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Parametric Relationships of Conventional Versus Repetitive Loading Triaxial Tests[1]

DARWIN E. FOX and J. M. HOOVER[2]

SYNOPSIS: Parametric Relationships of Conventional Versus Repetitive Loading Triaxial Tests. *Proc. Iowa Acad. Sci.*, 79(2):49-52, 1972. This investigation was developed to examine response of a field-mixed asphalt-treated granular base material to 100,000 repetitions of a load whose magnitude was determined by a failure criterion proposed by Hoover (1970), and Fish and Hoover (1969). Axial strain and load at the point of maximum volume of a specimen during a conventional triaxial test appear to produce a "proportional limit," indicating that failure may have started. Axial stress at this point was applied in the repetitive loading triaxial test at the same confining pressure, during which axial strain and pore pressure continuously increased and specimen volume decreased in each of three series of tests. Post repetitive specimen condition, determined by retesting in the conventional manner indicated that none of the specimens had "failed" during repetitive loading. Results of this series of tests indicate a further potential feasibility of the use of minimum volume failure criteria for thickness design of a granular base material.

INDEX DESCRIPTORS: triaxial shear, repeated loading, minimum volume, failure criteria, granular base materials.

Performance of a flexible pavement structure is related to the physical properties and supporting capacity of the various structural components. A rational design method requires quantifying these physical properties, relating the performance of the materials under laboratory testing to their performance in a completed flexible pavement subjected to transient traffic loads.

PREVIOUS RESEARCH

More than 15 years ago Seed *et al.*, (1955, 1957) were concerned with the fatigue failure of flexible pavements subjected to transient loads. Repeated load tests on a silty clay used in pavement subgrades showed that there was a marked increase in the rate of deformation of specimens subjected to repeated loading as compared to specimens under a sustained load.

Larew and Leonards (1962) also worked with subgrade materials, one being a limestone residual clay soil. A confining pressure was selected and the deviator stress to cause shear failure in a static triaxial test, σ_s, was determined. Under the same confining pressure repeated loading tests were performed using various deviator stresses, σ_r.

When the ratio σ_r/σ_s was 0.77, it was found that 40,000 applications of σ_r resulted in a constantly decreasing rate of deformation. When the ratio was increased to 0.84, the deformation was greater but also tended to level out. As the ratio was further increased, deformation increased and the rate of deformation began to appear constant, though followed by a sudden failure within a few hundred added cycles. A larger ratio produced failure at fewer cycles. When the ratio was 1.03, a slip plane developed and failure occurred in just over 100 cycles. Similar relationships were noted with a clayey sand and other subgrade materials. A

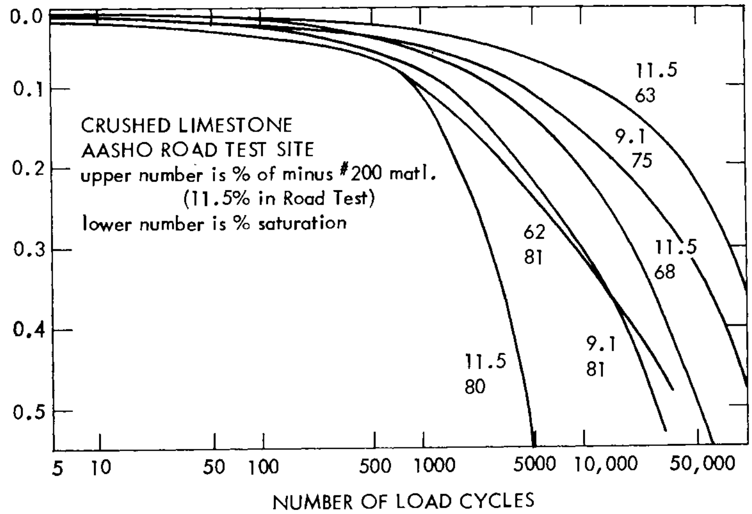

Figure 1. Deflection history of crushed stone specimens from Haynes and Yoder (Ref. 4).

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[1] This paper was prepared for presentation at the 1971 meeting of the Iowa Academy of Science.

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failure criterion of σ_r/σ_s maximum between 0.84 and 0.91 was postulated.

Haynes and Yoder (1963) performed repeated loading triaxial tests on specimens prepared from two base course materials obtained from the site of the AASHO Road Test; i.e., crushed limestone (Fig. 1) and gravel. Several levels of saturation were investigated along with variations in the amount of material passing the #200 mesh sieve. It was hoped that the study would determine why those materials behaved as they did under conditions of test traffic. Further research was needed to clarify the reason for the difference in the field performance between the gravel and crushed stone. However, a good correlation between field and laboratory stability was found at field moisture levels.

