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COMMITTEE ACTIVITY
Special Committee No. 8
Nuclear Principles and Applications
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SUMMARY AND EVALUATION OF NUCLEAR APPLICATION TO HIGHWAY WORK

Introduction

An Ad-Hoc Committee was formed in the fall of 1962 to ascertain if a committee on nuclear principles and applications was really needed by the Highway Research Board. This committee met September 6, 1962, in Laramie, Wyoming, to study its charge. It was decided that this type of committee was needed by the Highway Research Board and a recommendation was sent to the parent organization asking that a special committee be set up to deal with nuclear principles and their applications to highway engineering. The Board concurred with this recommendation, and Special Committee No. 8 was organized during the early part of 1963.

One of the first actions of the Committee was to begin a study of the use of nuclear principles and applications in highway engineering. It is, therefore, the purpose of this publication to pass on to people interested the state of the art at this present time. The report is divided into three parts. The first deals with "Moisture and Density Gages for Compaction Control of Soils and Aggregates." The second deals with "Density and Asphalt Content of Bituminous Pavements." The third deals with "Special Uses for Nuclear Energy in Highway Engineering." These three parts were prepared by C. Page Fisher, C.S. Hughes, and Robin P. Gardner, respectively.

MOISTURE AND DENSITY GAGES FOR COMPACTION CONTROL OF SOILS AND AGGREGATES

Introduction

The concept of use of nuclear techniques for the measurement of soil moisture and density in compaction control for highway material dates from the early 1950's. Since that time the equipment available for this use has progressed from modified versions of commercial laboratory scalers fitted to home-made probes to commercially available, self-contained, portable devices designed specifically for compaction control work. A number of American and foreign manufacturers are now offering equipment for sale that is

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both reliable and relatively simple to use. These devices are in use in either research or field control functions in most of the highway organizations in this country as well as in a large number of academic and governmental research groups. (See "Highway Research Circular No. 2 - Results of 1964 Questionnaire on Highway Applications of Nuclear Techniques.")

The strength of the radio-active sources used in field equipment has diminished from a few hundred millicuries in the early devices to a few millicuries in the most modern ones with an accompanying reduction in the health hazard and degree of training necessary for operation. The equipment has become a great deal simpler and more rugged and is therefore both easier to use and more reliable in operation.

Accuracy and precision have developed to the point that many engineers feel that the nuclear devices are capable of producing more consistent control data than their conventional counterparts. There is still a major problem in that calibration of the units has not been satisfactorily handled, but several organizations are working intensively on that point.

In the last two years there has been little basic change in the equipment commercially available for soil moisture and density measurement except for the introduction of the combination moisture-density gage by several manufacturers. All manufacturers have, however, incorporated numerous modifications and improvements leading to increased reliability and simplicity of operation.

Equipment Available

At the present time there are seven American manufacturers of nuclear moisture and/or density testing equipment for highway work. They are: Lane-Wells, Nuclear-Chicago, Numec, Seaman, Tellurometer, and Troxler. It is reported that equipment of this type is being manufactured in South Africa, France, England, Sweden, Japan, and Australia. Since a considerable amount of American made equipment is being exported to these and other countries, it is probable that current American equipment is at least as good and possibly superior to any available.

Four basic types of sensing units designed for highway work are currently available: (1) the surface moisture unit, (2) the surface reflection density unit, (3) the surface transmission density unit, and (4) the combination surface moisture-density unit. Each of these sensing units is used in conjunction with a readout unit that is common to all types. The readout unit may be either a scaler or of the integrating rate-meter type. Some manufacturers offer a full line of equipment and some specialize in one or two units. In addition to surface gages, several manufacturers produce subsurface probes both of the reflection and transmission type for the examination of buried soil masses. One device currently available makes a continuous record of moisture and/or density as it travels along the surface of the compacted material but all the others make single point measurements at selected locations and are then moved to another test point.

