

Characterization and Structural Design of Cement-Treated Base

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Proper mix design, adequate thickness, and diligent construction and control techniques are prerequisites to the successful performance of a cement-treated base (CTB) layer and, in turn, the entire pavement structure. A critical review and verification of the structural design procedures are presented. Highlighted are the structural characteristics relevant to the design procedure and design criteria, including distress modeling. Structural characteristics paramount to the thickness design procedure are discussed. On the basis of those properties only the predominant failure modes of CTB and the governing failure criteria are discussed. A short description highlighting the failure criterion of various design methods, six in all, is also discussed. Those methods vary widely in their use of mechanistic principles: for example, three methods are strictly fatigue-based and two others rely on precedent and experience. The validity of each design procedure is assessed by performance history of pavements in service, which is compiled from the literature. A comparison of CTB pavements for a typical sun-belt area for a range of traffic— 5×10^6 , 1×10^6 , 2×10^6 , 5×10^6 18-kip ESAL—indicates that the structural thicknesses mandated by the six design procedures are different. The most conservative design is approximately 30 percent thicker than the least conservative design.

Cement-stabilized materials have been used extensively in the United States and other countries primarily as base and sub-base in flexible pavements. More recently, those materials have been used as sub-bases to concrete pavings. All cement-treated base (CTB) pavements basically consist of a layer of CTB on a prepared sub-base/subgrade with an overlying surfacing of asphaltic materials. The surface type and thickness depend on traffic volume, availability of materials, cost, climatic conditions, and local practices. A common type of wearing surface for lightly trafficked pavements is a double bituminous surface treatment (DBST) about $\frac{3}{4}$ in. thick. Thicker hot mix asphaltic concrete surfacings are warranted as traffic volumes increase.

Proper consideration should be given to mix design, thickness design, and construction procedures when using soil-cement. The mix design determines the proper proportion of cement (and water) in the mixture to ensure that the soil-cement base will have the required strength for both load carrying capacity and durability. In the PCA method (1), for example, the trial mixtures of soil and cement used to determine the correct mix are subjected to tests to show both the compressive strength of the mixture and the durability. Structural design procedures, taking into consideration the traffic volume expected on the roadway in question and predicated on the assumption of adequate mix design, construction, and

maintenance practices, is confined to the selection of the thickness of the various layers of the pavement structure.

Mix design procedures have been standardized: ASTM Test Designations D559-57 and D560-57. Those tests serve well in formalizing a mix design for soil-cement and for recycled soil-cement. However, the structural design methodology, to say the least, is not well accepted.

For example, the question of structural design of cement-treated layer is altogether deleted from the draft state-of-the-art report on soil-cement (2). Also, the procedures vary over a wide range in sophistication and required material characterization. Some agencies use empirical procedures, where thickness of CTB is chosen by relying on precedent (e.g., the Province of Alberta (3)). Occupying the other end of the spectrum is the PCA design procedure, which is based on fatigue failure in CTB and which can handle the effect of mixed traffic in computing the life of CTB pavement.

Much information has been acquired regarding factors influencing the compressive strength of cement-treated material. However, there is a growing awareness among researchers of the need to examine the structural properties that influence pavement response for bases designed for heavy traffic. This interest is prompted by theoretical studies that show that the use of a stiff base material, such as a cement aggregate mixture having a high value of resilient modulus when compared with that of an unbound material, greatly reduces the vertical subgrade pressure but at the same time attracts tensile stresses at the underside of the base. Therefore, insofar as stresses induced by wheel loads are concerned, a need for information regarding resilient modulus, tensile strength, and fatigue resistance of cement-stabilized materials exists, especially under repeated loading conditions or thermal (shrinkage) loading or both. A better understanding of the structural properties of cement-treated material (CTM) is paramount for engineers to predict with greater certainty the performance of roads under changing traffic conditions.

This paper is an investigation of the structural inputs warranted for thickness design and, most important, their role in the distress modeling. In addition, the current structural design methodologies are critiqued and the resulting solutions are compared.

In accordance with the objectives of the study, the discussions are presented under the following subtopics:

1. Basic structural characterization of CTM relevant to thickness design,
2. Distress manifestations in CTB, and
3. Structural design procedures with special reference to failure criteria.

