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FINAL REPORT

74-2

FIELD EVALUATION OF A DIRECT TRANSMISSION TYPE NUCLEAR MOISTURE-DENSITY GAUGE

MISSOURI STATE HIGHWAY DEPARTMENT

FIELD EVALUATION OF A DIRECT TRANSMISSION TYPE NUCLEAR MOISTURE-DENSITY GAUGE

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Prepared by

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ABSTRACT

Results obtained by a nuclear moisture-density gauge were correlated to those obtained by a balloon type volume device and oven drying. The nuclear testing modes were direct transmission for wet density and backscatter for moisture.

Comparison tests were made on active construction projects in each of 10 soil types and graded aggregate bases from 10 stone formations. The test sites were located throughout the state.

The test results were analyzed statistically by regression, correlation coefficient and "t" test (comparison of the means). It was found that the manufacturer's wet density calibration curve provided acceptable results in all of the Missouri soil types and stone formations tested but that the manufacturer's water calibration curve frequently furnished unacceptable values for moisture content. However, acceptable moisture content values were obtained with the nuclear gauge by use of a computed correction factor. This factor was found to be a constant for a particular soil type or stone formation on a project.

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INTRODUCTION

Highway contractors increasingly have the ability to construct earthwork and crushed stone bases at a pace such that conventional means of compaction testing may produce untimely results. The testing equipment principally used by the Missouri State Highway Department has been the water balloon device for determining volume and stoves for drying of moisture samples. In an attempt to increase the speed of testing, a nuclear moisture-density gauge (backscatter-air gap mode) was evaluated in 1968-1969. The results were found to be strongly affected by soil type and stone formation. This indicated a need for field calibration of both wet density and moisture in most of the materials tested. Field calibration of wet density was considered a serious drawback since conventional methods, not considered the ultimate in accuracy, would be the standard. Mainly because of the wet density calibration problem, a decision was made to forego nuclear testing at that time.

Since the need for faster results remained, nuclear gauges were again considered. Recent literature has indicated the direct transmission mode produces better wet density results; therefore, it was decided to evaluate equipment using this mode.

The specific objectives of the study were:

1. To evaluate the accuracy of a direct transmission type nuclear gauge in making density and moisture determinations by field comparison testing with conventional test methods.
2. To determine if standard calibration curves are applicable to the variety of materials which may be encountered throughout the state.
3. To recommend acceptance or rejection of the nuclear direct transmission test method in compaction control on state highway projects.

CONCLUSIONS

A good correlation is indicated in the soils and stone bases tested between Volumeasure and nuclear direct transmission wet densities and between oven dry and nuclear moistures provided the tests are properly conducted and the nuclear gauge calibration curve for water is correct (a water correction factor was used in those soil types and stone formations where the manufacturer's calibration curve yielded inaccurate results). When these criteria were met, the means of the results by conventional and nuclear methods were not significantly different for wet and dry density or moisture and small values of standard errors of estimate and high values of correlation coefficients were obtained.

The data warrants the following specific conclusions with respect to the nuclear gauge evaluated:

1. The manufacturer's calibration curve, for wet density determined by the direct transmission mode, is acceptable for use in the soil types and stone formations tested.
2. The manufacturer's calibration curve for water content yielded erroneous results in some soils and in all of the stone bases tested. Acceptable moisture content values were obtained by use of a correction factor computed from field results. This factor was found to be a constant for a particular soil type or stone formation on a project.
3. The wide range in values of computed moisture correction factors indicate that one field moisture calibration curve for all soil types or for all stone formations will not yield acceptable results. Therefore, a correction factor must be determined for each material tested.

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IMPLEMENTATION

It is recommended that the nuclear moisture-density gauge evaluated be accepted for use in compaction control of earthwork and graded aggregate bases.

Wet density should be determined in accordance with AASHTO T 238-73I Method B-Direct Transmission.

Moisture content should be determined in accordance with AASHTO T 239-73I except that a moisture correction factor should be determined in the field on each material tested by the method outlined in Appendix 2 of this report.

