COMPACTION CONTROL OF A MAJOR CONSTRUCTION PROJECT WITH THE MICHIGAN NUCLEAR GAGE

US 127 Relocation, Holt Road to I 96 (F 33035B, C1; BI 33084A, C21)

J. H. DeFoe
R. C. Mainfort

Progress Report on a Highway Planning and Research Study
"Development of Nuclear Methods for Quality Control of Highway Embankment"
Conducted in Cooperation with
The U. S. Department of Commerce--Bureau of Public Roads

Research Laboratory Division
Office of Testing and Research
Research Project 61 E-22
Research Report No. R-592

Michigan State Highway Commission
Ardale W. Ferguson, Chairman; Charles H. Hewitt, Vice-Chairman;
Wallace D. Nunn; Richard F. Vander Veen
Lansing, November 1966

INFORMATION RETRIEVAL DATA

REFERENCE: DeFoe, J. H. and Mainfort, R. C. Compaction Control of a Major Construction Project with the Michigan Nuclear Gage: US 127 Relocation, Holt Road to I 96 (F 33035B, C1; BI 33084A, C21). Michigan Department of State Highways Research Report No. R-592. November 1966. Research Project 61 E-22.

ABSTRACT: In 1965 field tests, the Michigan combination-type moisture-density gage was a satisfactory means of compaction control for all soils and aggregate materials tested. Testing time using the nuclear gage was about half that required with conventional methods. Rainhart check tests indicated proper job control with the nuclear method. Normal job sampling procedures were compared with statistically random sampling with promising results. Further experimentation is planned for more careful evaluation of the statistical random sampling techniques.

KEY WORDS: nuclear applications, nuclear moisture-density determinations, nuclear testing, nondestructive testing, compaction control, sampling, randomization, statistical sampling, statistical quality control.

CONTENTS

COMPACTION CONTROL OF A MAJOR CONSTRUCTION PROJECT WITH THE MICHIGAN NUCLEAR GAGE

US 127 Relocation, Holt Road to I 96 (F 33035B, C1; BI 33084A, C21)

These studies represent one phase of Research Project 61 E-22 ("Development of Nuclear Methods for Quality Control of Highway Embankment Construction") begun July 1, 1964 in cooperation with the Bureau of Public Roads. The purpose of this phase of the project was to evaluate the usefulness and suitability of the Michigan combination nuclear gage in controlling compaction for a major highway construction project. A secondary objective was to introduce statistical methods into density control procedures, and to determine their suitability when using the nuclear equipment under construction conditions. Other phases of the project are continuing and will be described in a terminal report.

Previous Research Laboratory studies (1, 2) had shown that the principles of nuclear measurement of soil moisture and density were sound, that the equipment was suitable for field construction use, and that methods had been developed for calibrating and checking the performance of the gages during use. Statistical analysis of field and laboratory data had shown that the precision obtained by the nuclear method was comparable to that obtained by conventional tests, when the two were conducted under similar conditions. It was also shown, however, that there could be large variations in individual readings, taken in proximate locations, with either nuclear or conventional methods. These variations could have been due to differences in density of the test areas, to operational error, to faulty equipment, or to a combination of these factors. The fact that different volumes of materials were measured by the two methods contributed to the lack of good correlation between comparative readings.

Under laboratory conditions where the volume of material tested could be carefully controlled, reasonably good correlation between conventional (Rainhart balloon) and nuclear methods was obtained. From these past studies it was recommended that further attempts to obtain correlations between individual nuclear tests and corresponding conventional tests be abandoned, and that the nuclear gage, after proper calibration, be used in the field on its own merit as a method for controlling compaction.

Based on these recommendations, Departmental and Bureau of Public Roads approval was sought and obtained for using the nuclear method as the primary means of density control on the US 127 relocation project between Holt Road and I 96 (State designations F 33035B, C1, and BI 33084A, C21; Federal designations F 146 (17) and I-96-3(35) 150). For this work, nuclear gages were calibrated by the Research Laboratory and assigned to the Office of Construction for incorporation into their density control procedures as a replacement for conventional control equipment. Density inspectors were trained in the use of the equipment, which remained under their control throughout the duration of the project. Maintenance and repairs were furnished by the Research Laboratory. As a general check on the control methods, random compaction measurements using conventional Rainhart methods were made by the Soils Division of the Office of Testing and Research.

The work covered by this report was carried out during the 1965 construction season. All of the construction, including compaction control by the nuclear method, was under the supervision of H. VanderMolen, Project Engineer.

DESCRIPTION OF NUCLEAR EQUIPMENT

The nuclear instrument system used on this project consists of a combination density and moisture gage, commercial scaler, reference standard, stop watch, film badge, and calibration chart (Fig. 1). The early development and testing of this gage by the Department was described in an earlier Research Laboratory report (3).

The gage contains a single radioactive source (about 5 millicuries of radium 226-beryllium), radiation detector tubes, lead shielding, and a transistorized preamplifier arranged as shown in Figure 2. Radiation particles are detected by the gage and resulting electrical pulses are transmitted through a connecting cable to the scaler where they are electronically counted and the reading displayed. The scaler also contains a battery-operated power supply to provide proper voltages for detector tube and preamplifier operation. Radiation from the source is of two kinds, gamma rays (used to measure density) and neutrons (used to measure moisture).

Soil density is measured by the Geiger-Mueller tubes which detect unabsorbed gamma radiation that has passed from the source through the soil being tested. The greater the density, the less gamma radiation will reach the detector tubes. Thus, the number of counts recorded through the gamma detector tubes is inversely proportional to soil density.

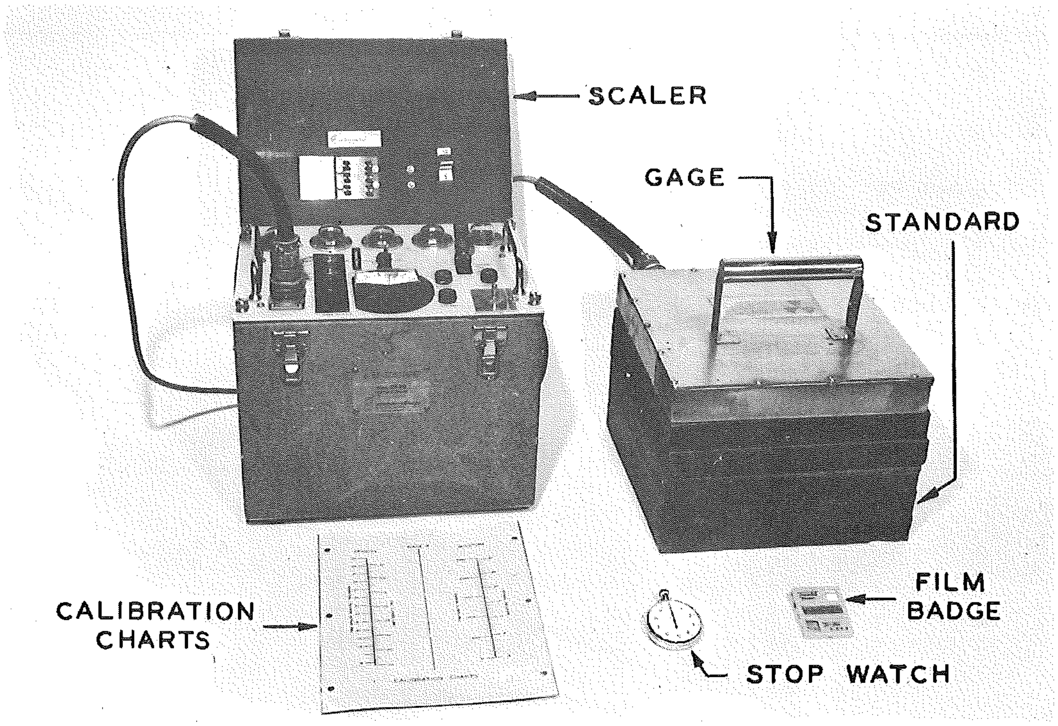


Figure 1. Nuclear soil density-moisture instrument system.

Moisture measurements are based on the phenomenon of neutron moderation by hydrogen atoms. Those neutrons that are scattered by hydrogen atoms lose most of their energy and return to the vicinity of their source as slow neutrons. Thus, as the number of hydrogen atoms increases in the material being tested, more slow neutrons will be deflected by the borontrifluoride tubes. Because practically all hydrogen present in soils is in the form of moisture, the count rate of the slow neutron detector tubes is directly proportional to the moisture content of the soil. The neutron pulses of the detector tubes are amplified in the preamplifier prior to transmission to the scaler for readout.

The Michigan gage, a surface backscatter type, is placed directly on the area to be tested. In this form of measurement the material nearest the gage has most influence on density results. For this reason, surface conditions can be critical and it is necessary to place and seat the gage with extreme care.

Field standards consisted of five 10-1/2 by 11 by 1-1/4 in. Colorlith stone sections bolted together to form a single block (Fig. 1). The standard was used both for moisture and density checks.

