Final Report
Highway Research Project TRC-69

Study of Engineering Material Properties which Influence the Utilization of Marginal Aggregates

Sponsored By
The Arkansas State Highway and Transportation Department
in cooperation with
The U.S. Department of Transportation
Federal Highway Administration

STUDY OF ENGINEERING MATERIAL PROPERTIES WHICH INFLUENCE THE UTILIZATION OF MARGINAL AGGREGATES

by

James R. Blacklock

FINAL REPORT

HIGHWAY RESEARCH PROJECT TRC - 69

conducted for

The Arkansas State Highway and Transportation Department

in cooperation with

The U. S. Department of Transportation

Federal Highway Administration

July 1984

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/AR-85/003		

4. Title and Subtitle	5. Report Date
Study of Engineering Properties Which Influence The Utilization of Marginal Aggregates.	July, 1984
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s) James R. Blacklock	
9. Performing Organization Name and Address School of Engineering Technology University of Arkansas at Little Rock 33rd and University Ave. Little Rock, Arkansas 72204	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. TRC-69
	13. Type of Report and Period Covered Final Report
12. Sponsoring Agency Name and Address Arkansas State Highway & Transportation Department P. O. Box 2261 Little Rock, Arkansas 72203	14. Sponsoring Agency Code

15. Supplementary Notes

This study was conducted in cooperation with the Arkansas State Highway and Transportation Department and the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This report contains chapters dealing with the technology of cyclic triaxial testing of typical Arkansas marginal aggregate base materials. Aggregate samples from three highway districts located in the northeast, southeast, and southwest regions of the state were tested during the term of the research project to determine their engineering properties and those findings are presented and compared to newly developed GB-4 "low" and GB-4 "middle" resilient modulus properties. The aggregate cyclic triaxial test method developed in the UALR laboratory is presented and offered for adaption of other testing laboratories for evaluation of both marginal and non-marginal base and subbase aggregates. The improvement of marginal aggregates with lime, lime/fly ash, Donna Fill, calcium chloride and sodium chloride was studied and those results are presented. Recommendations for partial selection criteria and specifications of treated, modified and plain marginal aggregates for low volume highways are presented.

17. Key Words	18. Distribution Statement
Marginal Aggregate, Dynamic Testing, Resilient Modulus, Cyclic Triaxial Testing, Low Volume Roads	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None			

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The modern method of cyclic triaxial soil testing to determine the dynamic stress-dependent response of highway construction materials is potentially useful for the evaluation and selection of Arkansas marginal aggregates for low volume county roads to be built under the State Aid Program. The School of Engineering Technology of the University of Arkansas at Little Rock (UALR) under contract to the Arkansas Highway and Transportation Department (AHTD), has performed a research program entitled "Study of Engineering Material Properties Which Influence the Utilization of Marginal Aggregates." The information contained in this report was collected and developed during this research project to assist highway engineers, contractors and aggregate material suppliers to obtain more effective and economical utilization of existing deposits of natural sand and gravel aggregates for construction of streets, roads, and highways. Because this method of aggregate testing is new, non-standard, and constantly undergoing modification and improvement, this report is far from definitive and provides only the existing information on the state-of-the-art of aggregate cyclic triaxial testing of plain and treated samples. There already exists a standard method of dynamic testing for soils, "Resilient Modulus of Subgrade Soils," AASHTO DESIGNATION: T - 274 - 82; however, as of yet, there is no similar method for aggregates. It is anticipated that a dynamic aggregate test method will become standard in the future and at that time the recommendations in this report should be adjusted accordingly.

UALR was awarded the AHTD research contract in 1982 to test typical samples of marginal aggregates from three regions of Arkansas, to evaluate their performance on low volume county roads, and to make recommendations for selection criteria for future utilization. The School of Engineering Technology of UALR has conducted this research and development study with a major emphasis on laboratory testing, and has reviewed relevant literature and assessed the progress and achievements of programs in progress concerning the many aspects of marginal aggregate utilization and testing. Indications are that marginal aggregates must be evaluated and selected based upon engineering properties from dynamic testing rather than grain size grading and plasticity of fines content, and that the test method for cyclic triaxial sample testing developed during the term of this contract is appropriate to be used in Arkansas and elsewhere for this purpose.

It is anticipated that this report will provide highway engineers, contractors, and material suppliers with useful information and direction in establishment of a reliable and accurate method for testing and selection of marginal aggregates for roadbed construction. It is the first report written for just this purpose, and therefore, it is subject to early revisions. Additional information may be obtained from the references in the Selected Bibliography.

The engineer, who is considering the use of cyclic triaxial aggregate testing for the first time, will find the entire report to be helpful, especially Chapter 4, Cyclic Test Method, and Chapter 5, Plain Marginal Aggregate Testing. These chapters along with the Appendices will be most valuable when developing an initial laboratory test and evaluation plan for evaluating sources of marginal aggregate. The new concept of establishing standard "high", "low", and "middle" dynamic material properties for "spec" materials should prove to be valuable in evaluating unknown aggregate sources. It is essential to develop both the new cyclic triaxial laboratory test method and to test standard materials prior to performing aggregate selection testing for the purpose of evaluating new material sources.

Contained within the several chapters of this report, the Appendices, and the references of the Selected Bibliography is given a thorough description of the present state-of-the-art of marginal aggregate cyclic triaxial testing. The test equipment, procedures, and techniques discussed in this report have been evaluated at UALR during the term of this research study. As the use of cyclic triaxial testing of aggregates continues to grow, it is anticipated that new equipment, procedures, and testing techniques will be forthcoming. However, the basics of the method are not likely to change appreciably; therefore, it is the opinion of the author, that cyclic triaxial testing of aggregates has come of age, and that with present techniques, the AHTD has a valuable method for efficient and accurate marginal aggregate selection and evaluation. Cyclic triaxial aggregate testing can play an important role in the continued search in Arkansas for economical construction materials and their future satisfactory utilization.

FINDINGS AND CONCLUSIONS

The findings and conclusions concerning the testing, evaluation, and utilization of marginal aggregates for use on low volume roads are:

1. The resilient and plastic behavior of certain naturally occurring Arkansas marginal aggregates under dynamic loading can be determined using the modified cyclic triaxial method of laboratory testing.
2. The ability of selected treatments to improve certain naturally occurring Arkansas marginal aggregates can be evaluated using the modified cyclic triaxial method of laboratory testing.
3. The cyclic triaxial test method is appropriate for measuring resilient modulus values of certain non-marginal aggregates mixed at "low", "middle" and "high" percentages of grain size grading.

IMPLEMENTATION

The cyclic triaxial method of marginal aggregate testing presented in this report, which has been shown to be useful for characterization of marginal low-volume-road base materials, should be utilized to determine the resilient modulus of a representative sampling of all Arkansas highway base and subbase aggregates either currently being used or intended for future use. The resilient modulus, which is determined from the cyclic triaxial test, can provide the basic constitutive relationship between stress and deformation of flexible pavement construction materials for use in computerized analysis of all layered pavement construction materials. This includes subgrade soils, subbase aggregates, and base aggregates, evaluated under a variety of environmental conditions and stress states that realistically simulate the conditions that exist in Arkansas highway pavements subject to heavy moving wheel loads. The subgrade soils can be tested according to AASHTO Test Designated: T 274 - 82. The method developed in this research project for marginal aggregates can also be used for non-marginal aggregates. The laboratory testing equipment necessary to perform the subgrade soil test can be utilized with only small modifications for medium gravel type aggregates. Large aggregate particles require a considerably larger test chamber; however, the cyclic control equipment would not change.

For further implementation of the cyclic triaxial method of testing for marginal aggregates, each gravel class could be characterized using laboratory cyclic triaxial testing equipment similar to that which was developed during the course of this project for GB-4 gravel base course material, to include for instance, GB-3 "low", GB-3 "middle", and GB-3 "high". All future purchases of aggregate could be tested in the same manner and over the next several years the purchase of marginal aggregates could be influenced by the cyclic triaxial properties of these materials, as determined by the dynamic testing method.

TABLE OF CONTENTS

TABLE OF CONTENTS CON'D

TABLE OF CONTENTS CON'D

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 The Problem

In many parts of Arkansas the sources of naturally occurring well-graded aggregates are being depleted without any expectation of replacement. Many of the remaining aggregate supply areas are rejected because of gap-grading, i.e., certain particle sizes are lacking, or the aggregate source contains excessive plastic fines, or the size and quantities of the course aggregate particles are insufficient to meet the AHTD standard specifications. These aggregates have been termed marginal, in that they almost pass the standard tests, but lack meeting the test criteria in only one or two small area.

One of the causes for the rising cost of highway construction projects is this diminishing availability of aggregate materials that meet AHTD standard specifications for highway construction. Past efforts to use marginal aggregates for highway base material have yielded mixed results of success and failure. Most or all of those instances have been in low volume county roads built under the State Aid Program. New laboratory testing methods to evaluate marginal aggregates and to help predict the performance and life cycle of low volume roads constructed of either plain, treated, or modified marginal aggregates must be developed if efficient and economic utilization of this material is to occur. In addition, new economical methods must be developed for treating and modifying unacceptable marginal aggregates in order that they can also be utilized successfully in low volume county road construction.

1.2 Project Research Objectives

The specific objectives of this research program were stated in the proposal to be the following specific tasks:

A. Review and catalog each relevant document concerning past and current marginal aggregate research.

B. Assess the progress and achievements of relevant research programs.

C. Assess the marginal aggregate utilization programs in other states.

D. Implement a laboratory and field testing program to evaluate samples from in-service roads.

E. Implement a laboratory and field testing program for gravel quarry sites in three prime instate marginal supply areas.

F. Develop selection criteria and specifications for treated, modified and plain marginal aggregates for low volume highways.

G. Plan and implement a one day highway seminar at the conclusion of the project at central office of ASHTD.

H. Issue a final report and required intermediate progress reports.

By direction of the subcommittee the deletion of objective D from the above listed objective tasks was approved on July 12, 1983. Work on all other objectives is complete at this writing and with the issuance of the final report and the planned one-day seminar in the fall of 1984, the contract will have been fulfilled.

1.3 Project Work Plan

The work plan outlined below describes the major activities of the project. Each relevant marginal aggregate research report available in the literature was reviewed and cataloged. This was accomplished with the assistance of a Highway Research Information Service, HRIS, data search. The progress and achievements of relevant research programs in progress were all assessed. This initial work, which comprised the majority of the data base acquisition, established the current "state-of-the-art" in testing and utilization of marginal aggregate base materials for low volume county roads.

Simultaneous with the above work, new laboratory testing equipment for aggregate was ordered for the UALR laboratory and the test plan for the fall, spring, and summer laboratory testing programs was developed and submitted to the research project coordinator for approval.

Concurrent with the above efforts, a field trip was undertaken soon after contract approval to study locations where past marginal aggregate applications had been utilized.

A laboratory test program for standard testing of quarry samples was implemented next. Field data was collected for a data base of environmental conditions beginning September 1, 1982. The goal of the fall, 1982, test program was to continue this effort and also to include standard laboratory testing of test site samples. In the spring of 1983 the cyclic triaxial test machine became operational and during the summer of 1983 all cyclic triaxial testing of marginal aggregates was accomplished. The test data was documented, analyzed, plotted, and all information gained from the research is written into this final report.

A one-day seminar to explain testing and analysis of data from cyclic triaxial testing will be conducted at AHTD Headquarters at the conclusion of the contract for the purpose of presenting information concerning the findings of the research project.

1.4 Report Objectives

The objectives of this report are to develop and summarize the status of current technology relative to procedures and techniques for evaluating marginal aggregate base material properties, to document the test results gained from testing three Arkansas marginal aggregates, and to recommend standard practice for testing, classifying, and selecting marginal aggregate sources for future highway construction.

1.5 Report Organization

The report is organized such that the major emphasis is placed on the laboratory testing of marginal aggregates using the cyclic triaxial method of testing. Chapter 1 presents the introduction to the report and Chapter 2 - The Highway Layered Support System, places the material in the proper perspective as a single ingredient in the multi-layered highway pavement system and then Chapter 3 - Base Material Properties, establishes the factors effecting the performance of those materials. Chapter 4 - Cyclic Triaxial Test Method, begins with a presentation of past work, then presents current information on cyclic triaxial testing of soils and aggregates and finally includes the cyclic triaxial testing of marginal aggregates from a general perspective. Chapters 5 and 6 are those chapters mainly concerned with the actual testing of Arkansas marginal aggregates during the term of this research program. The equipment required for testing and the test instructions are presented in Appendices A and B. The results of this research program are given in Chapter 7 - Summary and Conclusions, and Chapter 8 - Recommendations, presents the recommendations for further study. A selected bibliography is presented of those technical documents thought to be important to present and future utilization and study of cyclic triaxial testing of highway base marginal aggregates.

CHAPTER 2

THE HIGHWAY LAYERED SUPPORT SYSTEM

2.1 Pertinent Components of the Highway Support System

The conventional highway pavement support system is made up of certain component layers including pavement, base, subbase, and subgrade. Often one or more of the layers are treated with admixtures to increase their strength and to give them all-weather engineering properties. In the usually four-layer system as designated above, the subbase layer is included. Often this layer is thought of as an extension of the base layer; however, sometimes it is an extension of the subgrade layer, especially when the subgrade is treated with lime or cement in the upper six inches to form a stabilized layer. Typically in low volume county roads, such as those addressed in this report, the subbase layer is omitted. Therefore, in the sections to follow, only the subgrade, base and pavement layers will be discussed. In all cases, the function of the upper layers, whether two or three in number, is to protect the subgrade from traffic loads and weather. Their quality and thickness requirements will be determined by the subgrade conditions and traffic loadings.

2.2 Subgrade Materials

Subgrade is defined as the soil layer prepared and constructed to support the pavement system. In a three layer system, it is the foundation for the base and pavement layers. Typically the subgrade is the weakest portion of the highway pavement layered systems; therefore, the stresses induced by the moving wheel loads must be reduced sufficiently through a finite depth of base and pavement prior to reaching the subgrade for support reaction. In cases where subgrade soils are too weak to support even the reduced loads passed through the stronger top layers, the poor material must either be removed and replaced or stabilized. Thus, after obtaining a suitable subgrade layer, the base layer of aggregate can be designed to support the pavement layer and subsequently the wheel loads. The weaker the subgrade, the thicker and stronger the base material required. Because the highway support system functions as a multi-layered system, the engineering properties of each layer must be known. Typically the CBR or R-value tests are used for this purpose for modern highway design. The test values obtained are used to determine the load-bearing capacity, with these results used directly in design of layer thicknesses. Some agencies have developed correlations that relate CBR or R-values to resilient modulus values; however, many of these produce values too low or too high, which result in substantial thickness errors. The resilient modulus value should be correctly obtained for subgrade soils according to AASHTO T 274 - 82; otherwise, design methods utilizing CBR or R-values should be utilized.

"Subgrade stability requirements are dictated by both construction considerations and pavement performance. The most pertinent aspects related to construction are rutting and shoving and the need to effectively and efficiently place and compact the various pavement layers. The primary pavement performance considerations (as related to subgrade stability) are the resilient deflection of the pavement and the permanent deformation accumulation in the subgrade", Subgrade Stability Manual, 14.

2.3 Aggregate Base Materials

The base course is the layer immediately under the pavement or wearing surface and immediately over the subbase layer (if any) and thence the subgrade. Because the base aggregate layer lies directly under the pavement layer, it is subjected to loads approaching the loads directly applied to the pavement by the wheels. These loads are essentially dynamic repeating or cyclic loads caused by rapidly moving wheels under trucks and other vehicles. It follows, that the materials in a base layer must be of high quality and of proper thickness to insure protection of the subgrade and at the same time to prevent rutting and cracking of the pavement.

Properties required in granular base course materials vary with the type of pavement and the depth of the material in the pavement structure. Base courses under flexible pavements must distribute the load from the pavement to the subgrade, while at the same time, the stresses must be reduced as they pass through the base layer. This ability to distribute the load is primarily a function of the depth of the base course. The quality of material in the base course also affects rate of distribution to a certain extent; but depth has been the main factor considered in design methods. This implies that the base is adequate to carry the loads imposed upon it, and while distributing the load, the base course must not itself be a cuase of failure. Thus, it must be strong enough to carry the load without shear failure and resulting rutting. In the case of marginal aggregates, the design of the highway must be changed to provide for some less than desirable properties of the base layer. Current test methods for determining the load bearing capacity of untreated and treated aggregate base materials are the CBR and/or R-value tests. Future developments such as those presented in this report could result in future evaluation and design of aggregate materials using the cyclic triaxial method of testing.

Aggregate requirements for resistance to abrasion, resistance to penetration of water, and capillary properties are equally important in consideration of material acceptability of marginal aggregate base materials as well as for standard specification aggregates. Certainly, these properties should be considered during the selection process as well as those mentioned above.

2.4 Bituminous Pavement Materials

Bituminous pavements consist of combinations of mineral aggregates with bituminous binders. Mixtures of these two simple ingredients, rock particles, and asphalt in combinations make good pavements when designed for local conditions. If good service is to be received from bituminous pavement, it must, for its full life, retain freedom from cracking caused by fatigue failure. The design of a pavement is an exacting task; however, it is made much more difficult when the base course properties are unknown. Proper design and construction of subgrade and base course are a must; otherwise, pavement failure will not be long in developing, even on low volume county roads.

The design procedures for flexible pavement range from empirical methods that relate thickness to index properties of the base, subbase and subgrade materials, to mathematical analyses that require great detail about the elastic and nonlinear engineering properties and the environment in which they are used. In the past, the simpler empirical methods have prevailed; mainly because of their simplicity, but partly because of the difficulties in securing reliable material test properties to use in the computerized complex layer system analyses.

The principal design criteria for pavement thickness design relates loads on the surface of the pavement to horizontal tensile strain on the underside of the asphalt-bound layer, and vertical compressive strain at the upper surface of each support layer (base, subbase, and subgrade). The static and dynamic material properties are necessary for the proper design of the bituminous pavement system, if modern analytical layer analyses are utilized for thickness design. The new resilient modulus method of design presented in The Asphalt Institute Thickness Design Manual, 10, is one such approach for pavement design that utilizes the dynamic properties of the pavement and the underlying materials; however, it is based on CBR or R-value correlation rather than actual resilient modulus tests. A considerable improvement will be made in this approach when actual cyclic tests properties are developed and utilized during the design for each layer.

2.5 Loading Environment of the Pavement System

All pavement design methods begin with an estimate of expected traffic volume and character over the design life of the pavement. The several pavement design methods now in use in the United States are (1) design by precedence, (2) California (Hveem) method, (3) AASHTO method, and (4) the Asphalt Institute design method. Of these four methods, only the last, the Asphalt Institute design method relies on the laws of mechanics to predict critical stresses and strains rather than on empirical relationships, relating soil strength and traffic conditions to pavement thickness. All traffic is converted to equivalent 18,000 - lb. single axle load applications (EAL). The EAL is calculated in a manner similar to that described in the AASHTO procedure by multiplying the number of vehicles in each weight class by an appropriate truck factor and obtaining the sum. This is one of the few methods currently acceptable to highway design engineers that utilizes subgrade resilient modulus vs. EAL for design curves.

2.6 Environmental Consideration

An essential condition for roadbed stability is freedom from excess moisture. An increase in moisture content can quickly convert a stable material into one that is highly unstable. Because the load environment of the highway layered system is composed of repeated wheel loads applied dynamically, the infusion of moisture into the base material will greatly reduce its ability to carry the pavement loads and function properly. This is especially true for materials that wet-up under a freeze-thaw action; because not only does the freeze cycle store moisture, but the swelling action of the ice particles tends to spread the aggregate particles and in effect to "decompact" the material at the time of spring thaw. To properly evaluate base, and subgrade materials in the cyclic triaxial test, it is essential to experiment with moisture content and to establish the properties for various states of moisture content.

