CONTROL STRIP STUDY

Interim Report

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Research Report Number 59

Research Project No. 69-2S
Louisiana HPR 1(9)

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

January 1972

ACKNOWLEDGMENTS

Practically all of the nuclear testing was performed by Carl Hunt and Bobby Roberts of the Materials Section. The authors wish to thank them for their help.

Acknowledgment is also made to the District Laboratory and field personnel for their cooperation during the field evaluation of the procedure.

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ABSTRACT

This report is concerned with the application of the "control strip" technique using nuclear devices for compaction control of certain base courses and asphaltic concrete surface course. The technique, as evaluated here, consisted of applying increasing compactive effort to a small section (300 feet) of the material type to establish the optimum rolling pattern for that material. Nuclear testing was used to determine both the maximum density and desired roller pattern in the "control strip." The ensuing construction was then tested in segments (2000 feet) by nuclear means to check for conformance to certain percentage of the the "control strip" density.

The data collected and the field experience gained indicated (1) that the "control strip" technique using nuclear devices offered a very quick and flexible approach to the compaction control of base and asphaltic concrete surface courses; (2) that the variability of data using these procedures was normally within the magnitude of variation generally encountered with the conventional methods of density determinations; (3) furthermore, that the variation in the level of compaction from one section to the other was much more pronounced for cement stabilized base courses than unstabilized bases.

IMPLEMENTATION

At the present time, in Louisiana, interchangeability is indicated between the nuclear and conventional test methods of density determinations. In other words, the same requirements govern both the methods. Furthermore, acceptance or rejection is based on a somewhat semi-sequential sampling method. It is believed that the "control strip" technique, as discussed in this report, has a greater potential for quality control of base and asphaltic concrete surface course construction procedures. It is therefore recommended that the findings reported here be translated into Special Provisions for compaction control of base and asphaltic concrete surface course construction. The Special Provisions governing the use of this technique should be tried on a few selected projects as contract specifications.

1 - INTRODUCTION

The inherent advantages offered by use of non-destructive test methods in highway construction have begun to dawn upon those directly responsible for the quality control of the finished product. This has been brought to light in a recent issue of Highway Research Circular No. 121.[1] According to this circular, the use of nuclear equipment has jumped from 56 percent of the states in 1962 to 100 percent in 1970. Use of nuclear testing for specification materials control has likewise increased from 14 percent to 70 percent during the same 8 - year period.

Although nuclear devices are presently in use in Louisiana for compaction control, the requirements are specified on the basis of conventional methods using laboratory density as a parameter. Furthermore, these requirements are common to all projects regardless of the material and equipment. It is believed that nuclear methods of density and moisture content determinations, when used in conjunction with the control strip concept, will provide densities that are easily, quickly and practically obtainable, and furthermore, provide a more meaningful basis for decision making.

The purpose of this study is to examine the potential problems associated with the use of the "control strip" concept and nuclear gauges for compaction control of certain base and asphaltic concrete surface courses.

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(1) Highway Research Circular Number 121, Highway Research Board, Washington, D. C., February 1971.

II - SCOPE

The overall study encompasses evaluation of the "control strip" concept for compaction control of base courses and asphaltic concrete surface course using nuclear devices. More specifically, the following materials were included in the evaluation:

1. Aggregate bases
   a. Sand clay gravel
   b. Sand shell

2. Cement stabilized bases
   a. Sand clay gravel
   b. Sand shell
   c. Soil

3. Asphaltic concrete surface course
   a. Sand gravel mixes

This report is concerned with the evaluations of the technique as applied to all of the materials except 1(b) and 2(a). The data on these have not been made available mainly due to unavailability of projects at this time. Findings on these remaining base types will be reported in the form of a summary.

III - GENERAL PROCEDURE

The Control Strip

The technique, or concept, of "control strip" is not new. Ohio has been using it for many years. Virginia's specifications for base course compaction are based on this concept. California, on the other hand, has adopted the nuclear method together with the area concept for compaction of embankment and base course.

In general, the technique, as evaluated here involved construction of a control strip of the specified material at the construction site. This was accomplished by selecting an area on a firm foundation and rolling in increments of compactive effort with the specified minimum weight and with the material at the optimum design as determined in the laboratory. This procedure was continued until a definite roller pattern was obtained as determined by the nuclear equipment at three separate locations. The rolling pattern was discontinued when no further increase in density was detected with additional increase in compactive effort. The final estimate of the control strip density was obtained by taking ten random density-moisture tests. The average of these ten tests was then used as the basis for compaction compliance on the rest of the project.

Experimental Projects

Limited choice was offered for the selection of projects for data acquisition. Therefore, the technique was evaluated on whatever project was available at the time.

These were:

1. State Project 28-02-13 - this project was 3.3 miles long and called for an 8-inch thick cement stabilized soil base course. The project is in the southwest section of the State.

2. State Project 24-01-21 - this 6-inch cement stabilized sand shell base course was 3.56 miles in length and is also located in the southwest section of the State.

3. State Project 126-02-09 - this 4-mile stretch rests on an 8-inch sand clay gravel base course in the north-east section of the State.

4. State Project 50-07-28 - this asphaltic concrete overlay project required 1-1/2 inches of wearing course over 2 inches of binder course. The 7.9 mile stretch is located in the south central portion of the State.

On all of the above projects, the project engineers were familiarized with the concept and the scope of the study. This was helpful in minimizing the effect of extraneous variables other than those normally encountered during construction procedures.

Nuclear Equipment

The nuclear devices used in this study were Troxler Models 200-B Scaler, SC120F density guage, 104-117 moisture gauge and Troxler Model 2401 Compac combination unit.

The direct transmission mode was used for density determinations of base courses. The moisture contents were determined by the backscatter mode. Density determinations of the asphaltic concrete sections were obtained using the Troxler Model 2401 Compac and the air-gap method.

All of the above determinations were made with one one-minute count.

IV - ANALYSIS OF DATA

In this section, the analysis of data for each experimental project is presented separately, followed by discussion and comments. Furthermore, an attempt is made to present the analysis and evaluation of some of the concomitant information collected during the course of the study. These findings, although not germane to the specific objectives of the study, nevertheless provide information on some important aspects that may generally be encountered in the use of nuclear equipment during construction.

ASPHALTIC CONCRETE

Binder Course Sections

Table A-1 in the Appendix shows data on the roller pattern for binder course of a representative "control strip." The table lists only the optimum number of passes for each roller type at each of the three test locations in the control strip. The density values were obtained from the calibration charts supplied by the manufacturer for the equipment used in the study. The estimation of the "control strip" density appears in Table A-2. Ten random measurements were taken in the "control strip" area to arrive at an estimated mean value of 144. 0 pcf. This value was then used as the target value for the rest of the project which was tested in segments.