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STRUCTURAL CHARACTERIZATION OF CTM

Modulus of Rupture (M_R)

Because CTM cracking is associated with stress (fatigue-related or thermal/shrinkage) exceeding strength (modulus of rupture), the latter is crucial in assessing structural adequacy of CTM. Scott (4) reported the following relationship between 7-day compressive strength (f_c) and modulus of rupture:

$$f_c = 4.47 M_R \quad (1)$$

Resilient Modulus of CTM

Resilient moduli of CTM satisfying a given mix design criterion are not unique. A cursory study of previous results (4-6) suggests that resilient modulus is a function of soil type. Mitchell and Shen (5) reported flexural resilient moduli of 0.39×10^6 psi (2.69×10^6 kPa) and 2.1×10^6 psi (14.48×10^6 kPa) for silty-clay cement and sand cement respectively. A Maryland study asserted that different relationships between resilient modulus and unconfined strength exist for the cement-treated dense graded aggregate (DGA) and soil-cement materials. Data for Figure 1 are compiled from the author's (6) study and from a Saskatchewan study (4). The graphical representation of unconfined compressive strength (4 in. diameter (100 mm) by 4.6 in. (117 mm) high Proctor specimens) versus resilient moduli of various soil-cement mixtures reveals a trend for the data's falling into three bands: the first group consists of A-1 soils; the second, A-2 and A-3 soils; and the third, A-4 and A-6 soils. For an unconfined compressive strength of 600 psi, which is the design value adopted, the moduli for the three categories are 1.9×10^6 psi (13.1×10^6 kPa), 1.4×10^6 psi (9.65×10^6 kPa), and 1×10^6 psi (6.89×10^6 kPa), respectively.

One significant aspect of modulus is that modulus in compression is different from that in tension. Their relative magnitudes still remain unresolved. For example, Bofinger

(7) and Raad et al. (8) reported that the modulus in tension is lower than that in compression. But Wang and Huston (9) found the opposite to be true. Those conflicting results are of minor consequence only because Khanna and Kachroo (10) indicated that using nonequal moduli exerts little effect on tensile horizontal stresses. Raad (11) in a recent study concluded that the bimodular ratio (E_c/E_t) in bending ranges between 0.5 and 3 or 5 depending on soil type. His analytical studies indicate that the bimodular properties have a significant effect on the traffic-induced stresses and strains on the underside of the stabilized base and on fatigue cracking. Scott indicated that a lower tensile modulus will develop a lower stress that, when compared with a lower fatigue breaking stress, basically leads to no change in thickness of the CTB.

Fatigue Behavior

Cement-treated soils are susceptible to fatigue failure after repeated applications of stresses greater than some limiting value. Fatigue in flexure is of interest because of its impact on pavement cracking. Nussbaum and Larsen (12) developed the earliest method of accounting for fatigue. In this analysis, the fatigue life is expressed in terms of a ratio involving the radius of curvature, R , under repeated load.

$$\frac{R_c}{R} = aN^{-b} \quad (2)$$

where

- R_c = critical (failure) radius of curvature,
- R = radius of curvature developed for a given load and number of load repetitions,
- N = number of load repetitions, and
- a, b = coefficients depending on soil type and specimen thickness.

By using flexural strain criterion, Pretorius (13) indicated that excellent agreement occurs between Larsen's relationship and the results obtained from repeated flexural fatigue testing.

Some recent studies (4,14) advocate stress-related fatigue and strain fatigue (13) as well. One of the stress-fatigue relations (4) and the Pretorius strain-fatigue relation will be referred to later; for ready reference, therefore, they are included here:

$$\%M_R = 94.4 - 4.71 \log N_f \quad (3)$$

$$\log N_f = 9.11 - 0.0578 \epsilon_i \quad (4)$$

where

- $\%M_R$ = critical stress expressed as a percentage of modulus of rupture,
- ϵ_i = initial tensile strain at the bottom fiber of the base, and
- N_f = number of load (that induces stress of a specified magnitude) applications before fatigue failure occurs.

Additional results for allowable stress/strain to preclude excessive fatigue cracking are tabulated in Table 1. That there

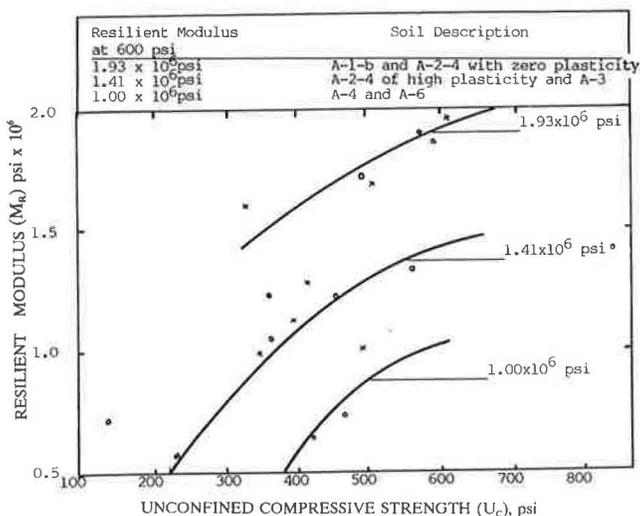


FIGURE 1 Resilient moduli of three classes of cement-treated soil. 1 psi = 6.89 kPa. [Adapted from George (28).]