TEST EQUIPMENT

A Model 2401 surface moisture-density gauge, manufactured by Troxler Electronics Laboratories, Inc., was selected for evaluation. This gauge is capable of making density tests in the backscatter, backscatter-air gap and direct transmission modes. Only the direct transmission mode was evaluated in this investigation. Moisture determination is limited to the backscatter mode. The radioactive source is 2.1 millicuries of radium-226: beryllium. Direct transmission density tests can be made in 2 inch increments with a minimum depth of 2 inches and a maximum depth of 8 inches. The manufacturer lists the following measurement specifications:

A. Direct Transmission density at 6 inch depth:

Precision at 120 pcf	± 0.30 pcf
Composition error at 120 pcf	± 0.5 pcf
Calibration error	± 0.5 pcf
Surface error (.050 inch 100% void)	- 0.5 pcf
Range of calibration	70-170 pcf

B. Moisture content:

Precision at 15 pcf	± 0.35 pcf
Surface error (.050 inch 100% void)	- 0.5 pcf
Depth of measurement at 15 pcf	5 inch
Range of calibration	0-40 pcf

The nuclear gauge did not meet the manufacturer's statistical test for density when first received. After factory repair, no malfunctions occurred during this investigation.

A Soiltest Model CN-980 Volumeasure, a small water balloon device equipped with a pressure gauge, was used to make the conventional volume determinations. The Volumeasure is used almost exclusively in compaction control by the Missouri State Highway Department. The only measurement requirement is that of AASHTO T 205 which indicates accuracy within one percent to be satisfactory. Other than the scale, which should be calibrated, potential sources of error in use of the Volumeasure include failure of the balloon to conform to the hole or deformation of the hole under pressure. These problems are affected by shape and roughness of the hole, stiffness of the balloon, pressure on the fluid, and the strength of the test material which must resist displacement under a fluid pressure not in excess of 5 psi. The Volumeasure is unsuited for use in materials which continue to yield at this pressure.

Calibration data for the Volumeasure used is included in Appendix 1.

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TEST PROCEDURE

The nuclear tests were performed in accordance with the manufacturer's instructions which conform to AASHTO T 238-73I. A probe depth of 6 inches was always used in soils and 4 inches in stone bases. A one minute counting period was used for all moisture and density counts. Time required for the nuclear tests (calculations excluded) was no more than 5 minutes depending on the difficulty encountered in preparing the surface.

The conventional tests, including those on the stone bases, were made in accordance with AASHTO T 205-64 except that the size of the hole was reduced to accomodate the equipment and volume readings were recorded with fluid pressures of 3, 4 and 5 psi (designated Volumeasure 3 psi, etc.). A previous, unpublished study by the Missouri State Highway Department indicated good agreement between the results of the conventional density methods when 5 psi pressure was applied to the fluid in the Volumeasure. Based on that study, the Volumeasure 5 psi results were considered the most valid; however, to make the study more comprehensive nuclear results were also compared to the Volumeasure 3 and 4 psi results. The conventional test was made between the location of the gauge source and detectors so that, in so far as practical, the same material was tested. All of the material removed was dried for moisture content.

TEST PROGRAM

The testing program consisted of ten comparison tests in ten soil types and in bases produced from ten stone formations. The general locations of test sites, all on active construction projects, are shown in Figure 1. Tests in soil were made on fills after rolling had been completed except for a few made in cuts behind scrapers. The ASTM classifications of the soils tested include SM, ML, CL, CH and GC.

The stone bases tested were dolomites or limestones of two gradations designated in Missouri specifications as Type 1 or Type 3. Type 1 is well graded with a one inch maximum size. The Type 3 tested was a considerably finer gradation with a maximum size of 3/8 inch. All tests were made after compaction on grade.

REPEATABILITY OF TEST METHODS

To evaluate the repeatability of the nuclear results, 20 consecutive gauge measurements of wet density and moisture were made on one soil and on one stone base without moving the gauge. The measurements were converted to corresponding wet density and moisture values from the manufacturer's calibration curves and standard deviations computed.

The results, shown in Table 1, indicate that variations can be expected, due to inaccuracies of the gauge, up to about 1.0 pcf wet density, 0.9 pcf water content and 1.5 pcf dry density (all 3 standard deviation values). These values indicate a repeatability satisfactory for the intended purpose.

TABLE 1

VARIATION OF NUCLEAR GAUGE MEASUREMENTS

Material	Test	Standard Deviation, pcf	Avg. Gauge Value, pcf
Soil	Wet Density	0.34	129.2
Soil	Water	0.35	19.2
Stone Base	Wet Density	0.29	137.7
Stone Base	Water	0.27	7.6
Soil	Dry Density	0.49	110.0
Stone Base	Dry Density	0.39	130.1

Since a conventional density test cannot be duplicated, the repeatability of such tests can be determined only by indirect means. Todor and Gartner (5) have reported a standard error of estimate of 2.33 pcf for wet density by a small water balloon device and of 1.95 pcf for a nuclear gauge. In their study, material was compacted into a box of known volume and standard errors of estimate computed from both the balloon and nuclear gauge wet densities versus the box average wet density. From data collected in a similar manner, Hatano, et al (1), report standard errors of estimate of 3.9 pcf for the conventional sand cone method and 1.8 pcf for a nuclear gauge. In an unpublished study, the Missouri State Highway Department compared field results using two Volumeasures and a sand cone and found the Volumeasure to have better repeatability. In a regression analysis, results from one Volumeasure (designated VM-2) were used as the base (X) data. The results obtained for dry density are shown in Table 2. Standard errors of estimate for the Missouri data, while smaller than those reported from the box studies, have the same order of magnitude, i.e., smaller for the balloon than for the sand cone method.