The cost of nuclear testing equipment has remained fairly stable for several years and the consensus of the various manufacturers is that it costs \$ 4,000. to \$ 6,000. to equip a field party for moisture and density measurements and to provide the needed accessories and safety precautions. Also most users find it necessary to assign a vehicle for transportation of technicians and equipment in the field.

Radio-active Sources and Radiation Hazards

The radio-active materials currently being used as sources are Ra226, Ra226-Be, Am241-Be, Cs137, and Co60. With the exception of the continuous-recording type device the sources used are usually in the range of 1 to 5 millicuries of activity. The continuous recording units use much larger sources with a great deal more shielding than the point measurement units. Except for americium all of the isotopes listed have a substantial gamma output and the safety precautions required for the gamma hazard are quite sufficient to protect the operator against neutron danger. In the case of Am241 the gamma field consists of very low energy radiation and the measurement of the level of radiation requires a more complex detector than the usual Geiger counter. Film badges are of course effective for total dose measurement but the operator should be specifically warned about the non-applicability of ordinary survey meters and dosimeters.

The ASTM Nuclear Measurement Study currently being prepared for publication indicates that no significant radiation dosage has been received by any operator using the equipment in accord with the instructions issued by the manufacturer. The few cases of excessive film badge reading that have been reported have in general been traced to improper use and storage of the badge itself.

Most using organizations rely on film badges as sufficient protection for the operators but a few use both badges and some supplementary dosimetry as well. All manufacturers currently recommend the use of film badges alone as being sufficient protection against the possibility of overexposure.

Training of Technicians

The training of field technicians in the use of nuclear equipment has been and continues to be an important problem. Some highway departments have set up an internal training program utilizing their own personnel and local consultants from the academic field. Others have relied exclusively on the training course at the Oak Ridge Institute of Nuclear Studies which is the only formal program on radiation technology presently available outside regular college curricula. Most equipment manufacturers provide one or two day training programs to purchasers of new equipment at a small extra charge but this is in general insufficient training for technicians who have had no other experience in nuclear technology.

Precision and Accuracy

Currently available nuclear moisture measuring devices have a precision (scatter within a series of test results) of approximately $\pm 1\frac{1}{2}$ pounds of water per cubic foot. The precision of reflection type surface density units appears to be about 2 lbs. per cu. ft. and for the transmission type slightly better than that. The accuracy (discrepancy between test result and value as determined by conventional test) is less well defined both because of the difficulty of calibrating the units and because of the difference in sample size for nuclear and conventional tests. There are several studies currently in progress both on the precision of nuclear and conventional testing devices and on the variability of moisture and density in real earth structures. The mathematical model being developed in the Research Triangle Institute study can be expected to provide better understanding of the accuracy of density equipment in the near future. A comprehensive calibration study was made at Charlottesville, Virginia, in the summer of 1965 to be reported on in the near future.

Equipment Ownership

The results of the HRB Nuclear Measurement Questionnaire and the forthcoming ASTM study indicate that most highway agencies are active to some degree in the application of nuclear equipment. Nearly all users of portable devices both in the highway field and otherwise own the equipment outright. There are a few reported leasing arrangements but these are mostly in the building construction industry. The only currently available, continuous recording device is available on a lease basis only and is not for sale. Its use, as yet, has been rather limited by the economics of the operation. It is estimated that not more than 5 % of the current total use is on a lease basis.

Current Research and Development

In the area of equipment development there have been few important ideas presented other than by commercial equipment manufactures for several years. With the exception of the combination moisture-density unit whose concept is not really new, the manufacturers have concentrated on modification and improvement of existing devices, in the soils field. The many developments in other fields are outside the scope of this paper. The improvements have generally been aimed at increasing the precision and reliability, both electronic and mechanical of the units. In some cases the equipment has been made smaller and more portable. Current models from all manufacturers are appreciably more precise, durable, reliable, and attractive than their predecessors of a very few years ago. Obsolescence of existing equipment that has been little used is becoming a problem in some highway departments and the size of the capital investment makes is an important one. Some installations that have been used for little more than personnel training are already obsolete for field control use.