TABLE 1 SUMMARY OF CRITICAL DESIGN VALUES OF CEMENT TREATED SOIL [ADAPTED FROM GEORGE (28)]

Source	Static		10 ⁶ applications		10 ⁷ applications		Unlimited applications
	Stress, psi	Strain, 10 ⁻⁶ in./in.	Stress, psi	Strain, 10 ⁻⁶ in./in.	Stress, psi	Strain, 10 ⁻⁶ in./in.	Strain, 10 ⁻⁶ in./in.
Mitchell (5)		150	50 % of flexural strength	50 ^a	-	65	
Scott (4)	95	-	66	-	62	-	60
Hadley et al. (15)	250	150-250	87.5	20			
Terrel et al. (30)	140		51				
Otte (31)				38 to 60			

^a33% of the strain at failure in bending.

1 psi = 6.89 kPa, 1in. = 25.4 mm

is hardly any agreement on permissible value can be inferred from the summary data in the table. The fact that Hadley et al. (15) used indirect tensile test and others relied on flexural bending stress should explain the large discrepancy between those critical values. The critical design strain value of 20×10^{-6} in./in. proposed by Hadley et al. is considered overly conservative. Accordingly, critical stress and strain values of 60 psi (410 kPa) and 50×10^{-6} in./in., respectively, is recommended.

Distress Manifestations in CTB

In the past 2 decades, researchers have given increased attention to performance of soil-cement as a structural material, particularly its behavior in regard to fatigue. Equally damaging to CTB are the cracks that appear because of volume changes. The latter, known as shrinkage cracks, have been recognized as a major deterrent in the use of CTM in the base. Simply put, load-induced fatigue cracking and shrinkage cracking owing to volume change are the primary distresses that detract from performance. Despite the interest and concern of highway engineers regarding the overall problem of cracking, their opinions differ as to the gravity of each type of cracking (16,17). The following discussion calls attention to the cracking problem, especially how and when cracks are initiated, the sequence in which the two types appear, and methods to minimize the incidence of cracking in the CTB.

There is no general consensus regarding how and when cracks originate (occur). The popular view is that shrinkage cracks appear at the surface during the early life of CTB, as early as a few days to a few years after construction. Fatigue cracks, on the other hand, are initiated at the bottom of the base when fatigue consumption exceeds a certain magnitude (1, according to Miner's hypothesis). In either case, the crack initiated at the top or bottom face, depending on the load, propagates through the depth of the layer in a matter of a

few weeks to a few years. Figure 2 is a schematic representation showing crack initiation and propagation in a finite series of steps owing to drying shrinkage alone. A thorough discussion as to how load-induced cracks—longitudinal and transverse—develop in cement-treated aggregate mixtures can be seen in Norling (16).

Chronologically, the first cracks in CTB occur during compaction. George (17), using theoretical calculations, indicated that slip planes, approximately perpendicular to the road surface and transverse to the direction of rolling, are induced in the CTB. Although those slip planes will be partially "healed" during curing, they present weak planes in the base. Because all cracks can be visualized as initiating at zones of weakness or flaws, those shear planes serve as the primary seat for further cracking. Perhaps, in recognition of these compaction cracks, Scott (4) asserted that CTM should be proportioned so that the young mix will not suffer fatigue cracking under construction traffic. If early cracking can be eliminated, then, according to Scott, CTM is likely to be fatigue resistant because it gains strength with time. Should the theory of early fatigue cracking prevail, shrinkage cracking can still occur at specific intervals because of tensile shrinkage/thermal stresses. It is reasonable to speculate that the fewer the compaction planes, the fewer (and perhaps narrower) the shrinkage cracks.

An experimental study conducted in Japan (18), and a complementary study in Switzerland (19), suggested opening the young soil-cement base to traffic, which induces many microcracks that enhance the performance of the base layer. On the surface this result appears to contradict the theory that heavy construction traffic should be avoided altogether for better performance. The difference seems to lie in the severity of induced cracks. Yamanouchi (18) recommended inducing microcracks under normal traffic, and Scott and others want to avoid larger cracks likely to occur under heavy construction traffic or smooth-wheeled rollers.

The question now arises as to how early trafficking minimizes cracking and improves performance of the cement base.

