STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

NUCLEAR TESTING FOR CONTROL OF EARTHWORK MOISTURE AND DENSITY

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Presented at
Ninth Annual Highway And Public Works Conference
University of the Pacific, Stockton, California
March 9, 1966

66-25

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By

William G. Weber, Jr.*

INTRODUCTION

The use of nuclear gages to determine the in-place moisture and density in compaction control is rapidly expanding. There are now about fifteen state highway departments, several other state agencies, federal, and local agencies now using nuclear gages in compaction control. There are now three or more states with test methods prepared for the use of nuclear gages, and ASTM Committee D-18 is preparing a standard test method. It thus appears that nuclear testing is becoming widely accepted and used.

In the period from 1954 to 1958 the Materials and Research Department, in cooperation with the University of California, undertook extensive studies involving the use of subsurface units to measure the changes in moisture and density of foundation soils. These units have been successfully used on several projects and are presently being used to follow moisture changes below concrete pavements. These subsurface units are not completely successful in determining the true moisture and density of the foundation soils, but are reasonably accurate in measuring changes in moisture and density. Their advantage is the ability of the gage to measure the same sample of soil as often as desired.

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The Materials and Research Department purchased the first nuclear surface gage in 1959. The early attempts to use this nuclear gage were unsuccessful with wide differences being obtained between the densities indicated by the nuclear and sand volume tests. A second nuclear gage was purchased from another manufacturer in 1961. An extensive laboratory study was then undertaken in 1961 followed by a field study in 1962. These and the following investigations are discussed in the following section, that have lead to the present State-wide use of the nuclear gages on an experimental basis.

During the 1959 to 1961 studies several important items were recognized that had an important influence on the following studies. There was no accurate standards to be used in obtaining calibration curves for the gages. The nuclear gages and the conventional density tests were measuring different soil properties. In field comparisons the nuclear gages and the conventional tests measured different volumes of soil and gave different weight to the various layers in the soil. These and many other items were studied as side issues in the various nuclear studies. These side studies had a large effect upon the present use of the nuclear gages.

PREVIOUS TEST PROGRAMS

In the laboratory phase of the 1961-62 test program, eight different soils, from various locations in the State, were compacted in a circular steel mold two feet in diameter and one foot in depth. Specimens of each soil were fabricated at various densities and moisture contents. Comparisons were then made

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between nuclear and oven dry moisture determinations. The standard mold soil density was determined by several methods given as follows:

(1) Calculated by soil weight and mold volume

(2) Sand volume test

(3) Chunk specimens

The findings of this laboratory study were not too encouraging. To obtain maximum accuracy in density determinations it was found that it is necessary to develop individual calibration curves for each soil type. At the 90% confidence level the nuclear readings were within 3-1/2 pounds per cubic foot (p.c.f.) using separate calibration curves for each soil. When one calibration curve was used for all soils, as recommended by one of the gage manufacturers, the 90% confidence limits were about 7 p.c.f. The nuclear gages were found to be very senstive to the surface condition of the soil with respect to the seating of the probe. Experiments also indicated that, for the backscatter type gages used, the effective depth of the density determination was only 3 to 4 inches and that the volume of soil being measured was about one-tenth cubic foot.

Considerable difficulty was encountered in obtaining a uniform density of soil within the mold to use as a standard for comparison to the nuclear readings. The best estimate was that the point to point density within the mold varied up to four p.c.f. from the average mold density. Also each layer compacted in the mold varied in density with the highest density at the top directly below the compaction device. The density of the soil directly below the nuclear gage greatly affected the nuclear reading even

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though the average soil density remained constant. No difficulty was encountered obtaining reasonably uniform moisture distribution within the compacted soil mass.

The field phase of the investigation was begun, with the same gages at the termination of the laboratory work. Ten highway projects within 100 miles of Sacramento, which were under construction in the summer of 1962, were selected for this study. As in the laboratory study, the objective involved the evaluation of the factors affecting the nuclear determinations. No attempt was made, at this time, to utilize nuclear testing for compaction control purposes.

In general, the findings in the field investigations confirmed those ascertained in the laboratory except that somewhat broader variations were noted in the field nuclear determinations. The 90% confidence limits ranged from 8-1/2 to 10 p.c.f. for density and about 1-1/2 to 4-1/2 p.c.f. for moisture. These values apparently reflect the adverse effects of operating under field conditions when compared to the laboratory where specimen fabrication, gage functioning, etc., are performed under the most ideal conditions.

At the time of this study there was little information available indicating the variation in soil moisture and density within a compacted embankment. Five readings were therefore made within a ten-foot square which indicated a standard deviation in the density of about three to seven pounds per square foot. Later studies have confirmed this data, see references 5, 6, 10 and 11. A study of the reproducibility of the maximum density test was made that indicated a minor variation in this

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density existed.

As a result of this 1962 laboratory and field investigation, we were reluctant to be committed to the State-wide use of nuclear control testing with the backscatter type gages used. The facts were that (1) the seating problems and separate calibrations for each soil type tended to obviate any time advantage the nuclear test might have over the sand volume method, (2) equipment investment would be considerable for construction control on a State-wide basis (approximately $4,000 per gage) and (3) we were not satisfied that the variations, indicated in the results, could be tolerated; all led to a conservative outlook towards nuclear testing. The results of these studies are reported in references 1, 2, and 4.

In the year following our initial investigation the nuclear industry had come out with production models of a new type of portable gage. Up to this time the surface density gages were designed to measure the Compton backscatter effect from gamma radiation acting upon the soil. In this type of device both the radioactive source and detector tube are fixed in a shielded container (called a probe) which rests directly upon the surface of the soil as shown in Figure 2. The new type density gage utilizes the principle of direct transmission of gamma radiation from the source to the detector through the soil. In this case the detector is fixed inside the probe which is resting on the ground surface and the source is contained in a rod which is inserted into a pre-drilled or punched hole in the soil to any depth ranging from ground surface to 12 inches. A schematic diagram of a transmission gage is illustrated in Figure 3. There is a manufacturer who makes a transmission probe of the style shown in

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Figure 3, while latest models of gages from another manufacturer reverses the arrangement by placing the detector in the rod and the source in the probe. A schematic diagram of a typical back-scatter moisture probe in shown in Figure 4.