TABLE 2

DRY DENSITY CORRELATION OF CONVENTIONAL TEST METHODS

	Standard Error of Estimate,pcf		Average Dry Density,pcf		
Material	VM-2 vs. VM-3	VM-2 vs. sand	VM-2	VM-3	Sand
Soil	0.5(155)	1.7(35)	95.0	95.0	96.6
Stone Base	0.9(119)	2.3(40)	136.5	135.9	135.6

NOTE: Numbers of tests are shown in parentheses. Volumeasure pressure was 5 psi for all tests.

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ACCURACY BETWEEN METHODS

Both the conventional and nuclear methods of density testing have errors and a difference between results can be expected. The data reported by others (1, 5) can be used to establish a limit for this difference.

The magnitude of the difference to be expected between the test results can be determined by combining the variances of the two methods:

$$S_t^2 = S_c^2 + S_n^2$$

where S_t^2 is the total variance, S_c^2 is the variance of the conventional method, S_n^2 is the variance of the nuclear method, and S_t is the total standard error of estimate.

If the values reported by Todor and Gartner or Hantano, et al, are used in this formula, the total standard error of estimate would be 3.0 and 4.3 pcf, respectively. For the purposes of this study, a standard error of estimate of 3.0 pcf or less between Volumeasure and nuclear results was considered a satisfactory value.

ANALYSIS BY SOIL TYPE AND STONE FORMATION

The data gathered was analyzed by regression, correlation coefficient and "t" test (comparison of the means). The results by the conventional methods were used as the X data.

Wet density. Wet density values determined by the two methods were first analyzed by soil type and stone formation to determine the validity of the manufacturer's nuclear gauge calibration curve in a wide range of materials. The correlation data developed is presented in Table 3.

The average wet density results indicate Volumeasure densities are related to the pressure applied to the fluid. This effect is pronounced in stone bases but is rather insignificant for soils. The only unusual results found were for the Knox Transitional soil. This soil was so silty and wet of optimum that a constant volume could not be obtained. This resulted in an indicated decrease in wet density of about one pcf for each one psi increase in pressure. Consequently, the "t" test was significant, at the 95 percent confidence level, for the correlation of the Volumeasure, 5 psi pressure, vs. nuclear in this soil. This material was unsuited for testing by the balloon method.

The computed "t" was also significant for four comparisons in stone formations. These were the Volumeasure, 3 psi pressure, vs. nuclear in the Bethany Falls Limestone, Gasconade and Bonne Terre Dolomites, and the Volumeasure, 4 psi pressure, vs. nuclear in the Bethany Falls Limestone. The "t" test was not significant in any stone formation where the means of results of the Volumeasure, 5 psi pressure, and nuclear were compared. This is considered the most valid comparison since 5 psi pressure reduces volume errors to a minimum in stone bases.

The standard errors of estimate varied somewhat between soil types and stone formations. However, they are smaller than the 3.0 pcf that might reasonably be expected between the two methods and are considered satisfactory.

The correlation data indicates no significant difference between the wet densities determined by the two test methods in the materials tested, provided the tests are conducted properly. Thus, the nuclear gauge manufacturer's wet density calibration curve appears applicable for a wide range of Missouri soil types and stone formations.

Percent Moisture. Although the nuclear gauge manufacturer's water calibration curve indicates water in pounds per cubic foot (pcf), percent moisture was determined and analyzed because it is the value desired in compaction and moisture control. The correlation data is contained in Table 4. Note that corrected nuclear moisture values and correlation data are included in the table. A moisture correction was applied only when the "t" value was significant.

The "t" test was significant at the 95 percent confidence level in till and at the 99 percent confidence level in the Boone and Sarpy soils. Organic debris (grass and roots) was found in the bottom of the conventional density hole at the three test sites in the Boone soil where the greatest difference in results between the two test methods was encountered.

The data, excluding the Boone soil type, indicates that a standard error of estimate of more than one percent can be expected in some soils. A portion of this value can probably be attributed to the difference in the volume of material tested by the two methods. Although a value of this magnitude can be tolerated for field control, a value of about 0.5 percent is certainly to be preferred.

