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REPORT **MR89-1**



**Laboratory Determination of
Resilient Modulus of
Missouri Subgrade Soils;
Phase I;
Equipment, Personnel,
and Testing Requirements**

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT



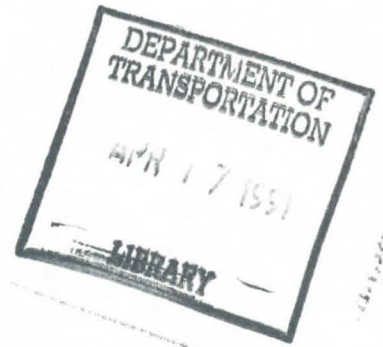
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16. Abstract <p>This study was designed to establish a basic resilient modulus testing capability, determine necessary test modifications, establish equipment capacity and determine future equipment and personnel requirements for production testing.</p> <p>The equipment acquired was a closed-loop, pneumatic test system manufactured by Research Engineering, Inc. Tests were conducted in accordance with AASHTO T 274 on both undisturbed and remolded subgrade samples of cohesive soils with liquid limits from 30 to 60 and plastic indices from 8 to 30. Remolded samples prepared using a Harvard miniature (kneading) compactor had adequate density but appeared to lack homogeneity.</p> <p>It was established that two complete tests per day could be performed provided backpressure saturation was not attempted. Backpressure saturation of cohesive soils required much more time and resulted in premature failure of most samples during conditioning.</p> <p>It was concluded that backpressure saturation is not practical for production testing of cohesive soils and that an automatic kneading compactor, a dual-channel oscilloscope and a strip chart recorder are desirable equipment additions. Restrictions on duration of tests and the number of confining and deviator stresses required are proposed and areas deserving of additional research are suggested.</p>					
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LABORATORY DETERMINATION OF RESILIENT MODULUS OF
MISSOURI SUBGRADE SOILS; PHASE I;
EQUIPMENT, PERSONNEL, AND TESTING REQUIREMENTS

FINAL REPORT

STUDY NO. 89-1



Prepared By
MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
DIVISION OF MATERIALS AND RESEARCH

MARCH 1990

In Cooperation With
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions
expressed in this publication are not
necessarily those of the Federal Highway
Administration.

ABSTRACT

This study was designed to establish a basic resilient modulus testing capability, determine necessary test modifications, establish equipment capacity and determine future equipment and personnel requirements for production testing.

The equipment acquired was a closed-loop, pneumatic test system manufactured by Research Engineering, Inc. Tests were conducted in accordance with AASHTO T 274 on both undisturbed and remolded subgrade samples of cohesive soils with liquid limits from 30 to 60 and plastic indices from 8 to 30. Remolded samples prepared using a Harvard miniature (kneading) compactor had adequate density but appeared to lack homogeneity.

It was established that two complete tests per day could be performed provided backpressure saturation was not attempted. Backpressure saturation of cohesive soils required much more time and resulted in premature failure of most samples during conditioning.

It was concluded that backpressure saturation is not practical for production testing of cohesive soils and that an automatic kneading compactor, a dual-channel oscilloscope and a strip chart recorder are desirable equipment additions. Restrictions on duration of tests and the number of confining and deviator stresses required are proposed and areas deserving of additional research are suggested.

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INTRODUCTION

Resilient modulus of soils is one of the major inputs needed to implement the AASHTO Guide for Design of Pavement Structures.¹ Prior to this study, the Missouri Highway and Transportation Department (MHTD) did not have the capability to perform resilient modulus tests. The purpose of Phase I of this study was to establish that capability and to determine time, personnel, and equipment requirements that would be necessary for full scale implementation.

Specific objectives for Phase I of the study were:

1. Establish the capability to perform tests.
2. Determine the productive capacity of the equipment.
3. Determine the need for backpressure saturation.
4. Determine future equipment and personnel requirements.

During the progress of the study, the latter objectives evolved and expanded into an overall evaluation of the AASHTO test procedure as other questions arose about some of the test requirements.

It is anticipated that the findings of Phase I of the study would lead to a second phase study in which it is proposed to test many different soil types and correlate the results of resilient modulus testing with other soil characteristics. The results of Phase II of the study are expected to lead to the development of guidelines for determining resilient modulus of soils which will be used

in implementation of the AASHTO Guide for Design of Pavement Structures.