With the advent of the transmission gage another major laboratory study was undertaken in 1964. In this study, the Materials and Research Department cooperated jointly with the Department of Water Resources in the undertaking, since both departments were engaged in similar endeavors. The research project had several objectives which are given as follows:

(1) Evaluate the laboratory accurace of both transmission and backscatter gages when used on soil specimens fabricated in a mold.

(2) Compare the transmission and backscatter techniques of nuclear density determinations.

(3) Evaluate the application of such concepts as, the use of scintillation detectors, energy discrimination, collimation of the source, air gap between the gage and soil etc.

An important variation in the technique used in this study was the compaction of the soil in the mold. The soil was compacted in a mold eighteen by twelve inches on top and eighteen inches deep. The eighteen by eighteen inch side was removed and all nuclear readings taken through the compacted soil layers. This eliminated a major portion of the density variation within the soil sample effect upon the nuclear readings. After the 1962 field study a special study established that a high or low density layer of one-quarter inch just below the gage had a major influence on the nuclear readings. This density variation within the soil

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mass would alter the indicated nuclear density by up to five pounds per cubic foot.

Another inovation used in this study was an investigation of surface roughness by cutting grooves of controlled depth on the soil surface. This enabled a controlled method of studying seating errors. A total of six soils from various locations in California were used in this study.

The findings of this study were much more encouraging than the previous studies. The transmission tests indicate a marked improvement over the conventional backscatter method, in several ways. For one thing, accuracy of density determinations were significantly increased when transmission is used. The transmission test had a standard deviation of about 2-1/2 p.c.f., which,it is felt, approaches the accuracy to which the soil samples were prepared. The conventional backscatter type test demonstrated a standard deviation of about 4-1/2 p.c.f. which is similar to the previous findings. The transmission test was also found to be far less sensitive to the roughness of the soil surface at point of probe contact. This minimizes the time and effort involved in site preparation. Another big advantage of the transmission method appears to be that one calibration curve could be applied to the soils used in this study. This also results in considerable savings in time and effort in calibrating the transmission gage, whereas the backscatter gage requires recalibration where changes in soil type are encountered.

One rather startling outcome, in connection with the backscatter method, concerns the pronounced effect upon the accuracy of the density determinations that collimating the source had. It lowered the standard deviation of the results from 4-1/2 to

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2-1/2 p.c.f. This results in the backscatter gage becoming more comparable to the transmission gage. It is our understanding that at least one manufacturer of backscatter gages will in the near future produce a device which includes the collimation principle.

The air gap method of backscatter nuclear measurements was found to eliminate the soil type effect upon the calibration data. However, the effect of surface roughness on the nuclear readings was increased thus reducing the value of this method. The data in reference 11 confirms this data. The data from this study also indicated that the transmission test was less sensitive than the backscatter test to density variation within the compacted soil mass.

A departmental report, covering this work, has recently been prepared and submitted to the Bureau of Public Roads for approval. The title of this report is "A Basic Study of the Nuclear Determination of Moisture and Density," reference No. 8.

In reviewing the data at this time, it was decided to attempt using the backscatter type gages in construction control utilizing the multiple testing concept recommended in reference 2. This concept would allow for the normal variation in density existing in compacted earthwork and the inaccuracy of the backscatter type nuclear gages. A two-phase field study was undertaken in the summers of 1964 and 1965.

One phase of this study consisted of using one nuclear soil gage, operating out of headquarters laboratory in Sacramento, to cover five projects located in highway Districts 03 and 10. This study was intended to investigate the practical aspects of

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controlling a number of projects at one time from a central field laboratory as is the current practice in several of the highway districts. The control tests were the standard sand volume tests and were supplemented by the nuclear tests. The major portion of the time was spent calibrating the gage to the soils encountered on the five projects and only limited time was available for multiple testing. This study indicated that difficulty could be expected is using a backscatter type gage on several projects at one time. The multiple testing concept was found feasible and appeared to have some advantages over the one point sand volume test presently being used.

The other phase of the field study involved the actual specifying of nuclear control testing, in the contract special provisions of a project, in lieu of the sand volume method. This was our first real trial of nuclear testing and it was intended that the method would stand on its own merits.

The contract selected for this purpose was a project in the Eureka Highway District on U.S. 101 near Garberville, This contract involved the placement of approximately 615,000 cu. yds. of fill and considerable structure backfill, permeable material, base and subbase. The project proved to be ideally suited for the study in that a wide variety of condtions and materials were encountered.

The construction started in the spring of 1964 and continued into the fall of 1965. It was necessary to utilize three calibration curves for three distinctly different soils. The calibration curves were obtained by correlation of the nuclear counts with the density as indicated by the sand volume test. The use of

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the three calibration curves did not cause any problems in the field.

The multiple testing consisted of taking several nuclear tests, and recording the nuclear test just below the average value as the official control test. A total of three to fifteen nuclear tests were utilized for each recorded relative compaction value. This provided a knowledge of the condition of the entire compacted soil. A defect of this multiple testing procedure was that all but one test was disregarded in the acceptance or rejection of the earthwork. A study of the data from this project established that a method of multiple testing, later termed the "area concept" would be of value in that all nuclear tests would be included in the acceptance or rejection of a compacted earthwork.

The resident engineer on this project was enthusiastic about nuclear testing. He was able to test rocky material that could not be tested by the conventional sand volume method. The multiple testing enabled the resident engineer to know the condition of the entire fill and not at just one point. Although there was no savings in time there was no appreciable increase in the total time required in the nuclear testing as compared to the conventional sand volume test. This field study was warmly accepted by the District 01 personnel involved.

