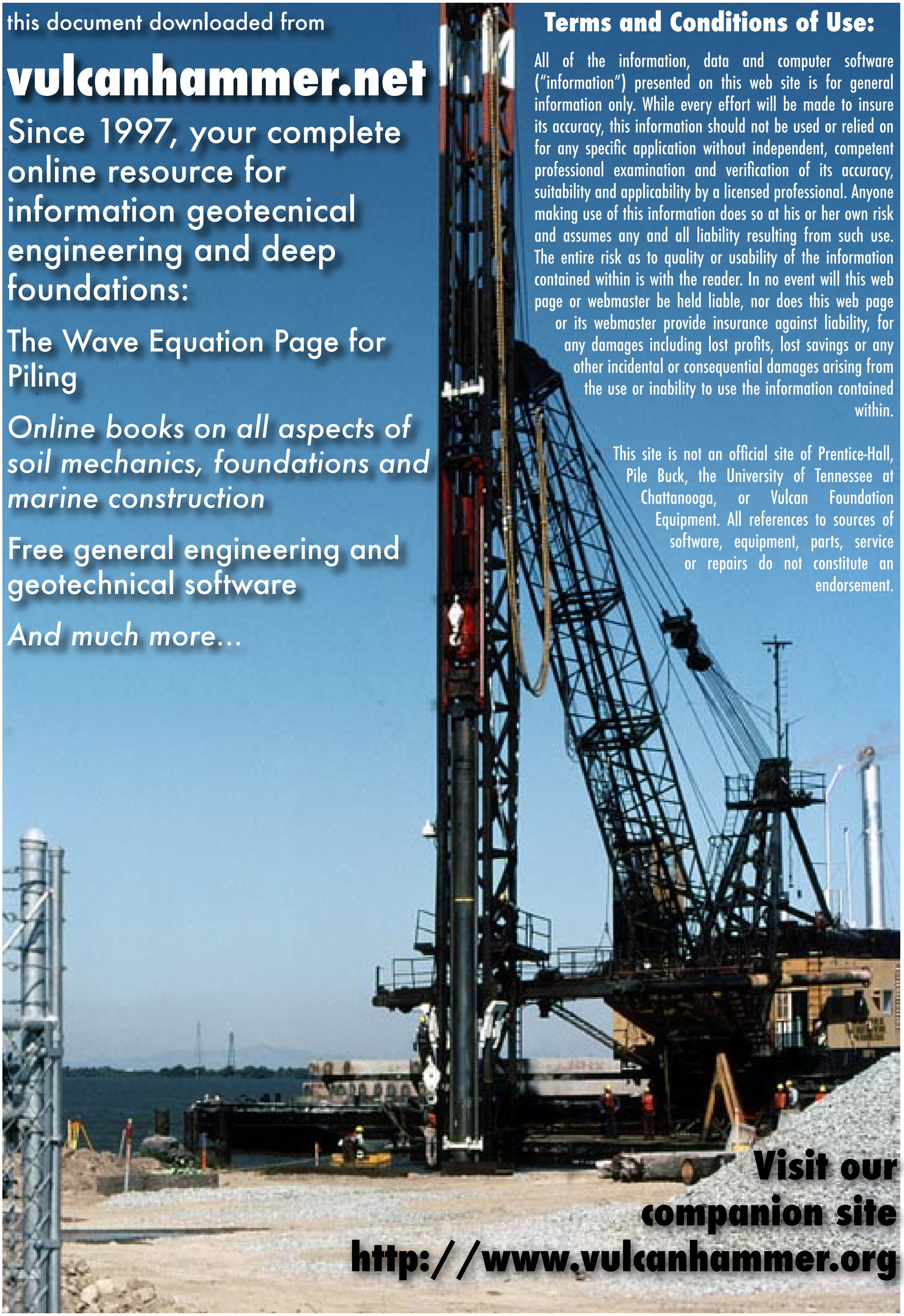

CONTRACT REPORT S-69-4

DUTCH FRICTION-CONE PENETROMETER EXPLORATION OF RESEARCH AREA AT FIELD 5, EGLIN AFB, FLORIDA

by

J. H. Schmertmann

October 1969

Sponsored by

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Conducted for

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

under

Contract No. DACA39-69-C-0035

by

John H. Schmertmann, Consulting Engineer
Gainesville, Florida

FOREWORD

The Office, Chief of Engineers, U. S. Army retains prominent engineers and scientists who are periodically convened as panels and consulting boards to advise and assist OCE in the conduct of their various research and development programs. In May 1966, the Board of Consultants for Dynamic Foundation Studies reviewed plans for conducting basic ground motion studies and recommended that a test site and instrumentation be set up for a long range program on a semipermanent basis and that the test facility should be set up in such a manner that the same soil conditions will be available over a long period of time for an extended program in which the test and boundary conditions may be changed.

In response to the Board's recommendations, the U. S. Army Engineer Waterways Experiment Station (WES) has studied two test sites to assess their suitability for ground motion experimentation. The first site considered is at WES, Vicksburg, Mississippi. Borings here show strata of loessial material and alternating layers of clay, silt, and sand with marl and limestone at a depth of 125 ft; the water table fluctuates at depths of 16-20 ft. Measured ground motion propagating along a surface radial from a surface source of vibration was found to depend strongly on the direction of the radial. The second test site considered is defined in this report. Initial vibration experiments here showed symmetric patterns of radiated surface motion. Borings indicated a predominately uniform fine sand with some silty or clayey sand layers; the permanent water table is around 100 ft deep.

The Eglin Field test site is better suited for a long range program than the WES site; however, a desirable site should remain seismically stable with respect to time and climatic conditions to ensure that meaningful data comparisons and unambiguous analyses of experiments can be expected during the anticipated long range program. Boring and well logs at Eglin Field often indicate clay or marl lenses; these lenses could support perched water tables or impede the infiltration of meteoric water. The presence of perched or transient water within the mass of soil at a test site could, of course, cause density contrasts that would be detrimental to precise and reproducible ground motion measurements.

The Dutch friction-cone penetrometer, a relatively new soil exploration tool, offered the most practical means of investigating the existence and extent of fine-grained sedimentary lenses at the

Eglin Field test site; this method can also reveal density variations within the mass of sand. A contract for soils exploration services at Eglin Field, Florida, using the Dutch friction cone penetrometer, was authorized and negotiated.

The work described in this report was performed under Contract No. DACA 39-69-C-0035 between WES and Dr. John H. Schmertmann, Consulting Engineer, Gainesville, Florida. Dr. Schmertmann is also Professor of Civil Engineering at the University of Florida, Gainesville, Florida. The special field exploration equipment used in this work was rented from the University of Florida by Dr. Schmertmann. The contract study is in support of project No. 4A024401A891, Permanent Construction Materials and Techniques; task No. -03, Environmental Isolation and Control; work unit No. -001, Ground Motion Studies. The project is sponsored by the Office of the Chief of Research and Development, Department of the Army.

The contract was monitored by Mr. L. W. Heller under the general supervision of Messrs. W. J. Turnbull, Chief (Retired), A. A. Maxwell, Acting Chief, Soils Division, and R. W. Cunny, Chief, Soil Dynamics Branch. Contracting Officer was Mr. J. J. Kirschenbaum, Jr. COL Levi A. Brown, CE, was the Director, U. S. Army Engineer Waterways Experiment Station.

CONTENTS

ABSTRACT

This is a report on the results of an investigation of the homogeneity of soil conditions at a research site within Eglin AFB, Florida. Twenty cone soundings, using a static, Dutch friction-cone penetrometer, reached an average depth of 70 ft, varying from 62 to 102 ft. The field work was accomplished in four working days. The load on the penetrometer was automatically recorded for 11 of these soundings, permitting greater precision in the determination of the ratio of soil friction against the cone friction jacket to the bearing capacity of the cone point. All mechanical equipment appeared to operate in an excellent manner.

No evidence was found to indicate significant thicknesses of cohesive soil layers. Friction ratios were unusually uniform over the entire site investigated and fell within the range usually interpreted as indicating clean sand. There was also no evidence of perched water tables.

The cone bearing logs for the upper 20 ft of sand, a natural deposit, also indicated that it is uniform in density variation with depth over the research area investigated in detail, and the surrounding area as well. Below 20 ft there is considerable point-to-point variation in sand density. However, on the average the research area and vicinity show a definite uniformity in the way in which density varies with depth.

The entire site area is as homogeneous as one can expect to find in natural, coarse-grained deposits of the depth considered herein.

DUTCH FRICTION CONE PENETROMETER EXPLORATION OF RESEARCH AREA AT FIELD 5, EGLIN AFB, FLORIDA

PART I: INTRODUCTION

1. The U. S. Army Engineer Waterways Experiment Station (WES) is considering the development of a previously studied research area into a major research site, provided that the soil conditions are suitably homogeneous. This site is located approximately 1000 ft southwest of the end of the NE-SW runway at Auxiliary Field No. 5, Eglin AFB, Florida. The existing soil information at this site consisted of data from two standard penetration test (SPT) borings to depths of 60 ft each, plus a third boring in which Shelby tube samples were obtained to depths of 52 ft. Much more detailed exploration of the homogeneity of soil conditions was required at this site. After due consideration of the relative precision, economy, and nondestructiveness of various field testing methods, WES decided to use the static friction-cone penetrometer method of exploration for this purpose.

2. The friction-cone method of exploration is relatively new in the United States, having been introduced by the writer in 1965. For the reader not familiar with this method, Appendix A describes the equipment, method of operation, and results obtained in detail. The appendix also includes references for those who are not familiar with, or who wish to read further about this method.

3. In conjunction with the performance of this contract, the writer and one assistant performed 20 friction-cone soundings with a total length of 1404.5 ft.* Thus, the average sounding depth was about 70 ft. The extremes were 62 and 102 ft. Appendix A presents the detailed log for each sounding, with the logs assembled in order of sounding number. The numbering system follows the chronological order of sounding performance in the field. When using Bourdon gage readings for static thrust pressures, these logs constitute the data sheets used in the field. When using chart recording, thrust pressures were first scaled from the chart record and then

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* Those readers interested in the relative speed of this method of exploration might like to know that the 1404 ft of sounding was completed in four working days. A single cycle of set-up, sound to 70 ft with readings every 8 in., retreive rods, pack, and move to another location about 300 ft away took about 1½ hrs. Greatest footage was achieved the first day when over 420 ft was sounded during a 10-hr day.

transferred to the log sheet columns labeled "field data".

4. These soundings, identified by number, are located in fig. 1 with respect to the circular concrete load-test plates used in previous research and still present at the site. Note that 12 of the soundings, 1-12, border and are within a 300-by 300-ft area surrounding the concrete plates. The location of the final 8 soundings, 13-20, was selected in the field by the WES contract monitor. The purpose of these additional soundings outside the research area was to explore the vicinity west and north for areas more homogeneous than the previous research site.

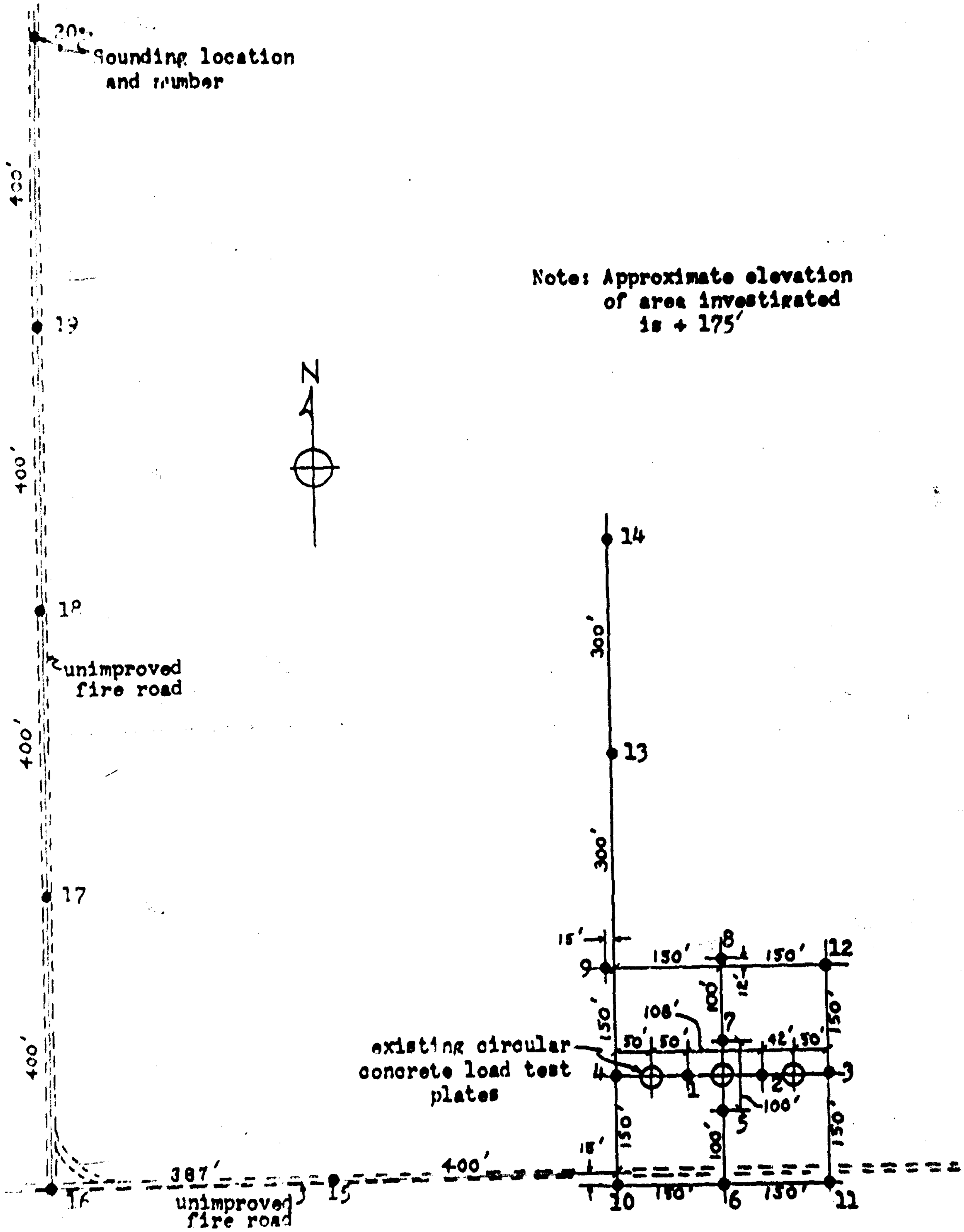


Fig. 1. Sounding location plan

PART II: TEST PROCEDURE

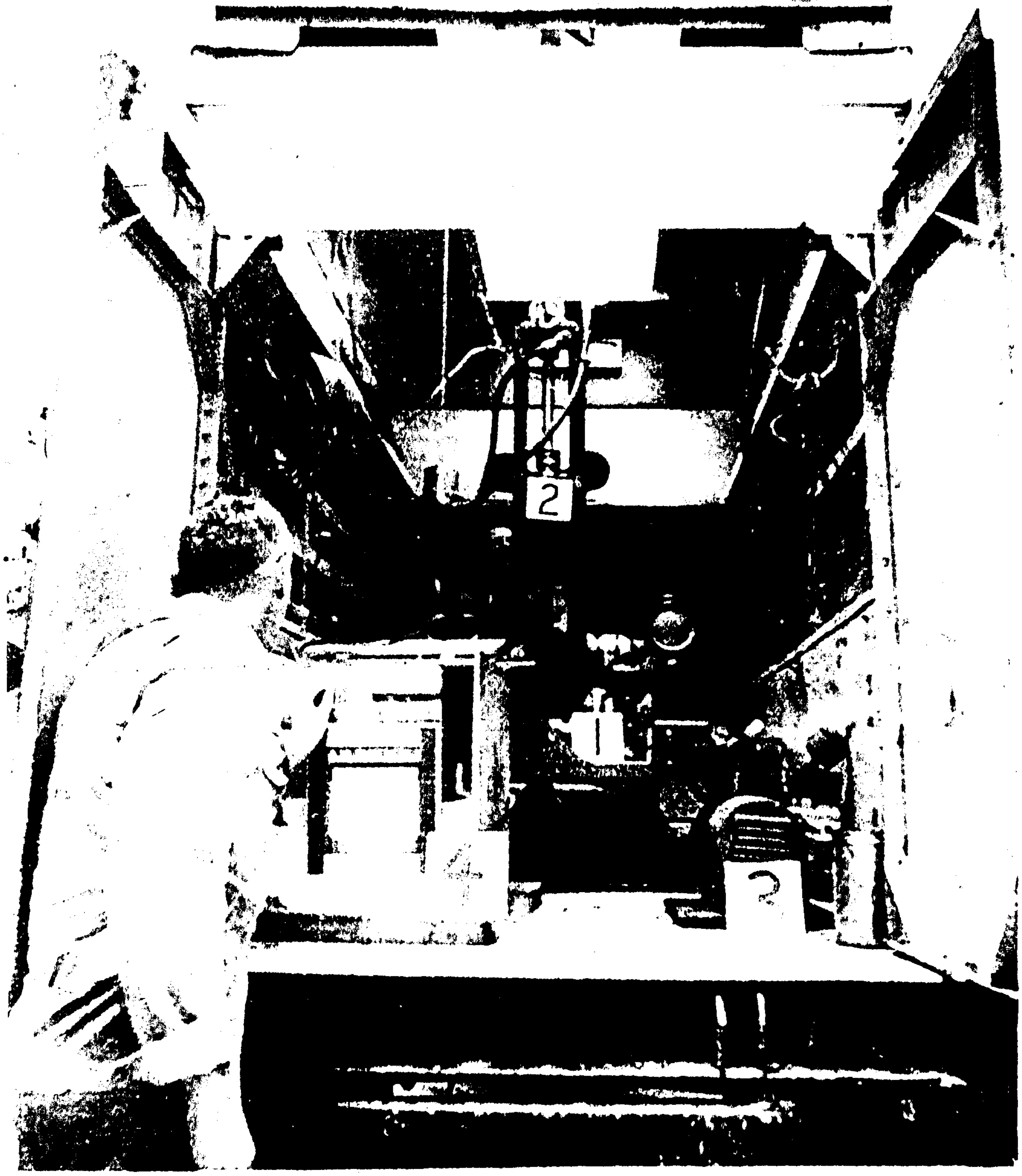
Recording Cone Pressures

5. As noted in Appendix A, the operator must ordinarily read the Bourdon gages on a hydraulic load cell to obtain the thrust pressure readings needed to compute the bearing capacity of the cone point and the unit local friction on the friction jacket. The ratio of friction to bearing, called the friction ratio, is a useful indicator of the type of soil being penetrated. Because WES was especially interested in having the friction ratio determined with the best possible precision, the hydraulic load cell was fitted with pressure transducers and recordings could thus be made of the cone pressure measurements at each test depth. Figure 2 shows a photograph of the load cell-transducer-recorder arrangement.