2.7 Economic Considerations

The true cost for any modern highway to perform its full service load carrying function is heavily dependent upon the cost of the maintenance cycle to periodically rehabilitate and repair environmental damage and wear. Once a highway is built the options for material selection, treatment and modification are limited by the need to protect the overlying pavement. The need for comprehensive laboratory material characterization and design are never more evident than when viewing a prematurely failed road. The new cyclic triaxial method of testing to evaluate dynamic material properties and to determine the resilient modulus is deemed by some to be too costly and time consuming; however, when compared to the cost of replacing or repairing a failed road the testing costs are small by comparison.

The proposed increased use of marginal aggregate for construction of low volume county roads makes testing and evaluation of those materials take on an importance that belies their inexpensive initial purchase. Correctly utilized, marginal aggregates can help to cut new construction cost of State Aid roads; however, unless properly utilized the cost savings will be long forgotten under the recurring maintenance needs generated by the resulting early failures.

CHAPTER 3

BASE MATERIAL PROPERTIES

3.1 General

Base courses in general are of two types, granular base course and treated base course. Granular base course materials consist solely of mineral aggregates. These are composed of a mixture of soil and rock particles ranging in size from fine to coarse. Treated base courses are constructed of mineral aggregates mixed with admixtures to make them stronger or more resistant to moisture. Common admixture treatments are Portland cement, lime, fly ash, calcium chloride, sodium chloride and various asphaltic products.

An acceptable base course, whether marginal or non-marginal, must have sufficient elastic stiffness and strength as well as depth to spread the dynamic wheel loads in order to reduce the stresses and deformations to an acceptable level to avoid cumulative rutting in the subgrade. An acceptable base material should also increase the total strength of the layered system in combination with the pavement and subgrade so that there will be no massive bearing failure of the subgrade. Selection of base materials and design of layer thicknesses have historically tended towards performance specifications and simple classification testing. Materials not having a known successful history were in the past usually rejected for highway construction, resulting in the depletion of the better quality aggregates. There has also resulted the establishment of a wealth of design and test information, only suitable for quality standard specification type aggregates. In the sense that marginal aggregates are aggregates not soil, it follows that the first attempt to evaluate their usefulness was based on aggregate standard specifications. In Arkansas this has resulted in a mixture of successes and failures, when utilized for the base course on some low volume State Aid highways. As to whether the observed failures are actually failures of base material, rather than design, it has not been determined; however, there are few base course/pavement/subgrade design methodologies developed to accommodate the substitution of marginal aggregates for standard specification type non-marginal aggregates.

3.2 Pertinent Base Material Properties

Base course engineering material properties are mainly dependent on the shape and size of the aggregate particles and the grain-size distribution. To what exact extent the strength and stiffness can be predicted for anyone of the infinite number of grain-size combinations, no one knows; however, it is thought to be known which range of sizes is best. The properties of strength, dynamic modulus, Poission's ratio, endurance, durability, and drainage are not well documented for such combinations of grain size grading resulting in marginal aggregate classifications. The percentage of fines is usually restricted to a low value to ensure that the base course is free-draining and free from frost damage. Excessive fines can fill too many of the voids in a base aggregate and greatly reduce permeability; this could increase the amount of capillary rise, and therefore, move excessive water up under the pavement resulting in wetting and loss of strength in the base and upper layer of the subgrade and/or frost heave.

The material properties most desired of individual particles are abrasion resistance, good freeze thaw soundness, and shape angularity. The material properties most desired in the base aggregate in-place mixture are free drainage, high strength, stability, and stiffness. To the extent that these mixture properties are usually rated in general remarks concerning such terms as high and low, the engineer must hope to achieve a measure of these good properties acceptable for design by performing standard classification tests such as grain-size and Atterberg limits; or if in doubt, static tests such as CBR, R-value, or triaxial can be specified. The main quality specification for a granular base course is the grain-size distribution requirement. When an aggregate fails the standard specification for grain-size distribution, it is concluded that it also fails in one or more of the above most desired material property categories. In that the actually specified tests are indicator test only, there is little to guide the engineer in the use of non-standard materials, (marginal aggregates). The engineer must design layered pavement systems without having had extensive previous experience with similar pavement systems.

3.3 Standard Methods of Evaluating Base Material Properties

The main test procedures recommended for base material property evaluation listed within the AHTD - Manual of Field Sampling and Testing Procedures, 2, are as follows:

1. AHTD Test Method 105 - Method of Test for Sieve Analysis of Base, Subbase and Surface Course Aggregates.
2. AHTD Test Method 108 - Method of Test for Liquid Limit of Soil.
3. AHTD Test Method 109 - Method of Test For Plastic Limit and Plasticity Index of Soil.

The following method of testing from the AASHTO Methods of Sampling and Testing are also utilized:

1. AASHTO DESIGNATION: T 180 - 74 Moisture - Density Relations of Soils Using a 10-lb. Rammer and an 18-inch Drop.
2. AASHTO DESIGNATION: T 103 - 62 Freeze - Thaw.
3. AASHTO DESIGNATION: T 104 Soundness Test.

4. AASHTO DESIGNATION: T 96 Los Angeles Abrasion Test.

5. AASHTO DESIGNATION: T 85 Relative Density of Coarse Aggregate.

The above two lists of tests are not all inclusive, nor are they independent lists, but rather all tests above are also listed in the ASTM Book of Standards, Section 4 and in most cases the tests are cross-referenced between the three documents. The commercially available laboratory testing equipment is usually sold to allow performance of tests under more than one specification.

3.4 Factors Effecting Aggregate Material Properties

The factors effecting marginal aggregate material properties are broadly separable into two catagories: the initial properties that are constantly undergoing changes with time due to environment and wear and the transient properties that develop during the service life of the aggregate material. Isolating the important properties of a given roadbed aggregate at a point in time for analysis, the physical properties representing chemical weathering. soundness, toughness and hardness can be set aside and the engineer can freeze the system and look at the transient physical properties, such as nature of the fines (plasticity), mineral grain size distribution, degree of compaction (density), and particle shape. Sample test results are very dependent on these transient physical properties, especially the shape and texture. The degrees of roughness, angularity, flatness, and roundness of the rock particles are greatly responsible for the dynamic performance of the compacted aggregates. The locking ability of rough angular shaped particles is necessary to counter the radial tensile stresses in the bottom of the base course layer. Without tensile strength between the lower particles, the dynamically loaded aggregate mixture will tend to decompact. Decompaction results in rutting of the pavement due to separation of the aggregate particles. The lack of rough angular particles is sometimes off-set by the presence of plastic fines in sufficient quantity to bind the aggregate mixture together and resist the on-set of decompaction due to loss of mechanical tensile holding power. Also, rough angular particles perform better under dynamic loading in the presence of excess moisture and are less sensitive to gap grading.

Many other factors affect the marginal aggregate material properties; however, percent of plastic fines, grain size distribution, density, moisture content, and particle shape were the most important factors to be evaluated during this program. During the life of a road these will be the changing base course aggregate transient properties.

3.5 Evaluation of Repeated Load Characteristics of Aggregates

The evaluation of the repeated load characteristics of marginal aggregates was at first difficult, because the marginal aggregate material is neither a fine-grained soil or a coarse-grained aggregate: it is somewhere between the two in static and dynamic properties. As this program developed, it was deemed best to test the three marginal aggregates in a subgrade or fine-grained soil mode. Because the marginal aggregate may be classed marginal due to gap grading, poor grading and/or excessive percentages of certain grain sizes, especially fines, it was deemed necessary to actually stress test the samples and measure strength and stiffness with the cyclic triaxial test method. Although this test is more time consuming and expensive than standard grain size testing, perhaps it will be justified, if it allows the use of an available inexpensive material that would otherwise be wasted or incorrectly utilized.

The important repeated load characteristics of base materials are the resilient modulus and plastic deformation. These should be evaluated by comparison to other proven aggregates and by incorporating these dynamic properties into layered analyses. Initially, only the first can be utilized in Arkansas; however, eventually new Arkansas roads should be subjected to an analytical design and analysis sequence based on suitable layer theories and dynamic stress dependent material properties. The true evaluation of the repeated load characteristics of marginal aggregates can then be finalized by examining field service life performance of these theoretically engineered roadbeds.

CHAPTER 4

CYCLIC TRIAXIAL TEST METHOD

4.1 General

The results of repeated load testing of highway roadbed construction materials began to appear in the literature of engineering research journals as far back as the 1940's; however, the reporting of the modern techniques of cyclic triaxial testing of highway subsoils and aggregates became numerous beginning during the later half of the 1960's, and extensive research and development began in earnest in the 1970's. The work on highway related cyclic testing has been paralleled by earthquake and railroad roadbed research. The increased emphasis of cyclic testing in the research laboratories in the 1970's resulted in the development and marketing of cyclic triaxial test equipment by several firms. In the 1980's, the automatic acquisition of test data by microprocessors, and the automatic plotting and analysis of data using digital computers began to be developed. At present standardized fully automated computerized cyclic testing equipment is being developed and marketed. The indications are that the want of better equipment in the past has somewhat held back commercial application of the method, but in spite of this difficulty, many laboratories are currently struggling to gain experience and expertise, in order that they can offer cyclic triaxial testing services to their customers. Committee D-18 of ASTM is currently refining the final version of the ASTM standard for cyclic triaxial testing of subgrade soils with plans for approval in 1985, and Committee D-4 of ASTM is planning to develop a cyclic triaxial testing standard for roadbed aggregates. Although the method has been slow to fully develop, it appears at this writing as if the 1980's will see the cyclic triaxial test method become fully accepted by most agencies of the federal government as well as many state agencies.

It is as yet, not written into the standard undergraduate university soil testing manuals; however, most universities now have operational cyclic triaxial testing equipment and, at the very least, they operate the equipment in support of graduate geotechnical research and teaching programs. It may very well be that undergraduate civil engineering students will soon have cyclic triaxial testing added to their curriculum.

4.2 Previous Research Findings

Because of the complexity of the cyclic method requiring many different ratios of load applied in several layers, a serious research effort has been in progress since the 1960's to evaluate the effects of testing procedures and parameters, the differences caused by various testing equipment designs, and the accuracy of different methods of data reduction and presentation. As a result of this concerted effort by many researchers, several suggested standard test procedures, test equipment designs, and data analysis methods have resulted. These have encouraged recent development and issuance of the ASTM and AASHTO cyclic test standards. Several key previous research findings which have mostly been adopted in the new standards are as follows:

a) Constant Cell pressure and repeated axial deviator stress is preferred.

b) Load pulse duration is not significant to resilient modulus results.

c) Only 200 cycles are necessary for each cyclic deviator stress ratio.

d) Conditioning cycles are crucial to the accuracy of test results.

e) Moisture content is crucial to the accuracy of test results.

f) Axial strain measurements are the most difficult to accurately achieve.

g) Load piston friction is significant to the end results.

h) Sample size is important to the end results.

i) High CBR soils and aggregates do not correlate well.

j) Number of stress repetitions and stress sequence has little effect on the resilient behavior of granular materials.

k) No evidence of a change in resilient behavior with changes in load duration or frequency.

l) For granular materials, the resilient modulus increases considerably with an increase in confining pressure and only slightly with an increase in axial stress.

m) Poisson's ratio increases with a decrease in confining pressure and an increase in repeated axial stress.

n) Primary variables that influence the resilient modulus response of granular materials are the stress state, degree of saturation, and degree of compaction.

o) Indications are that a general correlation exists between CBR values and measured resilient modulus values; however, the coefficient that relates the two must be stress dependent and not unique or constant valued.

4.3 Laboratory Test Equipment

Triaxial Test Cell - A triaxial cell suitable for use in cyclic triaxial testing of soils and small to medium aggregates is shown in Figure 4-1. This equipment can be originated from a standard triaxial cell; except the linear ball bushing for the loading piston is extra with some manufacturers, and load cell and LVDT leads need to have outlets.

Deformation Measurement Device - The deflection measurement device shown in Figure 4-1 is only one of many such systems currently in use by

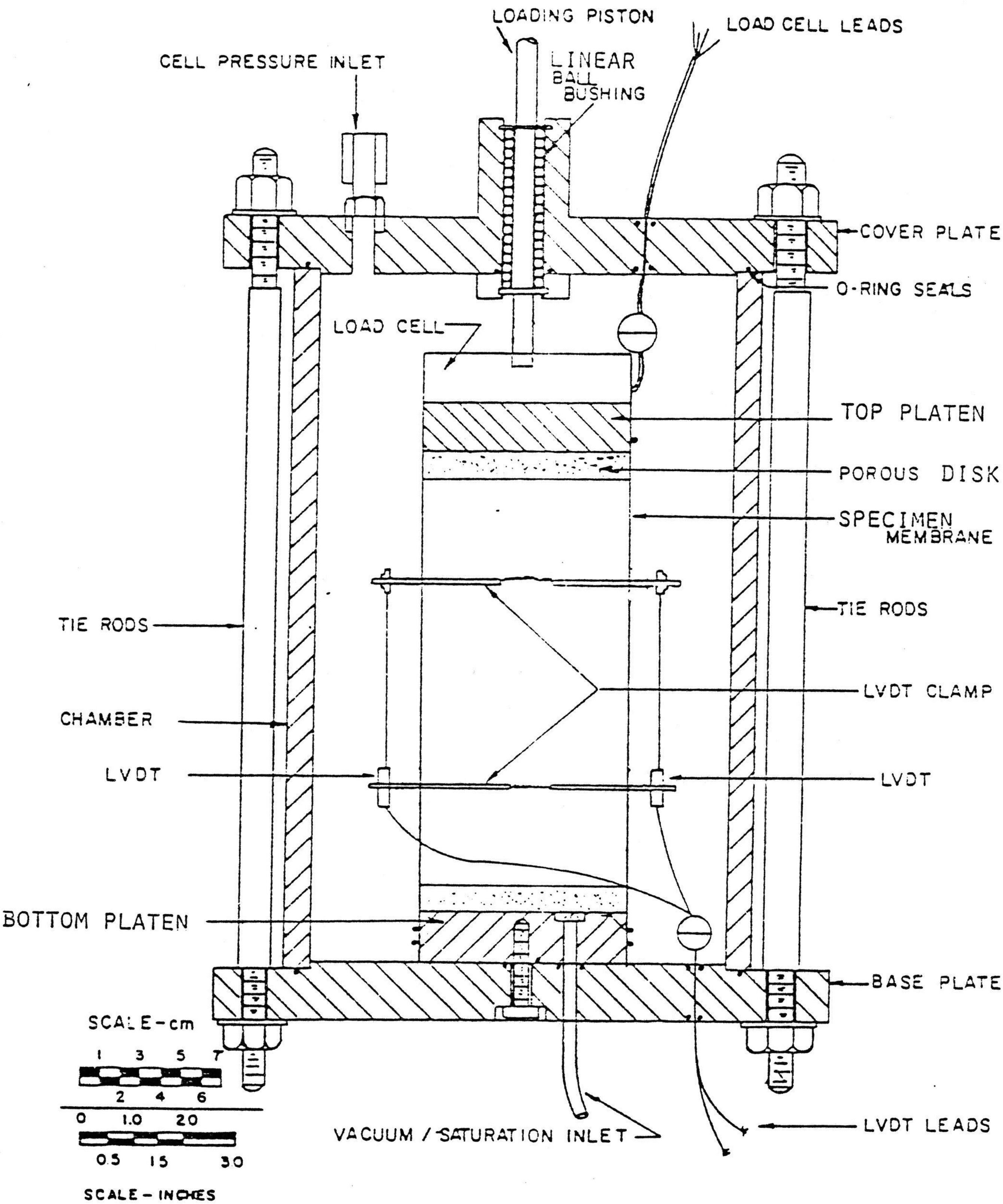


FIGURE 4-1 CYCLIC TRIAXIAL TEST CELL

testing laboratories and equipment manufacturers. Other systems utilize LVDT's attached to the top and bottom platens as well as axial rod measurement LVDT's and optical targets attached to the sides of the specimen. Currently, the method shown seems to be preferred by those writing standards and test procedures; however, indications are that the ASTM method will list optional deformation devices as requested by interested reviewers. All devices should be connected to an electronic data acquisition system.

Load Measurement Device - The use of an electronically operated load cell connected to a signal conditioner and a data acquisition device is recommended for load determination. In Figure 4-1 the load cell is shown mounted on top of the specimen; however, alternate equipment designs have the load cell under the sample inside of the cell, and under the sample outside of the cell. In both of these systems it is necessary to zero-out the imposed load prior to starting the test. Researchers are in general agreement that load measurement above the loading rod or above the cell is not satisfactory due to loss of load to friction of the rod in the bushing. Some newer systems are operated by electro-pneumatic closed loop servo-feedback cyclic systems connected to function generators. These are more expensive, but they should give considerably more accurate and consistent results.

Data Acquisition - Data acquisition can be as simple as hand tabulated numbers obtained from a digital read-out system and as advanced as fully automated continuously recorded and plotted charts or digital recordings. Most laboratories are currently converting to automatic data acquisition, conditioning, storing, printing, plotting and analysis systems. Several systems of data acquisition are currently being offered commercially for sale; however, advances in this area are in their infancy. The next few years should see major developments in this area from hardware and software suppliers.

4.4 Resilient Modulus Testing of Subgrade Soils

The cyclic triaxial testing of subgrade soils to obtain resilient modulus soil properties is best performed according to the AASHTO or ASTM test Standard. The AASHTO method is currently the only one of the two officially released. The testing of standard sands, silts, and clays is a recommended practice to standardize a new testing laboratory. This has been principally pursued in the past by those supporting earthquake research and soil liquification; however, as in any test method, it is essential to achieve accuracy and repeatability, and therefore, confidence prior to performing production testing.

The testing of fine grained soils, allows the use of either 1.4-inch diameter or 2.8-inch diameter samples of either the undisturbed or remolded type. The diameter of the specimen to be tested should be at least 4 times the maximum size of particles in the soil. Length should be 2 times the diameter. To obtain specimens that are representative of field conditions, one must use great care in preparing, handling, and storing test specimens. The resilient character of compacted cohesive soils is dependent on the structure imparted to the soil particles by the compaction process. Laboratory compaction processes must be selected in accordance with the expected field compaction conditions. Static compaction and dynamic compaction methods are both appropriate for cyclic soil testing.

4.5 Resilient Modulus Testing of Base Aggregates

The cyclic triaxial testing of base aggregates to determine the resilient modulus is not currently a standard test. Efforts to write a standard for large stone aggregates are progressing more slowly than for subgrade fine-grained soils. The major factor that prevents most laboratories from testing aggregates is the need of large samples and test equipment. The size and weight of large aggregate samples require expensive special handling procedures. The volume of a 6-inch diameter by 12-inch tall sample is 10 times that of a 2.8-inch by 5.6-inch tall sample, and the purchase of membranes, triaxial cells, and loading devices is also a magnitude more difficult. This is not a problem when testing small or medium aggregates of 1/2-inch maximum particle size, which can be tested in the same size cells as are commonly produced for cohesive soils. For 3/4-inch size aggregate particles, the 4-inch diameter by 8-inch tall sample is adequate. Both of these sizes are offered as standard by the major soil test equipment firms.

Of particular concern in the preparation of granular soil specimens is the handling of these samples after they have been compacted. They are difficult to hold rigid when removing them from a mold and while transporting and placing them in the triaxial cell. By placing a vacuum supply line on the sample cap, the 2.8-inch diameter and 4.0-inch diameter samples will remain rigid and easy to handle and load in the chamber. The vacuum must remain on the sample until the confining pressure is applied. This requires vacuum outlets inside of the cell, through the top and bottom platens.

Great care must be taken to seal membranes around the aggregate specimens, due to the ease with which the moisture dries out during the test. Aggregate samples have very little initial moisture content, usually 4 to 8 percent, and due to their open grain size they allow complete circulation of flowing air, causing them to rapidly dry out in the event of a leak. Very often the development of a leak in the middle of an aggregate test will cause the entire test to be voided. This can often be prevented by installation of a second thin membrane over the outside of the initial membrane used during compaction. Membrane wall thicknesses and number of layers add new variables to the test, that have thus far been little discussed for cyclic aggregate testing. Some researchers use rigid wall or semi-rigid wall containers for aggregate testing to alleviate the membrane problem.