These two projects are reported in References 7 and 9. Backscatter type gages were used in both of these studies.

During this period of intensive investigation of portable nuclear gages, there was also another important nuclear study being carried on by the Materials and Research Department in

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cooperation with the Construction Department. This project involved the trial of a truck mounted nuclear gage, called the "Road Logger" which is illustrated in Figure 5. This equipment is designed to produce a continuous strip chart recording of the density and moisture of the material over which the truck travels.

The Road Logger was leased from the Lane Wells Co. of Houston, Texas, for use by the Division of Highways from August to November of 1964. The equipment was used on 28 construction projects in nine highway districts for periods varying from one to five days per project. The operation of the Road Logger, on the various projects, was noted with respect to characteristics, deficiencies and limitations. Evaluations were made in terms of correlation with other tests, economics and potential for construction control purposes. The variation of the soils moisture and density in a six-foot square area was also studied.

In general, it appears that the Road Logger is technically feasible for construction control of both embankments and structural section materials. The equipment can log from three to seven miles of roadbed in a normal day's operation and under normal testing speeds and time constant, measures a volume of about six cubic feet of soil. The depth of soil affecting the nuclear readings is about five to seven inches and the portion of soil nearest the gage does not appear to affect the readings as much as in the case with portable gages. This reduced the affect of surface texture or roughness on the nuclear readings in comparison with the portable gages. The need to maintain a constant air gap was found to be critical with a change in one-eighth inch producing a change in density of three pounds per

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cubic foot. The air gap was controlled to one-quarter inch in the normal use of the Road Logger. The manufacturer has since modified his equipment so as to reduce its sensitivity to a change in the air gap. The variation in compacted embankment density in a six-foot square area was found to be in the order of four pounds per cubic foot.

There are several limitations in the use of the Road Logger. In embankment construction it is ncessary to blade the surface of the fill where sheepsfoot rollers are used for compaction. The use of the Road Logger is only practical where fairly long stretches of roadbed can be tested continuously. Spot locations, requiring considerable stopping and starting, maneuvering, or turning around, and structure backfill are not practical for this mobile equipment.

The greatest disadvantage, in the application of the Road Logger, appears to be the economic element. When using this equipment for compaction control, it is estimated that about 100 miles of logging could be performed per month. This would involve a total cost of operation of about $3,000 per month. The cost of the present compaction control is in the neighborhood of $1,000 per month per project for a man and vehicle. This would indicate that about three men would need to be replaced to economically justify the use of the Road Logger. As a consequence it appears that the following minimal conditions would have to exist, in one degree or another, in order to provide economic justification for this equipment:

(1) Operate concurrently on several medium or large projects which are either adjacent to each other or within a radius of 50 miles.

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(2) Projects must involve a large volume of earthwork being placed rapidly.

(3) There must be three or more normal high speed contractor operations.

While we intend to explore the application of the Road Logger further, with the possibility of actually specifying it as the only means of control on several projects, our main efforts are presently being concentrated on the continued investigation of portable nuclear gages for compaction control.

With the approval of the Bureau of Public Roads, we have published a report on the "Field Evaluation of the Lane-Wells Road Logger," dated June 9, 1965, Reference No. 5.

PRESENT USE OF NUCLEAR GAGES IN CONSTRUCTION CONTROL

After reviewing all of the previous work with the nuclear gages and related compaction studies it was decided to use nuclear gages in a limited program starting in 1965. Eleven construction projects are included in this program using five transmission gages and six backscatter gages. The new area concept is being specified as the method of accepting or rejecting the compacted earthwork. The Test Method No. Calif. 231-B is specified in the special provisions as the method to be used in compaction control of earthwork. This is a cooperative project undertaken with the U.S. Bureau of Public Roads and is federally financed with the one and one-half percent research funds.

This present research program is arranged so that nuclear gages are being used on eleven projects in ten of our eleven highway districts during the 1965-66 construction seasons. This

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provides a broad range of various soil types, terrain, climatic conditions and construction operations which should represent a good cross-section of typical situations normally encountered in California highway construction. It can be seen on the California map, shown in Figure 1, that the projects are variously located in the southeastern desert regions, the coastal areas, the central valleys and the mountain ranges. Quantities of embankment and structural section material vary from about one-quarter million cubic yards to fifteen and one-half million cubic yards per project. This means that the nuclear gages are required to check compaction compliance on a total of over 45 million cubic yards of material in this program.

In order to achieve the goal of being in a sound position to make the critical decision, it will be necessary to carefully evaluate many facets of the nuclear operation. Such items as the administrative aspects, practicality and technical credibility of the tentative test method, health safety, training of personnel, technical feasibility and durability of various makes of nuclear equipment, contractor's attitude, etc., will all be scrutinized in detail. This study will also provide a reservoir of experience in the event that a decision is reached to adopt the nuclear method as the standard means of compaction control.

Ten nuclear soil gages were purchased for this program from four manufacturers at a total cost of about $45,000. Of the four makes, two are backscatter types and two are transmission gages. There are three basic types of radioisotopes variously employed in these devices which have radiactive strengths ranging

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from 2 to 33 millicuries. Possession of these sources is authorized under license from the California Department of Public Health. Table I indicates the gage makes, manufacturer, types, and types of radioactive material used in this study. Photographs illustrating the operation of these gages under typical field conditions are shown in Figures 6 through 10.

TABLE I

Gage Make	Manufacturer	Gage Type	Radioactive Source
Hidrodensimeter	Viatec Limited South Africa	Transmission	Ra-Be
Nuclear Chicago	Nuclear Chicago Co. Des Plaines, Ill.	Backscatter	Ra-Be
Numec	Nuclear Materials & Equipment Corp. Apollo, Pa.	Backscatter	Ce 137 Am-Be
Troxler	Troxler Electronic Laboratories, Inc. Raleigh, N.C.	Transmission	Ra-Be

Table II illustrates the various details of the eleven projects and the gage assignments. The resident engineers and at least two technicians from each project have been trained in basic nuclear physics, health safety, gage operation and the test method by personnel of the Materials and Research Department.

