COMPARISON OF CONTAINED ROCK ASPHALT MAT (CRAM) WITH CONVENTIONAL ASPHALTIC CONCRETE PAVEMENTS

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January 1985

INTRODUCTION

A brochure proposing the use of "Contained Rock Asphalt Mat" (CRAM) provided a comparison of stress distributions throughout a CRAM structure (Figure 1) as compared to a conventional pavement (Figure 2). Experience has indicated that stress distributions do not always present the most sensitive or appropriate analysis of a pavement structure. Distributions of strains, and more particularly "work", are better indicators of load distributions throughout a pavement structure and subsequent performance.

PAVEMENT ANALYSES

Pavement sections were analyzed using the Chevron N-layer computer program. Input parameters were given numerical values typical for Kentucky conditions and known to be reasonable from past experience, both empirically and theoretically. The table below gives the combinations of layer moduli used in this comparison.

LAYER MODULUS, KSI

Problem Number	Asphaltic Concrete	Dense-Graded Aggregate	Open-Graded Aggregate	Asphaltic Concrete	Subgrade
1	480	30	20	300	7.5
2	480	100	100	480	7.5
3	480	50	50	400	7.5
4	480	30			7.5

Solutions 1, 2, and 3 are for CRAM pavements; Solution 4 represents a conventional flexible pavement design.

Figures 3 through 6 illustrate the stress distributions throughout the CRAM pavements under the imposition of an 18-kip single axleload on four tires. Figures 7 through 10 illustrate the strain distributions throughout the structures; significantly different "conclusions" are indicated, depending on whether stress distributions or strain distributions are being analyzed.

The CRAM brochure (Figures 1 and 2) include only the radial and vertical stress components and ignore the shear and tangential components. Inspection of Figures 3 through 6 reveal that tangential stresses are nearly equal to the radial stresses and shear stresses are in a tensile mode.

Figures 7 through 9 illustrate some startling results. Shear strains are much too large in the dense-graded and open-graded aggregate layers. Those materials, in that state of strain, should be susceptible to particle movement that could produce rutting in the overlying asphaltic concrete layer and possibly at the top of the subgrade.

Recent research has shown that "strain energy density" (or work) incorporates the effects of all strain components. Figure 11 illustrates the distribution of strain energy density throughout the pavement structures for all four examples. Distributions of strain energy density in Figure 11 clearly indicate the unbound aggregate layers between asphaltic concrete layers are subjected to excessive magnitudes of "work". It is doubtful that particles in the unbound layers would remain in their "as-constructed" locations. Even the most reasonable moduli combination (Problem 3) produces a magnitude of work in the unbound layers that is nearly twice that in the upper asphaltic concrete layer and approximately three times that in the lower asphaltic concrete layer. At the interface with the subgrade, the magnitude of "work" is nearly three times greater for the CRAM pavement (Problem 3) than the conventional pavement.

RUTTING ANALYSIS

A rutting analysis of the CRAM pavement was performed to determine where and to what extent rutting will occur in the various pavement layers. The analysis was made using a computer program entitled PAVRUT that is capable of providing a rutting estimate for any flexible pavement structure. The prediction models used in the program were formulated from an extensive laboratory investigation into the rutting potential of flexible pavement components (asphalt concrete, dense-graded aggregate, and subgrade soils). In addition, traffic and environmental models were incorporated into the program.

The rutting models take the following form for all three pavement components tested:

$$\log(Ep) = a(\log(N)) + b(\log(N))^2 + c(\log(N))^3 + d$$

in which Ep = permanent strain,
  N = number of load repetitions, and
  a,b,c,d = experimentally determined variables that are dependent on stress, temperature, moisture, and subgrade CBR.

Figure 12 shows the rutting strain in the various layers as a function of depth. The solid line represents strain for 1×10^6 EAL's and the dotted line is for 1×10^7 EAL's. Rutting accumulates rapidly in the upper portion of the dense-graded aggregate layer as EAL's accumulate up to 1×10^6 repetitions. However, from 1×10^6 to 1×10^7 EAL's the rate of strain in the dense-graded aggregate layer slows appreciably. In addition, the strain rate in the subgrade increases dramatically from 1×10^6 to 1×10^7 EAL's. This indicates the subgrade is beginning to fatigue and deteriorate, losing its load-carrying capabilities.

The total rut depth at 1×10^6 EAL's is estimated to be 0.857 inch. Both the subgrade and the dense-graded aggregate contribute approximately one-third, each, of the total rut depth. At 1×10^7 EAL's the subgrade contributes over two-thirds of the total rut depth of 2.2 inches. This is a further indication of

the weakened condition of the subgrade.

SUMMARY

While at first glance CRAM pavement sections appear to be reasonable, the inclusion in the analysis of all strain components and their combination into strain energy density clearly show CRAM pavements may not provide the same level of performance expected of conventional pavements.