The "t" test was highly significant in all of the stone formations. The means of the two methods unquestionably came from different populations. However, the standard errors of estimate approached 0.5 percent.

The small values of the standard errors of estimate obtained in both materials are an indication that a field calibration curve could be developed or that a correction factor could be computed that would result in acceptable nuclear moisture results. A correction factor would be faster and easier to determine in the field because a wide moisture range is not needed. This approach was used and a correction factor was computed as shown in Appendix 2.

This correction factor is expressed in pounds per cubic foot which can be summed with the nuclear water value, indicated by the gauge calibration curve, prior to computing dry density and percent moisture.

Correcting the nuclear moisture results eliminated the significant "t" values in both the soil types and stone formations. This is further evidence that nuclear wet density results are reliable since they were used in computing the correction factor for moisture.

Smith (4) concluded that it is satisfactory to assume that the free water calibration curves for nuclear gauges differ only by a constant which depends on the sum of the effects of the structural water and absorbing elements present. Smith's conclusion was substantiated by this investigation since a constant correction factor was found satisfactory for a given soil type or stone formation on a project.

The correlation indicates that the manufacturer's water calibration curve is likely to yield erroneous results and that the gauge results should be checked against oven dry results in each soil type and against any sample suspected of containing organic matter. A moisture correction factor should also be determined for the nuclear gauge in each stone formation. Since testing was repeated in only one stone formation, the data collected is insufficient to determine if the correction factor computed would hold true for the same stone formation or soil type located in a different area of the state.

As shown in Table 2, the computed correction factors have a wide range. It is obvious that one field calibration curve for all soil types or all stone formations would not yield acceptable results by the nuclear gauge.

Dry density. Dry density correlation data is presented in Table 5 with corrected nuclear dry density results and correlation data included. Corrected nuclear dry densities reflect only the correction applied to the moisture since the wet densities were not altered. Corrected nuclear results were compared only to the Volumeasure, 5 psi pressure, results because this pressure comparison was good in soils and definitely superior in crushed stone bases.

The computed "t" using uncorrected nuclear results was significant for only one comparison in the soil types, that for the Volumeasure, 3 psi pressure, vs. nuclear in till, even though data with the three significant "t's" for moisture were involved. Correcting the nuclear dry densities did not result in any significant "t" values.

In the stone formations, the majority of the computed "t's" for the uncorrected nuclear results are significant and about one half highly significant. This was anticipated since the computed "t" for moisture was highly significant in all the stone formations. None of the computed "t's" for the Volumeasure, 5 psi pressure, vs. the corrected nuclear dry densities are significant. Most of these "t" values are quite small indicating close numerical agreement between the means.

For the Volumeasure, 5 psi pressure, vs. nuclear, only one standard error of estimate reached 3.0 pcf. This was in the Marshall soil type. The values of the standard errors of estimate are considered satisfactory. These values are slightly smaller than was anticipated considering that they contain variance for both wet density and moisture.

The dry density correlation indicates that there is no significant difference between the results of the two methods when the tests are conducted properly and the nuclear gauge water calibration curve is correct (or corrected) in the material tested.

ANALYSIS BY MATERIAL

In this correlation, presented in Table 6, all of the test results in each material, soil or stone base, were compared. The values of the standard error of estimate and the correlation coefficient should be more meaningful due to the greater number of tests.

In soils, the wet density correlation data indicates that, regardless of the pressure on the fluid, the Volumeasure and nuclear results correlate well. In the stone bases, the effect of pressure on the fluid is more pronounced. This is indicated by the significant "t" value for the Volumeasure, 3 psi pressure, vs. nuclear comparison. In addition, average wet densities, standard errors of estimate, and correlation coefficients all indicate better correlation between the Volumeasure, 5 psi pressure, and nuclear results.

The "t" value for soil moisture correlation is of interest since it is not significant even though it contains data from three soil types that were significant when analyzed individually.

A standard error of estimate of about 2.0 pcf was indicated for both wet and dry density in both soil and stone bases. Based on the data reported by others, a standard error of estimate of 2.0 pcf is smaller than might be expected. This value is comparable to the standard errors of estimate of 1.7 pcf in soils and 2.3 pcf in stone bases between the Volumeasure and sand cone dry densities determined by the Missouri State Highway Department.

When corrected nuclear moisture data is used, all of the correlation coefficients were above 0.90 indicating a high degree of correlation between the results of the test methods.

REFERENCES

1. Hatano, M. M., et al, "Structure Backfill Testing". California Division of Highways, Final Report Number CA-DOT-TL-2130-2-73-41, 1973.