Fish and Hoover (1969) observed that during a conventional consolidated-undrained triaxial shear test a granular base specimen undergoes an initial volume decrease as axial load is applied. As can be seen in Fig. 2, a point of minimum volume is reached after which the specimen increases in volume during the remainder of the test. Axial strain and load at minimum volume (MV) are less than at maximum effective stress ratio (MESR). Strain and load at minimum volume appear to produce a "proportional limit", indicating that failure of the specimen may have started.

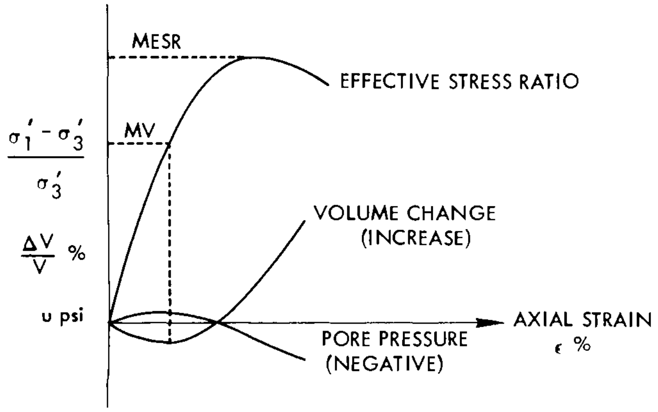

Figure 2. Relationships of volume change, effective stress ratio and pore pressure to axial strain.

In previous research by Hoover at Iowa State University (1970), conventional triaxial shear tests had been performed on a crushed stone base material obtained from the site of the AASHO Road Test. The stone was sieved and reblended to the reported AASHO Road Test gradation. Specimens were compacted at optimum moisture content for maximum density, with a resulting moisture saturation above 85%. Densities obtained were comparable to those reported as having existed in the Road Test base course.

Conventional triaxial tests were performed at confining pressures of 10 and 20 psi where it was observed that minimum volume deviator stresses were respectively 36 and 73 psi. According to the minimum volume failure criteria proposed by Fish and Hoover (1969), a large number of applications of deviator stress at the corresponding lateral confining pressure could be tolerated without failure.

In their previously mentioned work, Haynes and Yoder (1963) did repeated loading triaxial tests on AASHO Road Test limestone using a deviator stress of 70 psi. This was selected on the basis of approximate stresses that existed at the base course level in the Road Test pavement. The confining pressure used was 15 psi. At Iowa State it was suggested that if a confining pressure of 20 psi had been used, the repeated loading test specimens would have withstood an indefinite number of deviator stress applications at saturations of 85 to 100%.

The study reported herein evaluated a base course material with regards to the minimum volume failure criteria and repetitive loading triaxial tests by parametric comparisons with the conventional triaxial shear test. Material selected was an asphalt-treated base course material which is representative of the construction of high types of pavements in Iowa.

SPECIMENS AND TESTING

Field-mixed base material was made available through the cooperation of the office of the Research Engineer, Iowa State Highway Commission, samples being obtained from construction batch plants immediately following mixing with asphalt. An analysis was performed on this material in the ISHC laboratory (Table 1).

A syntron model V-60 electromagnetic vibrator was utilized for compaction, operating at a constant frequency of 3600 cycles/min, amplitude of 0.368 mm, surcharge weight of 35 lb, and vibration duration of 2 min. This procedure by Hoover (1965) minimizes aggregate degradation and segregation while producing uniform densities comparable to other methods.

Field-mixed samples were separated into portions, large enough to produce a 4-in. diameter by 8-in. high compacted cylinder, and heated to 250-260° F. Mixture was placed in a

TABLE 1. ASPHALT TREATED BASE (FIELD MIX) ISHC LABORATORY.

Marshall compaction density	141 pcf.
Asphalt by extraction	3.80%
Asphalt grade (for project)	120-150 pen.
Aggregate by extraction	96.20%
Aggregate sp. gr.	2.666

Aggregate source: Keokuk Co., St. Louis Formation, Limestone

Sieve size	1"	¾"	½"	⅜"	#4	#8	#16	#30	#50	#100	#200
Percent Passing	100	96	95	78	55	42	33	23	14	9.5	5.4

heated vibratory mold in three equal layers, each layer being rodded 25 times with a ⅝-in. diameter rounded tip rod. Surcharge weight was set in place and the specimen compacted. Following compaction, height of the specimen was measured while in the mold. The specimen was then extruded, weighed, and allowed to cool before being transferred to the curing room. Curing was maintained for a minimum of seven days at about 75° F and 50% relative humidity. Prior to testing, specimens were remeasured, weighed, and subjected to immersed vacuum saturation for at least 30 min. or until air bubbles ceased to be released from the specimen.

