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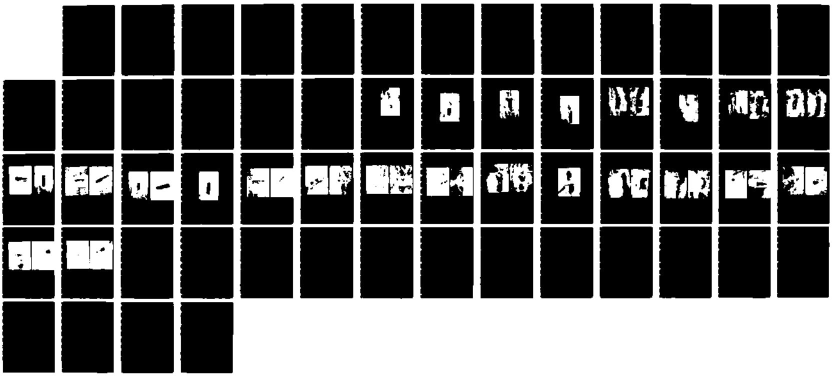

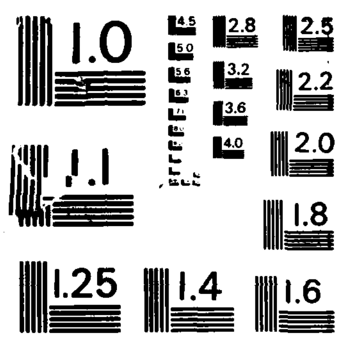

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RECOVERY OF MILL RACE GROUND MOTION CANISTERS AND EXAMINATION OF CANISTER EMPLACEMENT

C. T. Vincent
J. C. Cheeseborough
Physics Applications, Inc.
930 South La Brea Avenue
Suite 2
Los Angeles, CA 90036-4807

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Technical Report

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The canisters used for the strain-path project of the MILL RACE program were excavated, along with their emplacement grout, to find out why the grout had often risen to higher levels than those expected from borehole and canister geometry, and because some large variations in ground motion measurements from adjacent canisters could have been due to faulty canister installation. In most cases it was found that the canisters were embedded only partly in grout, and, in 11 of the 24 holes, half or more of the canister's surface proved to be grout-free; dirt had fallen from the side-walls to the bottoms of boreholes before or during grouting. However, no significant correlation was found at Applied Theory, Inc. between the degree of grouting and anomalies in ground-motion records.

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PREFACE

The purpose of this report is to document the efficacy of the gauge emplacement technique used in the MILL RACE Strain Path experiment through postshot examination of gauge canisters.

The field work reported herein was carried out by the authors with the able assistance of Mr. James Ingram of Waterways Experiment Station, U. S. Army Corp. of Engineers. Heavy equipment operators were provided under the auspices of DNA Field Command, Lt. Cmdr. Gary Reid.

The correlation between the degree (completeness) of canister grouting and both ground motion and the associated strain paths was examined and reported (Appendix) by Dr. James W. Workman of Applied Theory, Inc.

CONVERSION TABLE

1 meter = 3.28 ft. = 39.4 in.
1 centimeter = 0.033 ft. = 0.394 in.

1 foot = 0.305 m = 30.5 cm
1 inch = 0.025 m = 2.54 cm

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LIST OF ILLUSTRATIONS

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SECTION 1

INTRODUCTION

As part of the MILL RACE event, ground motion gages were deployed along two lines to measure strain paths. The volume of the grout used to emplace the canisters was measured in most of the boreholes along one line. In those boreholes, the depth below ground of the top surface of the hardened grout was also measured. Judged by that depth, the holes were often smaller in volume than the apparent canister/borehole geometry would permit - even though drilling foam was recirculated through the drill bit at the bottoms of several holes in an attempt to enlarge them at depth. In addition, large differences in ground motion were reported by MILL RACE instrument canisters as close together as 2 meters. It was reasonable to suspect that faulty emplacement of the canisters was the cause of the anomalous results. An effort was therefore undertaken by Physics Applications, Inc. in cooperation with the Defense Nuclear Agency to determine the actual gage/soil configuration in situ and especially to find out why, in a number of cases, grout around the gages extended farther uphole than expected.

Measurements of ground motion in explosive events have traditionally been made using buried instrumentation packages containing motion transducers of various kinds. These instrumentation packages were typically installed by first drilling a hole of the correct depth and diameter to emplace the instrument canister. The package was lowered into the hole to a depth slightly above the bottom and rotated to its correct orientation. A hose was then lowered to the hole bottom and the grout was pumped into the hole through the hose. The package was held in position while the hole was filled with the grout to a specified height above the top of the canister. The installation was completed by allowing the grout to harden and then backfilling the hole with the original material.

The grout used for the canister installation in this experiment was a chemical grout designated MILL RACE Quick-Set Grout (Reference 1). The setting time is short for this grout and it expands as it hardens. It was believed that expansion of the grout was adequate to provide good coupling of the package to the surrounding medium, and that the grout was dense enough to displace small amounts of drilling foam and cuttings which might have fallen into the hole while the canister was being emplaced.

The usual canister emplacement procedures were modified to meet the need for accurate as-built coordinates of the installed canister (+/-1 in.). Specifically, the medium for this experiment was a multilayered alluvium ranging from compacted sandy silt to uncemented gravels. As a result the borings were unstable and had to be drilled with foam to meet project requirements for a dry medium. Further, it was believed that the attempts to enlarge the hole bottoms increased the instability of the borings at the hole bottoms. The danger of hole collapse argued for rapid canister emplacement. However, the instrument devised for this purpose made it impossible to lower the grout hose below the canister. As a result the grout hose was lowered to a height just above the top of the canister. Enough grout was then pumped in to provide 4 to 6 inches of grout above and below the canister. When the grout had hardened sufficiently, the emplacement tool was removed. The top of the grout was measured and an increase or decrease in the hole-bottom volume was computed. The remaining hole was backfilled with masonry sand.

SECTION 2

EXPERIMENTAL

The method used to recover the MILL RACE canisters was to dig a large trench along the instrument line and then widen the trench using heavy equipment and finally hand tools to individually expose each canister. When a canister was partially excavated it was examined and photographed, after which the removal was completed with a pick axe and pry bar allowing a qualitative evaluation to be made of the canister coupling to the surrounding medium. After the canister was fully removed from the medium it was again examined and photographed. The emplacement positions of the instrument canisters recovered in this effort are shown in the shot lay-out diagrams in Figures 1 and 2. The canisters are referred to by their position numbers. The format of the canister position numbers is the shot line number followed by the approximate range and the position number of the canister in the instrument cluster (refer to Figure 2).

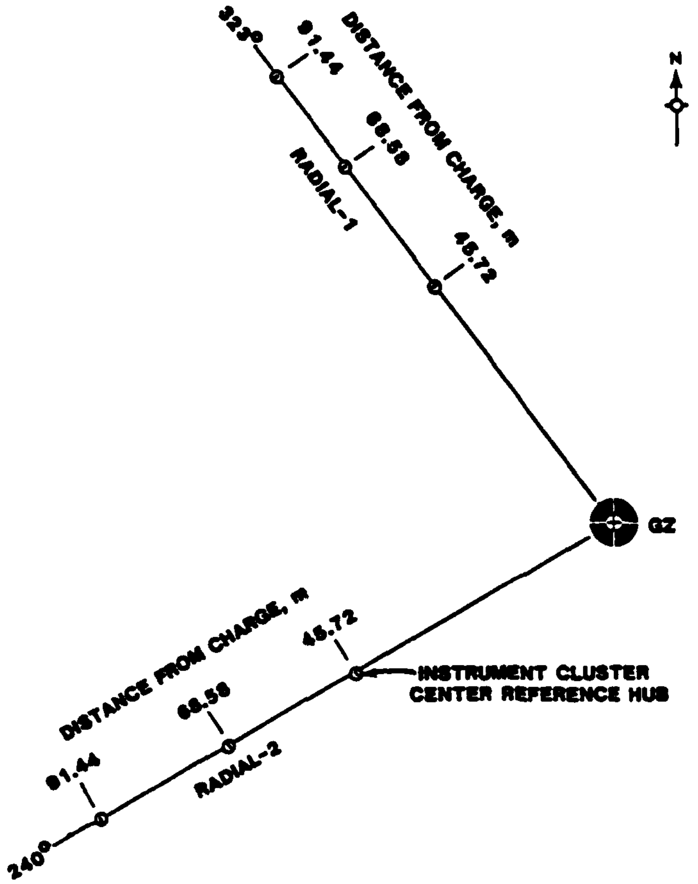


Figure 1. Strain path instrumentation layout diagram.

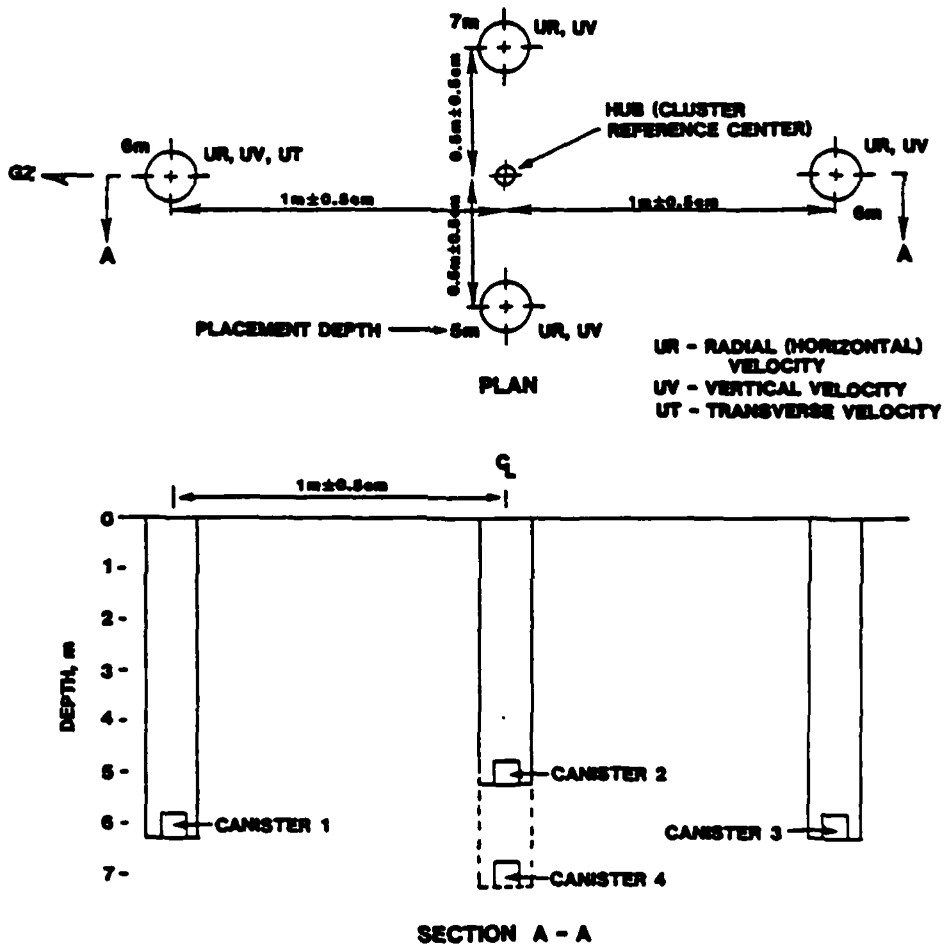


Figure 2. Strain path instrumentation cluster layout.
(Cluster range is measured from center hub)

SECTION 3

RESULTS

In the following paragraphs, which describe the findings at each canister position in numerical order, references are made to "void" and "exposed" areas. By "void" is meant a cavity in the grout cylinder, typically filled with dislodged soil and/or cuttings. Exposed areas are those parts of a canister surface that pressed directly against the intact medium. A summary of the findings at each canister position is provided in Table 1.

