PROJECT ADMINISTRATION DATA SHEET

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Sponsor: Georgia Department of Transportation

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1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:

Wouter Gulden
Georgia Dept. of Transportation
Office of Materials and Research
15 Kennedy Drive
Forest Park, GA 30050

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RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

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Date 9/23/86

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les Subproject No.(s) N/A

t Director(s) J.S. Lai GTRC / XXX

or Georgia Department of Transportation

Development of a Simplified Test Method to Predict Rutting

Characteristics of Georgia Mix Designs

ive Completion Date: 6/23/86 (Performance) 9/23/86 (Reports)

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- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [x] Closing Documents
- [x] Final Report of Inventions Sent questionnaire to P.I.
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

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Contract Research

FINAL REPORT

Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes

by

James S. Lai
Professor of Civil Engineering
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Prepared for

Department of Transportation
State of Georgia

July, 1986

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pavement rutting is the result of a channelized traffic whereby causing differential surface deformation under the regions of intensive load applications in the wheel paths. Rutting is a manifestation of densification and shear deformation. The amount of pavement rutting depends upon the following parameters:

(1) The distribution of traffic loads, particularly the transverse distribution of traffic loads;

(2) The stress induced in the pavement system, which depends on the response characteristics of the layer materials;

(3) The permanent strains induced as the result of the stresses developed in the pavement system. These permanent strains depend on the permanent deformation characteristics of the layer materials, particularly the asphalt concrete layer. Rutting of a pavement system can be due to inadequacy of the pavement system under the prevailing traffic and environmental conditions and/or due to improper asphalt mix characteristics.

Rutting reduces road serviceability and driving comfort and also the problem of hydroplaning and icing that result from accumulated water in rutting paths reduces highway safety.

Although the mechanism of rutting under repeated traffic loading is relatively well-known from various field and laboratory investigations [1-25], satisfactory means for rut depth prediction have not yet been developed. The current available methods for analyzing the pavement system responses and predicting pavement rutting such as [6,7,8] have the capability and potential of predicting pavement rutting, although the adaption of these methods has been quite reluctant by the industry. The main reasons are the difficulty of obtaining the required material properties and other system input parameters and the accuracy of the predictions.

Regarding the properties of asphalt mixes, although asphalt mixes obtained according to Marshall mix design criteria can eliminate extremely unstable mixes, there is no assurance that an asphalt mix with its properties satisfying Marshall mix criteria will not rut under normal traffic conditions. Many testing methods have been proposed in an attempt to improve the predictability of rutting tendancy of asphalt mixes. These include the triaxial repeated load test and the creep test [1-5]. These tests are usually elaborate in terms of apparatus, test procedure and data analysis and interpretations. In some instances use of such elaborate tests to determine the permanent deformation or rutting characteristics of asphalt mixes is needed. One such need is in the development and implementation of the mechanistic based flexible pavement design method such as the VESYS system [6-7] where such material properties are needed. On the other hand, there is a greater need for developing a simplified laboratory test to be used as a supplement to the Marshall method for the mix design so that asphalt mixes with better rutting resistance can be obtained in a routine laboratory mix design.

1.2 Objectives

The objective of this study is to develop a simplified test method to be used as a supplement to the Marshall method to assesspredict the rutting tendency of asphalt mixes. This stated objective implies that the method to be developed should, to the extent possible, be able to accurately assess the rutting potential of asphalt mixes in the field, the apparatus and the testing procedure should be relatively simple and the sample and its preparations should be compatible with that of the Marshall method.

The following are the specific objectives of this proposed study:

(1) Develop a simplified rut prediction test apparatus.

(2) Evaluate the rut prediction capability of the apparatus from the test results.

(3) Compare the results obtained from the test with that from the creep tests and the repeated load triaxial tests on rut prediction capability.

1.3 Outline of the Report

Chapter 2 of this report presents a brief review of the use of loaded wheel testing machines in evaluating permament deformation characteristics of asphalt mixes and other related materials. A summary of the study program proposed for this study is presented in Chapter 3 with the details regarding the development of the testing apparatus, types of asphalt mixes used in this study and the sample preparation and the test results presented in Chapter 4, 5, 6, and 7 respectively. Analyses and discussions of the test results are presented in Chapter 8 and conclusions and recommendations are presented in Chapter 9. The additional pertinent results and data obtained in the course of this study are included in Appendix A, B, C, and D.

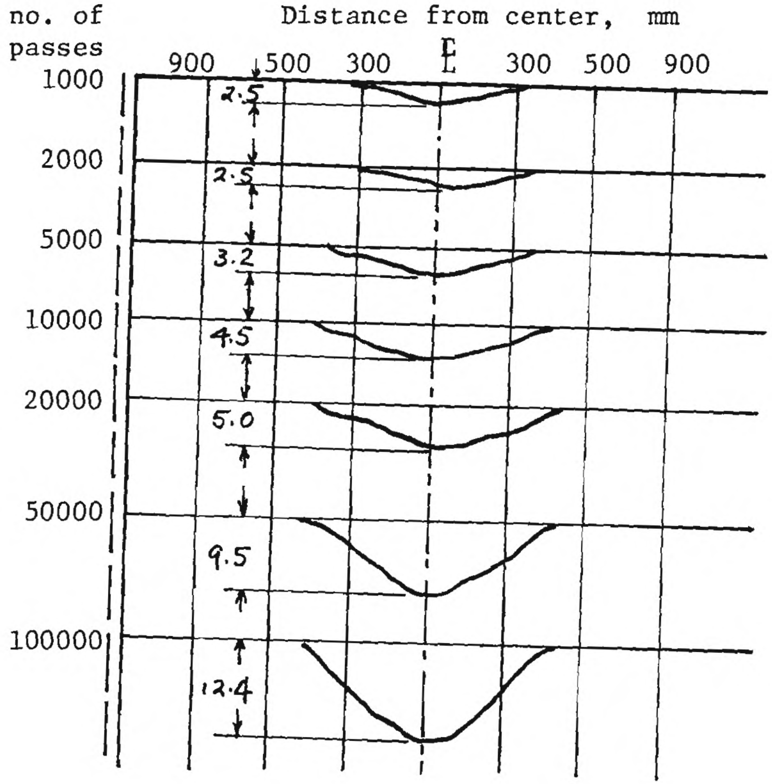
CHAPTER 2

REVIEW OF LOADED WHEEL APPARATUS FOR RUT PREDICTION

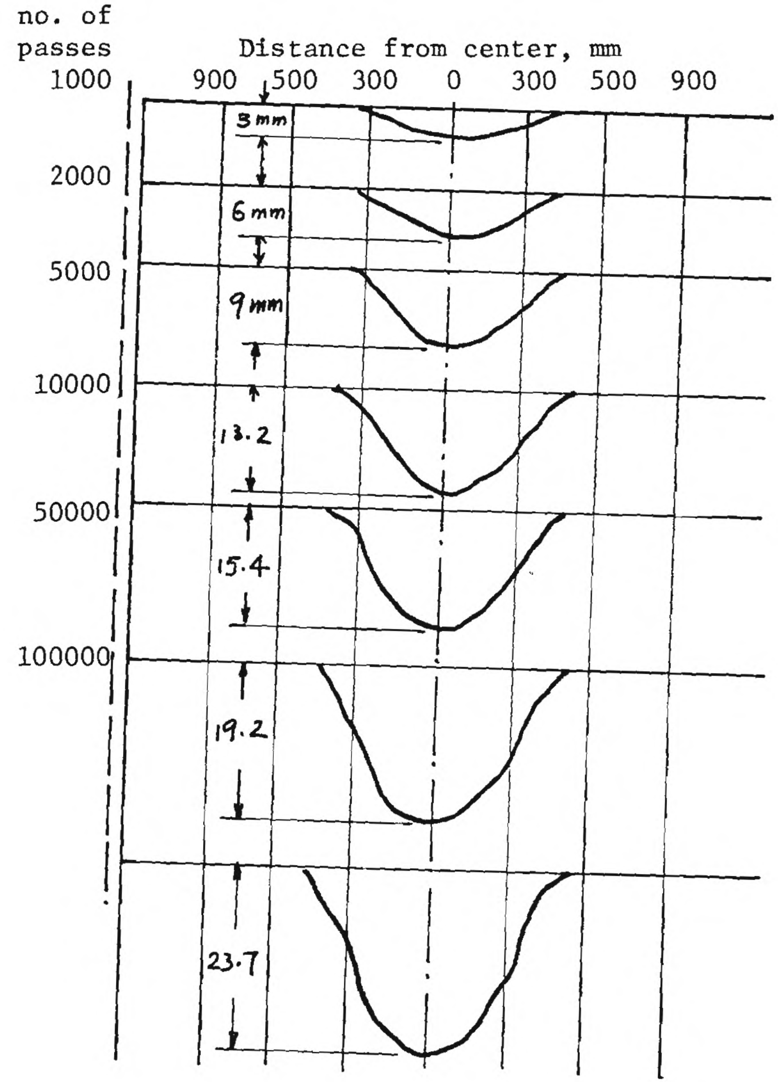
Many studies on the use of loaded wheel apparatus to evaluate permanent deformation in asphalt concrete have been carried out in the past. By subjecting asphalt concrete to a loaded wheel system under repetitive loading conditions and measuring the permanent deformation induced under the wheel path, the rutting potential of the asphalt concrete to be used in the fielf can be estimated. This approach to assessing rutting potential could be quite accurate, if the laboratory testing can closely simulate the field conditions. In view of the complexity of the material behavior and the state of stresses induced under traffic loading, which may prevent the theoretical and mechanistic based methods from obtaining accurate assessment of rutting of asphalt concrete, the use of loaded-wheel type testing may provide a fast and more accurate estimation of rutting of asphalt concrete.

Brown and Bell [26] developed a loaded wheel testing machine and used the machine to carry out two different experiments, multi-track test and single track test. For each of these tests, two asphalt concrete pavements of different degrees of compaction were used. The results of the multi-track test are shown in Figure 1. The authors report that the rut depth of Pavement 2 was twice that of Pavement 1 because of poor compaction in Pavement 2. Figure 2 shows the rut depths against number of wheel passes for both the pavements and the tests. For Pavement 1, the authors observed a favorable comparison between the two tests. As for the poorly compacted Pavement 2, rutting on the single track was found to develop much more rapidly.