Table 1 shows the summary of test section densities for binder course mix. The target density of 143. 6 pcf represents the mean value of the three control strips. The mean and standard deviation for each section are also summarized in the table. The last two columns of the table represent comparative density data using nuclear and conventional methods.

The weighted mean and standard deviation of the nuclear determinations is 141. 7 and 2. 81 pcf, respectively. The former is 98. 7 percent of the target density and 96. 8 percent in terms of laboratory compaction. The standard deviation of 2. 81 pcf is likewise equivalent to 1. 91 percent in terms of laboratory compaction. This is somewhat higher than generally encountered on core densities. For the data at hand, 97. 5 percent of the target density seems to be the dividing line between a passing and failing test section.

Five of the 40 sections failed to meet the current specification requirements of 95 percent of laboratory compaction. For these failing sections, almost half of the individual tests had failing values. It is difficult to ascertain the cause of these non-conforming tests because of lack of adequate data on core densities.

TABLE 1

SUMMARY OF TEST RESULTS ON NUCLEAR AND CONVENTIONAL DENSITIES

(Binder Course Mix)

Section No.	Section Length, ft	n	Mean Nuclear Density, pcf	Std.Dev. pcf	% of Target Density	Check Density for "t" test	
						Nuclear	Cores
						pcf	
Mean target density = 143.6 pcf Mean laboratory density = 146.9 pcf							
1	2000	5	141.2	5.01	98.3	-	-
2	2700	5	142.0	3.45	98.9	140.9	142.0
3	2000	14	138.5*	3.52	96.4	139.8	144.1
4	2000	11	139.0*	4.03	96.8	140.4	142.5
5	1665	7	137.2*	2.31	95.5	-	-
6	1100	5	137.0*	2.53	96.3	-	-
7	2000	12	139.4	2.62	97.0	-	-
8	2000	5	138.1*	3.73	96.2	136.3*	140.8
9	1600	6	141.5	2.04	98.5	139.3	142.8
10	1500	5	141.5	2.03	98.5	143.6	142.8
11	2000	5	140.5	3.82	97.8	-	-
12	1700	5	141.0	3.36	98.2	140.5	140.8
13	2500	5	140.0	3.18	97.5	142.4	144.9
14	2200	5	143.9	1.71	100.2	-	-
15	1700	5	141.5	2.12	98.5	143.9	143.8
16	2425	5	143.8	1.51	100.1	143.5	143.4
17	2200	6	142.8	1.99	99.4	142.2	142.9
18	2000	5	142.7	2.02	99.4	142.6	143.0
19	1600	5	142.5	1.97	99.2	-	-
20	2250	5	142.6	3.19	99.2	142.3	142.5
21	2325	5	143.4	1.89	99.9	142.4	143.5
22	500	2	144.9	1.94	100.9	-	-
23	2450	6	142.7	2.73	99.4	140.1	143.1
24	1465	5	143.8	2.78	100.1	141.9	140.8
25	2100	5	143.5	3.45	99.9	143.8	144.4
26	2520	6	142.8	1.90	99.4	143.0	143.4
27	1950	5	142.4	3.76	99.2	145.0	143.9
28	875	4	141.7	2.72	98.7	-	-
29	2465	6	143.8	2.28	100.1	141.8	141.1
30	1905	5	144.5	1.69	100.6	144.6	143.9

* failing tests

TABLE 1 (Continued)

Section No.	Section Length, ft	n	Mean Nuclear Density, pcf	Std.Dev. pcf	% of Target Density	Check Density for "t" test	
						Nuclear	Cores
						pcf	
31	1850	5	142.8	1.65	99.4	141.1	141.1
32	1050	3	143.8	3.88	100.1	-	-
33	2040	5	142.1	3.04	99.0	144.6	143.7
34	2550	6	143.1	1.49	99.7	142.1	143.3
35	1710	5	141.8	5.72	98.7	143.1	143.5
36	2230	5	142.3	4.14	99.1	146.3	146.6
37	1980	5	144.7	2.78	100.7	145.8	145.1
38	1990	5	144.8	2.16	100.8	144.1	144.8
39	1185	2	145.5	3.54	101.3	-	-
40	800	3	143.1	1.01	99.7	145.2	143.9
Weighted mean			141.7			142.5	143.2
Weighted stand deviation				2.81		2.17	1.39

A discrepancy between the nuclear density and the core density is indicated at one of the test locations in Section 8. Both these measurements were taken at exactly the same location. This is indicated in the last two columns of Table 1. The point in question here is that the disposition of the test would be different, since, one test method indicates a passing value and the other, a failing one. On the other hand, these occasional outliers fall within the realm of chance for any given test method and need not be of prime concern.

Wearing Course Sections

Appendix Tables A-3 and A-4 show control strip and target density determinations for wearing course mix. Table 2 shows the summary of test section densities. The target density of 142.1 pcf represents estimation of the control strip density.

The weighted mean of these test sections is 142.7 pcf and the standard deviation of 2.64 pcf is somewhat lower than that for binder course sections. The mean percent of target is 100.4 percent which is considerably higher than that for binder course sections. All of the above values in terms of the percent of laboratory compaction gives the following:

142.7 pcf = 97.6 percent
2.64 pcf = 1.8 percent

Only one out of the 43 test sections fails to meet the minimum requirement for percent compaction. Furthermore, a discrepancy, similar to the one indicated at a test location in Section 8, is observed for Section 51. However, the difference is not as pronounced as in Section 8. Nevertheless, it presents the same ramifications for disposition of the test.

Comparison of Nuclear Densities and Core Densities - The Statistical t-test

In order to compare the nuclear and conventional methods of density determinations, tests were run at random locations within the sections, first with the nuclear equipment, and then obtaining roadway core at that location. The results of these tests appear in the last two columns of Tables 1 and 2.