Figures 27 through 32 are diagrams of the soil stnata at each canister location. These diagrams were compiled from the boring logs obtained in the process of drilling each hole and from observations of the trench wall during the recovery excavation.

The soil strata found at the sites where the canisters were most exposed did not seem to be substantially different from those at the sites where the canisters were less exposed. Further, the type of soil found to be bonded to the canisters and in the voids was basically the same at each site. Typically the soil was a silty sand which in some instances contained drill cuttings, coarse sand or small pebbles.

Figure 3. The unearthed 1-150-1 canister.

1-150-1: The canister was found to be approximately 50% exposed. About 70% of the bottom of the canister was exposed indicating that a moderate amount of soil had fallen into the bottom of the hole before the canister was lowered into place. Apparently, the soil had fallen to one side of the hole or was pushed there by the grout, since the grout extends for several inches below the bottom of the canister on only one side. The wall of the canister was exposed for more than 180 degrees with a small void on top of the canister indicating that more soil had fallen in after the canister was lowered. The grout was strongly bonded to both the canister walls and to the surrounding soil. Interestingly, the soil in contact with the canister walls also bonded to the canister. Further, the soil in the void or exposed areas appeared to have been compressed by the expansion of the grout creating a fairly good coupling even where the canister was exposed.

Figure 4. The 1-150-2 canister, partially excavated.

1-150-2: The canister was found to be completely covered with grout. The grout was firmly bonded to both the canister wall and to the surrounding medium. There were about 8 inches of cemented cuttings below the canister bottom and about 9 inches of grout above the canister. The thickness of the grout was about an inch and a half on one side of the canister and about half an inch on the other side.

Figure 5. The 1-150-3 canister, partially excavated.

1-150-3: More than 30% of the surface was exposed. About 10% of the canister bottom was exposed indicating that a small amount of soil had fallen into the bottom of the hole before grout reached the bottom of the canister. More than 100 degrees of the canister side was exposed and a small void was also observed on the top on the same side as the exposed portion of the wall. Since so little of bottom was exposed, it seems likely that soil fell into the hole during grouting. The soil in the void and exposed areas seemed to have been compressed by the expansion of the grout. The grout was strongly bonded to the walls of the canister and to the surrounding medium. Again the soil in contact with the canister wall was also bonded to the canister.

Figure 6. The 1-150-4 canister, partially excavated.

1-150-4: The canister was found to be completely grouted in. The length of the grout cylinder was about 55 inches, and a curved tongue of grout extended downward from the bottom of the main cylinder for about 6 inches. The grout was firmly bonded to the surrounding medium.

a. Partially excavated. b. Fully excavated.

Figure 7. The 1-225-1 canister, partially and fully excavated.

1-225-1: Roughly 65% of the surface was exposed. The grout extended several inches below the bottom of the canister, yet more than 3/4 of the canister bottom was exposed and the grout occupied only one side of the hole below the canister bottom. It is likely that a substantial amount of soil was present in the bottom of the hole and was pushed to one side by the grout. The grout continued up the same side of the canister leaving about 240 degrees of the canister wall exposed. Further, a void was observed on the top of the canister on the same side as the exposed portion of the wall, possibly due to more soil that had fallen in on top of the canister before the grout had reached that level. The grout seemed, however, to be bonded strongly to the canister wall and to the surrounding medium. The soil in contact with the canister had bonded to the canister wall. The surrounding soil also showed signs of having been compressed by the grout.

Figure 8. The 1-225-2 canister, partially excavated.

1-225-2: The canister was about 50% exposed, with grout extending about 6 inches below the bottom of the canister on the grouted side. Eleven inches of grout lay above the canister, the lower 3 inches of which contained drill cuttings. The grout was found to be firmly bonded to the canister wall and to the surrounding medium.

a. Partially excavated.

b. Fully excavated.

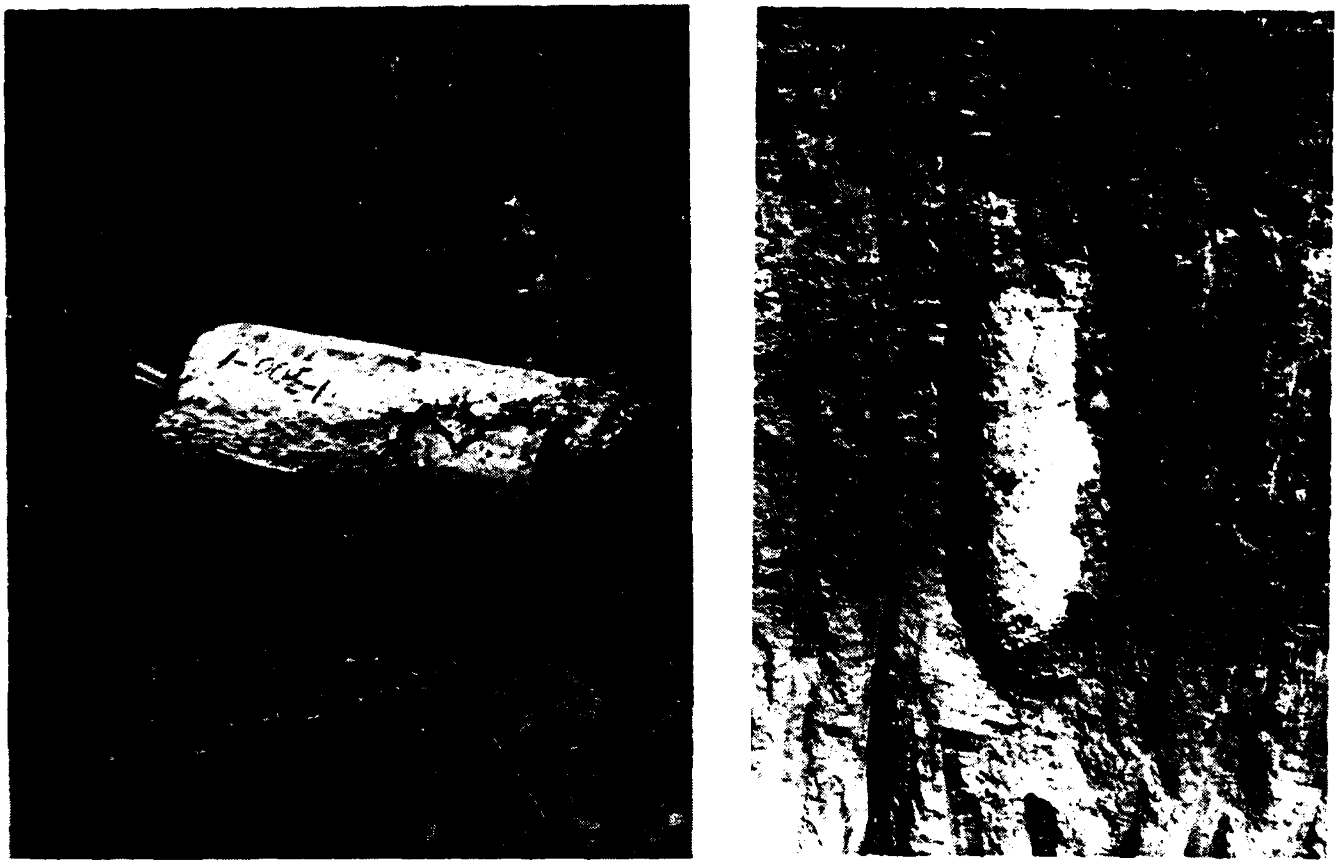
Figure 9. The 1-225-3 canister, partially and fully excavated.

1-225-3: The canister was roughly 50% exposed. Its entire bottom was exposed, indicating that a large amount of soil had fallen into the bottom of the hole partially burying the canister before the grout was pumped in. About 180 degrees of the canister wall is exposed and there was a moderate sized void on top of the canister on the same side as the exposed bottom. This would indicate that soil had fallen into the hole around the canister before the grout was being pumped in. The grout was strongly bonded to the canister wall and to the surrounding medium. The soil in contact with the canister wall had also bonded to the canister.

a. Partially excavated. b. Fully excavated.

Figure 10. The 1-225-4 canister, partially and fully excavated.

1-225-4: The canister was found to be roughly 70% exposed. The entire bottom of the canister including the wall up to a height of about one inch, and 180 degrees of the canister wall were exposed. This indicates that a large amount of soil was falling to the hole bottom both below and around the canister prior to the arrival of the grouting material. The discontinuous slope of the soil/grout interface at this level suggests that soil continued to fall downhole during the grouting process. In addition, a moderate sized void was observed on the top of the canister where soil had fallen prior to the arrival of the grout. The grout was strongly bonded to the canister wall and to the surrounding medium. The surrounding soil was also bonded to the canister wall.