Calibration of the devices is still generally unsatisfactory, particularly with regard to density measurements. Most manufacturers are recommending that the purchaser establish his own calibration curves for the materials used in his locality. The theoretical study mentioned previously may mitigate this problem but more work is needed.

Most of the current research in soil moisture and density testing by nuclear techniques appears to be concerned with the adaptation of these ideas to compaction control methods under the conditions peculiar to the individual agencies. Recent basic research, with the exception of that previously discussed, is principally concerned with the use of nuclear devices to study variation and change of soil moisture and density within soil masses.

DENSITY AND ASPHALT CONTENT OF BITUMINOUS PAVEMENTS

Although most of the research concerning the measurement of density and hydrogen content of highway materials has been in the area of soil mechanics, the same principles also apply in the area of bituminous concrete.

Since the nuclear method provides fast, non-destructive testing of large volumes, its use should expedite the determination of density and asphalt content of bituminous concrete to a great extent. Conversely, the conventional test procedures are lengthy and destructive, and require supplemental laboratory tests; these features preclude on-the-spot control, which is essential in specification enforcement.

DENSITY

The majority of the research performed to date with nuclear equipment in the area of bituminous concrete has dealt with density determinations, because this property is probably harder and more critical to control than is asphalt content. Two state highway departments, Colorado and Connecticut, are using nuclear equipment to control the density of asphaltic concrete. Two others, New Mexico and Utah, are using it for non-specification check on uniformity (1).

Calibration

One advantage in using nuclear density devices on bituminous concrete that does not occur in soil testing is the straight forward method of calibration. Probably a major reason that nuclear devices used for compaction control of subgrade materials have not been accepted more enthusiastically is that their results have not agreed with those of the conventional test methods such as the sand cone, oil, water balloon, etc. These conventional tests have, in all likelihood, been as far from the true density as have the nuclear tests. However, in bituminous concrete a core can be removed from the pavement and a more definite volume determination made, which results in a closer approximation of the absolute density.

Past Research

Sloane (2) at the University of Arizona found that because of excessive gamma ray penetration, attempts to develop a calibration curve for the Nuclear-Chicago surface density gauge were not successful. He then developed a filter of aluminum and steel plates bonded to asbestos sheets to serve as both a gamma ray shield and a thermal insulator. This shield reduced the gamma ray penetration without too great a loss in the sensitivity of the gauge. He found reasonable results with this equipment (accuracy of 1 percent with ten 2-minute readings and 2 percent with three 2-minute readings) but decided to develop a more sensitive surface gauge to use on pavements only. The Arizona gauge used a 3-mc radium-beryllium source and G/M tubes for detectors. Styrofoam was used to insulate the G/M tube and this performed quite well up to 260° F. Using this gauge, Sloane was able to get an accuracy of 1 percent with five 2-minute readings. Among his other findings was that surface texture is the principal factor limiting the accuracy of the pavement density measurement by nuclear methods; then in turn, is related to aggregate gradation.

Hughes and Ralston (3) of the Virginia Department of Highways agreed with Sloane concerning the effect of texture on calibration. The texture is most important in base courses because of the coarseness of gradation. The surface courses, having a finer gradation, show little effect of texture. However, it was reported that the calibration curve changes considerably from project to project, so that a calibration should be obtained on each project. They found that by establishing a calibration curve for each project and taking four 1-minute counts at each location, nuclear densities of 90 percent of these individual samples would be within ± 2.0 percent of the conventional cored density.

Problem Areas

One main difficulty in using the standard nuclear density gauges to test bituminous concrete in the past has been the temperature limitation, which is about 140° F. This limitation has been removed by the availability of density gauges which tolerate temperatures on the order of 300° F. These should be widely accepted in the bituminous concrete field because they allow measurement of density on hot pavements while density can still be controlled and not just checked.

