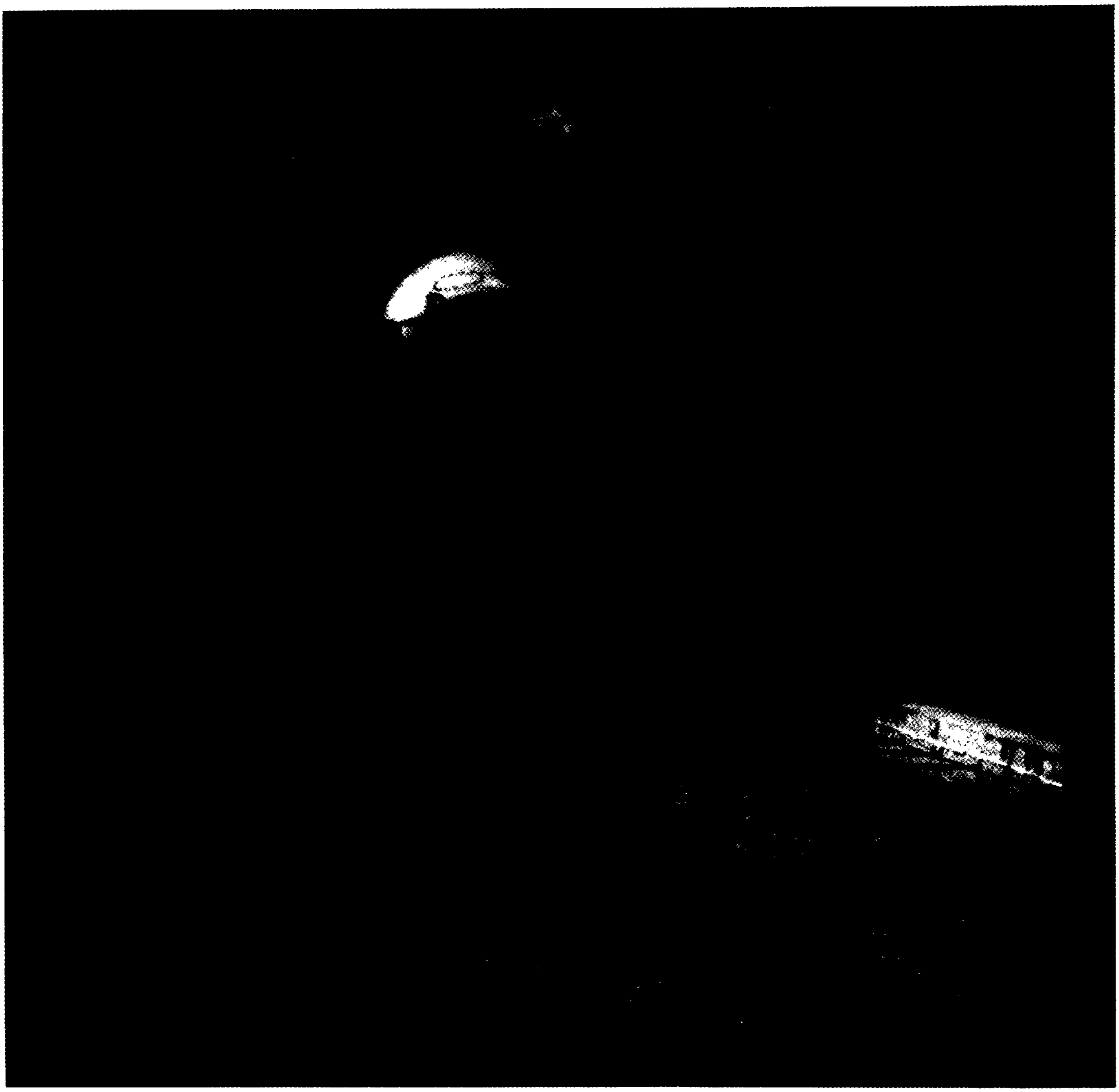
CONCRETE PAVEMENTS



Compilation 30

American Concrete Institute

Concrete Pavements

ACI Compilation 30

Contents

Preface

ACI Compilations combine material previously published in Institute periodicals to provide compact and ready reference on specific topics. The Material in a compilation does not necessarily represent the opinion of an ACI technical committee — only the opinions of the individual authors. However, the information presented here is considered to be a valuable resource for readers interested in the subject.