4.6 Cyclic Testing of Marginal Aggregates

The cyclic triaxial testing of marginal aggregate samples to determine the stress dependent resilient modulus was the method chosen at the beginning of this research project to evaluate and characterize the aggregates. It became clear after studying the small volume of directly applicable literature, see Bibliography, that in previous work to evaluate marginal aggregate base material for road construction, the researchers have relied specifically on Atterberg limits, plasticity, grain size, and the usual tests for durability and freeze-thaw characteristics. The Arkansas Standard Specifications for Highway Construction, 1978 edition, 1, does not offer any other test method to evaluate gravel aggregates other than these physical characterization type tests. It was for this reason that the decision was reached by the principal investigator and approved by the AHTD to try the new cyclic triaxial test method. At first, it was not actually clear as to how to apply the cyclic triaxial test, but as the project progressed, the plan for testing evolved from several months of preliminary trial tests. An important issue to be decided, concerned the question of how the results of the tests would be utilized to accept or reject a particular aggregate source. It was obvious from the start, that running the tests and characterizing the aggregates with the cyclic triaxial test was going to produce a considerable amount of data, but it was not clear that there would be a direct correlation between aggregate road performance and the laboratory tests results. It was known that a portion of the soil from the AASHTO road test had been subjected to cyclic tests and that several well graded sands and aggregates had been tested in past research programs; however, because the results might be equipment specific or influenced by test variables and procedures, it was decided to search for a better way of evaluating and comparing the data. The answer finally came with the successful testing of GB-4 "Low" and GB-4 "Middle" gravels assembled in the laboratory from particles of aggregate separated by sieving one of the actual marginal aggregates that had been selected for the test program. As decisions are often made in research, the aggregate from Star City was selected because it was readily available and because it was the first delivered to the laboratory for testing.

The actual testing of the three aggregates was conducted using the same moisture content and energy of compaction as the standard samples. Therefore, the comparison of the average resilient modulus versus the sum of the stresses curves was finally selected as the best available method to evaluate the test gravels. The proposed purpose being that the end result of the test program would be a new method of qualifying aggregate base material for road construction, based on comparison between its resilient modulus values and the established resilient modulus values of those aggregates with known performance service life, and the other data from standard tests for grain size, durability, and freeze-thaw. Because of the short duration of this research program, all variables of these aggregates could not be evaluated; however, it became clear that the research approach taken to base acceptance on cyclic triaxial test results and comparisons had merit.

4.7 Factors Affecting Test Results

Most factors affecting test results have been previously mentioned; however, sample moisture content, compaction, end conditions, and size are certainly four of the major contributors to test result variability and worthy of additional comments.

Sample Moisture - Not only is it important to select the proper test moisture content, but when the moisture is added to the test samples is also important. Most samples swell upon adding moisture and although this is known, it is more important in the cyclic triaxial test than most other unsaturated tests, because each test lasts several hours and this is long enough for most soils to swell during the test due to added moisture. This was especially true of one marginal aggregate used during this research program that contained expansive clay fines. As already mentioned, moisture drying due to leaks is a problem with all samples especially those containing few fines. Every effort must be made to keep the samples from drying out during the tests.

Sample Compaction - Sample compaction is important not only from the standpoint of achieving correct compaction corresponding to the field compaction effort, but a more important aspect of test compaction is the need to apply the compaction effect uniformly from top to bottom and side to side of each sample. Various schemes are suggested in the literature to alleviate this problem; however, the method found to work best during this research program was one of applying the compaction energy in softer blows, therefore more numerous, and in numerous layers of blows with fewer blows on the bottom layer and then increasing blows on each succeeding layer until the top layer was applied and compacted with the most blows. It was only through this method that uniform test specimens of compacted marginal aggregates were achieved.

Sample End Conditions - The effects of end conditions on the test results was noticable in several ways. First, the flatness and orthogonality of the top of the compacted sample was important to the proper seating of the porous stone and upper platen. This problem was not readily solved during the research program and a special piece of squaring equipment must be developed to help in this area. The second condition that developed at the sample ends was also at the top platen and this was caused by uneven tension in the rubber membrane, thus causing the stone and platen to float separately away from the sample between load applications. The application of a slight preload helped solve this problem; however, its affects on the test results was not determined. The third problem that developed at the ends, was at the lower end, and this was the tendency of the moisture and/or fines to tend to drift down to the bottom of the sample under the action of the repeated load and gravity. This only occured on a small number of the samples tested; however, when it did occur it could not be corrected without losing the test and the effects on the test results were not obvious since this was a progressive failure that occured during all test cycles.

Sample Size - The effects of the test sample size utilized during the research of marginal aggregates was a control factor affecting test results to some extent, because the aggregate was sieved through a 1/2-inch sieve eliminating the few large particles that occur naturally in each source. The testing of 4.0-inch diameter by 8.0-inch tall samples would have eliminated this problem for those marginal aggregates evaluated. The inclusion of the larger stones in a roadbed should not detrimentally affect the performance of the aggregate material; however, this is not substantiated by known theory or test results. Therefore, the size effect on the test results had more effects than desirable, though the actual effect in the roadbed may be negligible.

CHAPTER 5

PLAIN MARGINAL AGGREGATE TESTING

5.1 General

The cyclic triaxial testing method is a natural choice for a better method to evaluate marginal aggregates as highway base course construction materials. It is the dynamic (cyclic) loading of the marginal aggregate base course layer of the pavement system that spells its success or failure to function in its intended job capacity. It is apparently not possible to evaluate the infinite combination of grain size ratios, plastic properties, and particle shapes with any other single aggregate testing method. No other laboratory test method can come close to subjecting the marginal aggregate to its real world load and environmental service life. Grain size cannot be used as the criteria for acceptance, because it is mainly through grain size that these aggregates are originally rejected and classified as marginal. There are ample research findings reported in the literature and in the Selected Bibliography documents to support this conclusion, see references 4, 6, 10, 11, 30 and 37. The test results of this program leave little doubt that the cyclic triaxial test method has merit.

5.2 Test Plan

The research program requirement to test three representative Arkansas regional marginal aggregates was satisfied by the selection of the following marginal aggregates as sources:

Star City, Arkansas - Borriman Pit

Paragould, Arkansas - McCain Pit

Hope, Arkansas - Meeks Pit

The grain size distributions of the three aggregates are shown in Table 5-1. In addition to being chosen as a regional representative marginal aggregate, the Star City aggregate was selected to be segregated into grain sizes and used for the laboratory manufacturing of the GB-4 "Low" and "Middle" standard samples with grain sizes as shown in Table 5-1. The GB-4 "High" sample was not tested and therefore not included as a part of the test program because, due to the lack of certain grain sizes, particularly in the fine range, it could not be manufactured into useable samples.

The test plan which was established, allowed first for developing the test procedures, the material test moisture and compaction parameters and second for testing these in numerous test trials until consistent results could be achieved. At the conclusion of this preliminary test phase, the final plan was established to cyclic test at least 3 samples of each material, Star City, Paragould, Hope, GB-4 "Low" and GB-4 "Middle". Each sample was compacted with an energy of 12,375 ft-lb per cubic foot in 90 blows of a standard compaction drop hammer, at a moisture content of 6 percent. Each sample was manufactured with the standard dimensions of 2.8-inch diameter and 5.6-inch tall. Each sample was sealed in a thick rubber membrane for testing and made as closely as possible from material representative of the whole sample as received in the laboratory from the field.

The loading sequence was applied in five layers of conditioning stresses and 35 representative layers of test stresses as shown in Tables 5-2 and 5-3. Each layer was composed of a specific deviator stress and confining stress with the deviator stress cycled 400 times. Each load cycle was applied for a 0.2 seconds duration at the rate of 2 cycles per second.

TABLE 5-1
GRAIN SIZE CHART

SAMPLE NO	PERCENT RETAINED						
	PAN	#200	#40	#10	#4	3/8"	3/4"*
GB-4 MIDDLE	7.5	15.0	10.0	12.5	22.5	17.5	15*
GB-4 LOW	9.75	19.0	10.0	13.75	23.75	16.25	7.5*
STAR CITY	21.92	13.92	31.78	12.99	15.1	4.0	0
PARAGOULD	12.4	15.6	35.3	12.9	17.9	6.1	0
HOPE	19.7	20.4	11.2	14.6	24.0	10.2	0

*3/4" and larger omitted from tests

TABLE 5-2
CONDITIONING SEQUENCE

LAYER NO.	COUNTER	CYCLES	LOAD lbs	σ_d psi	σ_3 psi
A	400	400	75	12	6
B	800	400	125	20	10
C	1200	400	100	16	8
D	1600	400	150	24	12
E	2000	400	50	8	4

TABLE 5-3
CYCLIC TEST SEQUENCE

LAYER NO.	COUNTER	CYCLES	LOAD lb	σ_d psi	σ_3 psi
1	400	400	100	16	16
2	800	400	100	16	12.8
3	1,200	400	100	16	9.6
4	1,600	400	100	16	6.2
5	2,000	400	100	16	3.2
6	2,400	400	75	12	12
7	2,800	400	75	12	9.6
8	3,200	400	75	12	7.2
9	3,600	400	75	12	4.8
10	4,000	400	75	12	2.4
11	4,400	400	125	20	20
12	4,800	400	125	20	16
13	5,200	400	125	20	12
14	5,600	400	125	20	8
15	6,000	400	125	20	4
16	6,400	400	50	8	8
17	6,800	400	50	8	6.4
18	7,200	400	50	8	4.8
19	7,600	400	50	8	3.2
20	8,000	400	50	8	1.6
21	8,400	400	150	24	24
22	8,800	400	150	24	19.2
23	9,200	400	150	24	14.4
24	9,600	400	150	24	9.6
25	10,000	400	150	24	4.8

TABLE 5-3 CONTINUED

LAYER NO.	COUNTER	CYCLES	LOAD lbs	σ_d psi	σ_3 psi
26	10,400	400	100	16	19.2
27	10,800	400	75	12	14.4
28	11,200	400	125	20	24.0
29	11,600	400	50	8	9.6
30	12,000	400	150	24	28.8
31	12,400	400	100	16	22.4
32	12,800	400	75	12	16.8
33	13,200	400	125	20	28.0
34	13,600	400	50	8	11.2
35	14,000	400	150	24	33.6

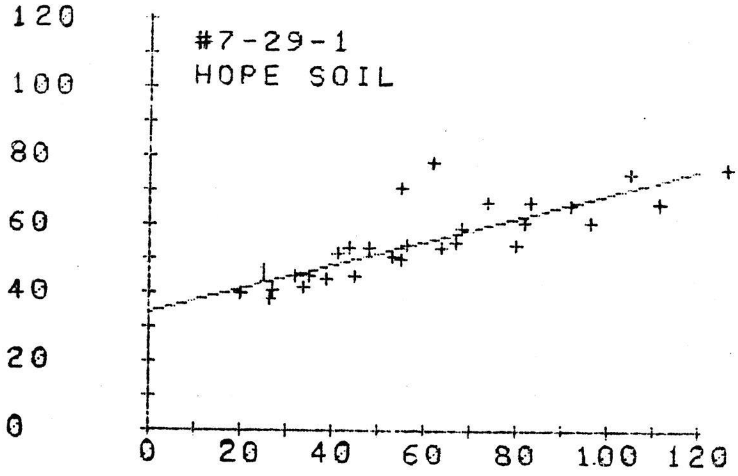
5.3 Data Acquisition

Data Acquisition during the cyclic triaxial tests was achieved manually by a single laboratory technician who constantly monitored and controlled the tests while recording the actual applied loads, the resilient deflections, and the total deflection at the end of each test layer. During the course of the full test of one sample the technician recorded the high load, low load, resilient deflection, confining pressure and total accumulative deflection five times for each layer, (200 bits of data) for each sample. The load values were read from the digital face of the electronic signal conditioner, the resilient and total deflections were read from the mechanical dial gauge, and the confining pressure was read from the chamber air pressure gauge.

5.4 Data Reduction

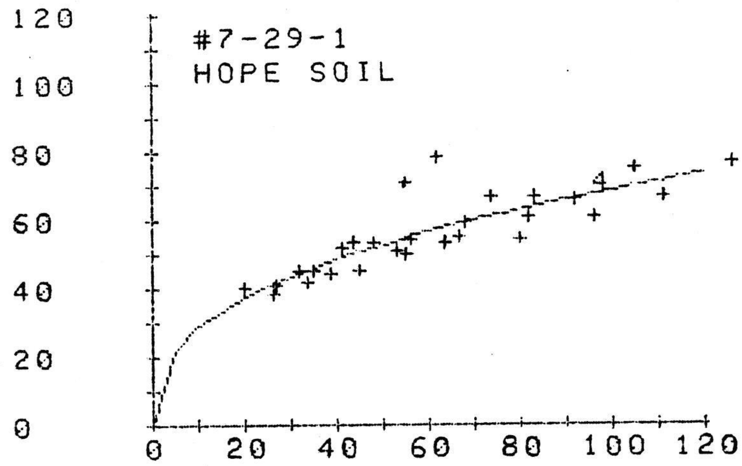
The cyclic tests data reduction consisted of three steps. Step 1 was the calculation of the stresses, strains and resilient modulus from the recorded test data. Step 2 was the calculation of the curve equations and plotting of three curves, linear, power and exponential for each sample, see Figures 5-1, 5-2, and 5-3. Step 3 was the averaging and plotting of the resilient modulus values from the power series curves for each sample and drawing the average curves, see Figures 5-4 and 5-5.

The calculation of three curves for each individual test sample was necessary in order to identify a best fit curve for the 35 data points for each of the 35 test layers for each sample. In most instances, the linear curve was the best fit of the three curves caluculated; however, the power curves were chosen for final plotting of average values as shown in Figures




```
   AOV: LINEAR REG:CODE 1
SOURCE/DF        SS        MS       F
TOTAL 27      3653.4
REG     1     2465.9    2465.9   54.0
RESID 26      1187.6      45.7
R SQUARE =            0.675

YHAT =      34.531 +          0.347 X

    X(I)          YHAT

    50.00      51.89
    X(I)          YHAT

  100 00      69.25
```

FIGURE 5- 1   TYPICAL LINEAR CURVE, HOPE SOIL, #7-29-1



ADV: POWER: CODE 4

SOURCE/DF	SS	MS	F
TOTAL 27	1.2		
REG 1	0.9	0.9	77.5
RESID 26	0.3	0.0	

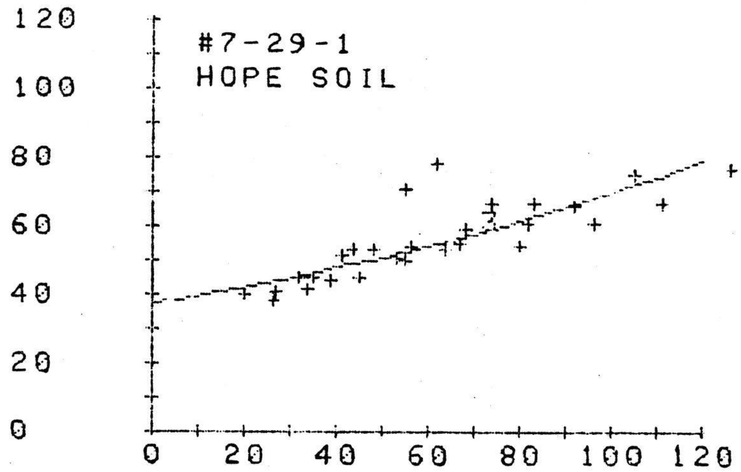
R SQUARE = 0.749

YHAT= 11.823X ^ 0.381

X(I)	YHAT
50.00	52.58

X(I)	YHAT
100.00	68.49

FIGURE 5-2 TYPICAL POWER CURVE, HOPE SOIL, # 7-29-1



AOV: EXPONENTIAL:CODE 3

SOURCE/DF	SS	MS	F
TOTAL 27	1.2		
REG 1	0.8	0.8	59.2
RESID 26	0.4	0.0	

R SQUARE = 0.695

YHAT= 37.187EXP(0.006 X)