The proportions of layer thicknesses given in the brochure should not be used as the brochure recommends. This analysis has not attempted to determine what combinations of layer thicknesses might produce comparable results with conventional designs. Additional analyses would be required to make those comparisons.
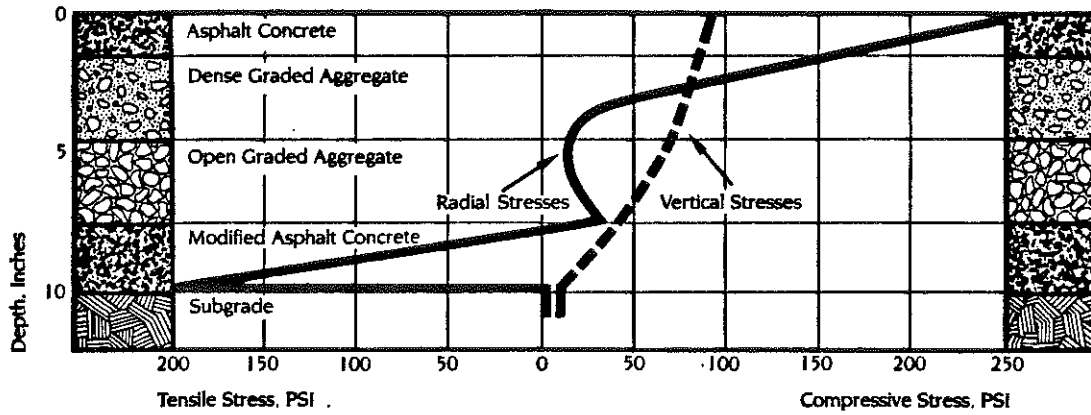
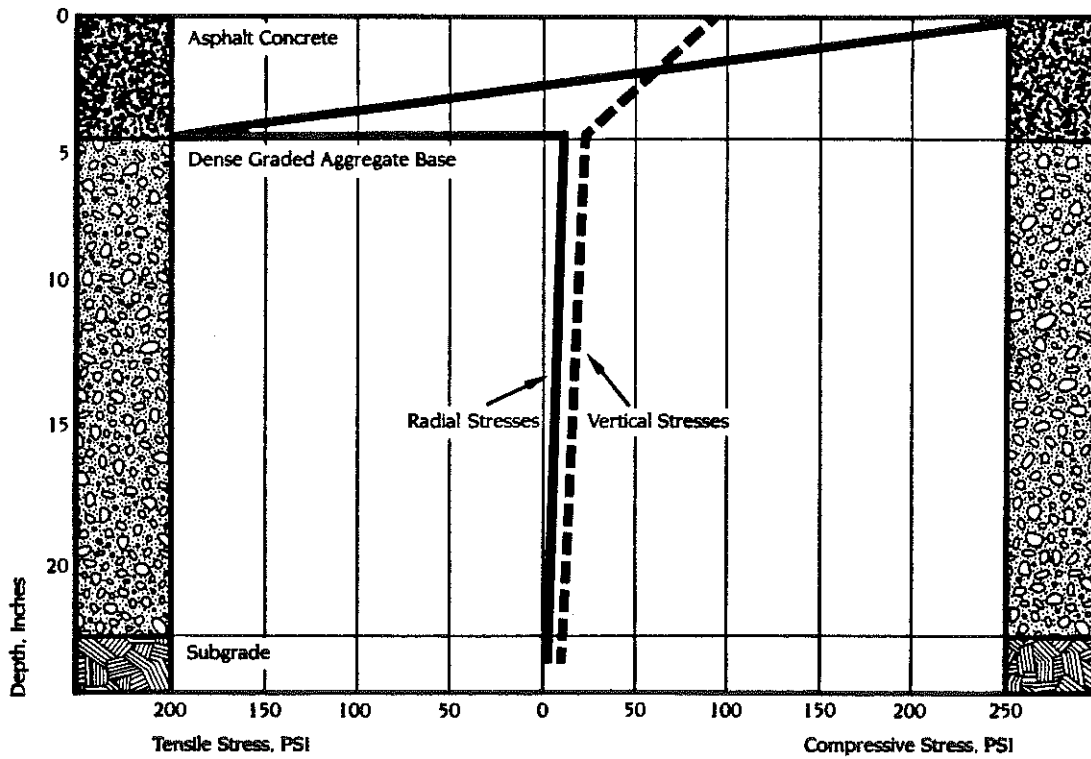FIGURE 1. RADIAL AND VERTICAL STRESS DISTRIBUTIONS IN
A "CRAM" PAVEMENT.

FIGURE 2. RADIAL AND VERTICAL STRESS DISTRIBUTIONS IN
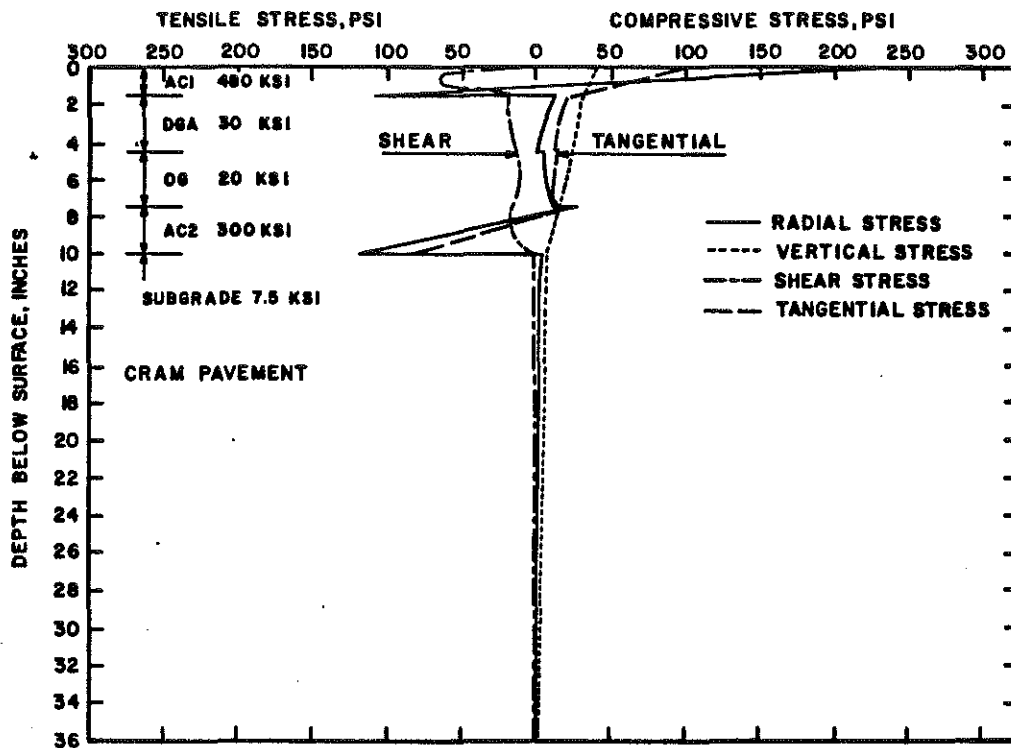A "CONVENTIONAL" PAVEMENT.