The resident engineers are responsible for the application of the nuclear gages with regard to the construction aspects of their respective projects, interpretation of the data for construction control purposes, maintenance of weekly health safety records, physical examinations, and considerations of nuclear

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sources storage and transport. Health safety is governed by regulations administered by the California Department of Public Health. Each operator and the resident engineers are equipped with film badges and dosimeters to monitor exposure to radiation.

The Materials and Research Department is accumulating the data records from the projects and will be responsible for the data analysis, from the research standpoint, and writing of the research reports. We also provide consultation services to the projects on nuclear matters and handle the maintenance and repair of nuclear equipment.

The Test Method No. Calif. T 231-B is established as the standard for the specification control of compaction on each of the projects. This test method has evolved from our 1962 field nuclear studies and numerous other studies conducted since then.

The method utilizes the area concept techniques. In this approach, a compacted area of roadbed having the same soil type throughout, is divided into at least two sections. A minimum of two sites are selected at random within each section and in-place nuclear density and moisture tests are performed at each location within all sections in the area. A minimum of six tests are required for each area. Relative compaction values are then calculated for each test density found, utilizing the maximum density obtained on the soil type from the Impact Compaction test. The average relative compaction of all tests within the area, is then used as a basis for determining whether the area passed or failed to meet the minimum specification limit

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for the material in question. In addition, an area with a passing average is required to have at least two-thirds of the individual tests within the area also having passing relative compaction values. Figure 11 gives a typical example of a compaction control determination.

This new concept of compaction control is based upon many phases of the nuclear and other studies. The rather large point to point variation in moisture and density of compacted earthwork shown in references No. 2, 3, 4, 5, 6, 7, 9, and 10 indicate the desirability of using multiple point control testing. The use of an average relative compaction value and limiting the number of individual failing tests is based upon the data in references No. 2, 5, 6, and 9, which assures that a normal statistical distribution exists. The variations in compacted density that exists also makes the use of a separate impact compaction test at each site superfluous. Studies in references No. 1, 2, 6 and 9 indicate that the errors in assuming one impact compaction test for each soil type is minor in relation to the in-place and test density variations.

In summarizing the program to date, there appears to be both advantages and disadvantages in applying the nuclear method to compaction control. One advantage is that a broader coverage of compaction is being accomplished. The contractor is being provided with an answer sooner than ever before. Some enthusiasm is being noted on the part of contractors, which if it "catches on" could possibly affect a reduction in bid prices. One contractor has stated already that if he knew that nuclear testing would be used on his next job, he would lower his price

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on roadway excavation by a penny a yard. Nuclear testing is often performed on materials and in locations where it is not possible to undertake the sand volume test. (e.g., rocky or sandy cohesionless materials).

A disadvantage is the high cost and complexity of the devices. Maintenance could be a major and continuing problem with these electronic devices which are more complicated than television sets. Unfortunately trained specialists for repair of this equipment may not be readily available. The most serious aspect of equipment breakdown is the interference with job operations caused by downtime for repairs. The use of backup devices has tended to minimize the affect of gage shutdown. However, in the case of backscatter devices, part of the advantage of alternate gages is lost in the time required for recalibration. This is not the case with transmission gages. Experience in this study so far indicates a total of 41 instances of equipment failure, in an eleven month interval, which resulted in out of service periods up to three weeks. It remains to be seen if this rate of maintenance difficulties represents typical expectations for the future. Table III summarizes the nature of the malfunctions encountered.

Health safety and the constant awareness of working with a potential hazard would present some problems, especially in the administrative category. State law requires that the radioactive sources be "wipe tested" at least twice a year. The inconvenience to the job and cost of this item would be considerable.

All in all these disadvantages do not appear insurmountable, but in the "final analysis" the big question is, will the

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advantages outweigh the disadvantages?

THE FUTURE

If the statewide project is successful, we will make extensive use of nuclear equipment for the control of compaction. Within a year we will know the results and, if favorable, we can start a transition from sand volume testing to the nuclear method. One word of caution, however, it is not likely that we can or will attempt to equip every project with nuclear devices. There is a point of "diminishing returns" where projects are so small that the investment becomes too great. In these cases either the use of the sand volume test will be continued or a central laboratory arrangement may be made to handle a number of small projects with a nuclear gage. In any event the transition will have to be gradual and the specifications will probably contain provisions for the use of optional methods.

There is already some evidence of interest in expanding nuclear control testing. We have had a request from District 01 to incorporate nuclear testing in a major project, with large fills, on U.S. 101 near Cummings. As a consequence, a specification is being written for the contract to accomplish this purpose. District 05 is using a nuclear gage, under contract change order, on an FAS project north of Hollister. District 06 has processed a contract change order to undertake nuclear testing on a project on route 33 just south of the existing nuclear project near Firebaugh. Ventura County is including nuclear testing in a contract, on a county road in the area, and intends to employ their own nuclear gage. These projects will not be included in our current research study.

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In order to accommodate these new projects and also provide ourselves with backup gages, we are in the process of ordering two new devices. Rather than purchase a particular make and model, we have written an equipment specification which embodies all of what we consider are desirable features on the basis of our experience to date. Basically the gage will be a transmission type with the detector in the rod, which goes below ground, and the source will be contained in the probe case on the ground surface. This device may also be used as a backscatter gage. Most of the features being asked for are available in various makes of production gages today and we believe that a qualified manufacturer can provide the specified item.

