General Discussion

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THE excellent papers on soil-cement mixtures cover a wide range of interests and viewpoints regarding this unique construction material. More than a quarter century has passed since the first scientifically controlled soil-cement road was built in South Carolina in 1935 (1). Incidentally, this road is still giving excellent service, carrying traffic loads many times greater than anticipated.

The summary of soil-cement test procedures by Norling gives an excellent review of the subject which can well serve as a standard reference of the basic principles governing soil-cement mixtures (also see 2).

The mix design for cement-treated bases presented by Hveem and Zube summarizes the eminently successful procedure used by California for many years. They have used these granular cement-treated bases for concrete pavements to prevent pumping and joint displacement due to consolidation. One of the specifications for cement-treated bases, which is the same as for California Class 2 aggregate base, includes the following gradations:

Sieve Size	Percent Passing
1 in.	100
3/4 in.	90-100
No. 4	35-55
No. 30	10-30
No. 200	3-9

This gradation specification, together with strength requirements and other tests, classifies the California cement-treated base as one in which concrete and cement technology govern most aspects of mix design requirements. An exception is the recognition of influence of degree of compaction as judged by optimum moisture and maximum density. Therefore, these test procedures are not comparable to those required for materials that contain substantial quantities of fine-grain materials passing the No. 50 and No. 200 sieve which also possess significant test constants and which are classified as soil-cement mixtures.

The British practice summarized by Maclean and Lewis of the Road Research Laboratory shows a considerable difference between British and American basic thinking and philosophies. Some of these differences are explained as being due to specific soil and climatic conditions in Great Britain. For example, there are relatively few soil categories in this geographical area and conditions of rather continuous rain and high humidities prevail. These conditions led to rather simple, straightforward strength determinations and criteria. However, experience has brought forward modifications of these criteria, as pointed out in the subject paper.

Several phases of British practice have been of interest through the years. One phase is the generality of considering a cement content of 10 percent as a maximum and a tendency to emphasize lower cement contents. A common practice in the United States is to add sufficient cement to meet mix design criteria after conducting the standard ASTM wet-dry and freeze-thaw tests. These criteria include brushing losses, gain in strength with increases in age and cement contents, volume changes, and moisture changes. After this cement requirement is determined, the next step is to prepare a construction cost estimate to determine the economic feasibility of the project.

This same approach is used in much of the research involved. For example, some of the black, organic surface soils of the United States may require 16 to 18 percent cement to meet the usual criteria. This presents the need of additional work to evolve a more economical answer. The cement requirements of underlying horizons are determined and they are usually less. Can a soil borrow pit be established nearby in one of the favorable horizons and this soil used for a soil-cement pavement on top of the black, organic surface soil? Another possibility often present in the general geology of the United States is the nearby location of a more favorable surface soil that may be used for a soil-cement pavement on top of the black, organic surface soil. Suitable economic studies are made of the various possibilities. There are cases, of course, where sufficient suitable gravel or crushed stone is available on the site to provide the most economical construction. However, just because the surface soil is black with a high organic content, it is not rejected as an economic possibility. An early 1936 pioneering project by the Missouri State Highway Department, using a black, heavy clay, illustrates practical construction procedures as well as economical results (3).

In the case of high organic content of sandy soils, occurring in coniferous tree bearing areas, practical and economical answers have been found in the addition of calcium chloride or clay (4, 5).

Whether or not the British climate will permit the use of moisture-density control as practiced in the United States is a question that can only be answered by an on-the-job study. However, the northwestern United States has much rain and high humidities and moisture-density control is entirely practical there. With suitable construction specifications, moisture-density control can be used successfully in England for most of the normal paving construction season applying to other types of paving.

George and Davidson present interesting data for one construction project in Iowa. Because only one major soil is involved, the conclusions drawn regarding cement contents cannot be extended to general criteria. The procedures used in analyzing data are important, however.

Packard and Chapman compare freeze-thaw and wet-dry tests and durability and, as justification and authority for such comparisons, cite early papers on the subject (6, 7), the ASTM Standard wet-dry and freeze-thaw tests (8), and the PCA Laboratory Handbook (9) giving criteria for cement contents required for construction.

This is an unintentional but most unfortunate interpretation and understanding of these references and the basic principles involved in soil-cement mixtures and their testing. The writer was chairman of the sectional committee that wrote and sponsored the ASTM test procedures. He was therefore familiar with all details of the procedures and their intent. Further, he is the author of the test criteria cited and of their purpose and uses. He also is the author of two papers (2, 10) that discuss all these details, having been involved in the development of soil-cement mixtures from their inception in 1935 until 1951, when he was assigned other responsibilities.

Introduction of the durability concept contradicts directly what is later stated as the purpose of the investigation and subsequent presentation of data. It also contradicts the facts presented in the Norling paper.

Packard and Chapman state that the purpose of the investigation covered two areas of interest, as follows:

1. Measuring techniques that might be developed and evaluated to replace the brushing technique and accompanying soil-cement loss criteria used in connection with the Standard ASTM wet-dry and freeze-thaw procedures.
2. A shorter series of alternate wet-dry and freeze-thaw procedures to lessen time of testing.