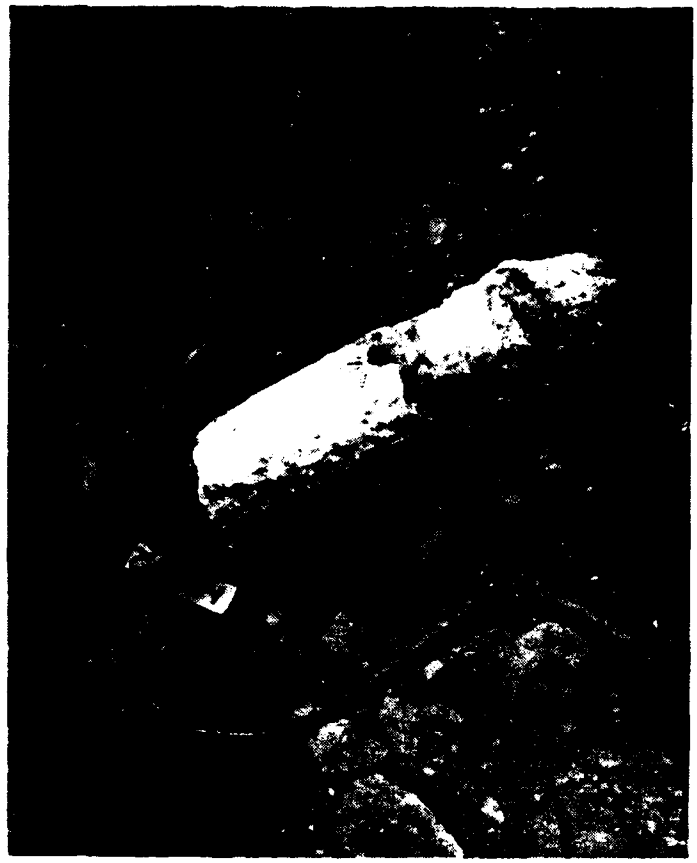


a. Fully excavated. b. Partially excavated.

Figure 11. The 1-300-1 canister, partially and fully excavated.

1-300-1: About 40% of the surface was exposed. The bottom of the canister was about 50% exposed with the grout continuing for several inches below the canister bottom. Apparently, there was a substantial amount of soil in the hole bottom when the grout was pumped in; that soil may have been pushed to one side by the falling grout. About 180 degrees of the canister wall was exposed with a small void on the top on the same side. The grout in this case is bonded strongly to the canister wall and to the surrounding medium. The soil in contact with the canister wall is also bonded to the canister.

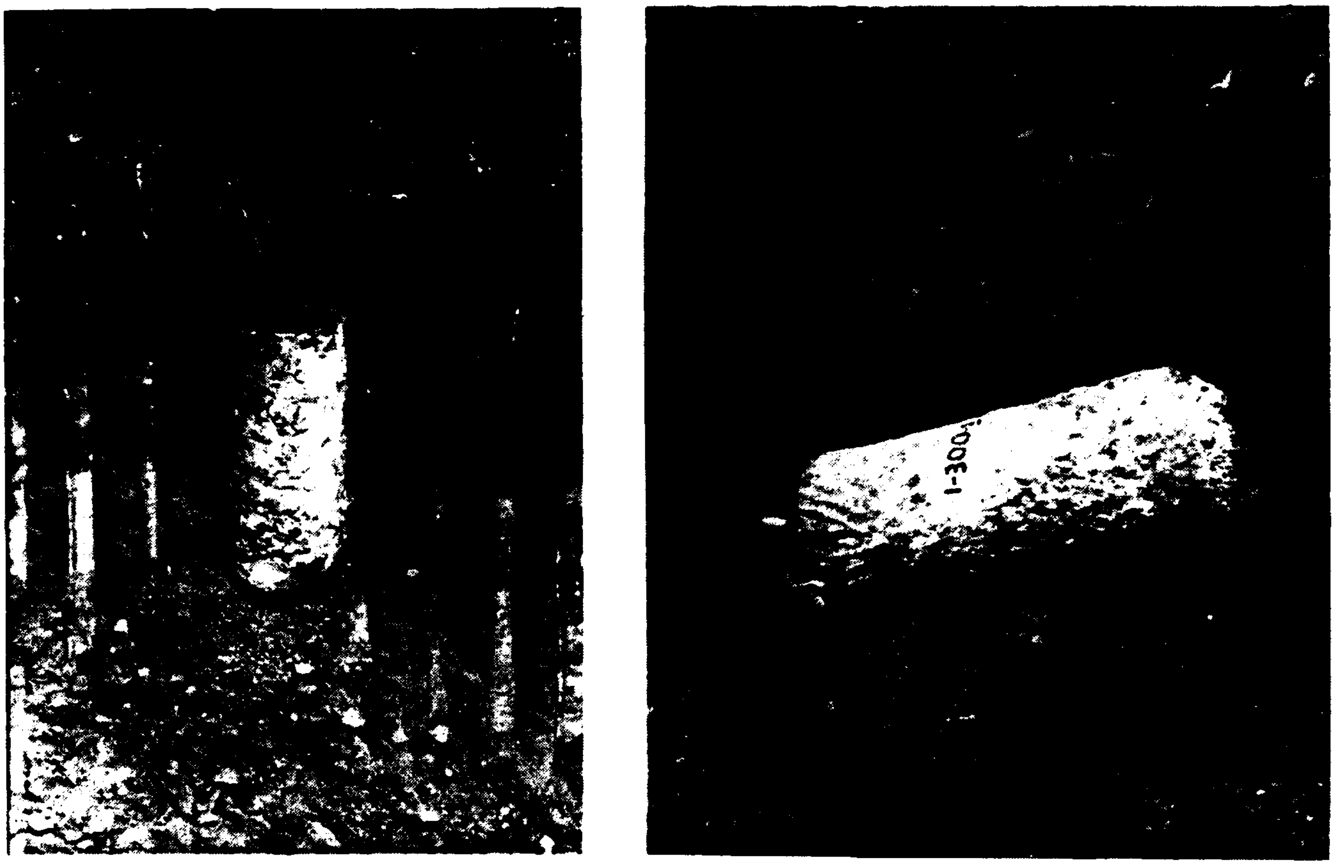
a. Partially excavated.



b. Fully excavated.

Figure 12. The 1-300-2 canister, partially and fully excavated.

1-300-2: The canister was found to be roughly 30% exposed. The bottom of the canister was about 30% exposed along with roughly 120 degrees of the canister wall. There was also a large void on the top of the canister on the same side as the exposed wall. The observed distribution of soil and grout could have resulted from the fall of soil into the hole before grouting. The grout was strongly bonded to the canister wall and to the surrounding medium. The soil in contact with the canister wall was also bonded to the canister.



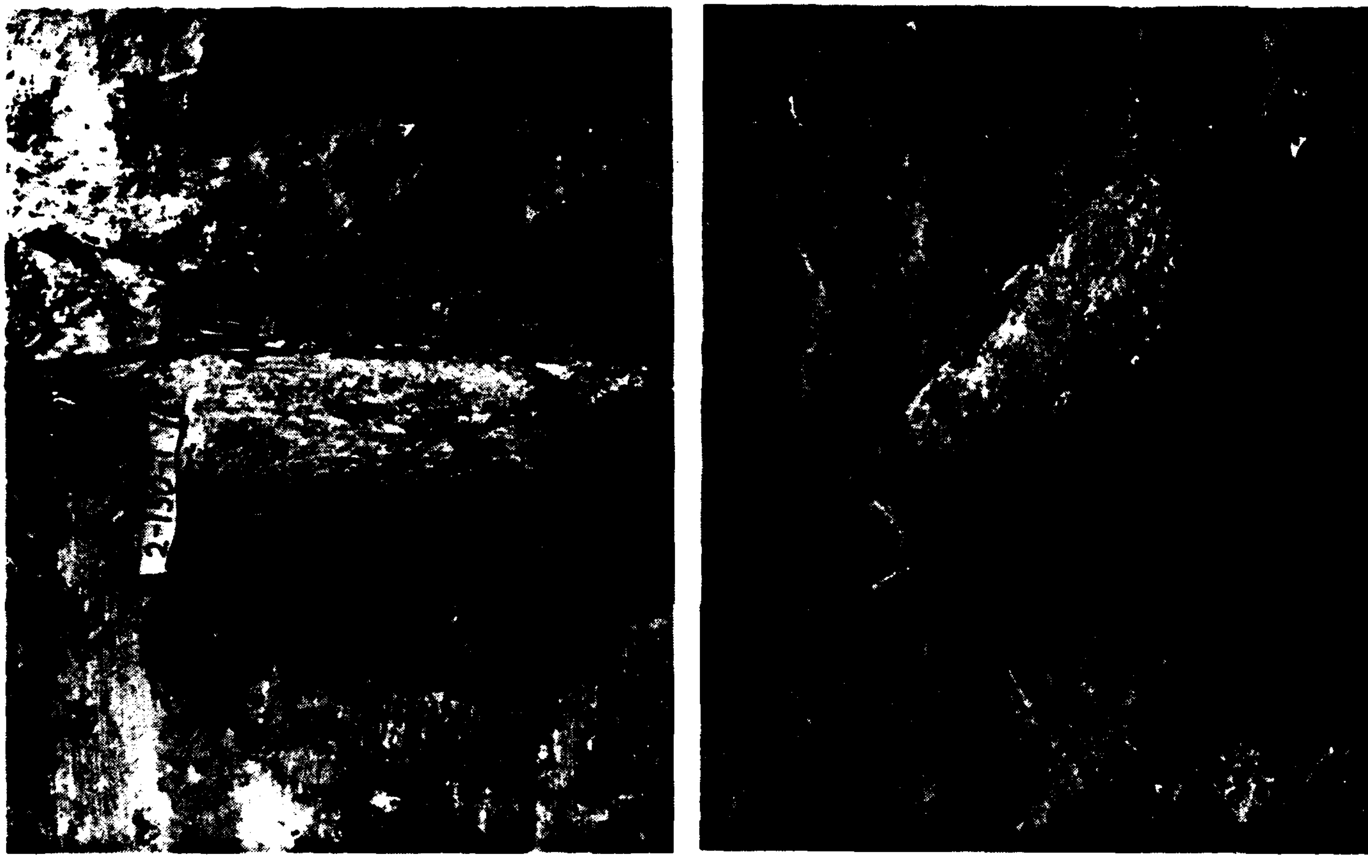
a. Partially excavated. b. Fully excavated.

Figure 13. The 1-300-3 canister, partially and fully excavated.

1-300-3: The canister was found to be fully grouted in. There were no exposed areas or voids observed. The grout was firmly bonded to the surrounding medium.

Figure 14. The 1-300-4 canister, fully excavated.

1-300-4: The canister was found to be completely covered with grout and the grout was strongly bonded to the surrounding medium.