One of the aspects of our compaction control testing today, which is time consuming and will not be remedied by introduction of nuclear in-place testing, is the Impact Compaction test. This test provides the compaction standard, in the form of a laboratory maximum density, from which relative compaction values are calculated. The method is not only time consuming but laborious and cumbersome. We currently have a research project under way on this problem in which we hope to embody nuclear equipment and a new concept. If this proves to be successful along with in-place nuclear methods, then we will have gone the "full circle" in modernizing compaction testing to keep pace with present day high rate construction practices.

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ACKNOWLEDGMENTS

The author wishes to express his appreciation to the many individuals who, over the years, have participated in the research projects described in this paper. The work reported has been performed by the Materials and Research Department of the California Division of Highways. The work was performed by the Foundation Section under Mr. A. W. Root (retired) and Mr. T. W. Smith.

Most of the work undertaken since 1964 was performed in cooperation with the Bureau of Public Roads. Since they have not yet had an opportunity to review this paper, the conclusions and opinions expressed are not necessarily those of the Bureau.

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TABLE II

DESCRIPTION OF PROJECTS INVOLVED IN NUCLEAR STUDIES

Dist.Co.Rte.	Location	Resident Engineers & Office Locations	Contractors	Amount of Earthwork	Type of Road Material	Soil Type	Gage Make & Type of Use
01-Hum-101	4 mi. S. of Scotia	H.A.Davis Rio Del	Green Const. Co.	3,400,000 cy 45,000 cy 162,000 T	Rdwy.Exc. I.B. AB & AS	Silt & Clay Shale Sandy Gravel	Hidrodensi-meter Transmission
02-Sha-5	At O'Brien	J.V.Kelly O'Brien	Ray Kizer Const. Co. R.A.Heinty Const. Co.	3,183,000 cy	Rdwy.Exc.	Sandstone Shale Sandy clay	Troxler Transmission
03-Sac-5	5 mi. No. of Sacramento	H.Lopez No.Sacto	Fredrickson & Watson Granite Const. Co.	16,500 cy 389,000 T	Rdwy.Exc. I.B.	Silty Clay Sandy clay	Hidrodensi-meter Backscatter
04-Ala-680	Nr. Scott's Corner	R.Warner Dublin	Gordon H. Ball ConstCo. Granite Const. Co. Price & Harris Const. Co.	3,360,000 cy	Rdwy.Exc.	Silty clay Clayey silt Sand & Silty gravel	Troxler Transmission
05-SBt-180	2 mi. S. of Hollister	F.A.Avila Tres Penos	Harm Bros.	130,000 cy 57,000 cy	Rdwy.Exc. I.B.	Clayey silt Silty clay	N/C Backscatter

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TABLE II (contd)

DESCRIPTION OF PROJECTS INVOLVED IN NUCLEAR STUDIES

Dist.Co.Rte.	Location	Resident Engineers & Office Locations	Contractors	Amount of Earthwork	Type of Road Material	Soil Type	Gage Make & Type of Use
05-SB-1,101	At Las Cruces	K.H.Miller Las Cruces	Milburn & Sansome Const. Co. Walter Bros. Const. Co.	2,730,000 cy	Rdwy. Exc.	Silty clay Clayey silt Sandstone Shale	N/C Backscatter
06-Fre-5	15 mi. southwest of Firebaugh	N.E.Humiston Firebaugh	Peter Kiewit Sons Co.	535,000 cy 2,970,000 T	Rdwy. Exc. I.B.	Silt Sand Scattered gravel	Numec Backscatter
07-LA-5	8 mi.north of Castaic	J.B.Byrne Castaic	Guy F.Atkinson Co.	15,400,000 cy	Rdwy.Exc.	Clay,clayey shale, silty sand	N/C Backscatter
08-SBd-40	At Newberry	Not assigned	Contract to be let in late spring 1966	410,000cy 4,050,000 T	Rdwy.Exc. I.B.	Sandy silt Sandy gravel Surface rock	Hidrodensimeter Transmission
10-Sta-5	2 mi.southwest of Patterson	C.Roderick Patterson	Peter Kiewit Sons Co.	3,680,000 cy	Rdwy.Exc.	Silty clay and gravel	Troxler Transmission
11-SD-5	San Diego 1 mile north of Old Town	G.A.Smith San Diego	R.E.Hazard Const. Co. W.F.Maxwell Co.	371,000 cy 901,000 T	Rdwy.Exc. I.B.	Silty sand Sandy clay & gravel	Numec Backscatter

Sheet 2 of 2 sheets

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TABLE III

Nuclear Gage Malfunctions on State-wide Study
from March 1, 1965 to February 1, 1966

Cause of Malfunction	No. of Occurrences
Scaler electronics	9
Probe electronics	3
Detector tube	2
Cable and/or connections	7
Binding of transmission rod	5
Timer	4
Moisture in gage	3
Battery	2
Battery Charger	3
Probe handle	1
Mechanical source elevator	1
Switches	1
Total Number of Occurrences	41

