JOINT HIGHWAY RESEARCH PROJECT

JHRP-78-9

FIELD EVALUATION OF A NUCLEAR DENSITY GAUGE FOR EVALUATING CONCRETE CONSOLIDATION

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Final Report

FIELD EVALUATION OF A NUCLEAR DENSITY GAUGE FOR EVALUATING CONCRETE CONSOLIDATION

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

June 1, 1978
Revised June 1979
Project: C-36-67G

File: 9-11-7

Attached is the Final Report on Phase II of the HPR Part II Research Study titled "Compaction of Concrete By Internal Vibration". The Report is titled "Field Evaluation of a Nuclear Density Gauge for Evaluating Concrete Consolidation". The research has been authored by Charles F. Scholer and Wayne P. Schumm of our staff. Dr. Scholer served as principal investigator of the research.

This Phase of the Project was considerably different from the first phase and as a result the Final Report does not review Phase I findings. The Final Report on Phase I stands by itself as a complete report of that phase.

The basic finding of the research is that nuclear density meters can be used to evaluate the density of fresh concrete if the probe and meter are protected from fouling in fresh concrete and if done on a comparison basis with results from concrete of known adequate consolidation.

The nuclear density gauge used in the evaluation was the same model as commonly used by the Indiana State Highway Commission, with the exception of having a different radio active source. This source was more stable hence desirable for research applications, but otherwise it performs in a similar fashion to those found on many construction sites in Indiana.

The Report is submitted for review, comment and acceptance as fulfillment of the objectives of Phase II of the project.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

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Final Report

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Project No.: C-36-67G
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Conducted by

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16. Abstract

A field evaluation of a nuclear density meter, using the direct transmission method, to evaluate the consolidation of fresh concrete on highway paving, was the primary effort of this investigation.

Prior to field testing the equipment was evaluated in the laboratory with dry sand and various arrangements of reinforcing steel and/or dowel bars. This was extended into the field where pavement reinforcing was not found to affect results. A technique was developed for evaluating concrete in areas of heavy doweled joints.

Field evaluation was done on actual paving projects, and as a result, little variation was possible on quality of mixes and amount of consolidation. The results of the field tests were within a close range. This probably was a reflection on the quality of the concrete paving operations.

A major problem to the use of this technique is fresh concrete adhering to the nuclear probe. It is not safe, due to the radiation danger, to clean the probe frequently. If this is not done the mechanical operation of the probe will soon fail to operate properly.

If the technique is to be used in the field it is recommended that a plastic tube and tray be used to protect both the probe and meter from the fresh concrete. This technique introduced more error. Nevertheless, it is recommended as a useful method of evaluating the density of concrete while it is still in a plastic condition.

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INTRODUCTION

Concrete vibrators have been used for many years in the placement of highway pavement. The first phase of this project was an investigation of the factors influencing the consolidation of concrete by vibration as used in highway pavements*. This showed that adequate consolidation was not always achieved. The principal reason for poor consolidation when a pavement vibrator was operating properly was that the concrete was not sufficiently flowable under vibration. Generally this would be described as too low a slump. Under these, or marginal conditions, the existence of reinforcing steel will appreciably reduce the consolidation of concrete beneath the reinforcing steel.

The consolidation of concrete is a process whereby the void spaces between aggregate particles are reduced. In so doing, the particles of the aggregate are packed more closely together increasing the density of the concrete. The usual goal is to approach the maximum potential density of the plastic concrete by proper vibration and thereby approach its maximum compressive strength. Due to the lack of an effective method of field inspection, engineers and contractors throughout the country have suggested that pavements are not getting optimum consolidation. Many field problems such as cold joints, honeycombing and early deterioration of pavement have been attributed to poor consolidation caused by inadequate vibration.

At the completion of Phase I of this project it was apparent that the field investigation contemplated in the original proposal was not

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* Laboratory Evaluation of the Response of Reinforced Concrete to Internal Vibration, JHRP No. 28, December 1973, by O. T. Olateju

technically feasible. The problem of field consolidation of concrete still remained and the recommendation was made by the projects advisory committee that a nuclear density gauge be evaluated as Phase II.

Great success has been received with the use of nuclear density gauges to determine the density of highway pavement subbases. Today, nuclear density gauges are used by most state highway departments for standard compaction tests. It would be ideal to use these nuclear density gauges, which are already being used on the construction site, for an accurate measurement of the density of the plastic concrete and correlate this measurement to the consolidation of the concrete. When such a concrete pavement was measured and found to be deficient in density, the concrete would still be in a condition such that remedial action could be taken.

This was not a new idea for others have shown it to be possible but more field evaluation of its practical application was desirable.

The objectives of this study were to determine the feasibility of using nuclear density gauges in plastic concrete for inspection. Other objectives of this report are to investigate the consolidation of plastic concrete around dowel bars at contraction joints and to compare consolidation above and below reinforcement steel.

This report starts with the description of the nuclear density gauge, proceeding to the working characteristics of the gauge investigated in silica sand and to the use of the nuclear gauge in plastic concrete. Further discussion is given to the data received from the use of the gauge on new pavement and the feasibility of the nuclear gauge as an actual procedure for the inspection of highway concrete pavement.

DESCRIPTION OF THE NUCLEAR GAUGE

During the recent years, state highway inspectors have used nuclear density gauges to measure the density and moisture content of subbases after the material has been compacted. Because the Indiana State Highway Commission was familiar with the equipment produced by Troxler Laboratories in Raleigh, North Carolina, the Troxler, Model 2401, Surface Moisture Density Gauge was chosen to be used in the field experiments.

The Troxler nuclear gauge is specifically designed to measure the density and moisture content of soils and soil-stone aggregates. It may also be used to measure the density of hot asphalt while the mix is still being compacted.

The 2401 nuclear gauge utilizes compton scattering and photoelectric absorption of gamma protons to measure the total or wet density of materials being tested. The instrument has two methods of measuring densities, the backscatter method and the direct transmission method (see figure 1). The simplest, but least accurate, method of measuring density involves the so-called backscatter method. To make this measurement the source and detectors are both on the surface and gamma photons passing into the material are scattered back to the detectors. This method is widely used by state highway commissions for the inspection of compacted soils. Because the backscatter method's measurements are largely influenced by the upper portion of the layer being evaluated and the reinforcing steel in the concrete pavement greatly affects the accuracy of the density reading, the direct transmission method was chosen for the density measurements of the plastic concrete.