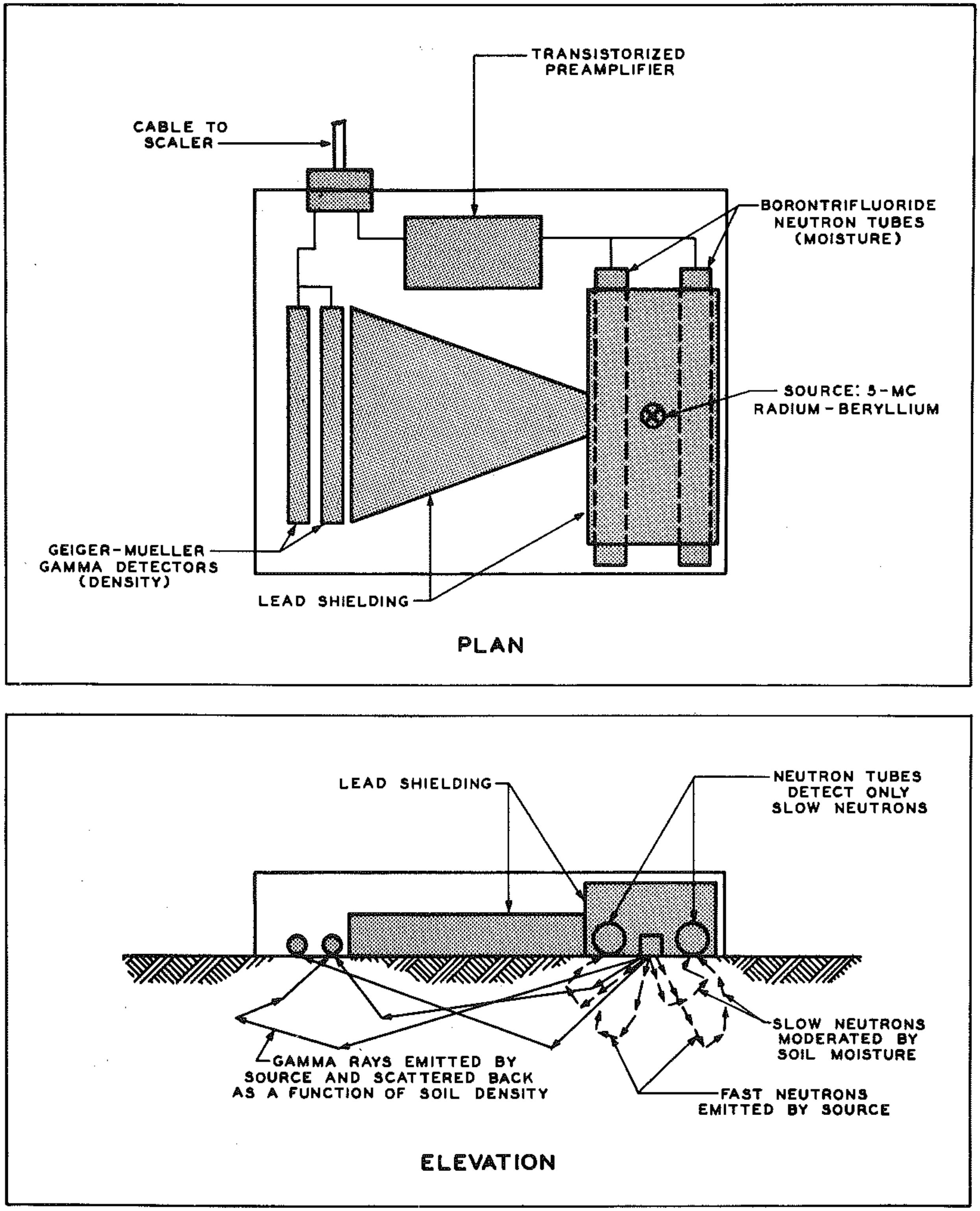


Figure 2. Details of the Michigan nuclear gage.

PREPARATIONS FOR FIELD TESTING

Prior to assigning the nuclear gages to density inspectors for field testing, certain preliminary operations were completed by the Research Laboratory.

Calibration of Gages

Four Michigan combination nuclear gages were calibrated for use on the project. Two of these were assigned directly to the Project Engineer and were under his control for the duration of the project. The other two were available as stand-by units or for supplemental testing by the Research Laboratory. Laboratory calibration was performed in the same manner as described in previous studies (2), using soil and aggregate samples 24 in. square by 12 in. deep. Each sample was constructed to a known density, using four layers of equal thickness and density. Densities were measured by the nuclear gages, the conventional method, and computation from an overall weight-volume relationship of the total sample. Moisture contents were measured by the nuclear gages and oven drying of representative samples obtained throughout the mass. The relationship between these measurements is shown in Figure 3. From these data, calibration nomographs (Fig. 4) were developed for each individual gage.

All calibration curves were developed using direct count rates of the nuclear gage. No advantage was gained by expressing nuclear readings as a percentage of values obtained on the reference standards (count ratio method).

Training of Personnel

During the winter of 1964-65, the Research Laboratory provided two one-week instruction courses concerning nuclear methods of compaction control to density inspectors and supervisors who would be associated with the US 127 project. The course included radiation safety, counting statistics, principles of radioisotope gaging and calibration, gage operation, and interpretation of results obtained. Through actual use, each participant was made familiar with the gage's ability to detect differences in moisture content and density, and with factors that might cause variations in results, such as surface texture of the material being tested, proximity of concrete or other structures to the gage during measurements, and proper calibration and standard checking techniques.

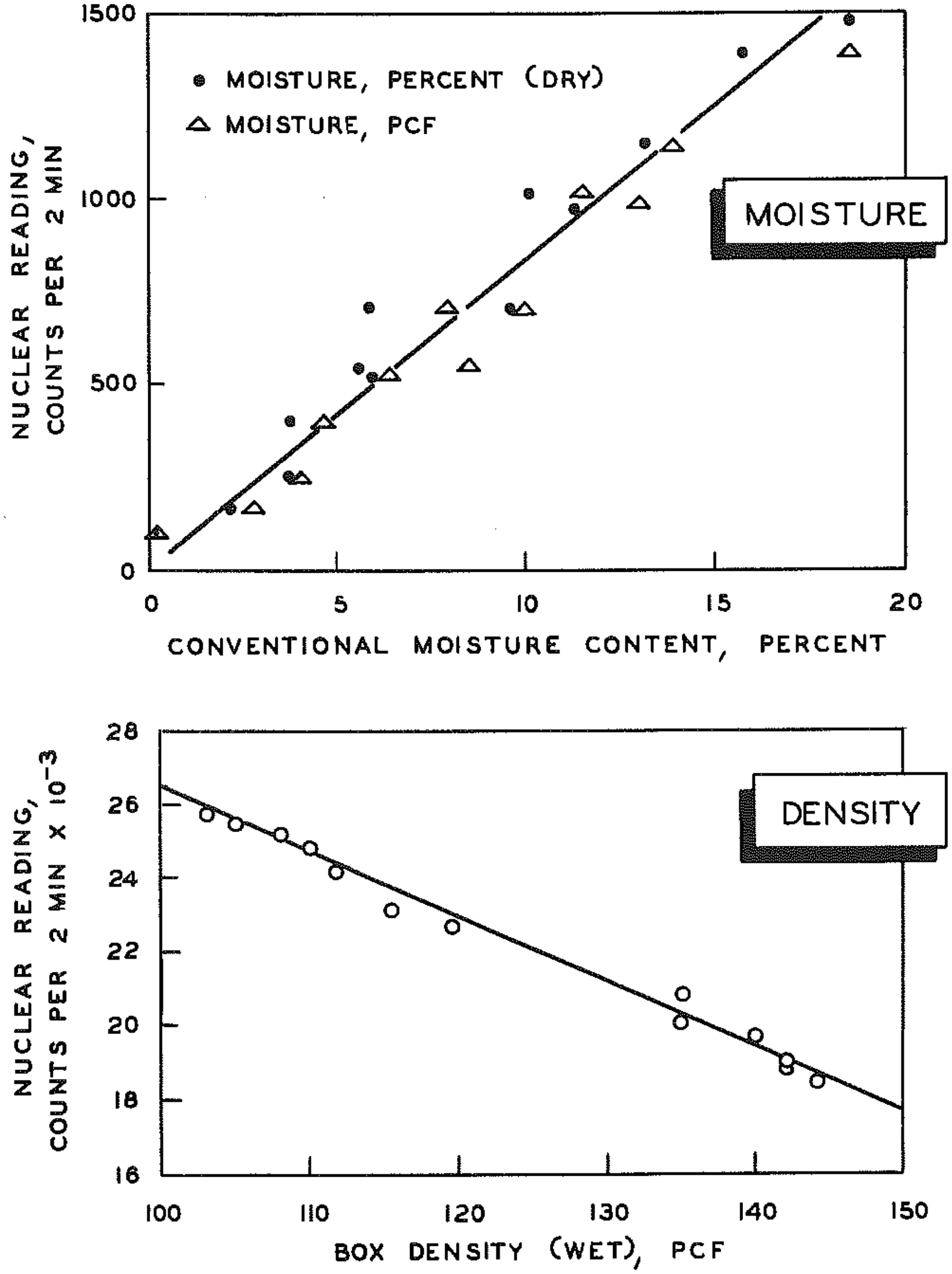


Figure 3. Laboratory calibration curves for nuclear gage.