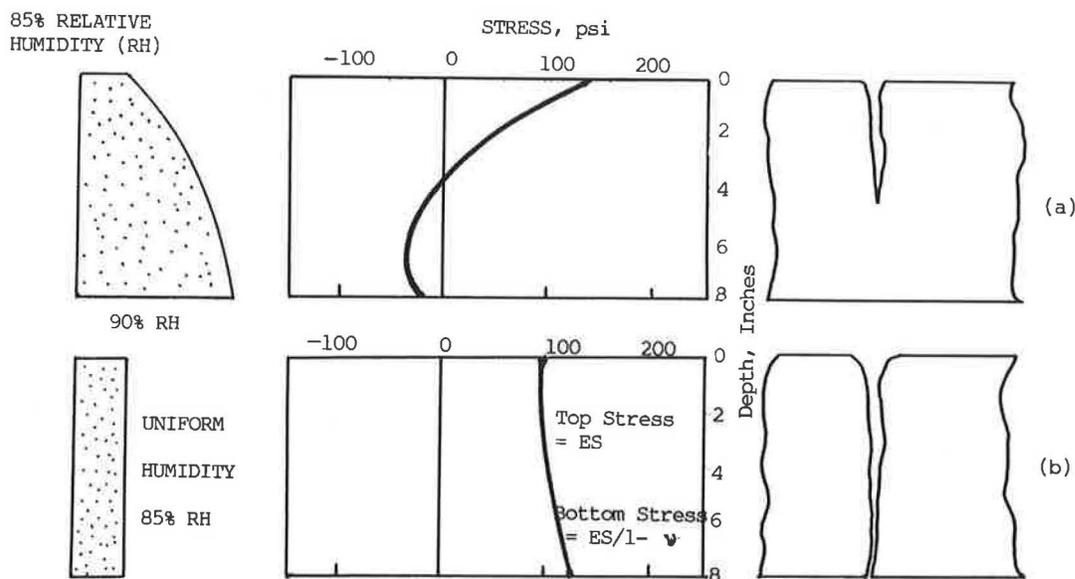


FIGURE 2 (a) Crack initiated owing to localized surface (tension) stress. (b) Crack propagated through owing to continued shrinkage (E = resilient modulus; S = free, unrestrained shrinkage, and ν = Poisson's ratio). 1 psi = 6.89 kPa. [Adapted from George (17).]

First, early trafficking helps to promote numerous fine cracks as opposed to fewer wide cracks. In addition, the young soil-cement can become denser on trafficking within a day or two of its placing. Healing of "compaction cracks" developed under rolling compaction can be another reason for superior performance. Fetz (19) speculated that a cement-treated layer with fine cracks induced in it will exhibit relatively low modulus and, in turn, attract lower wheel load stresses and thermal/shrinkage stresses.

Bofinger (20) appears to be more explicit in asserting what causes cracking in cement base. According to him, the characteristic cracking observed in soil-cement bases most often results from traffic loads rather than from shrinkage stresses. Controlling the spacing of cracks includes the early stressing of soil-cement base with rollers, a method claimed to be efficient for predetermining the crack size and spacing. A French study (21) is in general agreement with the predominance of load-related cracks in that cracking is attributed to load-induced tensile stresses and occurs at the base of the treated layer. The evidence is overwhelming that load-related cracking in CTB is more predominant than any other type (mostly shrinkage cracking).

Shrinkage Cracking

After the role of load-related fatigue cracking is understood, the significance of shrinkage cracking on the performance of CTM pavement can be investigated. Shrinkage cracking at times is considered a natural characteristic of soil-cement (16). Norling (16) asserts that such cracks are not the result of structural failure and, from an engineering standpoint, have not created a significant problem except in some very localized instances. Research and experience, however, suggest differently: for example, shrinkage cracks accelerate pavement deterioration. A Soviet study (22) indicates an increase in

moisture content in the zone around and beneath the cracks with concomitant increase in deflection. Costigan and Thompson (23) assert that critical pavement response affecting performance occurs at transverse shrinkage cracks.

Shrinkage cracking is one of the unsatisfactory aspects of the overall behavior of soil-cement bases. At the time of occurrence it has relatively little effect on the riding quality of highway pavement. However, "secondary deterioration" effects, such as deflection and the resultant weakening of the subgrade, can be highly detrimental to the performance and useful life of the pavement structure.

Shrinkage cracking mechanism has been studied by George (17), who attributes the cracks to internally developed shrinkage-induced stresses. Through a step-by-step initiation and propagation, the base indeed undergoes cracking in a predictable configuration. George (17,24), in a series of papers, recommended reducing molding moisture, increasing compaction density, and carefully avoiding soils with montmorillonite clays as a means for reducing shrinkage and, in turn, shrinkage cracking. Fetz (19) asserted that limiting the degree of saturation to 70 percent can significantly reduce cracking. By using soil mechanics principles he showed that the liquid is in continuous phase when the saturation exceeds 70 percent. This situation is conducive to shrinkage and cracking, as schematically shown in Figure 3. When the saturation is less than 70 percent, no continuity of the liquid phase is evident. Only microfissures can occur, possibly reducing shrinkage stresses.

Undoubtedly, load-induced (fatigue) cracking constitutes the predominant pavement distress manifestation followed by shrinkage cracking.