Terry W. Sherman
Chairman, ACI Committee 325
Concrete Pavements

On the cover: Fast track techniques are a relatively new innovation in the concrete paving industry, now in its second century. This method allows traffic to use pavement that was placed only 12 hours earlier; economical concrete mixes that provide high strength in less than 24 hours have made this possible. Photo was taken during a recent paving project in Michigan.

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COE Design of Cement Stabilized Base Courses for Airfield Pavements

by William N. Brabston and Raymond S. Rollings

The U.S. Army Corps of Engineers (COE) is the primary Department of Defense agency responsible for the design and construction of Army and Air Force airfields. In this role COE develops design criteria, guide specifications, and other technical guidance information that are used for pavement design and contract specifications preparation.

In the past few years, COE has made some changes to and introduced new concepts in its approach to the design of pavements with cement stabilized base courses.

Design manuals

Four technical manuals (TMs) are applicable in the design of cement stabilized base courses:

- TM 5-822-4 Soil Stabilization for Pavements
- TM 5-825-2 Flexible Pavement Design for Airfields
- TM 5-825-3 Rigid Pavements for Airfields
- TM 5-818-2 Pavement Design for Seasonal Frost Conditions

Design cement content

TM 5-822-4 provides guidance on selection of design cement content. Included are gradation requirements, initial cement content selection criteria, and strength and durability criteria. This manual is currently undergoing revisions that are included herein. COE gradation requirements for cement stabilized base courses are shown in Fig 1. These criteria are basically a relaxation of the conventional unbound base course criteria. For comparison, the Portland Cement Association (PCA) gradation requirements for a cement-treated aggregate base (CTAB) are also shown in Fig 1.

Soil classification is based on ASTM D 2487. A further stipulation is a maximum plasticity index between 20 and 30, the specific value depending on the fines content (percent finer than the No. 200 sieve).

Once it has been determined that a base course material is a candidate for cement stabilization, an initial design cement content is selected based on the soil classification. Recommended initial design cement content values for various soil types are shown in Table 1.

Soil is then prepared for laboratory compaction tests at the initial estimated cement content. Moisture density tests are conducted following ASTM D 1557. Specimens are then molded at the maximum dry density or appropriate percentage thereof and at optimum water content or appropriate design field water content for strength and durability tests.

The strength of the specimens is determined by unconfined compres-

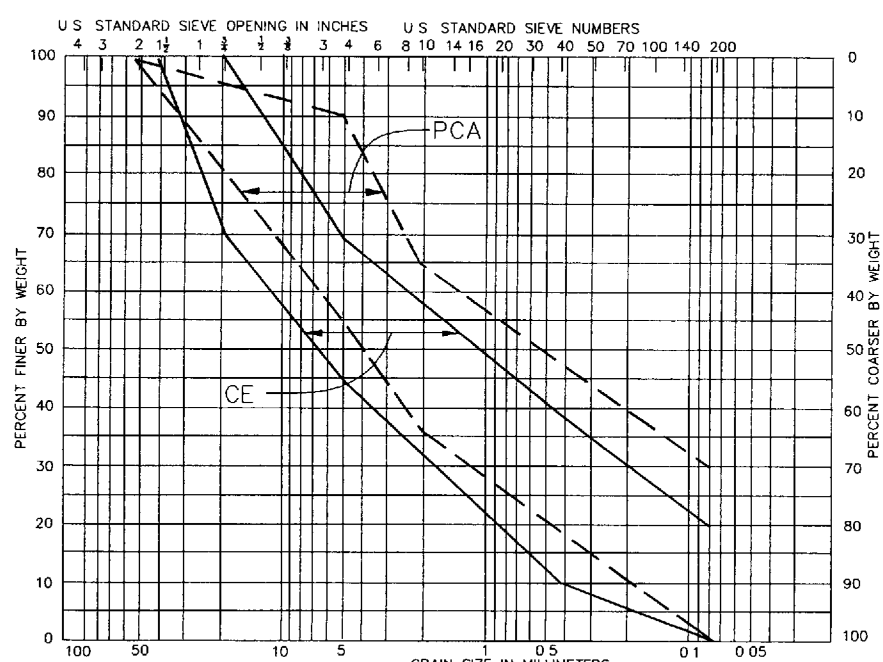

Fig. 1 — CE and PCA gradation requirements for cement stabilized base courses.