It is desired to test the hypothesis that there is no difference between the mean density as determined by nuclear method and that determined using cut roadway samples, i.e., there is no difference between the two methods. Since it is the difference within pairs and not the difference between pairs that is to be tested, the paired t-test for significance was applied to the observed data to test the hypothesis that there is no difference. Such an approach tends to overcome the

TABLE 2

SUMMARY OF TEST RESULTS ON NUCLEAR AND CONVENTIONAL DENSITIES

(Wearing Course Mix)

Section No.	Section Length, ft	n	Mean Nuclear Density, pcf	Std. Dev., pcf	% of Target Density	Check Density for "t" test	
						Nuclear	Cores
						pcf	
Mean target density = 142.1 pcf							
Mean laboratory density = 146.1 pcf							
41	2040	5	141.4	1.31	99.5	138.8	140.6
42	2000	5	141.7	2.37	99.7	-	-
43	2500	6	141.5	2.79	99.6	-	-
44	2930	6	142.6	1.49	100.4	142.8	143.4
45	2070	5	141.2	1.88	99.4	-	-
46	2450	6	141.5	1.83	99.6	144.5	143.0
47	1940	5	140.1	4.45	98.6	141.8	140.9
48	2180	5	141.2	3.01	99.4	-	-
49	2220	5	139.3	3.02	98.0	-	-
50	2300	5	139.8	3.41	98.4	-	-
51	1120	8	138.9*	3.48	97.7	139.6*	141.4
52	2080	5	143.0	4.03	100.6	145.0	143.6
53	2000	5	141.9	0.74	99.9	-	-
54	2000	5	144.0	2.91	101.3	-	-
55	1085	3	144.8	2.88	101.9	144.8	143.6
56	2050	5	142.6	3.62	100.4	149.2	144.5
57	2000	5	144.6	2.30	101.8	-	-
58	2000	5	142.3	3.01	100.1	-	-
59	2340	5	146.2	2.36	102.9	145.2	141.4
60	2015	5	142.0	2.68	99.9	-	-
61	2000	5	141.8	3.73	99.8	-	-
62	2000	5	142.3	2.20	100.1	-	-
63	1800	5	141.5	1.77	99.6	-	-
64	1060	3	141.3	4.51	99.4	-	-
65	2040	5	143.5	3.11	101.0	142.6	142.6
66	2265	5	144.8	1.91	101.9	-	-
67	2525	6	142.2	2.25	100.1	144.6	141.9
68	1200	5	143.0	3.06	100.6	145.3	142.4
69	1770	5	142.0	3.19	99.9	-	-
70	3005	6	143.9	2.32	101.3	144.0	141.4

* failing tests

TABLE 2 (Continued)

Section No.	Section Length, ft	n	Mean Nuclear Density, pcf	Std. Dev., pcf	% of Target Density	Check Density for "t" test Nuclear	Check Density for "t" test Cores
						pcf	
71	2075	5	144.2	2.58	101.5	-	-
72	1300	4	143.9	2.44	101.3	146.3	142.8
73	1995	5	144.1	4.96	101.4	-	-
74	1000	4	145.1	2.28	102.1	146.4	144.4
75	2000	5	143.3	1.84	100.8	144.8	143.3
76	2000	5	144.3	3.41	101.5	-	-
77	1245	3	145.3	1.98	102.3	147.8	144.7
78	2000	5	145.2	3.72	102.2	143.9	141.2
79	1645	4	144.1	2.31	101.4	146.2	142.0
80	2050	5	143.0	2.84	100.6	-	-
81	1950	5	144.9	1.55	102.0	142.9	141.1
82	1450	5	145.1	1.02	102.1	145.4	143.2
83	2535	6	142.8	1.71	100.5	-	-
Weighted mean			142.7			144.7	142.5
Weighted standard deviation				2.64		2.49	1.25

effects of some of the extraneous variables such as material, compaction procedures, etc., that may cause the difference to be significant when it is not.

The mean of the differences and the standard deviation of the mean differences for the pooled data are given below:

$$\bar{Y} = 0.59$$
$$\sigma(\bar{Y}) = 0.31$$
$$t = 1.91$$
$$t_{05,41} = 2.02$$

Since the calculated t value does not exceed the critical value at the .05 significance level, we accept the hypothesis, pending further data, that there is no difference between the two methods of density determination.

The numerical density values, for both the mixes using the two methods, are summarized in the form of bar chart in Figure 1. The trend is not the same. The average core density is higher than the nuclear check density for binder course mix and lower than the nuclear for the wearing course sections. This difference, however, is much more pronounced for wearing course sections. In fact, the statistical test of significance would lend itself to rejection of the null hypothesis of no difference for this wearing course data. This condition necessitates accumulation of additional data for further evaluation of test methods.

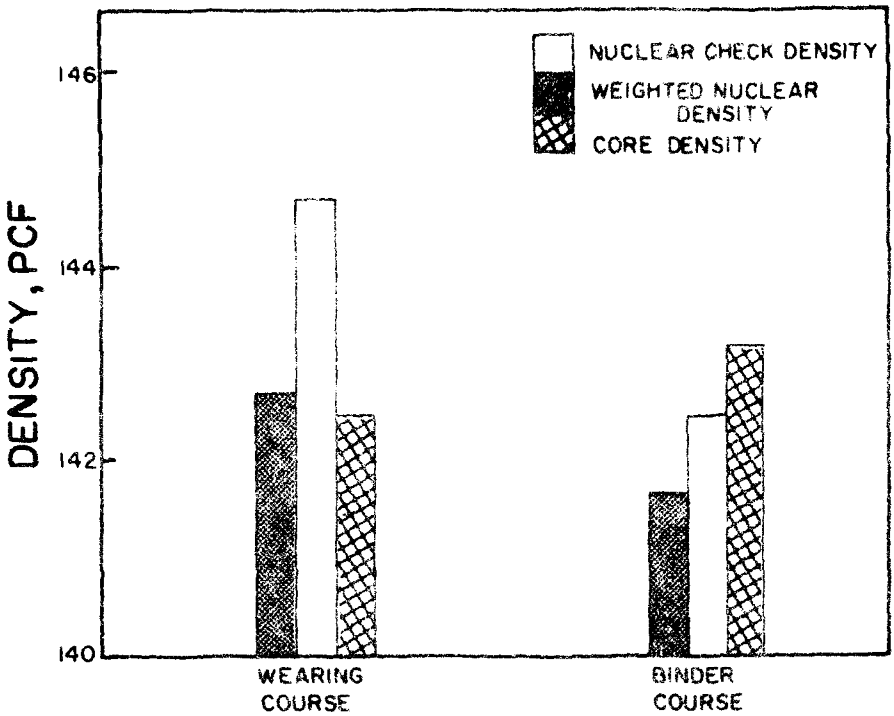

Figure 1
Comparison of Wearing Course and Binder Course Nuclear and Core Densities

The experience gained from the experimental field application of the control strip technique using nuclear equipment can be summed up in the following statements:

1. Ninety-eight percent of the target density seems to be an adequate criteria for compaction control of asphaltic concrete surface courses.

2. The results of the statistical analysis of the pooled data did not indicate any significant difference between the conventional densities and the nuclear densities. This means that the level of compaction obtained by use of the control strip technique using nuclear equipment was as good as that indicated by the conventional procedures.