Table 1. CALIBRATION CHART

MODEL - 2401 SER. - 3146 STD. SER. - 3146

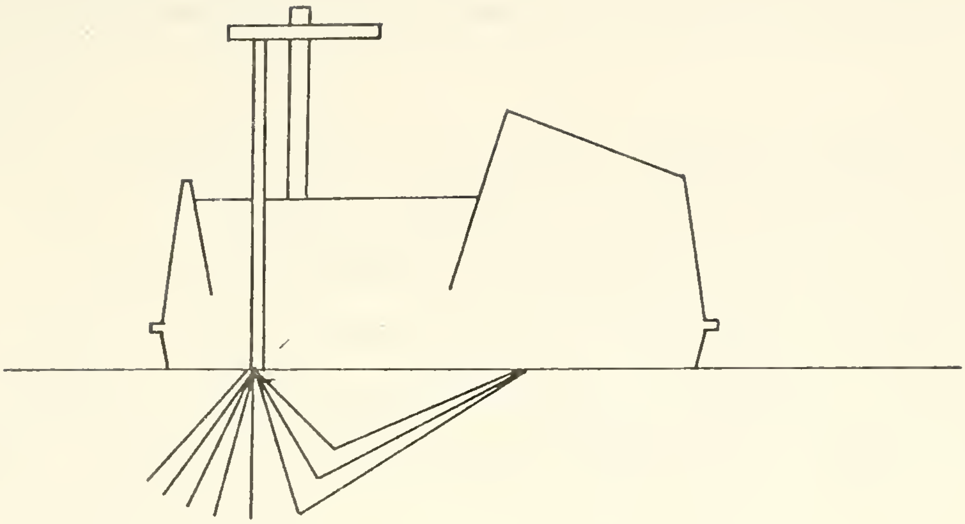
10.0 INCH DIRECT TRANSMISSION

CR IS MEASUREMENT COUNT/STANDARD COUNT

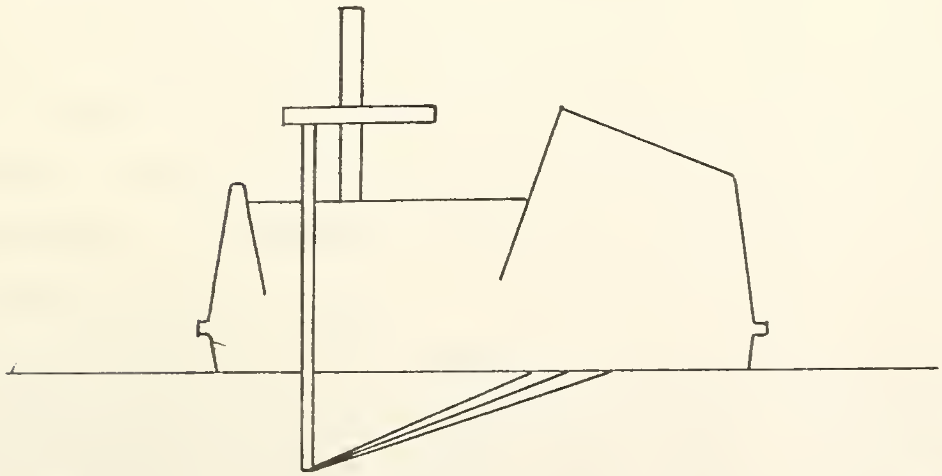
CR	DEN	CR	DEN	CR	DEN	CR	DEN
2.472	71.0	1.273	96.0	0.652	121.0	0.330	146.0
2.439	71.5	1.256	96.5	0.643	121.5	0.325	146.5
2.407	72.0	1.239	97.0	0.634	122.0	0.321	147.0
2.376	72.5	1.223	97.5	0.626	122.5	0.316	147.5
2.344	73.0	1.207	98.0	0.617	123.0	0.312	148.0
2.313	73.5	1.191	98.5	0.609	123.5	0.308	148.5
2.283	74.0	1.175	99.0	0.601	124.0	0.304	149.0
2.253	74.5	1.159	99.5	0.593	124.5	0.299	149.5
2.223	75.0	1.144	100.0	0.585	125.0	0.295	150.0
2.194	75.5	1.129	100.5	0.577	125.5	0.291	150.5
2.165	76.0	1.114	101.0	0.569	126.0	0.287	151.0
2.137	76.5	1.099	101.5	0.562	126.5	0.283	151.5
2.109	77.0	1.085	102.0	0.554	127.0	0.279	152.0
2.081	77.5	1.070	102.5	0.547	127.5	0.275	152.5
2.053	78.0	1.056	103.0	0.539	128.0	-.272	153.0
2.026	78.5	1.042	103.5	0.532	128.5	0.268	153.5
2.000	79.0	1.028	104.0	0.525	129.0	-.264	154.0
1.973	79.5	1.015	104.5	0.518	129.5	0.260	154.5

The direct transmission method, the more accurate method in terms of precision and composition error, involves placing the source at a precise depth in the measured material and the detection system on the surface. By using the direct transmission method and a little care in locating the instrument for readings, the affect of the reinforcement steel in the highway pavement can be eliminated. A further advantage of the direct transmission method with the source in the concrete is the accurately-defined depth of measurement. By making density measurements at various depths a profile of density may be approximated by calculation. This could be useful in determining the density of the concrete above and below reinforcement steel. Also, surface roughness errors are greatly reduced in the direct method, since the surface void volume is averaged into the much larger measured volume.

To measure the density of a given material by the direct transmission method, the operator takes and records a density count at the desired depth. The operator then obtains the ratio to the standard count and uses the correct data table to obtain the density. A typical direct transmission calibration chart supplied by the manufactor is shown in Table 1. The gauge calibration data has been ratioed to standard moisture and density counts made at the factory on the reference standard supplied with the nuclear gauge. A set of standard counts were taken at least twice every day the gauge was being used in the field experiments.



BACKSCATTER METHOD



DIRECT TRANSMISSION METHOD

FIGURE 1

LABORATORY TESTS

To help find the exact operating characterics of the nuclear gauge, tests were performed in dry silica sand. This sand was selected over other materials because of its constant and uniform density and its workability.

Tests were conducted in a 20 in. x 18 in. steel box containing 10 inches of sand. Initial test showed that the steel of the box had no effect on the density measurements of the sand using the direct transmission method. To prove this, the density of the sand was measured with the gauge at random points and depths in the steel box as shown in table 2. The manufacture of the gauge suggests 1 to 2 percent accuracy range of the nuclear gauge.

When the nuclear gauge was used in the field, all tests were performed in a manner an inspector on the construction site would possibly follow. Consideration was given to the problem of keeping the gauge free of fresh concrete, externally and internally. After experimenting with a number of materials (plywood, fiberglas) a sheet metal tray was determined to have the least affect on the accuracy of the measurement of the density of the material and allowed the readings to be well within the 2 percent accuracy range.

The most commonly used reinforcement steel used today by the Indiana State Highway Commission is steel gage #5 wire mesh. This gage of reinforcement steel was encountered in all the steel reinforced concrete pavement tested with the nuclear gauge. Tests conducted with the #5 wire mesh in the sand at a depth of 3 inches produced a difference of densities recorded at the 4 inch depth. These measurements were within

Table 2. Nuclear Gauge Measurements in Silica Sand

Depth	Plain Sand		Metal Tray		Wire Mesh	
	Average (lbs/cu.ft)	Standard Deviation	Average (lbs/cu.ft)	Standard Deviation	Average (lbs/cu.ft)	Standard Deviation
2	99.27	1.80	100.96	.97	99.60	1.22
4	99.94	1.50	100.88	.47	100.51	.89
6	99.79	1.42	100.70	.88	99.89	.89
8	99.86	1.03	101.14	.83	99.64	.89
10	100.11	1.17	101.40	.66	-	-

0.6 percent of the average densities recorded without the wire mesh and well within the 2 percent accuracy range of the instrument.