Sugawara [27] employed the wheel-tracking test originally developed by the British Road Research Laboratory, to measure the resistance of asphalt

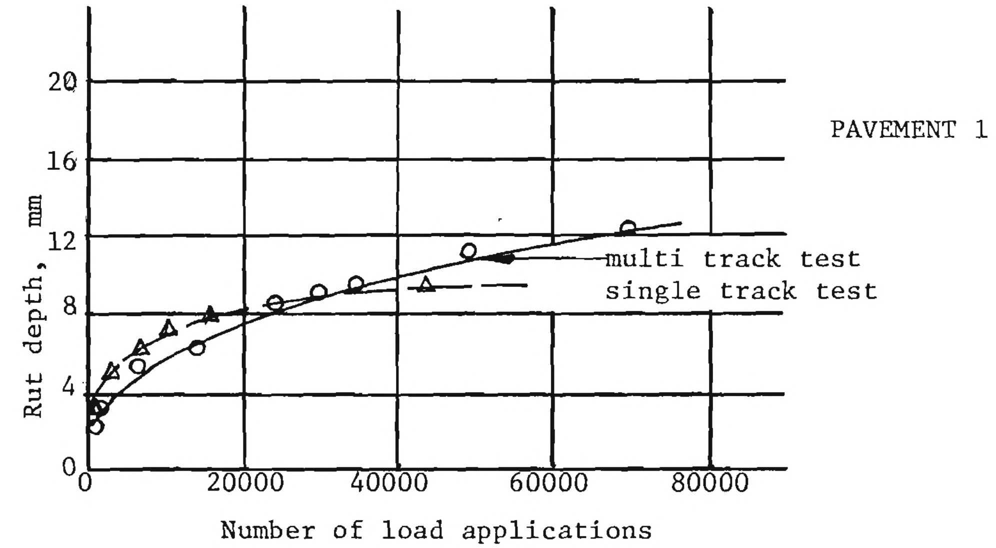


Pavement 1



Pavement 2

Figure 1. Rutting Profile of Pavements Under Repeated Wheel Load [26].



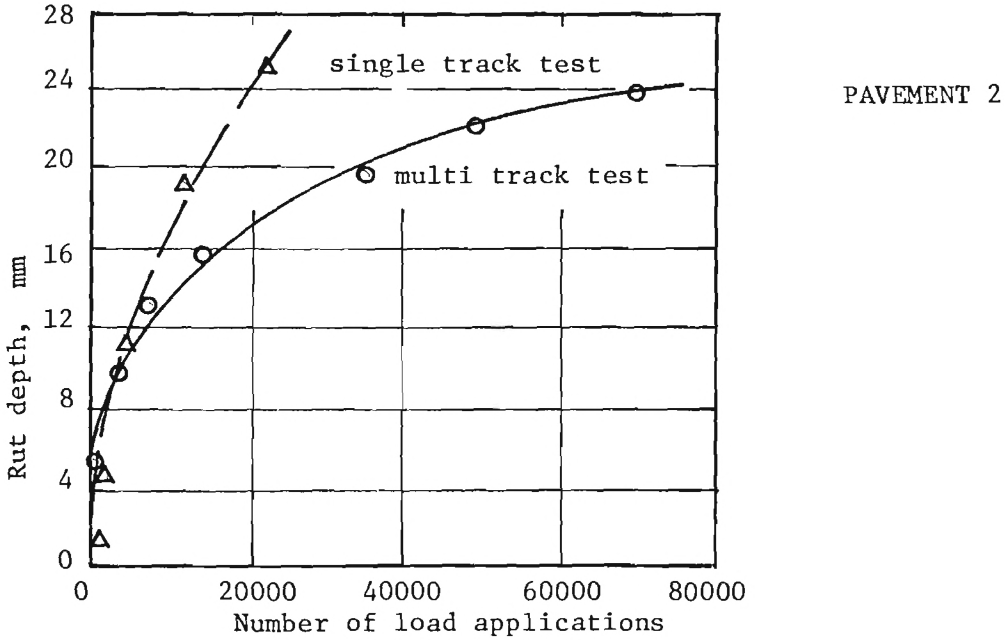


Figure 2. Rut depths against number of wheel passes [11]

concrete to permanent deformation. The variables in his test program included frequency of loading, magnitude of wheel load, the contact pressure, test temperature and mixture types. Figure 3 shows the relation between the Marshall stability and the rate of rutting for asphalt mixes having different asphalt contents.

The loaded moving wheel testing devices used by Livneh and Greenstein [28], by Shklarsky and Livneh [29] and by Uzan [30] are quite similar to the one used in this study. Livneh and Greenstein [28] used the device to determine the influence of aggregate on the rutting of asphalt mixtures. The results obtained for different mixtures are shown in Figure 4. Shklavsky and Livneh [29] used the device to study the use of gravel as aggregates in asphalt mixture for light and heavy traffic. A comparison made between Marshall stability and the degree of rutting obtained after 3,000 cycles using the moving wheel device is shown in Figure 5.

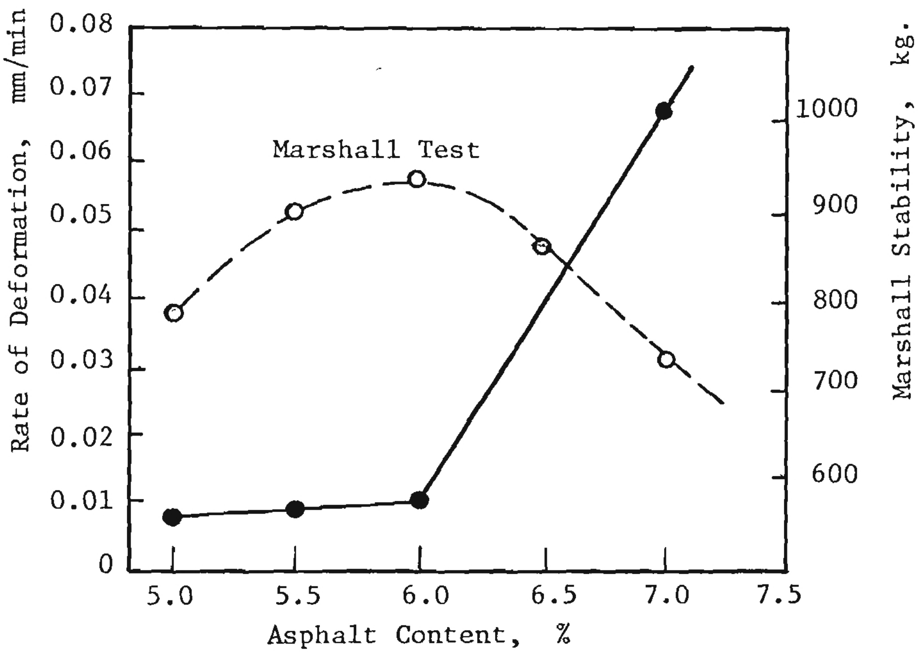


Figure 3. Marshall Stability and Rate of Deformation [27]

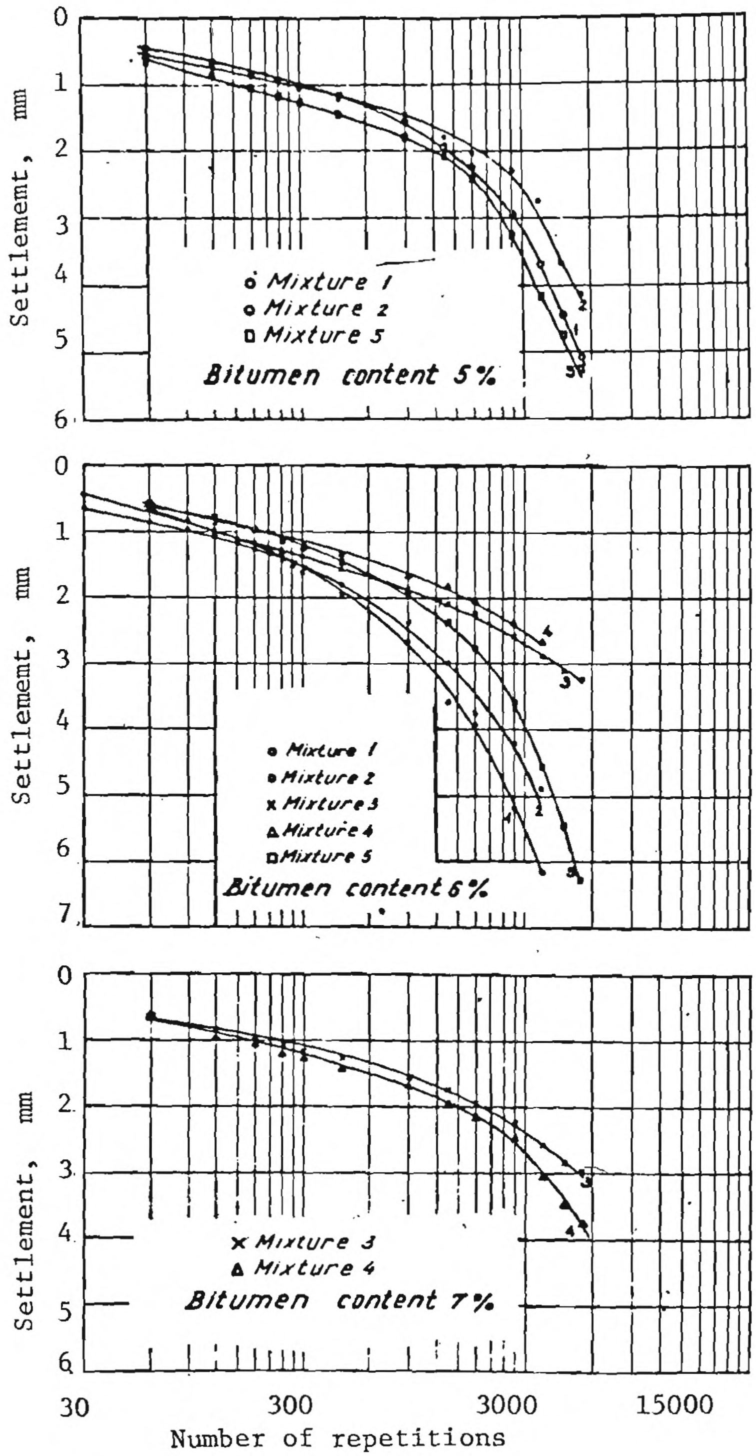


Figure 4. Rutting Test Results [28]