2. Johnson, A. W. and Sallberg, J. R., "Factors That Influence Field Compaction of Soils". HRB 272, 1960. pp 121-125.

3. Redus, J. F., "A Study of In-Place Density Determinations for Base Courses and Soils". HRB 159, 1957. pp 24-40.

4. Smith, R. E., "Nuclear Soil Moisture Correlation". California Division of Highways. Interim Report Number CA-HY-MR-2908-2-72-47, 1972.

5. Todor, P. C. and Gartner, W., Jr., "Evaluation of Direct Transmission - Type Nuclear Density Gauge for Measuring In-Place Densities of Soils". HRC 107, 1966. pp 13-24.

APPENDIX 1

VOLUMEASURE CALIBRATION

The Volumeasure was calibrated by two methods. One method was in accordance with AASHTO specification T 205-64 except that the readings were made at 5 psi pressure. The procedure for the other method, which is essentially a check of the scale, follows:

1. Remove graduated cylinder and replace inverted in the housing.
2. Place some water of known temperature in the Volumeasure.
3. Read Volumeasure and record.
4. Add 500 gm of water (same source as 2) to the Volumeasure.
5. Read Volumeasure and record.
6. Per cent error is the Volumeasure volume, or difference in scale readings, divided by the volume of water added as computed from its weight with temperature correction.
7. The AASHTO calibration indicated an error in volume of +0.9 per cent while the scale calibration indicated a volume error of +0.6 per cent.

APPENDIX 2

WATER CORRECTION FACTORS

Method of computation

The water correction factor, (C.F.) is computed in pounds per cubic foot as follows:

$$C.\ F. = \frac{\overline{\gamma}nw}{1+\overline{W}_c} \left| \overline{W}_n - \overline{W}_c \right|$$

where $\overline{\gamma}nw$ is the average nuclear wet density, $\overline{W}_n$ is the average nuclear percent moisture expressed in decimal form and $\overline{W}_c$ is the average conventional percent moisture expressed in decimal form.

Number of tests

The required number of tests can be determined from the following equation:

$$n = \frac{\sigma^2}{\sigma_{\overline{x}}^2}$$

where n is the number of tests, σ is the standard deviation and $\sigma\overline{x}$ is the standard error of the mean. Using the following values:

0.35 pcf	=	σ of 20 tests for soil water from this investigation
0.5 pcf	=	selected confidence interval
2.861	=	t.01, 19 (selected confidence level)
0.175	=	$\sigma\overline{x}$ as computed from the relationship of the confidence interval to t ($\sigma\overline{x}$ = 0.5/2.861),

then:

$$n = \frac{(0.35)^2}{(0.175)^2} = 4 \text{ tests}$$

The required number of tests then is 4 nuclear determinations of wet density and water content and four moisture tests by drying at 230 ± 9 F.

Samples for drying should be obtained, in so far as practical, from the volume of material tested by the nuclear gauge, i.e., between source and detector.