Repetitive axial loads applied to each specimen were those determined at the point of minimum volume of identical specimens in the conventional consolidated-undrained triaxial test apparatus. Minimum volume axial load at 10 psi lateral pressure produced a stress in the test specimen of about 70 psi, comparable to that created in a flexible pavement base course by a passing truck. Minimum volume loads at 20 and 30 psi confining pressure were equivalently higher. Each specimen underwent drained-consolidation for 36 min. under the lateral pressure. Load application dwell time was maintained at 0.5 sec. for each specimen, with 100,000 applications of load the arbitrary cutoff point. Axial and volumetric strain and pore pressure were continuously recorded during testing. Test temperature of the specimens was maintained at 100° F through a heating coil in the triaxial cell.

OBSERVATIONS AND CONCLUSIONS

Inspection of repetitive data showed that throughout each of the three tests volume continuously decreased as axial deformation and pore pressure increased. A plot on arithmetic scales of axial deformation and volume decrease against number of load applications shows that after about 300,000 cycles of loading, the rate of change becomes fairly constant (Figs. 3 and 4). Continuing decrease in volume with only small axial deformations points to a potential decreasing average radius of specimens. Under field conditions this may be the mechanism which leads to rutting of a flexible pavement.

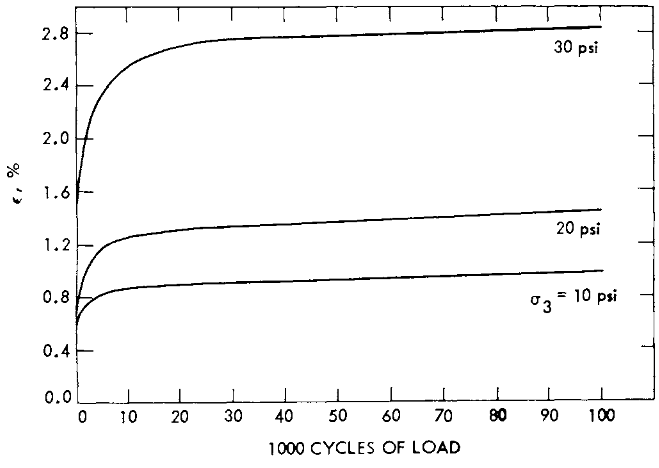

Figure 3. Relationship of axial strains and number of load applications.

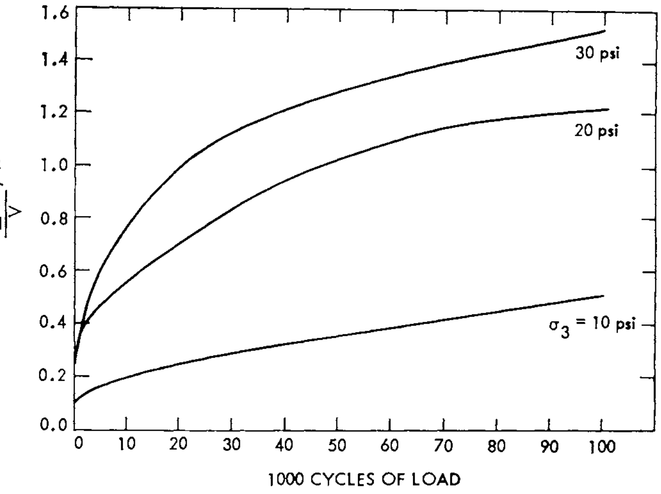

Figure 4. Relationship of volume decrease and number of load applications.

The post-repetitive test condition of each specimen was analyzed by retesting under the conventional consolidated-undrained triaxial test. Examination of data showed each specimen exhibited a decreasing volume and an increasing axial strain, pore pressure, and effective stress ratio to the point of minimum volume. Three factors were indicated:

1. None of the specimens had "failed" during repetitive loading.
2. Each specimen may have partially rebounded elastically during removal from the repetitive apparatus, resaturation process, and placement in the conventional apparatus.