FIGURE 3.   FOUR STRESS DISTRIBUTIONS IN A CRAM
PAVEMENT USING "WEAK" ASPHALTIC CONCRETE
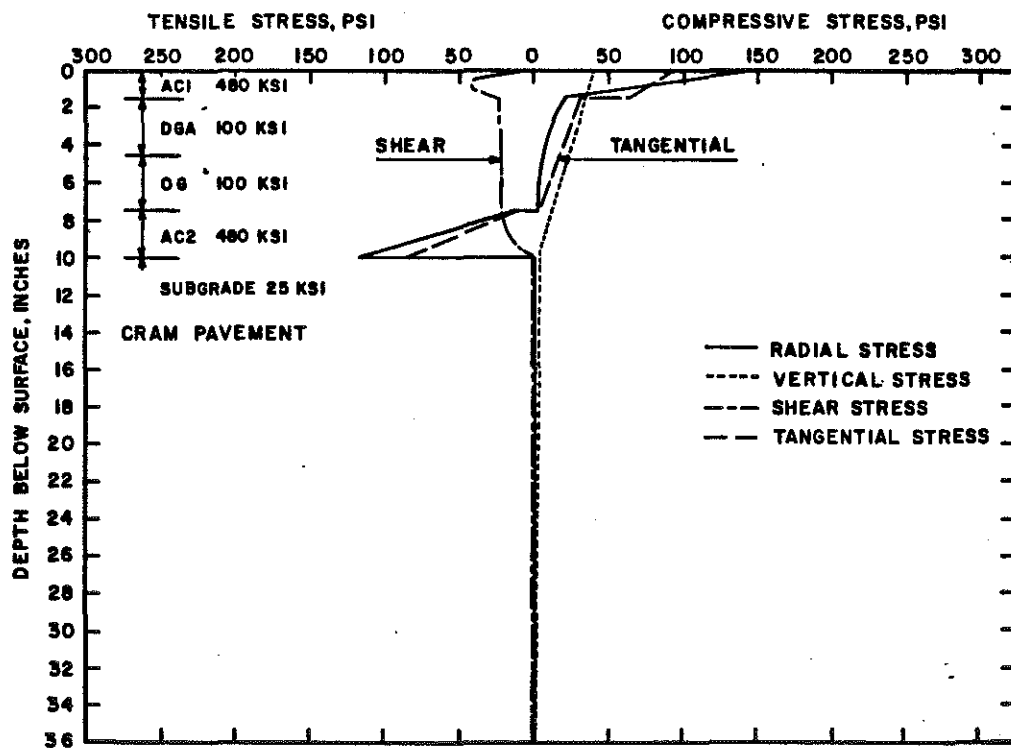MATERIAL IN THE BOTTOM LAYER.

FIGURE 4.   FOUR STRESS DISTRIBUTIONS IN A CRAM PAVEMENT
USING THE SAME ASPHALTIC CONCRETE MATERIAL
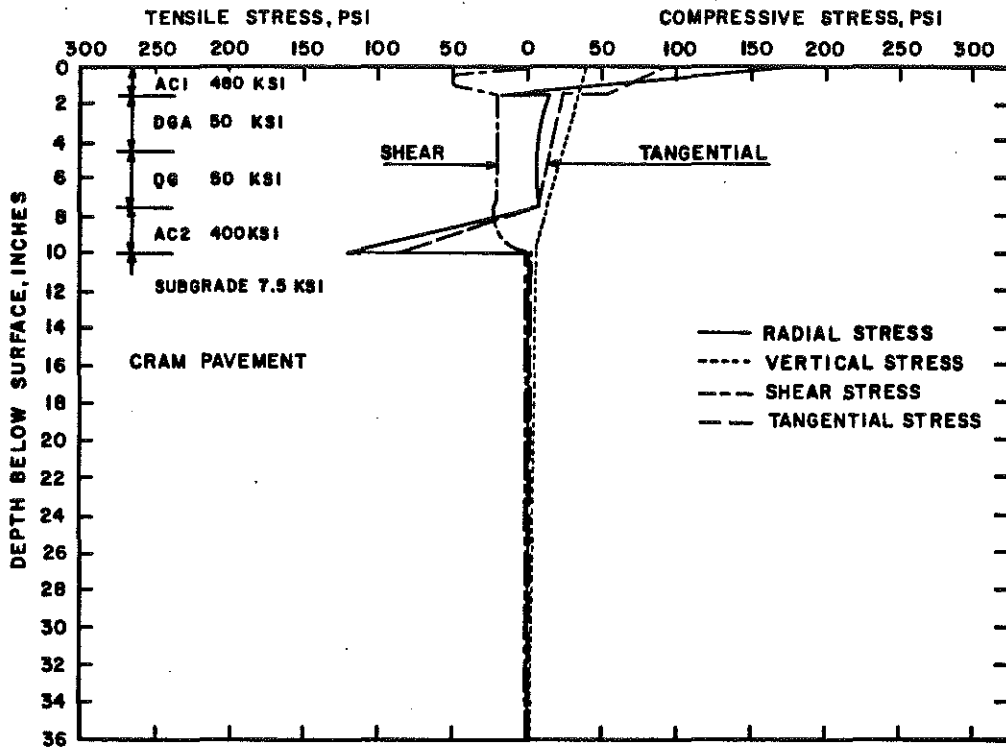IN TOP AND BOTTOM LAYERS.