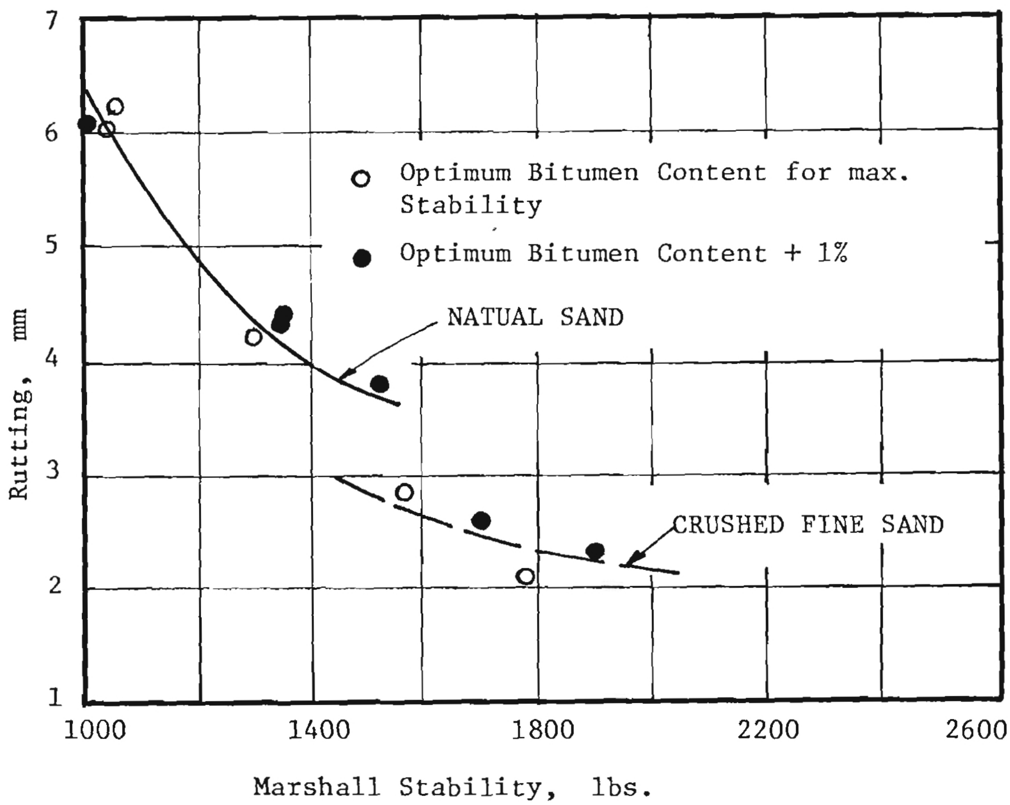


Figure 5. Relation Between Stability and Degree of Rutting [29]

CHAPTER 3

DESCRIPTION OF THE TEST PROGRAM

3.1 Objective

The overall objective of this research was to study the feasibility of developing a simplified test method to predict rutting characteristics of asphalt mixes. The works performed in this study to accomplish the stated objective included:

(1) Development of a Simplified Rut Predicting Apparatus

(2) Prepare asphalt concrete samples with different mixture types.

(3) Test the samples for rutting characteristics using the apparatus developed and from the creep tests and the repetitive triaxial tests.

(4) Evaluation of the results and recommendation of implementation plans.

Each of these activities are described briefly in the following sections in this chapter. The detailed information of the activities for each phase are presented in the subsequent chapters.

3.2 Development of a Simplified Rut Prediction Apparatus

Dueing the preparation of the proposal for this study, it was known that GaDOT Materials Testing Laboratory had a loaded wheel tester (LWT). This machine was similar to those used by Livnch and Greenstein [28] and Uzan [29] as described in Chapter 2. The machine at GaDOT Laboratory was developed by C. R. Benedict of Benedict Slurry Seals, Inc. and was origionally used by GaDOT Materials Testing Laboratory for design and testing of slurry seals. A preliminary examination of the machine indicated that with certain modifications the machine could be used for this study.

To enhance the rut predicting capability of the loaded wheel tester, certain modifications stated below are required:

(1) A simple and effective means has to be devised for heating and maintaining a constant temperature (90-130°F) in the asphalt concrete specimens throughout the test period.

(2) The loading mechanism has to be modified. The hard rubber loading wheel should be replaced with a wheel to which pressure ranging from 70 psi to 120 psi can be applied and controlled.

(3) Suitable means have to be developed for holding the 3" x 3" x 15" beam samples.

(4) An easy and accurate means to measure the rutting profile of the specimens.

The modifications proposed in this study were intended to produce a working machine which could be used to assess the feasibility of the concept of using a simplified apparatus to achieve easy and yet accurate predictions of rutting tendency of asphalt mixes.

3.3 Sample Preparation

To provide a preliminary assessment of the rut predicting capability of the modified LWT, four types of asphalt concrete mixtures were chosen. These mixtures had been used by the GaDOT in four separated pavement projects and had shown varying degrees of rutting. With the assistance of GaDOT Materials Testing Laboratory the aggregates and the asphalts from the origional sources were obtained. For each mix the same gradation of the aggregates was used and standard Marshall mix design was performed. The results of the Marshall design for each mix were compared with the known Marshall mix design results provided by GaDOT. Each mix formula based on the Marshall mix design results was then used to fabricate six 3" x 3" x 15" beam specimens and six 4" dia. x 8" high cylindrical samples. The procedures for preparing the beam and cylindrical samples were described in Chapter 5. To minimize the possible effect of curing all these samples were stored for at least two weeks before being tested.

3.4 Testing the Samples with the Modified Loaded Wheel Tester

Since the primary aim of this research was to evaluate the modified LWT's capability in predicting rutting tendencies of asphalt mixes, the testing was concentrated on only a few variables that were thought to be significant to potential rut development. The following testing conditions were used:

(1) Tire Pressure: 75 psi and 100 psi

(2) Temperature: 95°F. This temperature level has been shown to be critical for rut development [5]

(3) Load: 50 lbs., 75 lbs., and 100 lbs.

During the test, rutting profiles of the beam samples were measured at predetermined number of repetitions, such as at 0, 40, 100, 400, 1000 and 4000 cycles. The test was terminated when the maximum rutting reached a certain magnitude. Results from the tests were then used to determine if the modified LWT is capable of predicting the rutting potential of asphalt mixtures.

The creep test and the repeated load triaxial test have been shown to be capable of assessing the rutting potential of asphalt mixtures [1-5]. The results of these tests could be used to predict the rutting of asphalt pavements [6,7].

These tests were performed in this study so that a qualitative comparison could be made between the results obtained from the use of the modified loaded wheel tester and the results of these two tests. Such a comparison would be useful for assessing the potential of the modified loaded wheel tester as a simplified rut predicting apparatus.

For these two tests, the cylindrical specimens were used. The test variables were as follows:

(1) For the creep test, the applied constant vertical stress was 15 psi, which had been found to produce good results [5]. The duration of the loading was up to 10,000 seconds.

(2) For the repeated load triaxial test, the confining pressure was 5 psi and the deviator stress was 25 psi which were used by Barksdale [5] and found to give good results.

Both sets of tests were conducted at a constant temperature of 95°F. This is the average temperature at which rutting in Georgia has been found to occur [5].

CHAPTER 4

DEVELOPMENT OF A SIMPLIFIED RUT PREDICTION MACHINE (Modified Loaded Wheel Tester)

Since the objective of this study was to explore the feasibility of using a simplified testing machine to predict rutting potential of asphalt mixes, the purpose of this study was not intended to develop a refined testing machine, but to come up with a working machine which could be used to perform the testing in order to assess the concept of the intended objective. Therefore, many of the modifications made on the machine itself and the test procedures to be presented in the following should be viewed as such. Through this study, if the concept is proven to be feasible, then an improved version of the test machine can be developed in the future and a more rigorous implementation test program can be pursued.

4.1 Description of the Loaded Wheel Tester

The LWT was originally used by the GaDOT Materials Testing Laboratory for design and testing of slurry seals. A similar machine has been used elsewhere to evaluate the rutting potential of asphalt concrete [28,30]. This machine is quite simple and easy to use.

The machine, shown in Figures 6 and 7, consists of a 1 in. wide by 3 in. diameter number 180 basic soft rubber castel wheel mounted on a unitrust P-1000 framing. The dimensions are about 43" long by 14" wide by 16" high. A box to hole lead shot is mounted atop the wheel arms for loading the wheel. The loaded wheel is driven through a 12" reciprocating stroke by a .25 hp, 1750 rpm motor which is reduced 40:1 to give 44 cycles per minute or 1000 cycles in 24 minutes. Figure 7 shows the main components of the original LWT machine.