6. Figure 3 shows a typical set of pressure readings from the recorder chart paper. Note that there is both a high-and low-sensitivity record. When the capacity of the high-sensitivity transducer is exceeded, at a gage pressure of 70 kg/cm^2, then the low-sensitivity record must be used. As shown in fig. 3, at first there is a pressure buildup until the cone point begins to move. Penetration pressure then remains constant, increases, or decreases in accord with the varying bearing resistance encountered by the point moving downward. There is a sudden rise in pressure when the point engages the friction jacket and forces it to move downward also. There is a surge in pressure due to the j cket acceleration. Then, with equilibrium restored, the pressure again stabilizes (at a higher value). The difference between the two stabilized values is the additional pressure required to pull the jacket against the frictional resistance of the surrounding soil. The pressure values before and after this friction-jacket jump can obviously be obtained with more precision from a chart record of this type than from any record the operator might obtain from usually unsteady dial gage pointers and an observation time of only a few seconds.

7. Cone pressures and transducer-chart output were calibrated in the laboratory. Figure 4 presents the calibration curve obtained for the high-sensitivity transducer. Note that there is some up-down hysteresis due to gasket friction in the hydraulic load cell mechanism. The calibration line used for interpreting pressures from the chart records is also shown (in the middle of the hysteresis loop). This is also the exact theoretical calibration for this transducer pressure-voltage output (5.00 volts at 70 kg/cm^2).

8. The pressure readings for sounding no. 1 were recorded using the chart system, without any manual reading backup. Although there were some minor troubles with maintaining a consistent zero



1 - Gasoline motor and hydraulic pump to drive cone-thrust piston.
2 - Hydraulic load cell being pushed against cone rods (see Fig. A1 for detail).
3 - Gasoline driven alternator to supply current for recorder.
4 - Two pen, time base recorder connected to pressure transducers attached to hydraulic load cell.

Fig. 2. Vehicle mounted cone and recording system in this investigation

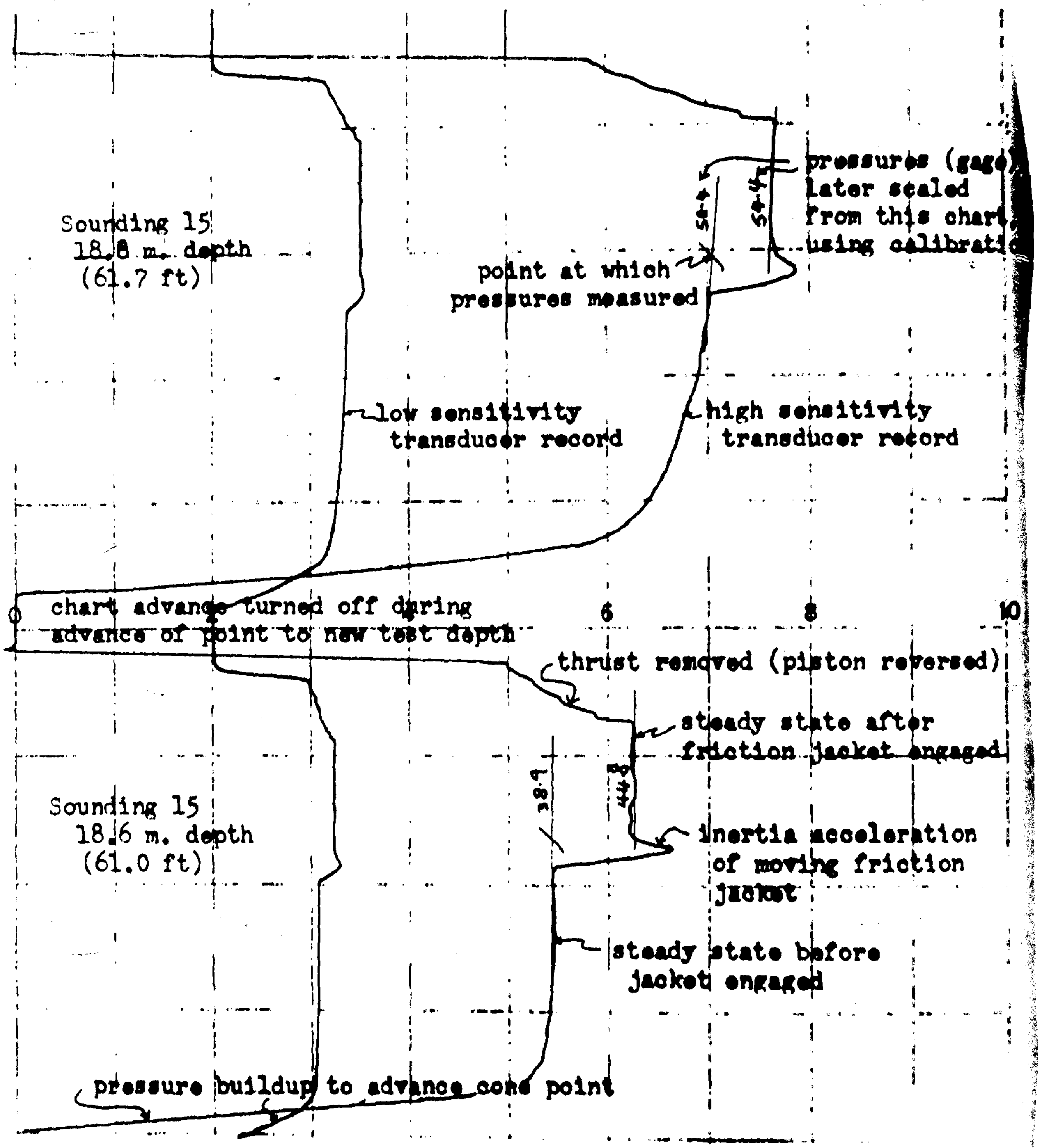


Fig. 3. Typical chart record (Annotated)

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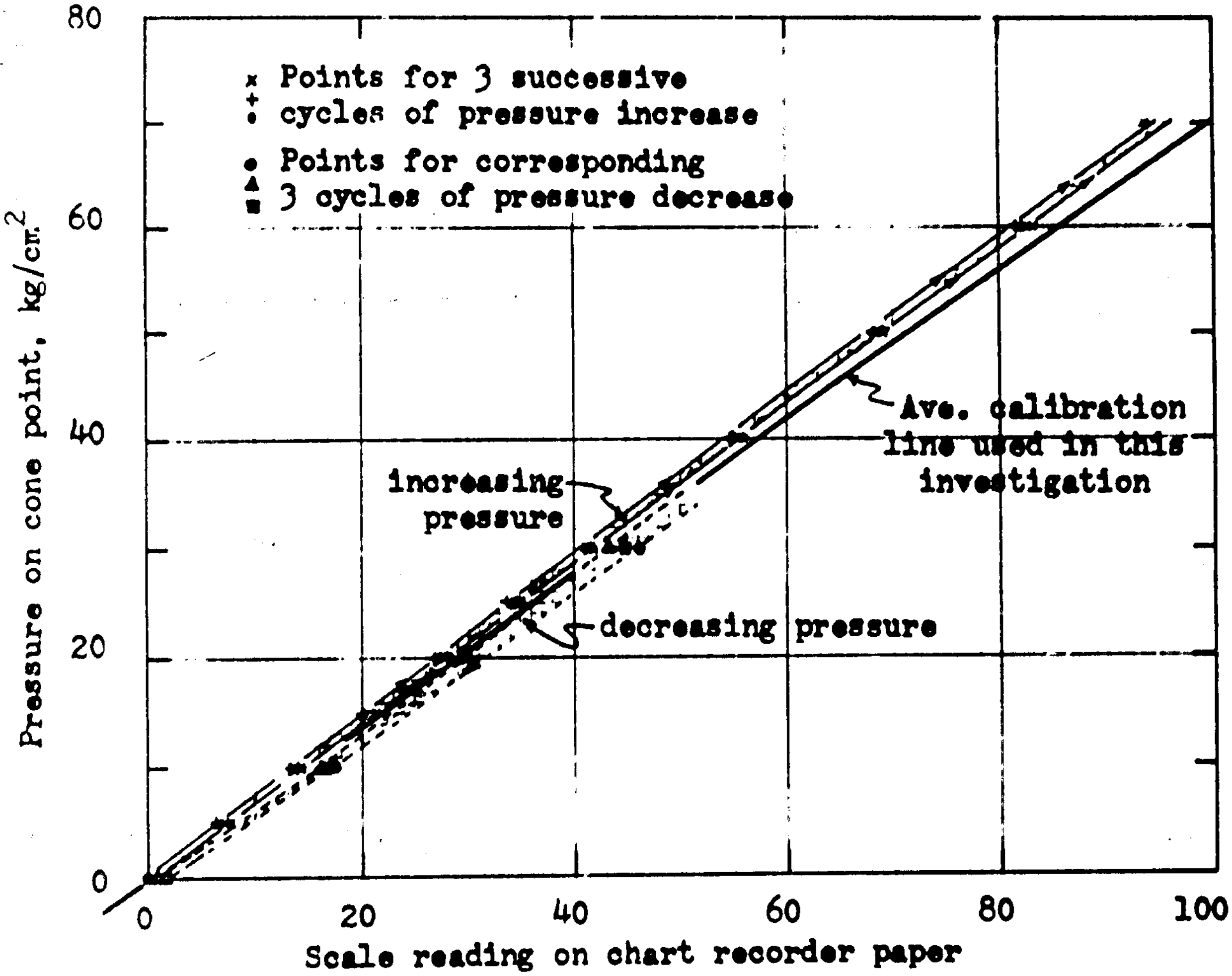


Fig. 4. Pressure transducer -- recorder calibration obtained immediately before this investigation

reading, there did not seem to be any reason to question the reliability of the chart data. However, during the first 20 ft of penetration in sounding no. 2, serious problems in maintaining a zero position became obvious. Chart recording was then temporarily abandoned and the work was continued using Bourdon gage readings, called out by the operator, immediately following a test sequence at each depth. The remaining tests in sounding 2, plus all the tests in soundings 3-9, were made using the Bourdon gages. At that time a representative of the manufacturers of the recorder made a field visit to the site, determined the cause of the recorder problem, and corrected it. The final 11 soundings, 10-20, were made with chart recording and with periodic Bourdon gage readings as a check on proper recorder performance. The recorder appeared to perform perfectly, and all Bourdon gage readings checked well with the chart records.

9. The reader will note in the logs in Appendix B that some of the friction ratios are computed to tenths and on other logs they are computed to hundreths. In all soundings where the recorder system was probably unreliable and when Bourdon gage readings were used as a basis for computing the friction ratio, these ratios are given to only tenths because hundreths would have no significance. These soundings are 1-9. Soundings 10-20 have friction ratios to hundreths because the information to compute the ratios was obtained from the chart records, which permits greater precision.

10. It is of some interest to compare the results obtained by these two recording methods. This is possible in only one case, the first 12-1/2 ft in sounding 10. Here Bourdon gage readings and chart recording were both used and both sets of friction ratios were computed. They are plotted together on the log sheet. Note that there is not much difference in the friction ratios, although the chart-determined ratios are perhaps more consistent. This comparison is pointed out to the reader so that he will have confidence in the friction ratios obtained using the gage-reading method, but will also recognize that some precision was lost.

Care of Equipment During Sounding Operations

11. A new cone point was used at the beginning of this exploration program and the same point was used throughout. From all indications, such as the proper telescoping of the extended point when it was advanced to a new test depth (which can be observed by the operator watching the relative upward movement of the inner rods) and the free operating condition of the point when it is finally removed from the ground, the point performed perfectly during this entire penetrometer sounding program.

12. All soundings were made with the aid of a friction reducer. This is a short section of rod placed immediately behind the cone point. A steel ring welded to this rod section slightly enlarges the hole, thus greatly reducing rod friction above that point because all rods above pass through a hole enlarged to a diameter greater than the rod diameter. The friction reducer has no influence on the cone resistance or friction jacket because it is located above these sensing elements. Without this reducer it would not have been possible to achieve the penetration depths attained with the 7-ton maximum thrust provided by the reaction weight of the sounding truck.

13. Before the beginning of each sounding, the cone point was cleaned and oiled and the assembly of the cone point plus the friction reducer rod section plus the first section of one meter length rod was connected and checked for axial alighment. No sounding was begun until such alignment was essentially perfect, as determined by spinning this assembly on the cone point and checking for wobble.

14. During the setup prior to each sounding, the hydraulic cylinder that provided the static cone thrust was carefully plumbed. The first section of rods was pushed into the ground with special care to help ensure that the sounding rods lined up properly with the guide sleeves on the machine and with the rod recess in the hydraulic load cell pressing at the end of the column of rods. This helped prevent unnecessary bending of the rod system and possible friction between the inner and outer rod systems. All sounding rods were rejected that appeared bent, even slightly, or where inner rods appeared to have burrs or other imperfections that might induce unnecessary friction between the inner and outer rods. About half the sounding rods used were new, in perfect condition, and used for the first time on this job.

PART III: TEST RESULTS

Field Observations

15. Certain observations made during the performance of these cone soundings reflect on the objectives of this work. Ordinarily, when cohesive soils are penetrated, a smear of clay is left on the point and rods. With only one rather special exception, no such smearing occurred. The single exception was the bottom 10 ft of the 102-ft sounding 18. Even then the material was not clay but rather a wetter, silty sand. The above indicates that probably no cohesive soils were encountered by the 20 soundings made during this investigation.

16. Ordinarily, when penetrating below the water table, the withdrawn rods are observed to be significantly wetter than when penetrating above the water table. Again, with only the single special exception noted above, the rods were always dry upon withdrawal. This confirms well-log data for Field 5 which shows that the ground water level at this site is quite deep and definitely below the 70 ft depth of most of these soundings. However, it also indicates that these soundings probably did not encounter any perched water table conditions. The single exception was the last 10 feet in the deep sounding, no. 18. The last three rods withdrawn were noticeably wetter than those previously withdrawn, but they were not as thoroughly wetted as would be expected if they penetrated below the water table. It is probable that the ground water level during the period of exploration was not much deeper than 102 ft.

Interpretation of Cone Logs

17. Any interpretation of the cone logs for site homogeneity requires a study of both the cone bearing capacity and the friction ratio logs. As noted in Appendix A, the friction ratio is an indicator of the fineness of the soil grain-size distribution, especially with respect to fine silt and clay content. As the fines content increases, the friction ratio also increases. However, it must be remembered that friction and bearing are an integrated mechanical behavior, and they do not necessarily reflect with desired sensitivity the details of layering, interbedding, fissures, coloring, cementation, etc., that may be important at a given site.

Friction ratios

18. The friction ratio logs for those soundings obtained with maximum precision, 10-20, show a remarkable uniformity. With few exceptions this ratio falls between 0.8 and 1.4%. The other logs, 1-9, show very similar results with respect to friction ratio, but there is a little more scatter, most likely due to reduced precision resulting from interpreting the less accurate Bourdon gage readings. Even these friction ratios fall in the middle of the 0.5-to-2.0% range that experience has shown to indicate a relatively clean sand. Considering all 20 soundings, these are the most uniform friction ratio conditions that have been encountered at any one site by the author.

19. It is concluded that this site, to a depth of 70 ft and probably to a depth of over 100 ft, consists of cohesionless sand containing only minor amounts of silt. The six gradation curves previously obtained by WES, one from each of the undisturbed samples in WES hole 3 (near sounding 1), confirm that, to a depth of 52 ft, the soils are non plastic fine sand, with some medium sands, and with only 3 to 9 per cent passing the 200 sieve. Field identification logs obtained during earlier standard penetration resistance tests on WES holes 1 and 2 indicate the presence of some clayey sands and a clayey silt. The friction ratios do not confirm the existence of such layers. If they were present it would be expected, on the basis of previous experience, that the friction ratios would fall within the 2.0-to-4.0 per cent range. If cohesive layers are present, the friction ratio logs indicate they would be less than 1 ft thick (see Appendix A).

20. There are a few locations, for example the 6-1/2-ft depth at sounding 16, the 25-ft depth at 15, the 55-ft depth at 13, and the 31-ft depth at 10, where small peaks in the friction ratio (to about 2.0 per cent) indicate thin layers wherein the sand may be somewhat more silty. However, the conclusion remains that this site

is unusually uniform with respect to friction ratio and consists almost entirely of relatively clean, noncohesive sands.

Cone Bearing Capacity

21. The detailed logs for the cone bearing from each sounding can be found in Appendix B. Each such log approximates a continuous record and reflects, in considerable detail, the natural variability to be expected in coarse-grained deposits with their high mechanical energy depositional environment. To facilitate a study of site uniformity, or lack of uniformity, each cone log was first simplified to a series of linear variations of cone bearing with depth. Each of the cone logs in Appendix B shows the adopted simplification by means of a light, solid line, which is labeled "approximate equivalent log". These equivalent logs were then used in the comparisons presented below.

300-by 300-ft research area

22. Figure 5 presents three series of superposed logs from soundings within the research area. Reference to the location plan (fig. 1) will show that each group of logs represents the cone data from a north-south section through the site. Figure 6 presents the same type of data for east-west sections. Although there may be some local variation in surface elevation, ± 1 ft, the site is approximately level. Because no elevation data were taken, these figures include no correction for possibly different surface elevations.

23. Inspection of each of these groups of logs shows that, while there is considerable variation in cone bearing from point to point at the same depth, around the site, there is also a general uniformity to the pattern within the site area. To demonstrate this more clearly, an average log was estimated through each of the groups of logs in fig. 5 and 6. These average logs were then superposed in fig. 7. Fig. 7(a) superposes the north-south sections and fig. 7(b) superposes the east-west sections. These superposed average logs clearly show that there is a general uniformity of cone bearing capacity conditions within the research area.

24. Furthermore, inspection and comparison of the detailed logs in Appendix B, the simplified logs in fig. 5 and 6, and the averaged logs in fig. 7, for both north-south and east-west sections, show that sections in both directions have about equal uniformity of conditions with depth. Thus, there is no obvious directional pattern in which the bearing strength logs are more uniform and which might indicate a direction to the geologic

processes that formed the sand deposits within the local research area.