General Location of Testing Sites

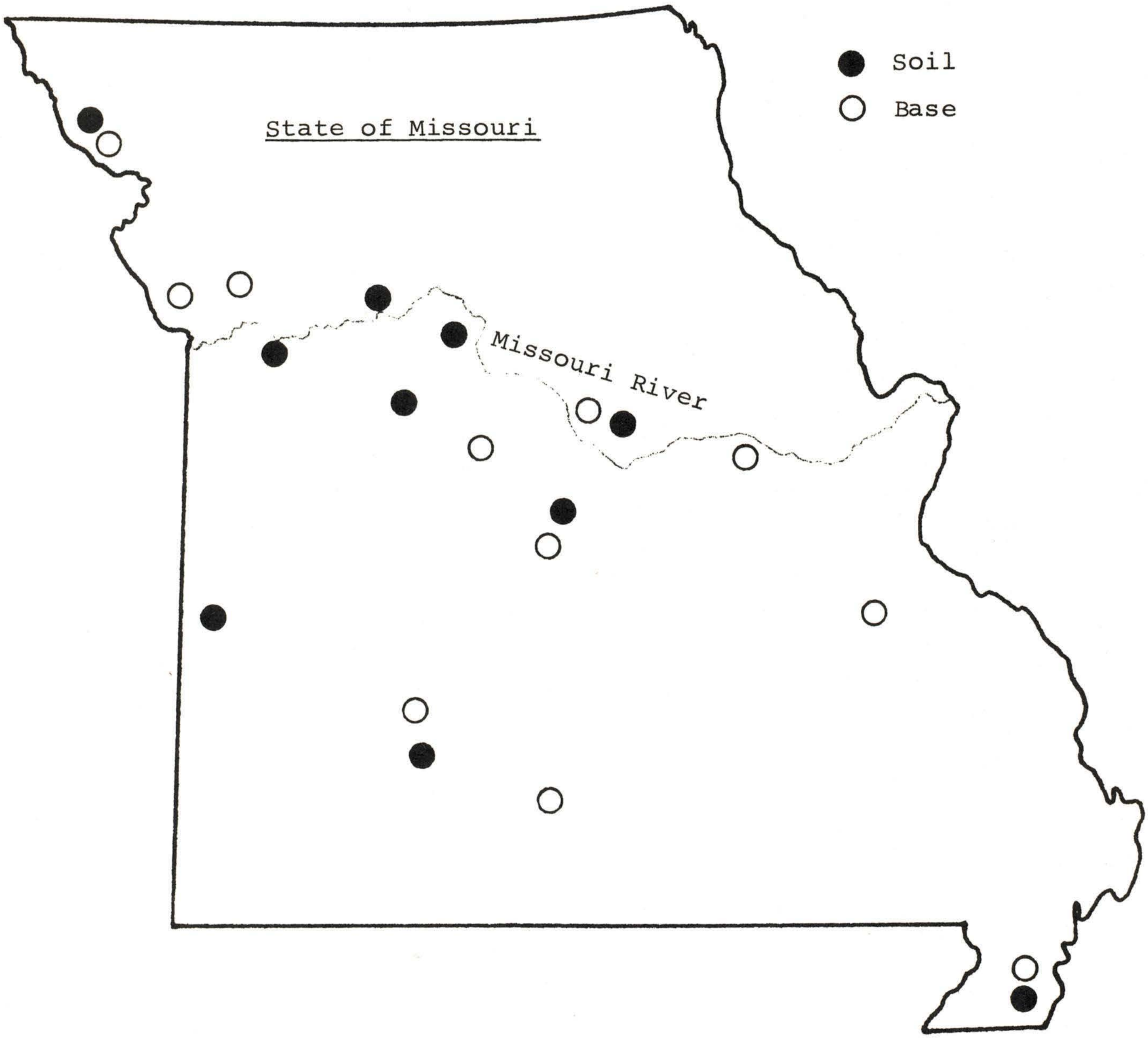

Figure 1

TABLE 3

WET DENSITY CORRELATION BY SOIL TYPE AND STONE FORMATION

SECTION A - SOIL

		Average Wet Density, pcf				Computed "t"			Standard Error of Estimate, pcf		
	No. of		Volumeasure								
Name	Tests	Nuclear	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi
Knox Tran.	9	122.0	122.0	120.9	119.9	0.04	1.19	2.16*	1.1	1.1	1.1
Till	10	129.9	130.6	129.8	129.6	2.08	0.20	0.98	0.4	0.4	0.4
Eldon	10	121.2	118.6	118.1	117.9	1.44	1.75	1.87	2.2	2.0	2.1
Mexico	11	123.4	124.1	123.4	123.3	0.39	0.01	0.10	1.5	1.3	1.4
Oswego	11	122.4	119.7	119.6	119.6	1.60	1.67	1.67	1.7	1.7	1.7
Boone	10	123.6	121.3	120.9	120.9	0.92	1.10	1.11	2.4	2.2	2.2
Sarpy	10	132.9	132.4	132.4	132.4	0.33	0.33	0.33	1.4	1.4	1.4
Crawford	10	125.3	127.2	126.0	125.4	1.04	0.45	0.07	1.6	1.3	1.8
Marshall	10	122.7	123.3	122.8	122.7	0.44	0.08	0.01	2.6	2.7	2.7
Knox	10	134.6	134.4	133.7	133.7	0.24	1.39	1.39	1.1	0.5	0.6

SECTION B - STONE BASE

Callaway	10	137.1	138.0	136.9	136.4	0.55	0.09	0.39	1.6	1.5	1.4
Callaway[a]	10	143.5	147.9	146.5	145.4	2.04	1.42	0.91	2.0	2.0	2.0
Gasconade	10	150.8	153.5	152.3	152.0	2.69*	1.51	1.22	2.0	1.9	1.9
Plattin	10	135.2	136.0	135.7	135.2	0.50	0.34	0.03	1.6	1.5	1.3
Burlington	10	134.9	136.2	134.7	134.6	0.86	0.17	0.21	0.8	0.9	0.9
Cotter	10	137.4	140.4	139.4	138.1	1.93	1.47	0.89	3.0	2.3	1.0
Bethany Falls	10	141.6	145.6	144.5	143.4	3.43**	2.57*	1.61	2.1	2.0	2.3
Winterset	10	133.3	136.0	134.4	133.1	0.94	0.39	0.06	2.1	2.3	2.3
Deer Creek	10	141.6	140.9	140.1	139.6	0.66	1.59	2.04	1.0	0.9	1.1
Bonne Terre	10	140.6	145.1	143.7	142.5	2.87*	1.94	1.20	1.1	1.2	1.1
Jeff City	10	126.7	128.1	126.9	125.9	1.08	0.18	0.65	1.0	1.1	1.0