3. The speed of nuclear testing provided, in addition to increased number of measurements, on-the-spot answers to the level of compaction achieved. This lends itself to better quality control procedures for decision making.

4. The construction of control strip for estimation of the compaction level did not burden the contractor in any manner with additional work, nor did it hamper the rolling activities. On the contrary, the contractor was able to achieve maximum utility from the material and equipment since he was informed of the level of compaction attained after each pass of the roller. This probably outweighs any other point that could be advanced in favor of the conventional procedures.

5. The full extent of the ramifications due to different levels of thickness was difficult to evaluate on this experimental study. It is, nevertheless, believed that the use of the nuclear equipment may have to be limited to some level of thickness. Further evaluation is deemed necessary to check the limitations with respect to the range of thickness and the maximum permissible error for the boundary conditions.

BASE COURSE

Cement Stabilized Soil Base Course

Tables B-1 and B-2 in the Appendix show control strip and target density determinations for soil cement base course construction. A summary of section densities is presented in Table 3. The variation in density within each section is expressed by the standard deviation.

For this experimental study two nuclear devices were used for comparison purposes. Additional information was provided by project engineers' personnel with one of the same nuclear units as used in the experimental study. The three sets of data were not taken at exactly the same test location but in close proximity to each other. The listing of this comparative data is also shown in Table 3. Figure 2 is a graphical representation of the tabled data. From the field experience of this experimental study and from the data presented in Table 3 and Figure 2 the following comments are in order:

1. There is considerable variation in base course density between sections. The reason for this variation becomes obvious if one considers the number of rolled subsections that generally make up a 2000 foot test section. The length of these subsections depend on the length of the cement spread which in turn governs the rolling length.

2. There is no statistical difference between any two mean density determinations at the five percent significance level. This means that the three nuclear devices measured the same population mean and hence, can be used interchangeably.

TABLE 3

SUMMARY OF NUCLEAR DENSITIES AND MOISTURES

(Soil Cement Base Course)

Section No.		Density Data, pcf			Moisture Data, %		
		Experimental		Project Control	Experimental		Project Control
	Nuclear Unit	33	7	7	33	7	7
1	Mean	117.4	115.4	113.8	11.8	11.0	12.4
	Std.Dev.	1.4	3.4	3.0	1.90	0.73	0.77
	% Target	99.7	98.0	96.7	-	-	-
2		116.1	118.0	117.4	9.5	9.2	9.6
		2.7	1.3	1.2	2.21	1.36	1.33
		98.6	100.3	99.7	-	-	-
3		114.4	113.8	113.5	8.6	9.3	9.7
		0.7	0.6	0.8	1.98	1.69	1.77
		97.2	96.6	96.4	-	-	-
4		110.6	111.2	108.4	11.2	10.2	11.5
		5.6	4.2	4.3	1.47	1.22	1.45
		94.0	94.5	92.1	-	-	-
5		116.4	116.1	115.4	8.6	7.7	8.4
		2.5	3.5	3.2	2.22	0.43	0.51
		98.9	98.6	98.0	-	-	-
6		112.7	113.8	113.4	10.3	8.5	8.8
		1.0	3.0	3.0	1.23	0.25	0.29
		95.8	96.7	96.3	-	-	-
7		116.3	114.3	113.4	7.4	8.0	8.7
		5.8	1.5	2.1	0.90	0.65	0.42
		98.8	97.1	96.3	-	-	-
8		112.9	112.3	111.0	8.5	7.7	8.8
		4.4	3.7	3.4	1.93	0.95	1.17
		95.9	95.4	94.3	-	-	-
9		111.9	115.1	114.2	10.5	10.3	9.3
		2.4	2.2	2.9	2.73	1.90	1.93
		95.0	97.8	97.0	-	-	-
Grand mean		114.4	114.5	112.9	9.6	9.2	9.7
Standard deviation		4.1	3.4	3.9	2.26	1.58	1.74
% of target		97.1	97.2	96.3	-	-	-