One objective of using the nuclear gauge on plastic concrete was to determine the difference in consolidation, if any, around the steel dowel bars at construction joints and the consolidation of concrete between the joints. By using a typical 1 inch diameter steel dowel bar in the sand, the effect of the steel bar and the correct positioning of the nuclear gauge near the steel dowel bar to avoid this effect was determined. The area of the material measured and the path of the gamma protons are shown in Figure 2. The position of the nuclear gauge to avoid the steel dowel bar is also shown. The help of this information was very useful in the field tests conducted near the contraction joints.

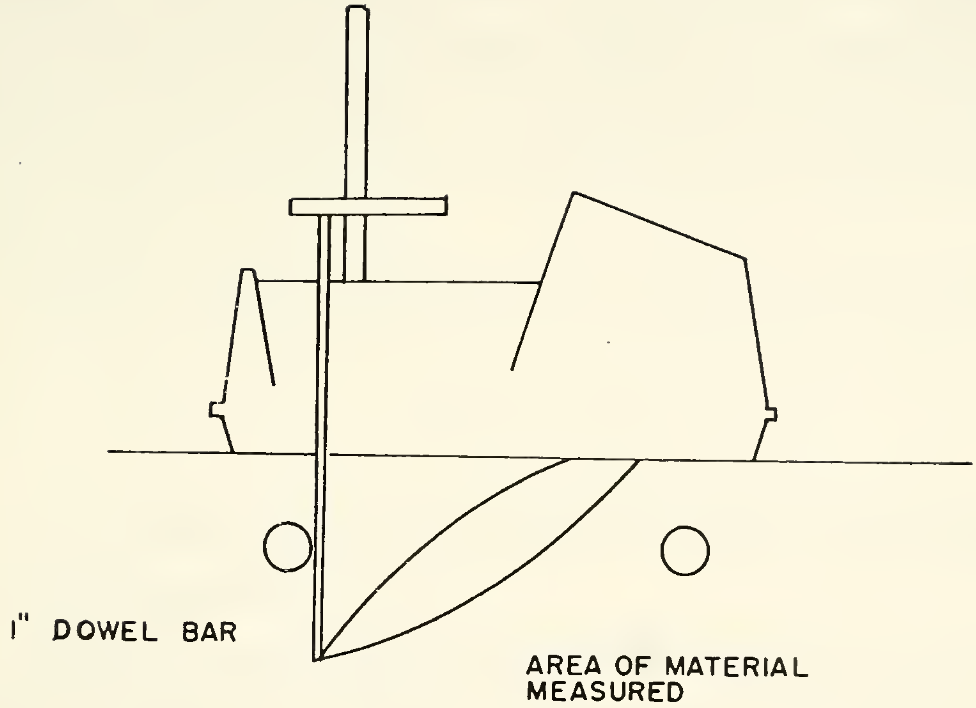


FIGURE 2 – POSITIONING OF NUCLEAR GAUGE

COLLECTION OF FIELD DATA

Four paving projects were selected in cooperation with the Indiana State Highway Commission, with each project performed by a different contractor. The projects were chosen on the basis of their geographic locations in the state and the paving schedules of the contractor. Different construction methods and pavement designs were desired for this evaluation; however, this was limited due to the construction schedule in the state.

The four projects visited and their objectives are listed below.

Projects Visited

1. I-65, Indianapolis, Keystone to Raymond; 12 inch, Plain Concrete, Slipform Pavement.

This was the first project visited and the procedure of using the instrument on fresh concrete was the main concern. To determine the capabilities of the instrument in detecting various densities, the nuclear gauge was set at different distances from the path of the vibrators on the paving equipment.

2. I-70, Indianapolis, Belmont to River Ave.; 12 inch. Reinforced Concrete, Form Pavement.

Tests on this project were concerned with the different densities and consolidation of the concrete above and below the reinforcement steel. Consideration was also given to the consolidation of concrete near the dowel bars at contraction joints. Later, core samples were taken to compare the actual concrete density with the measurement of the nuclear gauge.

3. I-64, SR. 66 to Crawford-Harrison County Line; 11 inch, Reinforced Concrete, Slipform Pavement.

   All testing was performed at the contraction joints.

4. US 41, South of Boswell, Indiana; 10 inch. Reinforced Concrete, Slipform Pavement.

Measurements were made at the contraction joints and at numerous locations, the concrete was measured for density, vibrated again with a hand held vibrator and remeasured to help find the affects of mechanical vibrators.

On each project, tests with the nuclear gauge were performed as through the tests were a daily routine of an inspector. Due to the different construction methods of the contractors and in order not to interfer with the progress of construction, a guideline for choosing the locations of the density tests had to be very flexible. The procedure for each test is best shown in Figures 3 thru 6.

After insertion of the nuclear probe relative minor repair to the surface was required and was accomplished by means of a hand trowel.

Concrete Core Samples

Concrete core samples were taken three months after the concrete was placed on I-70 in Indianapolis. The location of the core samples were carefully measured to insure their being the same as tested during construction with the nuclear density gauge. Two concrete core samples were taken as close to contraction joints as possible.

Fig. 3. Forcing Rod Into Fresh Concrete to Form Holes.

Fig. 4. Sheet Metal Tray Positioned Over Hole.

Fig. 5. Meter in Place With Probe Extended Into Hole. Test Underway.

Fig. 6. Refinishing Surface After Measurement.

Each sample was weighed dry and saturated and from this, dry and saturated densities were calculated. Pulse velocity tests were performed on each sample. The results of these tests are shown in Table 3 and illustrated in Figure 7, along with the nuclear gauge densities values. The core samples were later cut above and below the reinforcement steel to determine the difference between the densities of the concrete above and below the reinforcement steel. The results of the tests are recorded in Figure 8.

Table 3. CONCRETE CORE SAMPLE TEST RESULTS

Core Number	Pulse Velocity (fps)	Unit Weights Dry	Unit Weights Saturated	Nuclear Gauge Density (lbs/cu.ft)
1	12,820	138.7	144.6	145.2
2	12.543	139.3	145.1	143.5
3	12.990	138.7	144.8	144.0
4	13,272	141.4	147.5	145.8
5	12,991	135.3	141.6	143.7
*6	12.967	138.3	144.7	140.5
7	12,956	142.5	148.5	147.1
8	13,552	138.6	144.8	147.4
9	13,553	142.2	147.7	146.6
*10	12,424	137.4	142.7	144.8

* Sample taken adjacent to contraction joint.