X(I)	YHAT
50.00	50.92

X(I)	YHAT
100.00	69.72

FIGURE 5-3 TYPICAL EXPONENTIAL CURVE, HOPE SOIL, # 7-29-1

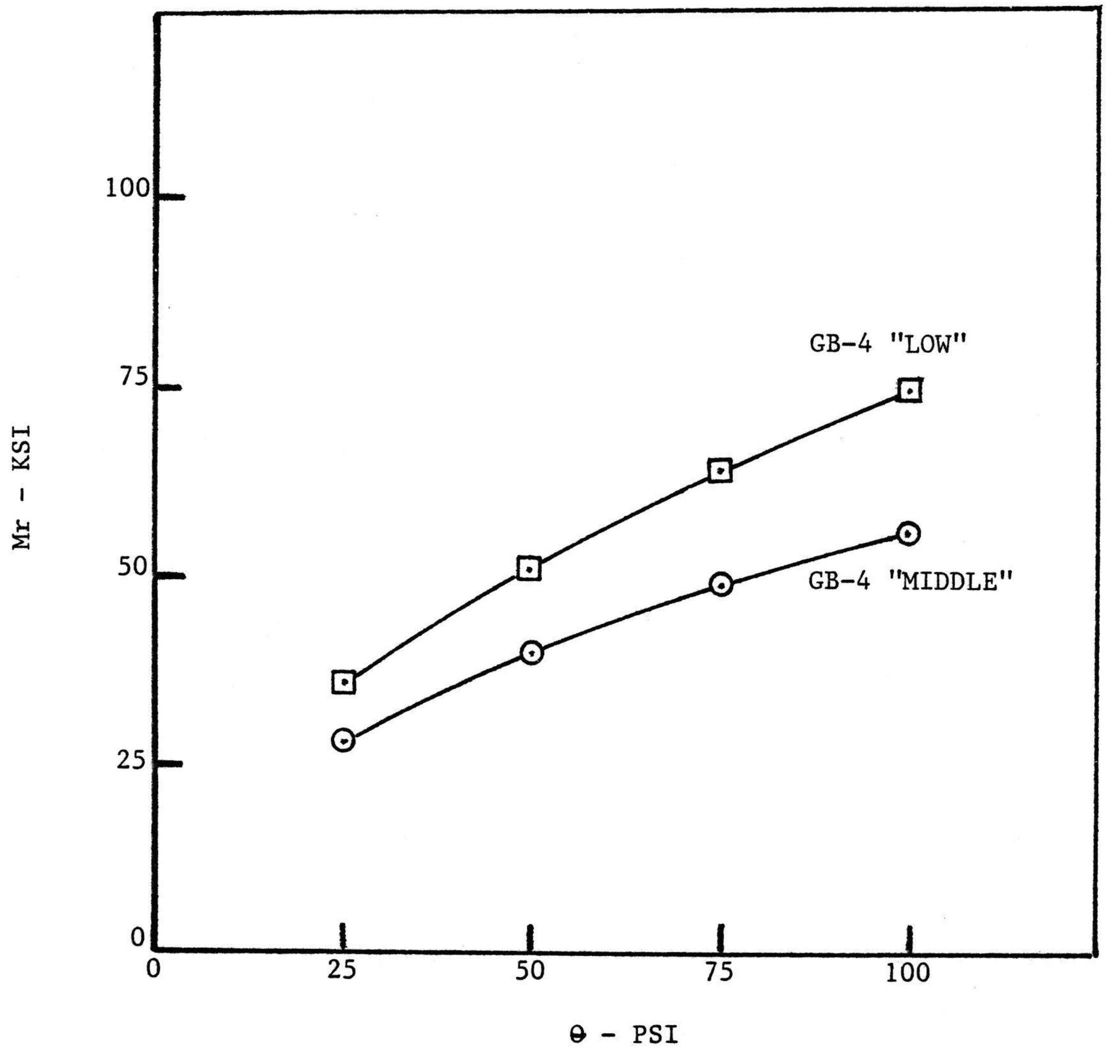


FIGURE 5-4 PLAIN STANDARD AGGREGATE DYNAMIC RESILIENT MODULUS TEST CURVES

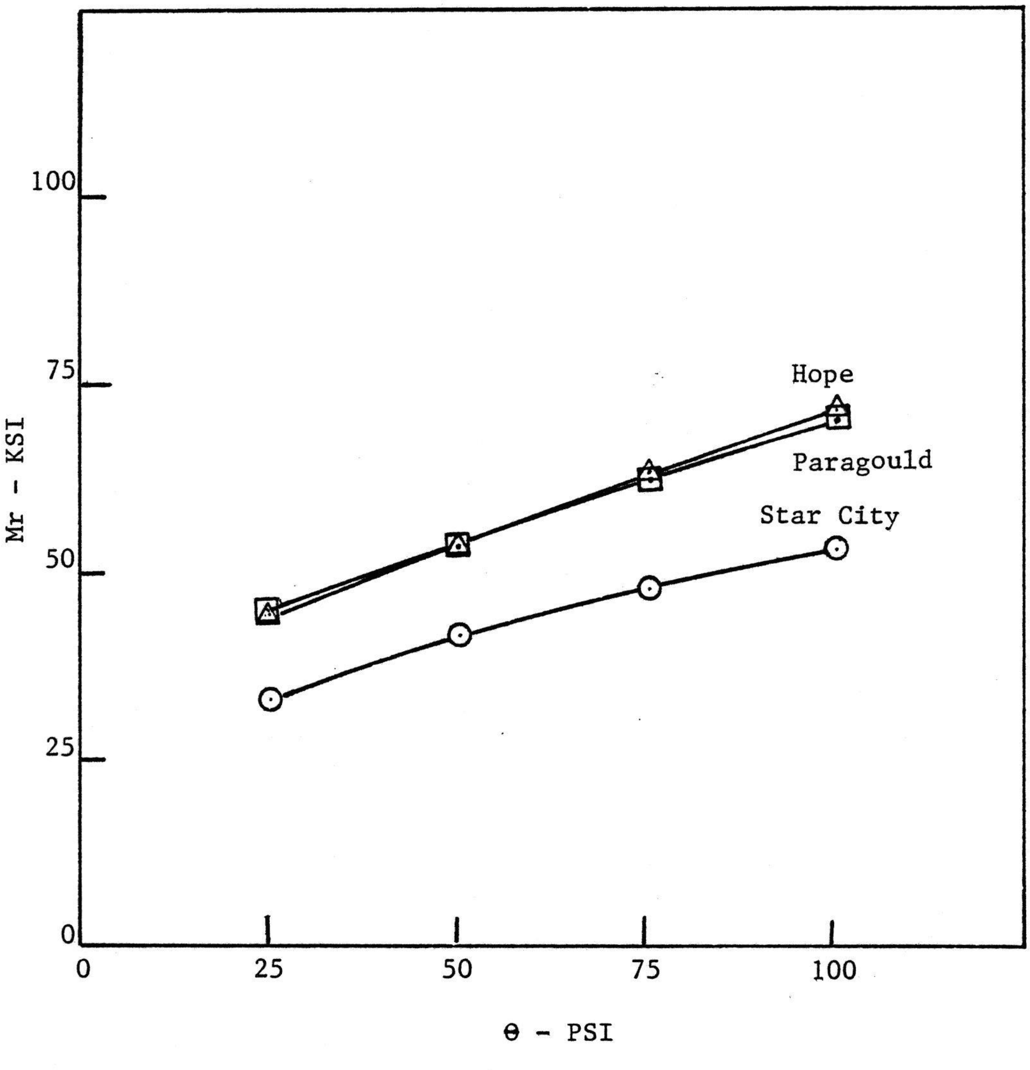


FIGURE 5-5 PLAIN MARGINAL AGGREGATE RESILIENT MODULUS TEST CURVES

5-4 and 5-5, because this is the data analysis method recommended in the AASHTO cyclic triaxial testing standard for subgrade soils.

5-5 Test Results

The results of the cyclic triaxial testing of the GB-4 "Low" and GB-4 "Middle" samples as calculated with the power series curves are shown in Tables 5-4 and 5-5. The resilient modulus, Mr, is shown calculated for four various representative values of θ, sum of stresses. These values were then averaged and the average values were plotted, see Figure 5-4.

The test results of the cyclic triaxial testing of the three regional samples as calculated with the power series curves are shown in Tables 5-6 thru 5-8. As in the above data presentation discussion, the results were calculated for four representative values of θ. These values of resilient modulus were then averaged and plotted for each of the three soils, see Figure 5-5. A comparison of the values in Figure 5-5 shows that the resilient modulus curve of the Star City aggregate is slightly less than that for the Hope and the Paragould aggregates and that the curves for the Hope and Paragould aggregates are almost identical. It is also interesting to note that all three curves line up in the same range of values as GB-4 "Low" and GB-4 "Middle". A comparison of the resilient modulus curves in Figures 5-4 and 5-5 shows that the Star City Mr curve is almost identical to the GB-4 "Low" curve. The reason for the GB-4 "Low" curve to be above the GB-4 "Middle" curve and the Star City curve to be lower than the Hope and Paragould curves is not evident; however, the differences are not too great. There is more scatter in the data than is desirable; however, it is believed that this is due to several unrelated factors including: equipment, instrumentation, moisture containment, and splitting precision. On the other hand, some of the data shows very little scatter and the curves generated are very representative.

TABLE 5-4
GB-4 "LOW"

SAMPLE NO	Mc %	γdry lb/cuft	K_1	K_2	$Mr = K_1\theta^{k2}$ ksi			
					θ=25	θ=50	θ=75	θ=100
6-28-1	5.8	135	8.52	.45	36.3	49.9	59.5	68.2
6-29-1	6.0	138	3.92	.64	30.8	47.2	62.1	73.3
6-30-1	6.3	132	6.44	.55	37.8	54.4	69.2	79.3
AVG	6.0	135	-	-	35.0	50.5	63.6	73.6

TABLE 5- 5
GB-4 "MIDDLE"

SAMPLE NO.	Mc %	γdry lb/cuft	K_1	K_2	$Mr = K_1\theta^{k2}$ ksi			
					θ=25	θ=50	θ=75	θ=100
6-23-2	5.9	138	9.03	.32	25.3	31.7	35.6	39.4
6-24-2	5.7	140	4.26	.49	20.6	29.0	35.3	40.7
6-24-1	5.8	139	4.895	.624	36.58	56.20	72.41	86.61
AVG	5.8	139	-	-	27.46	38.97	47.77	55.57

TABLE 5-6
STAR CITY-PLAIN

NO.	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1\theta^{k2}$ ksi			
					θ=25	θ=50	θ=75	θ=100
6-15-2	6.8	136	9.26	.40	33.6	44.8	52.1	59.2
6-16-1	6.1	135	11.13	.29	28.3	34.8	38.9	42.5
6-20-1	6.9	132	12.84	.32	36.0	44.5	51.1	55.5
AVG	6.6	134	-	-	32.6	41.4	47.4	52.4

TABLE 5-7
PARAGOULD-PLAIN

NO.	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1\theta^{k2}$ ksi			
					θ=25	θ=50	θ=75	θ=100
7-15-1	5.5	128	12.78	.39	44.8	59.2	68.8	77.0
7-18-1	6.2	128	7.04	.56	42.7	63.1	79.0	93.0
10-1-1	6.4	128.2	17.665	.183	31.84	36.12	38.93	41.00
AVG	6.03	128	-	-	39.78	52.80	62.24	70.33

TABLE 5-8

HOPE - PLAIN

SAMPLE NO.	Mc %	γ_{dry} lb/cuft	K_1	K_2	$Mr = K_1\theta^{k2}$ ksi			
					θ=25	θ=50	θ=75	θ=100
7-26-1	6.5	123	9.57	.42	37.0	50.0	58.7	66.2
7-27-1	7.5	122	6.99	.53	38.5	55.3	68.9	79.8
7-29-1	8.1	127	11.82	.38	40.2	52.6	61.0	68.5
AVG	7.4	124	-	-	38.6	52.6	62.9	71.5

CHAPTER 6

IMPROVED AND TREATED MARGINAL AGGREGATE TESTING

6.1 General

A major general objective of this research study is to help develop new economical methods for treating and modifying unacceptable marginal aggregates in order that they can be utilized in low volume county road construction programs with the specific objective to develop specifications for treated, modified, and plain marginal aggregates for low volume highways. The information contained in this chapter represents a positive step towards meeting this objective; however, it is clear that more work will be required to establish the separation line between acceptable and unacceptable marginal aggregates first, before the full effects of treatments and modifications can be assessed. Once the cyclic triaxial test method becomes fully developed, the tasks of evaluating and specifying methods of treatment should prove more straightforward.

The work with treatments reported in this chapter was accomplished on the naturally occuring Star City and Paragould aggregates, without the benefit of knowing whether they were acceptable or unacceptable. In the use of marginal aggregates on future construction projects, it is questionable whether or not treatments would be required of aggregates deemed acceptable; although even in those cases where marginal aggregates were shown to be acceptable by laboratory tests, it is possible that limited treatments similar to those used during this program could be shown to be cost effective, when considering costs of aggregate thickness requirements and future maintenance expenditures.

6.2 Research Test Plan

The experiment plan to evaluate the effects of admixtures on the cyclic triaxial test properties of marginal aggregates involved the testing of the Star City and Paragould aggregate samples with lime, lime/fly ash, Donna Fill, calcium chloride and sodium chloride. A summary of the tests is given in Table 6-1. No tests were included to evaluate the treatments with the Hope aggregate because it was received late in the program and the schedule did not allow for additional tests. An unexpected complication occured during the program when it was discovered that the fly ash being utilized was old and that its shelf life had expired. Six samples manufactured with the low strength fly ash were tested and the results were rejected, even though they showed a 40% improvement. These tests were rerun in the winter of 1983 with new lime and fly ash and the new tests gave a 140% improvement over the plain aggregate for the Star City aggregate. Similar results were obtained with the Paragould aggregate. The fly ash used on both occasions was from the Arkansas fly ash supplier - Chem Ash. The lime used in the pure lime tests and the first lime/fly ash tests was quicklime from St. Clair Lime Company of Oklahoma and the lime used with the new fly ash in the second test series was dry powdery hydrated lime from Cleburne Lime Company of Texas. The Donna Fill was supplied by the Donna Fill Company of Little Rock, Arkansas, and the other two chemicals were supplied to the program from the shelf stock at AHTD. The treatment portion of the experiment was arranged to make the best use of the resources available and be completed within the time and budget allotted.

TABLE 6-1
SUMMARY OF TREATED SAMPLE TESTS

NO SAMPLES	SOIL TYPE	TYPE TREATMENT
3	STAR CITY	3% LIME
2	PARAGOULD	3% LIME
3	STAR CITY	3% FLY ASH & 1% LIME
3	PARAGOULD	3% FLY ASH & 1% LIME
2	STAR CITY	20% DONNA FILL
1	STAR CITY	10% DONNA FILL
1	STAR CITY	10% DONNA FILL & 1% $CaCl_2$
1	PARAGOULD	10% DONNA FILL
3	STAR CITY	2% NaCl
1	PARAGOULD	1% $CaCl_2$

6.3 Lime Treatment Testing

Six lime treated samples were manufactured with marginal aggregate, quicklime and water. The quicklime was first mixed with water for slaking to allow the CaO to be converted to a slurry of $Ca(OH)_2$ and water. Once the lime water slurry was uniform, it was thoroughly mixed with the aggregate, sealed and left to mellow for 72 hours prior to compaction. The lime modified aggregate was then added to the mold in 5 layers, each layer being compacted by 9, 11, 14, 16, 19 and 21 blows of a drop hammer from bottom to top respectively.

Once the samples were compacted, they were removed from the mold, sealed and left to cure in the moist box for 14 days at room temperature. After the curing period, the samples were delivered to the test laboratory and subjected to the same multiple layers of conditioning and cyclic stresses. Afterwards, the data was analyzed and curves were plotted of the resilient modulus values vs the sum of the stresses. The test data are given in Tables 6-2 and 6-3 and the test curves are shown in Figures 6-1, 6-2 and 6-3. Very little gain in resilient modulus was achieved with the lime; however, it can be concluded that actual improvement might be achieved in the field after more curing at higher temperatures. The addition of lime should neutralize the swelling effects of excessive plastic fines and impart strength to samples containing lime reactive soil minerals. The results of these tests do not in any way reflect that lime will not improve these plastic reactive marginal aggregate mixtures; however, these tests were valuable to establish a procedure for testing marginal aggregates with lime in the cyclic triaxial test. Complete test procedures are given in Appendix B of this report.

6.4 Lime/Fly Ash Treatment Testing

The lime/fly ash treated aggregate samples were made using the Paragould (McCain) and Star City (Borriman) materials. The material was separated and sieved past a 1/2-inch sieve to remove large stones. The soil was weighed out (1265.9g), as was 1% lime (12.65g), and 3% fly ash (37.97g). First, the lime/fly ash was mixed dry until it was homogenous, and then it was added to the soil and the total amount of material was thoroughly dry mixed. After the dry mixing was complete, 6% moisture was added and mixed. The material was then sealed and allowed to sit for 3 days before the samples were compacted. The method of compaction and curing was the same as that used for the lime samples. At the conclusion of the 28 day cure period, the samples were tested. The test data was analyzed and test curves of the average Mr values were plotted. The lime/fly ash test data is given in Tables 6-4 and 6-5, and the curves are shown in Figures 6-4, 6-5, and 6-6. The curves show that the Star City marginal aggregate was improved more than the Paragould material and that treatment of both marginal aggregate materials with lime/fly ash resulted in substantial improvements.

6.5 Donna Fill Treatment Testing

Donna Fill was used as a stabilizer for both Star City and McCain soils. The Donna Fill was dry mixed with the aggregate to be tested (usually 1/10 or 2/10) and 6 percent moisture was added. The homogenous mixture was allowed to sit overnight and the following day it was compacted and tested. The method of compaction was the same as that used for the lime samples.

After the tests, the data was analyzed and average Mr vs θ curves were plotted. The tabulation of the analyzed test data for all four tests is given in Tables 6-6 through 6-9. The curves are shown in Figures 6-7, 6-8

TABLE 6-2
STAR CITY - 3% LIME

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1\ \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-27-3	5.35	130.4	18.22	.258	41.80	49.99	55.50	59.78
8-1-2	6.70	129.12	22.92	.181	41.04	46.53	50.07	52.76
8-1-4	6.80	129.2	15.92	.23	33.38	39.13	42.97	45.90
AVG	6.28	129.57	-	-	38.74	45.22	49.51	52.81

TABLE 6-3
PARAGOULD SOIL - 3% LIME

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1\ \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-15-2	8.15	130.32	10.71	.373	35.58	46.16	53.60	59.80
7-15-5	9.68	135.99	-	-	35.5	44.5	49.0	54.0
AVG	8.92	133.16	-	-	35.54	45.33	51.30	56.90