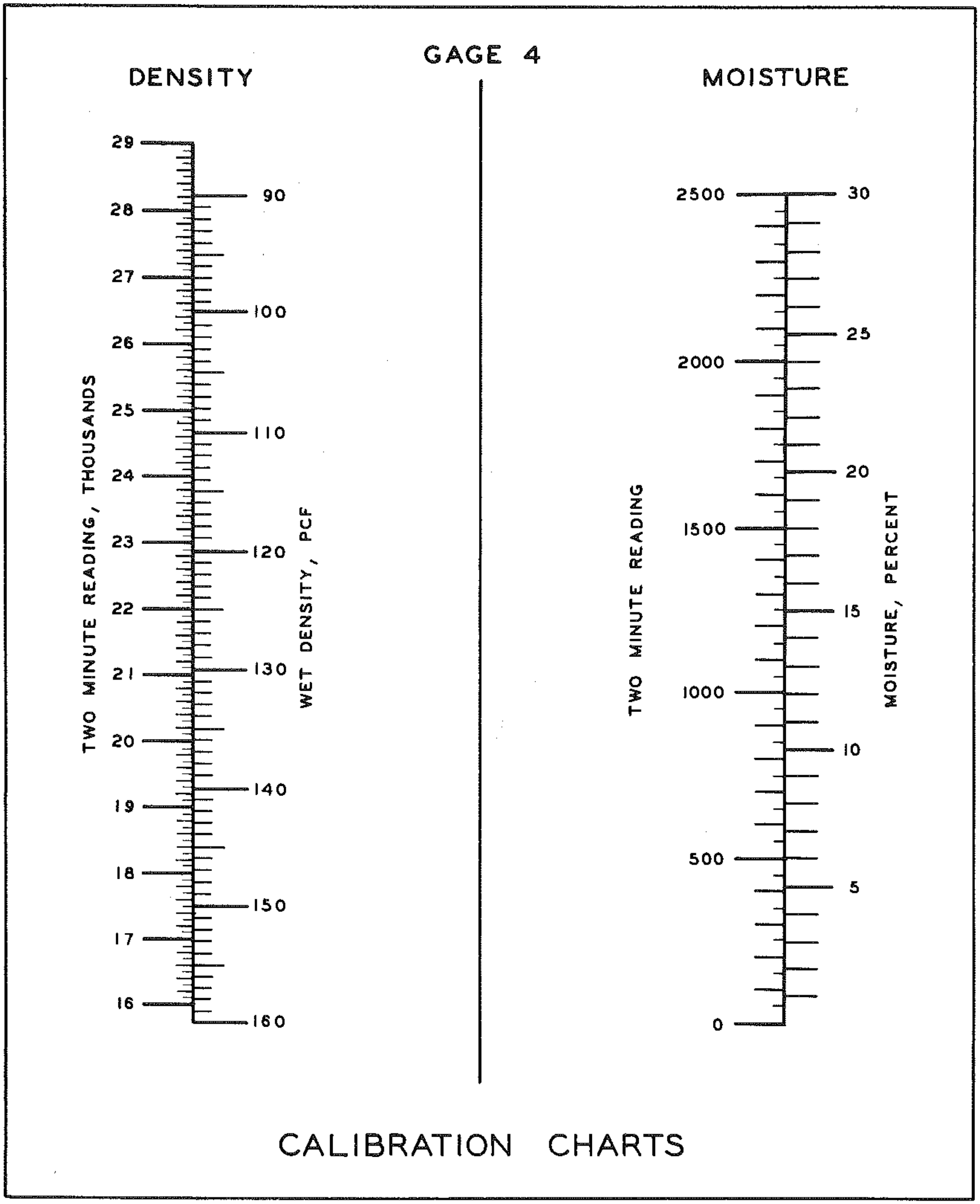


Figure 4. Typical calibration chart.

Operating Manuals

An operating manual concerning use of the gages and recommended testing procedure was issued to all personnel concerned before field work began. This is included as an Appendix of this report.

Equipment Kits

Each density inspector is normally assigned a pickup truck equipped with a complete density kit with which he can obtain in-place field densities and establish his design density (maximum unit weight) by either the Michigan Cone or the T-99 methods. Special forms are provided for computing and reporting the results. For this project, the kits were redesigned to accommodate the nuclear system instead of the conventional (Rainhart) equipment. The normal equipment for establishing design density remained the same. A new form, modified for use with the nuclear equipment, was provided (see Appendix). The equipment, prior to packing in the density kit, is shown in Figure 5.

Figure 5. Layout of equipment prior to placing in kit.

FIELD TESTING OPERATIONS

The portion of US 127 included in this project consisted of about 3-1/2 miles of divided highway to be surfaced with concrete (Fig. 6). The nuclear method was used to measure compaction in all phases of construction with some modifications in procedure required to meet different situations.

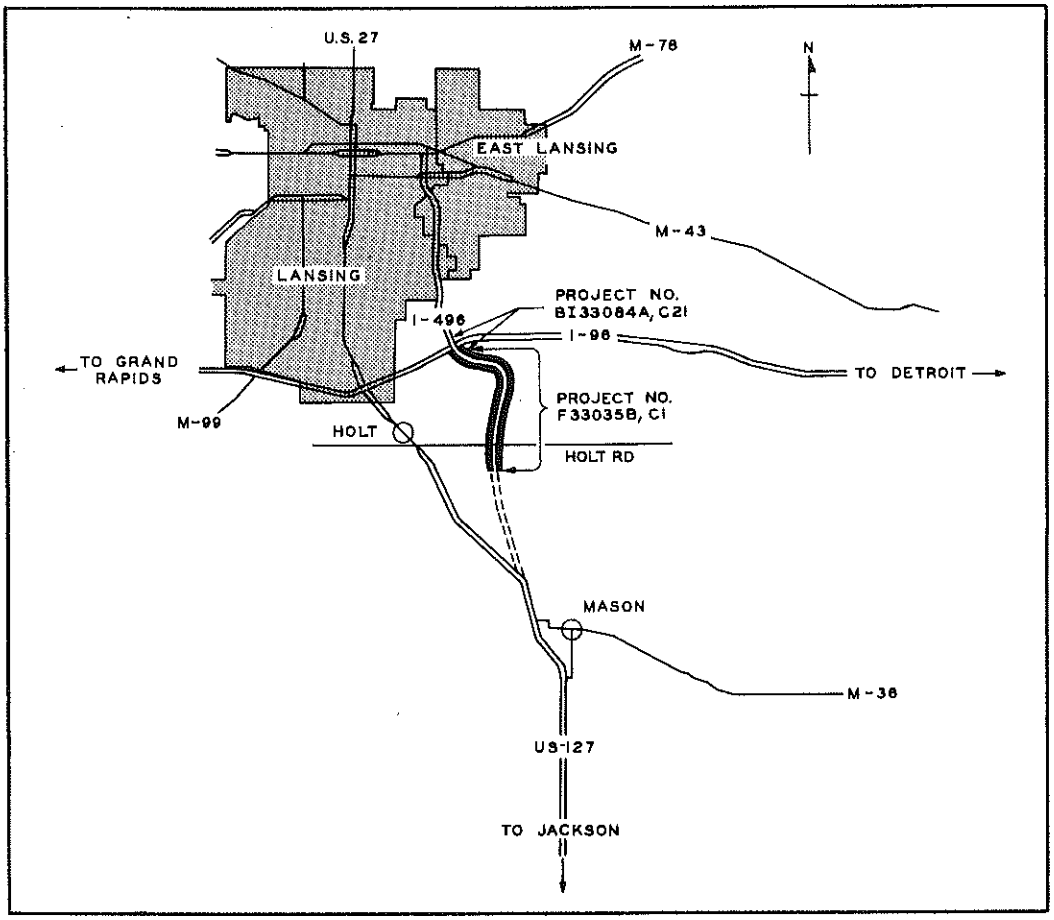


Figure 6. Project vicinity map.

Embankment Materials

Embankment materials largely consisted of clay soils native to the project area. These offered no particular problems during nuclear measurements except for extra effort required in some cases to prepare the test area surface for proper seating of the gage. When leveling the test surface, chunks were often dislodged, leaving large voids which required about 4 minutes hand filling and smoothing prior to seating the gage.

Sand Subbase

The sand subbase, consisting of Porous Material Grade A (Table 1), presented no problems for the nuclear method. Surface preparation required simply the removal of loose, dry material to the elevation desired, and then "ironing" the gage into place to assure firm contact between the sand and the flat surface of the gage. This procedure usually required no more than 1 minute to complete.