Area west and north of the 300-by 300-ft research area

25. Reference to fig. 1 will show that soundings 13-20 were made to investigate a larger area outside the 300-by 300-ft research area investigated in detail. For comparison purposes, the equivalent logs for soundings 13 and 14 are included in the appropriate group of soundings in fig. 5. Soundings 15 and 16 are included in the appropriate grouping in fig. 6. Soundings 16-20, at 400-ft centers along the center line of the north-south fire road about 787 feet west of the research area, are grouped together separately in fig. 8. Again, there is an overall similarity in the cone bearing profiles but with considerable local variation, especially in the 20-to 40-ft-depth range.

26. An average cone profile was also estimated for the sounding group 16-20. This average is presented on fig. 7(c). Also included there is an estimate of an average log from soundings 13 and 14, the average being estimated from the equivalent logs shown on fig. 5.

27. Comparison of all the average equivalent cone bearing profiles can now be made by studying fig. 7. It is quite clear from this figure that there is an overall site uniformity over the entire research area and that conditions in the investigated surrounding area were approximately, on the average, quite similar to the research area. This similarity is further improved if an elevation correction is made for the average log for 16-20. Field observations, but no measurements, indicate that the fire road is a few feet, probably less than 5 ft, higher in elevation than the research area.

28. From the cone bearing data presented and compared above, it is concluded that site-uniformity conditions are about the same over the entire area investigated. There would be no particular advantage to choosing another research area within the larger area, but of no disadvantage except for the lack of detailed investigation.

29. There is some question as to whether the upper 20 ft of sand in the local area could possibly be a man-made fill. In the author's opinion, this is very unlikely. First, the profile over this depth is quite typical of many natural deposits previously encountered. Furthermore, the fire road, along which soundings 16-20 were taken, is in a wooded area with 20-to 30-yr old trees and large stumps and is obviously not a recent fill area. Yet the cone profile for the first 20 ft is very similar to that obtained in the research area (see fig. 7).

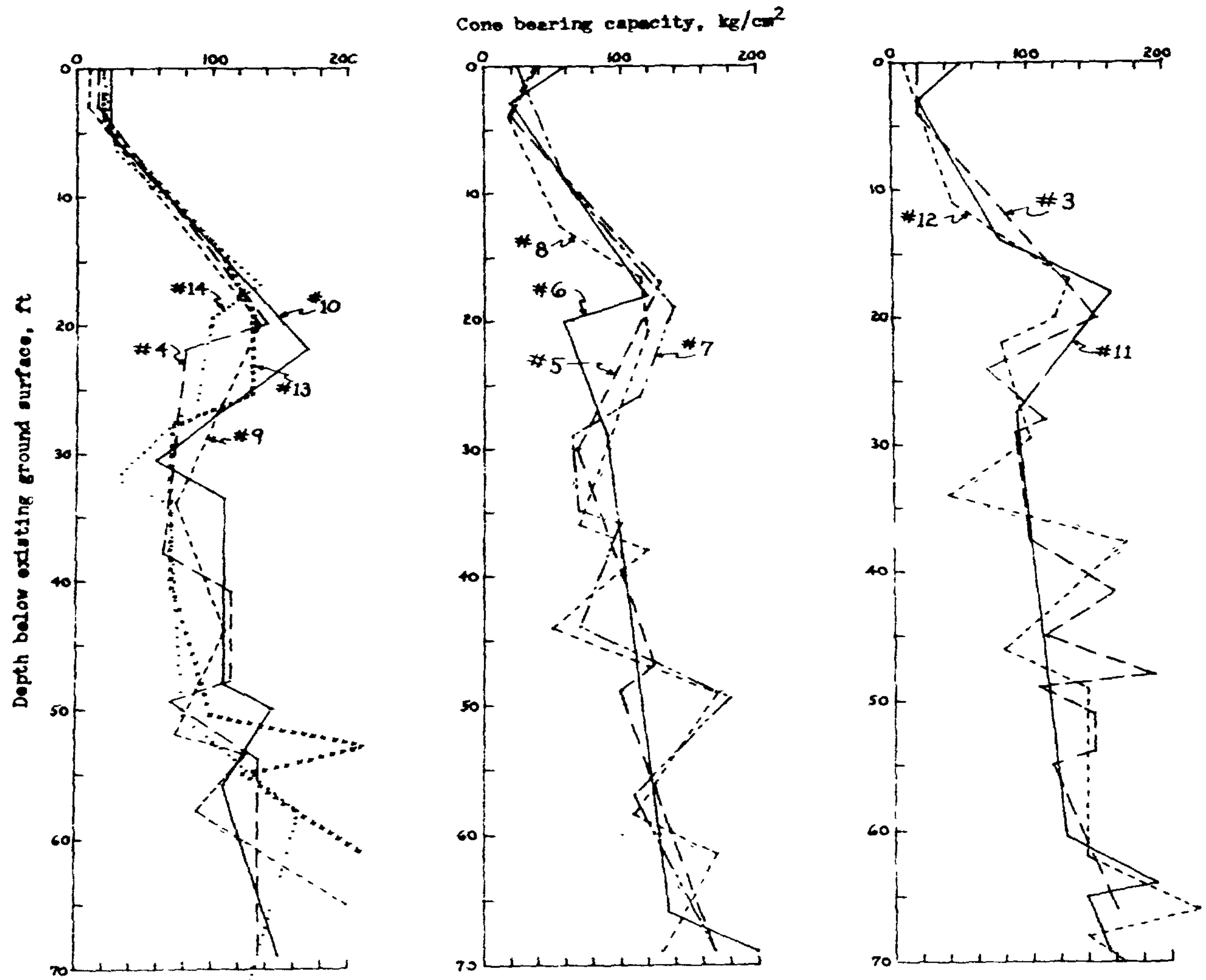


Fig. 5. Superposed Equivalent Cone Bearing Logs, N-S Sections Thru Research ·rea

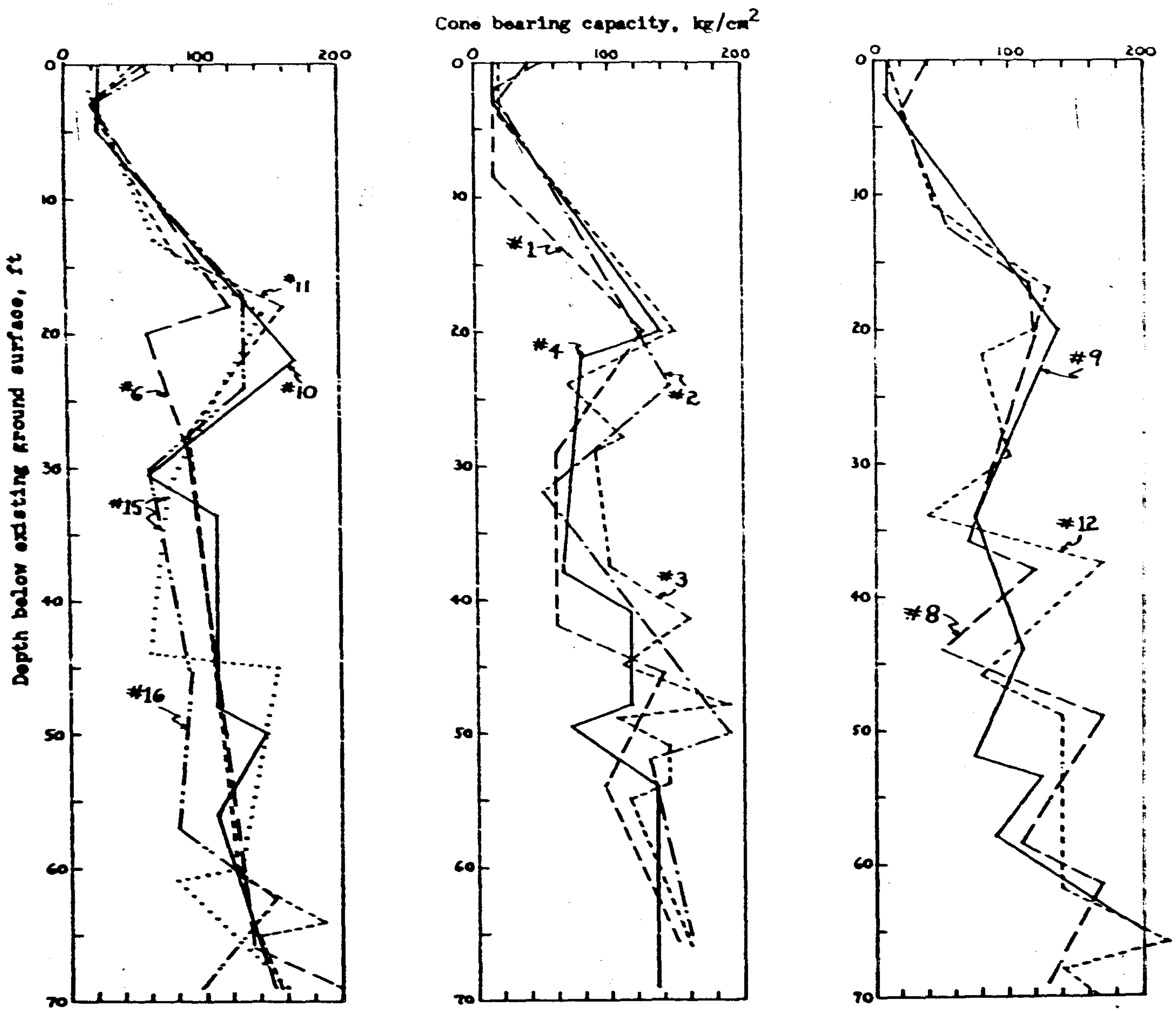


Fig. 6. Superposed Equivalent Cone Bearing Logs, E-W Sections Thru Research Area

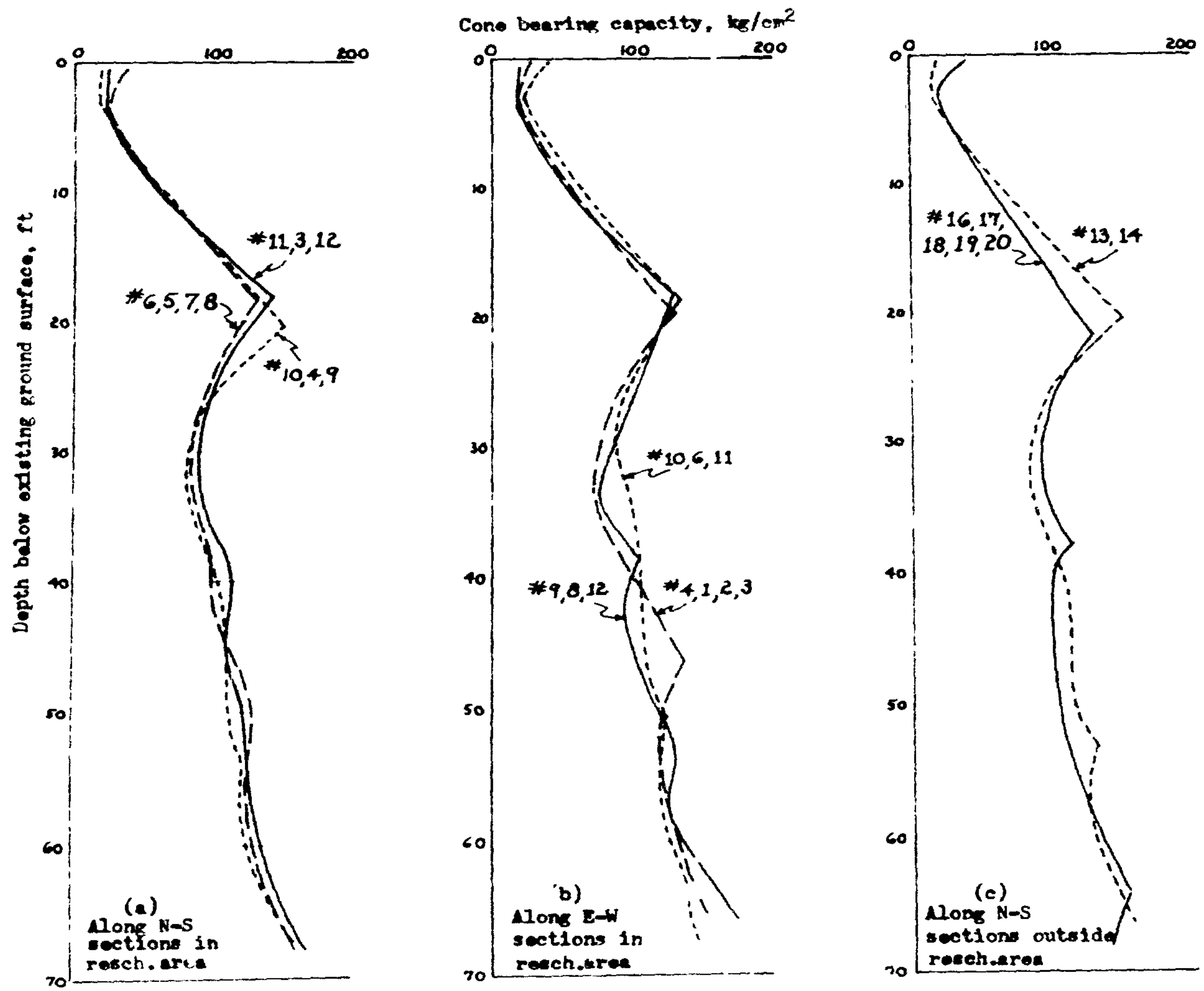


Fig. 7. Superposed Averages of Equivalent Cone B aring Logs

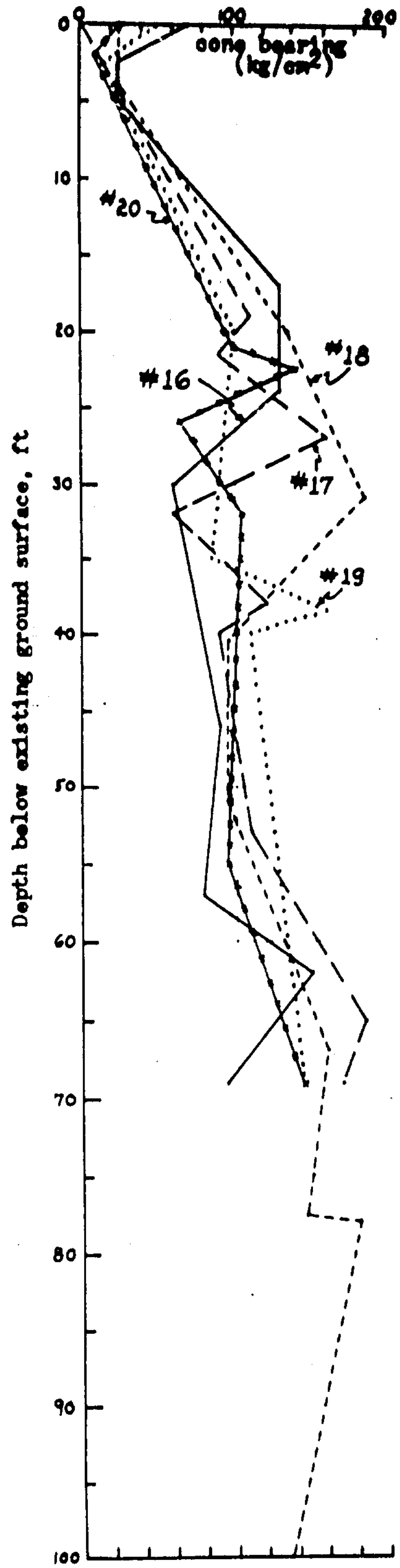


Fig. 8. Superposed Equivalent Cone Bearing Logs, N-S Section Along Centerline of Fire Road

Further Interpretation of Soil Conditions

30. On the basis of experience with friction cone soundings, the following additional interpretation of the soil conditions at this site are offered. The relative density estimates noted below are based on previous experience. They were subsequently checked against WES relative density data from WES hole 3 and found to be in fair agreement.

0-3 ft

31. The surface sand is loose with relative density ranging between 10 and 50%, depending on whether or not the particular sounding location has been loaded or otherwise influenced by vehicle activity.

3-20 ft

32. There is a continuous, almost linear, increase in cone bearing capacity over this depth interval, going from about 25 to 135 kg/cm^2. This, according to previous experience, represents a relative density increase from about 40% to 75%. The angle of internal friction increases from about 30 deg to about 42 deg.

33. This layer is the most homogeneous of the soil layers at the site, showing very similar cone bearing profiles at almost all sounding locations. This type of a resistance increase with depth is quite common to many sites in Florida involving natural soils.

20-30 ft

34. From a definite peak in cone bearing at about 20 ft, there is a drop in cone resistance to a value of about 85 kg/cm^2 at 30 ft. From experience this could mean that the relative density has dropped to about 60%, with a friction angle of about 38 deg, at the 30-ft depth. Reference to the approximate logs summarized in fig. 5 and 6 shows that this layer is particularly variable around the site. It possibly is a zone of nonconformity in the depositional environment and represents an interface that has since been covered.

30-70 ft

35. Over this large depth interval, there is a steady, almost constant, increase in cone bearing from about 85 to 160 kg/cm^2. On

course, reference to the more detailed logs shows considerable local variations. However, fig. 7 clearly illustrates the great similarity of the average trend over the entire site area. It is probable that the relative density of the sand gradually increases from about 60 to 70%. It may be of interest to note that the two previous SPT borings (WES holes 1 and 2) show blow counts over the 40-60 ft depth interval to range between 20-40, with a high of 52.

<u>70-100 ft</u>

36. Only two soundings, no. 14 to 82 feet and no. 18 to 102 feet, explored this depth interval. The logs for these soundings may be found in Appendix B. After noting the possible elevation difference between these two sounding locations, it is apparent that these two soundings show a very similar trend in cone bearing below 70 ft. The trend is one of gradually diminishing cone bearing, and therefore relative density, compensated by an abrupt increase at about the 73-ft depth at the research area. These cone bearing data, plus very similar friction ratios, show that the soils from 70-100 ft are not much different than the soils from 50-70 ft.

PART VI: SUMMARY COMMENTS AND CONCLUSIONS

37. The friction-cone sounding program reported on herein succeeded in obtaining considerable data regarding the homogeneity of the soils to the 70-ft depth, at both the research area and a larger surrounding area.

38. No special difficulty was encountered in reaching the general 60-70 ft sounding depths required. One sounding was taken to 102 ft. In all soundings a friction reducer was used. The only reaction required was the 7 tons available from the weight of the truck and penetrometer equipment mounted therein. All mechanical equipment appeared to perform in an excellent manner. The final 11 soundings were recorded via pressure transducer and continuous chart. This system worked well for these final 11 soundings, and friction ratios could be determined with precision.

39. The friction ratios were found to be constant and uniform within the area of this investigation. They indicate clean sands without cohesive fines. No cohesive soil, or even very silty soil, was observed on the rods or cone during withdrawal.

