1 shows the complete set of field permeability measurements including some early compressed air injection experiments.

Table 1. Indicated in situ values of pressure diffusivity and permeability from field experiments in Yucca Flat.

Site[a]	Area	Material region	Permeability μm^2 (D)[b]	Pressure diffusivity (m^2/s)	Test date	Remarks	Ref.
[illegible] 30.5	6	Alluvium Vitric tuffs G.C.[c] ashfall tuff Undifferentiated tuffs Carbonate rock	8.1 12.7 3.[illegible] 2.5 2.0		July 7-14, 197[illegible]	Radial steady state. Air injection.	12
U10AM-a	10	Alluvium	8-16		July 20-21, 1971	Radial steady state. Air injection.	11, 12
CB-1, DH-3 and 4 DH-3, recalc'd	10	Chimney in alluvium	25-50 62[d]	1.0	May 19-2[illegible], 1972	Atmospheric-pressure method.	1, 3
CB-2, DH-5 DH-5, recalc'd	2	Chimney in alluvium	10[d] 1[d]	0.2	March and April, 1973	Atmospheric-pressure method.	1
CB-3, DH-6 DH-6 recalc'd	2	Chimney in alluvium	33-66 30[d]	0.5-1.0 1.0	Nov. 29-Dec. 22, 1973	Atmospheric-pressure method.	2 3
CB-4, DH-7 and DH-8	6	Alluvium and chimneyed tuff	7[d]	0.1	Feb. and March, 1974	Atmospheric-pressure method (no surface collapse).	4
	6	Surface alluvium	7[d]	0.1			
CB-5 and DH-9	2 2	Alluvium Surface alluvium	41[d] 70[d]	0.6 1.5	July-Oct., 1974	Atmospheric-pressure method.	

[a] CB numbers are sequential test-site numbers. DH numbers are sequential hole numbers, one or more per test location.

[b] Since 1 darcy = 0.987 μm^2, the numbers in this column are essentially also in darcies.

[c] G.C. = Grouse Canyon.

[d] Porosity of 0.3 used arbitrarily to obtain these values from the pressure diffusivity.

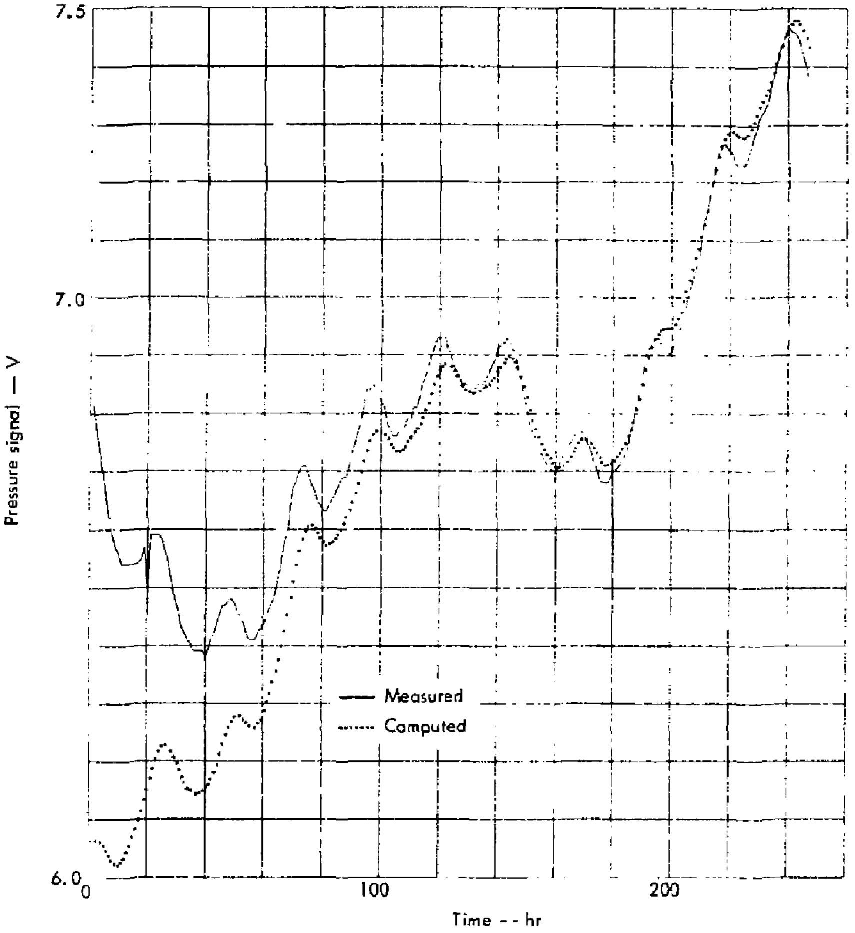

Fig. 4. DH-9 chimney experiment. Comparison of computer and measured downhole pressure. (Best fit with $L^2/4\alpha\Delta t = 7.3$.)