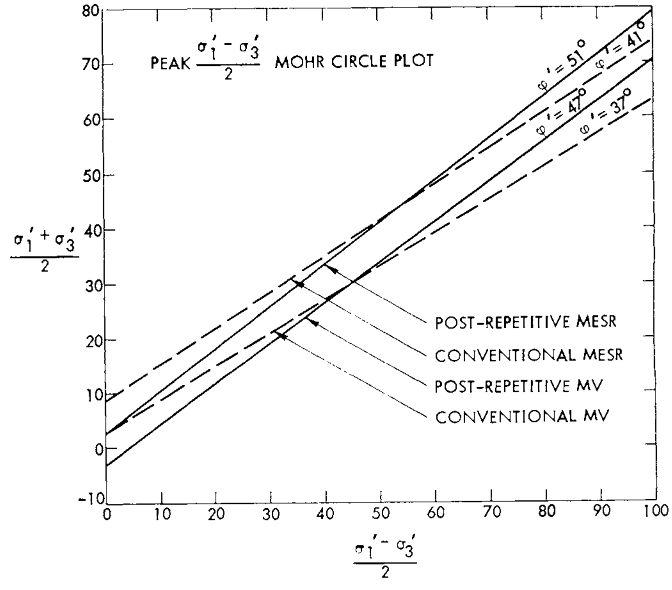

Figure 5. Angles of internal friction.

3. Because of the continued volume decrease during cyclic loading, each specimen had increased in density and undergone a "strain hardening" as evidenced by much higher internal friction angles in the post-repetitive specimens (Fig. 5).

Axial and volumetric strains are indicated in Fig. 6 for (a) specimens after 100,000 cycles of repetitive loading, (b) specimens tested only in the conventional manner, and (c) post-repetitive specimens retested in the conventional manner. Volumetric strains under repeated loading greatly exceeded those of the conventionally tested specimens at both minimum volume (MV) and maximum effective stress ratio (MESR).

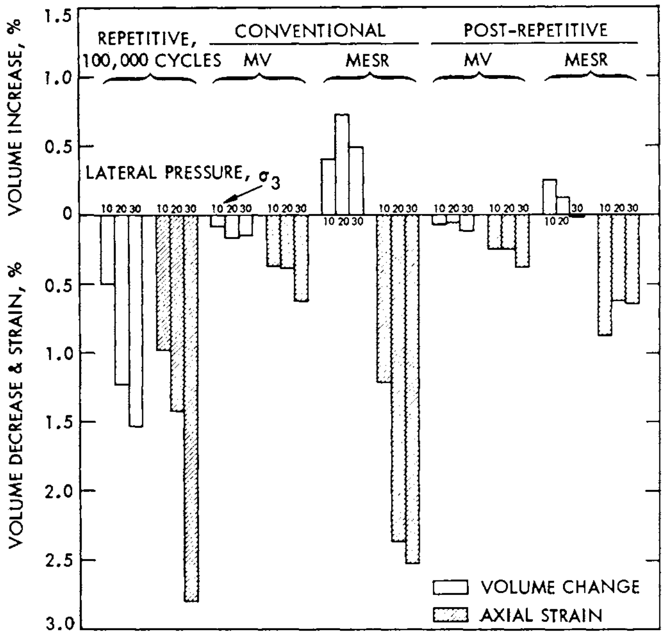

Figure 6. Comparison of volumetric and axial strains.

Axial strain for repeated loading greatly exceeded conventional MV axial strain, but was not always greater than the conventional MESR axial strain. For example, at 20 psi lateral pressure the conventional MESR axial strain was much greater than repetitive loading axial strain. Volumetric strain at conventional MESR indicates failure has occurred due to volume increase at each lateral pressure. Consequently, there may be a phase lag in the specimens volume change during repetitive loading, indicating some remaining resilience (elasticity) in the specimens due to sudden repetitive loading as compared with the slower, longer duration of stresses in the conventional test procedure. This is further evidenced from the post-repetitive MV volumetric strains being of less magnitude than those at conventional MV, and the post-repetitive MESR volumetric and axial strains, also being of lesser magnitude than those at conventional MESR.

On the basis of the previous observations the following conclusions can be formed:

1. Axial stress existing at the point of minimum volume of a specimen during a conventional triaxial shear test can be applied to an identical specimen at the same confining pressure in a repetitive triaxial shear test at least 100,000 times without failure by shear.

2. The magnitude of axial strain at 100,000 cycles may exceed the axial deformation of a conventionally tested specimen at the point of maximum effective stress ratio, which is a generally accepted failure criterion.

3. The volumetric decrease of a specimen during 100,000 cycles of loading exceeds by several times that of a conventionally tested specimen to the point of minimum volume. This possibly is the field mechanism which leads to rutting in flexible pavements.

4. During repetitive loading asphalt-treated granular base materials may undergo a "strain hardening" as evidenced by higher angles of internal friction in the post-repetitive tests.

ACKNOWLEDGMENTS

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