40. Although there are many local variations, there is a definite, overall uniformity in the soil conditions at both the research area and the surrounding area investigated. The surface 3-20 ft is especially uniform over this area.

41. The 20-ft surface layer noted above is a natural deposit and not a fill.

42. No groundwater table or indications of a perched water table were noted in this investigation.

43. The difference in cone bearing profiles between the material above and below 20 ft, plus the variability of the cone logs in the 20-to 30-ft range, suggest that this is a zone of nonconformity in the depositional history at this site.

44. A study of the cone logs suggest no obvious direction to the depositional environment. East-west and north-south sections show about equal uniformity in the cone bearing profiles.

45. It appears that the entire area investigated has about equal uniformity, or nonuniformity, of soil conditions. Thus, there is no particular advantage or disadvantage from a soils point of view to continuing to use the same research area. Of course, it has now been more thoroughly investigated, and this is an advantage if WES decides to continue using it.

46. From experience, it appears that the soil conditions at this site are about as homogeneous as can be expected in natural sand deposits of this depth. A considerable amount of exploration and investigation would probably be necessary before finding anything significantly superior. Sand, as a coarse-grain deposit, is naturally associated with higher energy environments of deposition and these are inherently more variable. Only the people who intend to use this site for specific research purposes can judge whether or not it is sufficiently homogeneous for their purposes.

APPENDIX A: THE STATIC, DUTCH FRICTION-CONE PENETROMETER TEST

Method and Equipment Used

1. The static cone sounding method of soil exploration is in common use in some parts of the world, particularly in Europe where it has been used in its modern form for some 35 years. The use of a cone able to measure local friction, the friction-jacket cone, is a relatively recent development -- only about 5 years old. The static cone exploration method is not common in the United States. A brief explanation is therefore appropriate.

2. The concept is a simple one. A steel cone is pushed with constant velocity into the soil. The thrust to accomplish this is measured in the form of pressure in a hydraulic load cell. This thrust divided by the projected end area of the cone is the cone bearing capacity.

3. It is presumed that the cone bearing capacity, and the way in which it varies with depth, is a useful indicator of some of the important foundation design properties of the soils penetrated. The addition of a friction jacket immediately above the cone point permits a similar measurement of local friction and/or adhesion of the soil, just at least partially remolded by point penetration, against smooth steel. This friction/adhesion is of direct use for the design of friction pile foundations. It has also proven useful in another way. The ratio of friction/bearing is an indicator of the fineness and/or cohesiveness of the soils penetrated by the cone. In this way it is often possible to estimate the type of soil penetrated, even though no samples are obtained with this penetrometer method.

4. The most common static penetrometer equipment was developed by the Dutch, and the method has become known as the Dutch cone test. Their equipment and method was used in this exploration. They long ago standardized the design of their hardened steel cone to have a point angle of 60° and a projected end area of 10 cm^2 (1.55 $in.^2$). The standard rate of penetration is 2.0 cm/sec. The motorized hydraulic pump and piston used to provide the penetration thrust has a special servo-valve, which is activated just before each thrust measurement and ensures a standard rate of penetration at all levels of thrust. The back-taper design of that part of the cone behind the point is such as to minimize the possibility of soil contamination and possible jamming of the cone mechanism.

5. The point is advanced mechanically from the surface, using a 2-rod system. The outer rod, of 36-mm OD, acts as a casing and provides structural strength (to ensure vertical penetration and prevent buckling) and also protects the solid inner rod from soil

friction. The ID of the outer rod is 16 mm, and the OD of the inner rod is 15 mm, thus providing 1/2-mm clearance. The clearance is small enough to prevent significant buckling and friction along the inner rod, yet large enough to prevent jamming by ordinary soil particles. All rods come in 1-meter lengths. The outer rods are hand-tight connected via a special tapered thread, and the inner floating rods have flat ends that fit flush when the outer rods are screwed together.

6. The hydraulic load cell, shown in fig. A1, has a simple lever that allows the alternate advance of the inner and outer rod systems. Pushing on the outer rods collapses the telescoping point and permits advancing it to a new test depth. At the completion of this push, the inner rods project above the topmost outer rod. Then the inner rod system only is pushed and only the point moves downward -- during which the thrust measurements of cell pressure are made, usually by the operator calling out the Bourdon gage readings (see fig. A1) to a recording assistant. The outer rods are then pushed, telescoping the point and advancing it to a new test depth, etc. Thus, the field operation is an incremental one with thrust readings usually taken every 20 cm (8 inches). This was the interval used in this investigation.

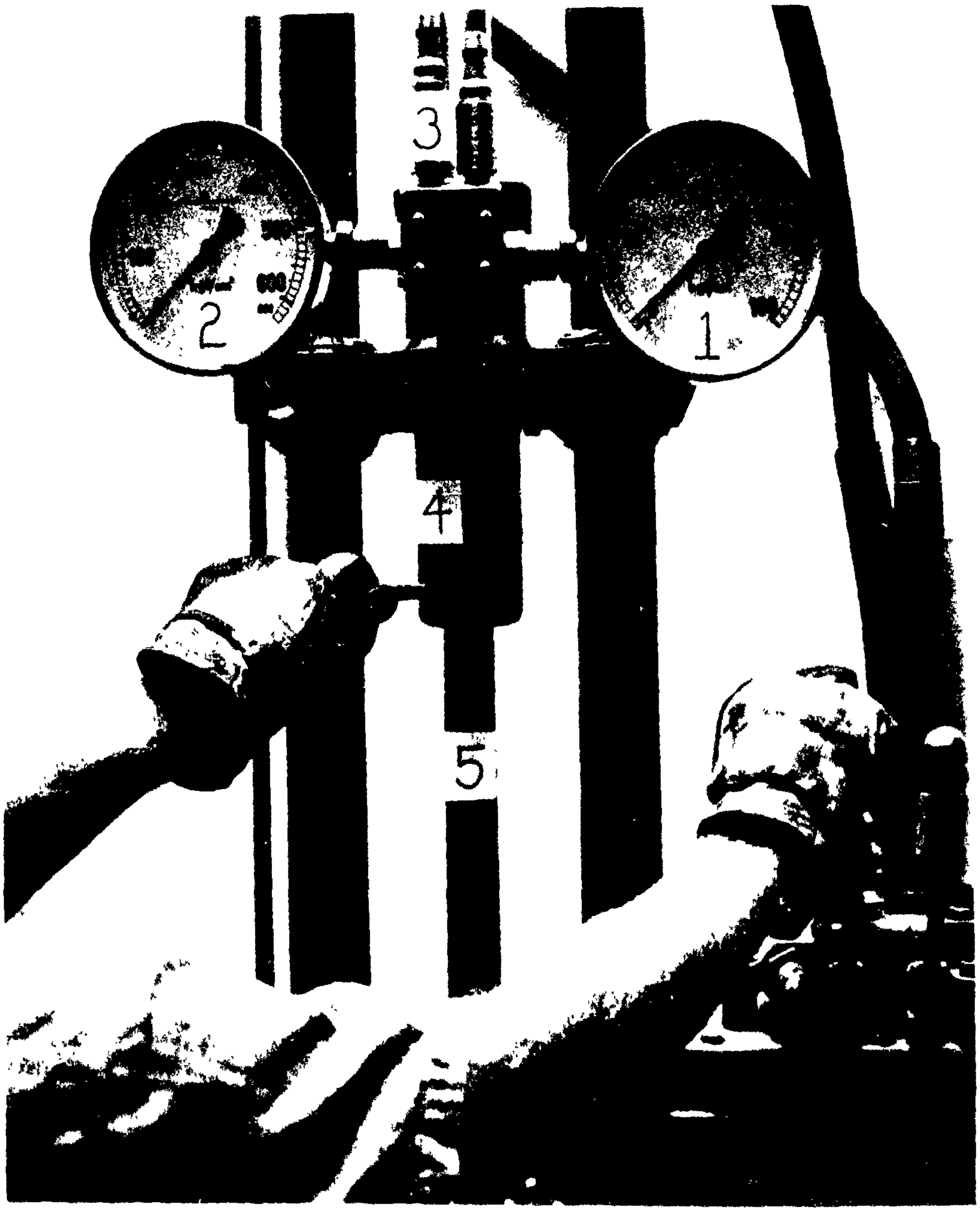
7. The friction-cone design has also been standardized by the Dutch. It is operated in the same manner as described above. Figure A2 shows a photo of this cone and also presents a diagram which helps visualize its operation. It is the use of this type cone that permits a determination of the friction ratio.

Friction Ratio

8. Note on any of the data-log sheets in Appendix B that the two lefthand columns are used for recording the thrust pressures required to advance the friction cone in a telescopic movement due to the thrust of the inner rods.

G and ($G + \Delta G$) readings

9. G and ($G + \Delta G$) are the respective load cell gage readings made just before and just after the downward movement of the penetrometer point engages and pulls the friction jacket. The operator attempts to get a steady-state reading both before and after. It often happens that the point resistance is gradually increasing or decreasing during the continuing movement. A good operator will attempt to call out gage readings that, for ($G + \Delta G$), takes account of the gradual shift in point resistance to get a more accurate ΔG determination. The assumption is made in later analysis



1 - Low range Bourdon gage. Gage pressures are 1/2 cone bearing pressures.
2 - High range Bourdon gage.
3 - Low and high range pressure transducers attached to hydraulic load cell.
4 - Lever the operator uses to place thrust on either the inner or outer rods.
5 - Rod system going to cone. Number on outer rod. Inner rod visible in slot next to above lever.
6 - Two levers the operator uses to control the direction and speed of the hydraulic piston producing the penetration thrust.

Fig. A1. The hydraulic load cell and controls used by operator that the point-only gage reading G can be subtracted from the subsequent (G + ΔG) reading to obtain the difference, ΔG. When it is obvious to the operator that this assumption is not properly fulfilled, he then will not record a value for G + ΔG reading but will make an appropriate note, such as m for missed. Of course, a chart record showing the complete pressure jump (see fig. 3) greatly aids in the accurate determination of G and (G + ΔG).

Meaning of friction ratio

10. Begemann* discovered that the friction cone could be used as an indicator of the type of soil penetrated. The writer has expressed this indicator as the friction ratio, which is the dimensionless ratio of unit friction/adhesion along the smooth steel friction jacket to the unit bearing capacity of the standard cone point. In general, but with some important qualifications, the higher the friction ratio, the greater the percentage of fines in the soil -- particularly cohesive fines.

How the friction ratio is computed

11. The reading ΔG is the additional pressure required, on a 20-cm^2 piston, in kg/cm^2, to overcome the friction force along the friction jacket. This jacket, or sleeve, is smooth steel, has an area of about 150 cm^2, and is in contact with soil that has been partially remolded by previous displacement by the cone point. The sleeve has exactly the same OD as the point. The center of this sleeve is about 20 cm above the point. Thus, the friction increment ΔG must be compared with the previous point resistance G to establish the friction ratio at the previous test depth (20 cm higher).

12. Expressing the friction ratio as a percentage, and noting the ratio of jacket to point area is 150/10, a factor of 6.6 is obtained by dividing 1000 by 150. The friction ratio is thus obtained from the equation

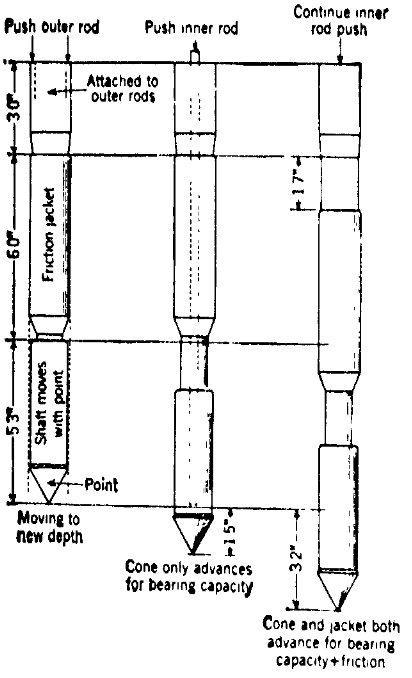
$$FR_n(\%) = \frac{6.6\,\Delta G_{n+1}}{G_n} \quad \text{or} \quad \frac{6.6\left[(G + \Delta G)_{n+1} - G_{n+1}\right]}{G_n} \qquad (1)$$

---

* H. K. S. P. Begemann, "The Friction Jacket Cone as an Aid in Determining the Soil Profile," Proceedings of the 6th International Conference on Soil Mechanics and Foundation Engineering, Vol I, 1965, p 17.

1- Assembled friction cone. 2- Friction reducer.
3- First section of 1 m. sounding rods.
4- Disassembled cone point.
5- Disassembled friction jacket.
6- Inner rod in cone.
1-2-3 Represent sequence as inserted into soil. Note floating inner rods.
4-5-6 Show the cone disassembled for cleaning.

(a) Parts and assembly
(scale in inches)



(b) Action

Fig. A2. Friction cone used in this investigation where the n+1 reading is at a 20-cm greater depth. Such friction ratio computations can be made step-by-step in the columns provided on the left side of the data-log sheet. When a small computer is available, these friction ratios can be (and were) determined in one step and recorded in the furthest-right column without the intermediate computations also recorded. The results are then plotted as a friction ratio log versus depth on the graph provided to the right of the cone bearing log.

Interpretation for soil type

13. From experience, primarily in, but not limited to, north-central Florida, the friction ratio interpretations noted in the following table have proven reasonably accurate. This table is in general agreement with similar information reported by Begemann*.

Usual Meaning of Friction Ratio Values
in North-central Florida

Friction ratio FR, %	Soil Type
0 - 1/2	Very shelly deposits, limerock (soft, shelly, partially indurated limestone)
1/2 - 2	Clean sand, no plastic fines (independent of relative density)
1-3/4 - 2-1/2	Silty sand
2-1/3 - 3-1/2	Clayey sand, silts, marls, moderately sensitive clays
3 - 4-1/2	Sandy clay
over 4	Relatively insensitive clay

* H. K. S. P. Begemann, "The Friction Jacket Cone as an Aid in Determining the Soil Profile," Proceedings of the 6th International Conference on Soil Mechanics and Foundation Engineering, Vol 1, 1965, p 17.

It is evident from the above table that there can be overlap ambiguity when interpreting soil type from the friction ratio. For example, a FR of 3% could be either a clayey sand, sandy clay, silt, marl, or sensitive clay. Other evidence must then be brought in to narrow the interpretation. The cone bearing log is always available. Sometimes a smear of soil adheres to the rods and/or point after withdrawal. Of course, local experience can be a great help.

Thinnest detectable layer

14. The determination of the friction ratio is inherently less accurate than the cone bearing value. It involves a division and an assumption regarding a constant cone value during the friction measurement. Because both G and ΔG vary with depth and because a ratio is involved, this ratio is susceptible to large percentage error. This is particularly true when the denominator G_n is small. The result is that any single friction ratio can easily be in error, especially with manual Bourdon gage readings. Too much reliance should not be placed on a single value. For example, if a single FR value suggests a clay layer with sand above and below, it is quite possible this clay layer does not exist but that the high FR resulted from an error in measurements, especially if there is no matching change in cone bearing at the same depth.

15. The friction jacket, or sleeve, has a length of about 5.2 in. Therefore, a friction/adhesion determination with this sleeve must be an average over this length (depth). This limits the minimum thickness layer that is detectable with this cone design. Furthermore, the point-friction measurement sequence is done in increments of depth, usually 20 cm ($\approx$8 in). In view of the previous paragraph, at least two consistent ratios are therefore needed to establish the existence of a layer of a different soil type. It then follows that the thinnest layer that is ordinarily detectable with some assurance is 8 + 5.2, or about 13 in.

16. Perhaps experience with chart recording will show that a single FR determination will then become reliable. If so, then the thinnest detectable layer will be about 5 in. Since this was the first known investigation using automatic load recorders, such experience is not yet available.