Other shortcomings include the difficulty in obtaining a single calibration curve that can be used on all projects and the time consumed preparing the surface so that surface voids are filled.

Present and Future Research

Research utilizing the new asphalt density gauges is being performed by various agencies around the country.

Brown (4) of the Colorado Department of Highways presented a paper concerning the development and testing of a new asphalt density gauge at the 44th Annual Meeting of the Highway Research Board. He found that roller patterns can be established to determine the proper number of passes to be placed on a pavement with each roller. He obtained good correlations between nuclear and conventional densities on all but open-graded mixes having a significant amount of surface air voids. He found the greatest advantage, other than a testing time savings, is testing while the pavement is still hot, thus allowing additional compactive effort to be applied if necessary. It is expected that Colorado will use this equipment for density control in the future.

Dr. Stephens of the University of Connecticut is conducting research with an asphalt density gauge which will include such variables as layer thickness, density range and aggregate type. He is also exploring the importance of cracks and is charting areas of varying density.

The Bureau of Public Roads has also been working with this equipment recently but no results have been published.

The Virginia Research Council (5) used a slightly different approach in 1964 in that nuclear testing was used in conjunction with statistical quality control techniques to control the density of asphaltic concrete. A control strip was laid on the roadway and an acceptable rolling pattern established by the use of an asphalt gauge. A number of nuclear tests were then made on the control strip and the average density determined. Ninety-eight (98) percent of this average was then used as a specification limit to control the density in other sections for the remainder of the project. The concept is based on statistical quality control techniques which, because of the number of tests necessary, can only be accomplished on a practical basis through the rapid techniques provided by nuclear equipment. The results of this study are very promising and a recommendation was made to the Virginia Department of Highways that bituminous concrete density be controlled by this procedure in the future. This recommendation has been accepted and will be used on a limited basis.

Cost

The cost of the nuclear asphalt density gauge is about $ 2,500. and it can be used in conjunction with the scalers used with the soils nuclear equipment.

ASPHALT CONTENT

The Past Research

Work has quite recently become accelerated in the measurement of asphalt content by nuclear means. Two papers were presented at the annual meeting of the HRB and one at ASTM this year. But the first work in this field was performed some time ago by Lamb and Zoller (6) using a radium-beryllium source for fast neutrons and a boron-fluoride 10 tube for detection of the slow neutrons. They reported their results were too variable and the equipment too costly to replace conventional extraction tests at that time.

Although Varma and Reid (7) indicated at the 43rd Annual HRB Meeting that asphalt content could be checked in the field with existing moisture content gauges, it seems that this approach is impractical from the viewpoint of specification enforcement because on the road it is an "after-the fact" test. If control is to be achieved, it should be accomplished at the plant.

Howard andCovault (8) found that neutron backscatter techniques did not prove feasible for measurement of asphalt content of in-place bituminous concrete pavement. They do acknowledge that asphalt content can be determined at the plant if the neutron backscatter measurement can be made in a controlled environment.

LaChaud and Paquet of France have reported that it appears feasible to use the principle of neutron thermalization to determine asphalt content.

Work done at Ohio State University indicated that moisture in the asphaltic concrete gave erroneous readings, since, naturally, neutrons cannot differentiate between hydrogen ions of asphalt and those of water.

Present and Future Research

Walters (9) of the Colorado Department of Highways presented a paper at the 44th Annual Meeting of the Highway Research Board concerning the use of a commercially available surface moisture gauge to test for asphalt content in the field. The nuclear gauge uses the thermalized neutrons interacting with a fresh asphalt sample of approximately 15 pounds placed in a static environment to read the hydrogen content in the asphalt mix. He reports that if either a change in penetration grade or aggregate grading is made, a new calibration curve is necessary. Testing time for this procedure is approximately twenty minutes. Although this new method has not been adopted as a standard procedure in Colorado, it is being used as a quick field check with good results.