Table 1 — Estimated cement requirement for various soil types

Soil classification	Initial estimated cement content (percent dry weight)
GW, SW	5
GP, GW-GC, GW-GM, SW-SC, SW-SM	6
GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP	7

Table 2 — Requirements after 12 cycles of durability tests

Type of soil stabilized	Allowable weight loss (percent of initial weight)
Granular, PI < 10	11
Granular, PI > 10	8

Table 3 — Equivalency factors for cement stabilized base courses

Material stabilized	Equivalency factor
GW, GP, SW, SP	1.15
GC, GM	1.00

sive strength tests. Durability is determined by wet-dry or freeze-thaw tests (ASTM D 559 or D 560) as appropriate. For both the strength and durability tests, specimens are prepared in triplicate at the initial design cement content and at cement contents two percent above and two percent below that value. Thus a total of 18 specimens must be prepared. Before testing all specimens are moist cured in a humid room for 7 days. Results of the strength tests are then compared to the criteria for minimum unconfined compressive strength for a cement stabilized base course. The strength must be at least 750 psi for a flexible pavement and at least 500 psi for a rigid pavement. Durability tests consist of subjecting the specimens to 12 cycles of wetting and drying or freezing and thawing depending on which type of test is conducted. In areas where frost design is a consideration the freeze-thaw test would be appropriate, whereas the wet-dry test might be run in non-frost areas.

In the wet-dry test, each cycle consists of a 48 hour period during which the specimen is submerged in tap water for 5 hours and then dried in an oven at 71 C (160 F) for 42 hours. It is then cleaned with a wire brush to remove loose material that may have become unbonded. After 12 cycles (24 days) the total amount of weight loss is calculated and compared to the weight loss criteria in Table 2. This table indicates the maximum allowable weight that can be lost from a specimen after 12 cycles of either the wet-dry or freeze thaw test.

In the freeze-thaw test cycle, each specimen is placed in an environmental chamber at a constant temperature of not more than −23 C (−10 F) for 24 hours, thawed in a humid room at 21 C (70 F) for 23 hours, and then brushed. These tests are considered to be a measure of the durability of a cement stabilized material when it is subjected to similar climatic conditions in a pavement structure.

To qualify as a cement stabilized base course, the material must meet both strength and durability criteria. The final design cement content is the lowest value of specimens meeting both criteria.

Flexible pavements

TM 5-825-2 provides guidance on the design of flexible airfield pavements. Designing a cement stabilized base course involves first designing a conventional flexible pavement with an unbound granular base course and then applying a reduction factor to the unbound base thickness to determine the thickness of the stabilized base. Equivalency factors for cement stabilized base courses are indicated in Table 3.

For example, if a pavement design calls for 11.5 in. (290 mm) of unbound base, then 10.0 in. (250 mm) of cement stabilized material may be substituted for the unbound aggregate. This table as currently presented in TM 5-825-2 does not include equivalency factors for soils classified as SC or SM or for those soils having a double classification symbol, i.e. GW-GC. However, this deficiency will be addressed in the next revision to the manual. The revisions will present the following equivalency factors for these soil types:

- 1.15 for GW-GC, GW-GM, SW-SC, and SW-SM
- 1.00 for GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC

As shown, only about half of the soil types qualify for an actual reduction factor (1.15). The factor for the remaining materials is 1.00 indicating that the materials can be used in a base course if they meet strength and durability criteria but no thickness reduction is allowed. Therefore, a locally available and more economical material that does not meet conventional base course criteria may be used in the base course if it is properly stabilized.[1]

The use of equivalency factors is an artifice to accommodate theoretical limitations of the COE design method in TM 5-825-2. This design approach uses Boussinesq theory (homogenous elastic half-space) and is unable to account for layered structures with significantly different stiffness characteristics. Consequently, equivalency factors provide a simple usable design method that, however, is not without theoretical drawbacks.