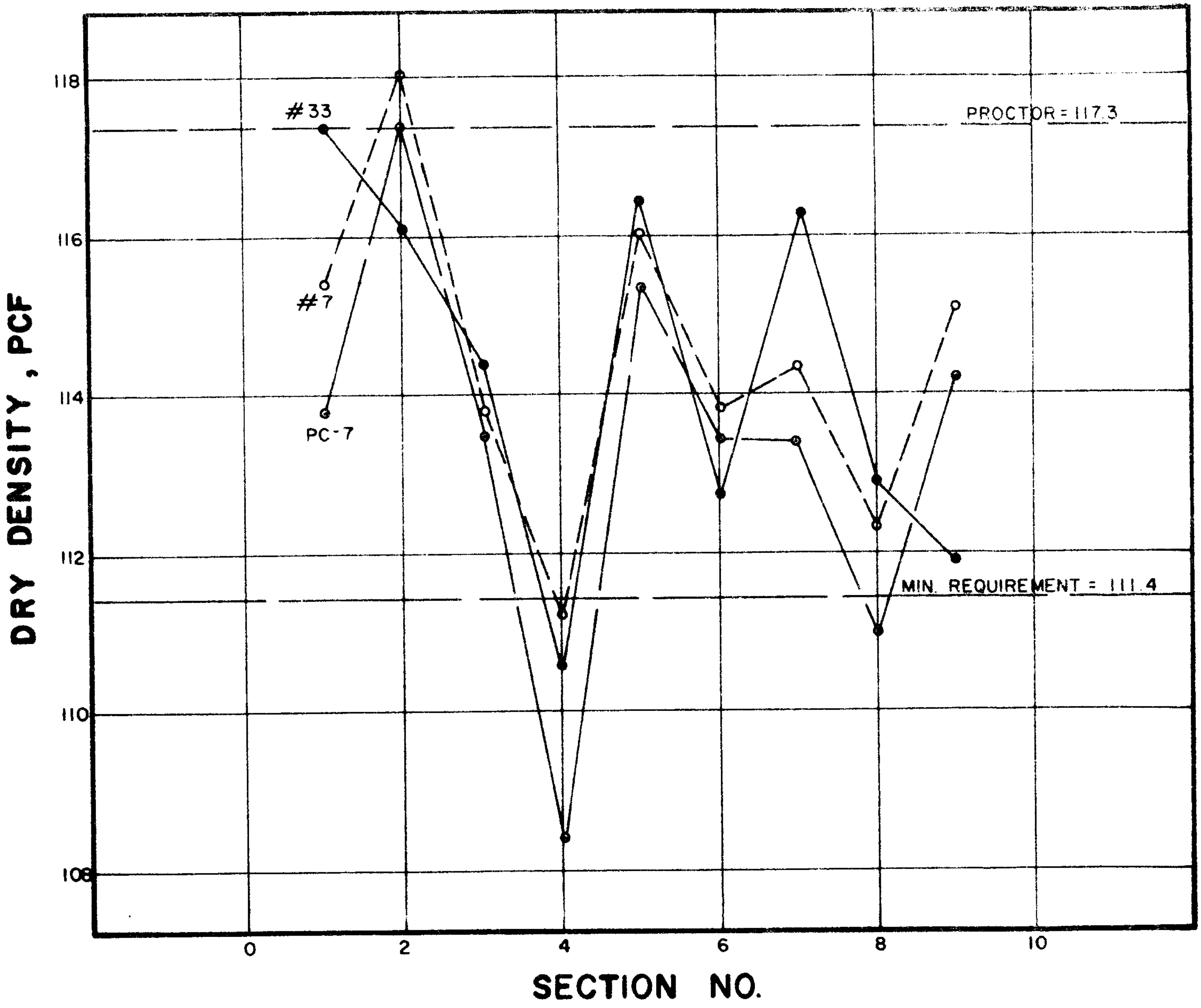

Figure 2
Section Comparison of Soil Cement Densities Using Different Nuclear Equipment

3. The pooled standard deviation of 3.9 pcf is in close agreement to the pooled sigma generally obtained with the conventional method of density determination.[2]

4. Approximately half of the sections have less than 98 percent of the target density. Section 4 shows the lowest for all 3 sets of data. Likewise, this section also fails to meet the minimum requirements for percent of laboratory compaction. Additionally, there is disagreement between the average densities for Section 8 as determined by the three sets of equipment. The equipment (PC-7) used by the project control personnel shows failing section density whereas the other two, No. 33 and No. 7, meets the minimum requirement. These conditions are indicated in Figure 2.

5. The two pieces of equipment used in the study indicate 16 percent of the individual test locations short of the 95 percent of laboratory compaction requirements. Likewise, 30 percent of the project control densities are short of this minimum requirement. The majority of the non-conforming densities were obtained in Sections 4 and 8.

6. The time required for construction of the control strip is about 15 percent longer than for normal routine project control for the same rolling length. Most of the delay was due to inadequate depth for density probe insertion which required additional time for reboring.

7. The magnitude of variation for moisture control data is in close agreement to that obtained using the conventional method of determination.[3]

Cement Stabilized Sand Shell Base Course

Use of this material for base course is strictly confined to south Louisiana. The base course material consisted of a mixture of 65 percent reef shell and 35 percent sand stabilized with eight percent cement by volume. Table C-1 gives pertinent information concerning the experimental control strip. Table C-2 represents target density data for the control strip. Table 4 summarizes section densities for the three nuclear devices used in the study for data acquisition. These measurements were taken in a manner described in the previous section. Figure 3 is a graphical comparison of the 3 sets of density data.

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(2) S. C. Shah, "Quality Control Analysis, Part II, Sand and Aggregate Course," Louisiana Department of Highways, Research Project No. 23, July 1966.

(3) Ibid, p. 37.

SUMMARY OF NUCLEAR DENSITIES AND MOISTURES

(Stabilized Sand Shell Base Course)

Section No.		Density Data, pcf			Moisture Data, %		
		Experimental		Project Control	Experimental		Project Control
	Nuclear Unit	8	7	7	8	7	7
1	Mean	-	127.6	125.3	-	7.9	8.3
	Std.Dev.	-	3.1	0.6	-	0.91	0.92
	% Target	-	100.9	99.1	-	-	-
2		127.3	128.4	126.8	8.8	8.9	9.2
		3.1	3.2	3.4	0.77	1.03	0.89
		100.7	101.6	100.3	-	-	-
3		126.1	125.6	124.4	7.3	7.2	7.3
		2.0	1.5	1.0	1.13	0.98	0.94
		99.8	99.4	98.4	-	-	-
4		122.8	126.1	125.1	8.5	7.8	8.0
		3.3	1.1	0.5	1.12	0.79	0.71
		97.2	99.8	99.0	-	-	-
5		123.9	125.3	124.6	7.5	7.5	7.8
		1.5	0.8	0.3	1.06	0.35	0.28
		98.0	99.1	98.6	-	-	-
6		126.6	126.9	127.6	8.5	8.4	8.9
		1.8	2.4	2.4	0.46	0.64	0.00
		100.2	100.4	100.9	-	-	-
7		125.8	126.6	126.8	7.6	7.4	7.4
		2.7	1.7	2.1	0.78	0.74	0.68
		99.5	100.2	100.3	-	-	-
8		126.2	125.4	124.6	6.9	7.4	7.8
		2.4	0.1	0.2	0.59	0.07	0.21
		99.8	99.2	98.6	-	-	-
9		125.2	126.2	126.0	9.2	8.7	8.1
		2.4	1.7	2.3	0.90	0.62	0.60
		99.1	99.8	99.7	-	-	-
10		122.8	125.7	125.6	8.7	7.0	7.0
		4.6	1.1	1.4	0.86	0.79	1.13
		97.2	99.4	99.4	-	-	-
11		124.2	125.5	125.1	8.5	8.1	8.5
		4.2	1.5	1.2	1.25	0.81	0.81
		98.3	99.3	99.0	-	-	-
Grand mean		125.2	126.4	125.6	8.2	7.9	8.1
Standard deviation		3.1	2.4	1.8	1.09	0.94	0.94
% of target		99.0	100.0	99.4	-	-	-