TEST EQUIPMENT

Test equipment from several manufacturers was evaluated prior to purchase. At that time, there were two basic types of equipment available that would suit our needs. These types were electrohydraulic and pneumatic. Most of the equipment available is "closed-looped" with regard to deviator stress loading. That is, after each load pulse, a control signal is returned from the load cell to the controller and the next load pulse is adjusted to ensure that the correct deviator stress is applied to the sample.

Generally, the electrohydraulic systems available consist of a large electrically powered hydraulic pump that provides hydraulic fluid under pressure to a load frame that transfers the load to the sample. Deviator stress is achieved by using a fast-acting servo valve in the hydraulic system that is connected to an electronic controller or computer. Because of the greater cost of the hydraulic pump and load frame, the electrohydraulic systems are generally much higher priced than the pneumatic systems.

Pneumatic systems generally consist of an electronic controller or computer that is attached to a fast-acting servo valve. Generally, the system is connected to the laboratory's compressed air supply. The equipment manufacturer may require that the compressed air pass through a refrigerated type air filter dryer to avoid damage to the valve. Rather than a load frame, the pneumatic systems generally use a load actuator that is mounted to

the top of the triaxial cell. Compressed air passes through the servo valve, is regulated by the system controller, then enters a diaphragm that transfers the load to the sample.

All of the systems evaluated were automated with respect to the deviator stress regulation. Some systems available are also automated with respect to the confining pressures, although this usually comes at a higher cost. While automation certainly makes testing much easier, it has the disadvantage that the test can only be performed in accordance with the method written into the software. Much of the software available allows for the adjustment of all or some of the test variables; however, the software provided with the purchased equipment allowed testing only by the AASHTO T 274 test method. The disadvantages of this limitation will be discussed later in this report.

Because of the cost advantage, the Missouri Highway and Transportation Department selected a pneumatic system manufactured by Research Engineering, Inc., for resilient modulus testing. The system is "closed-loop" with regard to the deviator stress loading as explained earlier (See Figure 1). The deviator stress loading is automated, however, confining pressures must be adjusted manually after each loading cycle. The Pegasus Model 212 servo-valve is controlled by a dedicated MTS Model 406 controller that receives a load pulse signal from an IBM compatible micro-computer. Stress is measured by a load cell located just

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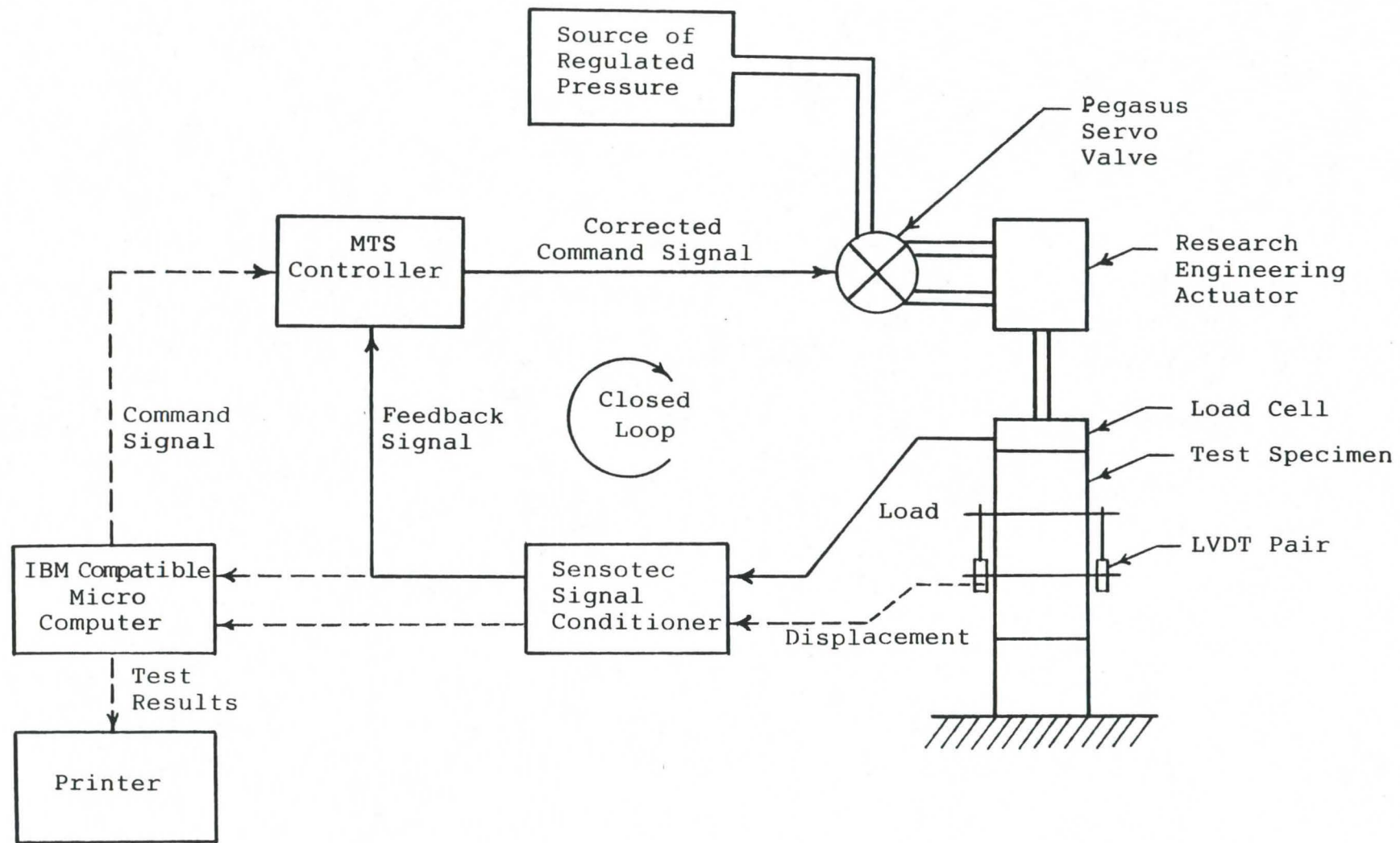