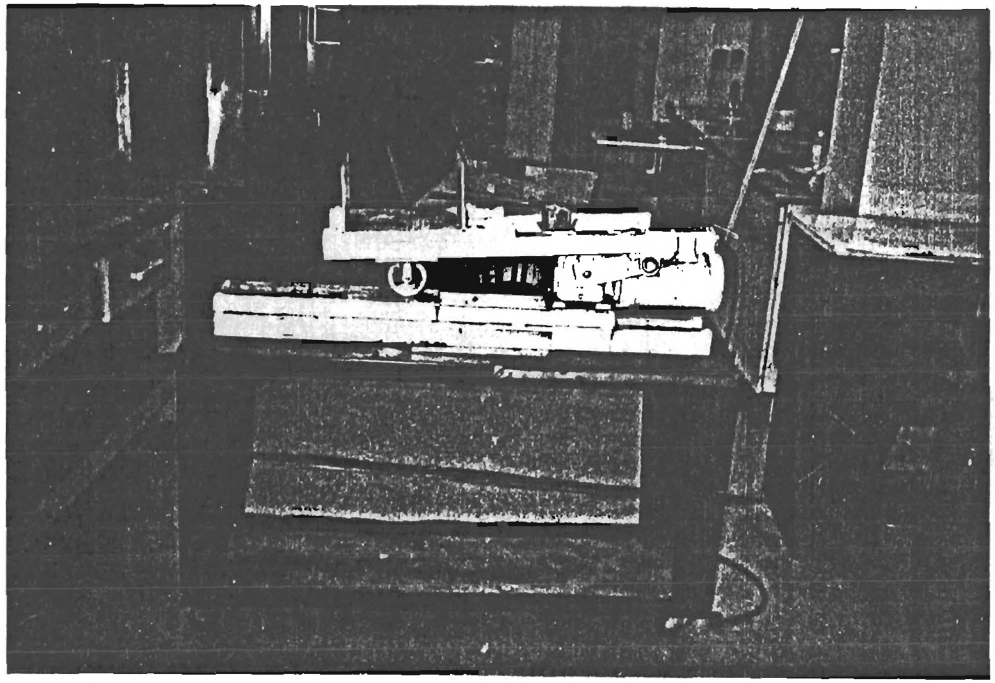
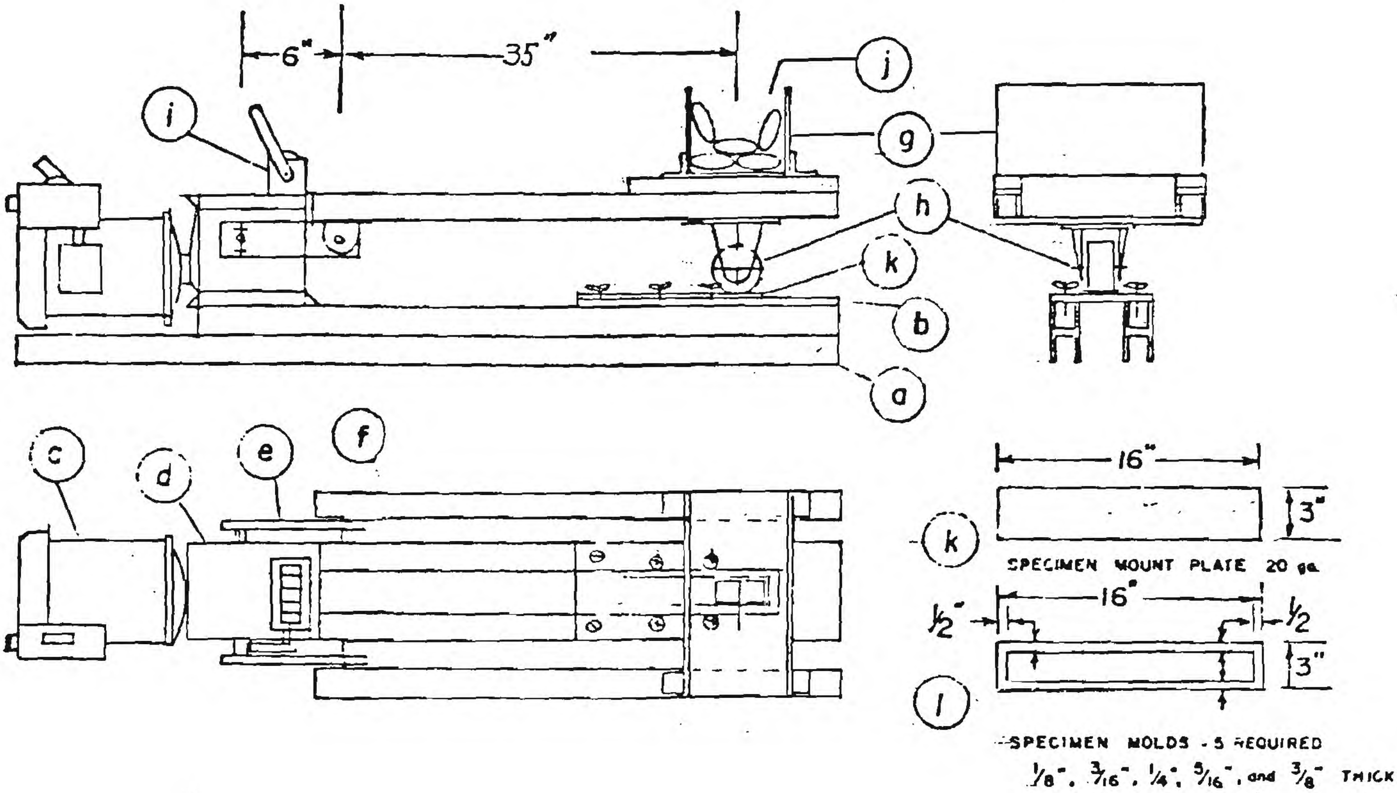


FIGURE 6. LOADED WHEEL TESTER(ORIGINAL MACHINE)



Description of Main Components

a. Frame of adjustable steel channel
b. Mounting plate for specimens
c. 1/3 HP, 1750 RPM flanged motor
d. 40 : 1 horizontal double output shaft gear reducer
e. Drive cranks, 6-inch radius
f. Driven connecting arms of adjustable, steel channel
g. Weight box, centrally adjustable over the wheel
h. Bassick #180 caster assembly with 3" diameter x 1" rubber tire mounted at a horizontal distance of 24" between drive and caster axles. (Other wheels may be used)
i. Resetable revolution counter
j. 5 - 25 pound bags of #7 or #8 lead shot
k. Specimen mounting plates, 20 ga. galvanized steel x 3" x 16" deburred
l. Specimen molds, variously .125, .188, .250, .313 and .375 inches thick. x 3" x 16" outside and 2" x 15" inside dimensions
m. Steel strike-off bar, .250" x .50" x 6.0" long
n. Steel sand frame, .188" x 2.5" x 15 " outside and 1.5" x 14" inside dimensions, completely lined on one side with 1/2" x 1/2" adhesive-backed foam rubber insulation.
o. Flat, platform scale, 250 pound capacity, sensitive to one pound

Figure 7. Loaded Wheel Tester (origional machine)

4.2 Modifications Made to the Loaded Wheel Tester

To enhance the rut predicting capability, the following modifications were made to the original LWT machine:

A. Loading Mechanisms:

The original 3 in. diameter hard rubber tire on aluminum wheel was considered to be inadequate because it cannot control the pressure. Originally it was throught that a suitable small tire of about 1 in. wide by up to 10 in. diameter with tire pressure inflatable up to 120 psi were commercially available. After a considerable effort was made in search for such tires, it became apparent that such tires were not available commercially, although a tire of these specifications could be custom made according to Goodyear Tire Company, at a considerable cost and time. For this study this was not a viable choice. It was decided then to develop a loading wheel with the abovementioned characteristics in the laboratory.

The first version consisted of a 8 in. diameter aluminum wheel with a 1 in. diameter high pressure rubber hose wrapped around the perimeter of the wheel. The hose can be pressurized to a controllable pressure up to 120 psi. This wheel assembly was tried on the machine and several trial runs were conducted. The testing was performed without much problem except that the reciprocating action caused the wheel to generate excessive skidding near the ends of the stroke which causes excessive wear of the rubber hose and excessive rutting on the asphalt concrete samples at these points. For these reasons, this version of the wheel assembly was abandoned.

The second version consisted of a linear tube, made of the same high pressure rubber hose, and a 3 in. diameter aluminum wheel. The rubber hose was placed stationary on top of the asphalt concrete specimen and with the hose pressurized to the desirable pressure by air pressure and a pressure regulator. The aluminum wheel was attached to the reciprocating arm of the machine. During testing the aluminum wheel was riding along the linear tube which at the point of contact generated the desirable contact pressure. Figures 8, 9 and 10 illustrate the assembly. The tube was held in position on both ends by end clamps. The end clamps prevented the horizontal movement of the linear tube while creating no vertical restriction.

The linear tube assembly was adopted for this study for the following reasons:

(1) The excessive deformation on both ends of the asphalt concrete sample was substantially reduced

(2) Less wear of the tube

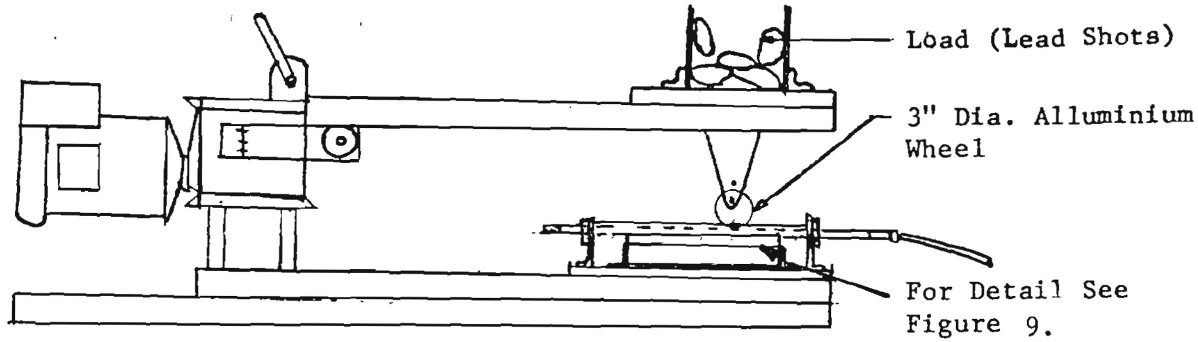
(3) Tube could be easily replaced

Undoubtedly further improvements could be made on this version of the assembly or other versions of "wheel" systems could be developed. For the purpose of this study, it was considered that the linear tube system was acceptable.

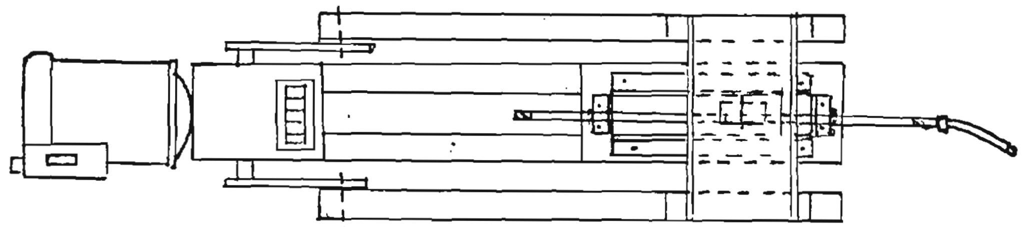
B. Sample Size and Holding Device

The machine was modified to accommodate 3" x 3" x 15" beam. The original 3" x 16" specimen mounting platen was replaced with a .25 in. thick, 12" wide by 27" long aluminum base plate. The sample holding device (shown in Figures 8 and 9) was fabricated with 3" x 3" angle plates. A 3" x 15" mild steel plate was placed below the sample to simulate a rigid base condition. This steel plate could be replaced with an equal thickness of a resilient material such as rubber to simulate a flexible base. When the asphalt concrete sample was placed in position it would protrude at about .5" above the holding device.