Presently, three highway departments - Colorado, Florida, and Oklahoma (1) - are performing research with nuclear equipment to determine the feasibility of controlling asphalt content.

An asphalt content gauge which can be installed at the plant is being developed commercially. The development of this equipment naturally depends on the needs of the highway industry and until the industry realizes it needs a more positive method of controlling asphalt content, this equipment will probably remain in the developmental stage.

CONCLUSION

In conclusion, it has been proven feasible to determine bituminous concrete density and asphalt content by nuclear means. And it is apparent, from the research reported, that nuclear methods will increase in acceptance as experience is gained with their use. The problem areas are being solved, confidence is being gained, and testing speed-up is being sought. The future should see more of this equipment being used in specification enforcement.

SPECIAL USES FOR NUCLEAR ENERGY IN HIGHWAY ENGINEERING

There are many special uses of nuclear energy in highway engineering. Some of these uses have already been realized, as for example, the use of radioisotopes as tracers for concrete mixing studies. Some uses are at the point of being realized fully, as for example, the nuclear devices for nondestructively measuring and controlling the density and moisture content of compacted base materials. Some uses are still in the research, development, or planning phases, as for example, the use of nuclear explosives for large-scale excavation. Many potential uses exist which have not yet been studied. These special uses of nuclear energy are discussed on the basis of the principle that is involved.

Nuclear Explosives

There are two potential uses of nuclear explosives in highway engineering that have received much study as part of the Plowshare Program funded by the Atomic Energy Commission. These potential uses are large-scale excavation projects for canals and highways and the production of crushed rock for use as aggregate for highway construction materials. The studies to date have identified those parameters pertinent to these uses for underground nuclear explosions, such as optimum burial depths, size and shape of the excavation, radiation safety considerations, and size of rock fragments. Sufficient information now exists on this subject to prove that these applications are technically feasible (10). Realistic cost estimates can now be made for specific proposed applications. In general, it can be said that the use of nuclear explosives for either excavation or aggregate production is economically more attractive as the size of the proposed application gets larger. This is primarily due to the large fraction of fixed costs associated with the use of these devices independent of their size.

A proposal has been made to demonstrate the use of nuclear explosives for excavation purposes in California. This project is called "Project Carryall". The funding of this project is still pending. The use of nuclear explosives has also been much discussed for use in excavation for the proposed alternate Panama Canal. It is likely that an actual application of nuclear explosives will be made within the next few years. Routine use of these devices for such purposes will likely come somewhat later - perhaps within the next decade. An extensive annotated bibliography on the testing and peaceful uses of nuclear explosives is available (10).

Radioisotopes as Sources of Power

Radioisotopes are useful as sources of energy. They have primarily been used to date to supply light or electrical energy. They are somewhat less practical for supplying heat and have not yet been used for this. (The final energy form is what is referred to here.) The radioisotope is useful as a source of energy because it supplies energy at a very constant rate for long periods of time; it supplies this energy reliably, independent of changes in ambient conditions; and it requires essentially no maintenance after initial installation. These advantages have led to the use of radioisotopes as sources of energy in cases where unattended, reliable operation of equipment is required for long periods of time.

Radioisotopes as sources of electrical energy have not been routinely used in highway engineering to date. One particularly promising area of application would appear to be in power supplies for traffic warning and control devices. Examples of this might be for instruments that monitor for ice on roads or bridges and monitor and control traffic. The greatest advantage of radioisotopes as sources of power are realized in applications where small amounts of reliable power are needed for long periods of time without maintenance.

In certain cases, radioisotopes have been used as sources of light for illuminating signs. Unfortunately, the amount of light output obtained with available technology has not been sufficient for general purpose highway traffic signs. Unless advances are made in this technology, the practical use of this technique will be limited to those applications in which relatively small light output is required. A "state-of-the-art" review of isotope power is given by Bloom (11).