TABLE 1
GRADATION OF SAND SUBBASE
AND SELECTED SUBBASE

Porous Material Grade A (Sand Subbase)

Sieve Size	Percent Passing
2-1/2 in.	100
1 in.	60-100
No. 100	0-30
No. 200 (washed)	0-7

24A (Selected Subbase)

Sieve Size	Percent Passing
1 in.	100
3/8 in.	60-85
No. 8	30-55
No. 200 (washed)	3-7

Selected Subbase

The selected subbase material was a 24A aggregate (Table 1) compacted to a 4-in. depth. To obtain good seating of the gage with this material, it was necessary to dress the surface with material of the same aggregate passing the No. 10 sieve and to follow this with tamping and leveling. This procedure required about 2 minutes or less. Because of the surface dressing, it was necessary to provide a modified calibration curve for this material. In general, the surface treatment lowered density readings by about 5 pcf less than would be obtained on a smooth, nondressed test site of equal density. Moisture values were not affected by the surface dressing.

General Testing Procedures

The gages were placed in service at the beginning of the construction season in the spring of 1965 and used throughout the construction season. During this time, more than 1300 in-place nuclear measurements were made, using procedures outlined in the operating manual (Appendix). Briefly, the following sequence of operations, some of which are shown in Figure 7, was used:

1. For each test, gage operation was checked by obtaining readings on the reference standards. Care was taken to have the gage located in exactly the same position on the standard block for every check reading.

2. The test area surface was leveled and prepared for proper seating of the gage.

3. With the gage properly seated, readings were obtained for both moisture and density.

4. Readings obtained on the standard and at the test area were entered in the appropriate columns on the inspection form (Appendix).

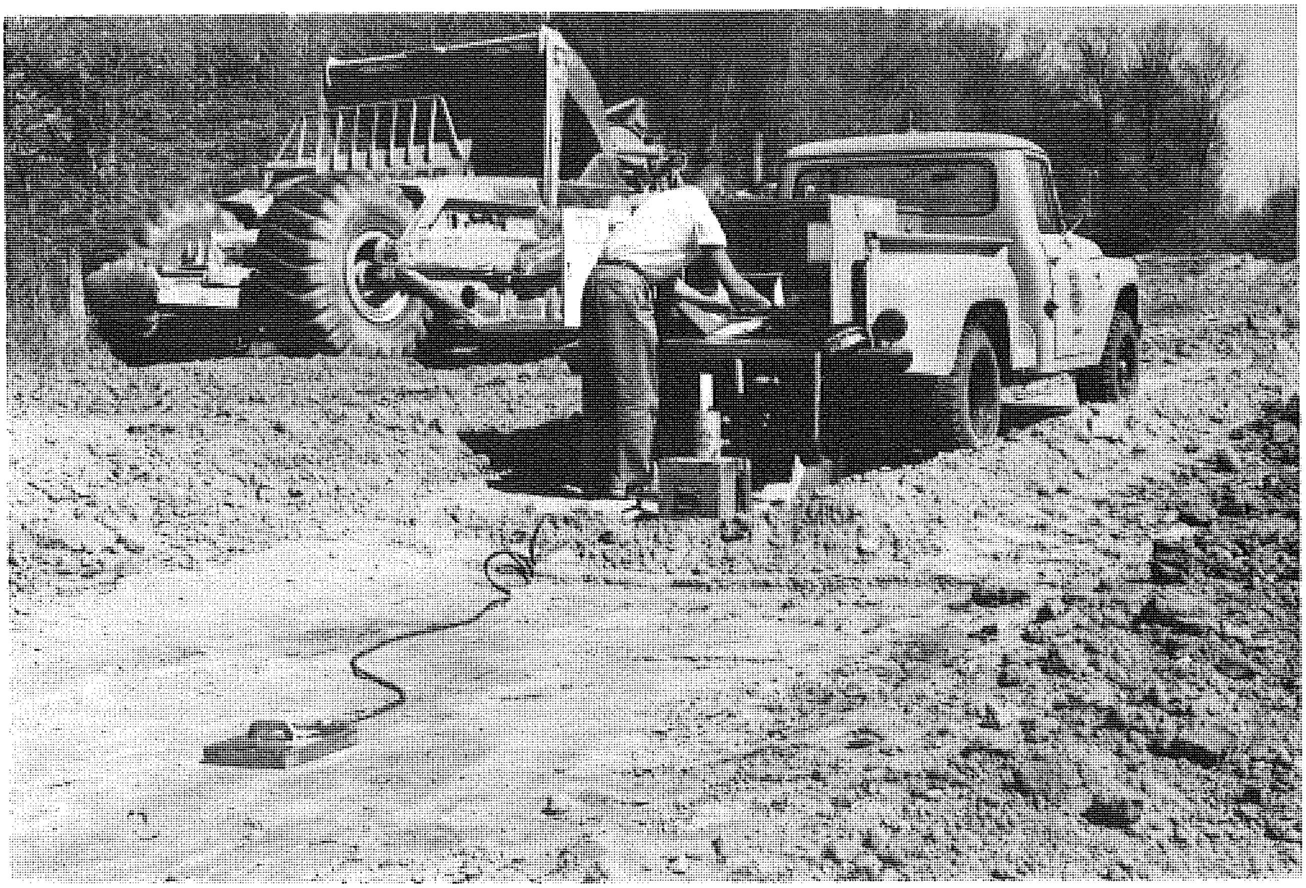
5. In-place density and moisture content values were determined, using the nomograph chart provided (Fig. 4).

6. Percentage of design density and other information pertinent to the particular test site were computed and entered on the inspection form in the same manner as with normal methods of compaction control (see Appendix).

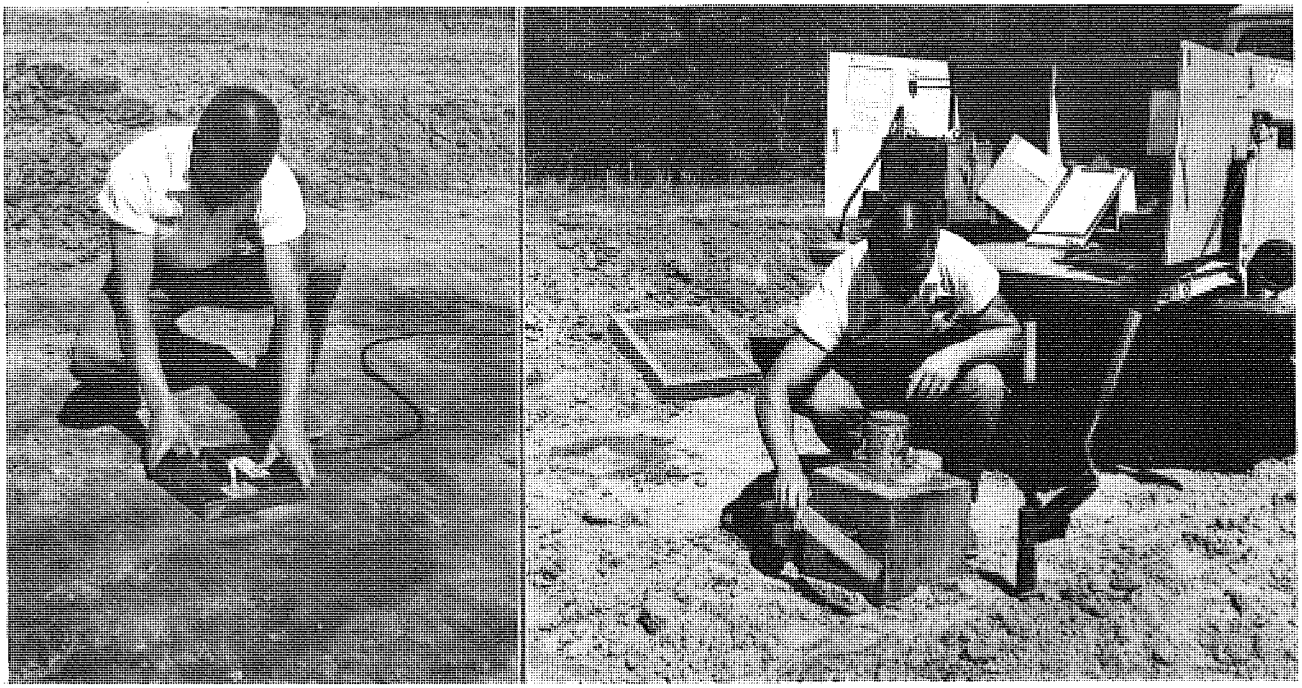
With the exception of those cases where a sand dressing was placed over rough aggregate surfaces for better seating of the gage, only one calibration curve was used for all soils encountered on this job. This procedure was also followed during previous tests when it was found that differences in soils normally encountered in Michigan had little if any effect on the calibration curves used to convert nuclear count rates to moisture or density.

Time Required for Testing

During these field tests, the time required to perform the nuclear readings was carefully checked for comparison with the time needed to perform the conventional Rainhart test. The time required to determine percent of design density by the nuclear method was generally 10 minutes.



Inspecting embankment



Seating the gage

Determining design density

Figure 7. Typical field operations.

The maximum time observed for such operations was 16 minutes. The time interval began when the inspector stopped his vehicle at the test site and continued until he had computed his moisture content and density values. In general, the nuclear operation could be completed in about half the time necessary for the Rainhart test and with much less operator fatigue.