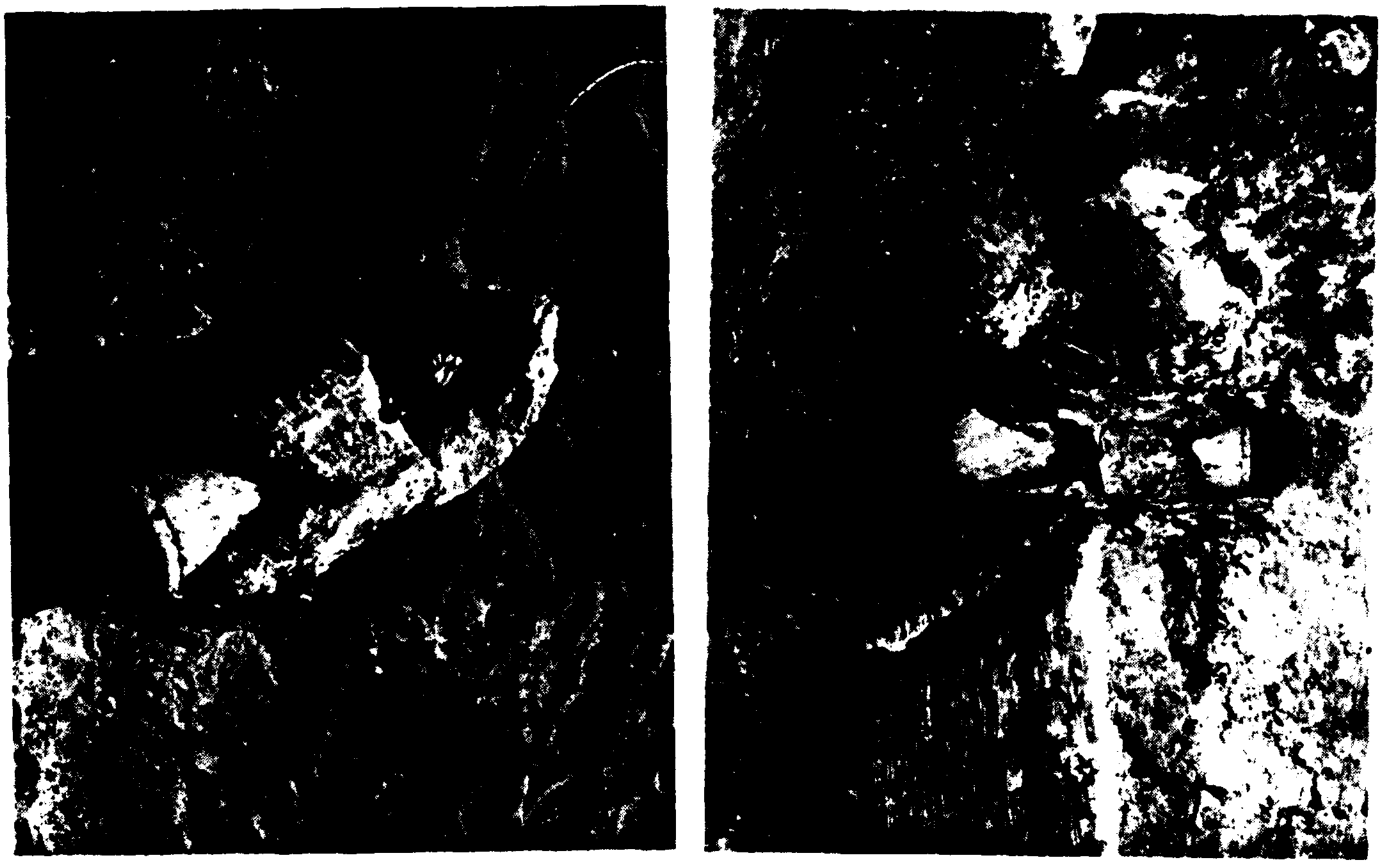


a. Partially excavated.

b. Fully excavated.

Figure 15. The 2-150-1 canister, partially and fully excavated.

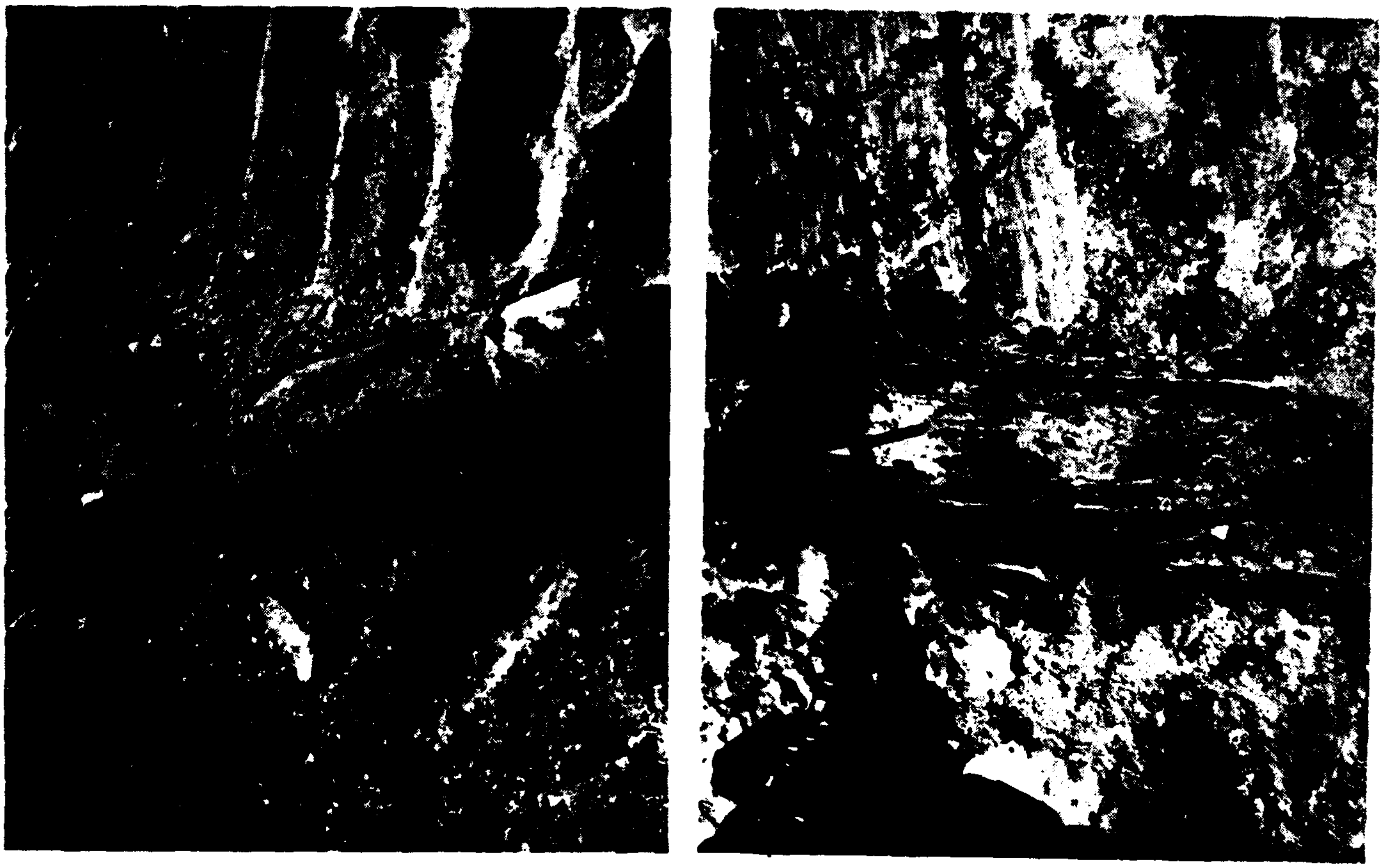
2-150-1: The canister had no exposed areas. Grout completely covered the canister and was strongly bonded to the surrounding medium.



a. Fully excavated. b. Partially excavated.

Figure 16. The 2-150-2 canister, partially and fully excavated.

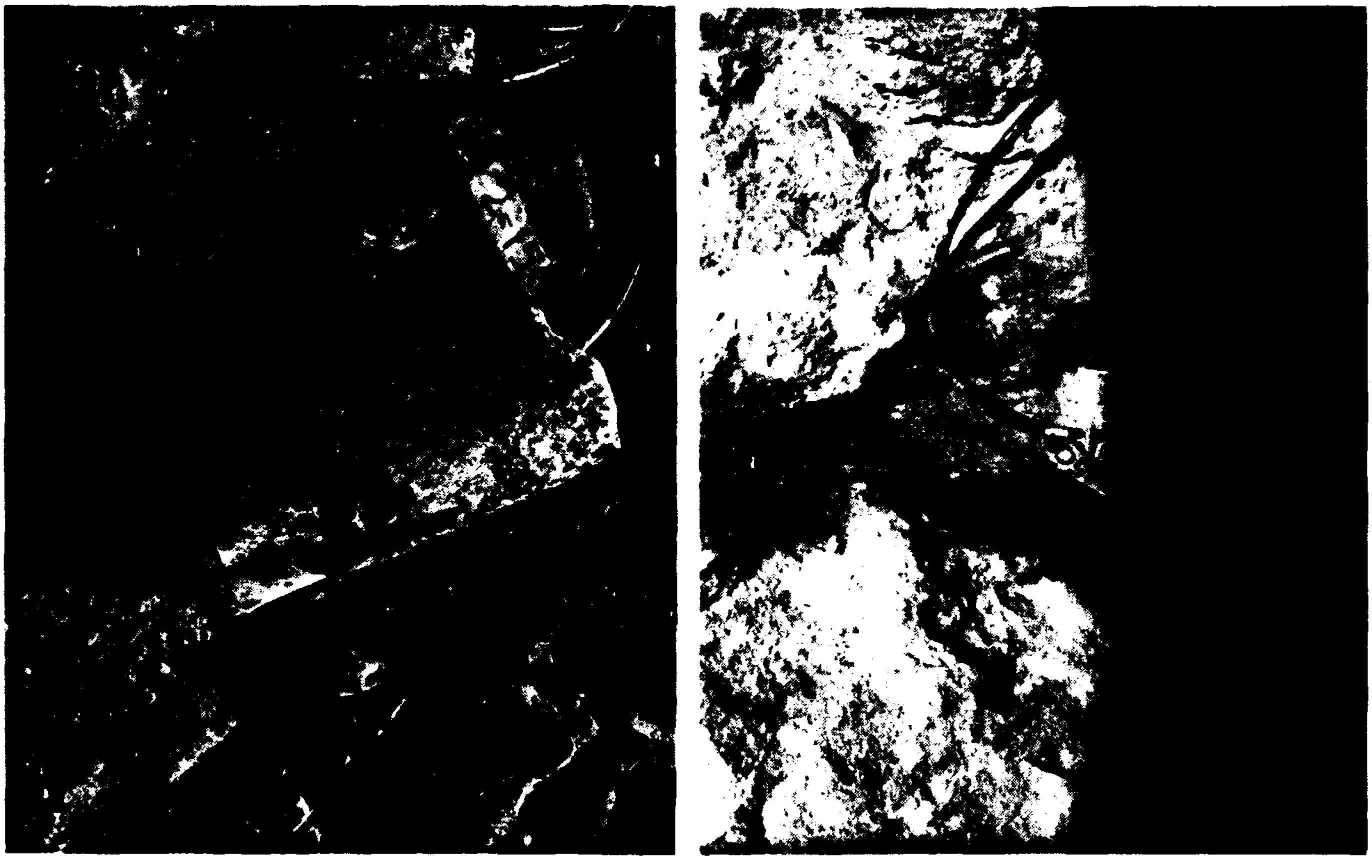
2-150-2: About 65% of the surface was exposed, including the entire bottom of the canister and the canister wall up to a height of slightly more than an inch. Evidently, a substantial amount of soil had fallen into the hole before the grout was pumped in. Roughly 270 degrees of the canister wall was exposed, yet there was no indication of voids on the canister top. A portion of the grout cylinder above the canister was dislodged during excavation. The grout was strongly bonded to the canister wall and to the surrounding medium. The soil in contact with the canister was also bonded to it.