FIGURE 5. FOUR STRESS DISTRIBUTIONS IN A CRAM
PAVEMENT USING "MODERATE" ASPHALTIC
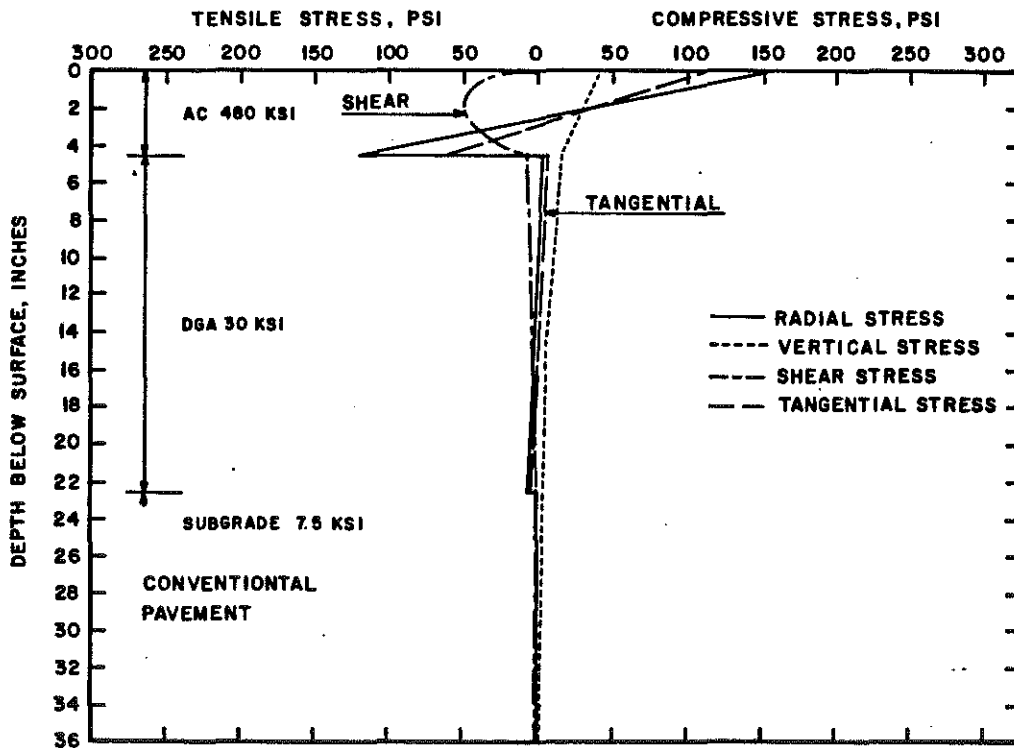CONCRETE MATERIAL IN BOTTOM LAYER.

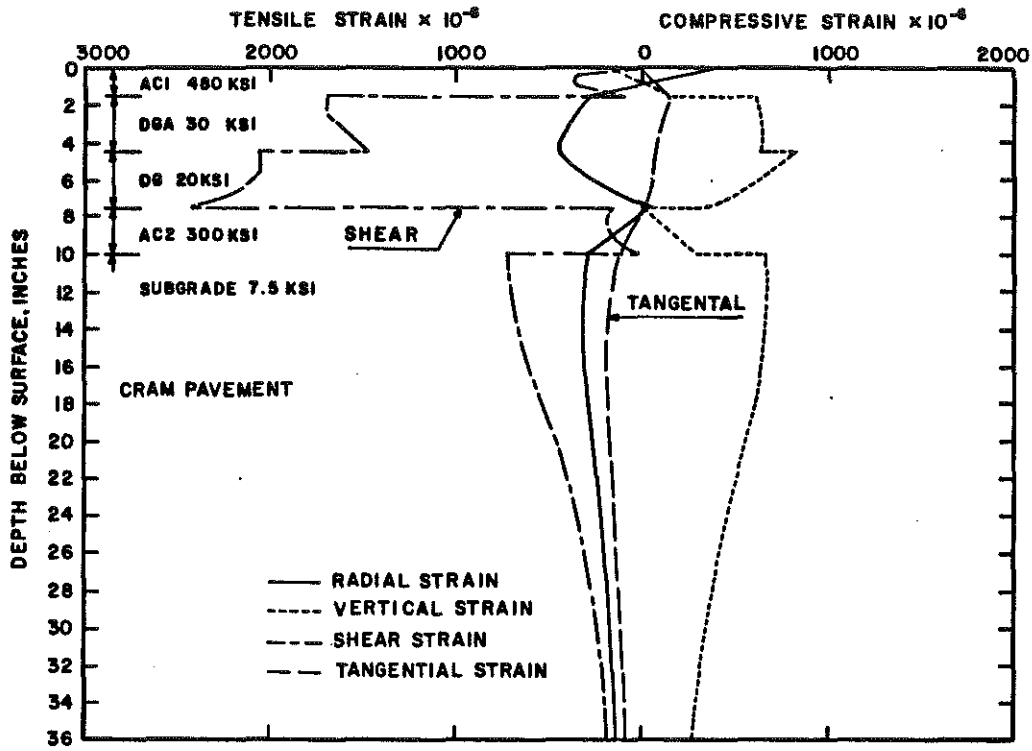FIGURE 6. FOUR STRESS DISTRIBUTIONS IN A
CONVENTIONAL PAVEMENT.