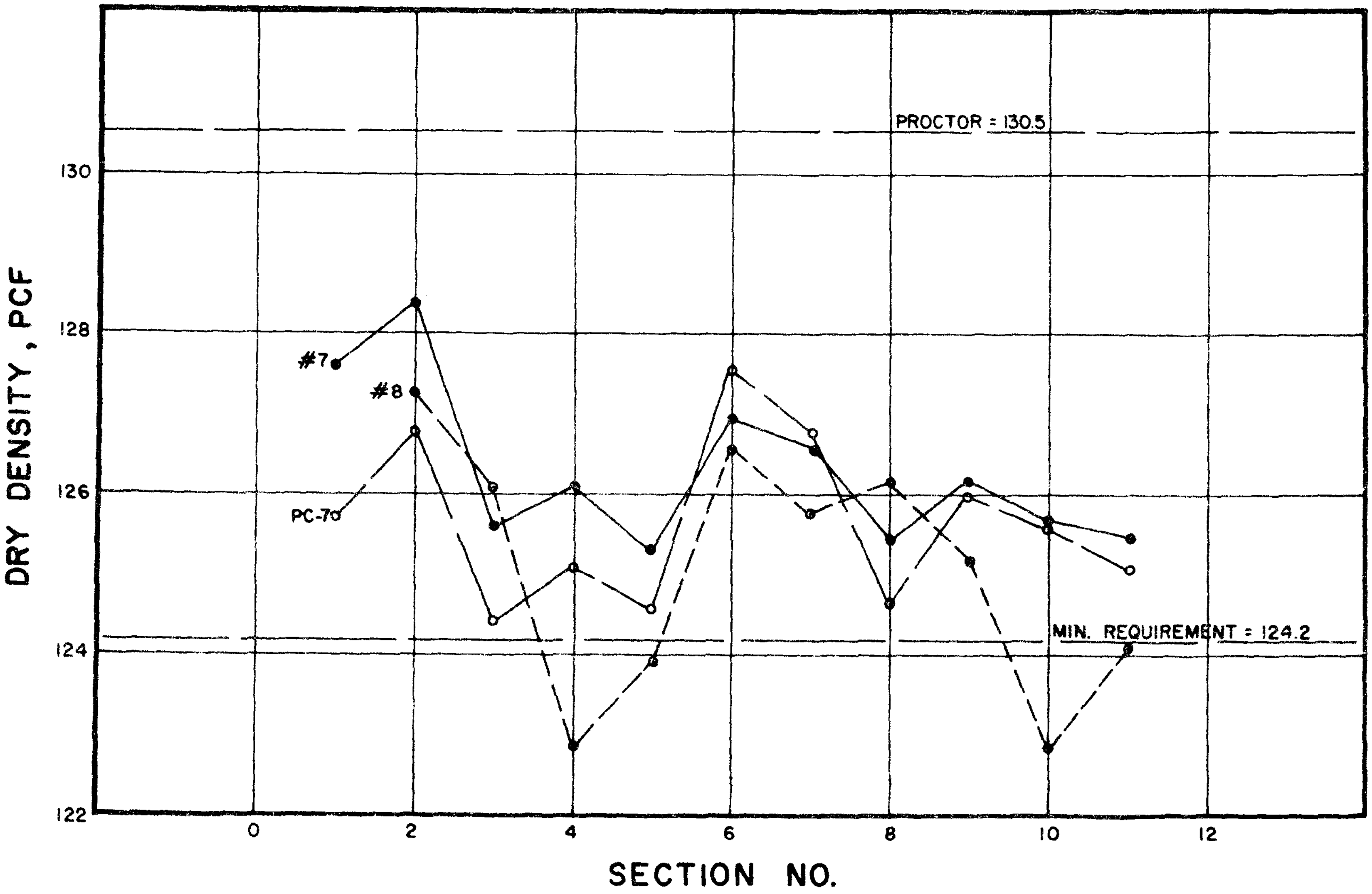

Figure 3
Section Comparison of Cement Stabilized Sand Shell Densities Using Different Nuclear Equipment

Once again, there is considerable variation in the level of compaction from section to section. This is indicated by the standard deviations in Table 4. The average level of compaction as measured by the 3 devices is better than 99 percent of the target density. Furthermore, 3 sections (4, 5 and 10) fail to meet the minimum criteria of 95 percent of the laboratory compaction. However, all these failing values are indicated by nuclear equipment No. 8.

The distribution of individual results are as follows:

1. For equipment No. 7 MB, three tests or six percent of the densities failed to meet the minimum requirements of 124.2 or 95 percent of the laboratory requirement.

2. For equipment 8MB, 14 locations or 29 percent failed to meet the required level of compaction.

3. Twelve percent of the density measurements obtained by the project engineers' personnel indicated failing test values.

The overall variability for this project was much less than that obtained on the projects using conventional method of density determination.[4]

Sand Clay Gravel Base Course

Tables D-1 and D-2 in the Appendix show pertinent data on density and moisture content acquired during the control strip construction. Table 5 summarizes section densities and moistures. On the basis of these data it is possible to make the following comments:

1. The variation in the level of compaction from one section to the other was not quite as pronounced as was observed for cement stabilized base courses. This is because the entire 2000 foot section was rolled in single effort rather than in small segments (400 feet±) as was necessary for cement stabilized base courses. The control strip technique is ideally suited for these aggregate bases where few interruptions are encountered because of rolling pattern.

[4] Ibid, p. 35.

TABLE 5

SUMMARY OF NUCLEAR DENSITIES AND MOISTURES

(Sand Clay Gravel Base Course)

Section No.		Density pcf	Moisture %
1	Mean	141.7	5.3
	Std. Dev.	2.2	0.10
	% Target	102.2	-
2		137.0	6.9
		2.7	1.07
		98.8	-
3		132.0	7.4
		2.2	1.79
		95.2	-
4		138.4	4.9
		2.8	0.42
		99.9	-
5		138.2	5.4
		1.3	0.18
		99.7	-
6		136.3	6.8
		2.9	1.21
		98.3	-
7		134.2	7.9
		0.5	0.31
		96.8	-
8		134.8	8.3
		2.2	1.67
		97.3	-
9		134.6	7.6
		1.1	0.47
		97.1	-
Grand mean		136.4	6.69
Standard deviation		1.99	0.80
% of target		98.4	

2. Only one test section failed to meet the current minimum requirement of 100 percent of the laboratory density. Three of the five test locations in this section had failing density values.

3. The overall variability for this project was 50 percent of that observed on the same type of base course construction obtained previously by conventional methods.[5]

[5] Ibid, p. 35.

V - QUALITY CONTROL REQUIREMENTS

The concept of "control strip" and the data previously discussed raises several questions that used to be resolved before routine field application can be considered. Questions such as length of the "control strip" and test section, disposition of the failing test value, etc., can be answered by using engineering judgment. However, questions pertaining to number of measurements, replications, and limits to be applied to the mean and individual measurements can best be answered through use of statistical tools. This section attempts to answer these and other pertinent questions for quality assurance and acceptance sampling using engineering judgment and statistical quality control procedures.

1. Length of the "Control Strip"

   Judgment will govern the selection of the optimum length. It should be of sufficient length to include representative material and yet not necessitate any additional work by the contractor. Accordingly, 300-500 feet of single lane should prove adequate for determination of the optimum rolling pattern for compaction.

2. Number of test locations in the "Control Strip"

   Statistically, the number of test locations should be five (5).

3. Number of test locations for target value determination

   Use ten (10) random locations. The means of these ten should be used for disposition of subsequent construction.

4. Length of each test section (lot size)

   Lots can be formed on the basis of quantity or linear measurement. It is suggested that the lot size be confined to a single day's production.

5. Number of tests in a test section

   Same as for control strip, five.