An asphalt concrete in a pavement surface is partically constrained laterally when subjected to a wheel load. Under the action of tire pressure



Side View



Plan

Figure 8. Modified Loaded Wheel Tester

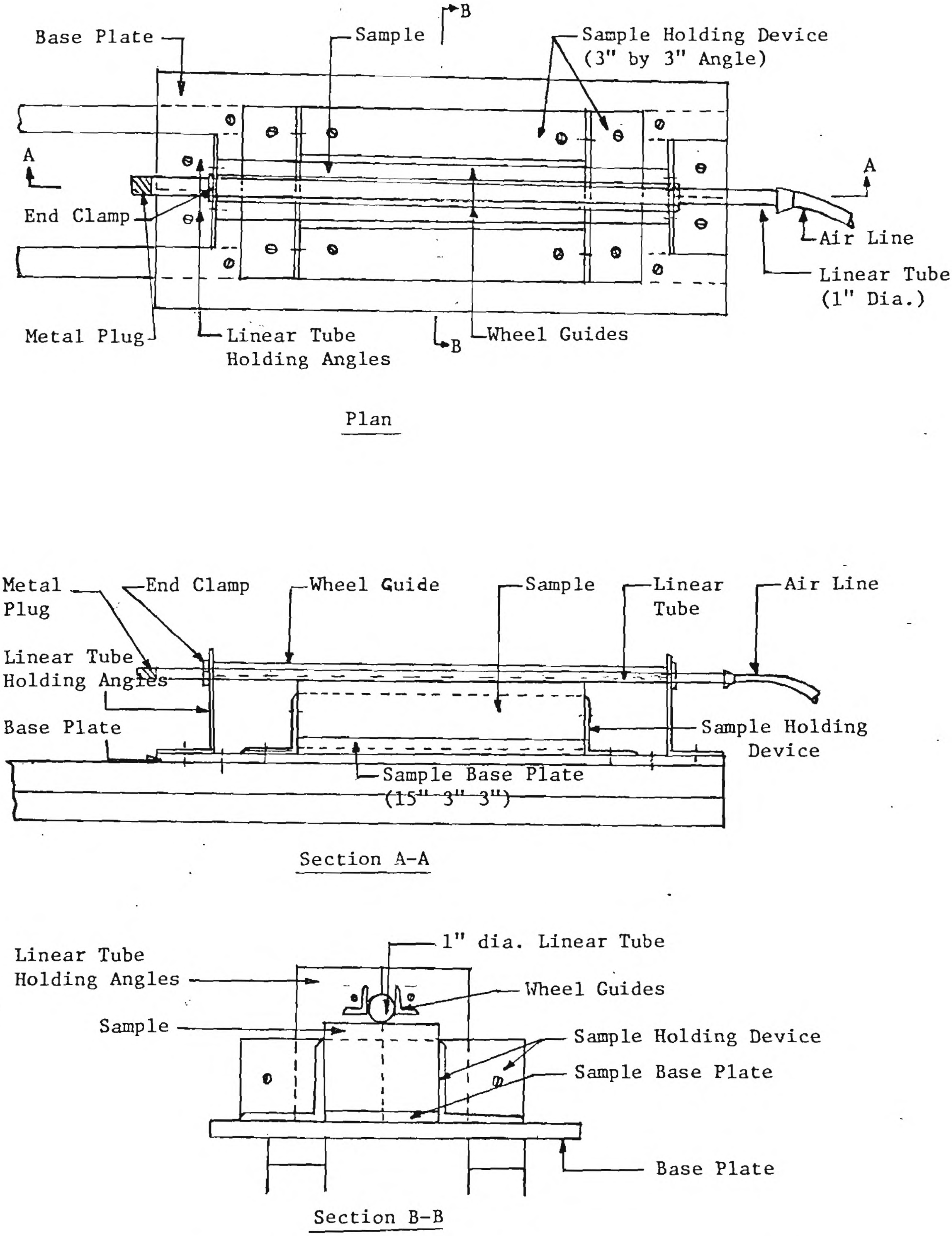


Figure 9. Sample Holding Device and Linear Tube Mechanism

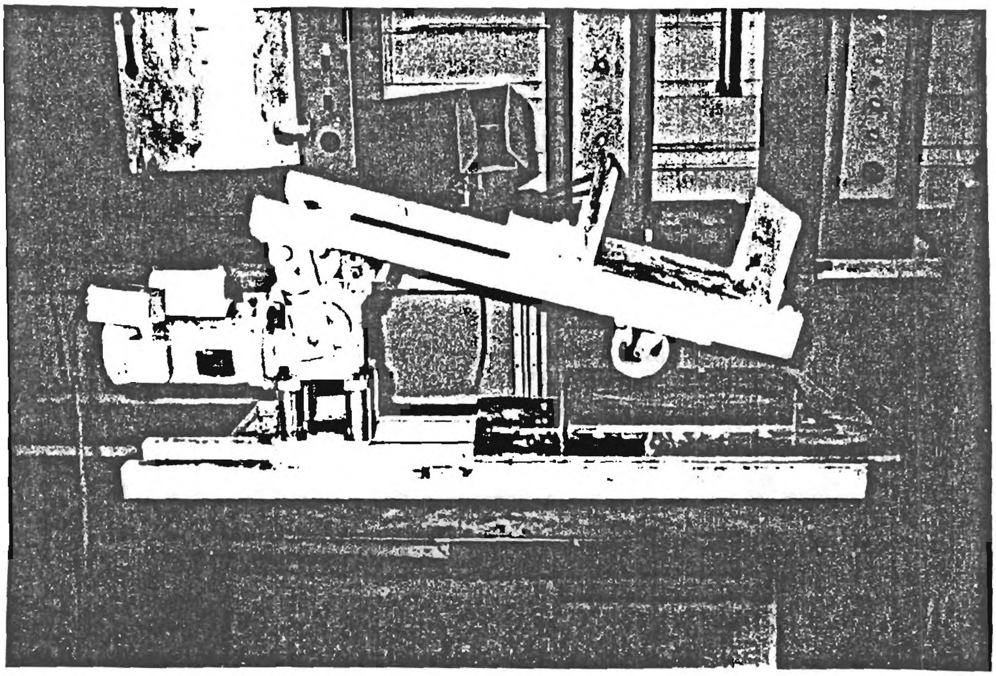


Figure 10. Modified Loaded Wheel Tester
(shown without linear tube)

asphalt concrete under the wheel will deform downward as well as laterally, with the lateral deformation restrained elastically and/or plastically by the surrounding asphalt concrete. To simulate this effect in a laboratory test, specimens should be sufficiently wide (about 6 time or greater to the width of the contact area). For the limited width of the sample used in this study, to leave the specimen totally unrestrained on the sides or totally restrained by the rigid holding device would produce the boundary conditions so much different from the actual conditions experienced in the field that the results of the laboratory testing may not represent the actual behavior of the asphalt concrete in the field. It was this concern that a portion of asphalt concrete sample protrude above the holding device as illustrated in Figure 9 was thought to be necessary although the amount of 0.5 in. used in this study was determined somewhat arbitrary.

C. Rut Profile Measuring Device

Figure 11 shows the channel section developed for the measurement of rut profile. The channel section has seven slots marked A-G, having equidistance of 2" from each other. Each slot is 3" long and 1/4 " wide. Lines were marked on the top surface of the channel section at 1/4" center to center so that cross profile readings could be taken. When the channel section was placed above the beam, slots A and B would be at a distance 1.5" from each end of the beam.

A 0.001 in. dial gauge was used to record the measurements along the slots. When measuring the surface profile, the channel was placed on top of the sample holding device which served as the common reference plane and the deformation readings were taken by the dial gage by positioning the gage at various positions in the slots.

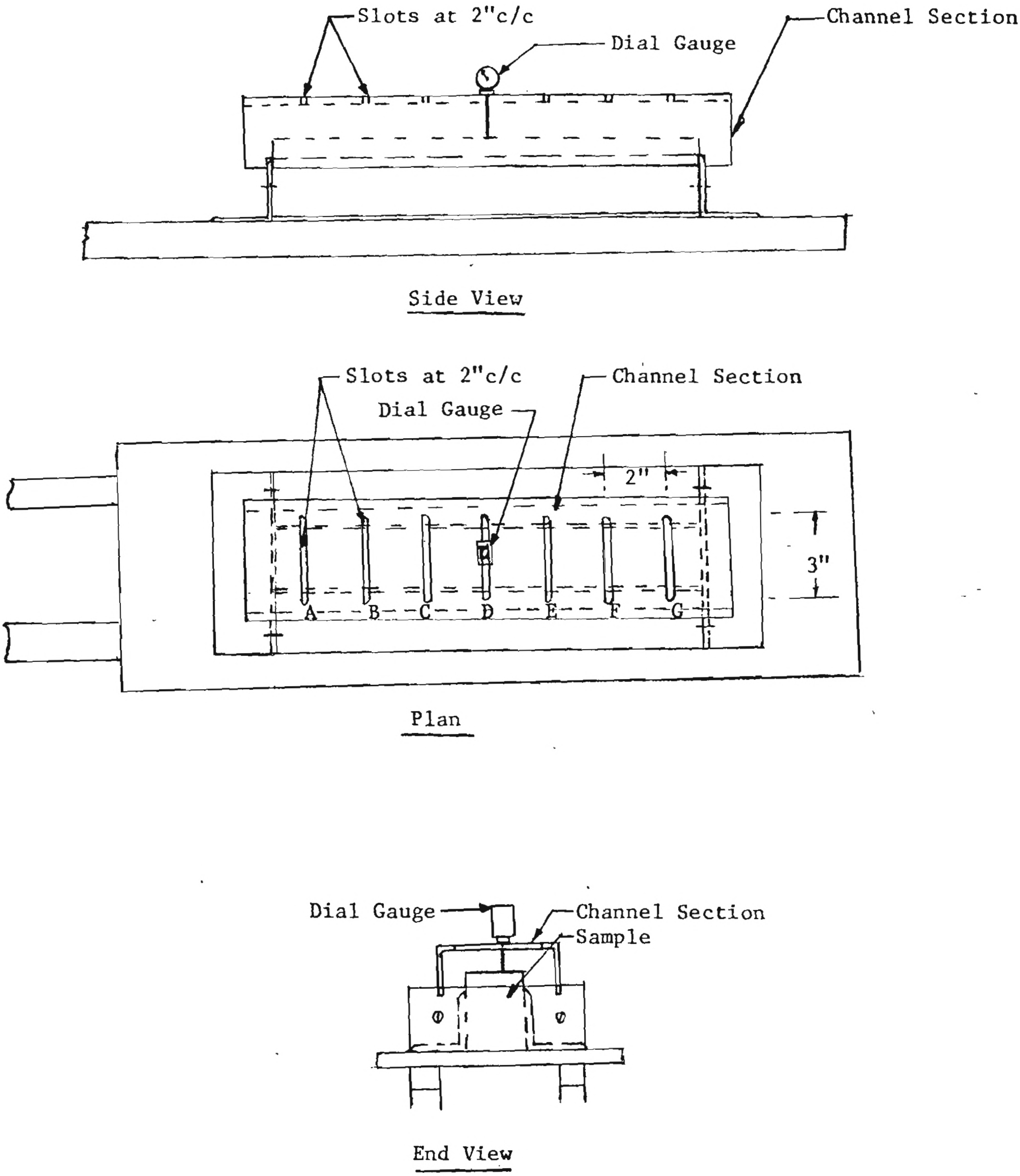


Figure 11. Rutting Profile Measuring Device

D. Mounting Table

The original mounting table was too light and it had a thin metal surface which did not have the capacity to provide a strong and firm base for the machine. A new table made of heavier steel section was constructed for the modified LWT to be mounted on. This new table provided a firm and stable base for the machine. a firm and stable base for the machine.

CHAPTER 5

MATERIALS AND SAMPLE PREPARATION

Four types of asphalt concrete mixtures used in four separated pavement projects which exhibited varying degrees of rutting were selected by the Georgia Department of Transportation (GaDOT) for this study. These four mixes were designated as Mix A, B, C and D in this study. Table 1 summarizes the descriptions of these mixes. The mix design data worksheets used by GaDOT for these mixes are presented in Appendix A. According to the information provided by GaDOT, except the asphalt concrete mixture D, the other asphalt concrete mixtures have shown rutting in the field.