a. Fully excavated. b. Partially excavated.

Figure 17. The 2-150-3 canister, partially and fully excavated.

2-150-3: Roughly 75% of the surface was exposed. The entire bottom of the canister including the canister wall up to about an inch and a half was exposed. About 270 degrees of the canister wall was also exposed and there was a moderate void on the top of the canister. This pattern of soil and grout probably resulted from soil falling into the hole prior to grouting. The grout was found to be strongly bonded to both the canister and to the surrounding medium. The soil in contact with the canister was also bonded to it. The soil contained in the void area showed signs of having been compressed by the grout.



a. Fully excavated. b. Partially excavated.

Figure 18. The 2-150-4 canister, partially and fully excavated.

2-140-4: Roughly 35% of the surface was exposed. About 50% of the bottom and 180 degrees of the wall were exposed. There was no sign of voids on the top of the canister and the grout extended for several inches below the canister bottom. It is likely that the observed pattern of soil and grout was the result of soil falling into the hole prior to grouting. The grout was strongly bonded to the canister wall and to the surrounding medium. The soil in contact with the canister wall was also bonded to it.

a. Fully excavated. b. Partially excavated.

Figure 19. The 2-225-1 canister, partially and fully excavated.

2-225-1: The canister was roughly 65% exposed. The entire bottom of the canister including the canister wall up to a height of slightly less than one inch was exposed. About 180 degrees of the canister wall was also exposed and there was a moderate void on the top of the canister. Evidently there was a large amount of soil in the bottom of the hole when the canister was emplaced. The grout was found to be strongly bonded to both the canister wall and to the surrounding medium. The soil in contact with the canister wall was also bonded to it. The soil in the top void had apparently been compressed significantly by the pressure exerted by the mass and expansion of the grout.

Figure 20. The 2-225-2 canister, fully excavated.

2-225-2: The canister was about 95% exposed. A small amount of grout was found in contact with the canister top surface. The result is that the canister was not grouted in.

a. Fully excavated.

b. Partially excavated.

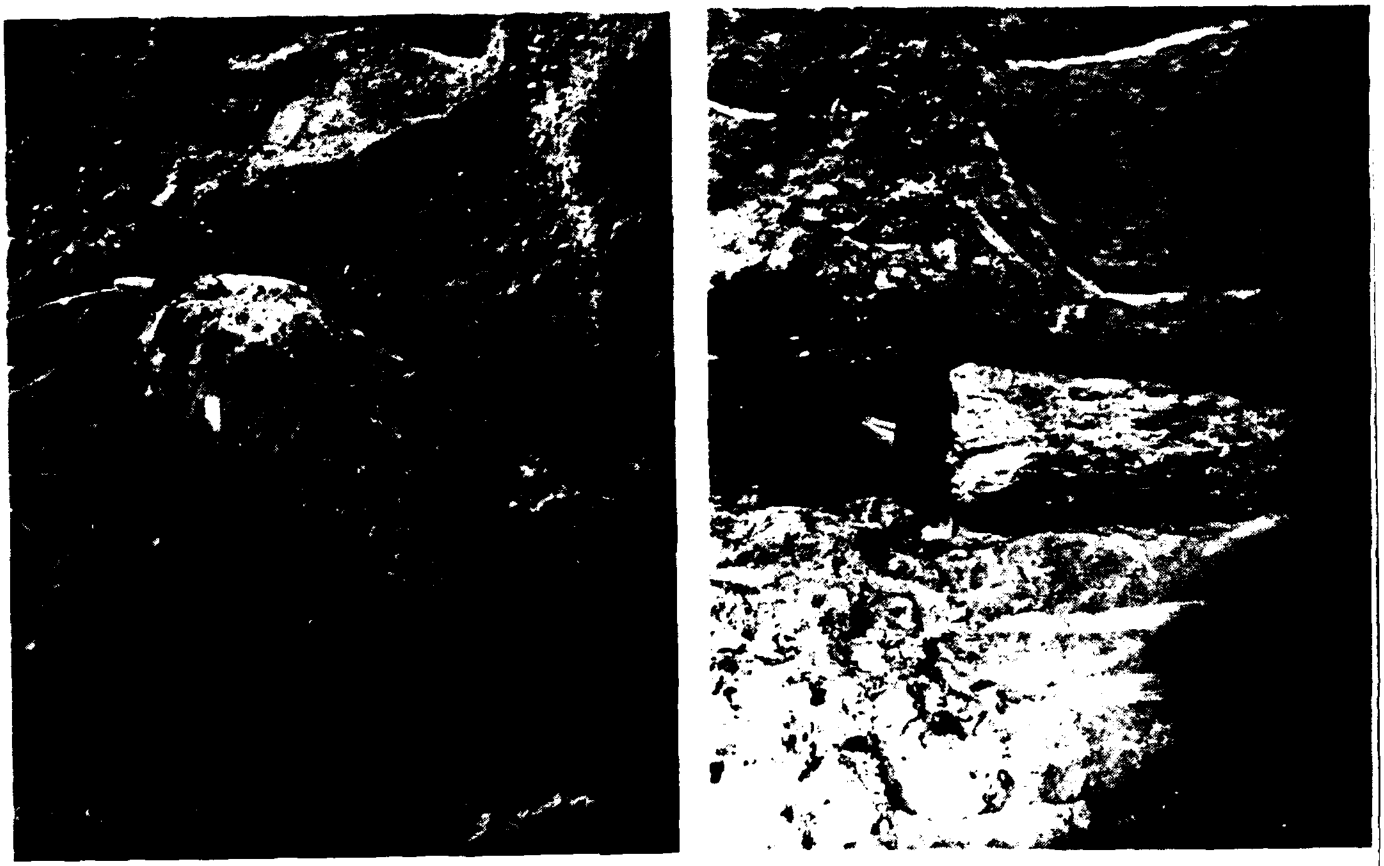
Figure 21. The 2-225-3 canister, partially and fully excavated.

2-225-3: Only about 5% of the surface was exposed. The exposed patch on the canister wall, which measured about 1-1/2 inches wide and 4 inches long, was the only exposed portion of the canister. The canister probably lay on one side of the hole when it was grouted in. The canister was well covered with grout and the grout had bonded strongly to the surrounding medium.

a. Partially excavated. b. Fully excavated.

Figure 22. The 2-225-4 canister, partially and fully excavated.

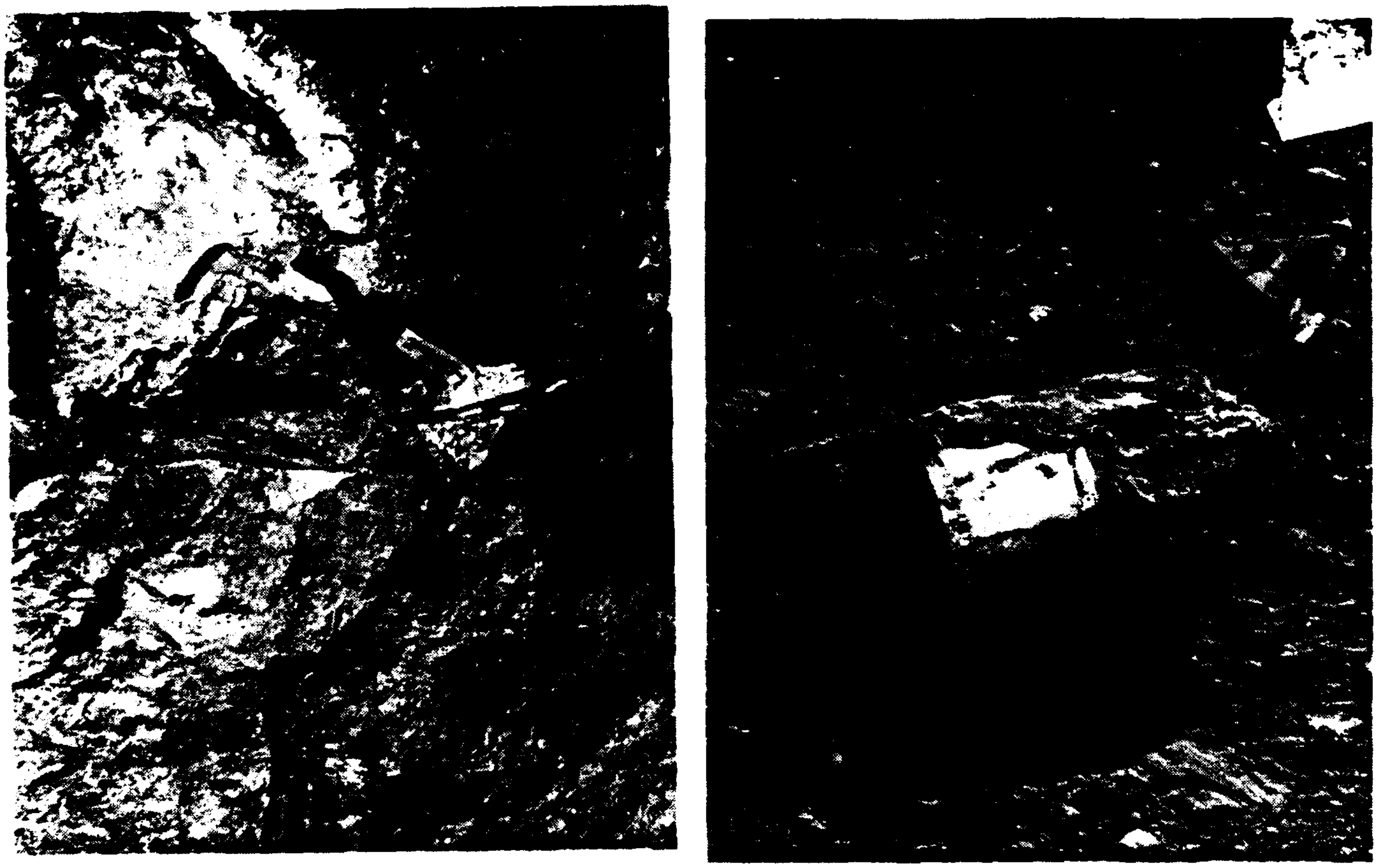
2-225-4: The canister was fully exposed, indicating that soil falling to the bottom of the hole had completely buried it before grouting began.