STRUCTURAL DESIGN PROCEDURES

Structural design methods currently used are briefly described, highlighting (a) the failure criteria, if any, employed and (b)

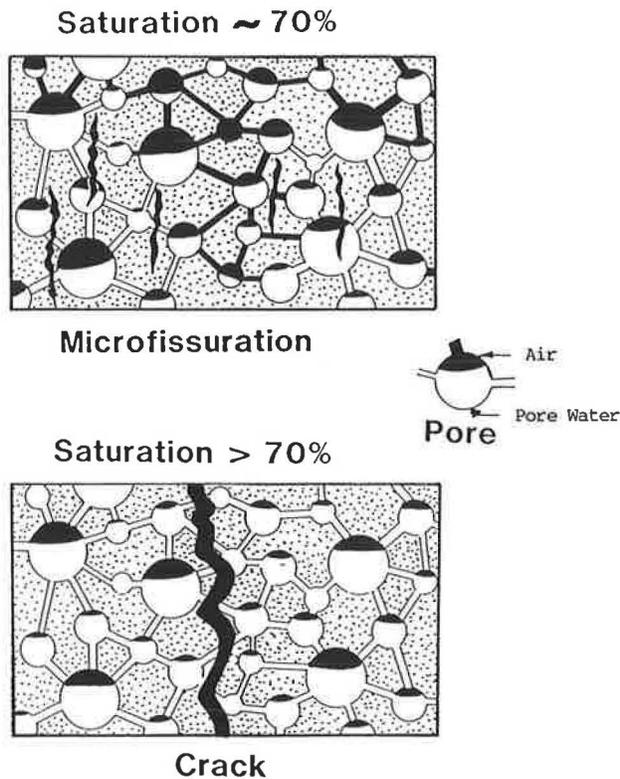


FIGURE 3 Degree of saturation influencing cracking in soil-cement. [Adapted from Fetz (19).]

the predominant material characteristic(s) that supports the failure criterion. In all of the methods the structural design is often predicated on the assumption of a high standard of mix design, construction, and maintenance practices. Procedures currently practiced include the AASHTO method (25), the PCA method (26), stress/strain fatigue-based methods (4,6), and other thickness selection procedures that rely on precedent and experience (3,27).

AASHTO Method

The AASHTO flexible pavement design procedure—either 1972 Interim Guide or 1986 Revised Guide—in conjunction with such input values as traffic, subgrade strength, and environmental conditions, determines a structural number. The layer coefficients of component layers need to be determined in proportioning the thicknesses of various layers. AASHTO Guide has furnished layer coefficient value for CTM in relation to compressive strength or resilient modulus. George (28), in a recent study, employed a fatigue criterion (either in the CTM layer or in the overlying asphalt layer) to derive the layer coefficient of CTM. The layer coefficient value, 0.24, for soil-cement [7-day compressive strength no less than 600 psi (4094 kPa)] is in good agreement with those reported by other agencies including AASHTO.

The AASHTO design procedure, especially the Revised Guide, includes several features that make it more realistic and site-specific. Nonetheless, the many physical limitations

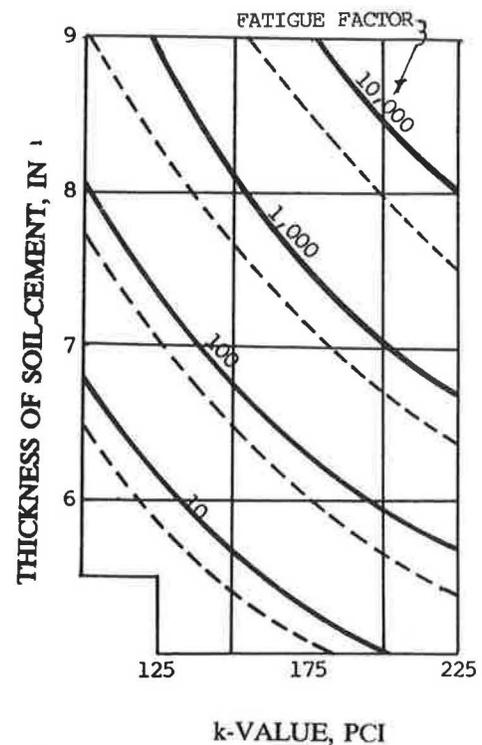


FIGURE 4 Thickness design chart for fine-grained soil-cement. [Adapted from *Thickness Design for Soil-Cement Pavements* (26).] 1 in. = 25.4 mm, 1 pci = 0.271 kPa/mm.

of the AASHTO Road Test—its short duration (2 years), its single climate, its narrow range of materials and construction techniques, and the ad hoc approach used for mathematical modeling including the definition of layer coefficient—undermine the validity of the design procedure.