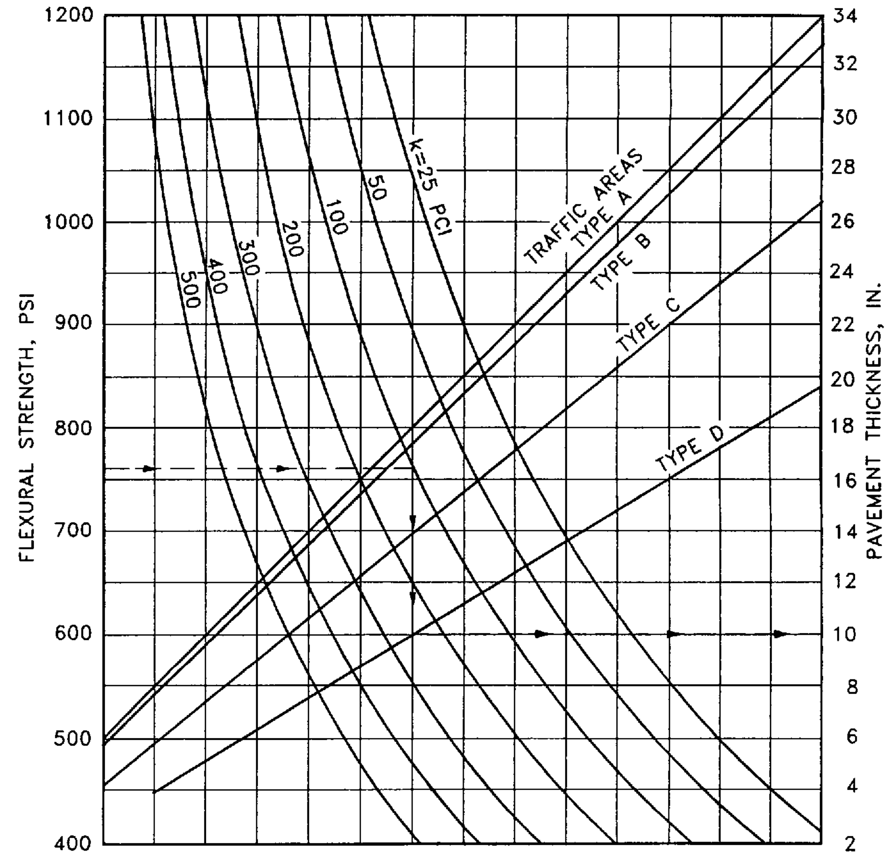

Fig. 2 — Plain concrete design curves for modified heavy load pavement.

Rigid pavements

TM 5-825-3 provides guidance for the design of rigid pavements. Background information for these design procedures may be found in References 2 and 3. Design procedures for five types of concrete pavements are addressed: plain, reinforced, fibrous, continuously reinforced, and prestressed. In all of the design procedures, the thickness of the stabilized base course is a selected value (6 in. [150 mm] minimum) and the slab thickness is determined as a function of the base thickness, the modulus of elasticity of the stabilized material, and other design parameters. Thus the design procedures may involve iteration between slab thickness and base thickness since the elastic modulus is essentially a fixed value determined by the quality of the stabilized material.

For plain, reinforced, fibrous, and continuously reinforced concrete design, a stabilized base is treated as a low-strength pavement and the concrete slab is considered as an overlay. Thickness design of the slab involves a modified, partially bonded, rigid-overlay-equation that theoretically allows a reduction in the slab thickness due to the structural support provided by the stabilized base layer. In actuality, a significant thickness reduction is achieved only if the base course has a high elastic modulus value (>2,000,000 psi [14,000,000 kPa]) as would be the case for a lean concrete base material. Use of the overlay equation for the design of plain concrete is presented below. The overlay equation is applied in a similar fashion for thickness design of reinforced, fibrous, or continuously reinforced concrete on a stabilized base course.

In this procedure, an initial design thickness is first developed for a plain concrete slab directly on an unstabilized subgrade. This thickness value is then used in the overlay equation to determine a final thickness based on a slab on a stabilized base. Design parameters used to develop the initial thickness value are: concrete flexural strength R; modulus of soil reaction k; and aircraft load factors such as gross weight pass level and pavement traffic area. A typical set of design curves for an Air Force modified heavy-load pavement is shown in Fig 2. These curves represent specific aircraft types and load factors.