5.1 Materials

The materials (aggregate and asphalt) needed to fabricate the samples for this study were provided by GaDOT. The source of aggregates and gradation used in each of the projects are indicated in Table 1 and in Appendix A. The aggregates received were sieved into different fractions as required, and the resulting sizes were stored separately according to their source. The weight of materials used for preparing the beam and cylindrical samples are shown in Table 2. The aggregates required for each sample were carefully weighed from each size fraction and put into the pan and blended. The aggregate samples were kept in the oven at 360^{o}F for 24 hours before mixing with asphalt.

The AC-20 viscosity grade asphalt cement was used in all the projects. However the source of the asphalt cement used in each project was different. The sources of these asphalts and some of their physical properties are summarized in Table 3. The asphalt was kept in the oven and heated at 315 ^{o}F for one hour before mixing.

Table 1. Summary of Asphalt Mixes Used in this Study.

MIX I.D.	MIX TYPE	Aggregate Source Coarse: Fine:	Asphalt Source	Project
A	F	Vulcan, Lithia Springs Vulcan, Lithia	AC-20 Chevron Lithonia	IR-20-1(62), Fulton Co. 4/28/82
B	B Mod.	Martin-M, Ruby Martin-M, Ruby Lamb Pit, Crisp	AC-20 St. Marks Fla.	MCP-401(73), I-75 near 4/9/80
C	E	All aggs. from Candler	AC-20 AMOCO	MPC-403(35) Lot 18, Jackson Co., 1/12/81
D	E	Gainesville Co., #7-- Candler #8-- Candler M-10 Athens	AC-20 AMOCO	MPC-403(35) Lot 26, Jackson Co., 10/15/80

Table 2. Summary of Materials Used in Preparing Test Samples.

	MIX A		MIX B		MIX C		MIX D	
	Beam	Cylinder	Beam	Cylinder	Beam	Cylinder	Beam	Cylinder
Design Bulk Specific Gravity Compacted Sample	2.348	2.348	2.346	2.346	2.349	2.349	2.361	2.361
% Asphalt by Ttoal Weight of Mix	6.0	6.0	5.0	5.0	6.2	6.2	5.3	5.3
Volume of Samples (cm^3)	2212.3	1646.6	2212.3	1646.6	2212.3	1646.6	2212.3	1646.6
Weight of Aggregate (grams)	4882.0	3634.0	4930.0	3670.0	4875.0	3628.0	4946.0	3682.0
Weight of Asphalt (grams)	312.0	232.0	260.0	193.0	322.0	240.0	277.0	206.0

Table 3. Asphalt Type, Source and Physical Properties.

MIX I.D.	Asphalt Source	Asphalt Grade	Penetration @ 77°F, 100 grams, 5 sec. (1/10 mm)	Softening Point Ball and Ring Test (sec.)
A	Chevron Jasper (Mobile)	AC-20 Special (Sp.Gr. = 1.037)	72	136
B	Seminole St. Mark (Shell Oil)	AC-20 (Sp.Gr. = 1.034)	76	130
C	Amoco Savannah	AC-20 (Sp.Gr. = 1.039)	93	120
D	Amoco Savannah	AC-20 (Sp.Gr. = 1.039)	93	120

5.2 Marshall Mix Design

For each mix, standard Marshall mix design was performed according to the procedure given by the ASTM 1559. The purpose of the Marshall test was to determine the Bulk Specific Gravity of the asphalt concrete and the optimum asphalt content. The bulk specific gravity values determined for each are shown in Table 2. This bulk specific gravity values were used to determine the weight of materials required for fabricating the 3" x 3" x 15" beams and 4" diameter by 8" height cylinders.

The results of the Marshall design for the four mixtures are presented in Appendix A. The origional Marshall test data for the four mixes provided by GaDOT Materials Research Lab are also presented in Appendix A. These two sets of the Marshall Mix data for the four mixes are shown in Table 4. It can be seen from this table that for all four mixes, the results of the two sets of tests are comparatively different. Investigation into the possible causes of this difference is presented in the following.

Stability values were consistently lower while flow values were consistently higher for the samples of all mixes prepared at our laboratory than that of the results from the original GaDOT mix design data sheets. Differences among air voids, bulk specific gravity, and VMA of all mixes did not show any consistent trend. This led us to suspect that the testing temperature for the Marshall stability and flow tests could be in error. After careful checking, it was found that the temperature in the water bath was stratified with about 6°F to 8°F difference between the top and the bottom of the water bath. This difference in temperature could contribute to the lower stability and high flow values for the mixes. The water bath problem was subsequently fixed.

The possible cause for the differences in the air voids, VMA, and bulk

Table 4. Comparison of Marshall Test Results (Lab) With the Known Results Provided by GaDOT Materials Research Lab (GaDOT).

PROJECT	% Asph. by Weight of Total Mix		Stability (lbs.)		Flow (1/100 in.)		Air Void Total Mix (%)		VMA (%)		Bulk Specific Gravity	
	LAB	GaDOT	LAB	GaDOT	LAB	GaDOT	LAB	GaDOT	LAB	GaDOT	LAB	GaDOT
IR-20-(62)	6.0	6.0	1920	2340	15.0	10.5	2.89	4.40	15.13	17.8	2.348	2.301
MPC-401(73)CRISP	5.0	5.0	1183	1987	9.7	8.2	5.31	4.1	15.23	13.8	2.346	2.389
MPC-403(35)LOT 18	6.2	6.2	1356	1712	17.1	12.9	4.12	4.48	16.7	18.1	2.349	2.319
MPC-403(35)LOT 26	5.3	5.3	2064	3208	19.9	12.1	2.80	4.58	14.1	15.3	2.361	2.323

density was thought to be the method employed in batching the minus #8 aggregate. For this research, the minus #8 aggregate was first sieved into various fractions. The predetermined amount of each fraction requird to meet the gradation was then weighed out and blended with the other aggregate fractions. The GaDOT, on the other hand, did not break the minus #8 aggregate further. To confirm the above, Marshall tests were performed on two asphalt concrete mixes using the aggregate samples batched and blended by the GaDOT. For each mix six 1200 grams aggregates samples were prepared by GaDOT Materials Laboratory and three samples each were used by our laboratory and by GaDOT Laboratory to prepare and perform the Marshall tests independently. The results are summarized in Table 5 and with the Detailed Test Results presented in Appendix A (A-14, A-15). In the two different mixes, results produced from our laboratory and that of the GaDOT Laboratory were in close agreement. This indicated that different ways of blending aggregate could affect the Marshall mix properties. The blending of aggregates for fabricating the beam and cylindrical samples for this research were prepared according to the procedures described in Section 5.1 where the minus #8 aggregate was sieved into various fractions and then recombined to meet the final gradation requirements. Because of this, the characteristics of the four mixes prepared in this study were not completely the same as that of the mixes used in the origional construction projects.

5.3 Preparation of Cylindrical and Beam Samples

The weight of materials required shown in Table 2 for fabricating the cylindrical and beam samples was computed based on the bulk specific gravity of the mixes obtained from the Marshall design (see Table 4).

The asphalt was heated in the oven at 315^{o}F and the mould and aggregate were placed in a separate oven and heated at 360^{F}. The aggregate was

Table 5. Comparison of Marshall Test Results.

Project	Results	Stability (lbs.)	Flow 1/100 in.	Air Voids (%)	VMA (%)	Bulk Sp.Gr.
85230	Ga Tech	3420	9	4.27	14.9	2.333
	Ga DOT	3283	10	4.2	14.9	2.333
85231	Ga Tech	1951	12	4.2	17.5	2.338
	Ga DOT	1980	12	4.2	17.5	2.338

weighed and correct amount of asphalt were added and they were thoroughly mixed in a bowl so that all the aggregate particles were coated with asphalt. The asphalt mixture was then immediately placed in the heated mould and compacted using the kneading type compactor.

A. Cylindrical Specimens

Six (4" diameter by 8" high) cylindrical specimens were fabricated for each asphalt mixture, and used for repeated load triaxial tests and creep tests. The specimens were compacted in a cylindrical steel mould using the kneading compactor. With the mould in place, the hot asphalt mixture was spooned into the mould; as the mould was filled the load foot was actuated downward so as to press down on the material in the mould one time between adding each spoonful of mixture. Filling the mould and compacting the specimen required approximately five minutes and took 60 spoonsful of material. This kneading action compacted the specimen to within 1/8 inch (3.2 mm) of the finished specimen height.

A circular piece of filter paper cut to fit the inside diameter of the mould was placed on top of the compacted specimen and a loading head was placed on top of the filter paper. The entire mould assembly was immediately placed in a testing machine. A static load was placed on the specimen to level the top and to finish compacting it to the specified height of 8" (203 mm). After cooling, the specimen was extruded from the mould and then measured and weighed.

B. Beam Specimens

The beam specimens used in this study for the rutting tests were 3" x 3" in cross section and 15" in length. All beam materials were mixed and compacted at the same temperature as those used in preparing the cylindrical specimens. After heating, the beam mould was placed in the kneading compactor on a sliding rack. Since the loading foot of the compactor does not move laterally, the beam was moved manually in the sliding rack during the compaction operation. The hot asphalt mixture was placed in the mould in two layers. Each layer was compacted by three to four passes of the compactor along the length of the beam. After all asphalt mixture was placed in the mould, a loading plate was positioned on top of the beam and loaded until a height of 3" (76 mm) was reached. This procedure also served to level the surface of the specimen.

The beam and mould were allowed to cool, and the mould was removed. After cooling each specimen was measured, weighed and then stored on a flat steel plate. The specimens were stored on the flat surface so they would lie flat on the sample base plate of the rut predicting machine. The use of the machined steel plates for storage of the beams was necessary to avoid inducing tensile strains in the beam before testing, and to give uniform subbase support to the beam during the rutting test.

CHAPTER 6

MODIFIED LOADED WHEEL TEST PROCEDURE AND RESULTS

6.1 Test Procedure

The modified LWT was installed in an air-tight room. An electric heater with a thermostat control was used to heat the room to 95°F with a maximum fluctuation of ± 1 °F. This temperature was maintained throughout the test. A thermometer installed outside the room was used to monitor the temperature. To avoid any drop in temperature the room was kept shut during testing.

The 3" x 3" x 15" beam sample to be tested was kept on a flat steel plate in the test room for 24 hours at 95°F to precondition it. After the 24 hour period, the beam was transferred to the Sample Base Plate. It was then firmly held in position with the Sample Holding Device.