PCA Method

Soil-cement base course thickness is governed by fatigue consumption under repeated loads. Demonstrating that the strength of the pavement is more accurately assessed by the degree of bending, radius of curvature (see Equation 2) rather than deflection was used as a principal factor in evolving the design formulations. PCA research has shown that the ultimate “fatigue factor” of soil-cement can be described by a single equation, regardless of soil type and cement content, as long as the final product meets the criteria for fully hardened soil-cement. Two sets of fatigue consumption coefficients, one for granular soil-cement and the other for fine-grained soil-cement, are proposed by PCA researchers. Fatigue consumption factors are multiplied by the numbers (in thousands) of axles in each weight group and then summed to give a single value fatigue factor. When fatigue factor is known, engineers can select a soil-cement base course thickness by using nomographs provided (a typical nomograph for granular soil-cement is shown in Figure 4). Additional inputs required for the design include (a) subgrade strength, measured in terms of Westergaard modulus of subgrade reaction, k ; (b) traffic, including volume

and distribution of axle weights; and (c) bituminous surface thickness (BST). Supported by research findings, PCA asserts that BSTs of under 2 in. (50 mm) do not appreciably add to the structural capacity of the soil-cement pavement.

Methods Based on Stress/Strain Fatigue

The first method [from Scott (4)] is based on the premise that if tensile stresses are limited to 60 percent of the modulus of rupture calculated by conventional elastic theory then no flexural fatigue will occur in soil-cement. Scott, from studying a few soils in Saskatchewan, derived the generalized relation (Equation 3).

The first step in the design procedure is to estimate the modulus of rupture and, in turn, resilient modulus. The latter also can be estimated either from compressive strength or from indirect tensile strength, both of which are relatively simple to determine. The limiting stress corresponding to number of load repetitions anticipated is obtained from Equation 3. When the resilient modulus is known, a layer analysis program (CHEV-5L) can be employed to estimate tensile stresses for various thicknesses of CTM and to choose an appropriate thickness for the design.

The fatigue relationship expressed by Equation 3 is perhaps the weak link in the design process because the $\%M_R-N_f$ equation is derived based on samples tested in the laboratory. As far as is known, the design procedure has not been substantiated, either by field tests or by matching performance of as-built pavements.

The second method, proposed by George (6), basically using stress/strain fatigue in CTM, was developed for the purpose of designing flexible pavements and uses the concepts of limiting subgrade strain to control permanent deformation and limiting tensile strain in the asphalt layer (or limiting tensile stress/strain in the cement-treated layer, if applicable) to control fatigue cracking. Besides the fatigue relationships (Equations 3 and 4), resilient modulus of CTM is the other characteristic employed in the development of the design procedure. Typical resilient modulus values can be seen in Figure 1.

Applicable to stabilized and DGA bases, the design charts include design reliability as well. Because the method was originally intended for designing flexible pavements, the procedure includes asphalt grade selection criteria and a rational adjustment factor to account for the variation of asphalt mix stiffness from one climatic region to another. A typical design chart for 50 percent reliability is included in Figure 5.

Empirical Approach Based on Field Trials

Many highway agencies determined CTB thickness based on experience backed by proven field technique. Some adjustment to thickness, however, is generally made to account for traffic volume. A typical example is the design practice adopted by the Province of Alberta (3). That design is composed of a CTB layer overlaid with asphalt-stabilized granular base course (ASBC) layer and surfaced with an asphalt-concrete pavement (ACP). The thickness of the various layers is varied to give the required structure for different traffic and environmental conditions.

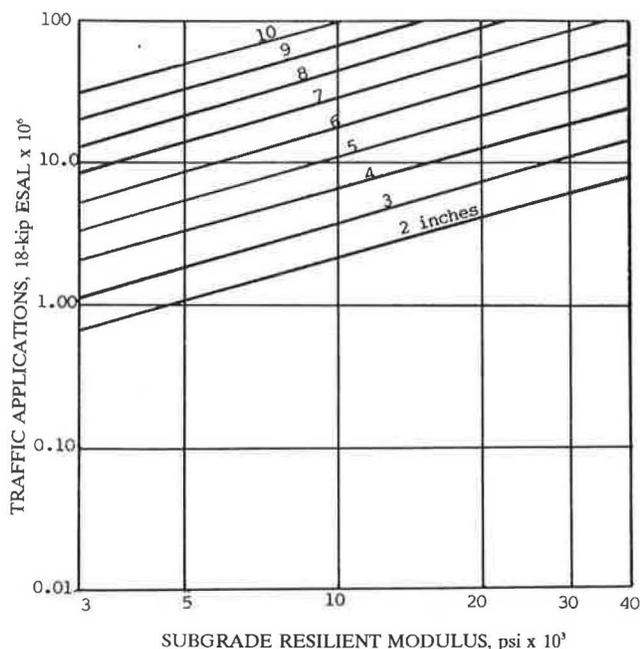


FIGURE 5 Design chart for CTB 8 in. thick. Fifty percent confidence level. 1 psi = 6.895 kPa; 1 kip = 4.448 kN; 1 inch = 25.4 mm. [Adapted from George (6).]