FIGURE 1
Closed Loop Pneumatic Test System
Schematic Drawing

above the sample inside the triaxial cell. Strain is measured by either two LVDT's (Linear Variable-Differential Transformers) mounted on the sample by two clamps, or by a single LVDT mounted on the actuator rod outside the triaxial cell (See Figure 2). Analog signals from the load cell and LVDT's are converted by a Sensotec SA series multi-channel signal processor to a digital signal transmitted to the microcomputer which reports the results. All required measurements of stress and strain are performed automatically and reported by the microcomputer. The printed report includes all the information required by AASHTO T 274 including a graph of resilient modulus versus deviator stress at each confining pressure.

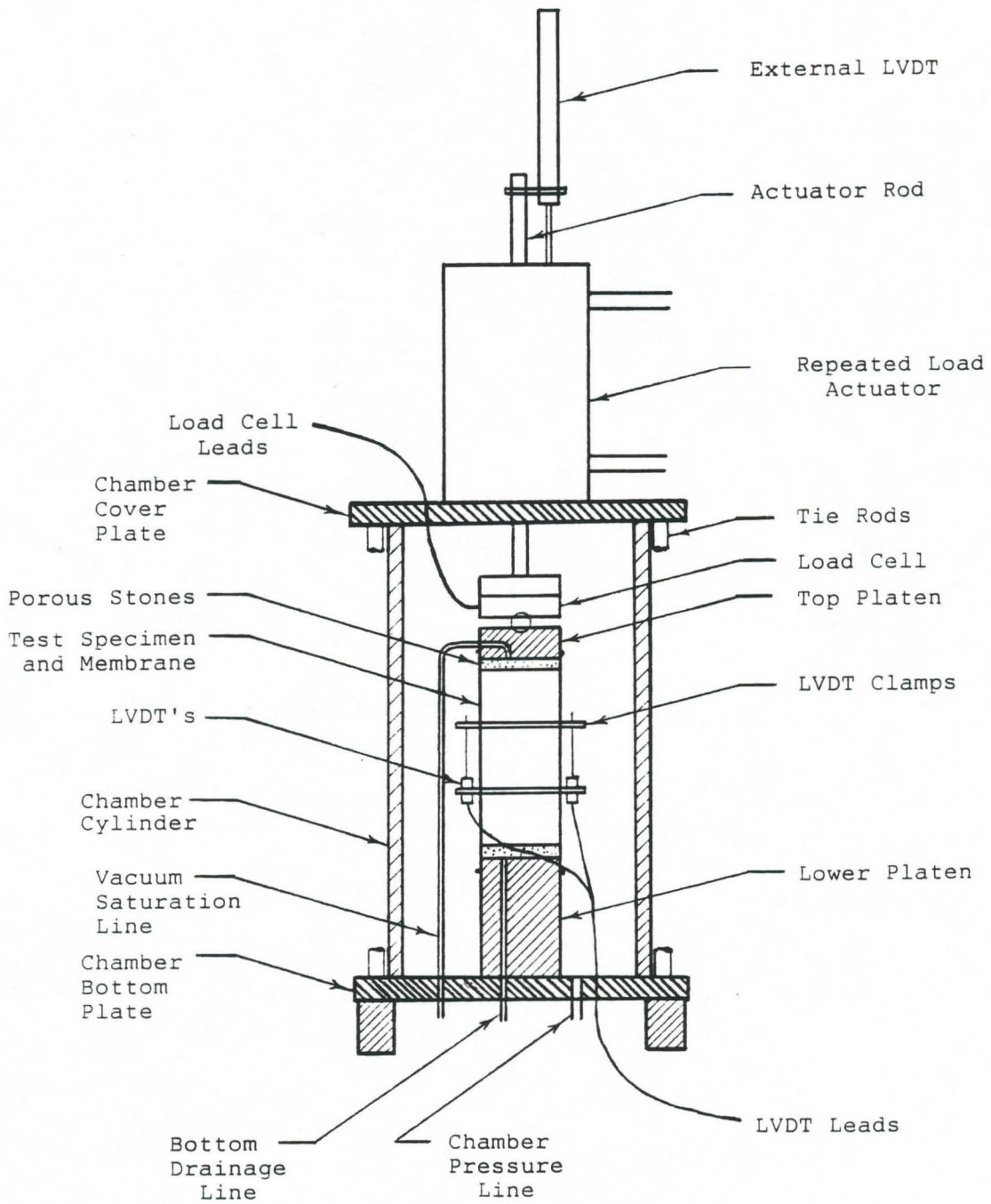


FIGURE 2
 Triaxial Test Cell
 With Pneumatic Load Actuator
 Schematic Drawing

TEST METHOD

The equipment purchased by MHTD meets the requirements of AASHTO Standard Method of Test Designation T 274-82 (1986). The software purchased conducts the test strictly by the test method and provides the required output.

There are several requirements in the AASHTO test procedure that MHTD as well as other researchers have found to be overly restrictive or that may lead to premature sample failure or erroneous results. These apparent deficiencies in the test method are reported in the paragraphs that follow.

SAMPLE CONDITIONING

The researchers believe that under certain sample conditions the conditioning procedures outlined in AASHTO T 274 can be extremely harsh, and may result in sample failure. MHTD has experienced premature sample failure in soft samples, and especially in those that have been prepared by backpressure saturation.

RESILIENT MODULUS DEFINITION

Resilient modulus is defined as the deviator stress divided by the resilient or recovered axial strain after the 200th load repetition. Other researchers have found there is no difference in recovered axial strain after the 50th load repetition; therefore, it seems that testing for 200 repetitions is excessive. More disturbing, however, the

resilient modulus of a sample at a specific confining pressure and deviator stress is based solely on the reading taken after the 200th load repetition. If this particular reading deviates from the norm or average it will result in an erroneous resilient modulus value. Since the last one hundred plus readings are essentially the same, the resilient modulus could be based on the average of several readings rather than relying on the accuracy of only one reading.

NUMBER OF CONFINING PRESSURES AND DEVIATOR STRESSES

The test requirements for the number of confining pressures and especially the number of deviator stresses seem excessive. Since much of pavement design is based on the maximum wheel loading to which a pavement will be subjected, testing at very low deviator stresses of one or two pounds per square inch seems to be of little advantage. Also, after conducting many resilient modulus tests, the results of these low deviator stresses have been found to be more erratic than the values obtained at higher stress levels. Testing at deviator stresses in the mid to upper range given in the test method would seem to be more cost effective.