Next, the Channel Section shown in Figure 11 was placed above the beam. The cross profile of the beam was measured with a dial gauge by sliding it along the slots at 0.25" center to center. The cross profile readings were taken at an interval of 2 in. along the beam.

After the readings were taken the Channel Section was removed and the Linear Tube and Wheel Guides were placed along the longitudinal center line of the beam. The Linear Tube and Wheel Guides were held in position by securely fixing the Linear Tube Holding Angles and the End Clamps in place.

One end of the air line was fixed to the Linear Tube and the other end to a pressure regulator which was installed in the testing room. A 100 psi or 75 psi pressure was applied in the Linear Tube by adjusting the pressure regulator. This pressure was maintained constant throughout the test, with the maximum fluctuation of 2 psi. The 3" diameter aluminum wheel was then mounted in position in between the Wheel Guides on the Linear Tube. Bags of lead shot were put on the load holding plate above the wheel. Load applied in the test series were 100 lbs., 75 lbs. and 50 lbs. With the resettable revolution counter set at zero, the test was begun by starting the machine.

At the end of each predetermined number of cycles (i.e., 0, 40, 100, 400, 1000 & 4000), the machine was stopped and the lead shots, the wheel and the Linear Tube mechanism were temporarily removed and the rutting profile was measured.

6.2 Results

Figure 12 represents the typical transverse rutting profile at different numbers of cycles while Figure 13 represents the typical longitudinal centerline rutting profile. The transverse profiles as shown were always symmetric as expected. The longitudinal profiles showed uneven rutting with the heaviest rut developed at the near end of the beam (closest to the pivot of the reciprocal arm). This severe rutting could be attributable to the downward shoving action of the reciprocal arm for pushing the wheel to move forward. The first modified version, using the high pressure hose wrapped around an aluminum wheel, as described in Chapter 3, resulted in an even more severe rutting. The excessive rutting at the ends was in no way representing the normal rutting developed on a pavement under a moving wheel load. Figures 14, 15, 16 and 17 represent the averaged centerline rutting of these four mixes at various numbers of cycles. Three curves were presented in each graph, one represents the mid-point (Position D) rutting, one represents the rutting at the middle region (average of positions C, D and E), and the third curve represents the average of all seven positions. From these four figures it became apparent that the rutting on the middle region of the beam is quite uniform, as the rutting curves at Point D and that of the averaged C, D and E were almost the same.

The rutting curves based on the average of all seven positions were much higher. Based on these findings, the results of all the rutting tests presented in Table 6 were based on the averaged values of the centerline rutting at position C, D and E. Figure 19 presents the rutting curves (permanent deformations versus number of repetitions) of the four different mixes at 100 lbs. total load and at 100 psi tire pressure. Each curve for Mix A, B and C shown in Figure 19 represents the averaged values (see Table 7) from two tests. The results from other loads and tire pressures are presented in Figures 20, 21 and 22. Analyses of these results will be presented in Chapter 8.