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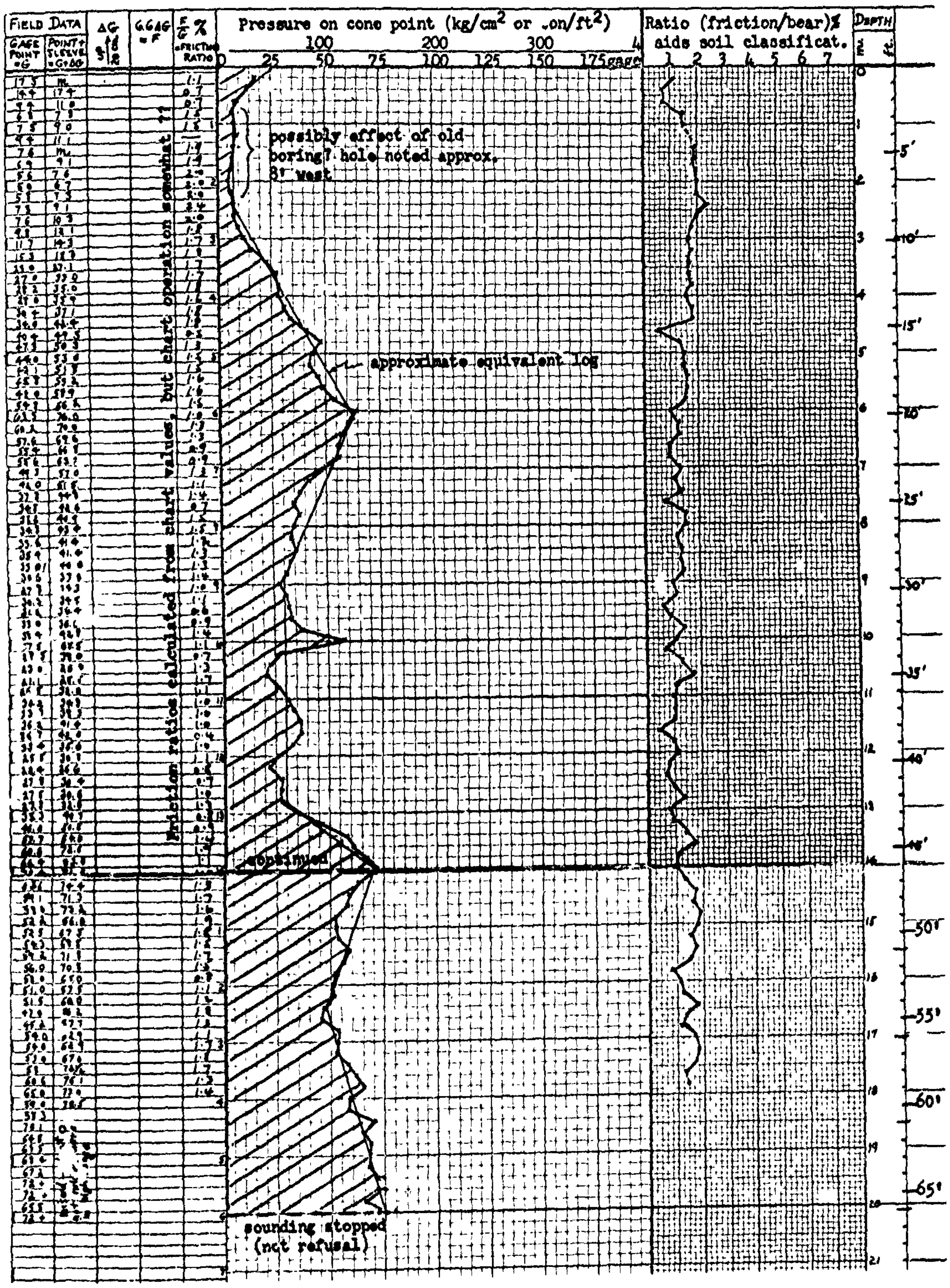
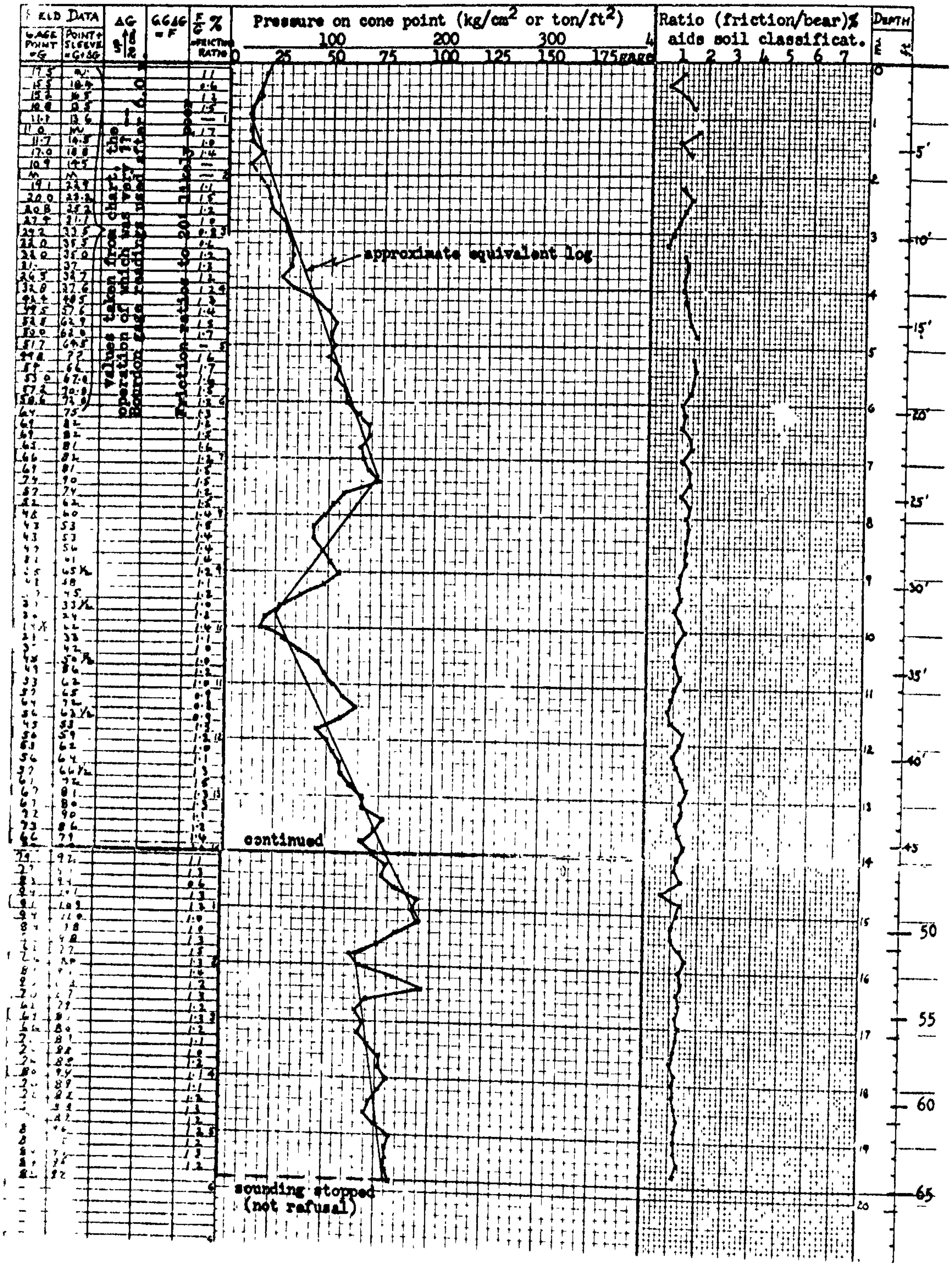
APPENDIX B: THE CONE LOGS

1-20, in order of number

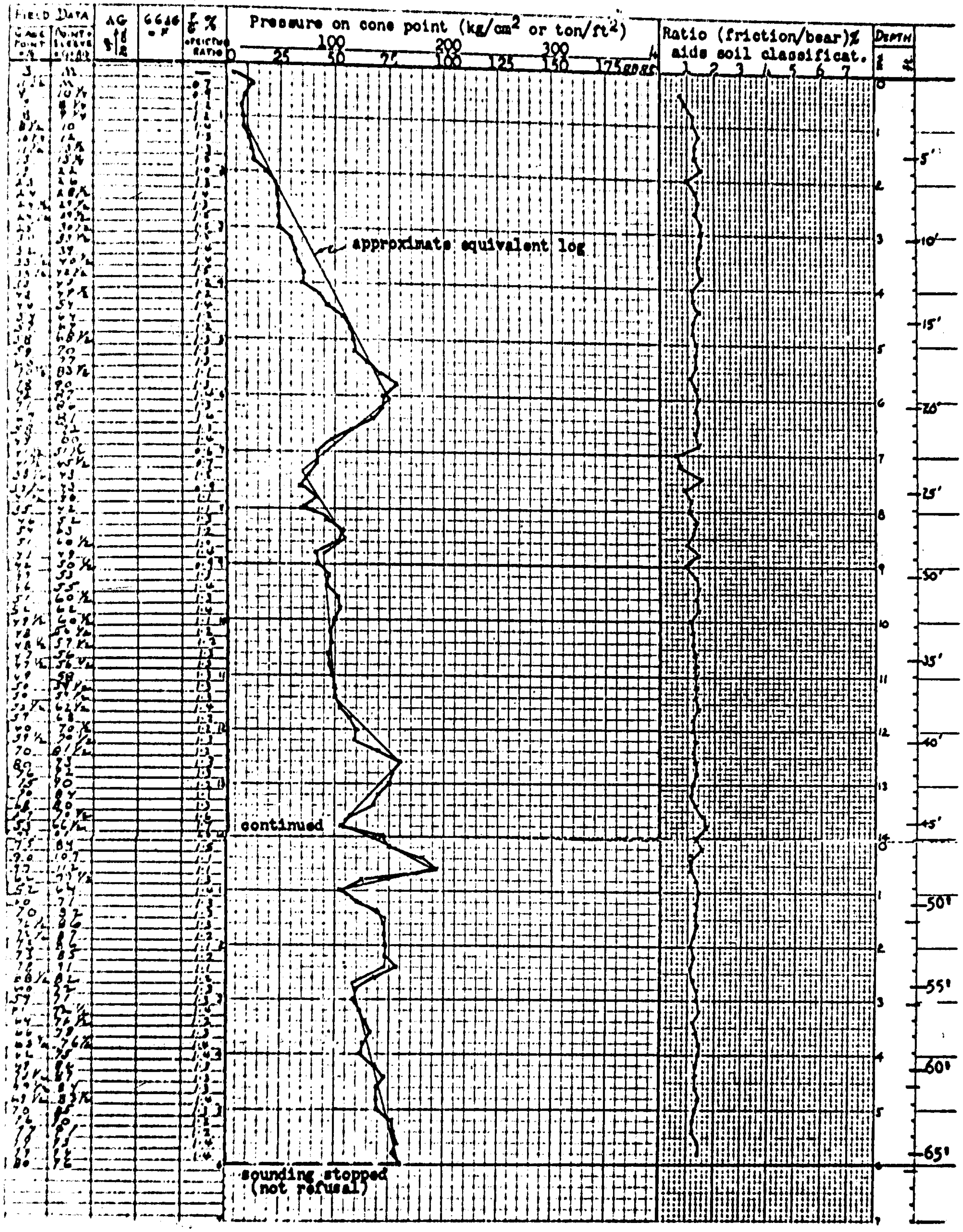


LOG OF SOUNDING 1



LOG OF SOUNDING 2

PLATE B2



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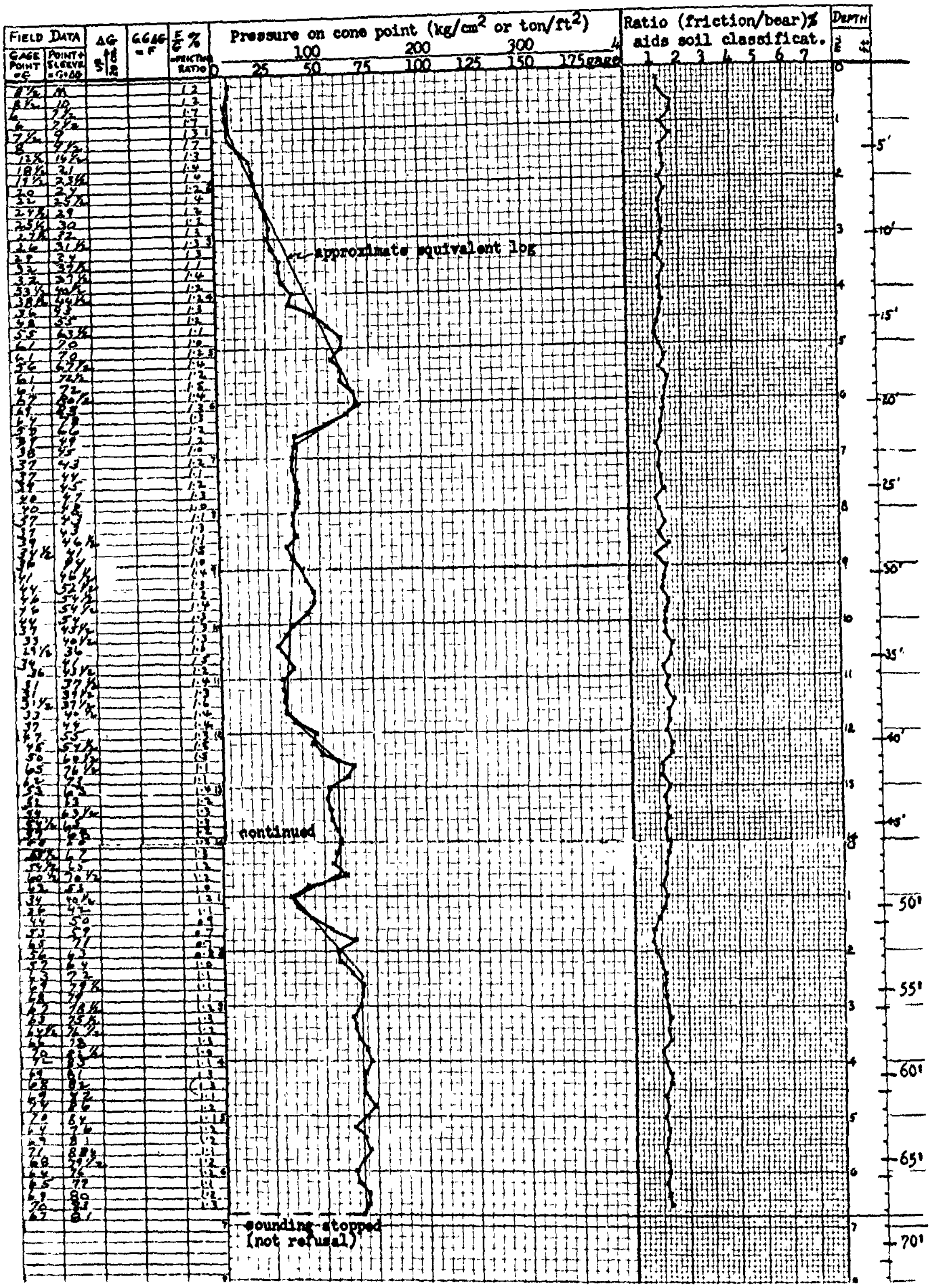

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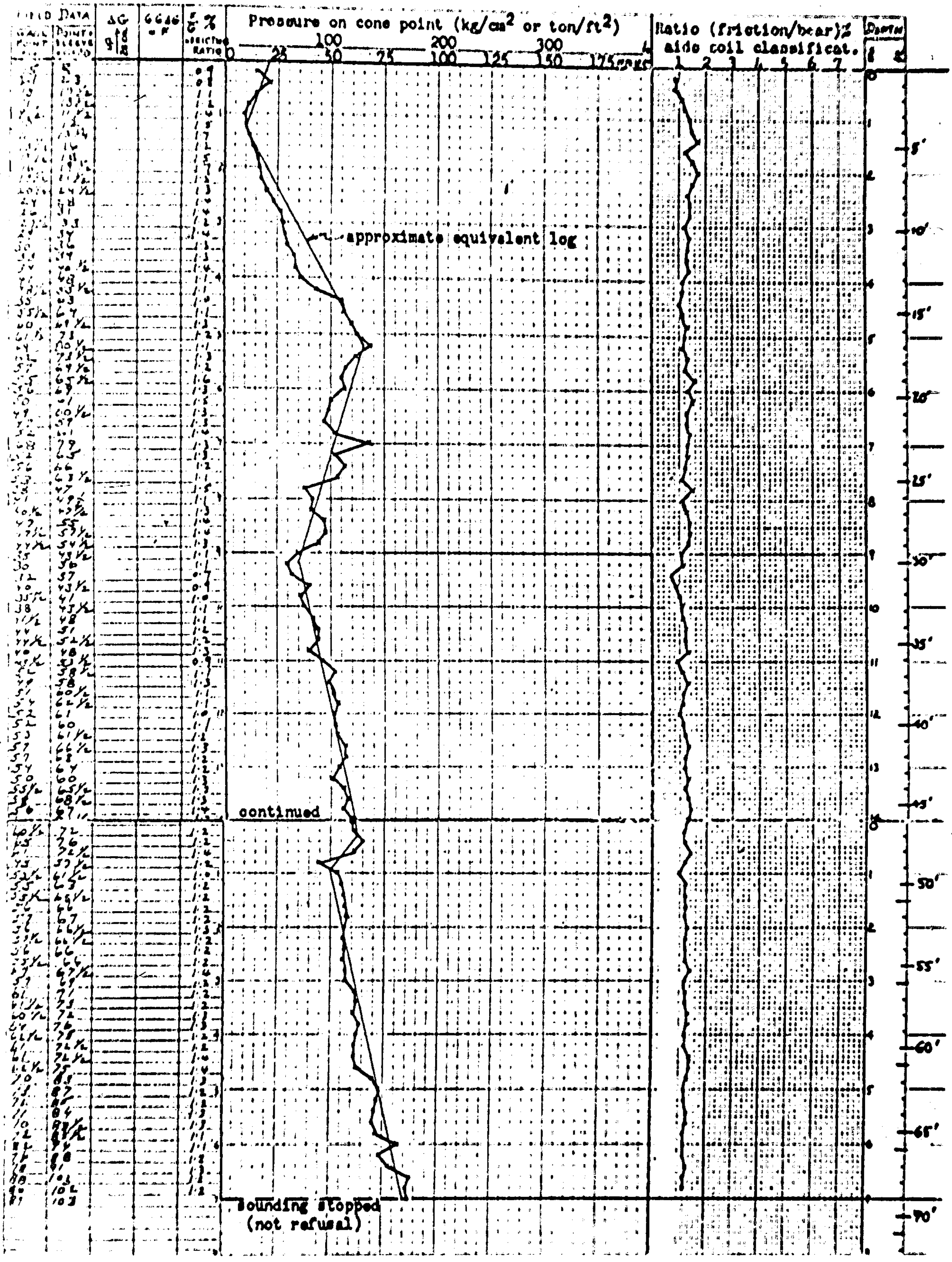