6. Requirements for compaction conformance

   The decision for acceptance, rejection or any other disposition of the lot should be based on the mean of the number of test determinations in a lot. However, to safeguard against any localized low compaction areas, a lower limit may be specified for individual test locations. The following limits are presented as guidelines for initial field application. All the requirements are minimum requirements based on percent of target value.

Material Type	Lot Mean	Lot Individual
HMAC surface course	98	95
Cement stabilized base course		
1. Soil	97	94
2. Sand clay gravel	*	*
3. Sand shell	97	94
Raw aggregate base course		
1. Sand clay gravel	98	95
2. Sand shell	*	*

VI - SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The preceding sections attempted to present the analysis and evaluation of data collected and the field experience gained during the compaction control of certain base and surface courses using the "control strip" technique and nuclear devices. Whenever and wherever appropriate, the results of the analysis were presented in the form of comments and conclusions. This section is intended to summarize those considered the most important.

1. The control strip technique using nuclear devices offers a very flexible approach to the compaction control of base and asphaltic concrete surface courses in Louisiana's highway construction.

2. The speed of nuclear testing provides, in addition to increased number of measurements, on-the-spot answers to the level of compaction achieved. This lends itself to better quality control procedures for decision making.

3. The variability of data using these procedures is normally within the magnitude of variation generally encountered with the conventional methods of density determinations. However, comparison of the variability for different base materials indicate this variability in compaction level to be the largest for cement stabilized soil base course and the least for unstabilized (sand clay gravel) base.

4. As with any new procedures, a certain level of competence will be required of the operator during the initial phase of control strip density determinations.

5. Its advantages of speed, better quality control procedures for decision making and economy warrant immediate consideration for field trial of this procedure for compaction control of a few selected base and asphaltic concrete surface courses. The quality control requirements presented in the previous chapter can be used as guidelines on these initial field trials.

APPENDIX

TABLE A-1

ROLLER PATTERN FOR ASPHALTIC CONCRETE BINDER COURSE CONTROL STRIP

Date: 4-15-70 | Project No.: 50-07-28

Control Strip No.: 1 | Station 112+00 to 119+80

Type of Material: Asphaltic Concrete (sand-gravel mix) | Thickness: 2 inch

Test No.	Station	Roller Sequence	Optimum Passes	Density Count		Density pcf
				BS*	AG**	
1	112+00	3-Wheel	6	234	484	141.0
		Pneumatic	7	232	485	142.5
		Tandem	3	232	486	143.5
2	114+00	3-Wheel	4	230	484	143.5
		Pneumatic	7	233	485	142.0
		Tandem	3	229	486	144.8
3	119+00	3-Wheel	6	236	484	139.8
		Pneumatic	7	236	485	140.3
		Tandem	4	231	486	143.3

TABLE A-2

ESTIMATION OF CONTROL STRIP DENSITY (TARGET DENSITY)

(Binder Course Mix)

Test No.	Station	Nuclear Count		Density pcf
		AG*	BS**	
1	111+50	487	225	147.5
2	111+10	485	230	143.8
3	111+92	485	226	146.2
4	113+40	484	237	139.0
5	113+05	480	231	141.8
6	112+95	484	232	142.2
7	114+00	484	227	145.2
8	119+80	484	231	143.0
9	119+40	484	226	146.0
10	119+00	482	227	144.8
Total				1439.5
Mean				144.0
Standard deviation				2.5
% of Control strip density				100.1
% of Marshall briquet density				97.8

* Back Scatter

** Air Gap

TABLE A-3

ROLLER PATTERN FOR ASPHALTIC CONCRETE WEARING COURSE CONTROL STRIP

Date: 5-15-70 | Project No.: 50-07-28

Control Strip No.: 1 | Station 196+30 to 199+30

Type of Material: Asphaltic Concrete (Sand-gravel mix) | Thickness: 1 1/2 inch

Test No.	Station	Roller Sequence	Optimum Passes	Density Count		Density pcf
				BS*	AG**	
1	196+80	Tandem	6	117	243	141.7
		Pneumatic	8	116	243	143.3
		Tandem	2	115	243	144.5
2	197+10	Tandem	6	117	243	141.7
		Pneumatic	8	116	243	143.3
		Tandem	2	116	243	143.3
3	198+30	Tandem	6	116	243	143.3
		Pneumatic	8	116	243	143.3
		Tandem	2	114	243	145.2
Mean density of tests 1, 2 and 3 = 155.3 pcf						

* Back Scatter
** Air Gap

TABLE A-4

ESTIMATION OF CONTROL STRIP DENSITY (TARGET DENSITY)

(Wearing Course Mix)

Test No.	Station	Nuclear Count		Density pcf
		AG*	BS**	
1	196+50	242	118	139.8
2	196+95	243	117	141.8
3	197+25	243	115	144.0
4	197+60	241	117	140.5
5	198+10	240	116	141.3
6	198+30	240	114	143.5
7	198+50	242	114	144.8
8	198+80	244	115	144.8
9	199+50	242	120	137.5
10	199+90	244	116	143.5
Total				1421.4
Mean				142.1
Standard deviation				2.40
% of Control strip density				98.5
% of Marshall briquet density				97.4

* Air Gap
** Back Scatter

TABLE B-1

ROLLER PATTERN FOR SOIL CEMENT BASE COURSE
CONTROL STRIP

Date: 6-12-70 | Project No.: 28-02-13

Control Strip No.: 1 | Station 159+00 to 162+00

Type of Material: Soil Cement | Width: 24' Thickness: 8 inch

Test No.	Station	Roller Sequence	Optimum Passes	Density Count		Moisture Count	
				Std.	Actual	Std.	Actual
1	161+45	Initial (Sheep's foot)	15	165	129	174	109
		Final (Pneum.)	8	165	104	174	-
Wet density and weight of water				132.0 pcf			12.3 pcf
Dry density and moisture				119.7 pcf			10.3%
2	161+65	Initial (Sheep's foot)	15	165	125	174	110
		Final (Pneum.)	8	165	110	174	-
Wet density and weight of water				128.5 pcf			12.4 pcf
Dry density and moisture				116.1 pcf			10.7 %
3	161+85	Initial (Sheep's foot)	15	165	126	174	103
		Final (Pneum.)	8	165	111	174	-
Wet density and weight of water				128.0 pcf			11.3 pcf
Dry density and moisture				116.7 pcf			9.7 %
Mean dry density of tests 1, 2 and 3				=	117.5 pcf		
Mean moisture content of tests 1, 2 and 3				=	10.2%		

TABLE B-2

ESTIMATION OF CONTROL STRIP DENSITY (TARGET DENSITY)