Road Note 29 (27) permits the use of two types of cement-stabilized materials, cement-bound granular material (CBGM) and soil-cement, both of which have grading requirements. CBGM should give minimum 7-day compressive strength (cube strength) of 500 psi (3445 kPa), and its use is limited to roads with a design life of less than 5 million standard axles. The load repetition limit stands at 1.5 million standard axles for soil-cement. In both of those mixes, it is commonly assumed that the frost resistance will be adequate if the compressive strength requirements have been met. The design chart in Figure 6 is reproduced from Road Note 29.

Adequacy of Design Procedures

Evaluating the performance of as-built pavements in which the design procedure in question was used is a technique often adopted for assessing the adequacy of design procedures. Many highway agencies, including Mississippi, have used the AASHTO method or slightly modified versions in designing CTM bases. Seventy one road sections with CTB, ranging in thickness from 4 to 10 in. (100 to 254 mm) with DBST or varying thicknesses of ACP, were investigated for their performance. All of those sections are in service in north Mississippi and have been overlaid once or more. With the tacit assumption that the useful life of the pavement is exhausted when an overlay is placed, the mean life of CTB pavements were computed and are presented in Table 2. The mean life increases slightly with ACP thickness but is independent of the CTB thickness. Traffic loading is poorly correlated to pavement life owing to either collinearity between loading and strength (consequent to design) or to dominant environmental effects. The fact the lives of CTM pavements average

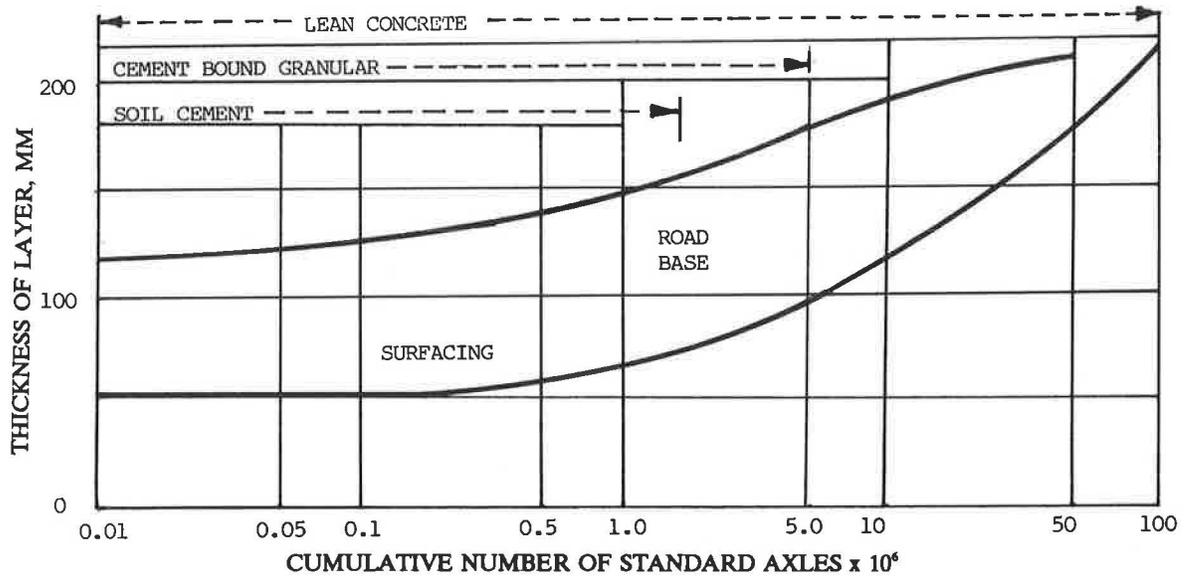


FIGURE 6 Lean concrete, soil-cement, and cement-bound granular road bases: minimum thickness of surfacing and road base. 1 in. = 25.4 mm. [Adapted from *A Guide to the Structural Design of Flexible and Rigid Pavements for New Roads* (27).]

TABLE 2 SUMMARY OF MEAN LIFE OF IN-SERVICE CEMENT-TREATED BASE PAVEMENTS IN NORTH MISSISSIPPI

Asphalt Surface Course Thickness, mm	Number of Sections in the Database	Mean Life, Years	Coefficient of Variation percent
19 (Double bituminous surface treatment)	42	16	35
50	3 ^a	16.7	61
75	2 ^a	23.5	15
100	15	18.9	17
200	9	19.6	2.7

^aToo few sample points to be of significance

more than 15 years attests to the validity of the AASHTO design procedure. According to Scott (4), several hundred miles of cement-treated bases have been in place in Saskatchewan. To this author's knowledge, however, no performance evaluation of those roads has been reported. The structural design procedure (3) used in Alberta, although empirical in nature, has been successfully used for the construction of 1,800 mi (3000 km) of CTB roads. Engineers attribute the success to high standards of materials, mix design methods, construction, and maintenance practices used in the province. Inclusion of the 2-in. (50-mm) thick asphalt stabilized course has been very beneficial to the overall performance of the

pavement and serves as a protective layer against reflective cracking. The performance evaluation of Alberta's CTB roads indicates that a useful service life of at least 15 years can be expected of CTB pavements built in the province provided the proper mix design, structural design, and construction and maintenance procedures are followed.