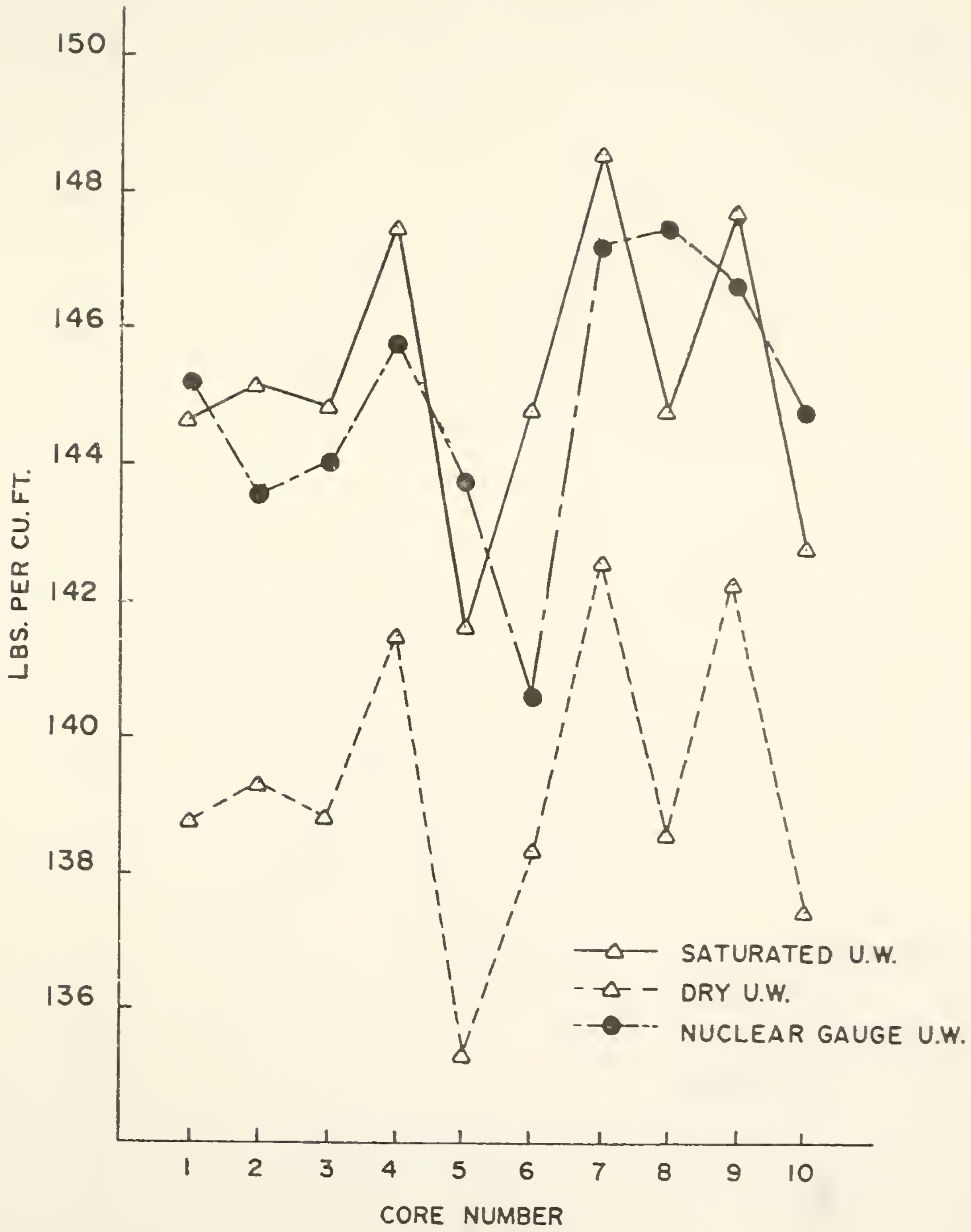


FIGURE 7 — CONCRETE CORE SAMPLE DENSITIES

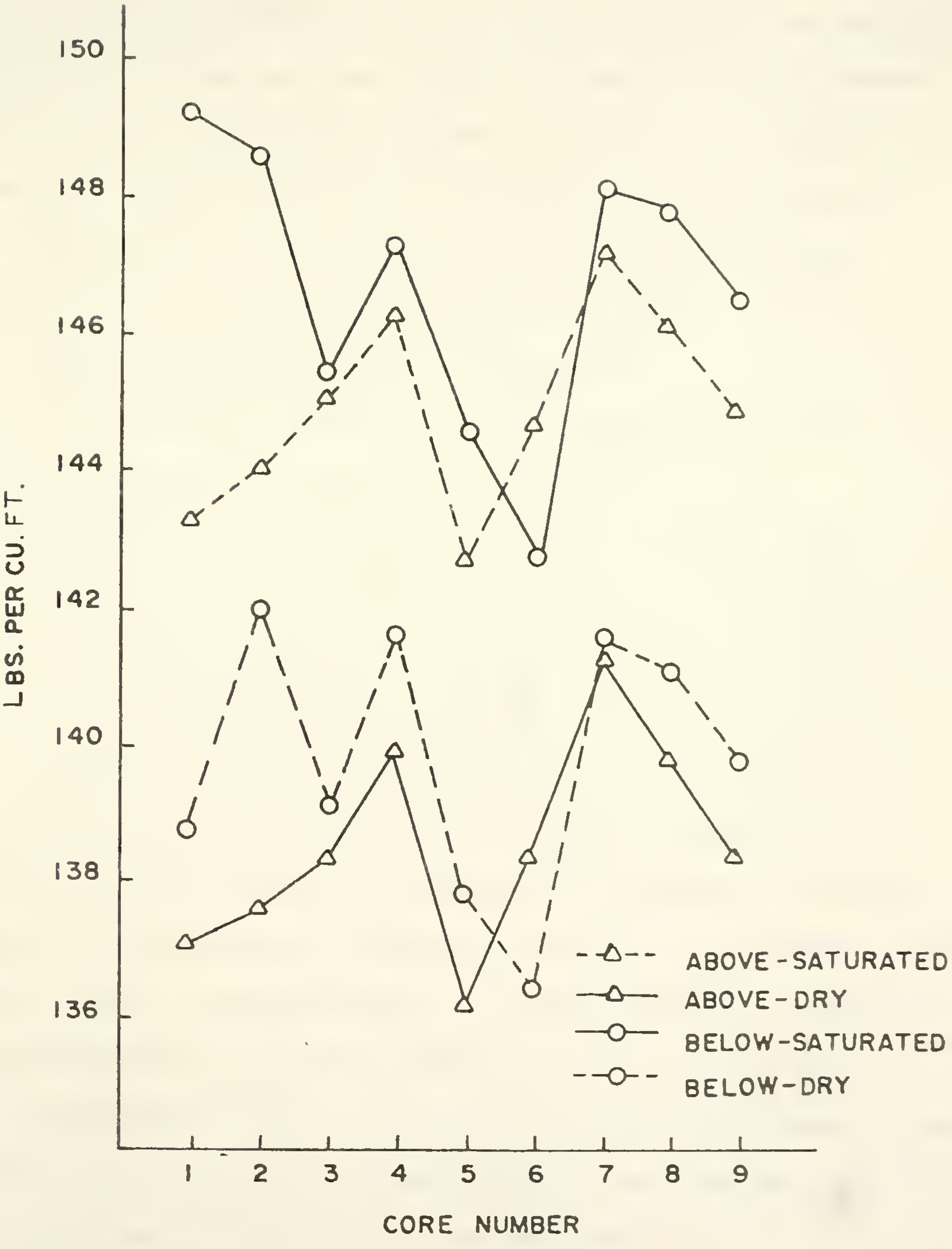


FIGURE 8 — DENSITIES ABOVE & BELOW REINFORCEMENT

Statistical Analysis of Field Data

The data gathered during the field experiments dictated an analysis by computer. The first step was to reduce the density counts recorded directly from the nuclear gauge to actual measurements of the density of the concrete. Due to the different forms of pavement, data from each construction project was evaluated separately, with the following locations of the nuclear probe as variables of the data:

1. Depth of the nuclear probe in the pavement.
2. The nuclear probe above or below the reinforcement steel.
3. At contraction joints and between contraction joints.

It was found from the results of the computer analysis (Tables 4, 5, & 6), that there is a small difference only in the density of the concrete through the depth of the non-reinforced slipform pavement (I-65). No differences were found either in the study of contraction joints or in the investigation of density above and below the reinforcement steel of the pavement. At the fourth construction project tested (U.S. 41), in which the concrete density was measured and then measured again after the concrete was revibrated, no difference between the two readings could be found. Also, no comparisons could be found between the concrete core samples and the nuclear gauge measurements at either the contraction joints or away from the joints. It should be noted that the range of tests gathered for the core samples and the revibrated tests was small and may not be a good representation of the true conditions.

Table 4. Summary of Tests taken on I-64 (11 inch, Reinforced, Slipform)

Location	Mean (lbs./cu.ft)	Standard Deviation
All tests		
Above Reinforcement	146.43	1.78
Below Reinforcement	145.60	1.66
At Contraction Joints		
Above Reinforcement	145.46	1.76
Below Reinforcement	145.72	1.74
Not at Contraction Joints		
Above Reinforcement	145.09	1.50
Below Reinforcement	145.53	1.63
All tests	146.02	1.76

Table 5. Summary of Tests taken on I-65
(12 inch, Plain, Slipform)

Location	Mean (lbs/cu.ft)	Standard Deviation
Depth		
4 inch	148.56	1.66
6 inch	148.08	1.40
8 inch	147.81	1.40
All tests	148.16	1.52

Table 6. Summary of Tests taken on I-70 (12 inch, Reinforced, Formed)

Location	Mean (lbs./cu.ft.)	Standard Deviation
All tests		
Depth 2 in.	144.92	2.15
4	145.27	1.75
6	144.94	1.79
8	144.90	1.62
10	145.66	2.02
At Contraction Joints		
Depth 2 in.	143.92	2.78
4	145.08	2.04
6	144.96	1.71