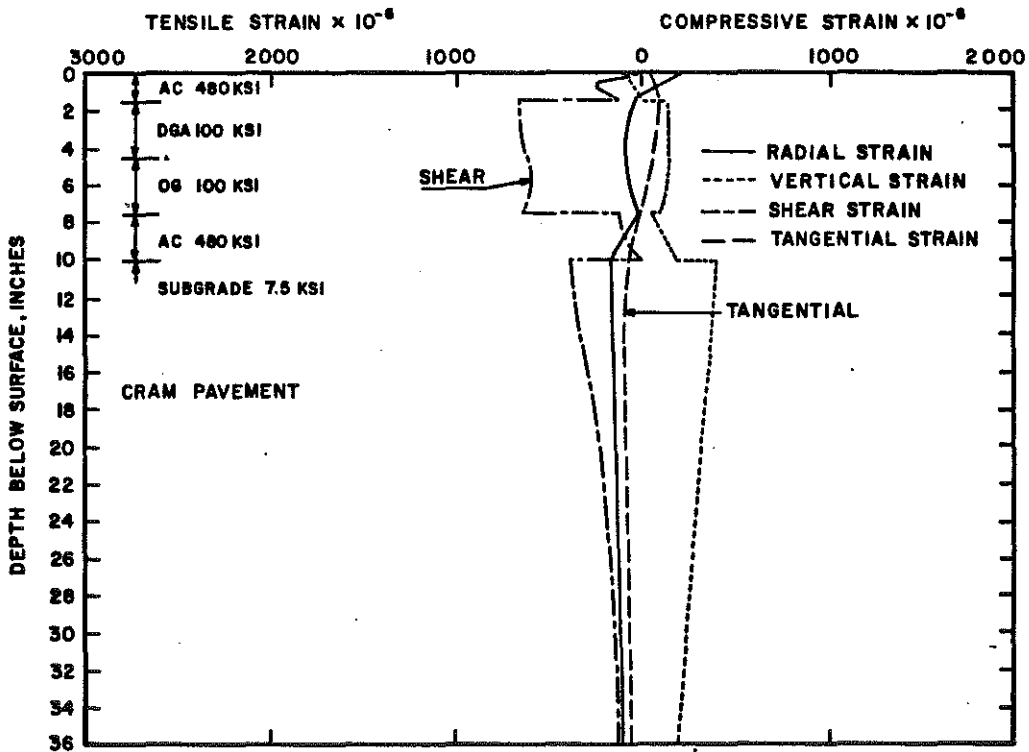FIGURE 7. FOUR STRAIN DISTRIBUTIONS IN THE CRAM
PAVEMENT OF FIGURE 3.

FIGURE 8. FOUR STRAIN DISTRIBUTIONS IN THE CRAM
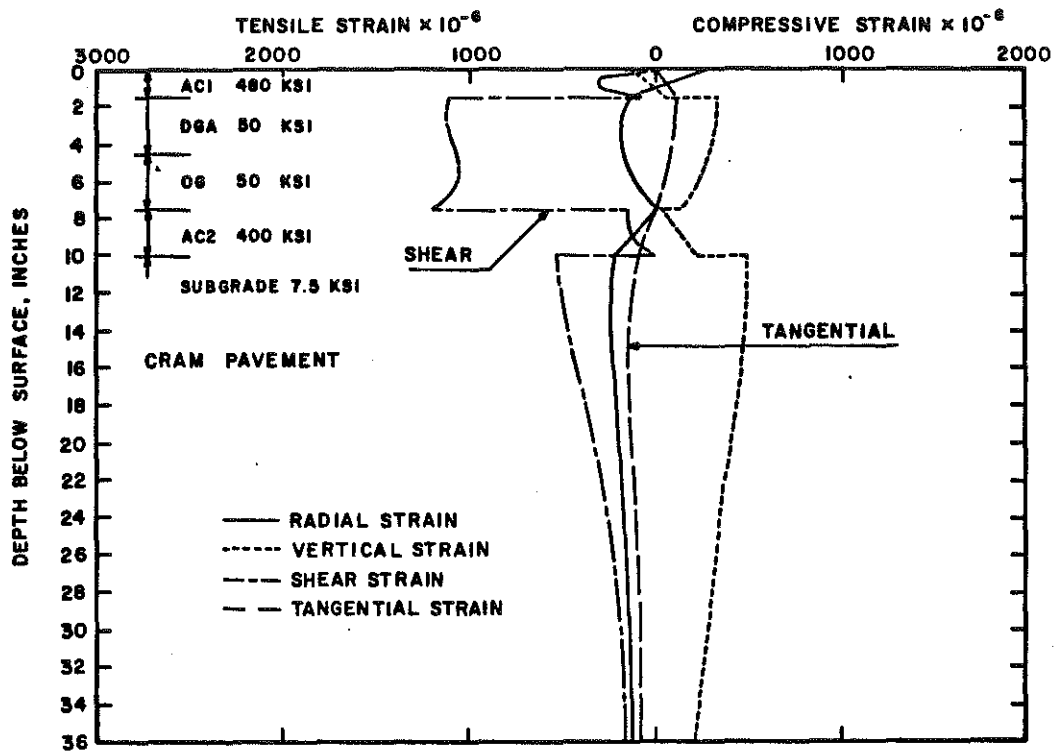PAVEMENT OF FIGURE 4.

FIGURE 9.   FOUR STRAIN DISTRIBUTIONS IN THE CRAM
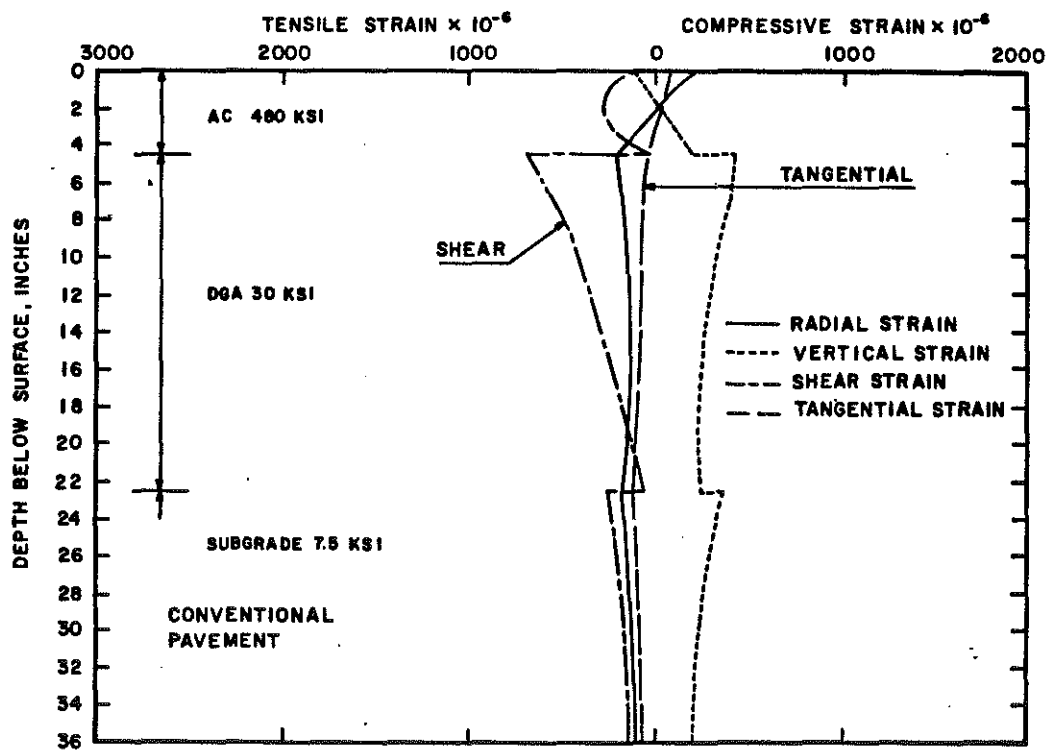PAVEMENT OF FIGURE 5.