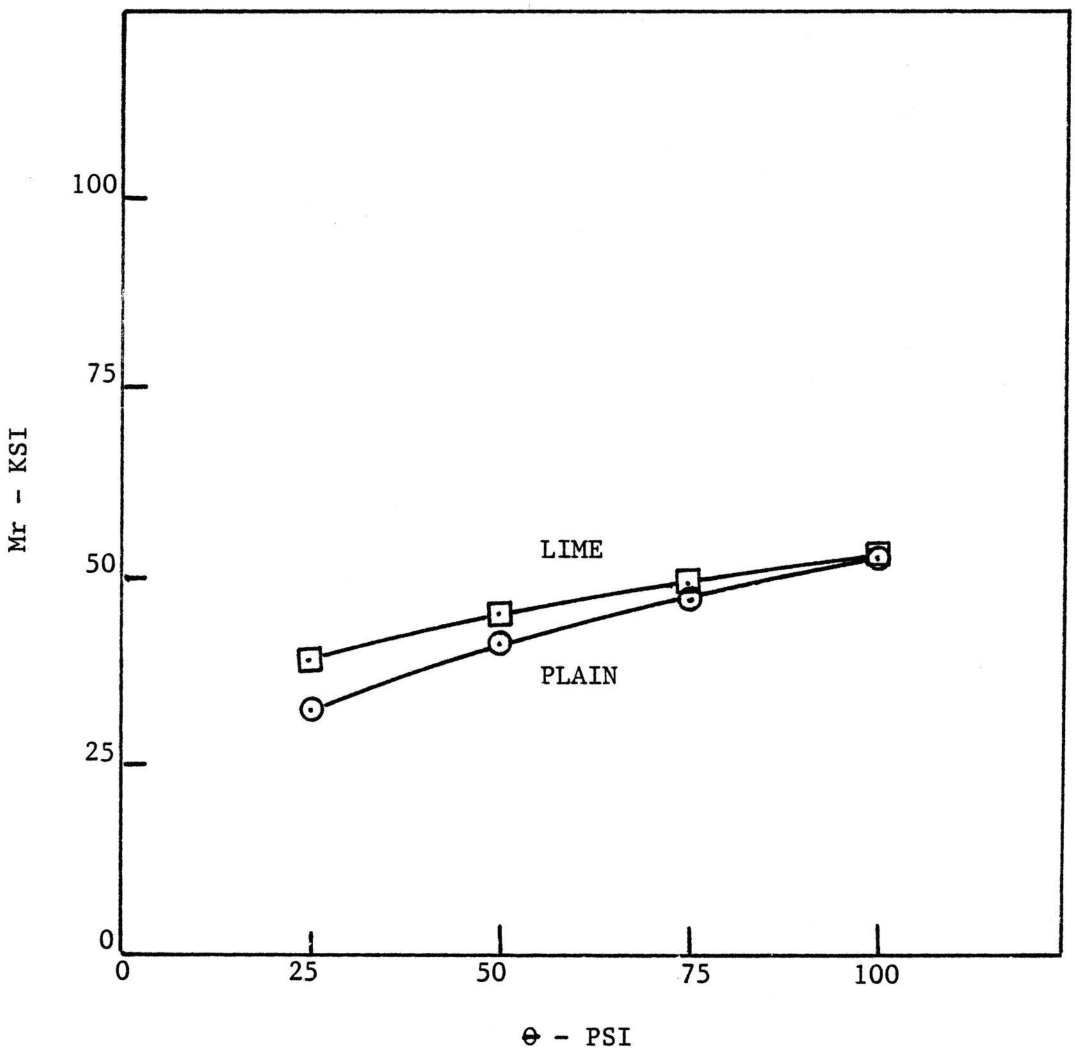


FIGURE 6-1 STAR CITY, PLAIN VS 3% LIME

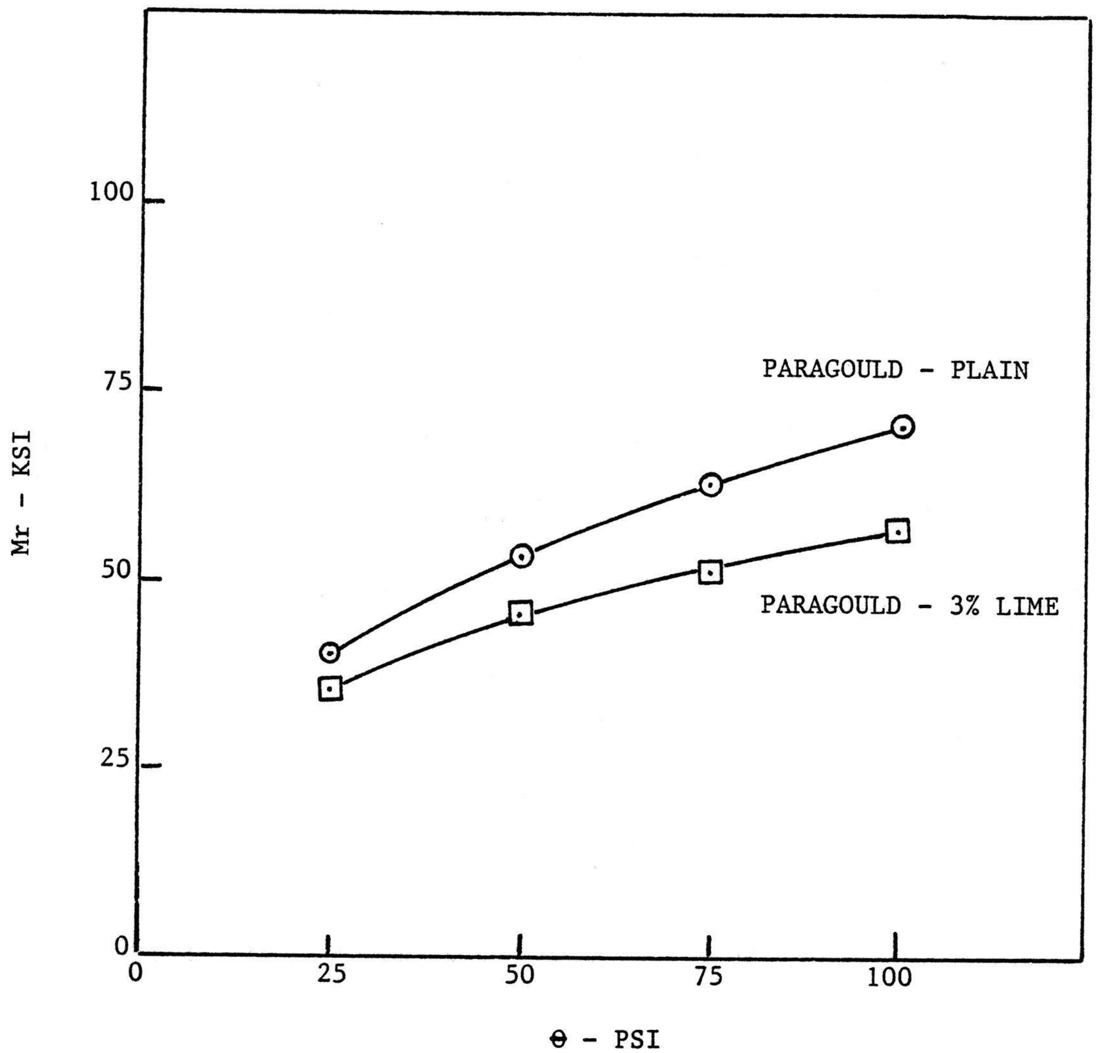


FIGURE 6-2 PARAGOULD, PLAIN VS 3% LIME

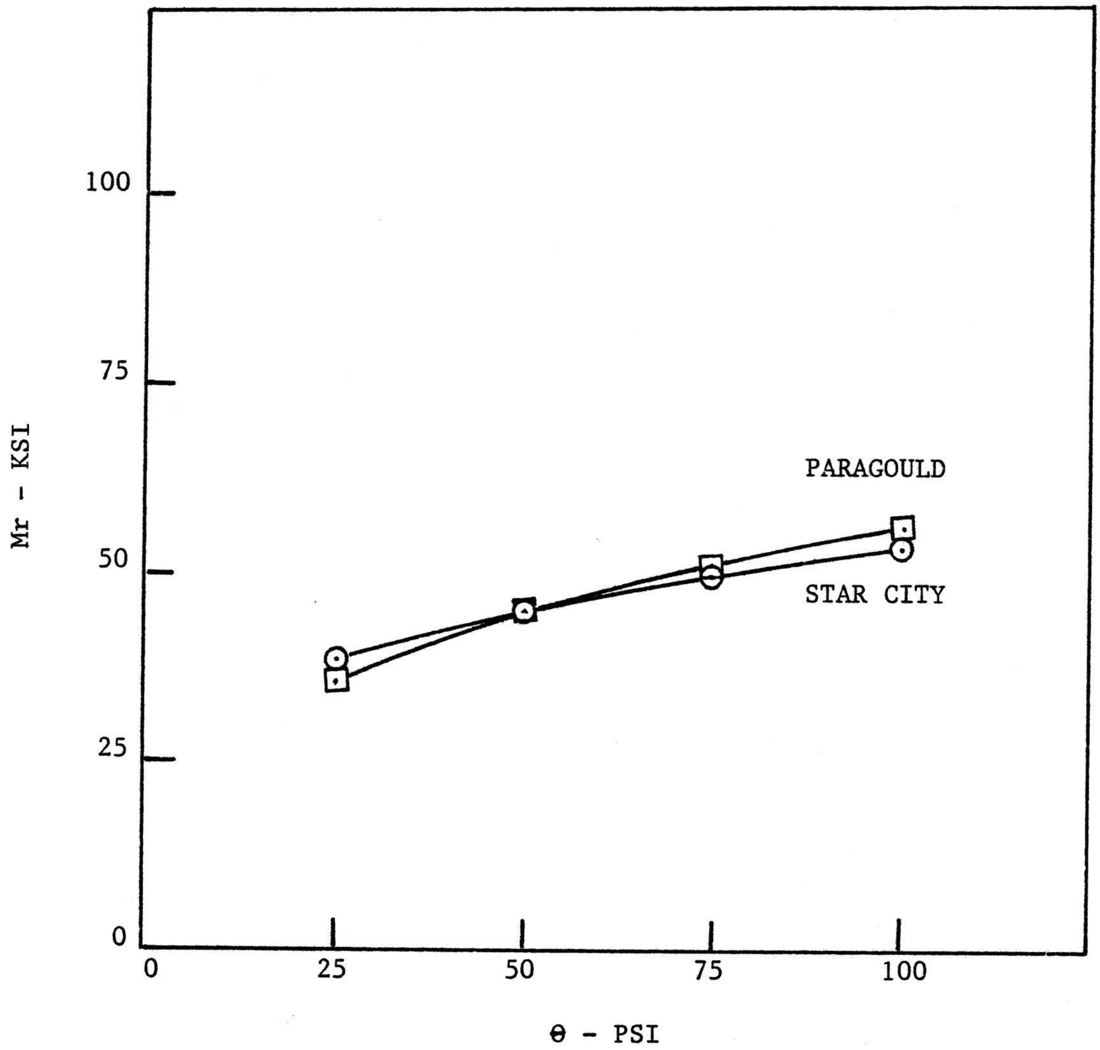


FIGURE 6-3 STAR CITY AND PARAGOULD AGGREGATE - 3% LIME

TABLE 6-4
STAR CITY - 3% F.A. & 1% LIME

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
11-16-1	6.9	124.96	77.64	.229	161.22	188.97	206.88	221.22
11-16-2	7.4	126.73	36.975	.145	58.96	65.10	69.15	71.96
11-16-3	7.1	125.68	16.55	.247	36.65	43.57	48.08	51.72
AVG	7.25	126.20	-	-	85.61	99.21	108.04	114.97

TABLE 6-5
PARAGOULD - 3% F.A. & 1% LIME

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
9-28-1	6.97	125.48	16.902	.499	84.23	119.12	145.74	168.36
9-28-2	6.95	123.99	94.187	.112	65.67	60.74	58.07	56.20
9-28-3	6.30	124.98	21.952	.245	48.30	57.31	63.22	67.93
AVG	6.74	124.82	-	-	66.07	79.06	89.01	97.49

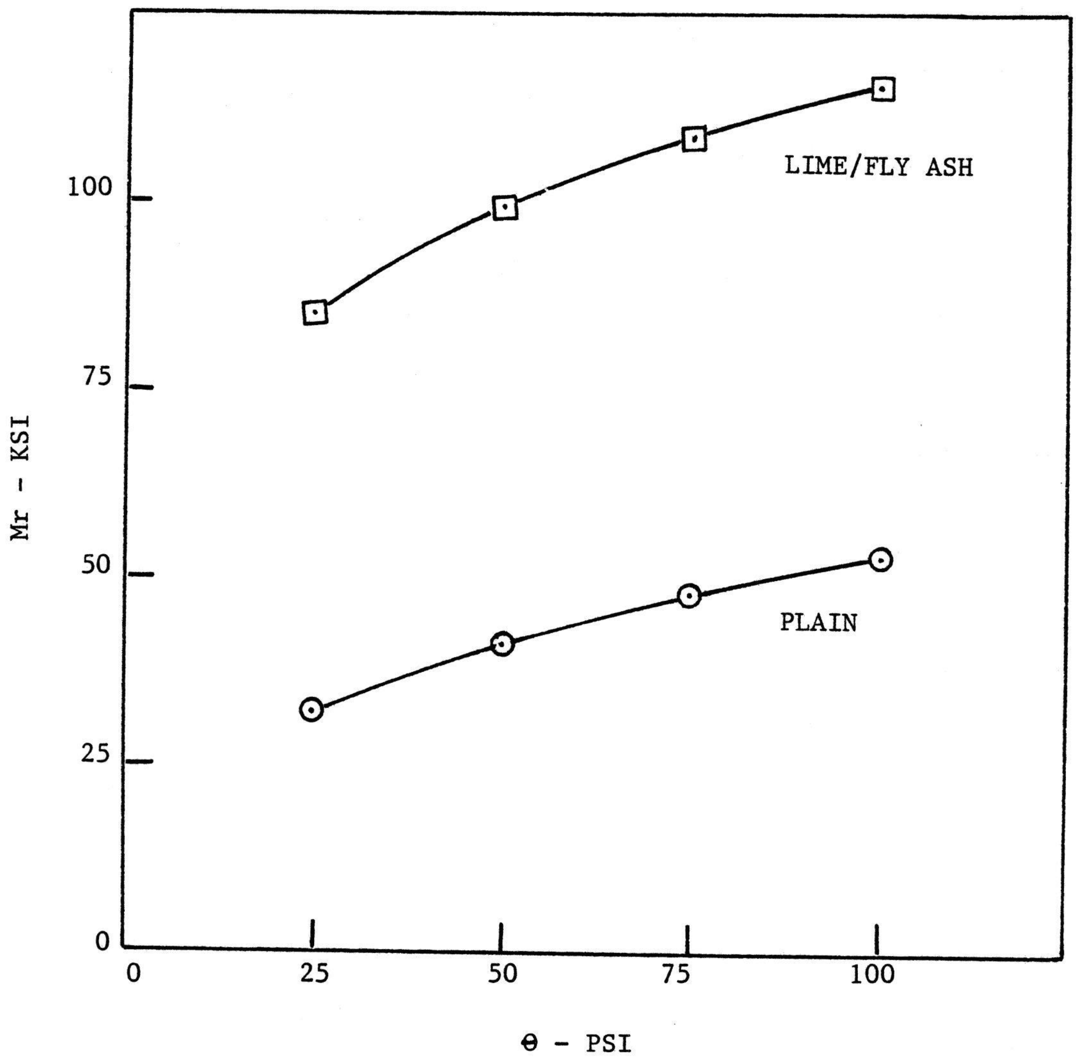


FIGURE 6-4 STAR CITY PLAIN VS 3% FLY ASH, 1% LIME

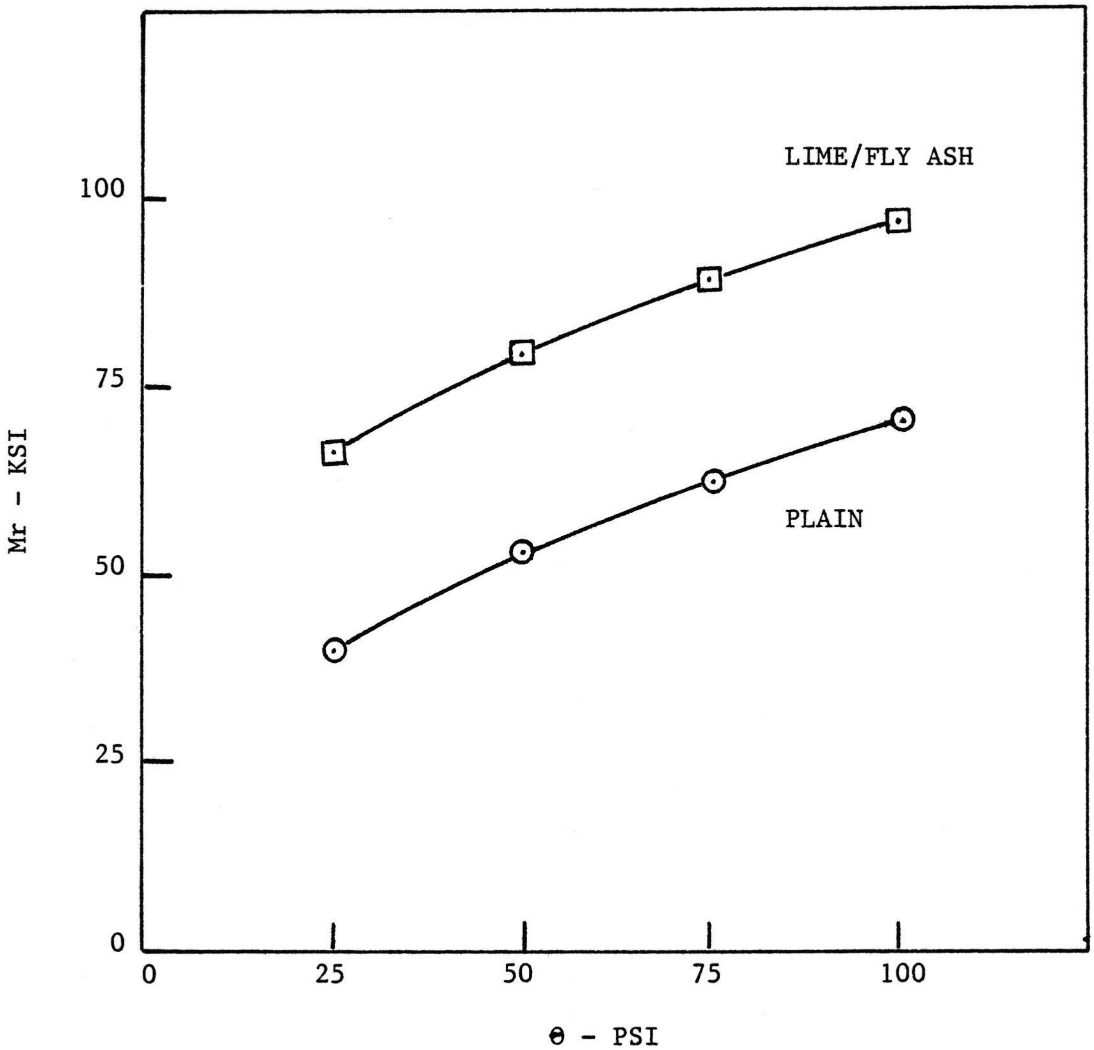


FIGURE 6-5 PARAGOULD PLAIN VS 3% FLY ASH, 1% LIME

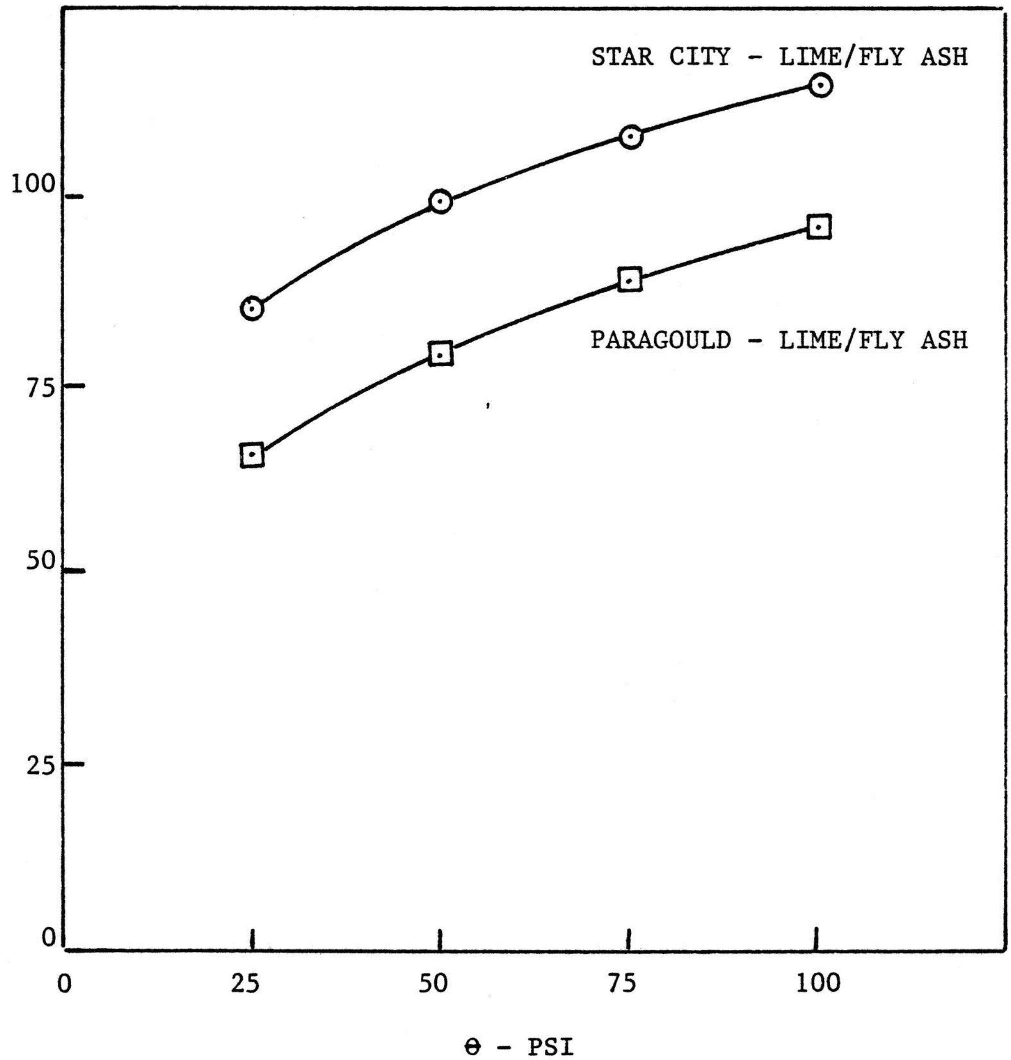


FIGURE 6-6 STAR CITY AND PARAGOULD AGGREGATE - 3% Fly Ash AND 1% LIME

TABLE 6-6
STAR CITY - 20% DONNA FILL

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-7-1	6.46	133.48	2.450	.701	23.39	38.07	50.53	61.89
7-11-1	4.85	133.67	6.65	.504	33.68	47.89	58.59	67.93
AVG	5.65	133.57	-	-	28.54	42.98	54.56	64.91

TABLE 6-7
STAR CITY - 10% DONNA FILL

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-6-1	6.6	132.02	11.082	.478	51.62	71.84	87.28	100.04
AVG	6.6	132.02	11.082	.478	51.62	71.84	87.28	100.04

TABLE 6-8

STAR CITY - 10% DONNA FILL + 1% $CaCl_2$

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mc = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-22-1	5.62	138.2	5.521	.383	18.94	24.66	28.85	32.15

TABLE 6-9

PARAGOULD - 10% DONNA FILL

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	$Mr = K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-20-1	6.42	129.13	11.265	.266	26.52	31.89	35.52	38.35