a. Fully excavated. b. Partially excavated.

Figure 23. The 2-300-1 canister, partially and fully excavated.

2-300-1: The canister was completely covered with grout showing no sign of exposed areas. The grout was strongly bonded to the surrounding medium.

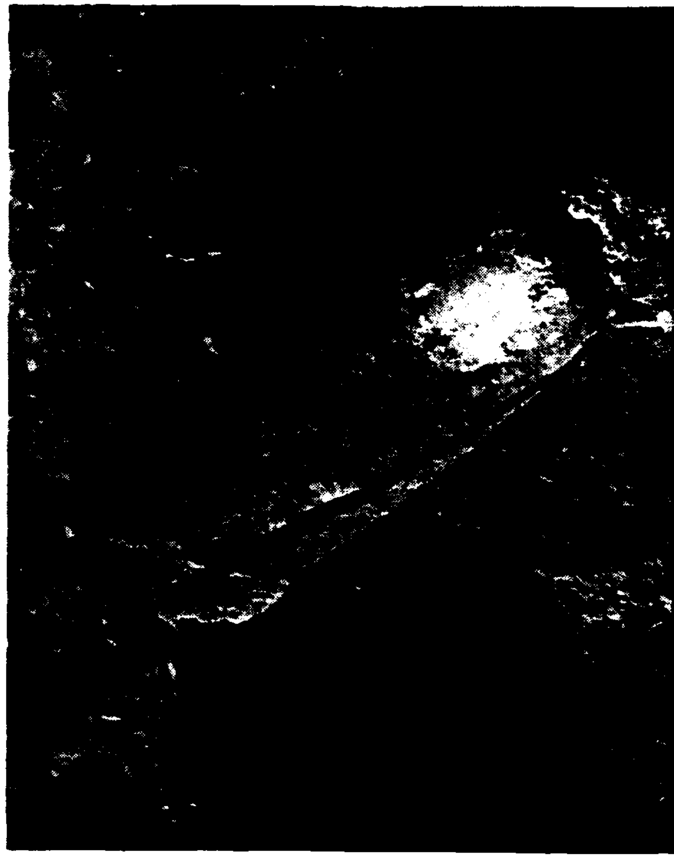


a. Partially excavated. b. Fully excavated.

Figure 24. The 2-300-2 canister, partially and fully excavated.

2-300-2: Roughly 50% of the surface was exposed. The bottom of the canister was about 60% exposed along with roughly 120 degrees of the canister wall. There was also a large void on the top of the canister. Soil appears to have fallen to the bottom of the hole prior to grouting. The grout was strongly bonded to the canister and to the surrounding medium. The soil in contact with the canister wall was also bonded to it.

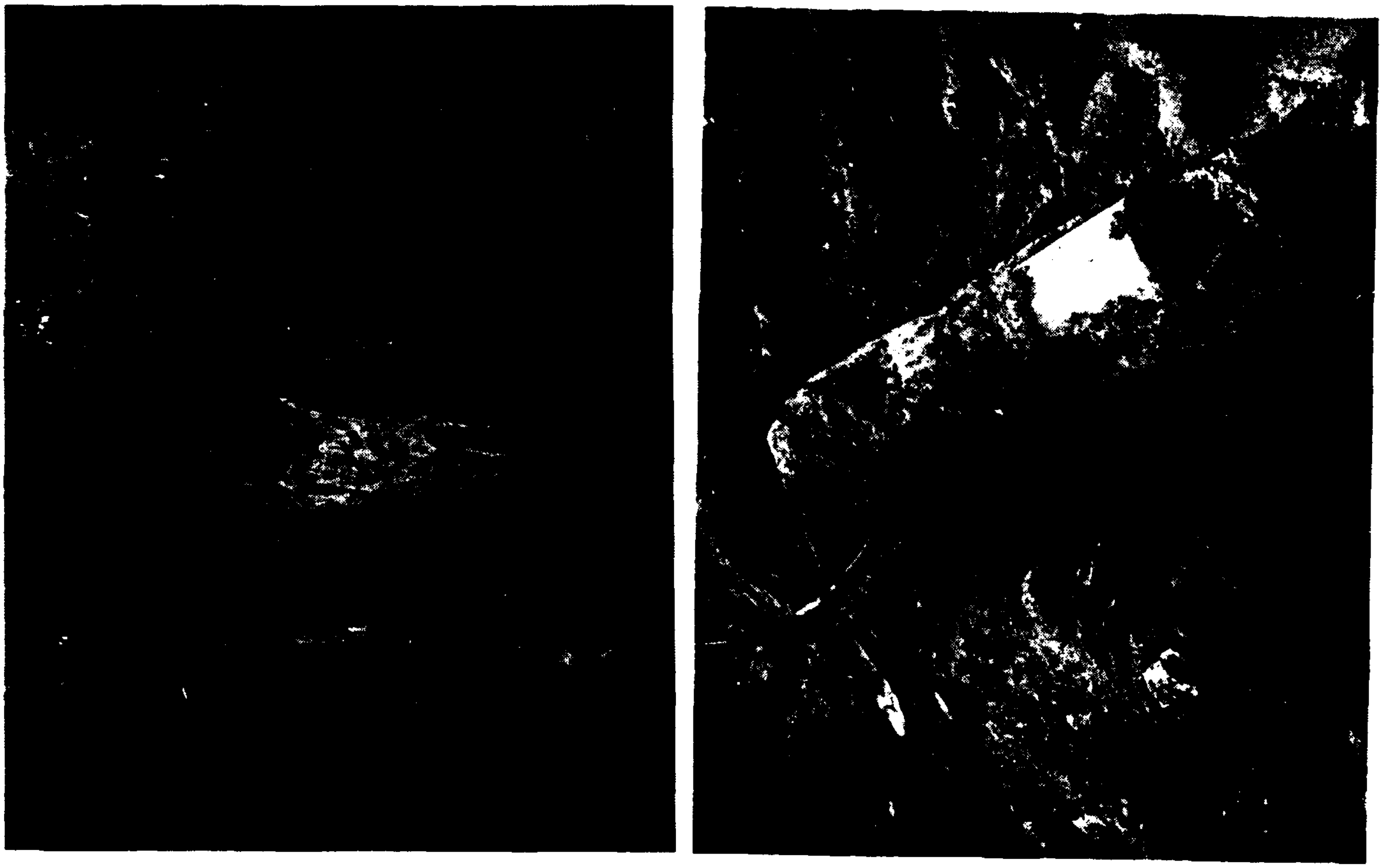
a. Partially excavated.



b. Fully excavated.

Figure 25. The 2-300-3 canister, partially and fully excavated.

2-300-3: The canister was found to be roughly 15% exposed. A void exposed about 10% of the canister bottom; about 45 degrees of the canister side was exposed and there was a small void on the canister top. Since grout extended below the vertical soil column on the side of the canister, it seems likely that soil fell down around the canister during grouting. The grout was bonded strongly to both the canister and to the surrounding medium. The soil in contact with the canister wall was also bonded to it.



a. Partially excavated. b. Fully excavated.

Figure 26. The 2-300-4 canister, partially and fully excavated.

2-300-4: Roughly 35% of the surface was exposed. The canister bottom was about 50% exposed along with about 110 degrees of the canister wall. The grout extended several inches below the bottom of the canister. It appears that soil had fallen into the hole before grouting and that some of it was pushed to one side by the grout. The grout was strongly bonded to the canister wall and to the surrounding medium. The soil in contact with the canister wall was also bonded to it.