FIGURE 10.   FOUR STRAIN DISTRIBUTIONS IN THE
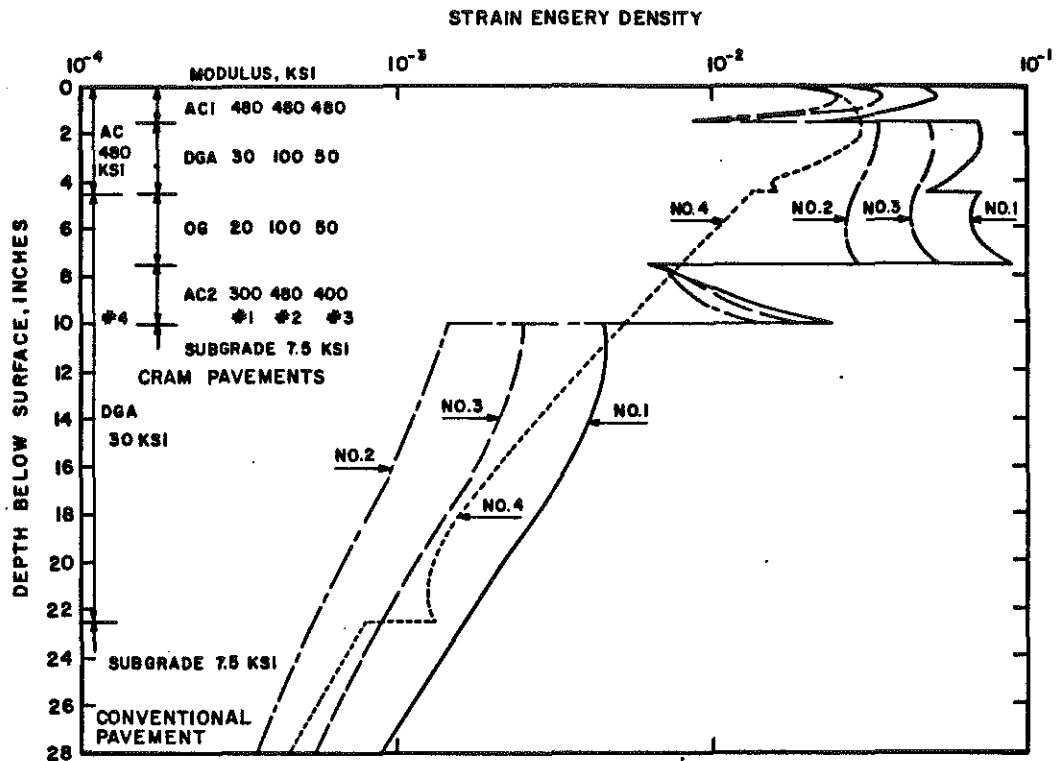CONVENTIONAL PAVEMENT OF FIGURE 6.

STRAIN ENGERY DENSITY

10^{-4} 10^{-3} 10^{-2} 10^{-1}

MODULUS, KSI

ACI 480 480 480

DGA 30 100 50

OG 20 100 50

AC2 300 480 400
     #1 #2 #3

SUBGRADE 7.5 KSI

CRAM PAVEMENTS

AC 480 KSI

#4

DGA 30 KSI

SUBGRADE 7.5 KSI

CONVENTIONAL PAVEMENT

NO.4   NO.2   NO.3   NO.1

NO.3   NO.1

NO.2

NO.4

DEPTH BELOW SURFACE, INCHES

FIGURE 11. STRAIN ENERGY DISTRIBUTIONS FOR
PAVEMENTS IN FIGURES 3-6.

RUTTING STRAIN × 10^2

O 2 4 6 8 10 12 14 16 18 20 22 24 26

AC
DGA
OG
MAC
SUBGRADE

DEPTH (INCHES)