8	144.75	1.93
10	145.47	3.26
Not at Contraction Joints		
Depth 2 in	145.14	1.99
4	145.35	1.64
6	144.93	1.84
8	144.94	1.54
10	145.74	1.28

It will be recalled that the initial objective of this phase was to determine the feasibility of using nuclear density gauges in plastic concrete for quality inspection. From the data gathered in the field, it was found that the different types of construction methods (formed and slip-formed) and the different concrete mixtures used on each project resulted in different density ranges on the nuclear gauge. To inspect the quality of concrete with the nuclear gauge, a set of control charts could be drawn for each project. From the analysis, a set of control charts (Figures 9 and 10) for the three highway projects was constructed. For any project, a set of control charts can be set up in the following steps:

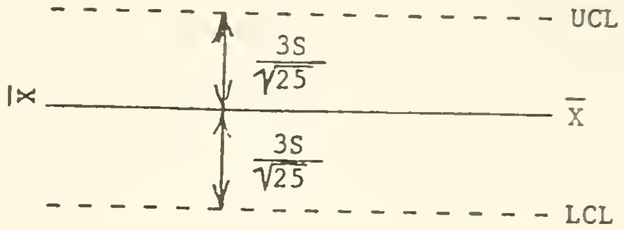
Step 1. For reinforced formed and slip-formed pavement, choose a sample location and take a reading at each depth. Find the mean and range (largest minus smallest) of the sample and plot them on Figure 9. Repeat for 10 locations.

Step 2. It is very likely that the means will not be within the control limits. If so, a new control chart will have to be drawn (see Step 3). The ranges plotted should be in the control limits because the standard deviation should be the same for all locations. If the ranges are not in control, completely new control charts must be drawn for both the means and ranges.

Step 3. If the ranges are in control, but the means are not, calculate the mean for the 10 points already found and adjust this mean to be the new midpoint of the new upper and lower control limits. If both the ranges and mean are not within limits, 25 samples should be taken and the mean (u) and standard deviation (s) calculated. The new control charts will have limits:

$\overline{X}$ - CHART

Statistical Mean, $\overline{X}$; $u \pm \frac{3S}{\sqrt{25}}$



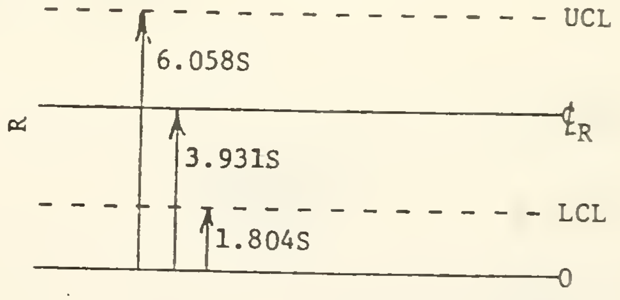
Mean Values, $\overline{X}$ = Mean of the densities at a given sample site.

R - CHART

Range; UCL = 6.058 S

¢_R = 3.931 S

LCL = 1.804 S



Range Values, R = Largest minus smallest of the values from different depths of a sample site.

Step 4. The procedure for non-reinforced slipform pavement is generally the same as above except a control chart (see Figure 10) is needed for each depth.

After the control charts have been set up for a project, any density reading taken that falls below the control limits of the charts would be considered low density concrete.