The additional time required to determine the design (maximum) density varied from 7 minutes for granular materials to 14 minutes for cohesive soils. This operation was exactly the same for both the conventional and nuclear methods and thus does not enter into a comparative study. Throughout the project, only one nuclear reading was obtained at each test site.

Control Chart Check of Operations

Figure 8 shows a sample control chart of the type used by the Research Laboratory to check density control operations and gage performance as field work progressed. As data became available from a particular area, the mean (average) and the control limits (based on two standard deviations or approximately the 95-percent confidence limit of the data) were established in terms of 2-minute gage count rates. Also established was the count rate equivalent of the 95-percent design density, below which no acceptable values should fall.

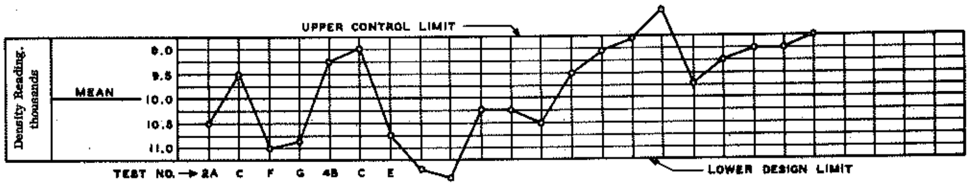


Figure 8. Sample control chart for nuclear gage tests.

As count rates were determined for a given site they were entered on the chart. If they fell outside the established limits or showed a continued drift toward the upper or lower limits, corrective measures were indicated. These phenomena could be caused by improper functioning of the gage requiring a check of the gage readings on the standard; a change in the material, requiring a new determination of maximum design density; moisture variation or improper compaction procedures; or other causitive factors.

As data were accumulated the control chart limits changed somewhat because they represent values based on the total number of tests taken. Such control charts could be maintained easily by regular field inspectors. Similar control charts also were maintained for gage operation on the standard.

Maintenance of Equipment

During the April-December construction season, 21 service calls were made by Research Laboratory personnel because of malfunctions of the nuclear instruments. Most repair work was performed in the Laboratory, during which time replacement instruments were provided to keep inspector down time to a minimum. Broken wires in cable connectors or in cables adjacent to connectors were the most frequent cause of trouble. This particular problem was corrected by use of a more flexible cable.

Broken and cold-soldered connections in the moisture preamplifiers also caused trouble and sometimes were hard to locate and correct. Such poor connections were not obvious on inspection and caused intermittent problems. A gage with a poorly soldered connection might operate well on the laboratory service bench, and even in the field for several days, but would eventually require two or three more service calls before the problem could be corrected. Design modifications, and newer, better engineered equipment should help correct electronic trouble.

Effective Depth of Measurement

Prior to placing the 4-in. selected subbase, concern was expressed that the influence of nuclear gage radiation might extend below this depth and include the density and moisture content of the underlying sand subbase in the scaler indications. A special study (4) was conducted to determine the effective depth of influence of the nuclear gage. This work clearly indicated that neither moisture nor density of a compacted 24A aggregate were influenced significantly by materials underlying a 4-in. lift, and thus lift compaction could be properly controlled by the nuclear method.

COMPARISON OF NORMAL AND STATISTICAL CONTROL METHODS USING THE NUCLEAR GAGE

One objective of this research project is to study the applicability of statistical quality control procedures for controlling field compaction.

The US 127 construction project permitted exploration of the feasibility of such methods under ordinary field conditions. Due to the typically diverse operations at the embankment stage of construction, the statistical approach could be introduced with less confusion to other, more continuous operations, such as placement of the sand subbase and selected subbase.

A statistical control procedure was planned for all density tests of sand and aggregate placements. Shortly after construction began, however, other duties prevented density inspectors from obtaining more data than were required for normal compaction control. For this reason, they abondoned statistical control procedures but continued using nuclear equipment for sand and selected subbases in the manner normally used for regular density inspection.*

To study the concept of density control by statistical methods, the Research Laboratory undertook this phase of the project. The regular project density inspectors performed tests at locations selected according to conventional testing methods using the nuclear equipment and controlling the job from their results. Statistical testing procedures were conducted by Laboratory personnel in areas previously tested by the regular inspectors. This permitted comparison of the results obtained by the two inspection methods, both utilizing the nuclear gages.

The statistical procedure consisted of selecting test locations at random, along with control chart analysis of the test data. Because this procedure was not used for actual job control, the control chart analysis was performed at the Laboratory and is described here for comparison with regular control inspection results.

A 2000-ft section of roadway was subdivided into five 400-ft blocks. The section and block widths covered the full width of the material as placed on the roadway--28 ft for selected subbase and about 42 ft for sand subbase. Two 400-ft blocks were selected at random for testing. The 400-ft blocks were further subdivided into eight equal areas, each a half-roadway in width by 100 ft long. Four 100-ft test areas were then randomly

---

*For regular density control inspection, test sites are chosen according to the judgment of the project engineer or the density inspector with a <u>minimum</u> of one density test for each 3000 cu yd of subbase or selected subbase material. To obtain proper compaction control, however, project engineers usually require more frequent testing than this. At least one test for each 250 ft was made for this project.

selected from each of the two blocks. One nuclear density and moisture test was performed in each of the eight selected areas. Figure 9 shows a typical test section, locations of tests performed by inspectors for construction control, and locations of the eight randomly selected tests. In this study, there were twelve test sections for selected subbase and four for sand subbase, each 2000 ft long.

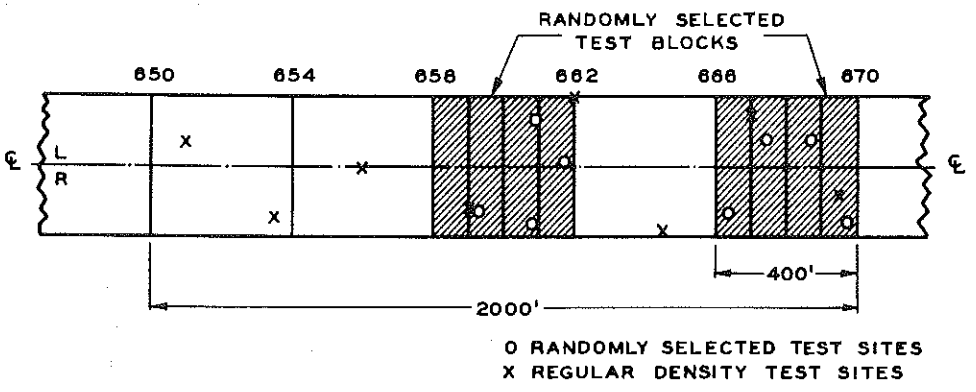


Figure 9. Typical test section for statistical control methods.

Results of both the random method and job control method of density site selection are shown in Figure 10. These data include all tests performed within the selected 2000-ft test sections of sand and selected subbase. Those data obtained as part of the regular control procedures are designated "Job Control" in the histograms, and those obtained by the random method, "Statistical Control." The statistical control samples, in all cases, were obtained several hours after the regular control tests. Values obtained after low densities were brought up to passing by additional compaction are not included in the data shown in Figure 10.

In general, results are similar for both methods of sampling, with the average compaction value about 97 percent in both cases. However, data do indicate that more values below specification requirements were revealed by the random sampling method, particularly in sand areas. Some of these could be due to loss of moisture (and density) during the time between job control testing and random sample testing.

Random sampling was limited on the project, amounting to only 128 tests. Additional evaluation of this method is necessary before its suitability for construction control can be determined.