1×10^6 EAL ———
1×10^7 EAL ·········

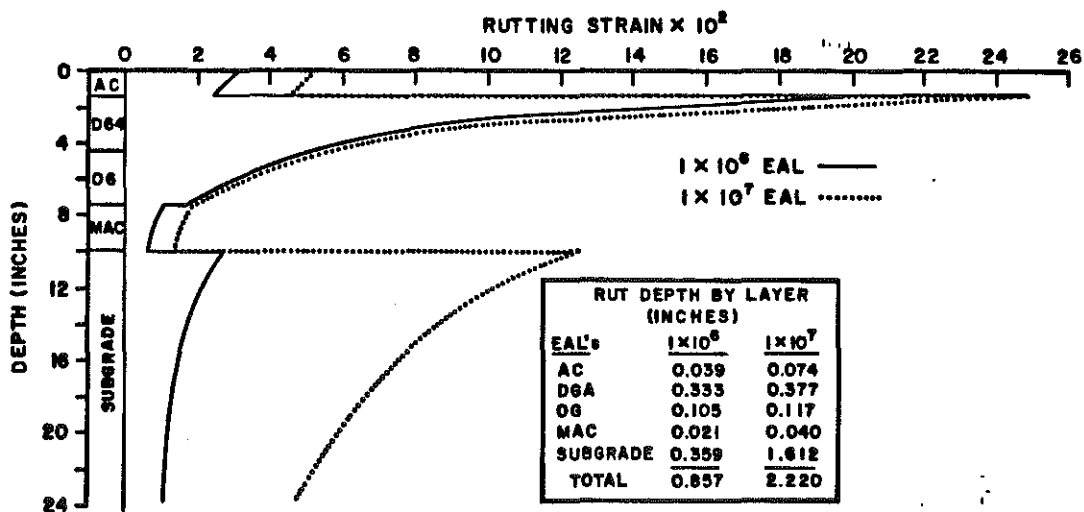| RUT DEPTH BY LAYER (INCHES)		
EAL's	1×10^6	1×10^7
AC	0.039	0.074
DGA	0.333	0.377
OG	0.105	0.117
MAC	0.021	0.040
SUBGRADE	0.359	1.612
TOTAL	0.857	2.220

FIGURE 12. RUT DISTRIBUTIONS THROUGHOUT "CRAM"
PAVEMENTS IN FIGURES 3-6.
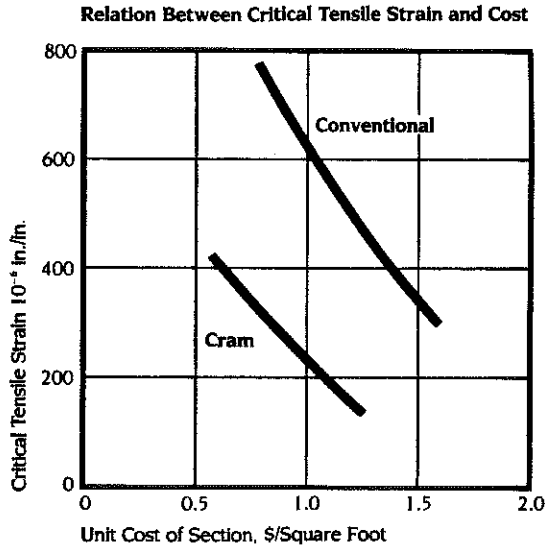
CRAM
Contained Rock Asphalt Mat

INTRODUCTION

Contained Rock Asphalt Mat (CRAM) is a cost effective pavement system engineered to meet today's demanding need for high performance surfaces for roadways, ports, airports, and industrial facilities. By *efficiently* distributing heavy repetitive wheel loads to subgrade soils, while retaining a smooth riding surface, the CRAM system is demonstrably superior to conventional pavements.

The CRAM pavement system maximizes the advantages of conventional and modified conventional construction materials by arranging them compatibly with the stress, temperature, and moisture environments unique to every application. This is accomplished by utilizing a computer aided design (CAD) system which produces the optimum structural section to yield maximum long-term performance with a minimum capital investment.

Since long-term economic considerations are important factors in selecting a pavement system, the CRAM system has proven itself to be an outstanding value. The superior structural strength of the CRAM pavement allows engineers, designers, and developers to provide their clients and the public with a safe and lasting road surface.

Figure 1

Relation Between Critical Tensile Strain and Cost

Unit Cost of Section, $/Square Foot

THEORY

The theory of the CRAM pavement system is founded on the selection of materials based on their compatibility with the stress, temperature, and moisture environments. In this way the individual material properties are utilized to form the optimum structural section for the intended use. This is in contrast to the concept of conventionally designed asphalt pavements where pavement materials are ordered in the structural section in accordance with their quality, with progressively "better" quality materials placed nearer the pavement surface.

As in conventional engineering structures, pavement failures occur when stresses or strains at critical locations are exceeded. The maximum tensile strain on the bottom of the asphalt concrete layer has been found to correlate well with the number of load repetitions to cause fatigue failure, which is manifest when cracks initiate at the bottom and propagate upward through the layer. Also, the maximum compressive strain on the subgrade has been found to correlate with the number of load repetitions to cause accumulative plastic deformations in the subgrade soil. Failure in an asphalt pavement structure is thus expressed by the fatigue-caused cracking and/or subgrade deformation-caused distortion, either or both resulting in an unacceptable riding surface. The CRAM pavement system combines materials in the structural section to efficiently distribute imposed stresses and strains. Graphical representations presented in accompanying Figures 2 and 3 display the stresses developed beneath the center of a wheel load for CRAM and conventional pavements, respectively.

The CRAM pavement effectively utilizes the surface course and aggregate for the imposed radial compressive stresses, utilizes the lowermost asphalt concrete primarily for the radial tensile stresses, and produces a reasonably uniform reduction of the vertical stresses through the full depth of the structural section. In contrast, in conventional pavements the asphalt concrete is utilized for both the compressive and tensile radial stresses and is thereby subjected to a major stress reversal. The aggregate base below experience only minor compressive stresses. Also, vertical stresses reduce rapidly through the asphalt concrete and slowly through the aggregate base.