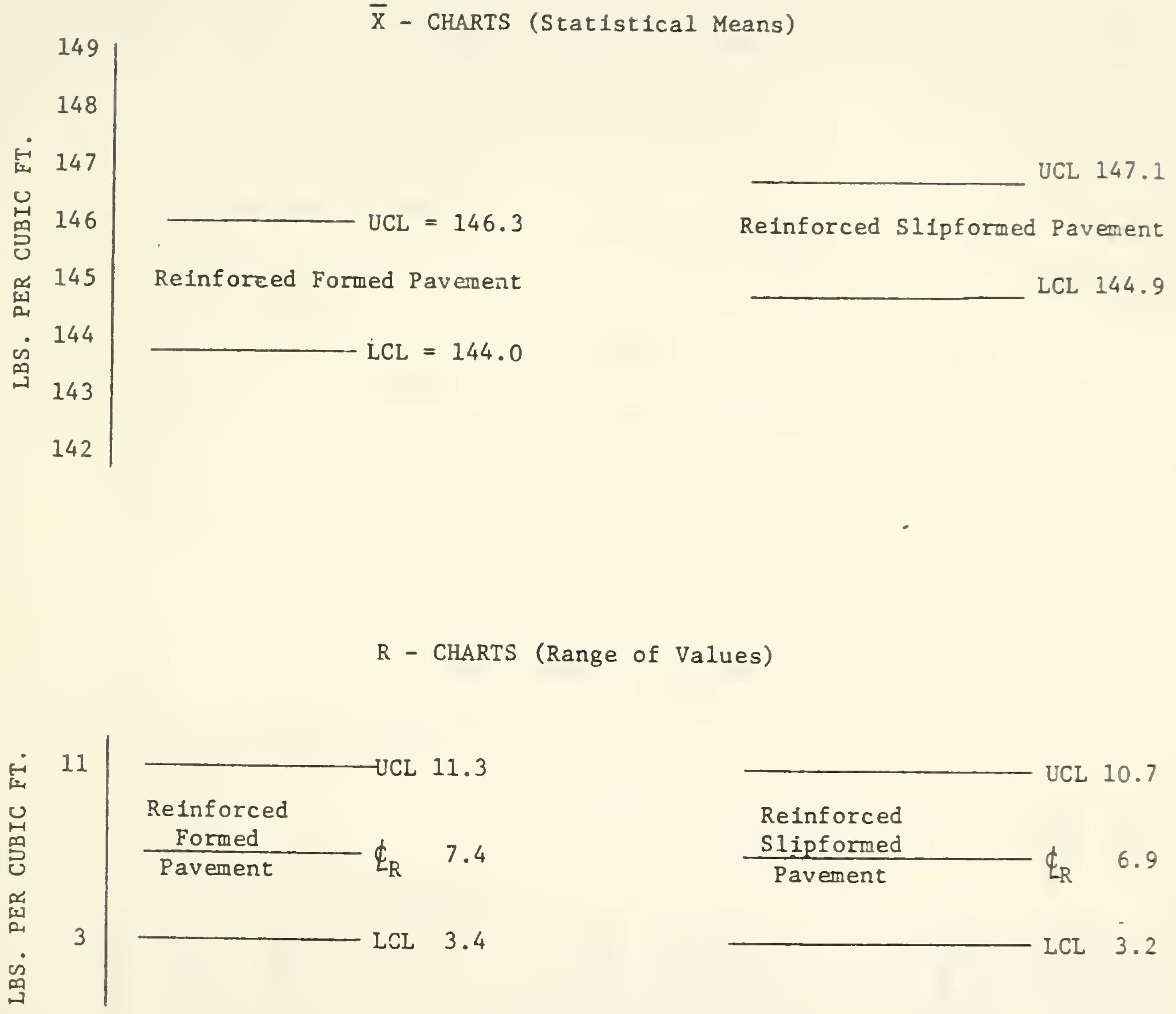


FIGURE 9 - CONTROL CHARTS

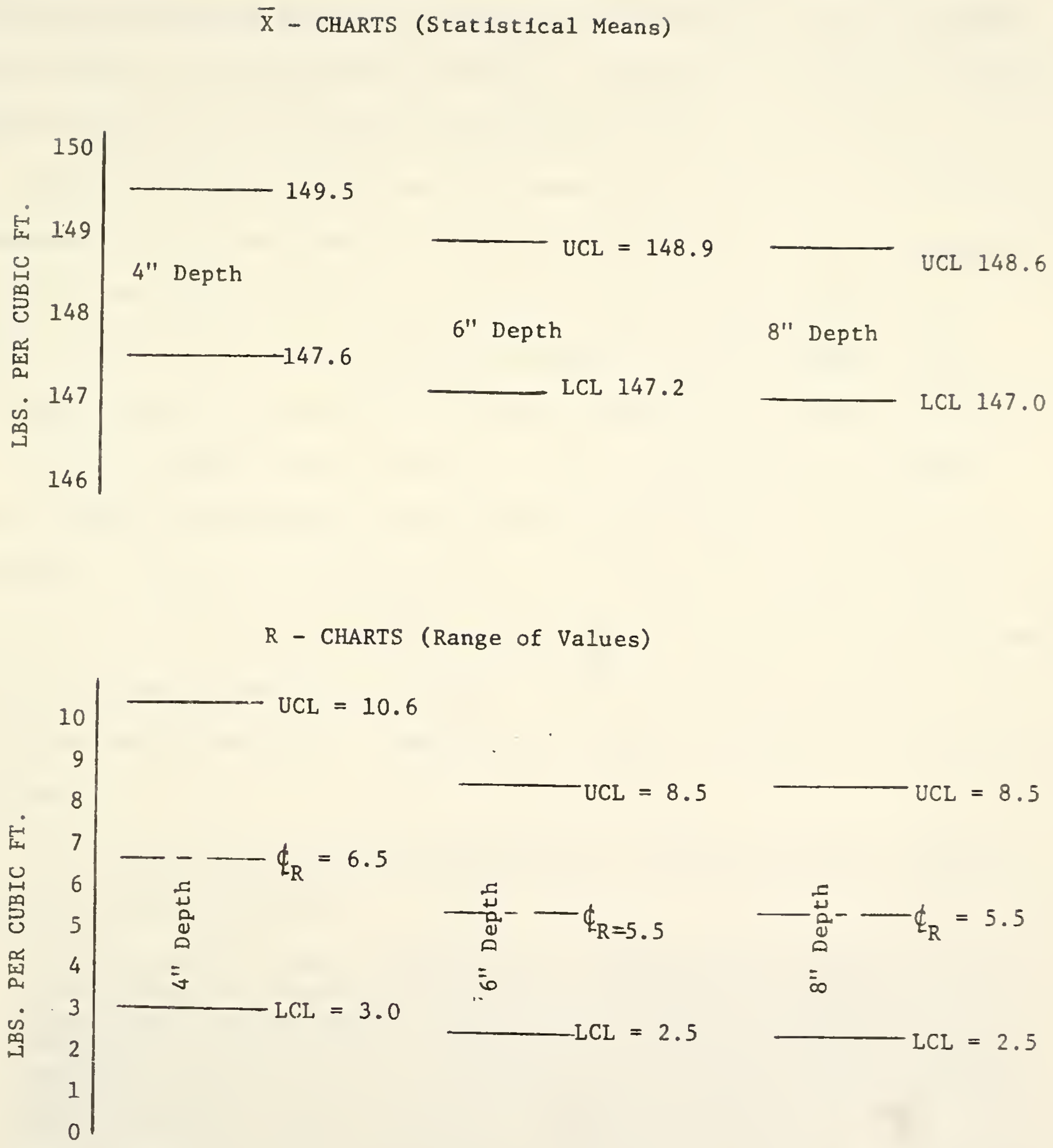


FIGURE 10 CONTROL CHARTS
NON-REINFORCED SLIPFORM PAVEMENT

Significance of Field Procedure for Routine Field Control Tests

The tests which have been reported were made with the actual probe of the nuclear instrument being in contact with the concrete. The sheet metal tray helped in positioning and in cleaning; nevertheless, two serious problems exist which make that technique undesirable for routine field tests.