(a) Same formation, different source
* Significant at the 95 percent confidence level
** Significant at the 99 percent confidence level

TABLE 4

MOISTURE CORRELATION BY SOIL TYPE AND STONE FORMATION

SECTION A - SOIL

Name	No. of Tests	Average Percent Moisture: Nuclear	Average Percent Moisture: Corrected Nuclear[b]	Average Percent Moisture: Oven Dry	Computed "t"	Standard Error of Estimate,%	Corrected[b]: Computed "t"	Corrected[b]: Standard Error of Estimate,%	Correction Factor,pcf
Knox Tran.	9	24.4		24.5	0.15	1.0			
Till	10	22.3	21.5	21.6	2.24*	1.0	0.15	1.0	-0.7
Eldon	10	22.9		22.2	0.26	0.8			
Mexico	11	20.9		20.3	0.30	1.4			
Oswego	11	23.3		22.9	0.26	1.2			
Boone	10	23.3	20.1	20.6	3.26**	2.2	0.69	1.8	-2.8
Sarpy	10	14.4	12.3	12.5	3.29**	0.6	0.33	0.6	-2.2
Crawford	10	20.5		19.6	0.65	0.9			
Marshall	10	24.1		24.9	0.82	1.5			
Knox	10	15.4		15.5	0.25	0.4			

SECTION B - STONE BASE

Name	No. of Tests	Nuclear	Corrected Nuclear[b]	Oven Dry	Computed "t"	Standard Error of Estimate,%	Corrected[b]: Computed "t"	Corrected[b]: Standard Error of Estimate,%	Correction Factor,pcf
Callaway	10	4.4	2.0	2.2	9.40**	0.4	1.25	0.1	-3.0
Callaway[a]	10	5.5	3.2	3.3	10.14**	0.5	0.65	0.5	-3.1
Gasconade	10	6.4	2.7	2.8	14.93**	0.4	0.58	0.4	-5.2
Plattin	10	5.3	2.9	3.0	8.04**	0.6	0.32	0.5	-3.0
Burlington	10	7.4	6.0	5.5	6.34**	0.4	1.72	0.4	-1.7
Cotter	10	9.7	5.9	6.2	14.00**	0.5	1.23	0.5	-4.5
Bethany Falls	10	5.2	2.8	2.9	5.67**	0.6	0.15	0.6	-3.2
Winterset	10	7.8	6.1	5.7	5.50**	0.5	1.11	0.5	-2.0
Deer Creek	10	10.3	7.7	7.9	10.14**	0.4	0.69	0.4	-3.1
Bonne Terre	10	6.3	3.8	3.9	6.27**	0.6	0.29	0.6	-3.2
Jeff City	10	7.5	3.5	3.8	8.66**	0.7	0.59	0.7	-4.5

(a) Same formation, different source
(b) Corrected nuclear water values used where "t" is significant
* Significant at the 95 percent confidence level
** Significant at the 99 percent confidence level