The comparative analysis presented in Figure 1 shows that generally a *two-fold* increased efficiency in the use of pavement materials can be obtained. This efficiency in the CRAM pavement system results in corresponding minimum initial and long-term costs while providing maximum protection from adverse environmental effects.
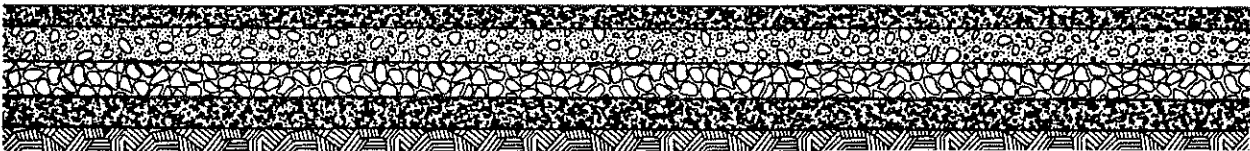
Figure 2

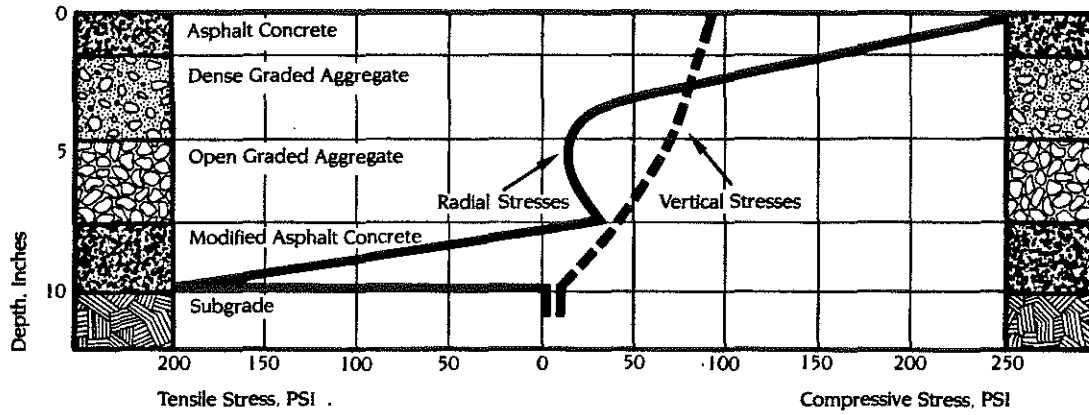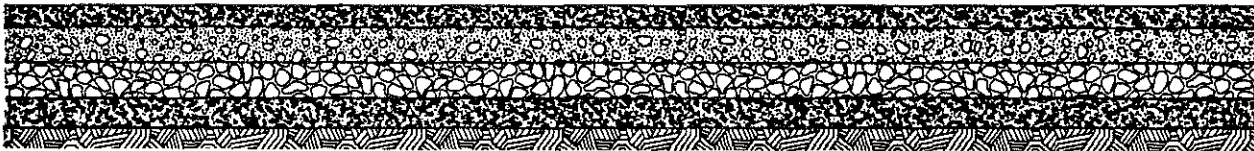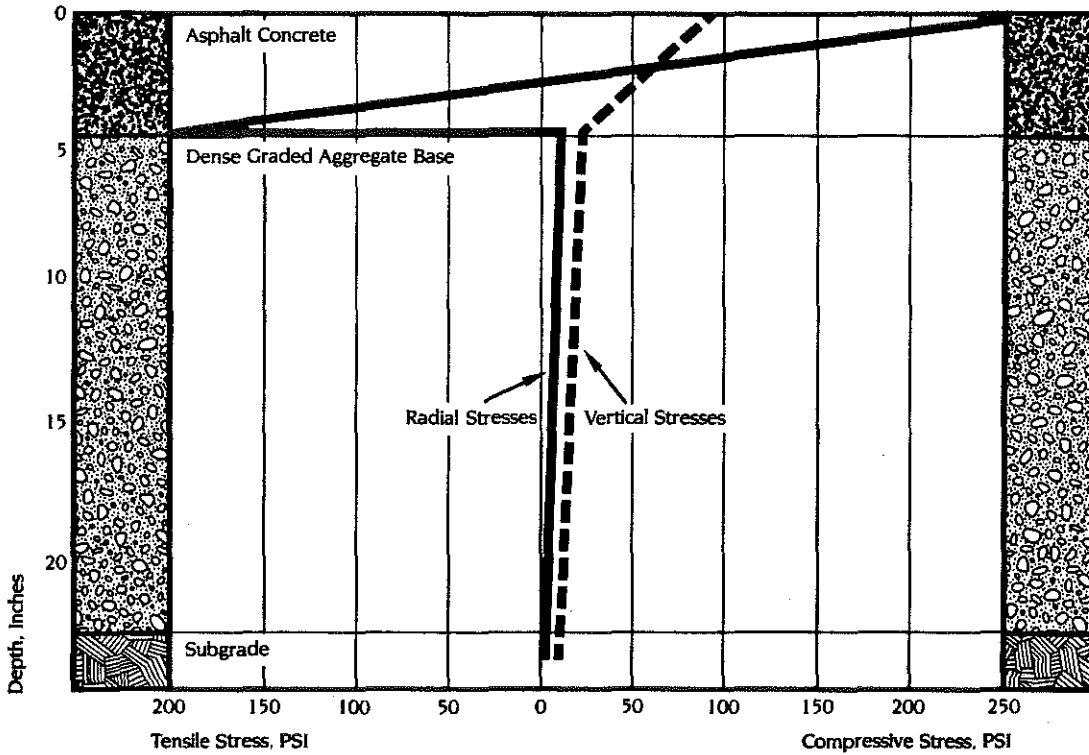## CRAM Pavement
Stresses Beneath Center of One Wheel

Asphalt Concrete

Dense Graded Aggregate

Open Graded Aggregate

Radial Stresses   Vertical Stresses

Modified Asphalt Concrete

Subgrade

Depth, Inches

200   150   100   50   0   50   ·100   150   200   250

Tensile Stress, PSI .

Compressive Stress, PSI

Figure 3

Conventional Pavement
Stresses Beneath Center of One Wheel

Asphalt Concrete

Dense Graded Aggregate Base

Radial Stresses   Vertical Stresses

Subgrade

Depth, Inches

200   150   100   50   0   50   100   150   200   250

Tensile Stress, PSI

Compressive Stress, PSI

2R

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