Radioisotopes as Tracers

Radioisotopes are very useful as tracers because of their extreme versatility of application. One may trace everything from elements such as calcium in cement to complicated mixtures such as the aggregate used in a particular concrete mix. It is difficult to assess the value of the radioisotope as a tracer because the primary application of tracers is in research rather than routine measurement or control. The radioisotope as a tracer has already been extensively used to study highway engineering problems such as the performance of mixing equipment, the mapping of groundwater flow, and the study of the movement of subsurface material. The role of the radioisotope as a tracer for research into highway engineering problems will probably be enlarged as the highway researcher gains more familiarity with this powerful tool.

It is also possible that the radioisotope might be useful as a tracer for routine measurement and control of parameters of interest to the highway engineer. Such things as pavement thickness, asphalt content in bituminous concrete mixes, and cement content in concrete could be measured and controlled by the addition of appropriate short-lived radioisotope tracers. Unfortunately, this type of application involves the use of radioactivity in natural, uncontrolled environments which has not been done on a routine basis to date. This type of application is technically feasible and safe but will probably not be used until the public is better informed and more receptive to such ideas.

To circumvent this public opinion problem while maintaining the high sensitivity of nuclear measurement methods, it is possible to use inert tracers in conjunction with "activation analysis". A representative application of this type is the measurement of stream flow reported by Gardner and Dunn (12). It should be noted that though this technique alleviates the necessity of putting radioisotopes into uncontrolled environments, it has the disadvantages compared to radiotracer techniques of: Less accuracy, more expense, more experimental effort required, and one must wait a considerable time for the experiment results. Tracing applications are discussed in the book by Kohl, Zentner, and Lukens (13).

Radioisotopes for Gauges.

Radioisotopes are very useful as signal sources in gauging devices. Examples of these broad areas might include gauges for the measurement of the soundness of wood, gauges for monitoring the amount of snow in remote areas, and gauges for the continuous measurement and control of asphalt content in mixes at asphalt plants. Gauging applications are discussed in the book by Kohl, Zentner, and Lukens (14).

There are many other potential gauging applications to highway engineering problems. Two particularly promising areas of broad applications appear to be in the routine testing of construction materials and the continuous monitoring of weather and other traffic control factors.

Radioisotopes for Radiography

Radioisotopes are extensively used in radiography applications where portability and cost are the primary concerns. It is probable that potential applications of radiography exist in the non-destructive testing of highway construction materials. An example of this might be the determination of the number and position of steel reinforcing rods in concrete. This subject is also treated by Kohl, Zentner, and Lukens (15). There are also several papers on this subject in the Symposium on Radioactive Isotopes and the Construction Industry (16).

Miscellaneous Principles and General Conclusions

There are many miscellaneous nuclear energy principles that have not been discussed here. The choice of material in a discussion of this type must necessarily be somewhat subjective, but every effort has been made to include the nuclear energy principles most promising to the highway engineering field. The use of portable nuclear reactors as a power source in remote areas has been mentioned as a possible area of interest to highway engineers. This application has been considered by the Army. It is concluded here that this application is not very pertinent to highway engineering, since cost is a controlling factor to the highway engineer. Activation analysis has also been discussed for use in highway engineering programs. One disadvantage of this technique is that in-place, portable analysis by this principle must await the development of high-intensity, portable sources of neutrons. A study has been made by the University of Minnesota on the possible use of nuclear reactor waste materials for the removal of snow and ice from highways (17). It was concluded in this study ~~that~~

that the total heat yield from existing waste fission products is too small for this application and also the costs would not be competititve with existing methods of snow and ice removal.

It is concluded that the future for nuclear energy principles in the highway engineering field is bright but not blinding. There are many potential applications of nuclear energy principles, but successful applications will be accomplished only by perseverance and hard work. It would appear that the biggest problem to the increased application of nuclear energy principles to highway engineering is the lack of familiarity of the highway engineer with nuclear energy principles.

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