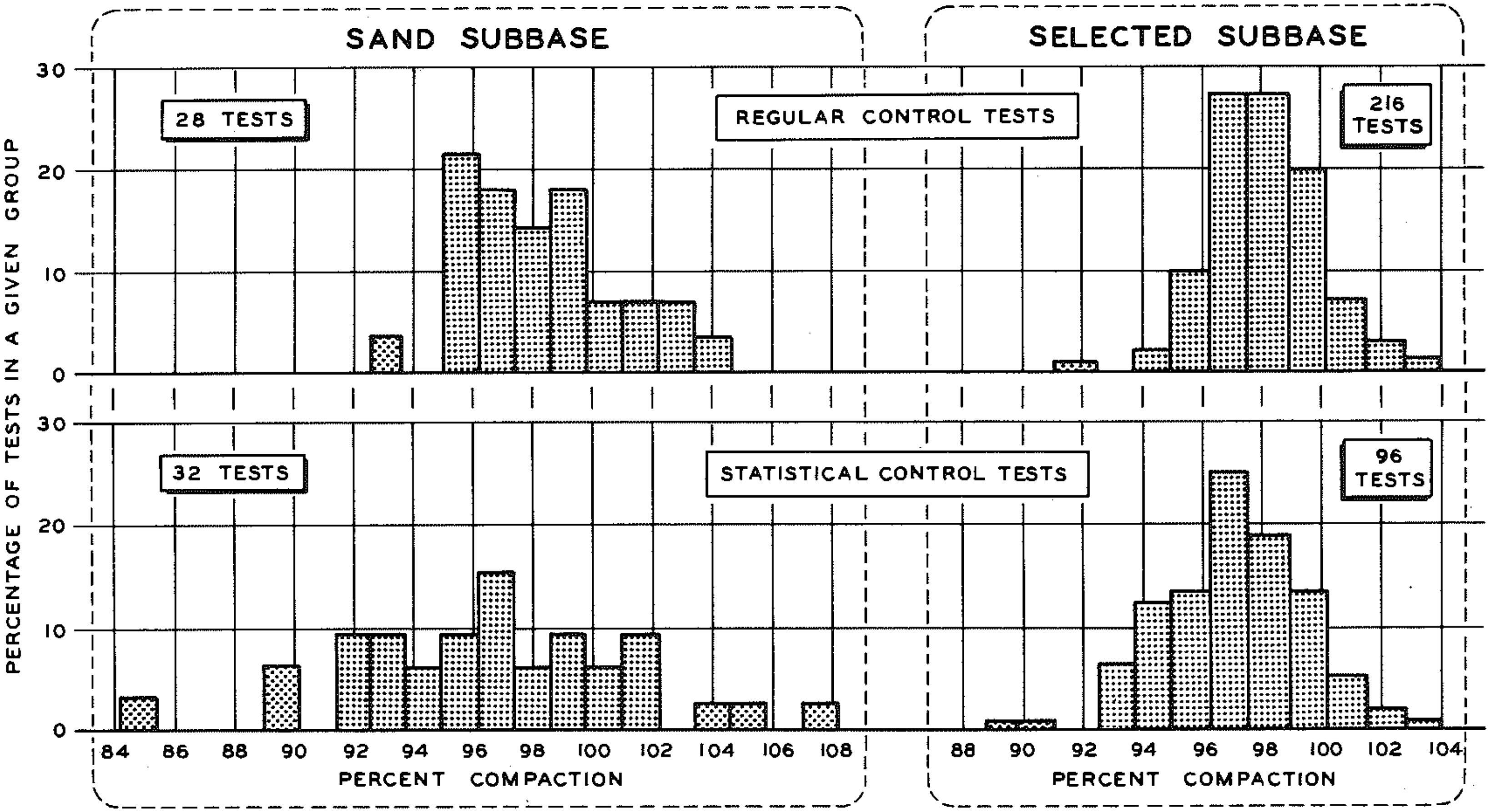


Figure 10. Comparison of regular nuclear control method with statistical nuclear control method.

COMPARISON OF NUCLEAR AND RAINHART TEST PROCEDURES

Because this was the first Michigan construction project where the nuclear method was the only means of compaction control, it was thought desirable to make spot check tests with the more familiar, time-tested conventional Rainhart method, to assure that normally expected compaction control was being achieved. For this purpose, 76 conventional in-place density tests were performed by the Soils Division, at the same locations which had been tested by construction inspectors using the nuclear method. These tests included clay, sand, and aggregate materials. In all cases, however, the nuclear method continued to be used as the job control.

Figure 11 shows a control chart comparison of the nuclear and Rainhart methods of density measurement. In these charts, upper and lower control limits are two standard deviations from the overall mean density. Because the experiment was conducted using subsamples, the standard deviation was estimated from the moving range of two consecutive samples. From these charts, which represent 76 comparative tests, one would expect that 95 percent of the density tests would fall within the band shown.

The charts indicate that both methods were under control throughout the test, with the exception of a few erratic values. The data indicate no tendency toward erratic performance or drifting in the measurements. Based on the smaller difference between the upper and lower limits for the nuclear gage method, it is indicated that slightly better control is obtained by this method. The average densities obtained by each method are approximately the same, with those of the nuclear method being slightly lower. The control charts established by these tests indicate the range within which all variables associated with normal compaction procedures would fall, including instrument error, variation in soil density, and operator error. Any single factor, such as gage operation, would vary to a lesser degree than shown for the overall operation. No significant difference was found in the performance of different gages (Nos. 1, 3, and 4) during this evaluation. The Figure 12 histogram shows the distribution of test-by-test differences between nuclear and Rainhart results, expressed in terms of percent of compaction. Each bar represents the number of comparative tests having differences falling within the range shown on the abscissa. The average difference between the two methods was found to be about 1.4 percent of compaction, with a standard deviation of ± 4.8 percent.

No attempt was made to correlate individual Rainhart and nuclear test values because previous work (2) had clearly indicated that such data

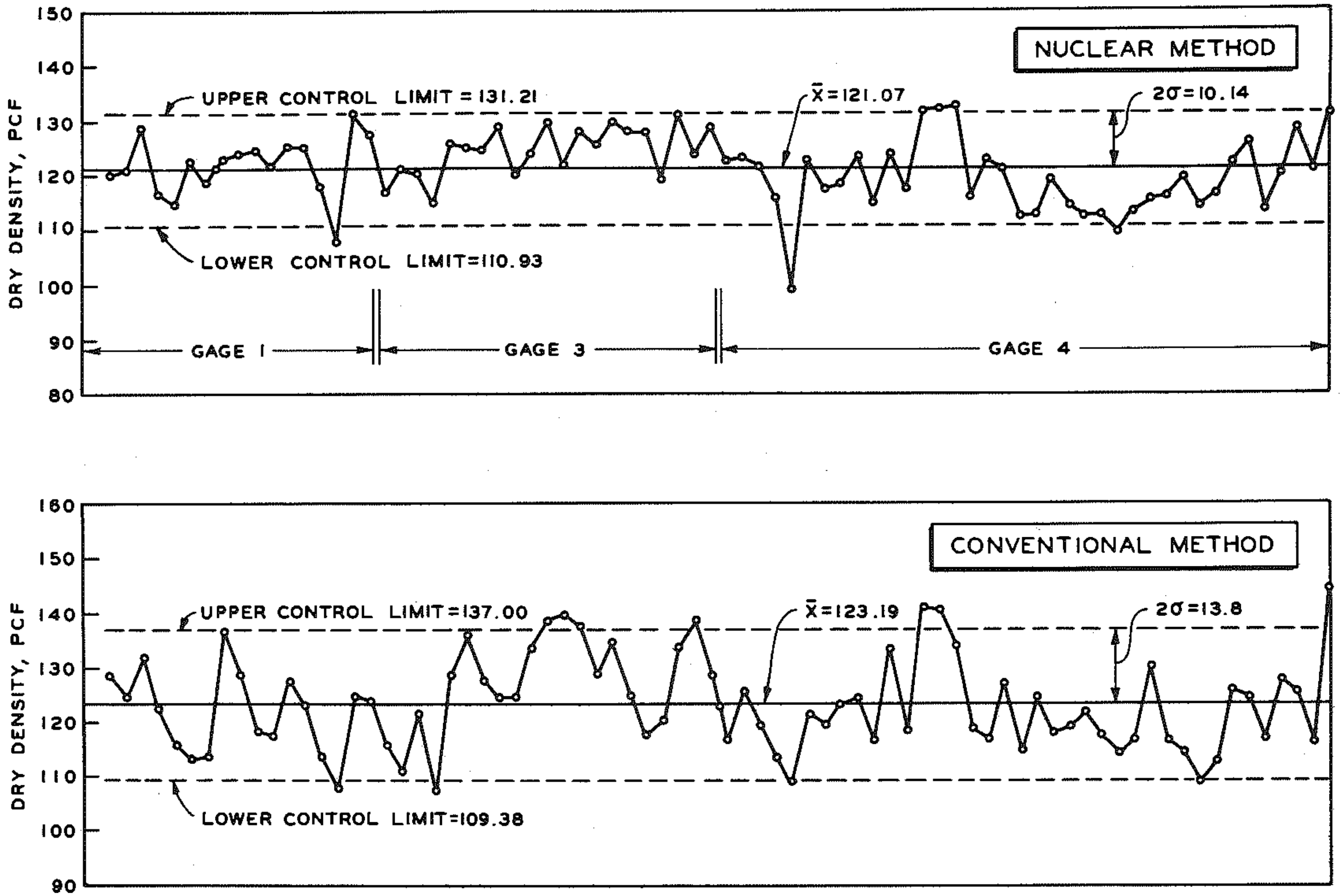


Figure 11. Density control charts for nuclear and Rainhart methods of compaction control; control limits estimated from moving range of two samples. Points on graphs correspond to paired nuclear and Rainhart tests taken at identical locations.

are too scattered for usable results. Both methods have proved satisfactory for measuring density and under controlled laboratory conditions, yield a usable correlation. Due to variables in both methods, however, field test results cannot be correlated on a practical basis.