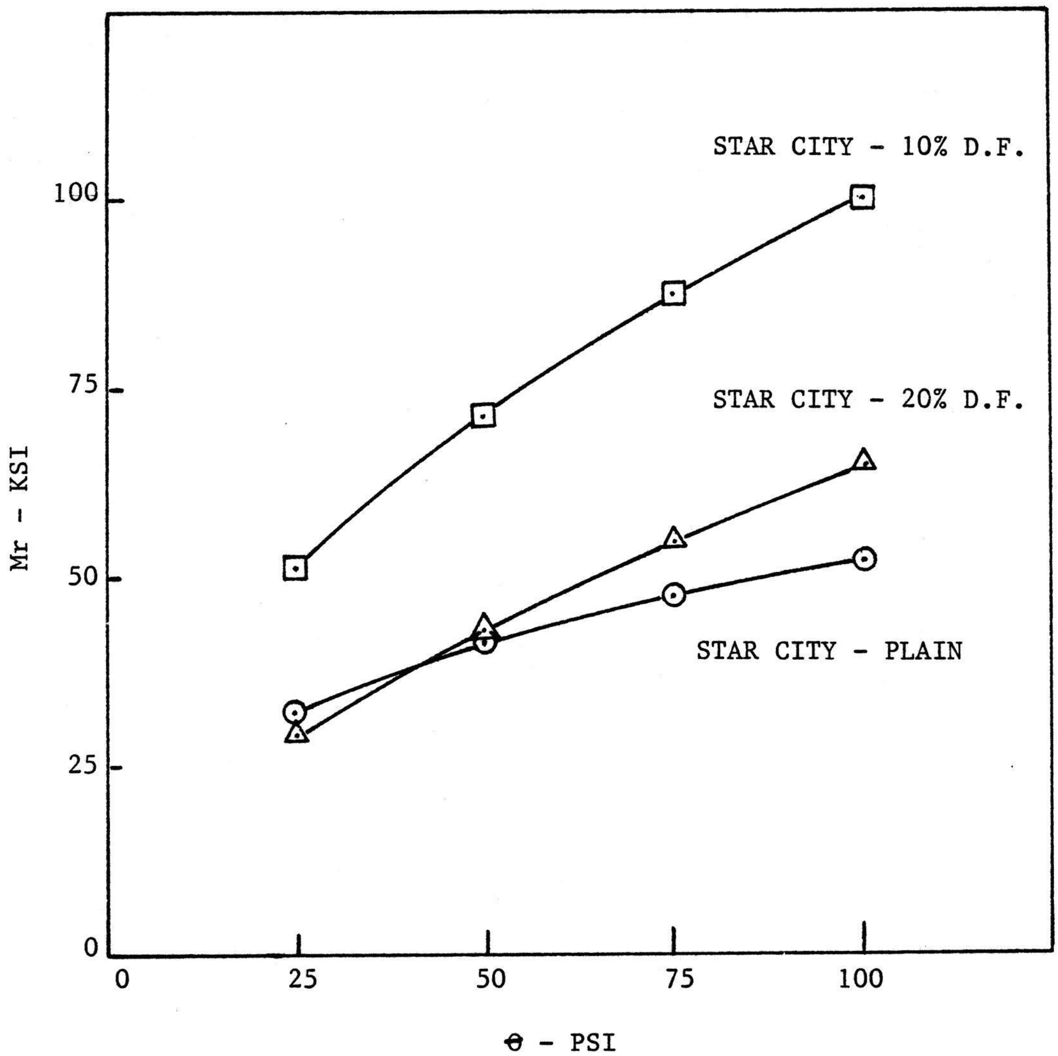


FIGURE 6-7 STAR CITY, PLAIN VS DONNA FILL

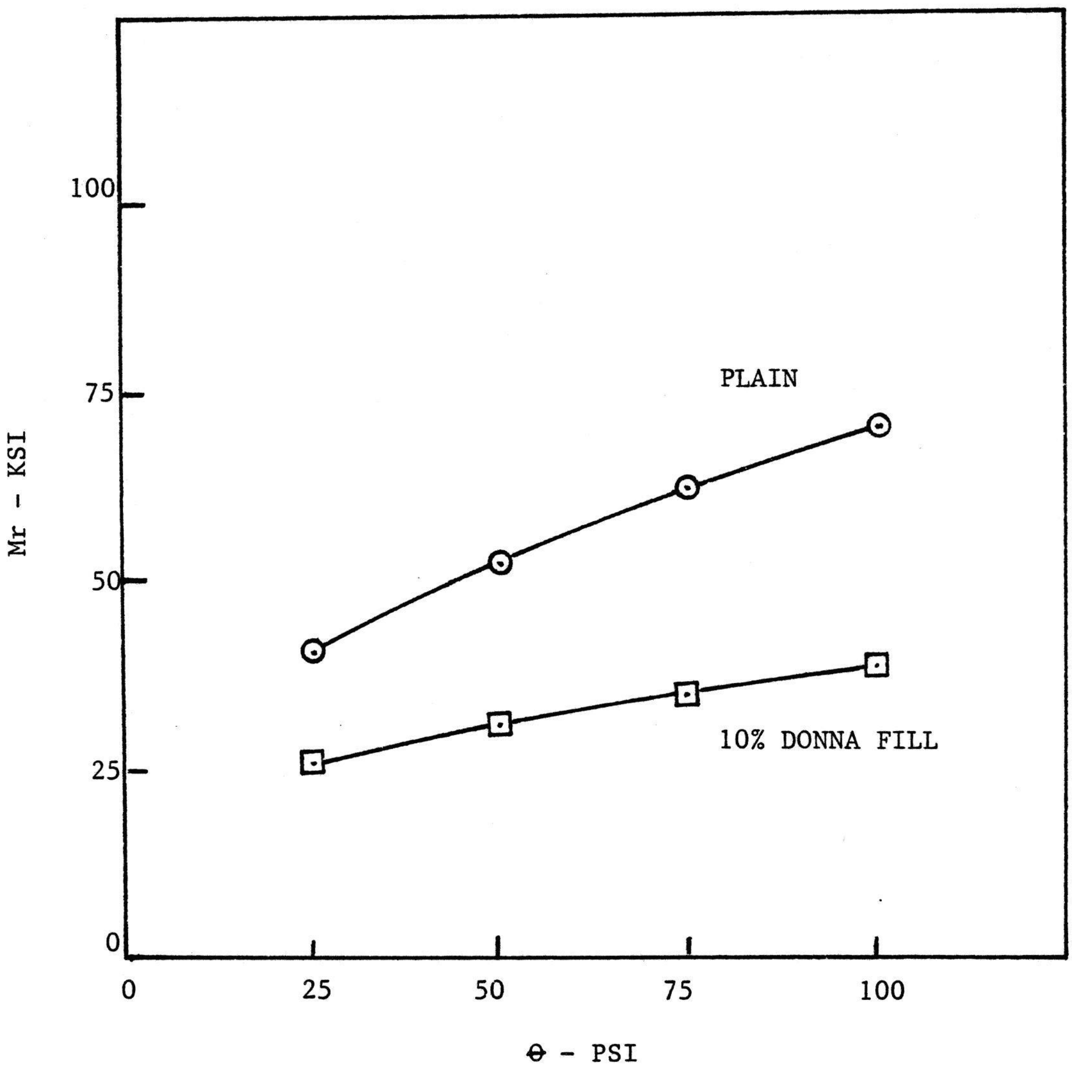


FIGURE 6-8 PARAGOULD, PLAIN VS 10% DONNA FILL

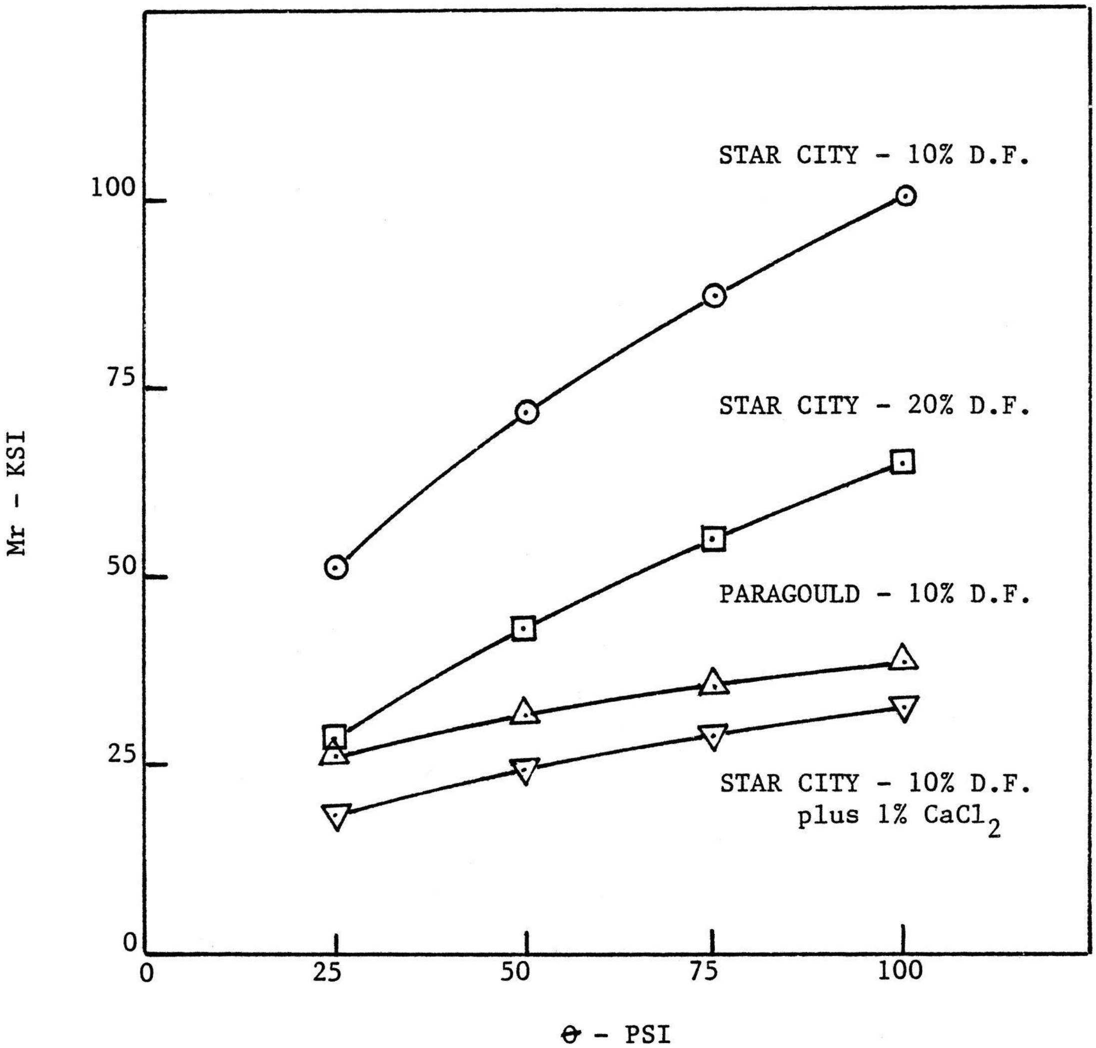


FIGURE 6-9 STAR CITY AND PARAGOULD AGGREGATE - DONNA FILL (D.F.)

and 6-9. As the curves show, especially those in Figure 6-9 the addition of Donna Fill resulted in mixed results. The addition of 10% Donna Fill to the Star City aggregate gave unusually high values, whereas the addition of 10% Donna Fill to the Paragould aggregate gave reduced values. In both cases, there was only one test sample, so it is not possible to draw a definite conclusion, except to say that perhaps the Donna Fill has some promise; however, it needs additional study.

6.6 Sodium Chloride Treatment Testing

The sodium chloride was one of the experimental substances used to stabilize the marginal aggregate samples in the program. The NaCl samples were prepared by first mixing the NaCl (2%) with the water (6%) to be added to the soil. The water was warm and the salt was allowed to dissolve and form a homogenous NaCl-water solution. This was then added to the dry soil sample, and well mixed. The samples were sealed and allowed to cure 3 days and were then compacted. The compacted samples were allowed to cure approximately 14 days before testing.

Three samples were manufactured with the Star City aggregate and 2% NaCl. The analyzed test data is given in Table 6-10. The Mr vs θ test curves comparing Star City-plain versus Star City-NaCl (2%) are shown in Figure 6-10. As it can be seen from the data, very little improvement was achieved.

6.7 Calcium Chloride Treatment Testing

Calcium chloride was one of the chemicals used to stabilize the marginal aggregates that were tested. The $CaCl_2$ (1%) was added to the dry aggregate and the mixture was thoroughly stirred until it was homogenous. Moisture

(6%) was added and the sample was sealed and allowed to sit overnight. It was then compacted and tested. No curing time was allowed. The test results are shown in Table 6-11 and Figure 6-11. The sample lost a considerable amount of strength and stiffness due to the addition of the $CaCl_2$. All remaining tests were cancelled with $CaCl_2$ after it appeared that it was not a good stabilizer for marginal aggregates. The results of this test bore out what was written in the literature. Namely, that $CaCl_2$ should not be used as a stabilizer for marginal aggregates.

6.8 Test Result Comparisons

The results of the research conducted to evaluate the effects of certain selected treatments was mostly successful. Because prior decisions were necessary to establish the admixtures to be evaluated and the ratios to be used, the results are only indicative of what could be accomplished with treatments in general. Unfortunately, specific recommendations for each individual marginal aggregate source do not necessarily follow from the results presented.

In general, the lime/fly ash looked best and Donna Fill, lime, and salt appear to show promise. Blending in general, with sand or clay should also be considered as should other chemicals and waste materials not tested. For the present, the use of calcium chloride should be ruled out for base course layers, although it is acceptable as a dust control on gravel surfaced roads.

Since all samples were tested with the cyclic triaxial method, it can be concluded that it is no more difficult to test modified and treated samples with this new method than it is to test plain aggregates. The comparisons of the two different types of samples seem appropriate and beneficial.

TABLE 6-10
STAR CITY - 2% NaCl

SAMPLE NO	Mc %	γdry lb/cuft	K_1	K_2	Mr = $K_1 \theta^{K_2}$ PSI			
					θ=25	θ=50	θ=75	θ=100
7-20-2	6.3	140.4	91.144	.386	31.68	41.35	48.41	54.03
7-20-3	6.8	142.3	17.018	.093	22.96	24.45	25.43	26.07
7-22-3	6.1	141.5	30.039	.191	66.65	76.17	82.21	86.97
AVG	6.4	141.4	-	-	40.43	47.32	52.02	55.69

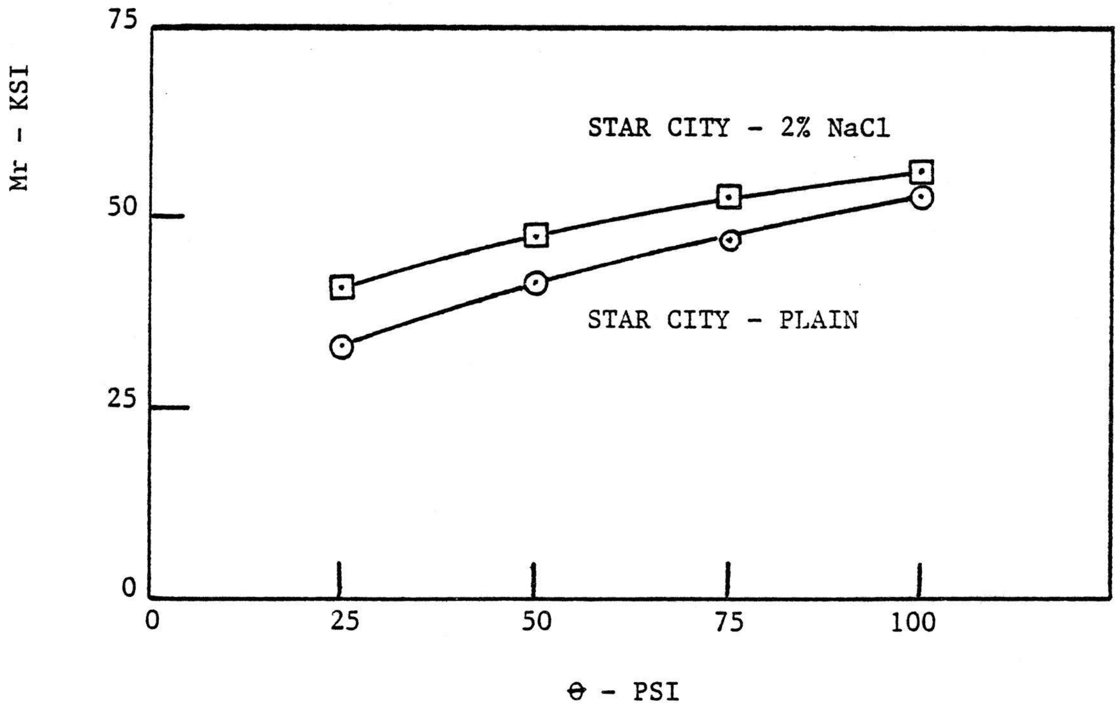


FIGURE 6-10 STAR CITY, PLAIN VS 2% NaCl

TABLE 6-11
PARAGOULD - 1% Ca Cl_2

SAMPLE NO	Mc %	γ dry lb/cuft	K_1	K_2	Mc = K_1 θ^{K_2} PSI			
					θ=25	θ=50	θ=75	θ=100
7-19-1	7.05	134.6	4.518	.516	23.78	34.02	41.93	48.66

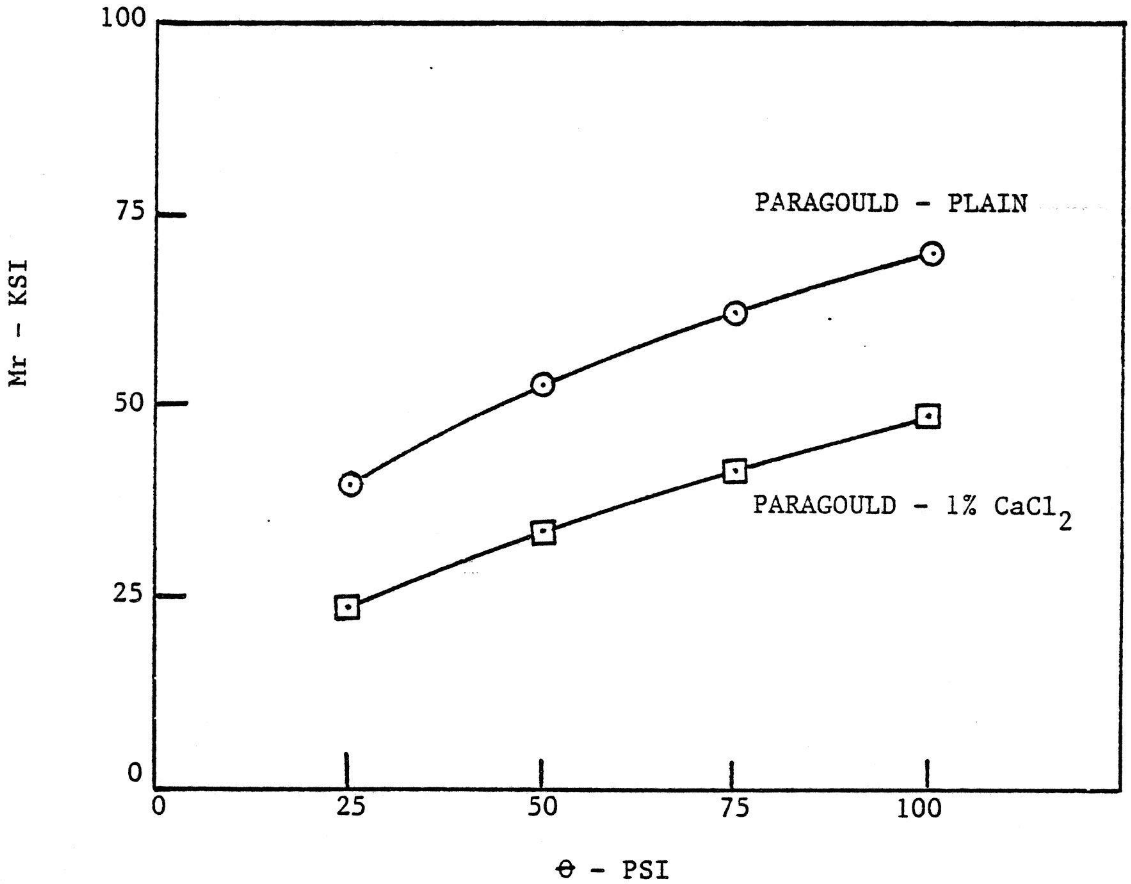


FIGURE 6-11 PARAGOULD, PLAIN VS 1% $CaCl_2$

CHAPTER 7

SUMMARY AND CONCLUSIONS

The research conducted during this project resulted in the first attempt in Arkansas, or documented elsewhere, to utilize the cyclic triaxial test method to evaluate the suitability of a marginal aggregate base material for low volume road construction. The consideration of a marginal aggregate is in itself a regional requirement because marginal aggregate evaluation only becomes important in a region after all economical sources of standard-specification aggregates have been depleted. Few states are currently involved in the utilization or evaluation of marginal aggregates. One marginal aggregate study in Maryland was terminated after it began, because the researchers found little evidence that marginal aggregates were available in sufficient quantity to warrant a study. This was not the case in this study. There seems to be a large enough stock of naturally occurring marginal aggregates economically situated in Arkansas to justify a continuing effort into their evaluation, classification, and utilization. The initial goal of this research study, to find testing and analysis methods to evaluate marginal aggregates and to help predict their performance and service life in road construction applications on low volume roads, has been successfully begun and the direction the research has led appears to be promising.