Table 1. Summary of observations

Canister No.	Proportion Exposed	Overall Coupling	Apparent Bottom Hole Volume* (cubic inches)
1-150-1	50%	Good	NM
1-150-2	0%	Very Good	NM
1-150-3	30%	Good	NM
1-150-4	0%	Very Good	NM
1-225-1	65%	Fair	NM
1-225-2	50%	Good	NM
1-225-3	50%	Good	NM
1-225-4	70%	Fair	NM
1-300-1	40%	Good	NM
1-300-2	30%	Good	NM
1-300-3	0%	Very Good	NM
1-300-4	0%	Very Good	NM
2-150-1	0%	Very Good	-64
2-150-2	65%	Fair	-127
2-150-3	75%	Poor	-323
2-150-4	35%	Good	-241
2-225-1	65%	Fair	-71
2-225-2	95%	Very Poor	+331
2-225-3	5%	Very Good	-48
2-225-4	100%	Very Poor	+663
2-300-1	0%	Very Good	+154
2-300-2	50%	Good	+70
2-300-3	15%	Very Good	+70
2-300-4	35%	Good	+224

*NM=Not Measured
+ = Diminished Apparent Hole Volume
- = Enlarged Apparent Hole Volume

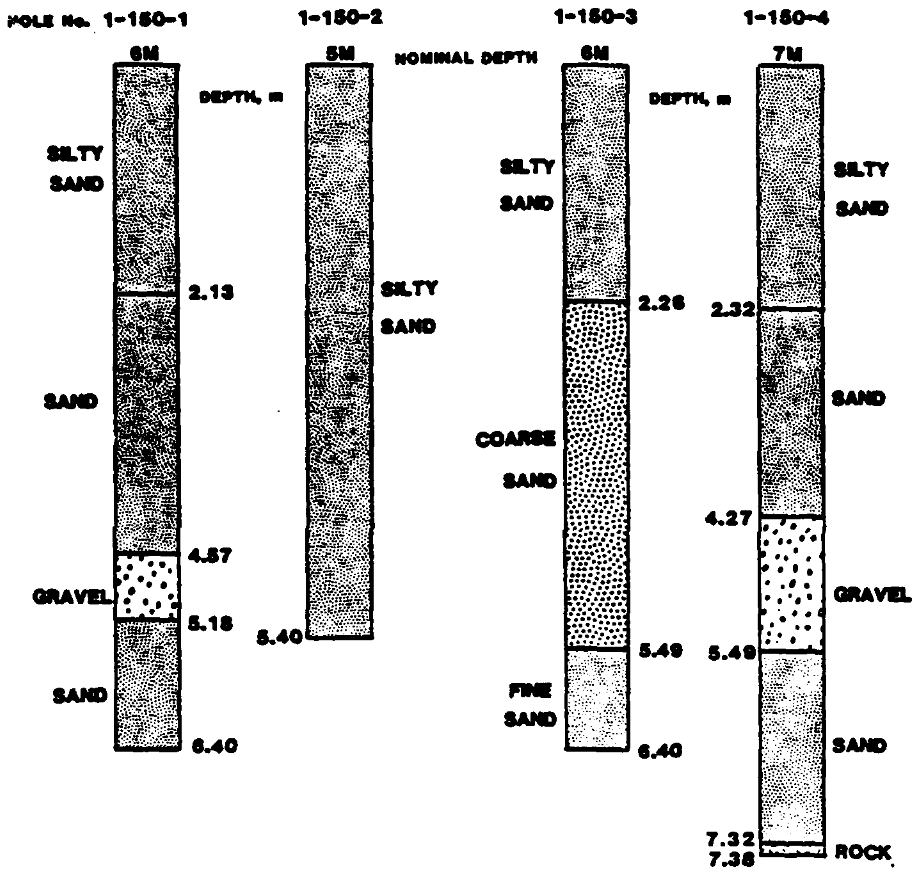


Figure 27. WES Boring logs for strain path cluster at 46 metres (328 degrees azimuth) from GZ.

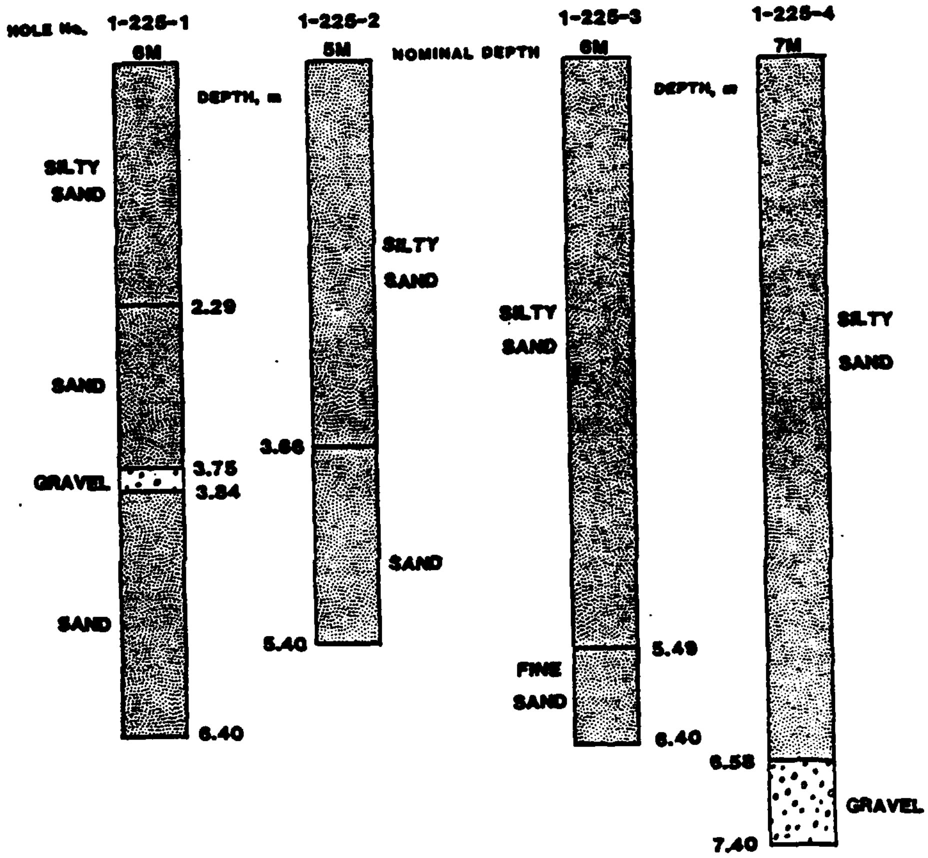


Figure 28. WES Boring logs for strain path cluster at 68 metres (328 degrees azimuth) from GZ.

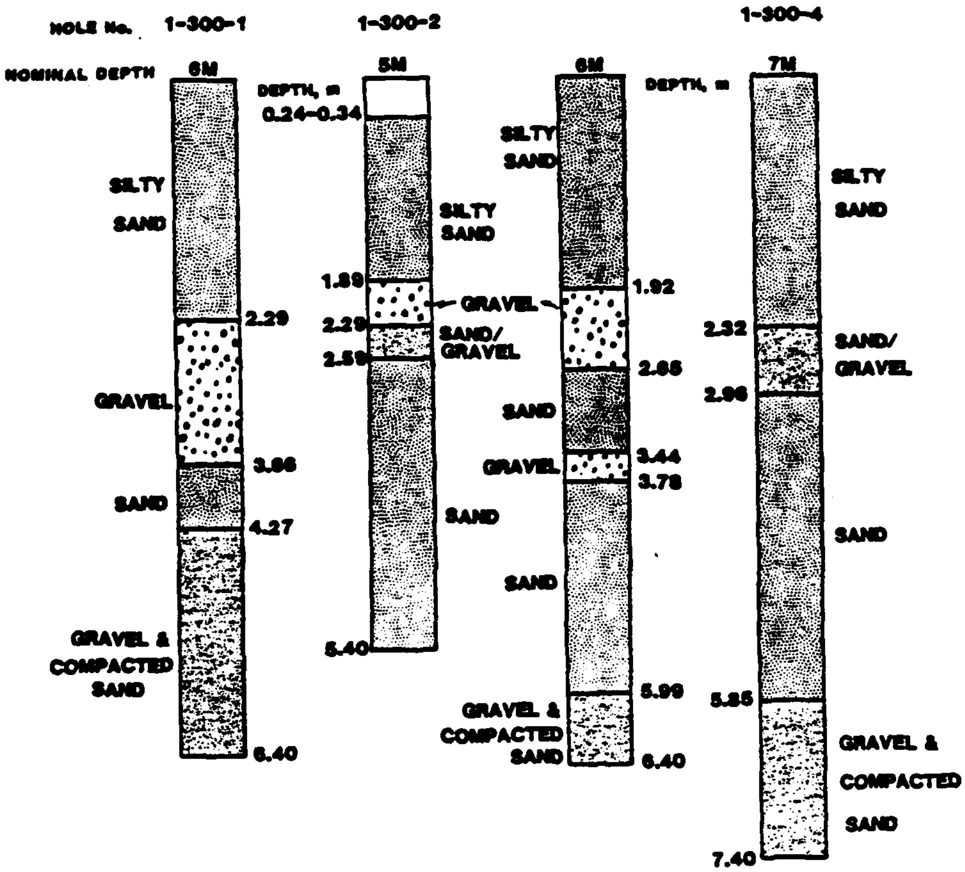


Figure 29. WES Boring logs for strain path cluster at 91 metres (328 degrees azimuth) from GZ.

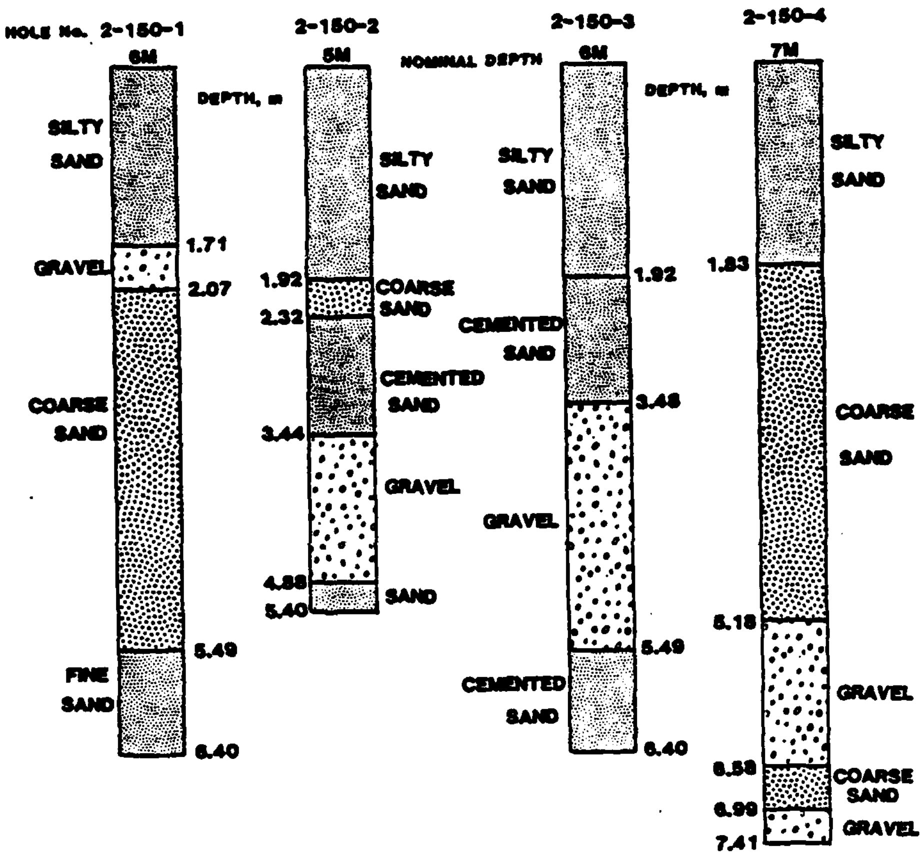


Figure 30. WES Boring logs for strain path cluster at 46 metres (240 degrees azimuth) from GZ.