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Figure 1

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BACKSCATTER OR COMPTON TYPE NUCLEAR DENSITY GAGE

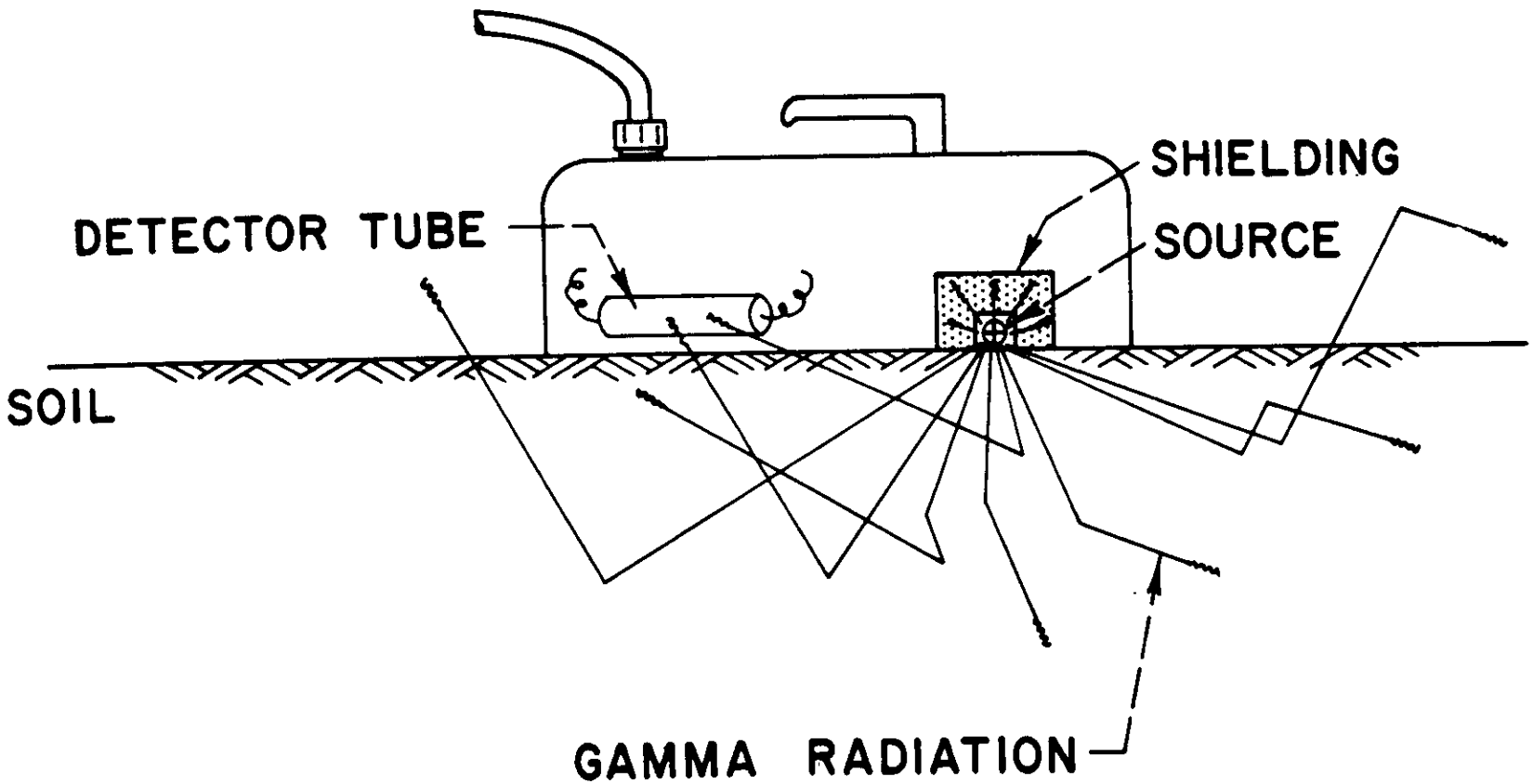

Figure 2

TRANSMISSION TYPE NUCLEAR DENSITY GAGE

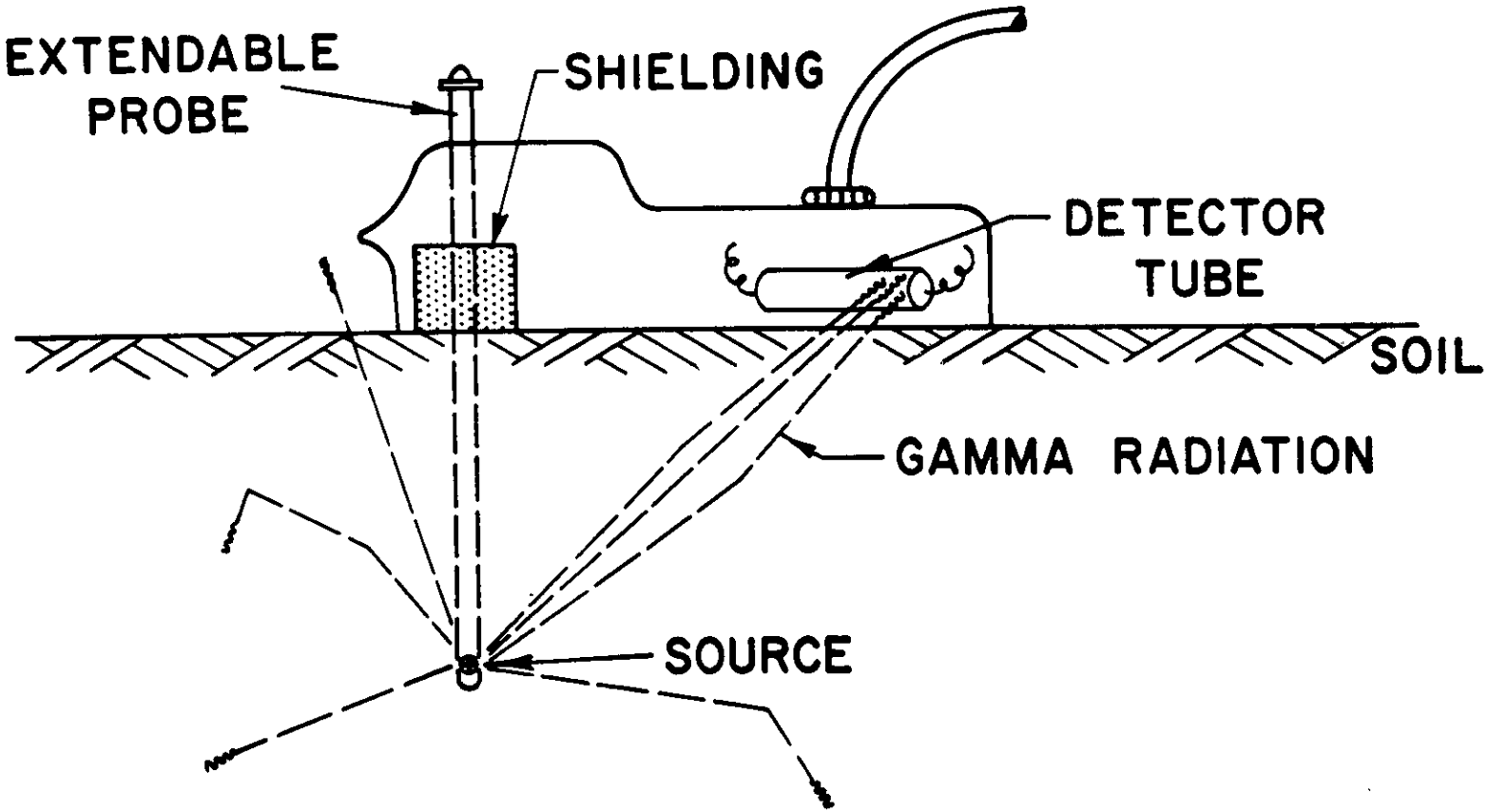