Investigations in these two areas are highly desirable. One of the original criteria established concerned itself with volume change during testing. This criterion was evidence that the cement and soil had reacted together to form a structural material that was not disrupted by the high expansive or shrinkage forces of clay.

The data presented by Packard and Chapman on length (volume) change give preliminary evidence that it may be possible to establish criteria for length change that can replace the brushing technique and criteria. This would be worthwhile, as the measuring technique is more sophisticated and accurate. However, comparison must be made of test results on many more soils and by using the ASTM Standard procedures for wetting and drying and freezing and thawing. Also, as emphasized by Packard and Chapman, the adequacy of cement contents so determined must be verified by field performance over a considerable period of time. In no case does the writer consider the wet-dry and freeze-thaw tests as durability tests. Durability must be demonstrated by long-time field exposure. No laboratory procedure can duplicate weather for any location—the variables are too great. The expansion and shrinkage forces that may be produced by clays can be, and often are, many times those produced by freezing water. Also, the procedures evaluate soil and cement reactions, soil clay minerals, pozzolanic reactions, soil and cement hydration products, and other surface chemistry phenomena.

The other data presented on compressive strength, pulse velocity, and rate of weight loss as measures for developing criteria present many ambiguities and reversals. They appear to hold little promise of practical use.

The other item of interest, a shortened wet-dry and freeze-thaw period, presents many problems. Concrete technicians have worked with such procedures for many years; there are several recognized ASTM procedures. The concrete technician has learned that any small change in the procedure changes results so they cannot be compared. It would seem that with soil-cement mixtures having thousands of variations in physical and chemical composition, as compared to a few in concrete, the experience of the concrete technicians could well be used to demonstrate that changes in the soil-cement procedures could best be left alone. However, appreciably more data are needed on clay mineral composition, pozzolanic reactions, hydration products, classification of soils in terms of length change differences, criteria for length change for various soils, and the reproducibility of test procedures and results before changes in the test procedures can be considered and evaluated.

The extensive discussions and explanations of freezing and thawing, durability, etc., are confusing and contradictory. Extensive data in the literature demonstrate that soil-cement technology is unique and entirely different from the concrete technology repeatedly cited and compared by the authors. The important finding of the paper relates to the specific data presented on length change and the simple, rational, short, accompanying explanation. It permits a conclusion that with further, careful, extensive work, length change criteria might be developed as a replacement for the brushing technique in the present, widely accepted and most successful ASTM procedures.

The paper by Herzog and Mitchell is a valuable contribution to soil-cement literature. They include this important comment:

> Consideration of the nature of cement hydration, the physico-chemical characteristics of clays, and lime-clay interaction, leads to the hypothesis that during the hydration of a clay-cement mixture hydrolysis and hydration of cement could be regarded as primary reactions which form usual hydration products....

Their recognition of clay minerals and the reaction products of these clay minerals and cement is a most important, fundamental approach to a study and evaluation of soil-cement mixtures. Continued, extensive research in these areas is justified by the data obtained and analyzed by Herzog and Mitchell. This can be the most valuable research area for soil-cement mixtures which will result in an evaluation and delineation of the basic principles governing soil-cement mixtures.

The work reported by Laguros and Davidson also deals with reaction products of soils, cement, and compounds of sodium, calcium and magnesium and commercial lime. Their physical test results show that extensive chemical reactions take place. Investigation by X-ray diffraction to determine the hydration products produced would be most valuable. Inclusion of various clay minerals would also be valuable.

In the past, other investigators have explored these areas and reported on their importance and significance (11, 12, 13, 14).

The soils engineer and the cement chemist can combine their respective fields most effectively to make a productive team for research of this nature. Physical tests and results will no longer suffice to evaluate soil and cement reactions. As shown by Herzog and Mitchell, a new approach is now possible.

REFERENCES

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Discussion

R.G. PACKARD and G.A. CHAPMAN—Mr. Catton's remarks are primarily concerned with principles involved in the development and use of the standard soil-cement testing procedures. His discussion of these principles appears to be based on his interpretation of the term "durability testing" as "climate simulation testing" only.

This definition is not the intent of the authors. As used by them, the term "durability testing" does not imply climate simulation except where specifically stated, but refers to a general classification of tests employed to evaluate various physico-chemical properties that may not be completely evaluated by "strength tests." Because these properties may influence the quality of field performance, their evaluation is stated as a major objective in mix design procedures. It is recognized that the standard tests are not climate simulation tests, and the associated PCA criteria do not relate to any specific climatic conditions. The paper is certainly ambiguous if these points are not clarified.

Mr. Catton also states that the reliability of a new procedure depends on verification by long-term field performance. This is true. Verification of a procedure can be established directly by comparison with field performance; or, it can be established indirectly, but more quickly, by correlation of results with the reliable standard tests and PCA criteria for a large number and variety of soils.

The authors agree that development of accelerated procedures for obtaining the same cement factor determined by standard tests presents many difficulties. However, the need for faster procedures justifies the attempt.

Items such as the determination of compressive strength and pulse velocity, discussion of reactions during freezing-thawing and wetting-drying, and notations of similarity of some reactions to those of concrete, are worthy of reporting and useful to the objectives of the study.