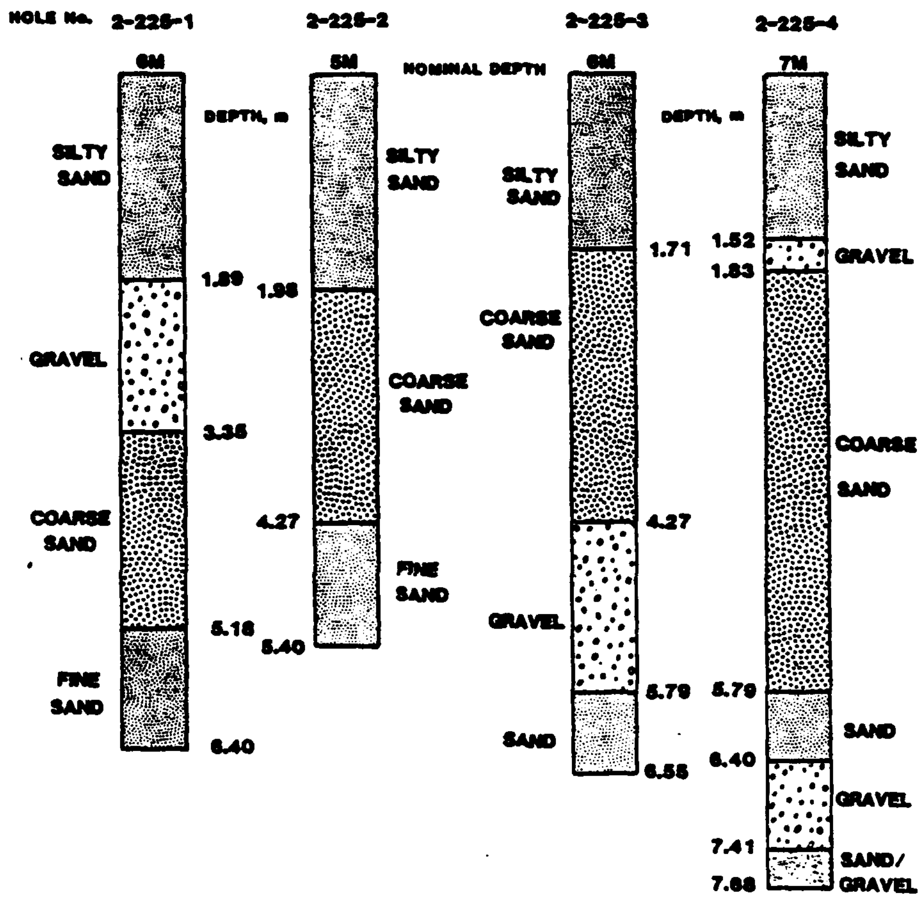


Figure 31. WES Boring logs for strain path cluster at 68 metres (240 degrees azimuth) from GZ.

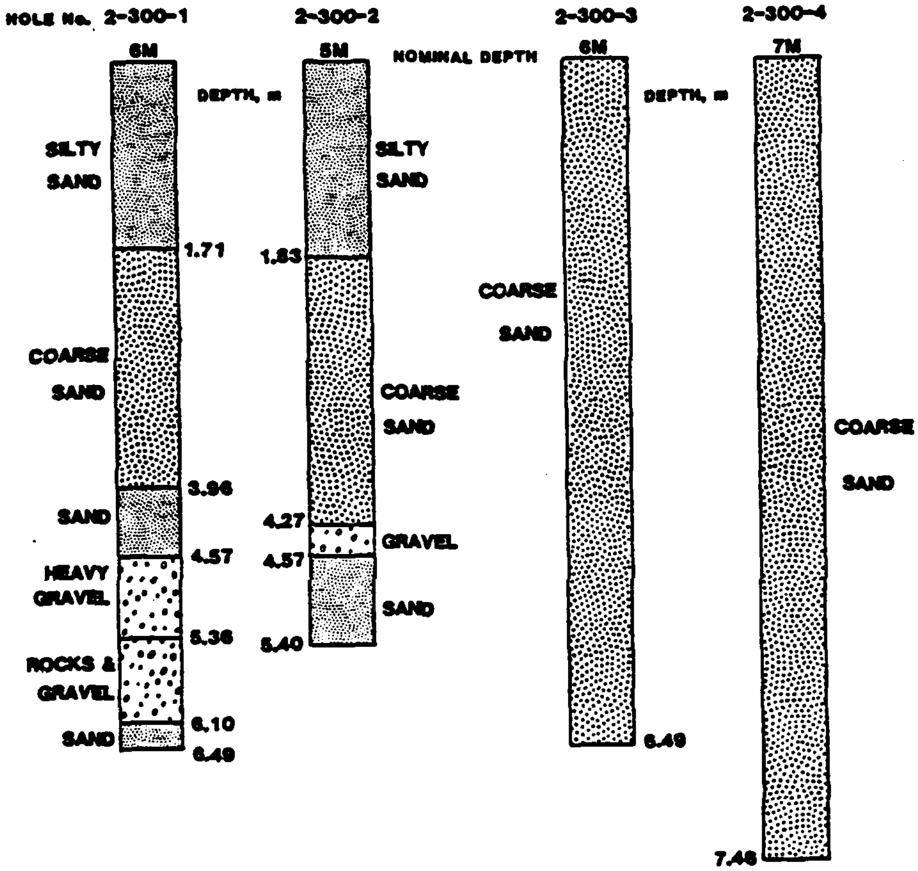


Figure 32. WES Boring logs for strain path cluster at 91 metres (240 degrees azimuth) from GZ.

SECTION 4

CONCLUSIONS

Where feasible, debris at the bottom of a hole is removed prior to emplacement of a canister. In media such as that at the MILL RACE site the borings are unstable, making it necessary to install the canisters immediately after completion of the hole. From the observations made in this effort it would seem that one of the major problems of canister installation in loosely cemented alluvium sites in general and the MILL RACE site in particular is that sidewall material falls to the bottom of the hole. This material may detach itself spontaneously due to insufficient cementation or it may be scraped loose during canister installation. Further, due to the instability of the hole sidewalls, the spontaneous detachment of material may occur even though foam was applied to the hole. The loosened material may then fall in sufficient quantity to fill the hole bottom before and possibly during grouting, In cases where the canister was only partially grouted, it appeared that the grout did not flow to the bottom of the hole and force the cuttings and other debris above the canister and to the top of the grout column. This may not have been the case had the grout hose been placed at the bottom of the hole well below the bottom of the canister. The force of the grout being pumped in did seem to have the effect of compressing the material in the hole bottom. It was also observed that the soil found in the void areas at the tops of some canisters was significantly compressed, indicating that the mass and the force of the expanding grout had exerted some pressure on the material. In all cases the grout was found to be bonded to the canister to the extent that the force required for its removal with hammer and chisel were were considered to be dangerous to the survival of the canister contents. The bonding of the grout to the surrounding soil was such that in a typical instance a canister had to be more than 3/4 excavated before it could be pried loose from the trench wall using a hand pick.

Overall, the installations examined in this effort in cases where the canister was less than 50% exposed, appeared to be sound. In cases where the canister was unexposed or partially exposed, the bonding of the various components and the strength of the grouting material are believed to have provided good coupling between the instrument package and the surrounding medium.

SECTION 5

LIST OF REFERENCES

1. "GROUND MOTION MEASUREMENT, MILL RACE EVENT," J. K. Ingram, Structures Laboratory US Army Engineer, Waterways Experiment Station.

2. "STRAIN-PATH ANALYSIS AND TESTING," J. G. Trulio, Proceedings of the Strategic Structures Review Conference, 4-6 May 1982. pp. 267-290, DNA-TR-82-23-V1 Defense Nuclear Agency, Washington, D. C., 20 May 1983.

APPENDIX

DEGREE OF GROUTING AND VARIATIONS IN MEASURED GROUND MOTION

When the velocity-gauge canisters deployed for the MILL RACE strain-path experiment were excavated, it was seen that many of the canisters had not been completely encased by grout. Since an ungrouted canister might not faithfully follow the motion of nearby undisturbed soil, attempts were made to relate the fraction of exposed canister-surface with a) relative values of measured peak velocity, b) characteristic times (e.g., rise times) in the measured velocity pulses, and c) the shapes of strain paths derived from groups of pulses.

No correlation has been found between the amplitudes of velocity peaks and the exposed fractions of canister surface. For each instance of apparent correlation, a counterexample was found. Velocity peaks from canisters with high fractions of ungrouted surface (decoupled (?) canisters) did not fall regularly above or below peaks for more completely grouted canisters. Arrival times and times of peak velocity also failed to show variations that correlated with the degree of grouting of canisters.

A further test, based on the cumulative fraction of ungrouted canister surface for the six records used to deduce a single strain path,[2] showed no correlation with strain-path type for either the ten best or ten worst cases. The ten best (having ungrouted surface fractions from 0.70/6 to 1.60/6) included four types of path-shape: i) uniaxial compression followed by uniaxial extension or stretch (3 paths); ii) uniaxial compression followed by shear (3 paths); iii) oddly shaped paths

[paths without the easily identified shapes that denote uniaxial compression or stretch, simple shear, loops like those traced in contained bursts, or a few shapes of somewhat greater complexity from surface-burst calculations] (3 paths); iv) mixed paths [paths with segments typical of several different simple strains but not dominated by any one type] (1 path). The ten worst cases (with ungrouted surface fractions of 2.80/6 to 4.25/6) showed greater variety: uniaxial compression followed by stretch (4), oddly shaped paths with a dominant stretch phase (1), oddly shaped paths (1), oddly shaped paths with a dominant period of simple shear (1), uniaxial compression followed by shear (1), mixed paths with a major period of simple shear (1), and mixed paths (1). For comparison, of the total set of 44 paths from Mill Race, there were 22 of type i), 9 of type ii), 5 of type iii), 3 of type iv), 3 mixed paths with a dominant period of shear, an odd path with a major period of shear, and an odd path with a major period of stretch.

Furthermore, whether canister exposure was large, small or moderate, paths of the three main types (i), ii) and iii) above) were generated. The rarest types of path - stretch/odd and shear/odd - appeared only for fairly high exposure (ungrouted surface fractions of 2.85/6 and 3.5/6).

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