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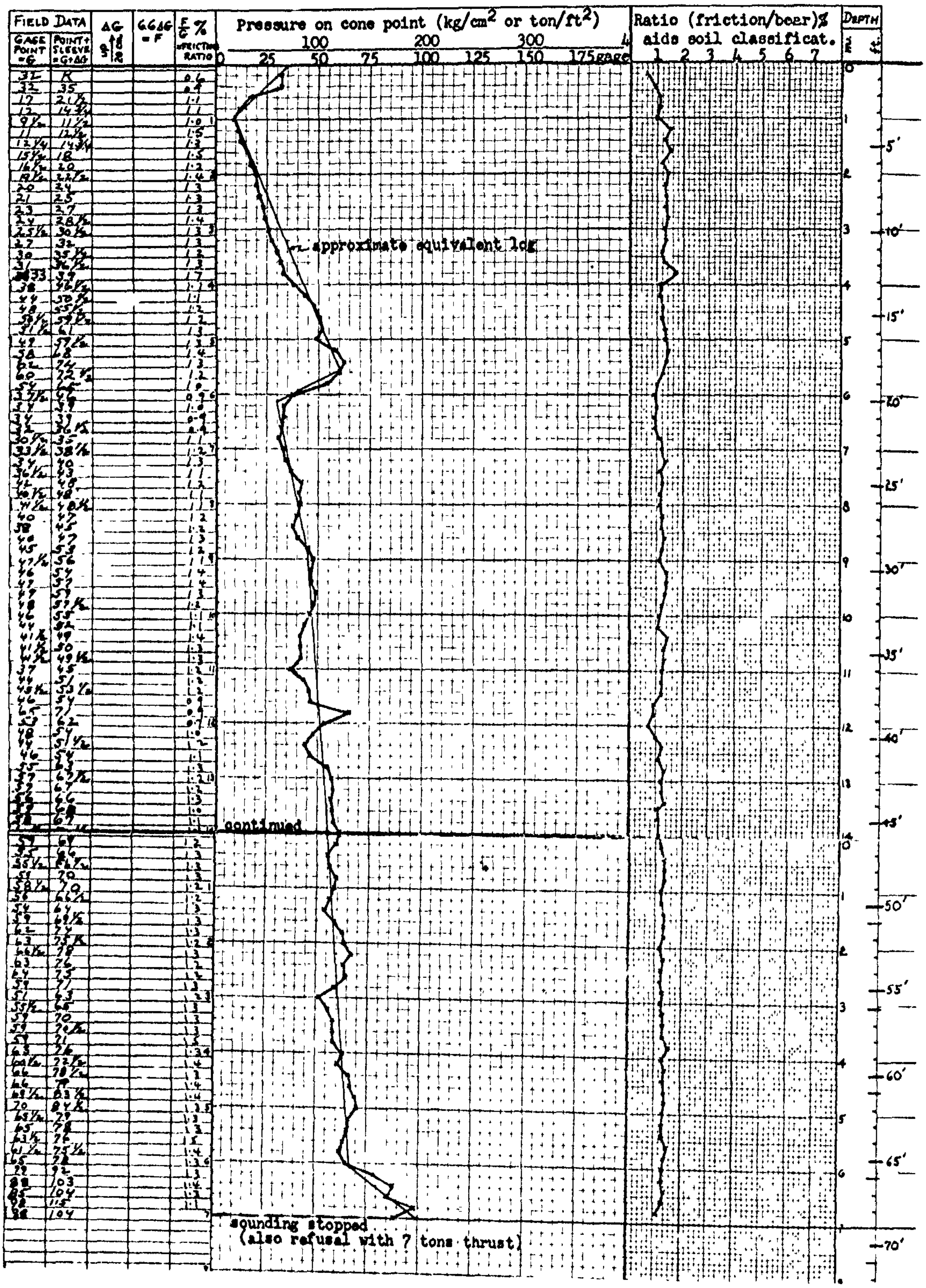
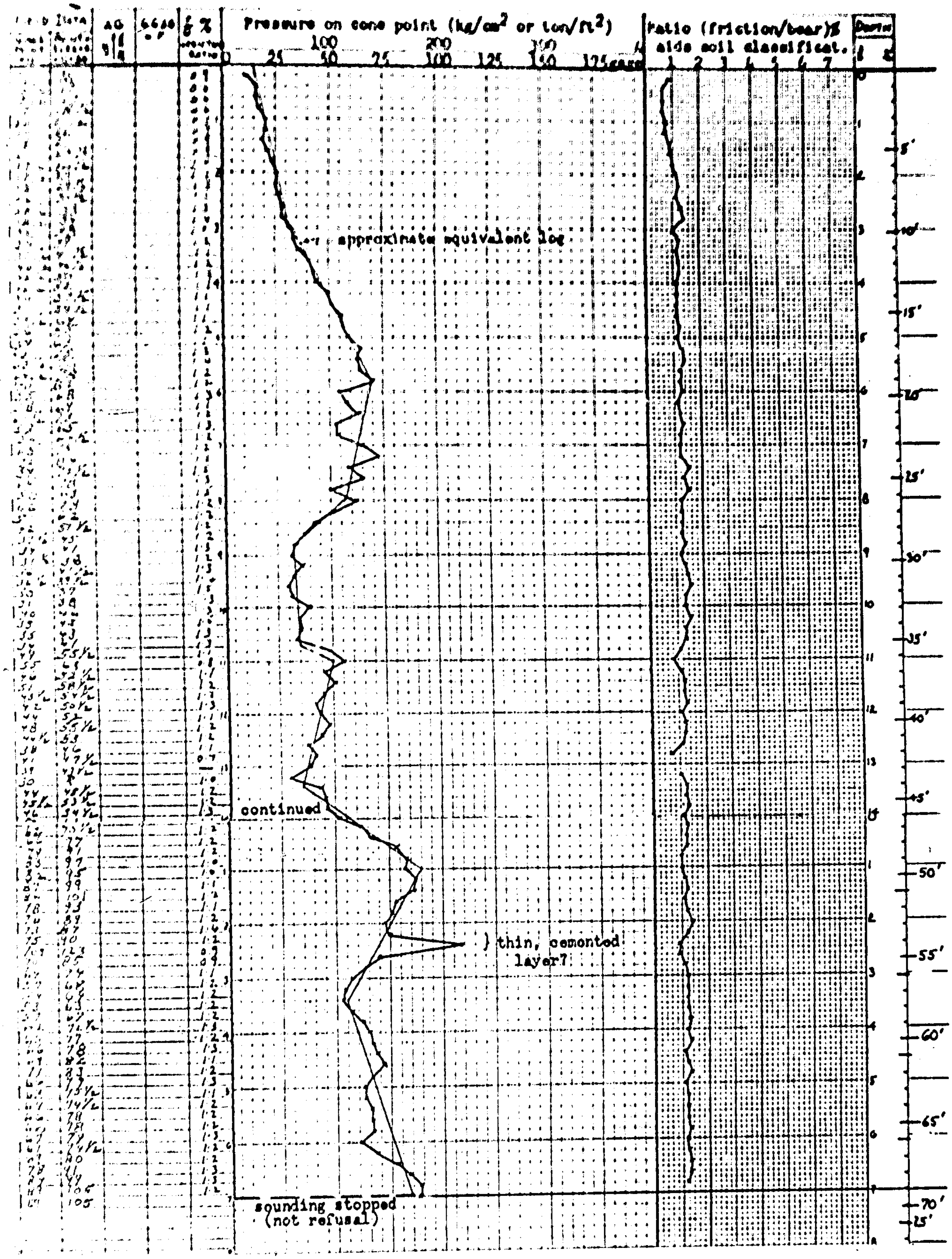


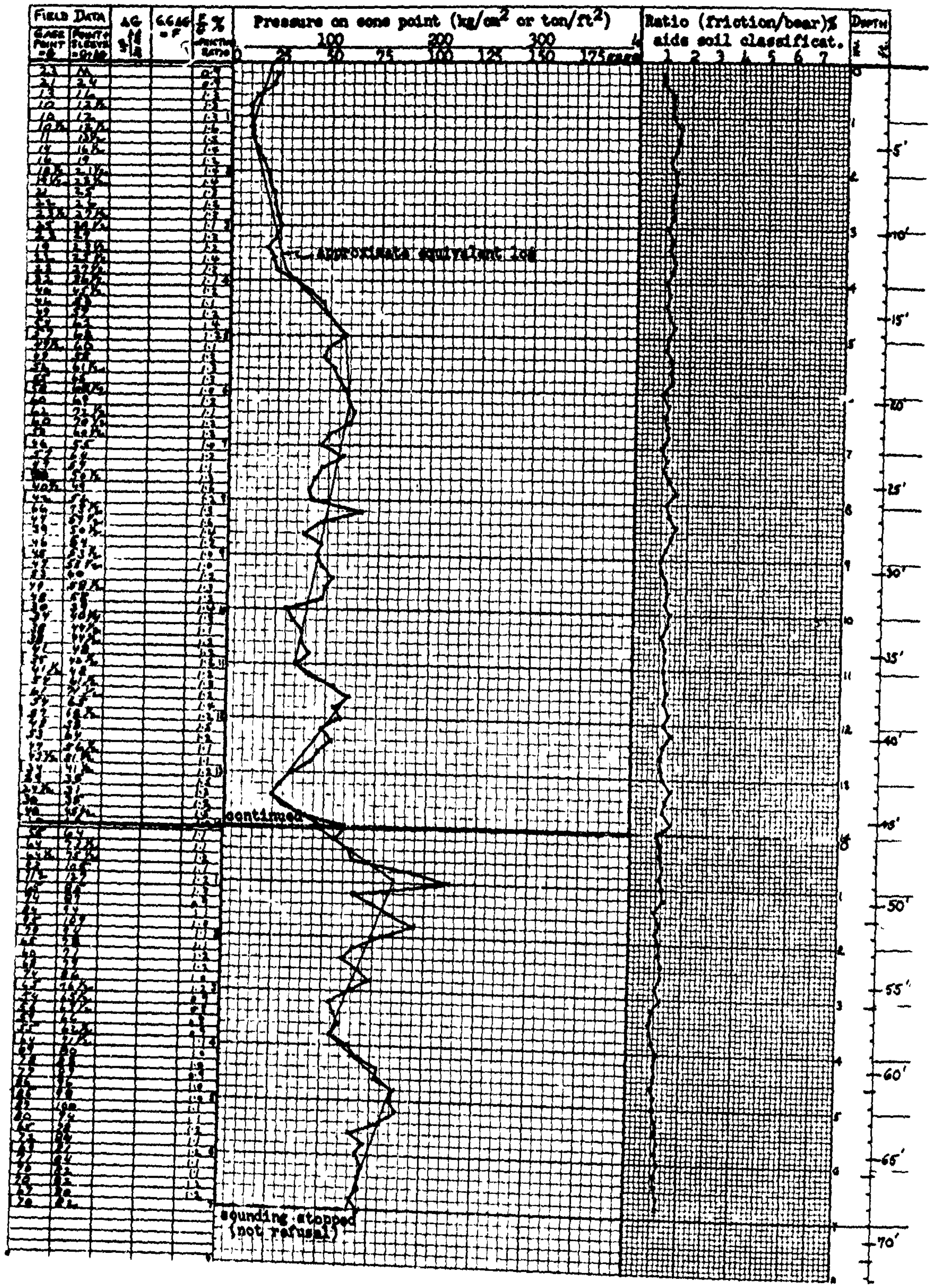
LOG SOUNDING 6

PLATE B6



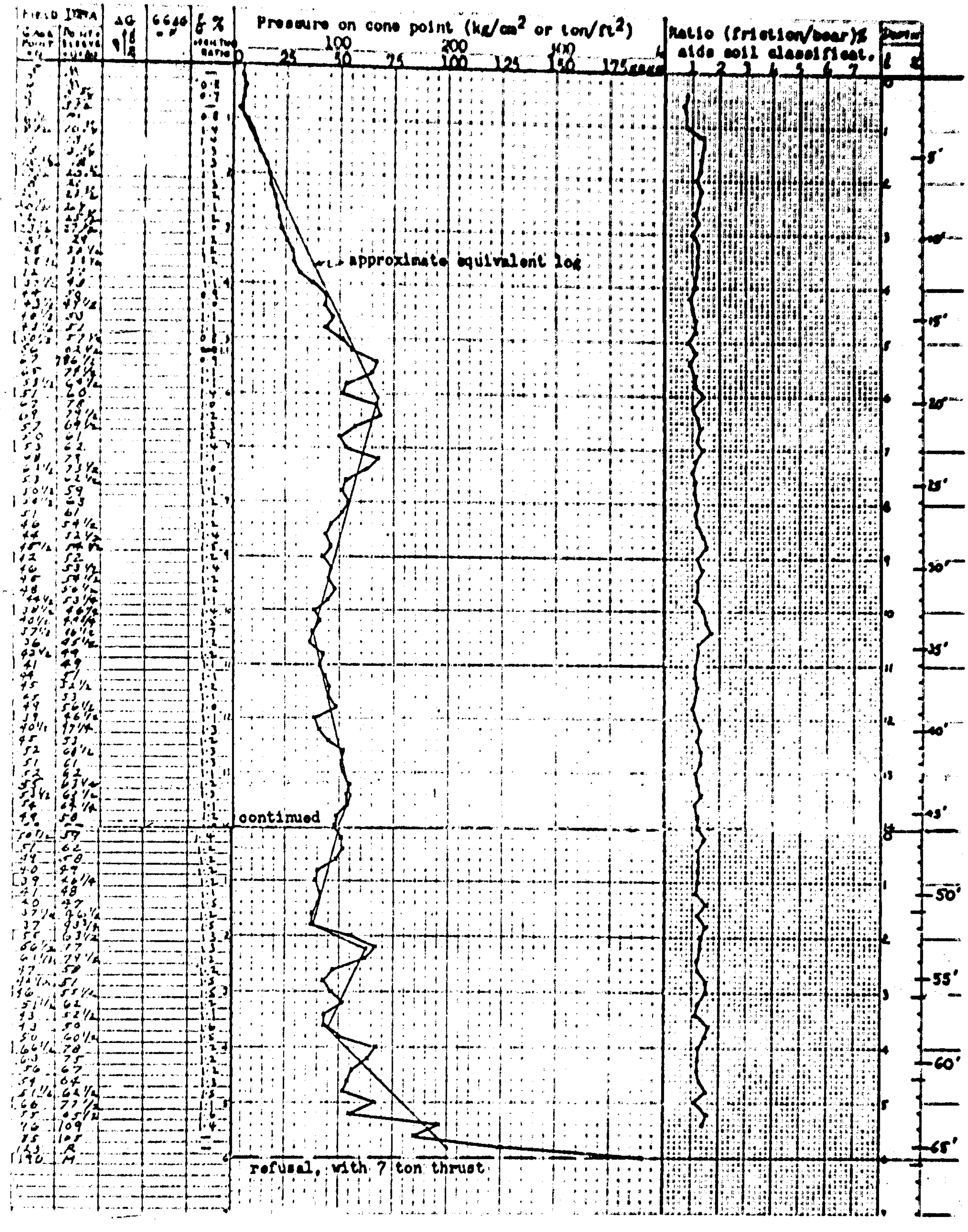
LOG SOUNDING 7

PLATE B7



LOG SOUNDING 8

PLATE B8



LOG SOUNDING 9

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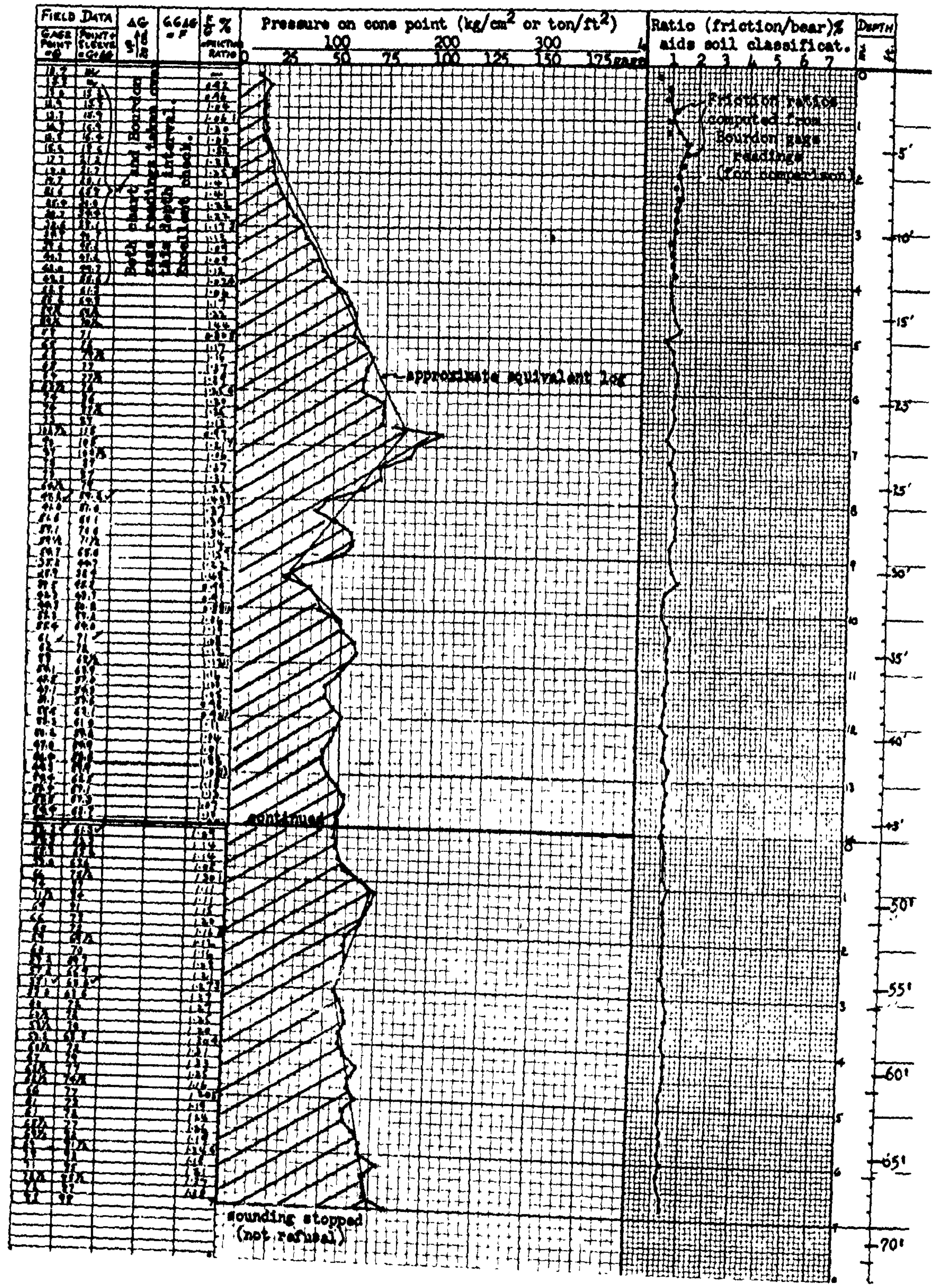
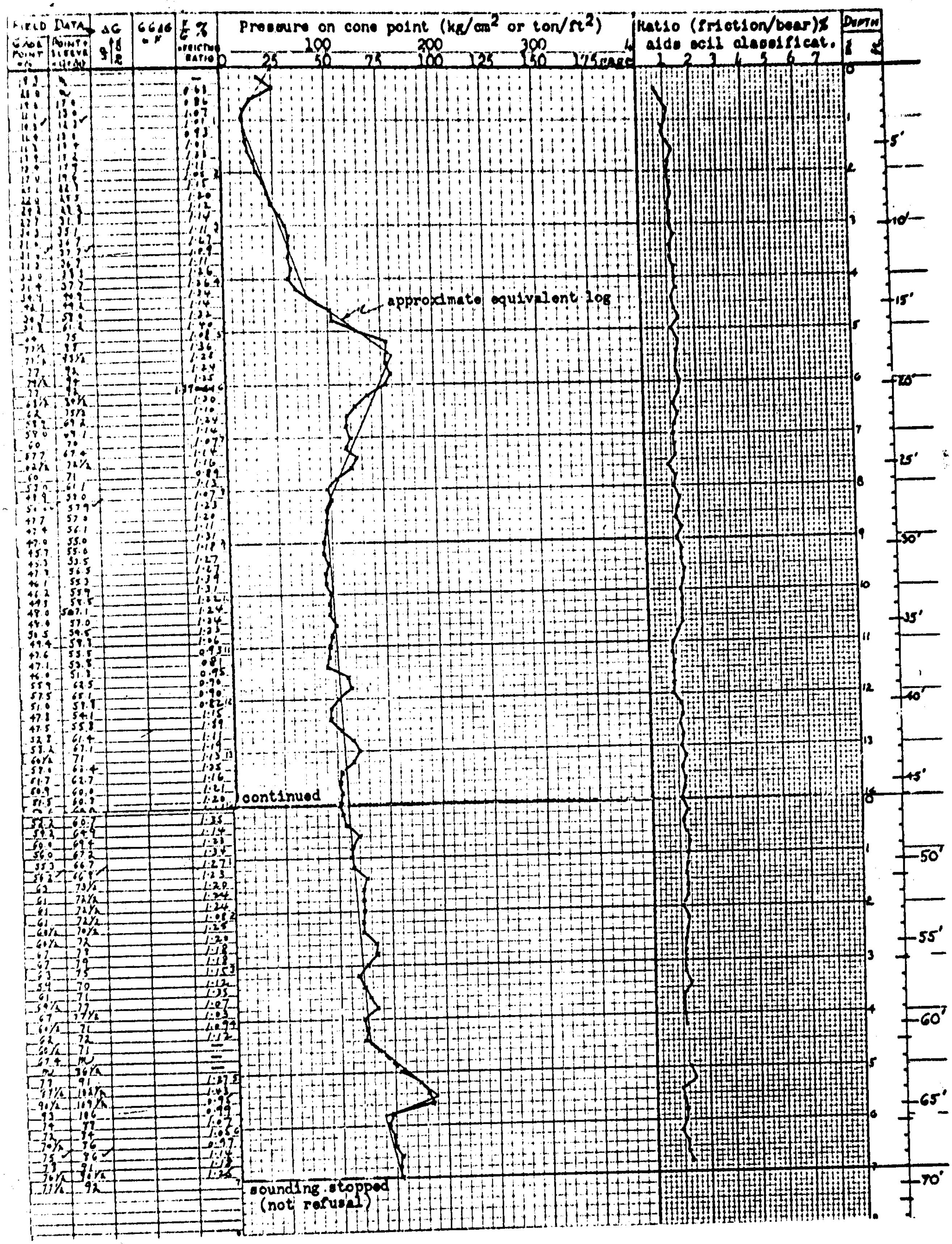