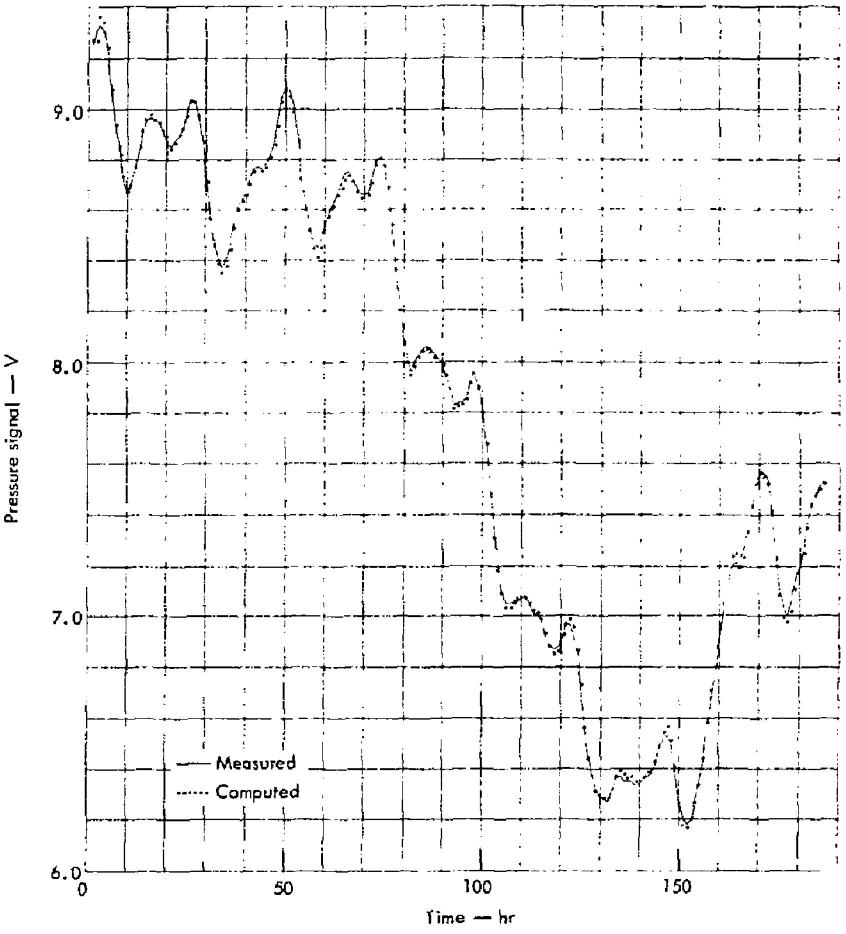

Fig. 5. DH-10 surface alluvium experiment (30 m). Comparison of computed and measured pressure. (Best fit with $L^2/4\alpha\Delta t = 0.064$.)

REFERENCES

1. D. F. Snoeberger, J. Baker, and C. J. Morris, Measurements and Correlation Analysis for Nuclear Chimney Permeability, Lawrence Livermore Laboratory, Rept. UCID-16302 (1973).
2. D. F. Snoeberger, C. J. Morris, and J. Baker, Data and Results, Nuclear Chimney Permeability – Test 3, Lawrence Livermore Laboratory, Rept. UCID-16436 (1974).
3. R. B. Rozsa, D. F. Snoeberger, and J. Baker, Chimney Permeability Data Analysis, Lawrence Livermore Laboratory, Rept. UCID-16440 (1974).
4. D. F. Snoeberger, J. Baker, C. J. Morris, and R. B. Rozsa, Permeability of a Nuclear Chimney and Surface Alluvium at the AEC Nevada Test Site, Lawrence Livermore Laboratory, Rept. UCID-16479 (1974).
5. J. Z. Grens, ALPHA – An Interactive Language for the ALPHA-16 Computer, Lawrence Livermore Laboratory, Rept. UCID-16328 (1973).
6. J. Baker, The LLL PDP-16 Data Acquisition System, Lawrence Livermore Laboratory, Rept. UCRL-75216 Preprint (1973).
7. V. Streeter, Ed., Handbook of Fluid Dynamics (McGraw Hill, New York, 1961) 15th ed., Sec. 16.
8. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids (Clarendon Press, Oxford, 1959) 2nd ed., p. 63.
9. C. S. Mathews and D. G. Russell, Pressure Buildup and Flow Tests in Wells (Society of Petroleum Engineers of AIME, Dallas, 1967) p. 14.
10. G. A. Morris, D. F. Snoeberger, C. J. Morris, and V. L. DuVal, Field Measurements of Permeability of NTS Alluvium in Area 10, Lawrence Livermore Laboratory, Rept. UCID-15919 (1971).
11. R. B. Rozsa, Permeability of NTS Alluvium – Numerical Simulation of Air-Injection Experiments, Lawrence Livermore Laboratory, Rept. UCID-15791 (1971).
12. D. F. Snoeberger, C. J. Morris, and G. A. Morris, Field Measurement of Permeabilities in NTS Area 9, Lawrence Livermore Laboratory, Rept. UCID-15895 (1971).
13. D. F. Snoeberger, G. A. Morris, and R. Rozsa, Chimney Permeability by Atmospheric Pressure Change – Preliminary Permeability Calculations, Lawrence Livermore Laboratory, Rept. UCID-16161 (1972).

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