Figure 3

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NUCLEAR MOISTURE GAGE

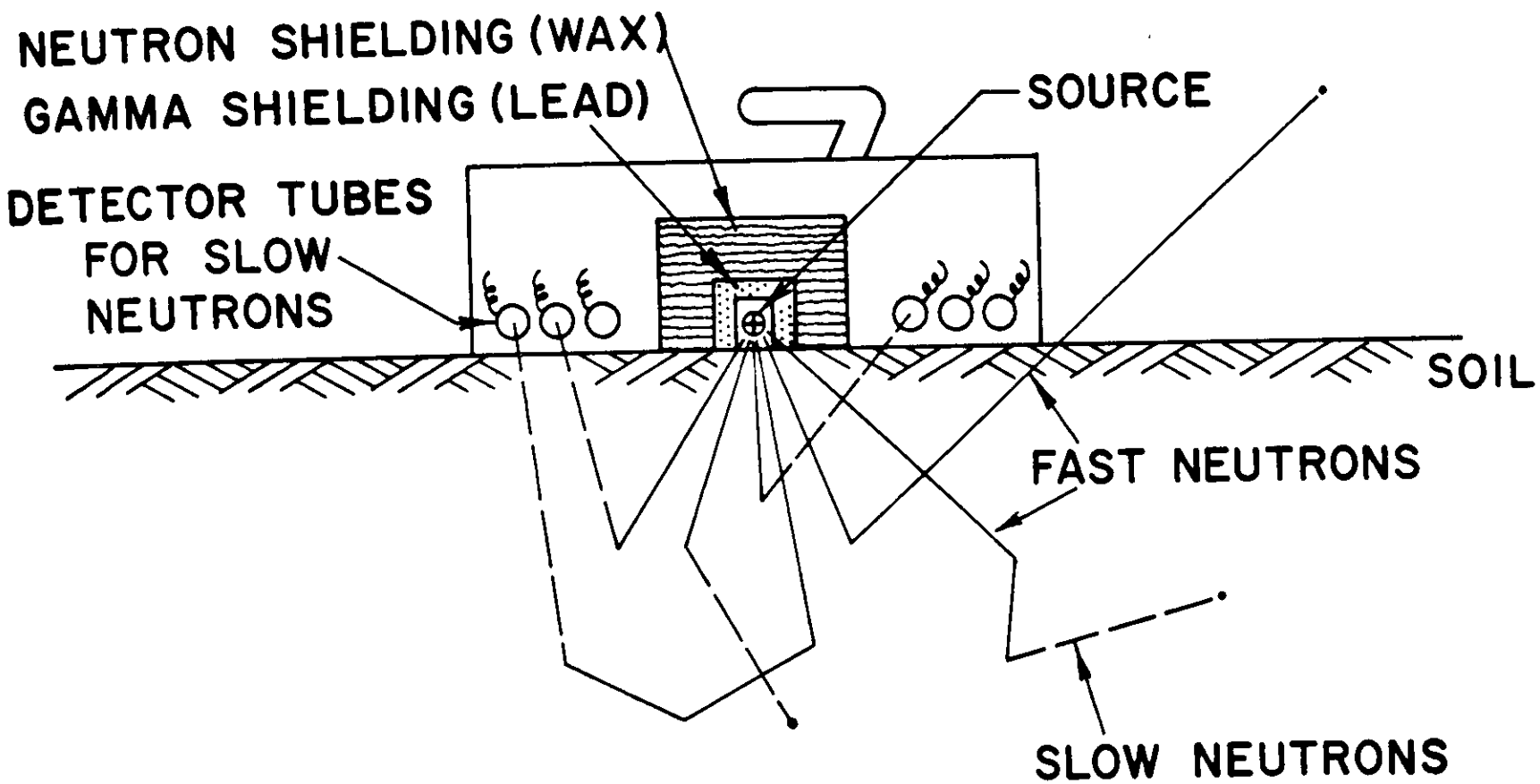

Figure 4

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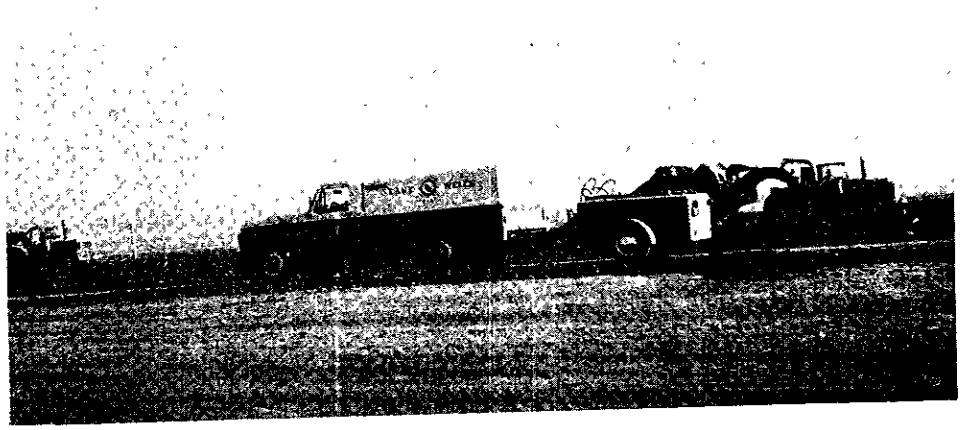

Figure 5. Lane Wells Road Logger in operation.