LOG SOUNDING 10

PLATE B10



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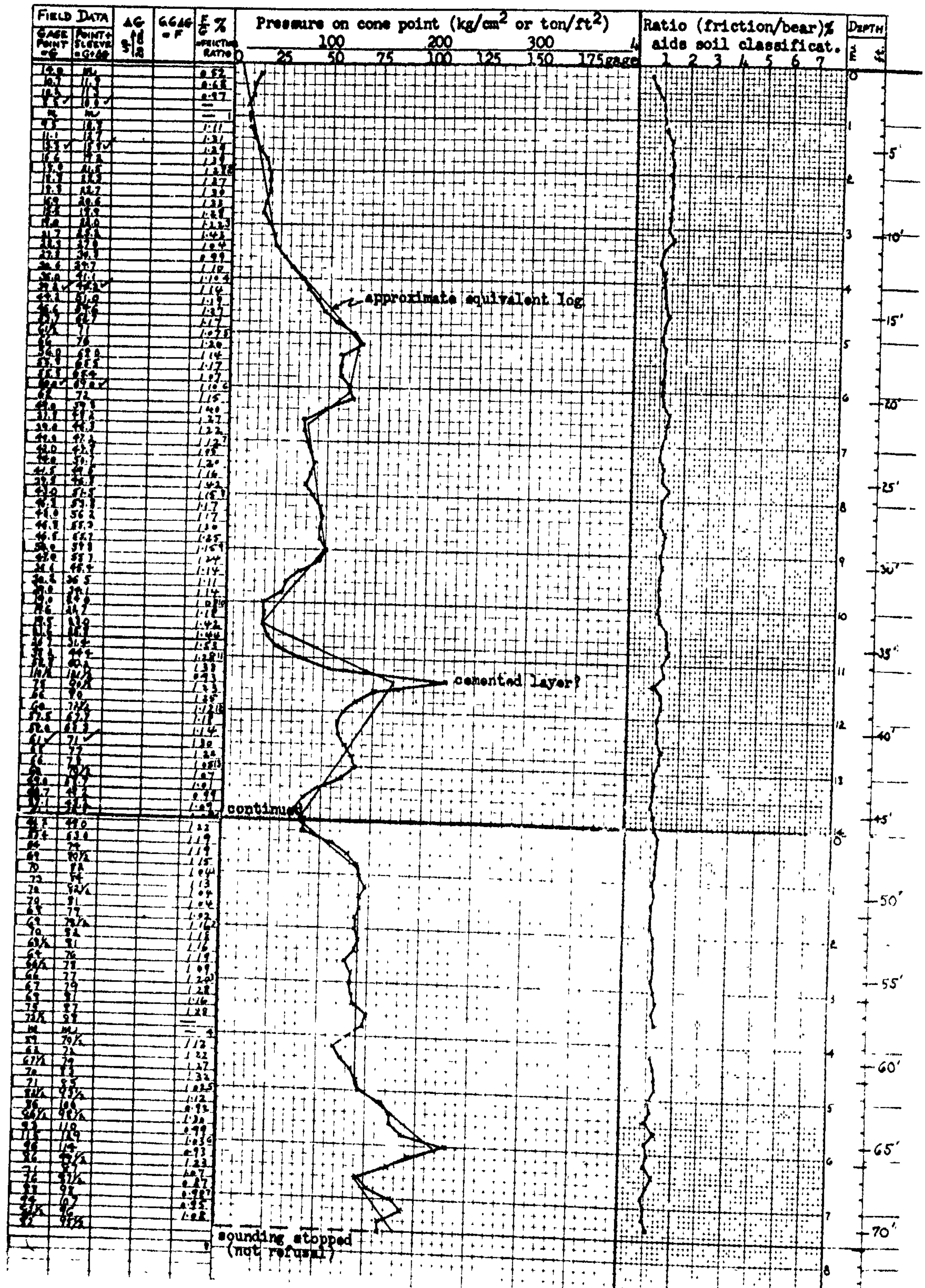

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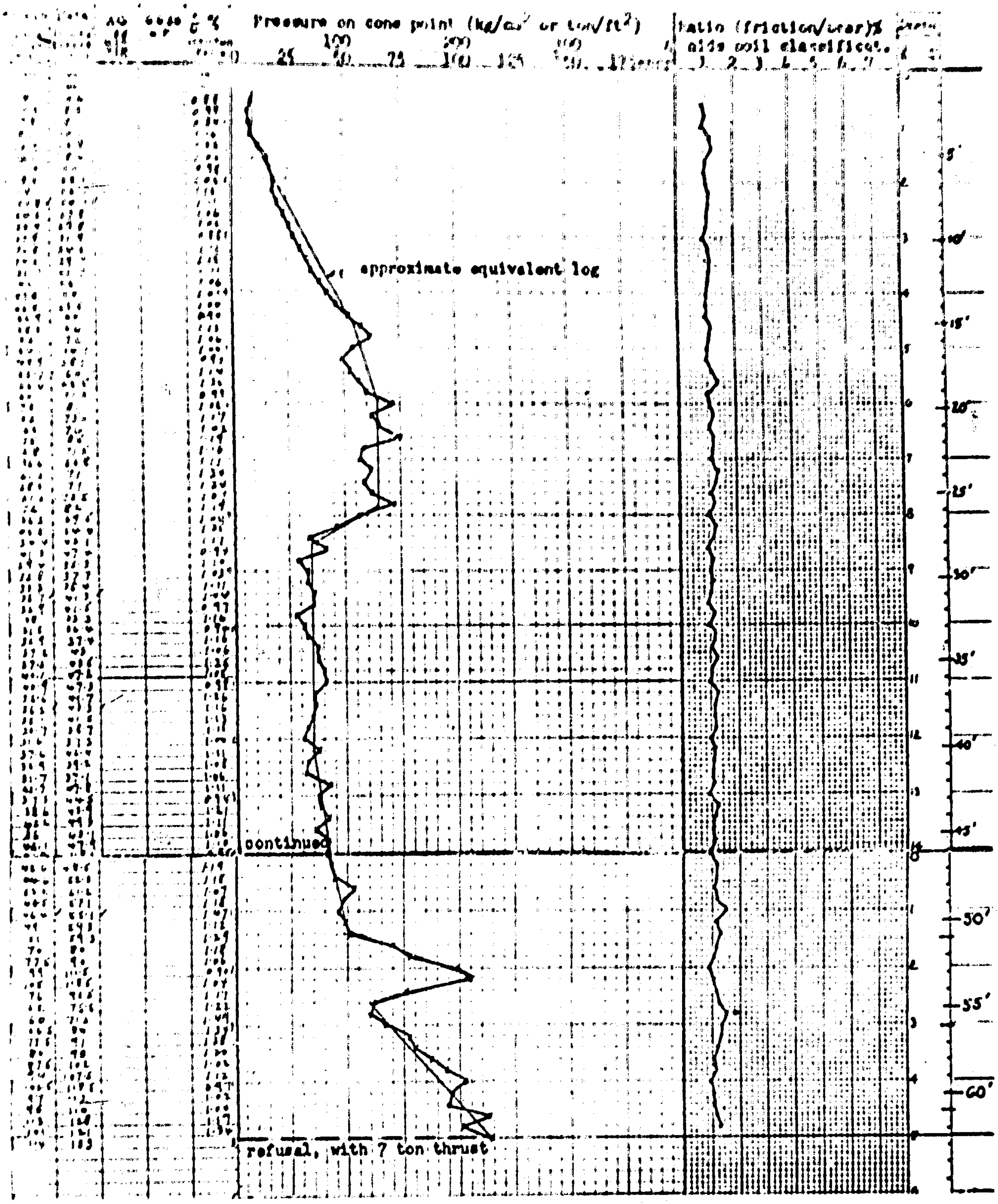

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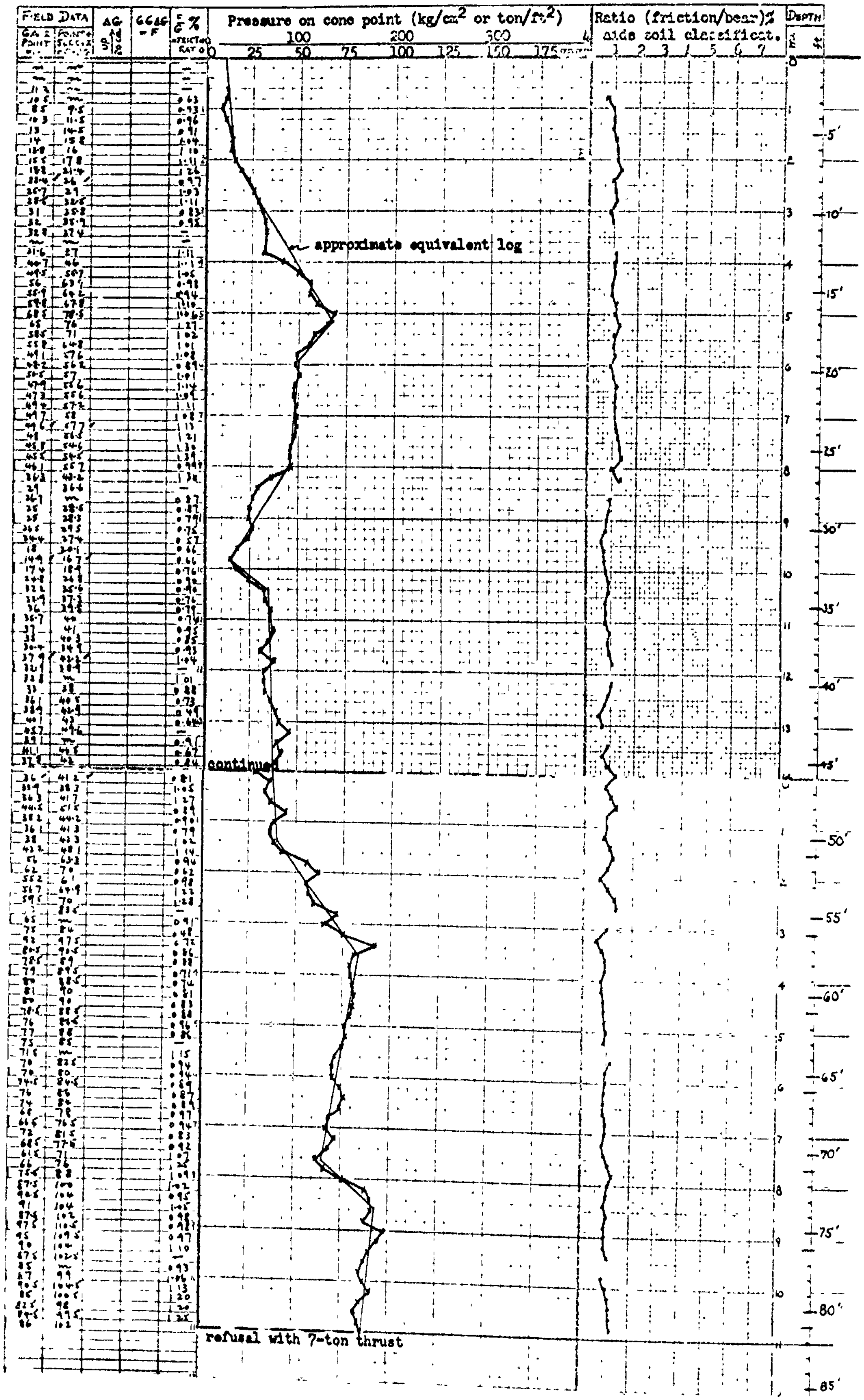
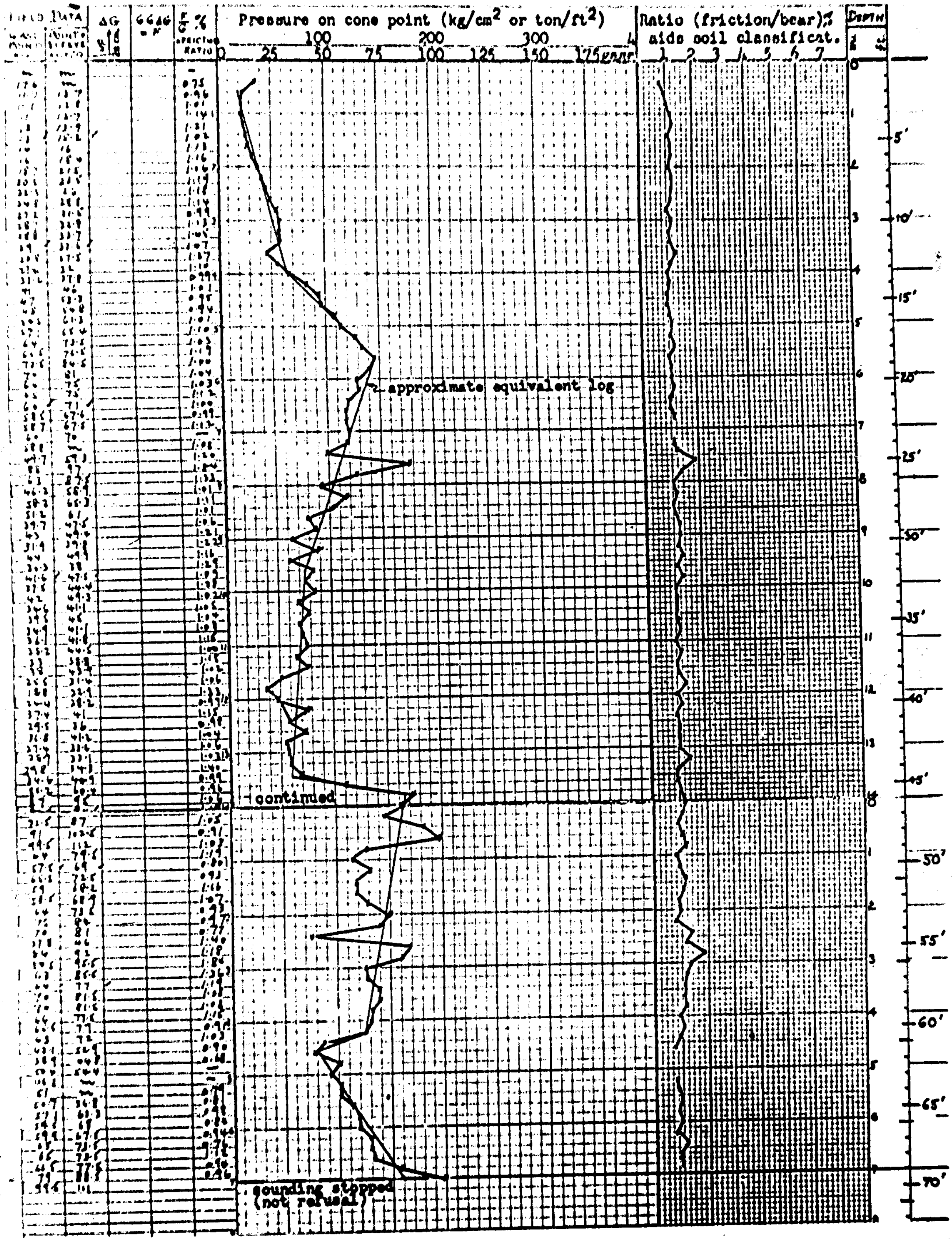