TABLE 5

DRY DENSITY CORRELATION BY SOIL TYPE AND STONE FORMATION

SECTION A - SOIL

		Average Dry Density, pcf					Computed "t"				Standard Error of Estimate, pcf			
				Volumeasure										
Name	No. Of Tests	Nuclear	Corrected[b] Nuclear	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	Corrected[b] 5 psi	3 psi	4 psi	5 psi	Corrected[b] 5 psi
Knox Tran.	9	98.1		97.9	97.1	96.3	0.11	0.88	1.58		1.4	1.3	1.4	
Till	10	106.2	106.9	107.4	106.8	106.6	2.97**	1.27	0.84	0.84	1.0	1.0	1.1	1.1
Eldon	10	98.8		97.3	96.9	96.8	0.51	0.64	0.72		2.9	2.6	2.7	
Mexico	10	102.3		103.5	102.9	102.8	0.38	0.20	0.15		2.1	2.0	2.0	
Oswego	10	99.3		97.6	97.6	97.6	0.67	0.70	0.70		1.7	1.7	1.7	
Boone	10	100.3	102.7	100.6	100.3	100.3	0.13	0.00	0.00	1.09	2.2	2.1	2.2	2.5
Sarpy	10	116.2	118.4	117.8	117.8	117.8	0.90	0.90	0.90	0.34	0.8	0.8	0.8	0.8
Crawford	10	104.1		106.5	105.5	105.0	0.98	0.62	0.37		1.5	1.4	1.9	
Marshall	10	98.9		98.8	98.4	98.3	0.02	0.26	0.30		2.9	3.0	3.0	
Knox	10	116.8		117.2	116.5	116.5	0.38	0.25	0.25		1.4	1.2	1.2	
SECTION B - STONE BASE														
Callaway	10	131.3	134.4	135.0	134.0	133.5	2.53*	1.70	1.42	0.56	1.4	1.2	1.2	0.9
Callaway[a]	10	136.0	139.1	143.2	141.8	140.8	3.36**	2.81*	2.32*	0.81	1.9	2.0	1.7	1.7
Gasconade	10	141.7	146.9	149.3	148.1	147.8	7.30**	6.15**	6.15**	0.91	1.9	1.8	1.8	1.8
Plattin	10	128.4	131.4	132.3	132.0	131.3	2.38*	2.22	1.80	0.02	1.0	1.0	0.9	0.9
Burlington	10	125.6	127.3	129.1	127.7	127.7	2.45*	1.48	1.44	0.25	0.8	0.8	0.9	0.8
Cotter	10	124.6	129.1	132.2	131.4	130.2	5.39**	4.65**	3.86**	0.77	3.0	2.4	1.2	1.2
Bethany Falls	10	134.5	137.7	141.5	140.5	139.5	5.46**	4.78**	4.08**	1.45	2.4	2.3	2.2	2.2
Winterset	10	123.7	125.7	128.0	126.6	125.3	1.38	0.90	0.50	0.12	2.6	2.6	2.7	2.6
Deer Creek	10	128.3	131.4	130.6	129.8	129.4	2.33*	1.58	1.16	2.10	1.2	1.2	1.3	1.3
Bonne Terre	10	132.3	135.5	139.7	138.3	137.2	4.42**	3.57**	2.86*	1.01	1.2	1.3	1.9	1.3
Jeff City	10	117.9	122.4	123.5	122.3	121.3	3.98**	3.17**	2.51*	0.78	0.7	0.8	0.7	0.7

(a) Same formation, different source
(b) Corrected nuclear water values used. Dry density comparisons at best pressure correlation (5 psi) only.
* Significant at the 95 percent confidence level
** Significant at the 99 percent confidence level

TABLE 6

CORRELATION BY MATERIAL
Wet and Dry Density and Percent Moisture

SECTION A - WET DENSITY

		Average Density, pcf				Computed "t"			Standard Error of Estimate, pcf			Correlation Coefficient		
			Volumeasure											
Material	No. of Tests	Nuclear	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi
Soil	101	125.8	125.3	124.7	124.5	0.53	1.23	1.50	2.2	2.0	2.0	0.92	0.93	0.93
Stone Base	108[a]	138.4	140.7	139.6	138.8	2.32*	1.19	0.39	2.3	2.1	1.9	0.94	0.95	0.96

SECTION B - DRY DENSITY

Material	No. of Tests	Nuclear	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi	3 psi	4 psi	5 psi
Soil	101	104.1	104.4	103.9	103.7	0.25	0.16	0.33	2.2	2.1	2.1	0.96	0.96	0.96
Soil Cor.[bc]	91	104.8			104.1			0.57			2.2			0.97
Stone Base	108	129.6	134.9	133.9	133.1	5.19**	4.14**	3.37**	2.3	2.2	2.0	0.95	0.95	0.96
St. Base Cor.[c]	108	132.9			133.1			0.25			2.0			0.97

SECTION C - PERCENT MOISTURE

		Average Moisture, %				
Material	No. of Tests	Nuclear	Oven Dry	"t"	Standard Error of Estimate, %	Correlation Coefficient
Soil	101	21.1	20.4	1.08	1.5	0.95
Soil Cor.[bc]	91	20.6	20.4	0.25	1.3	0.97
Stone Base	110	6.9	4.3	10.42**	0.9	0.89
St. Base Cor.[c]	110	4.2	4.3	0.19	0.7	0.94

(a) Tests at 5 psi, 110 tests at 3 psi and 109 tests at 4 psi
(b) Results from Boone soil type eliminated
(c) Corrected nuclear water values used. Dry density comparisons at best pressure correlation (5 psi) only.
* Significant at the 95 percent confidence level
** Significant at the 99 percent confidence level