The AASHTO test procedure requires that cohesive soils be tested at confining pressures of zero, three, and six pounds per square inch. Since all subgrade soils are somewhat confined, and all samples are taken from

approximately the same depth, it is believed that all resilient modulus testing could be performed at a particular confining pressure. Elliot and Thornton have suggested that three pounds per square inch may most accurately reflect the actual confining pressure under pavements.⁵

SAMPLE PREPARATION

Samples tested were of two types. Many tests were performed using undisturbed thin wall tube samples obtained from subgrade soils at SHRP (Strategic Highway Research Program) test sections throughout the state. These samples must be cut square on each end but no other preparation is necessary before testing.

The majority of tests were conducted using remolded samples compacted from bulk materials. AASHTO T 274 requires kneading compaction for samples representing subgrades subjected to a post construction change in water content or those compacted at a water content greater than 80% of saturation. Since almost all subgrade soils in Missouri fall into one of these two groups, kneading compaction was used for all reconstructed samples.

Kneading compaction was accomplished using a Harvard miniature compactor. The soil was compacted in a 2.8 inch diameter mold in five equal lifts using 25 blows per lift and a spring force of 20 pounds. This method achieved densities of over 95 percent of maximum (AASHTO T 99, Method C). While test results from similarly prepared samples of the same material yield similar results, dissection of the samples after testing revealed different degrees of density within the sample. It is felt that more consistent samples could be obtained using an automatic kneading compactor.

PRODUCTIVE CAPACITY OF EQUIPMENT

All tests conducted by MHTD have followed AASHTO T 274-82 (1986). The test method allows the cycle duration to vary from one to three seconds. Depending on the cycle duration chosen, the actual testing time for cohesive soils will then vary from 3 minutes, 20 seconds to 10 minutes for each 200 repetitions, or from 1 hour, 6 minutes, 40 seconds to 3 hours, 20 minutes for each complete test. This does not include the time to change confining pressures between load repetitions as required by the test method. Most testing was performed at an intermediate cycle duration of two seconds for an actual test time of 2 hours, 13 minutes, 20 seconds. The practical testing time including changing confining pressures, cell setup, cell teardown, and a fifteen minute break would be closer to three or three and one half hours. As a practical matter then, one can expect to conduct two tests per 8-hour day, one in the morning and one in the afternoon, using the AASHTO test method.

It should be noted that the above time requirements are only for the actual testing time including setup and teardown. It does not include sample preparation or saturation. Additional time and/or an additional technician is required for these duties.

A limited number of tests were conducted at the shortest cycle duration allowed by the standard test

procedure (one second). The results using this cycle duration seem to be consistent with those from tests conducted at greater cycle durations. The test results may even indicate slightly greater precision at the shorter cycle duration. At this cycle duration, it may be possible to conduct resilient modulus testing on up to four samples per day.

BACKPRESSURE SATURATION

The need for post-compaction backpressure saturation of cohesive soil specimens seems to be of little relevance when using the current standard test method. In almost all cases where backpressure saturation was used, the sample failed during the conditioning portion of the test. In those few cases where the sample survived conditioning, it failed before completion of the test.

Another major drawback to using backpressure saturation of clays or silty clays is the length of time required to saturate the sample. As stated previously, two tests and perhaps as many as four can be performed per day using AASHTO T 274 without backpressure saturation. To saturate a clay subgrade sample may require well over a week. This severely limits the practical productive capacity of the test equipment. Possible alternatives to backpressure saturation include compacting samples at higher moisture contents, securing undisturbed samples during wet seasons or perhaps establishing relationships between the results of tests from saturated and unsaturated samples.

Many testing agencies have apparently chosen to ignore the test procedure requirements for testing saturated samples. Most likely this is due to the reasons listed above. Other agencies may also deal primarily with granular

soils where saturation, if required, is relatively quick and simple to achieve.

It can be argued that sample saturation is unnecessary since complete saturation is unlikely to be achieved in the field at the low confining stresses acting at the level of the top of the subgrade. More likely, this state of full saturation is approached but never fully realized on a transient, seasonal basis. It has been conventional wisdom that subgrade moisture contents increase with time after paving and, of course, vary seasonally. MHTD, however has only limited data confirming actual degrees of saturation of the subgrade.