PLATE B14

LOG OF SOUNDING 14



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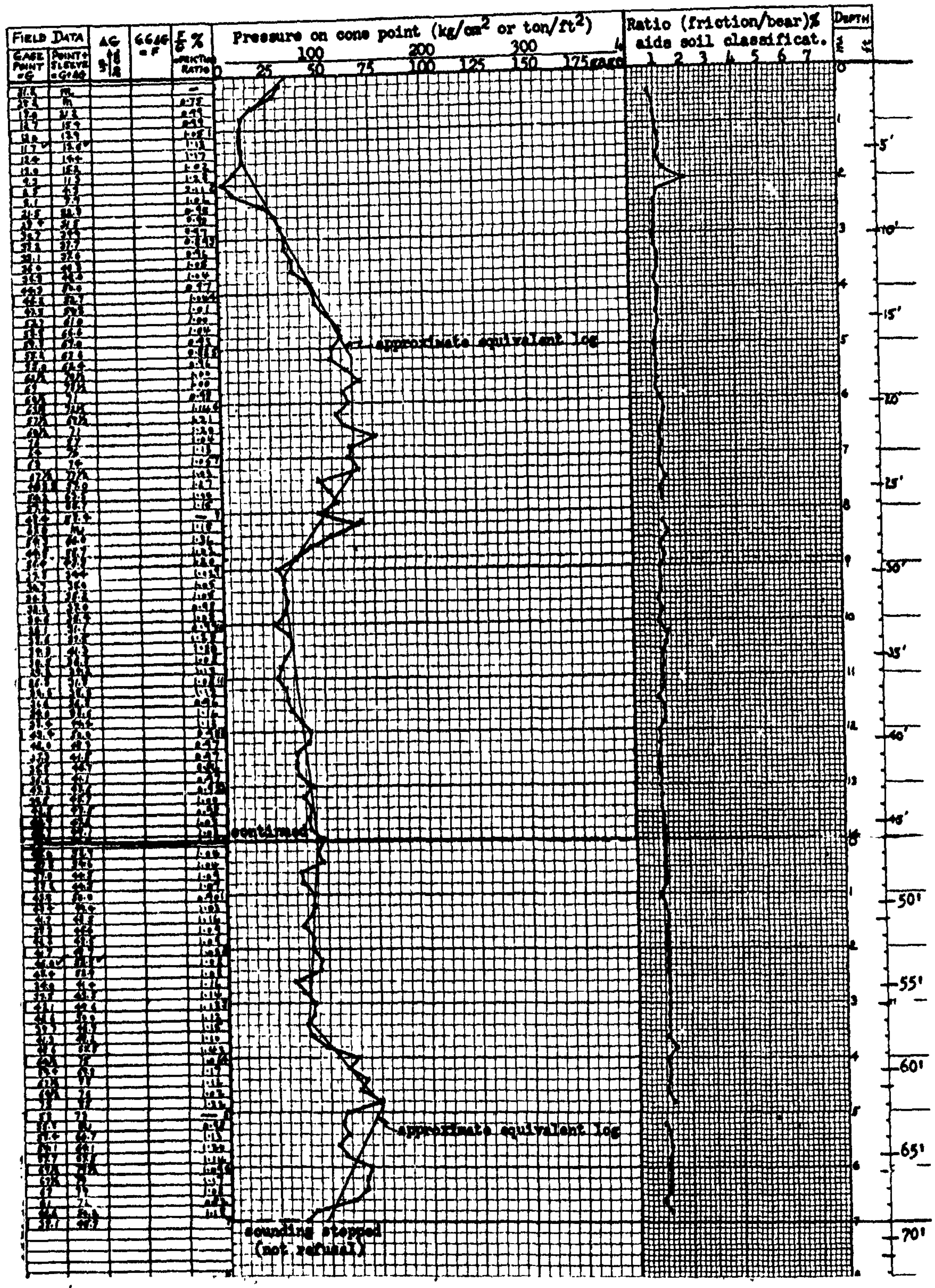

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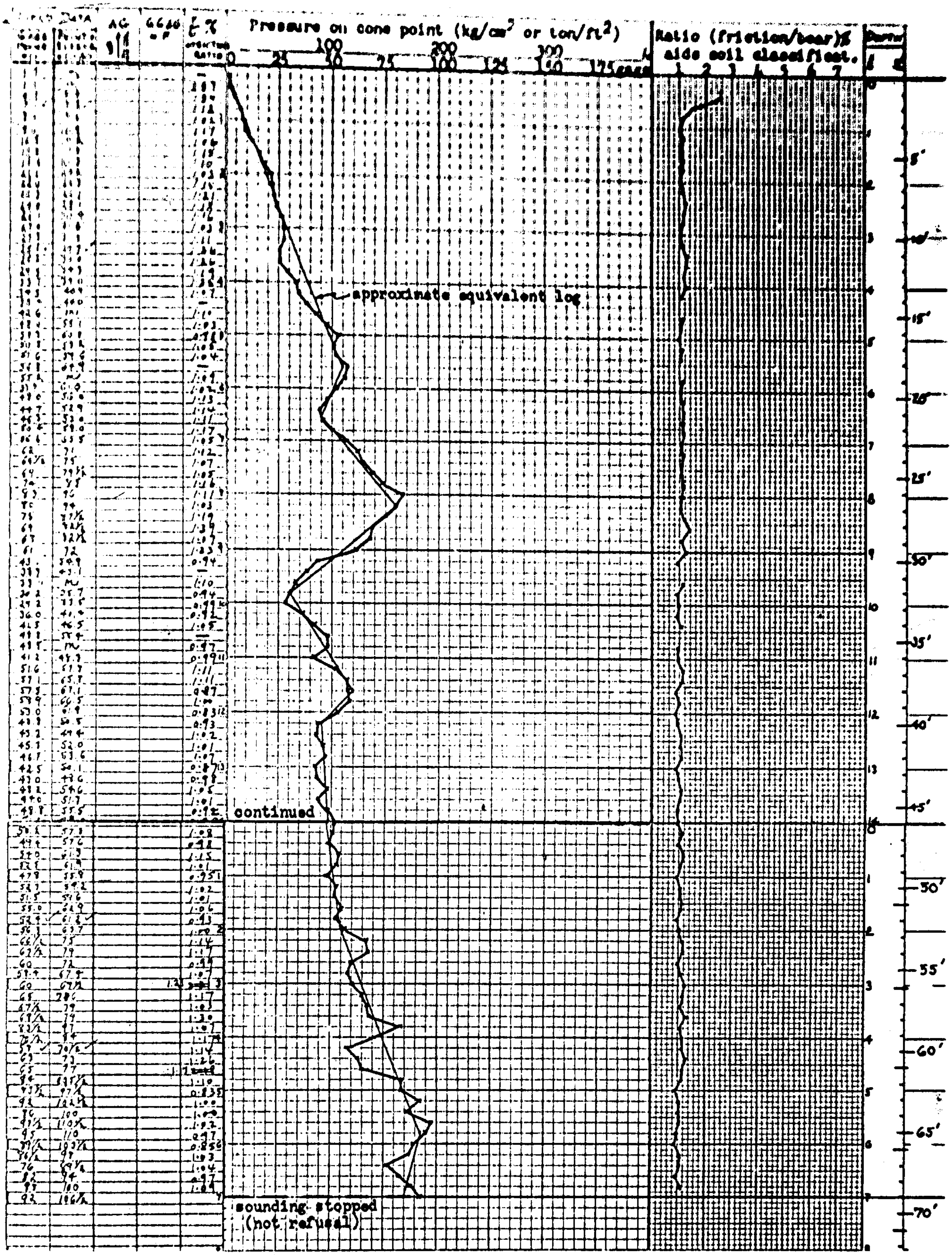

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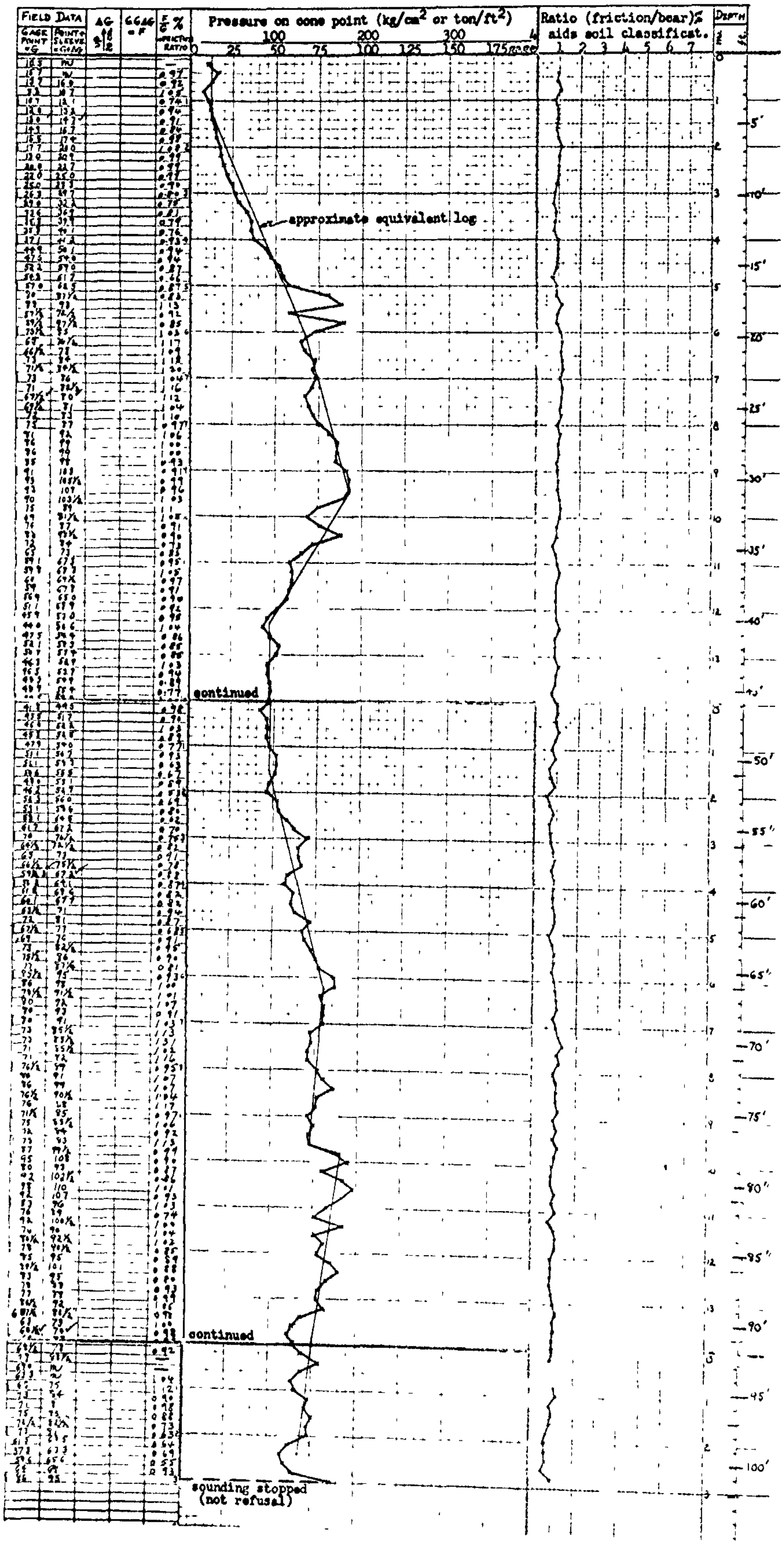
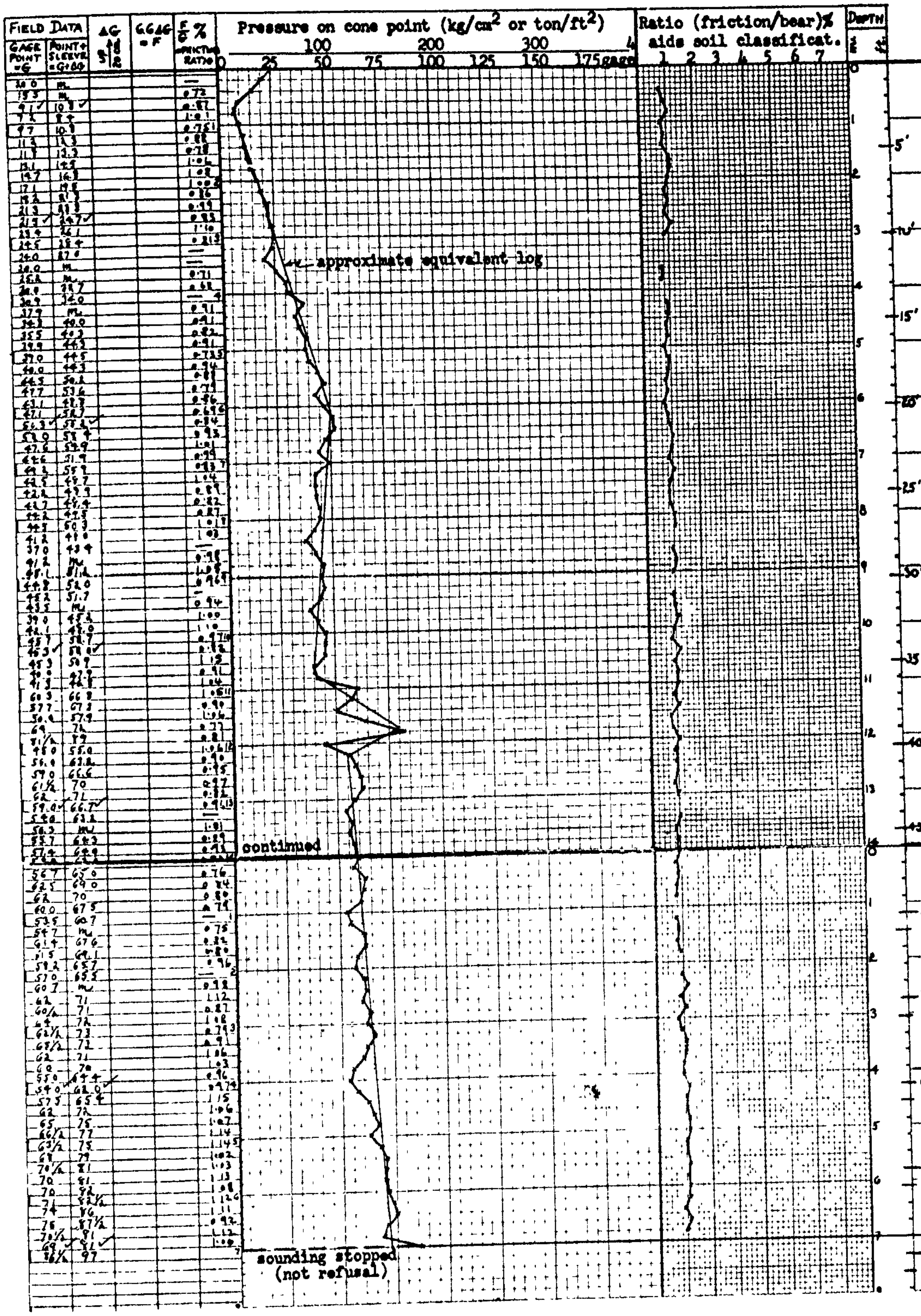


LOG OF SOUNDING 18

PLATE B18



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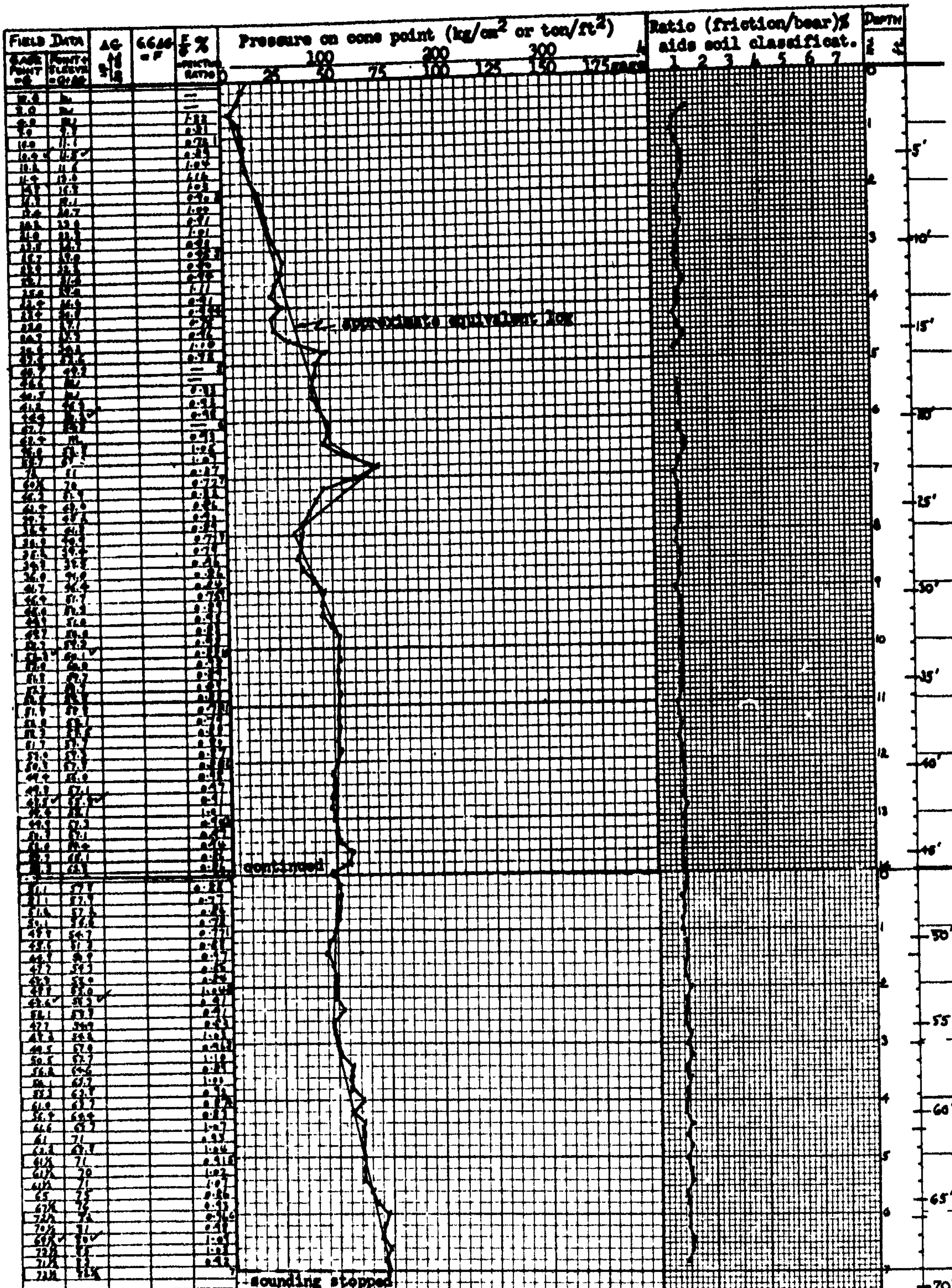

LOG OF SOUNDING 20

PLATE B20

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13. ABSTRACT

This is a report on the results of an investigation of the homogeneity of soil conditions at a research site within Eglin AFB, Florida. Twenty cone soundings, using a static, Dutch friction-cone penetrometer, reached an average depth of 70 ft, varying from 62 to 102 ft. The field work was accomplished in four working days. The load on the penetrometer was automatically recorded for 11 of these soundings, permitting greater precision in the determination of the ratio of soil friction against the cone friction jacket to the bearing capacity of the cone point. All mechanical equipment appeared to operate in an excellent manner. No evidence was found to indicate significant thicknesses of cohesive soil layers. Friction ratios were unusually uniform over the entire site investigated and fell within the range usually interpreted as indicating clean sand. There was also no evidence of perched water tables. The cone bearing logs for the upper 20 ft of sand, a natural deposit, also indicated that it is uniform in density variation with depth over the research area investigated in detail, and the surrounding area as well. Below 20 ft there is considerable point-to-point variation in sand density. However, on the average the research area and vicinity show a definite uniformity in the way in which density varies with depth. The entire site area is as homogeneous as one can expect to find in natural, coarse-grained deposits of the depth considered herein.

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Penetrometers						
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