(Soil Cement Base Course)

Test No.	Station	Nuclear Count Density	Nuclear Count Moisture	Dry Density pcf	Moisture %
1	161+03 Rt. c/L	392	552	121.0	10.9
2	160+80 c/L	432	497	117.6	9.4
3	160+68 Lt. c/L	409	527	119.6	10.2
4	160+52 Lt. c/L	442	512	115.9	10.0
5	160+43 Rt. c/L	408	595	117.3	12.5
6	160+21 Lt. c/L	446	494	116.2	9.4
7	160+05 Rt. c/L	447	464	117.2	8.4
8	159+84 Lt. c/L	454	494	115.1	9.6
9	159+75 Lt. c/L	393	543	121.2	10.6
10	159+30 Rt. c/L	425	461	119.8	8.2
Total		4248	5139		
Mean		425	514		
Standard Count		657	689		
Count Ratio		64.7	74.6		
Wet Density, pcf		129.6			
Moisture, pcf			11.9		
Dry density, pcf				117.7	
Standard deviation of 10 densities				1.25	
Moisture content, %					10.1
Standard deviation of 10 moisture contents					2.2

Percent of control strip density = 100.1

Percent of mean Proctor density = 100.3

TABLE C-1

ROLLER PATTERN FOR CEMENT STABILIZED SAND SHELL BASE COURSE CONTROL STRIP

Date: 8-25-69 Project No.: 24-01-21

Control Strip No.: 1 Station 259+50 to 262+50

Type of Material: Cement Stabilized Shell Width: 22' Thickness: 6 inch

Test No.	Station	Roller Sequence	Optimum Passes	Density Count		Moisture Count	
				Std.	Actual	Std.	Actual
1	262+40	Initial	9	117619	56435	11445	8452
Set #8		Final (Pneum.)	10	117619	52354	11445	8459
Wet density and weight of water				142.5 pcf			11.7 pcf
Dry density and moisture				130.8 pcf			8.9 %
2	261+50	Initial	6	117290	75199	11312	7848
Set #7		Final (Pneum.)	11	117290	62133	11312	8486
Wet density and weight of water				143.3 pcf			12.4 pcf
Dry density and moisture				130.9 pcf			9.5 %
3	259+55	Initial	10	117619	54036	11445	
Set #8		Final (Pneum.)	18	117619	52496	11445	
Wet density and weight of water				142.4 pcf			12.0 pcf
Dry density and moisture				130.4 pcf			9.2 %
Mean dry density of tests 1, 2 and 3 = 130.7 pcf							
Mean moisture content of tests 1, 2 and 3 = 9.2%							

TABLE C-2

ESTIMATION OF CONTROL STRIP DENSITY (TARGET DENSITY)

(Cement Stabilized Sand Shell Base Course)

Test No.	Station	Nuclear Count		Dry Density	Moisture
		Density	Moisture	pcf	%
1	262+50 Lt. c/L	63679	8359	129.6	9.1
2	262+20 Rt. c/L	65136	8376	128.2	9.2
3	261+90 Lt. c/L	66086	8243	127.7	8.8
4	261+60 c/L	66538	8289	127.2	8.9
5	261+30 Lt. c/L	68255	8300	124.9	9.0
6	261+00 Lt. c/L	67224	8187	127.0	8.5
7	260+70 c/L	67458	8481	125.1	9.9
8	260+40 Rt. c/L	64885	8266	128.8	8.8
9	260+10 Lt. c/L	72801	8216	120.4	9.1
10	259+65 Rt. c/L	66125	8192	128.1	8.4
Total		671185	82909		
Mean		67119	8291		
Standard Count		117290	11312		
Count Ratio		57.2	73.3		
Wet Density, pcf		137.8			
Moisture, pcf			11.4		
Dry density, pcf				126.4	
Standard deviation of 10 densities				2.7	
Moisture content, %					9.1
Standard deviation of 10 moisture contents					0.42

Percent of control strip density = 96.1

Percent of mean Proctor density = 96.2

TABLE D-1

ROLLER PATTERN FOR SAND CLAY GRAVEL BASE COURSE CONTROL STRIP

Date: 4-5-71

Project No.: 126-02-09

Control Strip No.: 1

Station 308+50 to 314+50

Type of Material: Sand Clay Gravel

Width: 22' Thickness: 8 inch

Test No.	Station	Roller Sequence	Optimum Passes	Density Count		Moisture Count	
				Std.	Actual	Std.	Actual
1	311+00	Initial (Sheep's foot)	10	645	432	706	396
		Final (Pneum.)	7	645	364	706	416
Wet density and weight of water				144.6 pcf		7.3 pcf	
Dry density and moisture				137.3 pcf		5.3 %	
2	311+35	Initial (Sheep's foot)	10	645	388	706	440
		Final (Pneum.)	7	645	368	706	428
Wet density and weight of water				143.9 pcf		7.7 pcf	
Dry density and moisture				136.2 pcf		5.7 %	
3	311+75	Initial (Sheep's foot)	10	645	348	706	432
		Final (Pneum.)	7	645	348	706	428
Wet density and weight of water				147.0 pcf		7.7 pcf	
Dry density and moisture				139.3 pcf		5.5 %	
Mean dry density of tests 1, 2 and 3 = 137.6 pcf							
Mean moisture content of tests 1, 2 and 3 = 5.5 %							

TABLE D-2

ESTIMATION OF CONTROL STRIP DENSITY (TARGET DENSITY)

(Sand Clay Gravel Base Course)

Test No.	Station	Nuclear Count		Dry Density	Moisture
		Density	Moisture	pcf	%
1	310+00 c/L	356	424	138.3	5.5
2	310+50 c/L	375	398	136.3	4.8
3	311+00 Rt. c/L	368	414	136.6	5.3
4	311+35 c/L	365	429	136.8	5.7
5	311+75 c/L	343	429	140.2	5.5
6	312+50 Lt. c/L	359	419	138.0	5.3
7	312+50 Rt. c/L	347	469	138.1	6.7
8	313+65 Lt. c/L	348	406	140.2	4.9
9	314+00 c/L	317	414	144.8	5.0
10	314+50 Rt. c/L	356	464	136.8	6.6
Total		3534	4266		
Mean		353.4	426.6		
Standard Count		645	706		
Count Ratio		54.7	60.4		
Wet density, pcf		146.2			
Moisture, pcf			7.6		
Dry density, pcf				138.6	
Standard deviation of 10 densities				2.6	
Moisture content, %					5.5
Standard deviation of 10 moisture contents					0.65

Percent of control strip density = 100.7

Percent of mean Proctor density = 103.8