The principal conclusion of the research is that the cyclic triaxial method of resilient modulus testing is a viable method of determining the worth of marginal aggregate sources to support dynamic wheel load applications; and that through the use of this method, the best aggregates can be selected from multiple sample sources, and that a set of standard test values can be developed, that the highway design engineer can use as standards for selection and/or rejection of candidate material sources.

The secondary purpose of the research program, which was to develop and evaluate new economical methods for treating and modifying otherwise poor aggregates, resulted in the studying and testing of several methods of cementing, modifying and blending marginal aggregates. Without question the use of the cyclic triaxial method is well suited to accurately and economically compare and evaluate the dynamic response of different improvement methods. The addition of lime/fly ash slurry gave substantial improvements to the test samples; and it appears that based on the limited results of the testing of improved and treated marginal aggregates in this program, that this method should be ranked as the best of those evaluated. Three methods evaluated - lime, Donna Fill, and salt - offered measurable improvements, and it was concluded that marginal aggregate utilization can possibly be enhanced through the use of one or more of these methods. Depending on the clay content and the gap grading specifics of a particular marginal aggregate source, the actual method best suited for improvement of an individual source must be determined through chemical reactivity and compatability testing and cyclic triaxial test method evaluations.

CHAPTER 8

RECOMMENDATIONS

The indications of success of the cyclic triaxial test method to evaluate three Arkansas marginal aggregates points to the need for a comprehensive cyclic triaxial aggregate materials characterization effort by the AHTD construction materials laboratory. The first step in developing cyclic triaxial test capability is the design, purchase and installation of a reliable test system. The cyclic triaxial test system currently in use at UALR is an older machine, which relies on manual controls for varying load intensity and manual electronic digital read out. It would be well to initiate a short study to evaluate the advantages and disadvantages of the many machine systems currently being marketed. There exists no current standard for comparison; however, the likelihood of the entire test community settling on one design in the near future is good. It is the opinion of the author, that cyclic systems of the future will be automated electronically, controlled by microprocessors, and equipped with computerized data acquisition systems with computerized analysis and plotting systems. Many systems in the United States in both the public and private sector are now of this new type. The Bureau of Reclamation laboratories in Denver, Colorado, and the Corps of Engineers Waterways Experiment Station laboratories at Vicksburg, Mississippi, are two examples of federal testing agencies with computerized systems. Many large universities and commercial testing laboratories have also acquired various variations of this type of equipment. It is recommended that the AHTD test laboratory enter the field of cyclic triaxial testing and develop the capabilities to perform the tests on highway subgrade soils and base aggregates for materials characterization.

SELECTED BIBLIOGRAPHY

1. Arkansas State Highway Commission, "Standard Specifications for Highway Construction," Edition of 1978.

2. Arkansas State Highway and Transportation Department, "Manual of Field Sampling and Testing Procedures," No. 0072, Division of Materials and Research, Little Rock, Arkansas, Nov. 1982.

3. Barenberg, E. J., "Lime or Lime and Cement-Fly Ash-Aggregate Mixtures for Use in Pavement Construction," presented at the October 22-27, 1978, conference on Ash Technology and Marketing, held at London, England.

4. Barksdale, R. D., "Repeated Load-Test Evaluation of Base Course Materials," No. 7002, Department of Transportation State of Georgia, Georgia, May 1972.

5. Barksdale, R. D., "Crushed Stone Base Course Performance," presented at the December, 1983, Annual Transportation Research Board Meeting, held at Atlanta, Georgia.

6. Brown, S. F., "Repeated Load Testing of a Granular Material," July 1974, ASCE Journal of the Geotechnical Engineering Division, pp. 825-841.

7. Chou, Y. T., "Evaluation of Non Linear Resilient Moduli of Unbound Granular Materials from Accelerated Traffic Test Data," No. S-76-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1976.

8. Fuller, M. G., and Dabney, G. W., "Stabilizing Weak and Defective Bases with Hydrated Lime," Roads and Streets, 1952.

9. Gray, J. E., "Characteristics of Graded Base Course Aggregates Determined by Triaxial Tests," No. 12, National Crushed Stone Association, Washington, D. C., July 1962.

10. Haynes, J. H., and Yoder, E. J., "Effects of Repeated Loading on Gravel and Crushed Stone Base Course Materials Used in the AASHO Road Test," Highway Research Record No. 39, 1962.

11. Hicks, R. G., and Monismith, C. L., "Factors influencing the Resilient Response of Granular Materials," presented at the Committee on Strength and Deformation Characteristics of Pavement Sections, 1972.

12. Highway Research Board, "Salt Stabilization" Highway Research Record, No. 294, National Research Council, Washington, D. C., 1969.

13. Highway Research Board, "Influence of Stabilizers on Properties of Soils and Soil-Aggregate Mixtures," presented at the January 11-15, 1960, Highway Research Board 39th Annual Meeting, held at Washington, D. C.

14. Illinois Department of Transportation, "Subgrade Stability Manual," Departmental Policies, Illinois, Mar. 1982.

15. Kalcheff, I. V., and Hicks, R. G., "A Procedure for Determining the Resilient Properties of Granular Materials," Journal of Testing and Evaluation, Vol. I, No. 6, 1973, pp. 472-478.

16. Kidwai, S. A., "Evaluation of the Resilient Properties of Selected Soils and Aggregates," No. 82-12, Transportation Research Institute and Civil Engineering Department, Corvallis, Oregon, Aug. 1982.

17. Larew, H. G., and Leonards, G. A., "A Strength Criterion for Repeated Loads," Department of Soils, Geology and Foundations, pp. 529-556, Purdue University, 1960.

18. Larsen, M. B., "Stabilization of Soils and Surfaces by Use of Various Stabilizing Agents of Iowa Secondary Roads," American Association of State Highway Officials, Ames, Iowa, Dec. 1964.

19. Lottman, R. P., "Practical Laboratory Measurements and Application of Stiffness or Resilient Properties of Soils and Granular Base Materials for Idaho Flexible Pavement Design Procedures," Division of Highways Idaho Transportation Department, Boise, Idaho, Oct. 1976.

20. Marks, B. D., and Haliburton, T. A., "Salt Lime Stabilization," Project Agreement No. 6, State of Oklahoma, Department of Highways, Stillwater, Oklahoma, June 1970.

21. Mitchell, J. K., Veng, T-S., and Monismith, C. L., "Performance Evaluation of Cement - Stabilized Soil Layers and Its Relationship to Pavement Design," Report 5, Berkeley, California, Aug 1982.

22. Monismith, C. L., Hicks, R. G., and Salam, Y. M., "Basic Properties of Pavement Components," No. FHWA - RD 72-19, U. S. Department of Transportation Federal Highway Administration, Washington, D. C., Sept 1971.

23. Moore, R. K., and Kennedy, T. W., "Tensile Behavior of Subbase Materials under Repetive Loading," No. 98-12, Cooperative Highway Research Program with Texas Highway Department and U. S. Department of Transportation Federal Highway Administration, Austin, Texas, Oct 1971.

24. Petroff, L. J., "The Development of a Soils Laboratory Machine for Repeated Load Testing," The University of Arkansas Graduate Institute of Technology, Little Rock, Arkansas, April 1977.

25. Prysock, R. H., "Triaxial Testing of Large Diameter Compacted Soil Speciments," No. FHWA/CA/TL - 79/19, California Department of Transportation, Sacramento, California, Oct 1979.

26. Rada, G., and Witczak, M. W., "Comprehensive Evaluation of Laboratory Resilient Moduli Results for Granular Material," Transportation Research Record 810, 1977.

27. Richardson, E. S., et al., "The Investigation of Present Aggregate Gradation Control Practices and the Development of Short-Cut or Alternative Test Methods," No. FHWA - RD - 77-53, Offices of Research and Development Federal Highway Administration, Washington, D. C., April 1977.

28. Silver, M., "Laboratory Triaxial Testing Procedures to Determine the Cyclic Strength Soils," No. NURE G-31, Dec 1976.

29. Smith, W. S., and Nair, K., "Development of procedures for Characterization of Untreated Granular Base Course and Asphalt - Treated Base Course Materials," No. FHWA - RE 74-61, U. S. Department of Transportation Federal Highway Administration, Washington, D. C., Oct 1973.

30. The Asphalt Institute, "Thickness Design-Asphalt Pavements for Highways and Streets," No. 1 (MS-1), The Asphalt Institute, College Park, Maryland, Aug 1981.

31. Thompson, W. E., "Analysis of Dynamic Behavior of Roads Subject to Longitudinally Moving Loads," Committee on Stress Distribution in Earth Masses, Highway Research Record No. 39, 1962.

32. Thornton, S. I., "Correlation of Subgrade Reaction with CBR, HVEEM Stabilometer, or Resilient Modulus," Arkansas State Highway and Transportation Department, Little Rock, Arkansas 1983.

33. Townsend, F. C., and Chisolm, E. E., "Plastic and Resilient Properties of Heavy Clay under Repetitive Loadings," No. S-76-16, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Nov 1976.

34. Transportation Research Board, "Design and Upgrading of Surfacing and other Aspects of Low-Volume Roads," No. 875, National Academy of Sciences, Washington, D. C., 1982.

35. Transportation Research Board, "Lime-Fly Ash-Stabilized Bases and Subbases," National Research Council, Washington, D. C., 1976.

36. Transportation Research Board, "Soil Mechanics: Rutting in Asphalt Pavements, Embankments on Varved Clays, and Foundations," No. 616, National Academy of Sciences, Washington, D. C., 1976.

37. Transportation Research Board, "Test Procedures for Characterizing Dynamic Stress-Strain Properties of Pavement Materials," No. 162, National Academy of Sciences, Washington, D. C., 1975.

38. Usmen, M. A., Moulton, L. K., "Construction and Performance of Experimental Base Course Test Sections Built with Waste Calcium Sulfate Lime and Fly Ash," Department of Civil Engineering, Morgantown, West Virginia, Jan 1983.

39. Wissa, A. E. Z., Paniagua, J. G., "Equipment for Studying the Effect of Repeated Loading on the Stress-Strength Behavior of Stabilized Soils," No. 10, U. S. Army Material Command, Vicksburg, Mississippi, June 1972.

APPENDIX A

LABORATORY TESTING EQUIPMENT FOR CYCLIC TRIAXIAL MARGINAL AGGREGATE TESTING

The UALR cyclic triaxial testing equipment used during this research program consisted of the following: triaxial cell, load frame, hydraulic loading cylinder, cycle control module, pressure control valves, pneumatic compressor, deflection dial gauge, air pressure gauges, electronic load cell and load cell signal conditioner-digital display.

A photograph of the cyclic triaxial testing system in operation is shown in Figure A-1. The loaded triaxial cell, load cell, signal conditioner and load frame with all necessary fittings and accessories are shown in the left half of the picture and the cyclic control module with its Eagle timers is shown in the right half of the picture. The control module also contains the hydraulic accumulator to convert pneumatic pressure to hydraulic pressure.

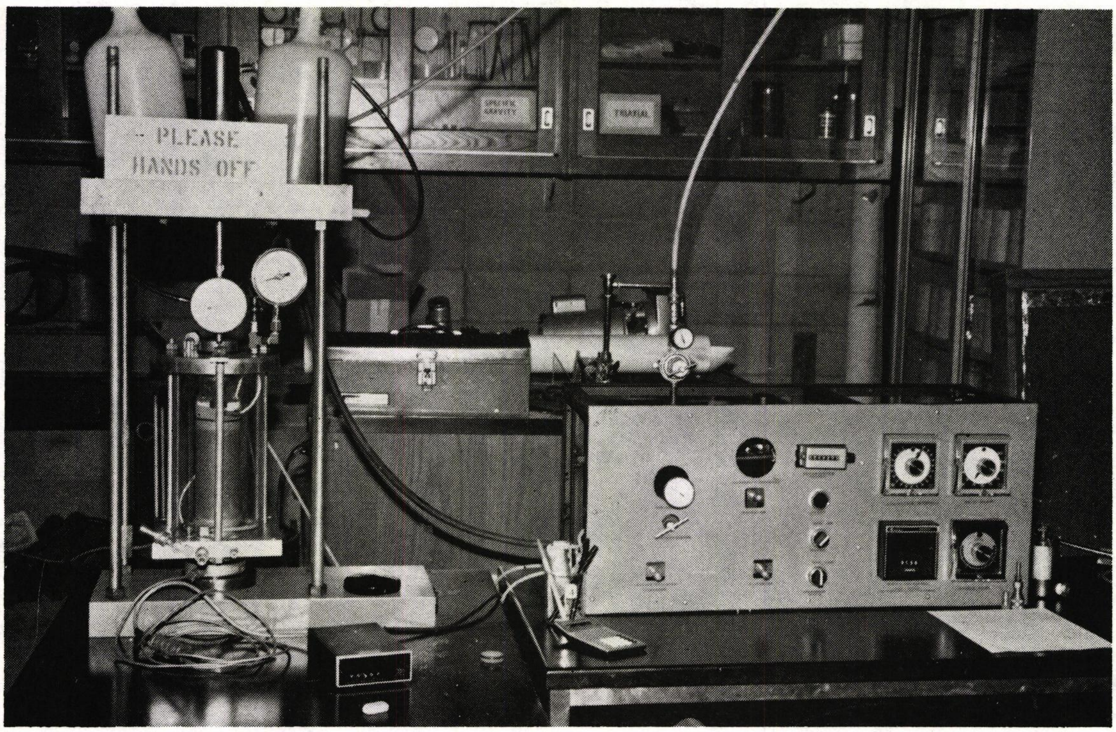


FIGURE A-1 Cyclic Triaxial Test System

A partial list of equipment part numbers and manufacturers follows:

1. Triaxial Cell - Hogentogler & Company, Triaxial Chamber, No. S7121.
2. Load Frame - Built by L. J. Petroff, See Reference 24.
3. Hydraulic Loading Cylinder - 2-inch double action cylinder - Built by Clark Hydraulics.
4. Cyclic Control Module - Built by L. J. Petroff, See Reference 24.
5. Pneumatic Compressor - Ingersoll-Rand, 5-HP.
6. Pressure Gauge - Marshall Town, Model G2306, 0.5 psi Accuracy, 0-60 psi.
7. Deflection Dial Gauge - CONBEL DIAL INDICATOR, 0.500 "Range, .0001" Accuracy.
8. Load Cell - Structural Behavior Engineering Laboratories, 500 lb. max., Low Profile Model.
9. Signal Conditioner, DAYTRONIC MODEL 3270, Conditioner/Indicator.

In spite of the design simplicity and low initial cost of the entire system (estimated at $10,000), only one full day of testing was lost during the testing period due to equipment malfunction. Many minor repairs were required and several parts were replaced; however, these were deemed routine and not excessive for a machine required to perform 12,000 load cycles each day.

In addition to the equipment for the testing system listed above, the cyclic testing program also required the use of sample preparation equipment including a vacuum source, a membrane installation/compaction mold, and a compaction hammer. The compaction mold utilized was a Soil Test Model P-48 Triaxial Compaction Mold and the compaction energy was applied with a Soil Test Model CN-415 Standard Compaction Hammer, see Figure A-2. The membranes

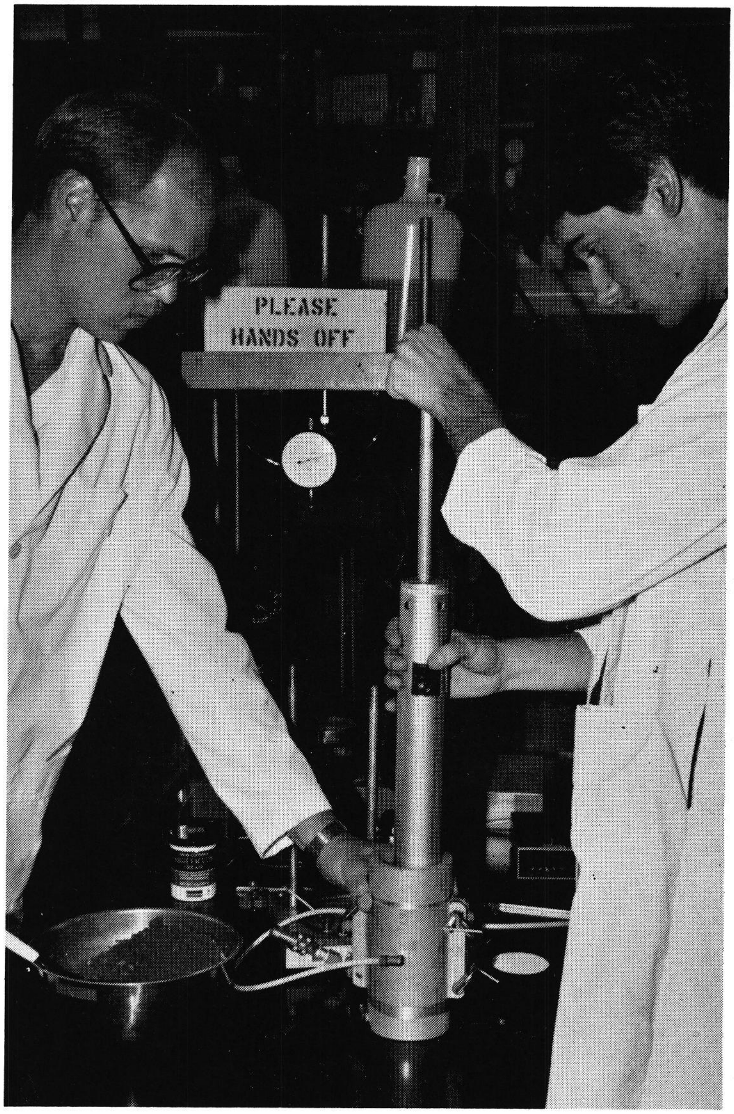


FIGURE A-2 Compaction Mold and Drop Hammer utilized were Soil Test Model T-610 or T-630 Triaxial Membranes. The vacuum source was a Dayton Speedaire Model - 42336, 1/2 H.P. Pump.

The significant advantages of the equipment utilized were the ease of operation, maintenance and reliability. The significant disadvantages were the lack of automated data acquisition equipment, excess moisture accumulation and the restricted accuracy of the dial gauge deflection system. To increase reliability and ease of operation, all pneumatic and hydraulic hoses were equipped with brass positive seal quick-disconnect fittings, see Figure A-3. Also, several micro-filters were utilized in the air lines to help reduce the accumulation of excess moisture generated by the air compressor. The problem of excess moisture accumulation persisted during the entire program especially during the hot humid summer days. It is recommended for the future that the system be equipped with a refrigerated air moisture condenser to dry the air to prevent contact of moisture with the valves and gauges. The small air filters which were utilized in the present system for this purpose were essentially unsuccessful.