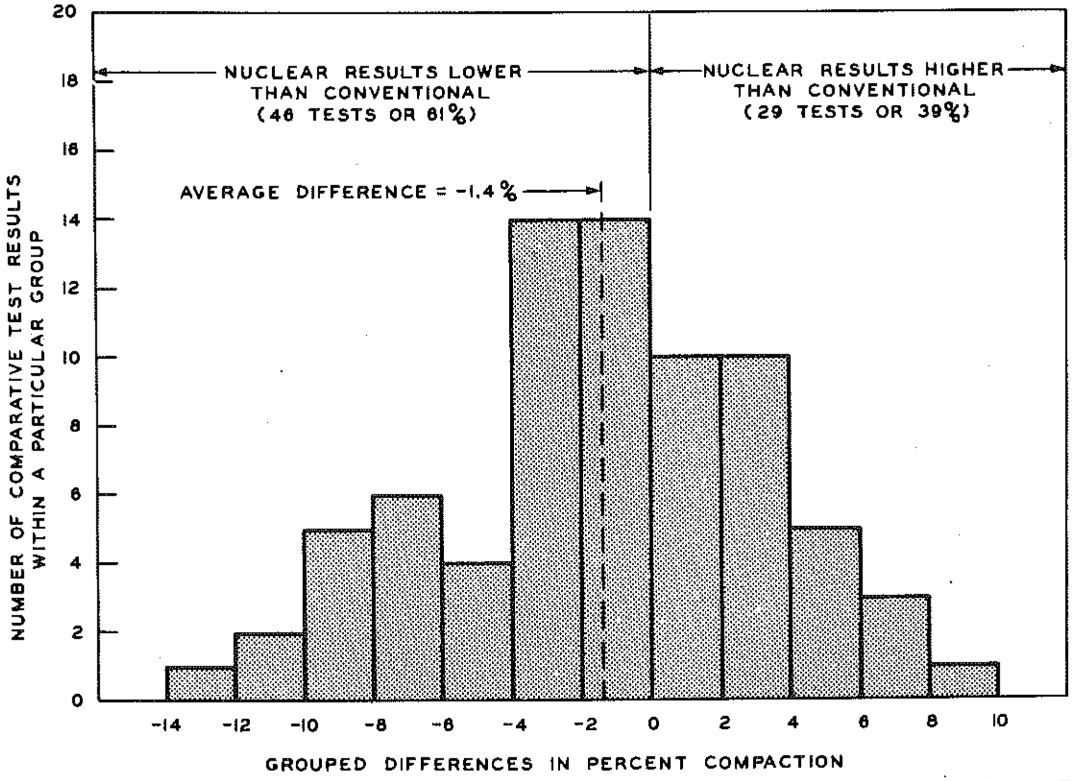


Figure 12. Distribution of test differences between nuclear and conventional tests, expressed in terms of percent compaction.

On an overall average of the 76 tests, the nuclear method measured about 1.4 percent lower density (on the conservative side) than did the Rainhart. The two methods agreed on the rejection or acceptance of 67 out of the 76 tests compared. In general, check tests with the Rainhart method indicated the job to be under satisfactory density control when using the nuclear gage.

CONCLUSIONS

Based on field work performed during the US 127 construction operations covered by this report, and the Department's previous work in this subject field, the following conclusions are warranted:

1. The nuclear method proved suitable for controlling the compaction of a major construction operation. This was indicated by the reaction of the project engineer, check tests with the Rainhart device, and the general performance of the nuclear equipment.

2. The nuclear method can be performed in about half the time required for the conventional test, is simple in operation thereby reducing operator fatigue, and being a direct reading method is less susceptible to experimental error. The rapidity and simplicity of the test allows and encourages more frequent check tests in proximate areas.

3. Separate calibration curves were not required for converting nuclear count rates to moisture or density values for any of the soils or aggregates used on this job.

4. Check tests with the Rainhart method, although not always closely comparable to corresponding nuclear tests, showed that satisfactory job control was obtained by the nuclear method on this project.

5. Random sampling methods, associated with statistical quality control testing, appear to be adaptable to compaction control with the nuclear gages. Under some conditions, however, the randomly selected test sites must be supplemented by additional sites selected by the density inspector in order that obviously weak spots, not falling within the randomly selected areas, can be checked and corrected. Continued study of the random sampling method should provide more information concerning its suitability for normal job operations.

6. Stand-by gages should be available to prevent loss of time due to possible malfunction of nuclear equipment. If new, modern equipment is used, repairs should not be required as often as on this project. Some of the Michigan gages are over 10 years old and electronically out of date.

7. As more experience is gained in using the gages, less time should be required for each test. The number of reference standard checks could eventually be reduced to about five or six a day and computations could be speeded up by increased use of charts and nomographs.

8. In spite of the relatively high initial cost of nuclear gage systems ($4,000), the safety requirements necessary (film badge handling, physical examinations, special handling and storage requirements, and leak testing), the maintenance required for the electronic portion of the equipment, and the special training needed for the operators, it appears that the nuclear method of compaction control has enough to offer to assure it a place in future highway construction. It is recommended that nuclear gages be used to control compaction on additional jobs in Michigan, and that more modern equipment should be purchased for this purpose.

REFERENCES

1. Mainfort, R. C. and DeFoe, J. H. Field and Laboratory Evaluation of the Michigan Nuclear Gage. Michigan Department of State Highways Research Report No. R-358 (August 1961).

2. Mainfort, R. C. and DeFoe, J. H. Further Development of the Michigan Nuclear Gage. Michigan Department of State Highways Research Report No. R-494 (January 1965).

3. Pocock, B. W., Smith, L. W., Schwartje, W. H., and Hanna, R. E. The Michigan Combination Density-Moisture Gage for Soils. Michigan Department of State Highways Research Report No. R-311 (March 1959).

4. Mainfort, R. C. Depth of Nuclear Gage Influence in Subbase Testing. Michigan Department of State Highways Research Report No. R-544 (August 1965).

NOTE

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

APPENDIX

Operating Manual for the Michigan Nuclear Soil Density-Moisture Gage

OPERATING MANUAL FOR THE MICHIGAN NUCLEAR SOIL DENSITY-MOISTURE GAGE

This manual has been prepared to provide nuclear gage operators with basic information to ensure reliable and uniform use of the equipment. It is also intended as a reference for all Department personnel involved in use of nuclear gages for soil testing.

General Instructions and Precautions

Although the nuclear gage is a fairly rugged instrument there are several electronic components that could be damaged or jarred out of adjustment by severe shocks. It is recommended that the instrument system be given the same care in handling and transporting as a transit or engineer's level.

The instrument should not remain inoperative for prolonged periods of time. Experience has shown that gages not operated regularly are more liable to malfunction than gages in regular use. When no field testing is required, the instrument should be operated for at least 1 hr each week, preferably a few minutes each day, and the battery checked for water and recharged each week. Both regular operation and weekly battery maintenance should be performed without fail to minimize battery failure and down time for repairs.

Description of Equipment

Principal items of equipment required for determining in-place soil density and moisture by the nuclear method include the following:

1. Gage. The unit containing the radioactive source and radiation detector tubes. It is placed directly on the soil to be tested. The term "gage" is also frequently used in referring to the entire instrument system; the intended meaning of the term is usually clear from the context in which it is used.

2. Scaler. An electronic counter that presents the gage reading.

3. Standard. A block of material having constant density and moisture content. The gage is placed on the standard and checked for proper performance.

4. Calibration Curves. Charts provided with each instrument for converting gage readings to density and moisture values. These charts are to be used only with the particular instrument for which they are issued.

Operating Instructions

Initial preparation for field testing:

1. Connect the gage and scaler. Turn the power on and allow the instrument to warm up about 5 min. When tests are to be performed frequently throughout the day, leave the equipment connected and turned on all day. Be sure the scaler power is turned off when connecting or disconnecting the cable, to avoid electric shock and to prevent damage to electronic components.