FUTURE EQUIPMENT REQUIREMENTS

One of the original objectives was to establish future equipment and personnel requirements for both the continuation of resilient modulus research and for full production testing should the AASHTO Guide for Design of Pavement Structures be implemented. It is concluded that one loading apparatus capable of running two to four resilient modulus tests per day is probably adequate but that some additional equipment is needed for sample preparation and testing:

1. Kneading Compactor.

As discussed in Section D on sample preparation, a Harvard miniature compactor was used for sample compaction. It is believed that this method would not be cost-effective for full scale production testing and that samples prepared using this method are probably not as consistent as is desirable. An automatic kneading compactor is recommended to both improve production capacity and increase sample consistency and test reproducibility.

2. Oscilloscope.

It was found that a dual channel oscilloscope is almost a necessity when conducting tests with this equipment. The gain on the dedicated controller must be adjusted for each sample to create a load pulse that is near equal to the ideal pulse generated by the microcomputer. That is, the

haversine pulse transmitted to the servo valve should be roughly equal to the feedback pulse received from the load cell. A gain set too low will result in sluggish actuator response and low deviator stresses. A gain set too high will cause the actuator to react very quickly and there is a tendency to go into oscillation or "servo instability". The borrowed oscilloscope used for this study should be replaced with a dedicated oscilloscope for production testing.

3. Strip Chart Recorder.

As mentioned in Section C on Test Method, AASHTO T 274 defines resilient modulus as the deviator stress divided by the resilient or recovered axial strain after the 200th load repetition. As some erratic results have been calculated using only this single data point, it would be desirable to establish the capability to record all deviator stresses received by the load cell and all resilient axial strains as shown by the LVDT's. It is believed this could best be accomplished through the use of a strip chart recorder. This would also provide the capability to establish the accuracy and precision of the equipment

CONCLUSIONS

Most of the goals of this study phase have been satisfied. The Missouri Highway and Transportation Department now has the capability to conduct resilient modulus tests. Productive capacity of the equipment was determined as well as desirable modifications to test procedures and equipment. Uncertainties remain, however, as to the accuracy, precision, and reliability of the test equipment and procedures.

The productive capacity of the test equipment, not including sample preparation, is related more to the test procedures than the equipment itself. If AASHTO T 274 is used as now written, two to four tests can be conducted in an eight hour day. However, the required numbers of confining stresses, deviator stresses, and load repetitions seem overly restrictive. Productive capacity can be increased by lowering the number of load repetitions from 200 to 100 without degrading test results. Likewise, selecting fewer confining pressures and deviator stresses that most accurately model field conditions will increase productive capacity. Use of a confining pressure of three pounds per square inch and a deviator stress in the mid to upper portion of the range given in the standard test method, as recommended by other researchers, will provide results adequate for the intended use.

It is also concluded that the resilient modulus should be determined from an average of many recovered axial strains rather than just one, since basing the calculated resilient modulus solely on one reading of recovered axial strain has greater potential for error. Other researchers have found no significant change in recovered axial strain after the 50th deviator stress loading.

No conclusion was reached as to the need for sample saturation. However, it was concluded that the post-compaction backpressure saturation required by AASHTO T 274 for cohesive soil specimens is impractical since all backpressure saturated samples failed either during conditioning or before completion of testing. The relevance of testing fully saturated soils can best be determined by measuring the degrees of saturation of samples taken from under pavements over a period of many seasons. However, MHTD has only limited data to confirm actual degrees of saturation in the field. A detailed investigation to determine field saturation conditions is therefore recommended to define the relevance of, and need for, backpressure saturation and to determine appropriate degrees of saturation for testing and selecting modulus values for pavement design.

Additional equipment needed for continued research and/or production testing include an automatic kneading compactor to improve production capacity and sample

consistency, a dedicated oscilloscope to define and confirm the shape of the load pulse, and a strip chart recorder to monitor deviator stress and recovered axial strain. The strip chart recorder would also provide a means to calculate the average resilient modulus over a period of several repetitions and would help in establishing the accuracy and precision of the current test equipment.

Further research is needed to determine representative resilient modulus values for various subgrade soils in Missouri, and to increase understanding of the effects of different degrees of saturation on the resilient modulus of a particular soil. A confidence level adequate for use in design must be established and other soil characteristics correlated to resilient modulus before specific guidelines can be developed for MHTD's use of resilient modulus values with the AASHTO Guide for Design of Pavement Structures.

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