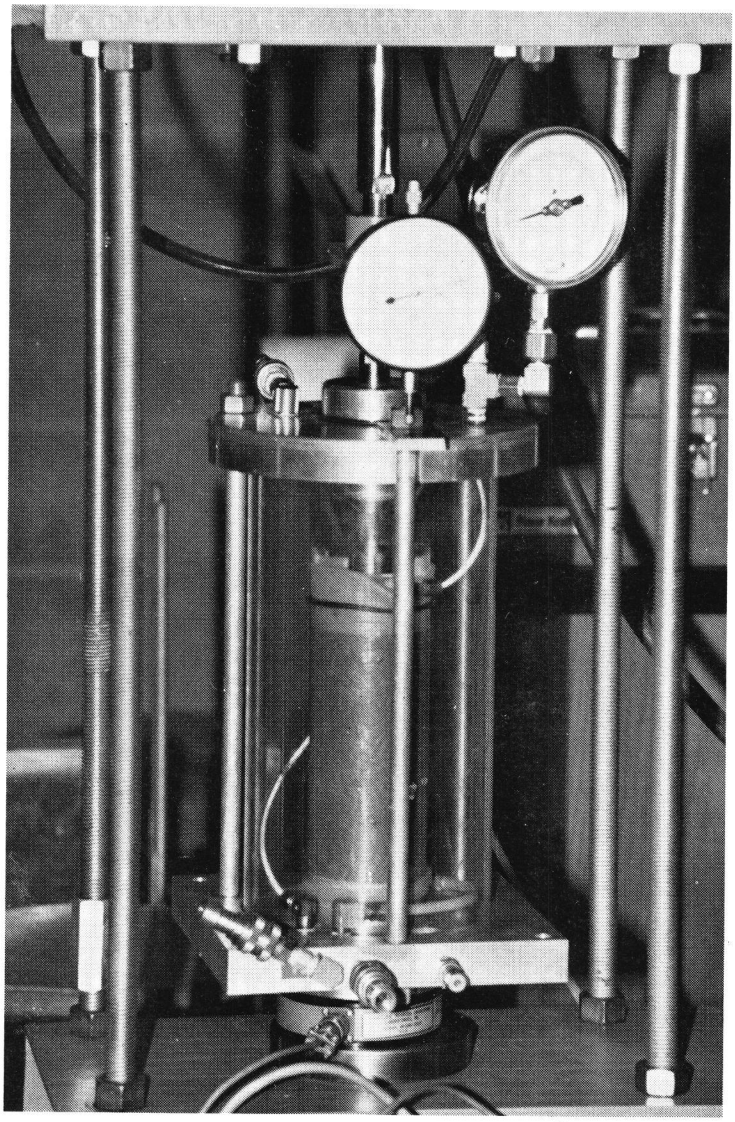


FIGURE A-3 Triaxial Cell, Gauges, Fittings and Sample

APPENDIX B

TEST INSTRUCTIONS FOR CYCLIC TRIAXIAL TESTING OF MARGINAL AGGREGATES

There are many steps required for the preparation of remolded test specimens and the completion of the resilient modulus test procedure. Some of these steps will vary according to the grain size distribution of the aggregate sample, size of the triaxial test specimen utilized and laboratory testing equipment available. The steps utilized in this test program are partially illustrated by Figures B-1 thru B-6 and completely outlined in the list of 40 steps that follows:

1. Air dry aggregate sample to be tested and break up aggregations.
2. Sieve sample to remove large stones and quarter sample to reduce size.
3. Calculate water and aggregate quantities for single sample test.
4. Weigh out dry aggregate and water for single sample test.
5. Add water to aggregate and mix sample in pan.
6. Cover and let sample stand for 30 minutes, (or overnight for swelling soils).
7. Install membrane in compaction mold (see Figure B-1).
8. Place aggregate in mold in shallow layers (see Figure B-2).
9. Compact sample in mold (see Figure B-3).
10. Measure final height of compacted sample.
11. Weigh sample in mold prior to test.
12. Install sample and mold in cell (see Figure B-4).
13. Remove compaction mold (see Figure B-5).
14. Install cell in machine and attach all connections.

15. Zero load cell signal conditioner/digital indicator.

16. Check sample membrane for air leaks.

17. Zero deflection dial guage under small pre-load.

18. Apply conditioning cycles as specified (see Figure B-6).

19. Zero deflection dial gauge under small pre-load.

20. Apply level one load cycle.

    Record needle elastic recovery reading.

    Record permanent deflection reading.

    Record pressure in cell.

    Record hydraulic pressure.

    Record load cell reading.

21. Apply level two and over load cycles.

    Repeat readings as above under level one.

22. Stop load applications when all levels have been applied.

23. Record parmanent axial deflection reading.

24. Remove sample from cell.

25. Measure height of sample.

26. Weigh sample in membrane.

27. Remove sample from membrane.

28. Place sample in oven pan, weigh and dry for 48 hours @ 105°C.

29. Remove sample from oven.

30. Weigh sample.

31. Wash sample through #200 sieve.

32. Place sample in oven to dry 24 hours @ 105°C.

33. Remove sample from oven.

34. Weigh oven dry sample.

35. Sieve sample and obtain grain size distribution.

36. Plot grain size curve.

37. Calculate moisture contents before and after test.

38. Calculate wet and dry density before and after test.

39. Calculate resilient modulus values.

40. Plot cyclic triaxial test curves.

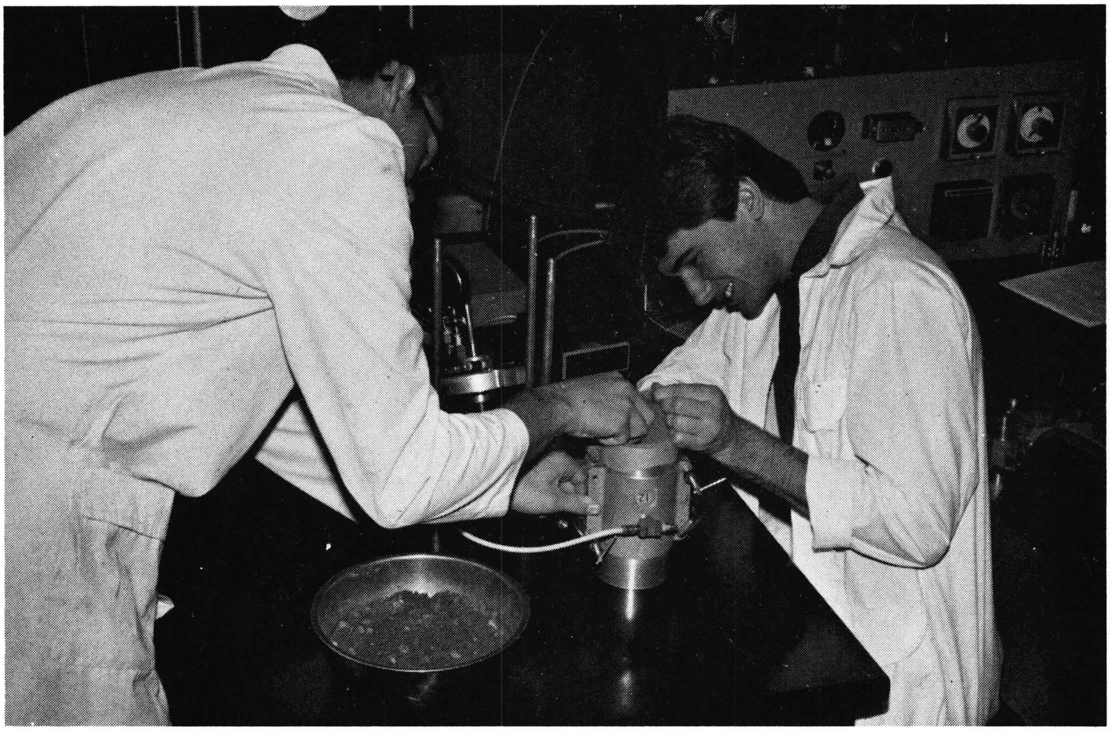


FIGURE B-1 Membrane Installation

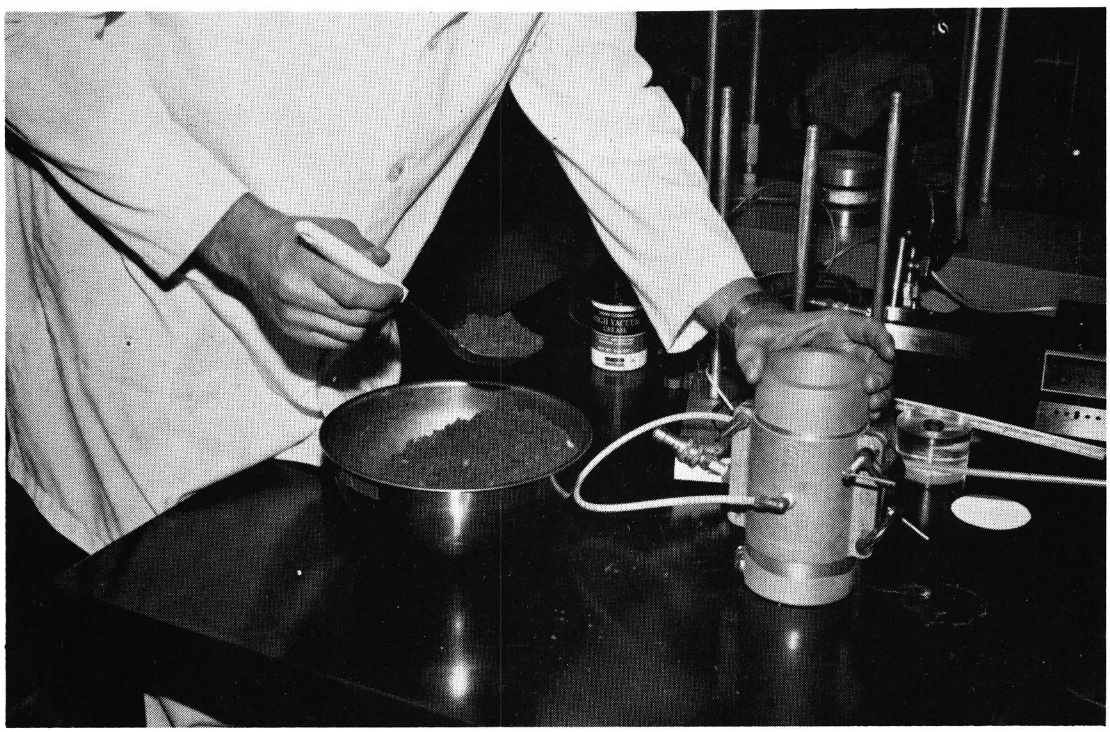


FIGURE B-2 Aggregate Placement

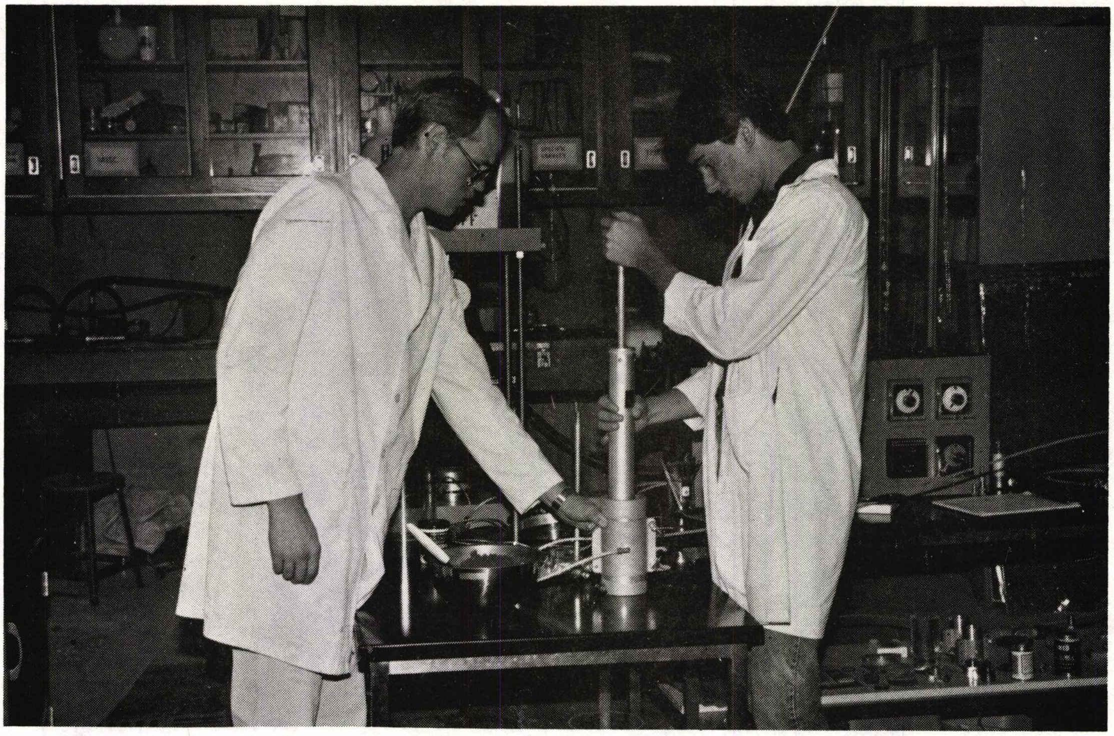


FIGURE B - 3 Sample Compaction

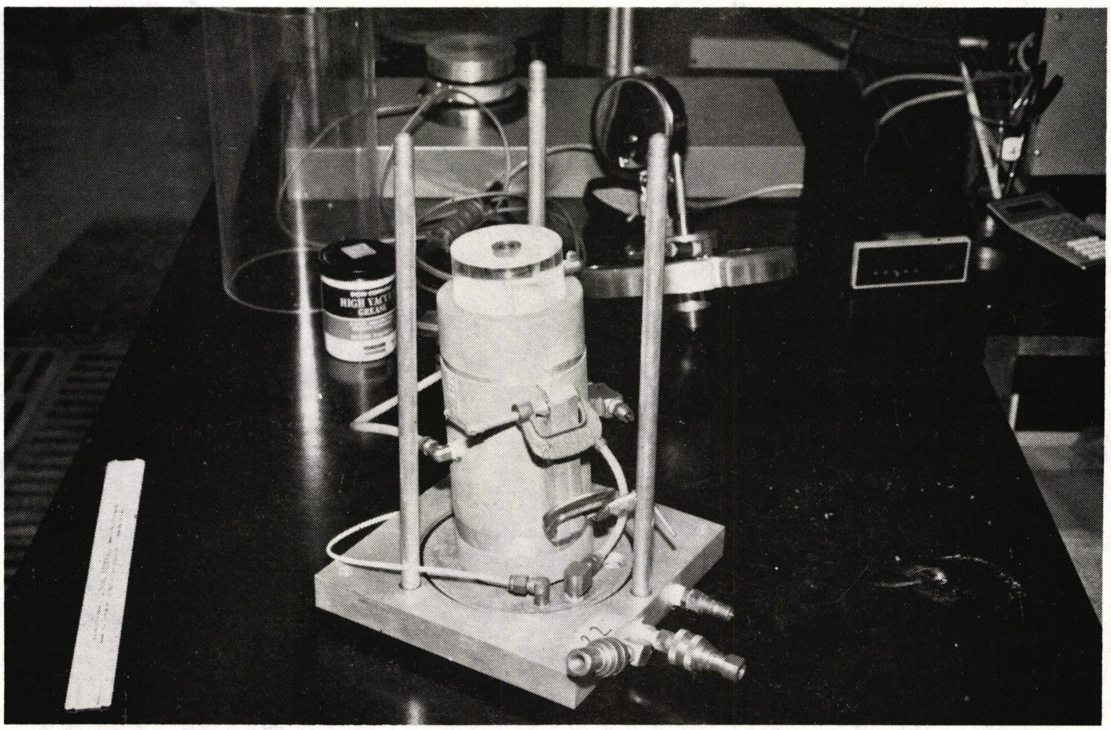


FIGURE B - 4 Sample Installation

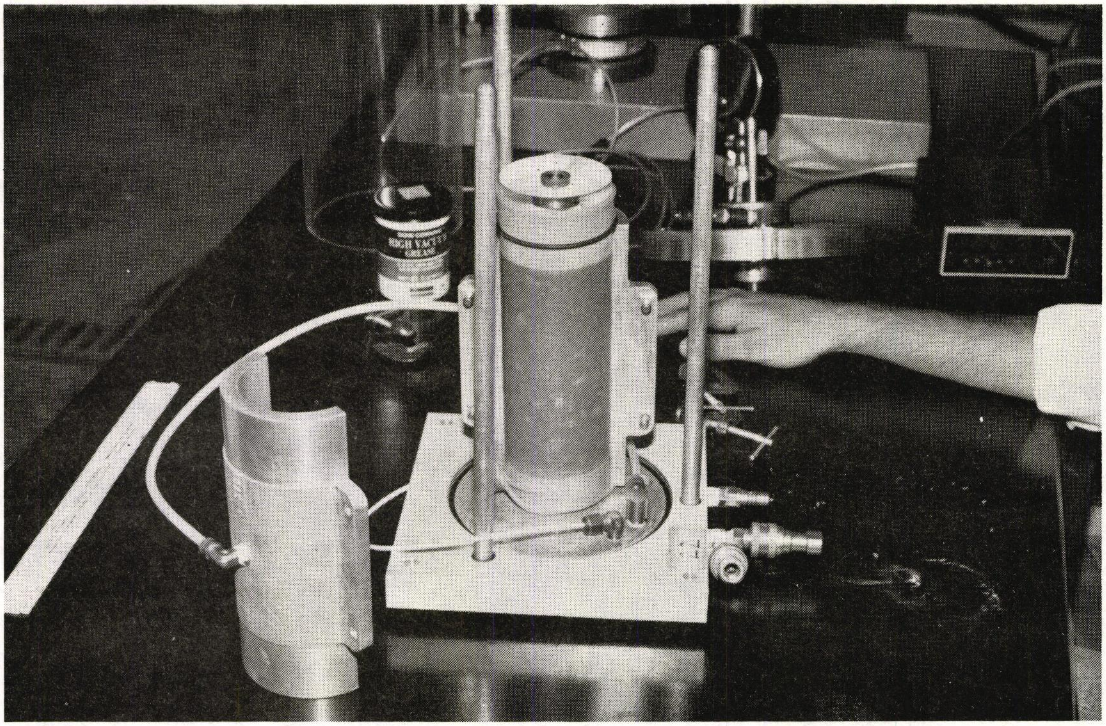


FIGURE B - 5 Mold Removal

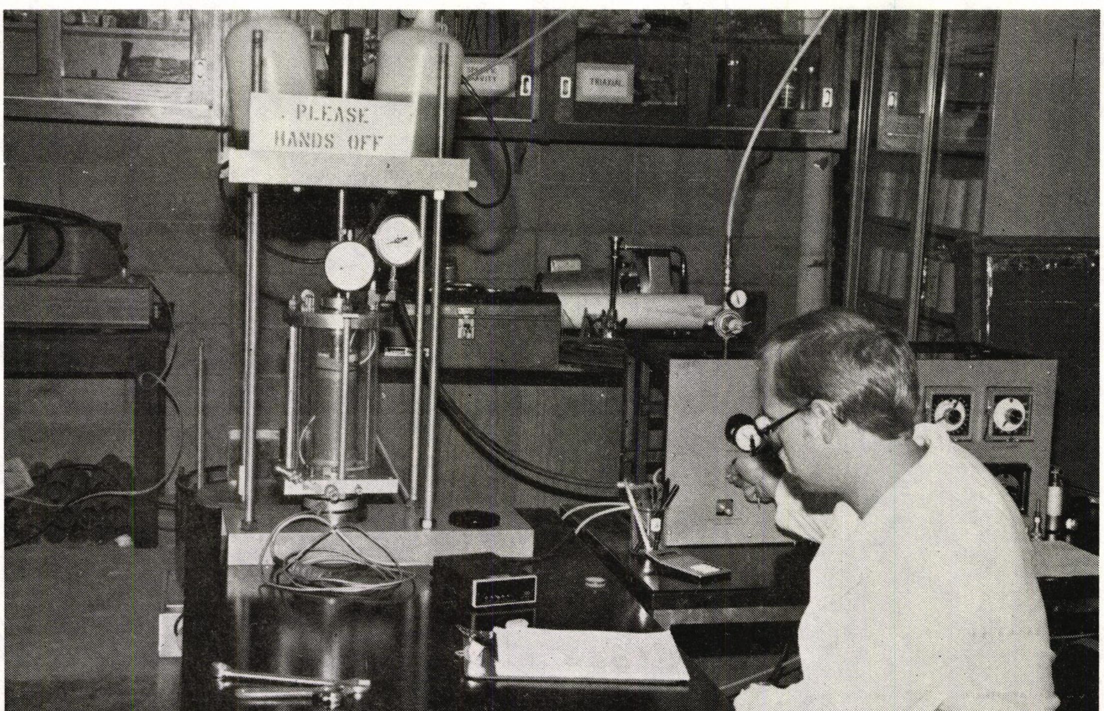


FIGURE B - 6 Cyclic Testing