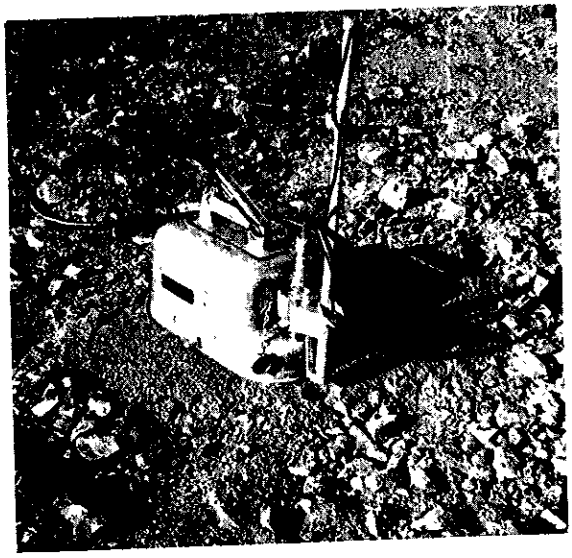

Figure 6. Hidrodensimeter transmission gage. Note hole in grade beneath rod.

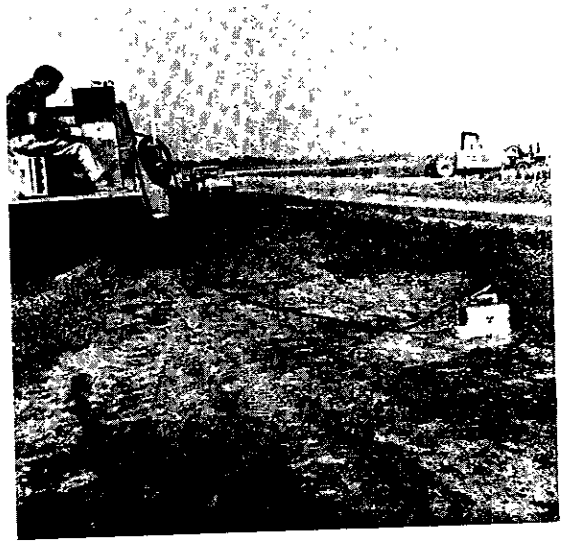

Figure 7. Hidrodensimeter transmission type gage used as a backscatter device (District 03).

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Figure 8. Nuclear Chicago backscatter gage.

Figure 9. Numec backscatter gage.

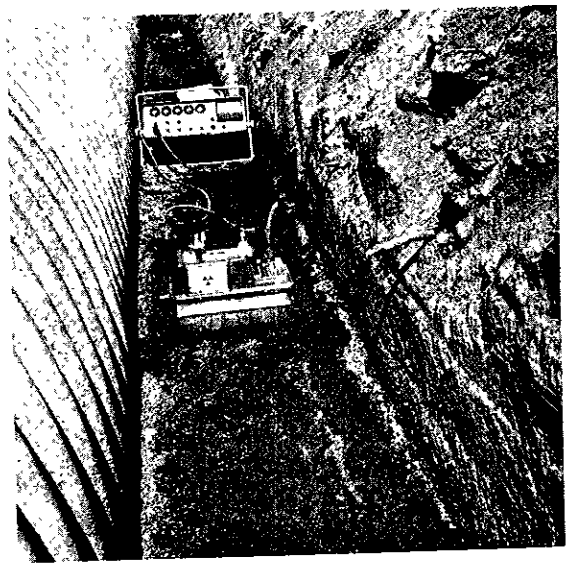

Figure 10. Troxler transmission gage being used in structure backfill.

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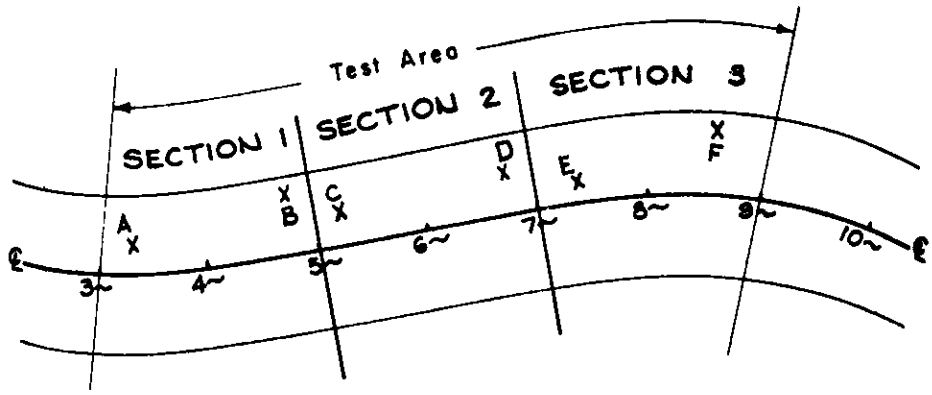
EXAMPLE OF FIELD DENSITY CONTROL



Location: EXAMPLE PROBLEM
STA. 3+00 TO 9+00

Field Test Data:

SECTION	SITE	SITE DENSITY	RELATIVE COMPACTION SITE	RELATIVE COMPACTION SECTION AVG.
1	A	119	86	89
	B	128	92	
2	C	131	94	92
	D	125	90	
3	E	124	89	91
	F	129	93	
Relative Compaction, Area Average			6\544 / 90.7	

Laboratory Test Data: ADJUSTED WET DENSITY SITE D = 139#/ft³
90% = 125#/ft³

Figure 11

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