Next the modified, partially bonded rigid overlay equation is used to develop a final thickness design value. This equation is:

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left(\sqrt[3]{\frac{E_b}{E_c}}\, h_b\right)^{1.4}}$$

where:
h_o = thickness of plain concrete slab on stabilized base course
h_d = initial thickness design of slab on unstabilized subgrade
E_b = modulus of elasticity of base material
E_c = modulus of elasticity of concrete, usually taken as 4 x 10^6 psi
h_b = thickness of stabilized base course

For example, the design thickness for a concrete slab with a flexural strength of 760 psi (5240 kPa) on a subgrade modulus of 100 pci (2.8 kg/m^3), Type D traffic area, is 10.0 in. Assuming that design calls for a cement stabilized base course 10 in. thick having a modulus of elasticity of 400,000 psi (2,800,000 kPa), the

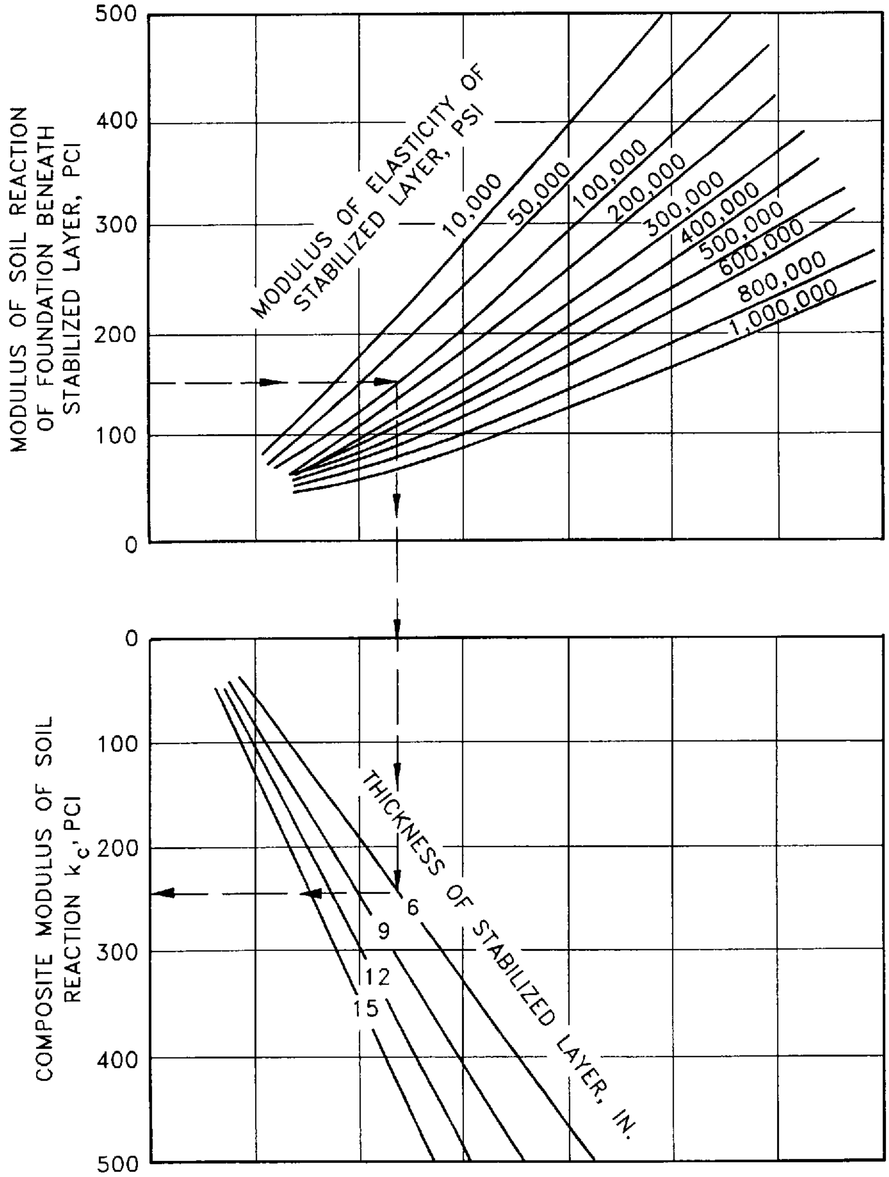

Fig. 3 — Composite modulus of soil reaction.