The British experience with soil-cement has been mixed at best. In the pavement design experiment at Alconbury Hill, six of the seven stabilized base sections with a single-sized sand mixed with 8 percent cement failed during the first 6 years. The poor performance is attributed to difficulty in compacting the soil-cement on site: the mean 7-day strength

achieved was only 140 psi (980 kPa). According to Wright (29), 164 lightly trafficked soil-cement roads in the United Kingdom that were 8 to 23 years old have performed well.

This author was unable to ascertain the field performance of roads constructed according to the PCA method and the reliability-based flexible pavement method. From limited comparisons, the authors of the two methods have demonstrated that they are valid.

Comparison of Structural Designs

Because data regarding field verification of the design procedures have been lacking, an alternative approach has been followed here for validating the design procedures. Employing the various design methods the CTB thickness to use in comparison has been computed (adopted in some cases). The input values for the pavement presumed to be located in the

TABLE 3 MATERIAL CHARACTERISTICS FOR SAMPLE PROBLEM

Description/Property	
Soil for Stabilization	SP sands (A-3) with 6-8 percent cement
Subgrade, A-4, (medium plasticity silty clay)	CBR = 8.0 percent Resilient modulus = 12000 psi (83,760 kPa) Modulus of subgrade reaction = 180 pci (0.049 N/mm ³)
Modulus of Rupture of CTM	108 psi (754 kPa)
Resilient Modulus of CTM	1x10 ⁶ psi (6.98x10 ⁶ kPa)
Resilient Modulus of ACP	5x10 ⁵ psi (3.50x10 ⁶ kPa)
Regional Factor	2.0
Traffic	varies (see Table 4)

TABLE 4 COMPARISON OF CTB THICKNESS REQUIREMENTS. MATERIAL PROPERTIES LISTED IN TABLE 3

Method	CTB Thickness /AC Surface		Single Axles, 2x10 ⁶	ESALs 5x10 ⁶
	Cumulative Equivalent 5x10 ⁶	(18-kip) 10 ⁶		
AASHTO Revised Guide ^a (25)	171mm/50mm	168/75	162/100	181/125
PCA Method (26)	158mm/50mm	167/50	171/63	182/63
Stress-Fatigue (Scott, 4)	228mm/50mm	222/75	207/75	191/125
Stress/Strain- Fatigue (George, 6)	152mm/40mm	203/40	203/57	203/95
Alberta (3)	150mm/50mm	175/- ^b	200/100	230/150
United Kingdom, Road Note 29 (27)	135mm/60mm	145/70	160 ^c /75	

1 in. = 25.4 mm

^aTerminal Serviceability level of 2.5

^b Not available from reference

^c Soil-cement bases recommended upto 1.5x10⁶ 18-kip; therefore, some extrapolation is required

sun belt are presented in Table 3. The subgrade soil is a medium plasticity silty clay, and the soil to be stabilized with cement is a poorly graded sand.

Despite the fact that an explicit comparison of thicknesses (because total thickness = CTB thickness + ACP thickness) between designs is not valid, some clear trends are evident. First, the PCA design and the Road Note 29 give lower overall thicknesses, and the Alberta design tends to be conservative, especially for heavily trafficked roads, not to mention the 2-in. (50 mm) ASB provided in conjunction with the CTB. Scott's stress-fatigue approach, though satisfactory for heavy trafficked roads, tends to overpredict the CTB thickness for light-trafficked roads. Second, the designs, from the thinnest (PCA design) to the thickest (Alberta method), vary by as much as 30 percent at the traffic level of 2×10^6 18-kip ESAL. This calculation assumes (a) 2:1 layer equivalency for ACP, CTM, and (b) the mean of all six methods estimates the required thickness.

CONCLUDING REMARKS

This review examines material characterization and failure criteria that spearhead structural design procedures of CTB. Modulus of rupture, resilient modulus, and fatigue behavior comprise the structural properties sought for in design. Load-induced fatigue cracking, followed by shrinkage cracking, constitutes the predominant distress manifestations in CTB. Six different structural design methods have been identified. Hypothetical designs employing those methods and compiled for a range of traffic reveal that the designs—from the thinnest to the thickest—vary as much as 30 percent. Therefore, a need exists for additional performance data regarding pavement in place to substantiate the validity of the design procedures.

Despite the fact that shrinkage cracking detracts from serviceability, only the Alberta design procedure includes provision for a 2-in. (50 mm) asphalt-stabilized granular base course, provided between the CTB and the asphalt concrete surfacing. This author believes that an open-graded, stabilized intermediate layer should be encouraged to minimize reflection cracking.

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