Both problems concern the concrete contacting the probe. To clean the probe at the end of each period of testing, generally twice a day, it was best to extend the probe outside of the concrete and then very quickly wipe the probe clean of all mortar and parts which might have been adhering. This technique cannot be recommended for routine operation with a nuclear device.

If this cleaning were not done at the end of each series the internal gears within the meter would rapidly be worn and/or clogged. Even with the cleaning of the probe, it was necessary to have the meter dismantled every week or two. In this procedure the nuclear probe is removed and then the gears could be cleaned without haste or danger. This was done at the University's radiation control facilities - something not readily available to construction projects.

It is therefore essential that some device be used to eliminate contact of concrete with the probe.

In the review of a draft of this report questions were raised as to the necessity of the above restrictions. It was pointed out that the State of Colorado* has implemented a procedure of partially dismantling and cleaning the nuclear gage. It is the author's opinion that the trained personnel are unlikely to be available at the pavement inspection site. In addition, the exposures are not desirable and could be dangerous if done by the same person throughout a construction season.

See Appendix A for the correspondence pertaining to exposure and possibly health dangers.

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*Spalti, Richard R., Nuclear Testing for Density Control of Concrete Pavement, Report No. FHWA-CO-RD-77-4, June 1977 (Draft)

Following the field evaluation, work was done to evaluate a thin wall rigid plastic tube having a sealed bottom which could be placed into the concrete. In conjunction with a plastic tray, this insures that the meter would not be in contact with the concrete. This procedure worked reasonably well. The small air gap and plastic thickness was averaged into the concrete, hence causing error, but if used for comparative purposes, this would not be serious. The variation in results did appear to be slightly greater but this comment was based on a limited number of tests.

Recommended Procedure Using a Plastic Tube to Protect Probe

1. A thin wall rigid plastic tube, PVC water pipe is satisfactory, having an inside tube diameter not exceeding the diameter of the probe by more than 1/8 inch (3mm), shall be used. The bottom end shall be blocked with a metal head, a convenient form consists of a machine screw, nut and washers, fastening into the bottom of the tube to seal and provide protection for the plastic when forced into the concrete. The total length of the tube must not exceed the depth of the pavement.

2. The tube shall be forced into the concrete with a metal rod inside the tube. When nearly flush with the surface of the concrete a plastic tray having a hole properly located, may be placed around the top of the tube similar to Figure 4. The rod should be removed.

3. The nuclear gage may then be placed on the tray and the probe extended into the tube and the measurements obtained.

4. Results should be evaluated as previously outlined. The results obtained will allow for an evaluation of the uniformity of the concrete consolidation. Control charts are still a viable method. The numerical value of the density may be slightly less than that which could be obtained if concrete were allowed to be in direct contact with the probe and base of the meter.

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Summary

The results of the tests taken in the field provide evidence that nuclear density gauges can record the density of plastic concrete. It was found that the reinforcing steel in the pavement did not affect the density evaluations. Also, the density of plastic concrete near contraction joints can be recorded if the nuclear gauge is properly positioned over the dowel bars.

All the concrete densities recorded were within a close range. The probable reason for this close range is because all the concrete tested in the field was of a good consistency and well consolidated by the paving procedure.

In some instances it was used on pavements such as ramps and tapers which were consolidated by hand held vibrators. In these circumstances notable improvements in density were sometime determined when the concrete was given extra vibration by probing with the vibrator. In several instances similar procedures were done on main line paving, with the help and great cooperation of the contractors, but in these cases, no effect was measured.

Insofar as evaluating the technique it would have been best to vary the mixes in order to obtain one that did not consolidate well; however, this was out of the question on actual construction.

The problem of keeping the probe and the internal (mechanical) portion of the meter clean is important. For routine use it was felt that protection to insure that fresh concrete would not touch the probe was essential. The tests reported were made using non-recommended procedures. Tests conducted with rigid plastic tubes to protect the probe, in conjunction with a thin plastic tray to protect the bottom of the meter, showed that measurements could be conducted but with apparently more variability of the results.

The results obtained should not be considered as an average unit weight of the concrete at any given position on the pavement at which the measurement was made. It must be considered as a relative measure in which a low unit weight would give a low nuclear density measurement, hence, it is a technique that can be used to insure and to check consolidation of concrete in a comparative way. Values would be checked against a portion of pavement known to have received excellent vibration. This would be of particular value near construction joints, and when evaluating the performance of the various elements for consolidating concrete in the paving train.

Conclusions

1. The nuclear density meter when used for direct readings can give meaningful evaluations of the density of fresh concrete. This includes both reinforced and non-reinforced concrete pavements.
2. It is not feasible to use the equipment on a routine basis with the probe in contact with fresh concrete because the necessity of frequently cleaning the probe is a radiation danger to personnel. To reduce cleaning would cause a severe problem with the mechanical operation of the probe.
3. The use of rigid plastic tube and tray to protect the probe and meter introduces more error, but the technique can still be used to verify performance especially on new start ups and whenever doubt exists as to adequacy of consolidation. It should be done on a comparison basis, i.e., compare with concrete known to have been well consolidated. The existence of nuclear density meters on many field jobs makes this especially feasible.

APPENDIX A

This report's recommendation that the probe be protected from contact with the fresh concrete in order to eliminate radiation exposure to the person who must clean it after each period of use, probably twice a day, was questioned by reviewers of an earlier draft. The following items of correspondence document the action taken to substantiate the recommendation based on reliable estimate of exposure.

Item 1 - Memo Scholer to Ziemer, 12/18/79

Item 2 - Memo Ziemer to Scholer, 1/19/79

PURDUE UNIVERSITY inter office memorandum

To Dr. P. L. Ziemer file: 9-11-7

From Dr. C. F. Scholer

Date December 18, 1978

Subject Radiation safety in routine use of Troxler Nuclear gage, Model 2401

The model 2401 gage, which is now in your custody, has a ^{137}Cs/Am - ^{241}Be (8.1mci/50mci) sealed source in an extendable probe. In the research project completed the probe was extended into fresh concrete and then quickly cleaned by means of a damp rag passing over the probe. This was kept to a minimum and several persons shared this work. Those involved understood the danger and we kept exposure to the minimum possible periods of time.