equation is entered and the final design thickness is determined to be 9.7 in. (246 mm). Thus there is no significant reduction in design thickness. (If the base were a lean concrete of equal thickness and a modulus of 2,000,000 psi [13,800,000 kPa], then the final design thickness based on the overlay equation would be 9.4 in. [239 mm].)

The basic COE concepts for rigid pavement design were developed in the 1940s and 1950s when the best available analytical model was the Westergaard edge loaded model represented by an elastic plate supported on springs. However, the model could not accurately represent a layered structure such as a concrete pavement over a stabilized base and a subgrade. Consequently, the initial design approach for stabilized bases converted the stabilized base and the subgrade into an "equivalent" single spring constant *k* or a composite modulus of elasticity. This approach is still used with continuously reinforced and prestressed concrete pavements. When increasingly strong and stiff cement stabilized bases ("econocrete," lean concrete bases, roller-compacted concrete bases, dry-rolled concrete bases, etc.) became more widely used the modified overlay equation was introduced. These various design subterfuges were necessary because of the design limitations of the Westergaard model. More recent work with layered elastic and finite element theory offers a more theoretically sound method of examining the effect of cement stabilized bases under rigid pavements.

The design of prestressed concrete pavement is very complicated and requires several iterative procedures. When a cement stabilized base course is involved in pavement design, the structural contribution of the base is included by use of a composite modulus of soil reaction. This value is determined graphically based on the modulus of soil reaction of the subgrade below the stabilized layer, modulus of elasticity of the stabilized layer, and thickness of the stabilized layer which is a selected value. The graphical procedure is presented in Fig. 3.

For example, if it is desired to use a cement stabilized base course having a thickness of 6 in. (150 mm) and a modulus of elasticity of 100,000 psi (690,000 kPa) over a subgrade having a modulus of soil reaction of 160 pci (4.4 kg/m^3), the composite modulus of soil reaction as determined from Fig. 3 would be 240 pci (6.6 kg/m^3). This composite modulus value is used in the iterative design equations to determine a design thickness.

Frost design

TM 5-818-2 provides guidance on design of pavements for frost conditions. Chapter 6 is directed towards the use of stabilized materials. Two items in the manual are of particular interest. First, stabilized base courses may not be used directly under a bituminous paving course. This limitation was placed because of previous experience with reflective cracking. Secondly, the freeze-thaw test (ASTM D 560) is required in areas where frost design is a consideration.

Future work

Much of the past work with cement stabilized materials has emphasized the strength of the material and often the durability of the cement stabilized base has received only cursory attention. Cement stabilized bases have often been prescribed as a panacea for preventing pumping under rigid pavements but they have proven to be susceptible to erosion from pumping in some cases.[4]

A dramatic example of the erodibility of cement stabilized bases recently occurred during the accelerated traffic tests at Beerburrum, Australia.[5,6] A cement stabilized base was placed in three lifts, surfaced with a seal coat, and trafficked with an accelerated load facility (ALF). Water accumulated in the base's vertical shrinkage cracks and severe erosion occurred along these cracks and along the interfaces between lifts. This led to premature failure of the pavement test section.

The current COE design and mix proportioning methods for cement stabilized bases emphasizes strength and more work is needed to determine how durability should be included with the strength requirement. Reflective cracking from shrinkage cracking also remains a problem and better guidance is needed in this area.

There have been reports of chemical attack of sulfates on lime stabilized materials. Although the sulfate attack of lime stabilized materials has been relatively rare, repairs have been very costly. The potential for such problems for cement stabilized materials needs to be addressed.

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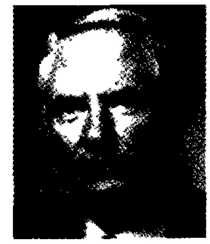

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