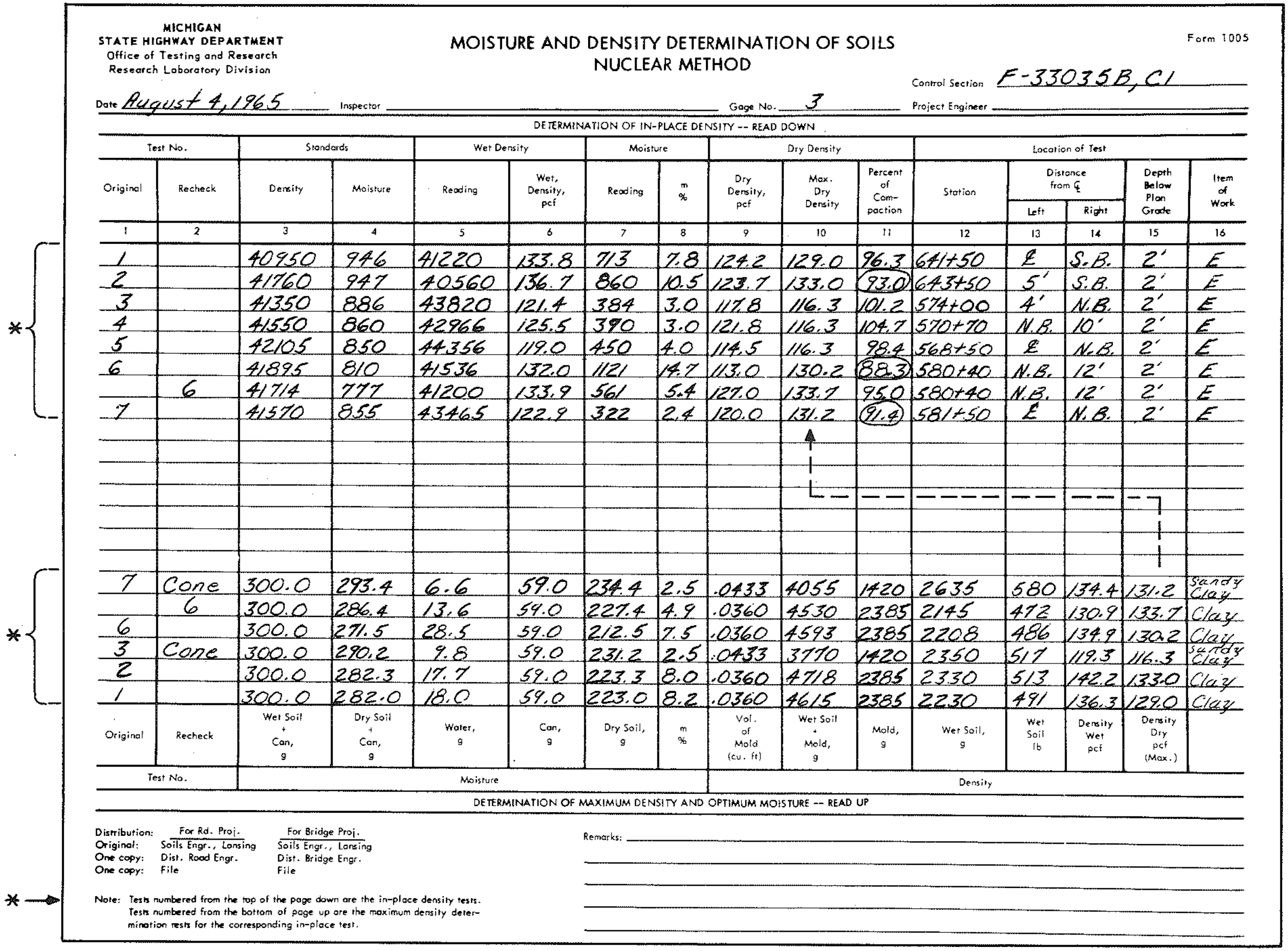
2. Place the gage on the standard and obtain a density reading and a moisture reading. Enter these readings in Columns 3 and 4, respectively, on the nuclear density inspection form (a sample copy of this form is included in this Appendix).

3. Prepare the surface of the soil to be tested by removing all loose dry material. Level the surface and remove voids with a straight edge so the gage will sit flat without rocking.

Determination of in-place density and moisture:

1. Place the gage on the prepared surface and obtain density and moisture readings. Enter these readings in Columns 5 and 7, respectively, on the form.

2. Using these readings (Columns 5 and 7), determine the wet density and percent moisture from the appropriate calibration curve. Enter these values in Columns 6 and 8 on the form.



MICHIGAN
STATE HIGHWAY DEPARTMENT
Office of Testing and Research
Research Laboratory Division

MOISTURE AND DENSITY DETERMINATION OF SOILS
NUCLEAR METHOD

Form 1005

Control Section F-33035B, C1

Date August 4, 1965 Inspector ______ Gage No. 3 Project Engineer ______

DETERMINATION OF IN-PLACE DENSITY -- READ DOWN

Test No.		Standards		Wet Density		Moisture		Dry Density			Location of Test				
Original	Recheck	Density	Moisture	Reading	Wet, Density, pcf	Reading	m %	Dry Density, pcf	Max. Dry Density	Percent of Compaction	Station	Distance from ℄ Left	Distance from ℄ Right	Depth Below Plan Grade	Item of Work
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		40950	946	41220	133.8	713	7.8	124.2	129.0	96.3	641+50	℄	S.B.	2'	E
2		41760	947	40560	136.7	860	10.5	123.7	133.0	93.0	643+50	5'	S.B.	2'	E
3		41350	886	43820	121.4	384	3.0	117.8	116.3	101.2	574+00	4'	N.B.	2'	E
4		41550	860	42966	125.5	390	3.0	121.8	116.3	104.7	570+70	N.B.	10'	2'	E
5		42105	850	44356	119.0	450	4.0	114.5	116.3	98.4	568+50	℄	N.B.	2'	E
6		41895	810	41536	132.0	1121	14.7	113.0	130.2	88.3	580+40	N.B.	12'	2'	E
	6	41714	777	41200	133.9	561	5.4	127.0	133.7	95.0	580+40	N.B.	12'	2'	E
7		41570	855	43465	122.9	322	2.4	120.0	131.2	91.4	581+50	℄	N.B.	2'	E

7	Cone	300.0	293.4	6.6	59.0	234.4	2.5	.0433	4055	1420	2635	580	134.4	131.2	Sandy Clay
	6	300.0	286.4	13.6	59.0	227.4	4.9	.0360	4530	2385	2145	472	130.9	133.7	Clay
6		300.0	271.5	28.5	59.0	212.5	7.5	.0360	4593	2385	2208	486	134.9	130.2	Clay
3	Cone	300.0	290.2	9.8	59.0	231.2	2.5	.0433	3770	1420	2350	517	119.3	116.3	Sandy Clay
2		300.0	282.3	17.7	59.0	223.3	8.0	.0360	4718	2385	2330	513	142.2	133.0	Clay
1		300.0	282.0	18.0	59.0	223.0	8.2	.0360	4615	2385	2230	491	136.3	129.0	Clay
Original	Recheck	Wet Soil + Can, g	Dry Soil + Can, g	Water, g	Can, g	Dry Soil, g	m %	Vol. of Mold (cu. ft)	Wet Soil + Mold, g	Mold, g	Wet Soil, g	Wet Soil lb	Density Wet pcf	Density Dry pcf (Max.)	
Test No.		Moisture						Density							

DETERMINATION OF MAXIMUM DENSITY AND OPTIMUM MOISTURE -- READ UP

Distribution:	For Rd. Proj.	For Bridge Proj.
Original:	Soils Engr., Lansing	Soils Engr., Lansing
One copy:	Dist. Road Engr.	Dist. Bridge Engr.
One copy:	File	File

Remarks: ______

Note: Tests numbered from the top of the page down are the in-place density tests. Tests numbered from the bottom of page up are the maximum density determination tests for the corresponding in-place test.

Typical inspection form for compaction control. Dashed arrow indicates design density data carried up to Col. 10.

3. Compute the dry density from the following formula (in which m = percent moisture, dry basis), and enter in Column 9 on the form:

$$\left[\text{dry density} = \frac{\text{wet density}}{1 + \frac{m}{100}}\right] \quad \text{or} \quad \left[\text{Column 9} = \frac{\text{Column 6}}{1 + \frac{\text{Column 8}}{100}}\right]$$

This procedure uses the nuclear method to determine in-place soil conditions. Tests for determining maximum unit weight are conducted in the conventional manner and the results entered working up from the bottom of the form.

Routine Maintenance

1. The battery must be charged daily when the instrument is in use. Plug the charging cord into any ordinary electrical outlet (110-v ac, 60-cycle). Recharge overnight with scaler set on "automatic."

2. Check the water level in the battery before charging. Refill only with distilled water, which can be obtained from either a drug store or the Research Laboratory.

3. When the instrument is not used for prolonged periods, it should be operated at least 1 hr each week by obtaining several moisture and density readings on the standard. The battery should also be checked for water level and charged at this time. If checked and maintained in this manner, the equipment should be in condition for use at all times.

4. Other maintenance and repairs should be performed by Research Laboratory personnel.

Personnel Safety

A 5-millicurie source of Radium-Beryllium, contained in the gage, constantly emits ionizing radiation which could cause damage to human tissue, if the gage is handled improperly. However, the gage is designed with adequate protective shielding, provided persons do not remain near the gage for too a long period of time.

1. Operators should wear film badges at all times while working with the gage. These badges measure the exposure received by the wearer, and are processed and read every two weeks. When not in use, badges should be stored well away from gages to avoid indicating exposure that the operator does not actually experience.

2. Personnel not wearing a film badge should remain at least 5 ft from the gage. Operators can handle the gages safely and work nearer than 5 ft during the time needed to perform tests, because any buildup in absorbed radiation would be indicated on the film badge and corrective measures taken. No person, however, should remain near the gage longer than necessary.

3. The gage should be stored in a locked container when not in use. The gage can be locked either in the density kit on the truck or in a box inside the project office. The kit or box should be clearly marked with a yellow-and-magenta sign "Caution--Radioactive Material."

Accident Procedure

In case of an accident causing damage to the gage there is danger that the source may be ruptured, allowing the radioactive material (which is a powder) to spread over a wide area. This would create a definite radioactive hazard to persons exposed.

In event of any accident, take the following immediate steps:

1. Keep persons away from any fumes, smoke, etc. Stay upwind of the source.

2. Seal off at least a 50-ft radius around the source to prevent possible tracking of radioactive material.

3. Call the nearest State Police post (Area Code 517, 332-2521, for the Lansing area).

4. Call the State Health Department (Area Code 517, 373-1410).

5. Call the MDSH Safety Section (Area Code 517, 373-2288).