In the concluding report for the project, I recommended that the direct exposure of the probe to fresh concrete be avoided in order to reduce or eliminate the need to hand clean the probe. This is apparently not in agreement with other investigators (See enclosure). I made the recommendation without scientific evidence hence I may be reflecting undue concern for the danger if this technique was used by regular highway inspection personnel on a routine basis.

Would you please answer the following questions for me and for the Federal Highway Administration.

1. Assuming that a persons hand would be in contact with the probe for a period of one second, at each cleaning, how many or what frequency of contact, should be considered as the maximum safe number. Such contact should be considered to occur at the same frequency for 5 months or more each year.

2. Assuming that the center of the persons body will be an average distance of four feet from the extended probe for another ten seconds, will this change the frequency of question No. 1.

3. Would a "lead glove" be of great benefit? I assume it would increase the time of contact to perhaps three seconds. I have heard of a "lead glove" but know nothing more about them.

I sincerely thank you or whoever answers this report. Everyone concerned is anxious to have a safe method. Your sincere and frank evaluation will be appreciated. Your reply, by January 17, would be greatly appreciated.

Thank you,

CFS:am
Encl.
cc: H. L. Michael

Charles F. Scholer
Associate Professor of Civil Engineering

PURDUE UNIVERSITY
OFFICE OF HEALTH PHYSICS AND RADIOLOGICAL CONTROL
BIONUCLEONICS DEPARTMENT
WEST LAFAYETTE, INDIANA 47907

January 19, 1979

TO: Dr. C. F. Scholer, Civil Engineering

FROM: Paul L. Ziemer, Radiological Control

RE: Radiation safety in use of Troxler gauge

In response to your memo of December 18, 1978, I have evaluated the hand and body exposures associated with cleaning of the probe as you described.

First let me say that the current philosophy of radiation protection is that all exposures should be kept "as low as reasonably achievable", even if they are already below the numerical permissible dose limits. This means that if an exposure which is in the "acceptable" range can be readily lowered or eliminated, it should be. Accordingly, your suggestion to eliminate the need to clean the probe is in keeping with all of the current recommendations of the International Commission on Radiological Protection (ICRP), and the National Council on Radiation Protection and Measurements (NCRP). Two good references on this concept are:

a) NCRP Report No. 39, Basic Radiation Protection Criteria, NCRP Publications, Washington, D.C. (1971).

b) ICRP Publication 22, Implications of Commission Recommendations that Doses be Kept As Low As Readily Achievable, Pergamon Press, N.Y. (1973).

In terms of a quantitative evaluation of the doses involved in cleaning the probe, these can be estimated as follows:

1) Hand dose

Assumptions: 1) Contact time per cleaning: 1 sec.
2) Distance of hand from source (average): 0.5 cm.

Given: Specific gamma constant for ^{137}Cs is 3.226 R/hr per mCi at 1 cm; Specific gamma constant for ^{241}Am X-ray is only 0.025 R/hr per mCi and will be neglected.

Dose calculation:

Exposure rate to hands would be:

$$3.226 \frac{R/hr}{mCi} \times 8.1\ mCi \times \left(\frac{1\ cm}{0.5\ cm}\right)^2 \cong 100\ R/hr$$

or about 30 mR/sec.

For gammas, an exposure of 1 R corresponds to a dose equivalent of about 1 rem, so a 1 sec hand exposure gives about 30 mrem.

Permissible dose:

The maximum permissible dose for hands is 18,750 millirem/calendar quarter. Thus, a 30 mrem per cleaning, some 600 cleanings per quarter or about 200 per month would be permitted per individual.

Most institutions attempt to keep worker exposure well below the permissible dose by a factor of at least 4, and preferably 10, in which case only 20 to 50 cleanings per month per person would be acceptable.

2) <u>Whole body dose</u>

Assumptions: 1) Exposure time: 10 seconds per cleaning
2) Body centered 4 feet (120 cm) from source

Given: Specific gamma constant for ^{137}Cs is 3.226 R/hr per mCi @ 1 cm

Dose calculation:

Exposure rate to body would be:

$$3.226 \frac{R/hr}{mCi} \times 8.1 \text{ mCi} \times \left(\frac{1 \text{ cm}}{120 \text{ cm}}\right)^2 \cong 0.0015 \text{ R/hr}$$

or 1.5 mR/hr

For a 10 second exposure, this corresponds to a dose of only about 0.004 millirem. The whole body dose limit is 1250 millirem per quarter. Thus it is clear that the hands rather than the whole body become the limiting factor on number of cleanings that could be permitted.

3) <u>Use of leaded gloves</u>

Leaded gloves would not be of any significant value in attenuating the ^{137}Cs gamma rays. Typical leaded gloves have an equivalent thickness of the order of 0.25 mm to 0.5 mm of lead. The half-value for ^{137}Cs gammas is 6.5 mm of lead, so the effect of a leaded glove would be minimal. Indeed, if the contact time were increased from 1 sec to 3 sec by the use of the gloves, as you suggest, then the use of gloves would lead to a higher dose than without.

APPENDIX B

Original Field Data,

Densities and Locations

Note: A sample data sheet is attached. All data is available upon request to the Joint Highway Research Project, School of Civil Engineering, Purdue University.

PROJECT NO. F-3503
PROJECT LOCATION I-7 ,INDY,ENT.RAMP EAST OF BELMONT
TYPE OF PAVEMENT 12 IN. R. C. FORMED
NUMBER OF TEST 8
DATE JUN.9,1975
STANDARD COUNTS 322,324,322

TEST NO. 1
LOCATION 7.17FT PAST 2ND JT. BEFORE STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	0	0.0
4	626	146.8
6	398	145.6
8	215	145.5
10	107	145.8

TEST NO. 2
LOCATION 6.75FT PAST 1ST JT. BEFORE STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	0	0.0
4	640	145.3
6	392	146.5
8	214	145.7
10	107	145.8

TEST NO. 3
LOCATION 13.17FT AFTER 1ST JT. BEFORE STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	0	0.0
4	621	147.4
6	396	145.9
8	217	145.2
10	109	145.2

TEST NO. 4
LOCATION 15.83FT AFTER 1ST JT. AFTER STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	0	0.0
4	628	146.6
6	402	145.1
8	221	144.3
10	108	145.5

TEST NO. 5
LOCATION 15.83FT AFTER 1ST JT. AFTER STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	811	145.4
4	627	146.7
6	396	145.9
8	217	145.1
10	106	145.5

TEST NO. 6
LOCATION 19.25FT AFTER 4TH JT. AFTER STA 844
COMMENT NO JOINT

DEPTH	COUNT	DENSITY
2	790	147.7
4	635	145.9
6	402	145.0
8	217	145.1
10	109	145.2

COVER DESIGN BY ALDO GIORGINI