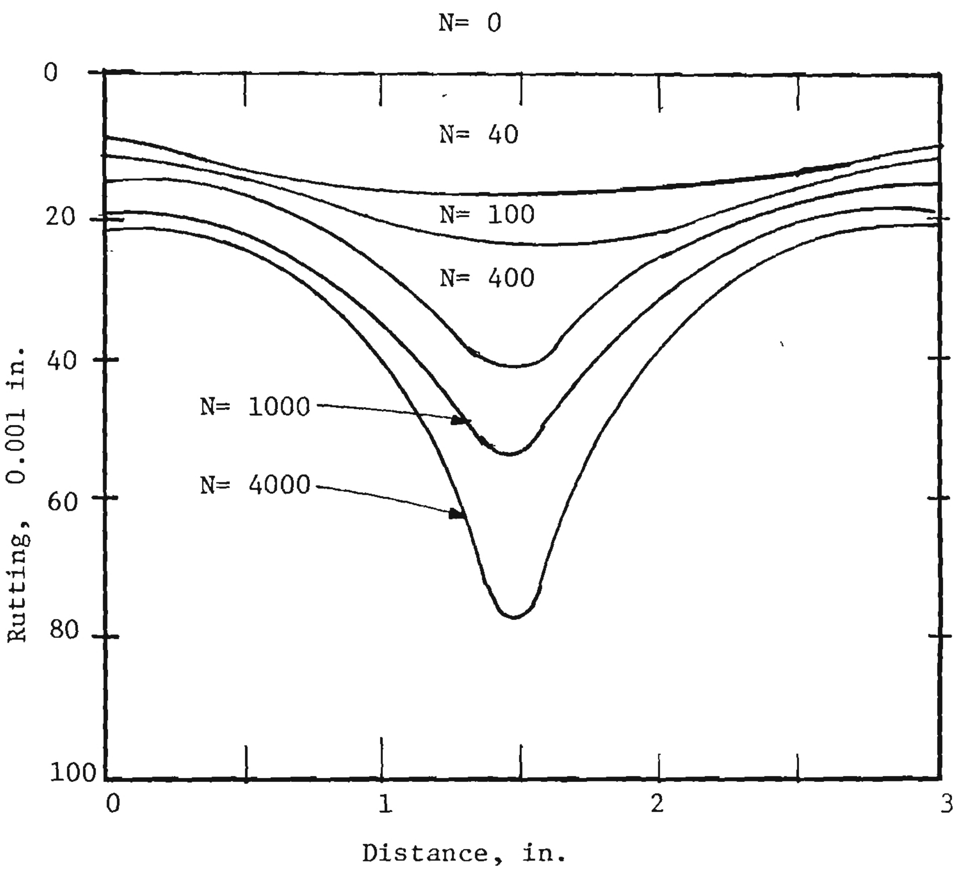


Figure 12. Typical Transverse Rutting Profile

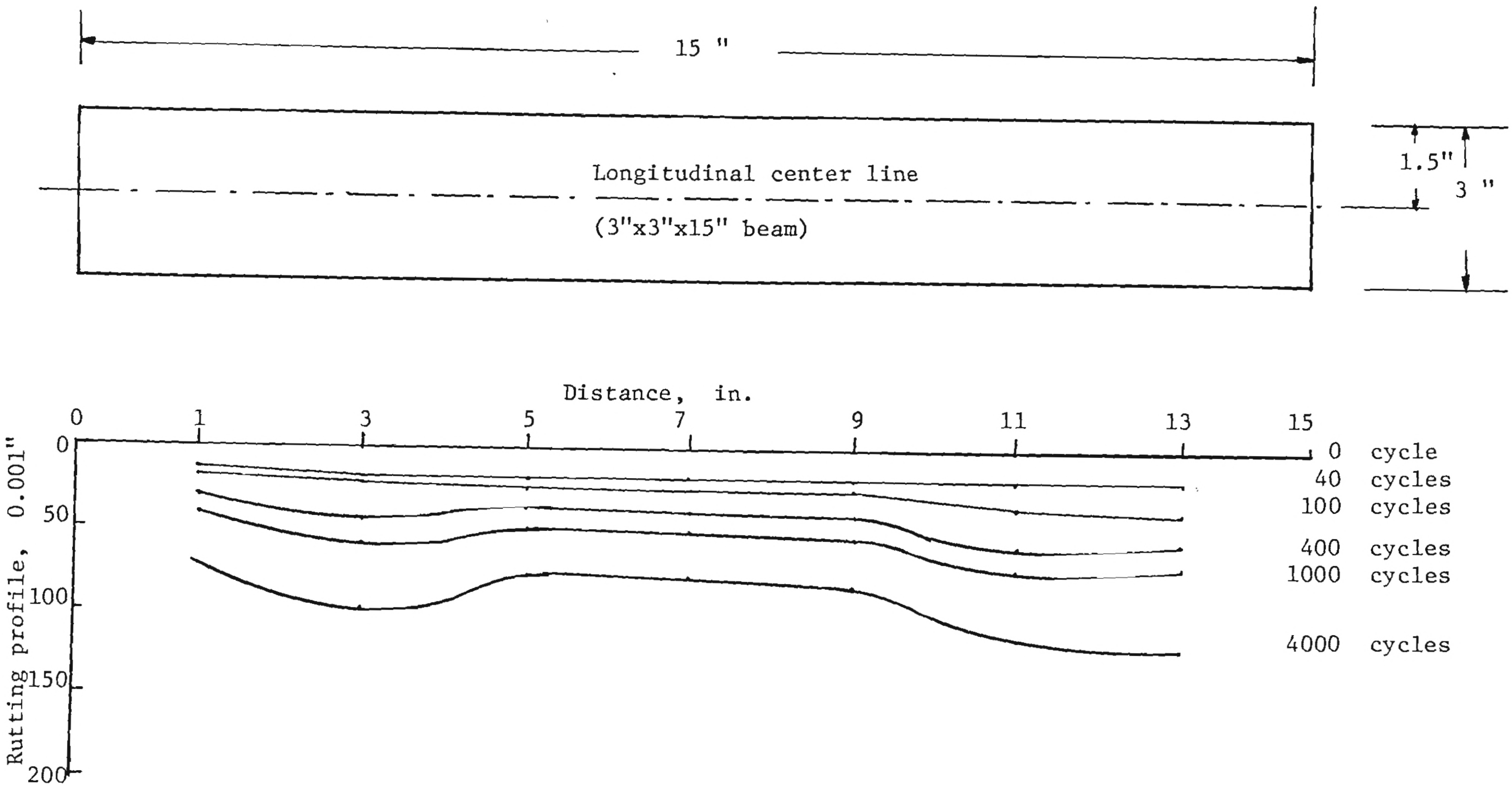


Figure 13. Rutting Profile Along the Longitudinal Center Line

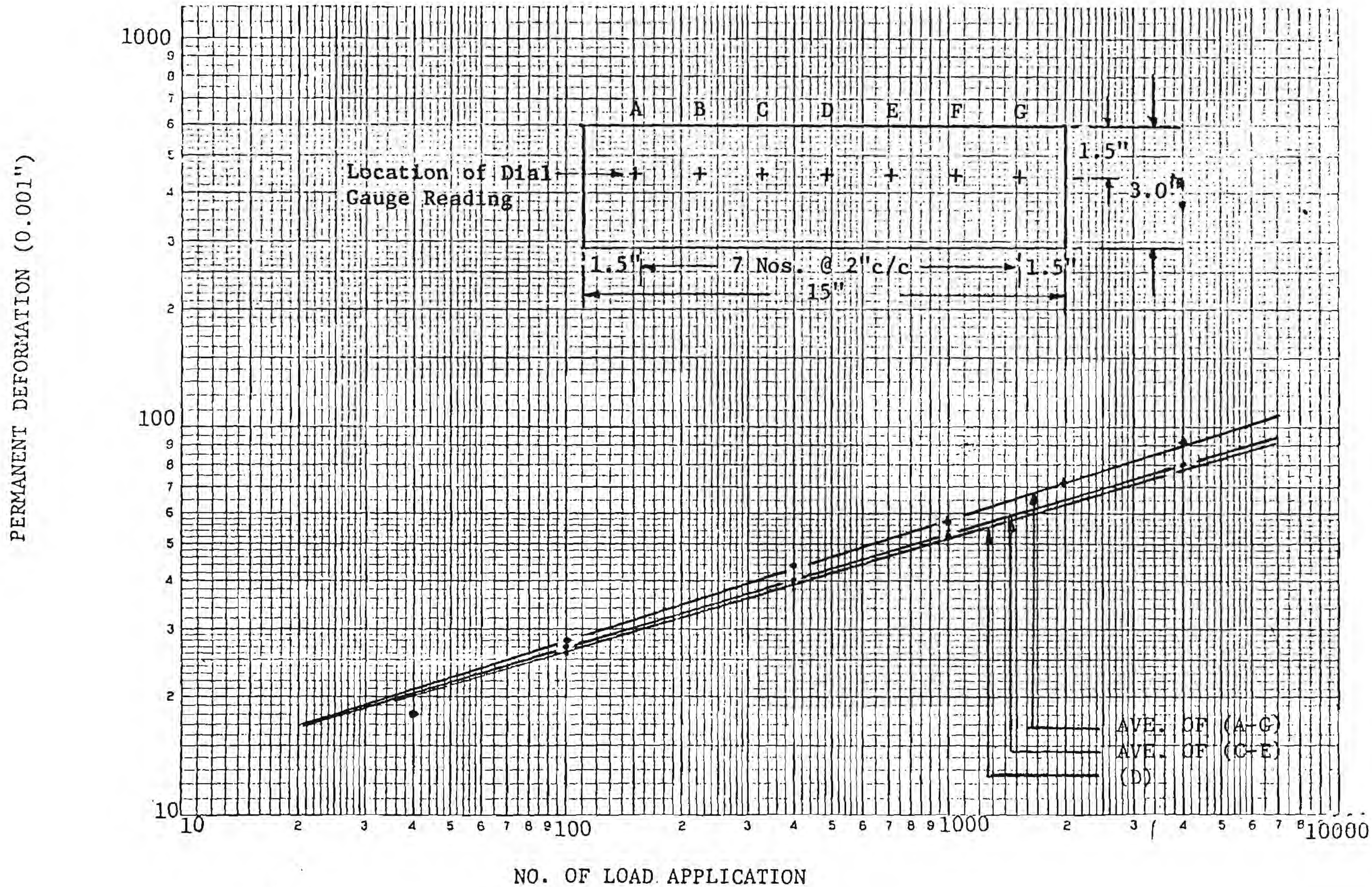


Figure 14. Modified Loaded Wheel Test Results

Sample: A1

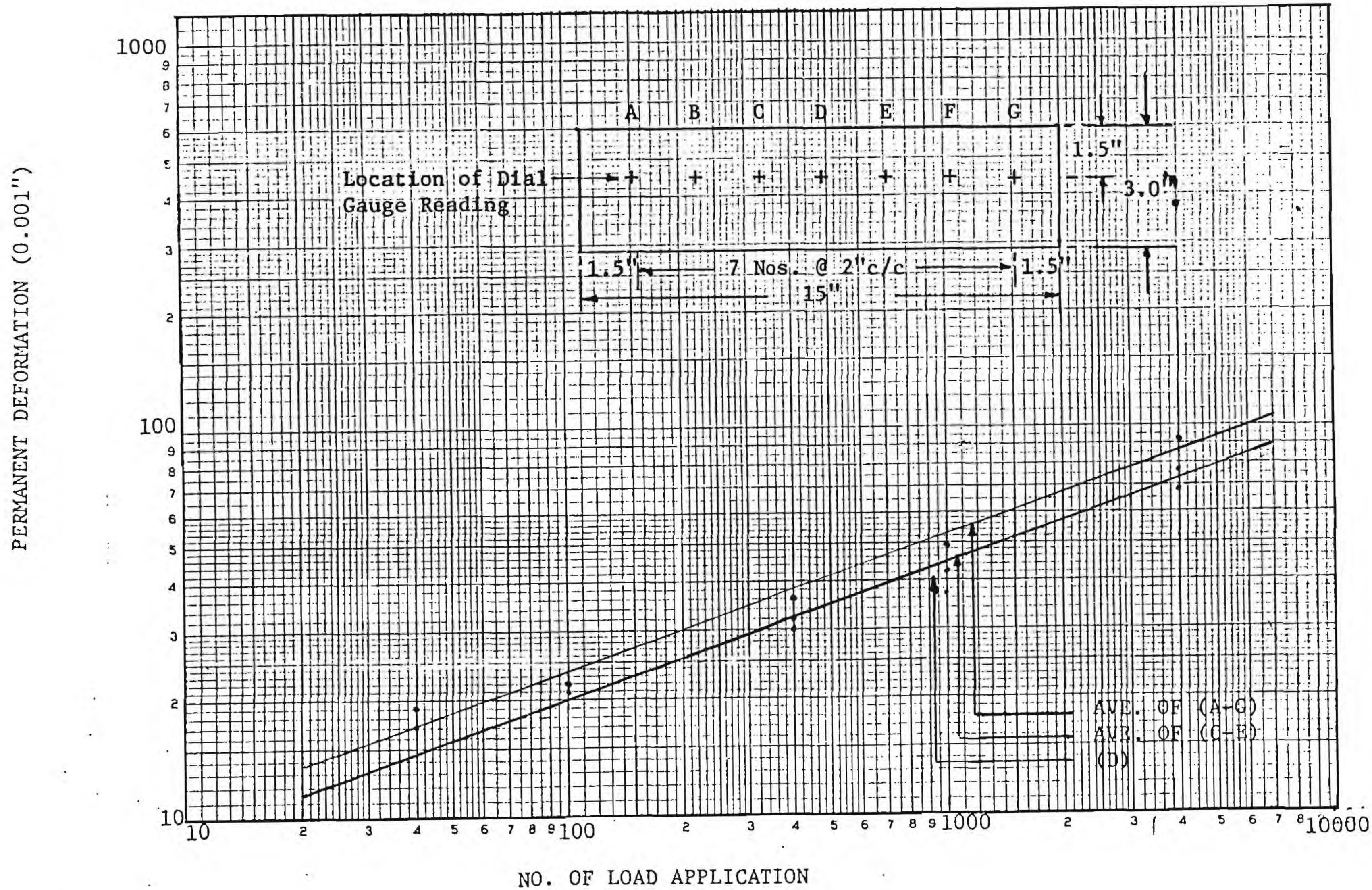


Figure 15. Modified Loaded Wheel Test Results

Sample: B1

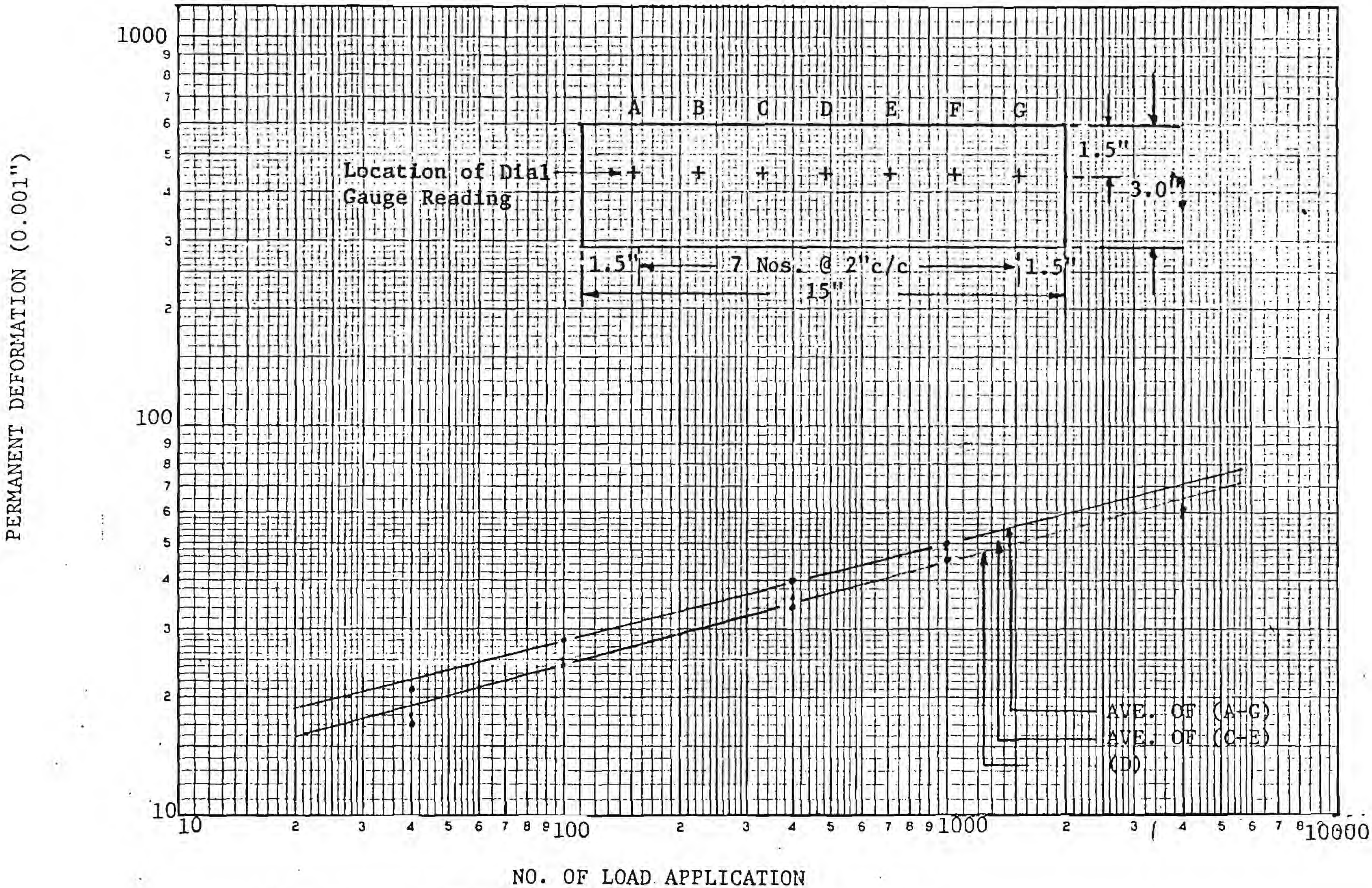


Figure 16. Modified Loaded Wheel Test Results

Sample: C1

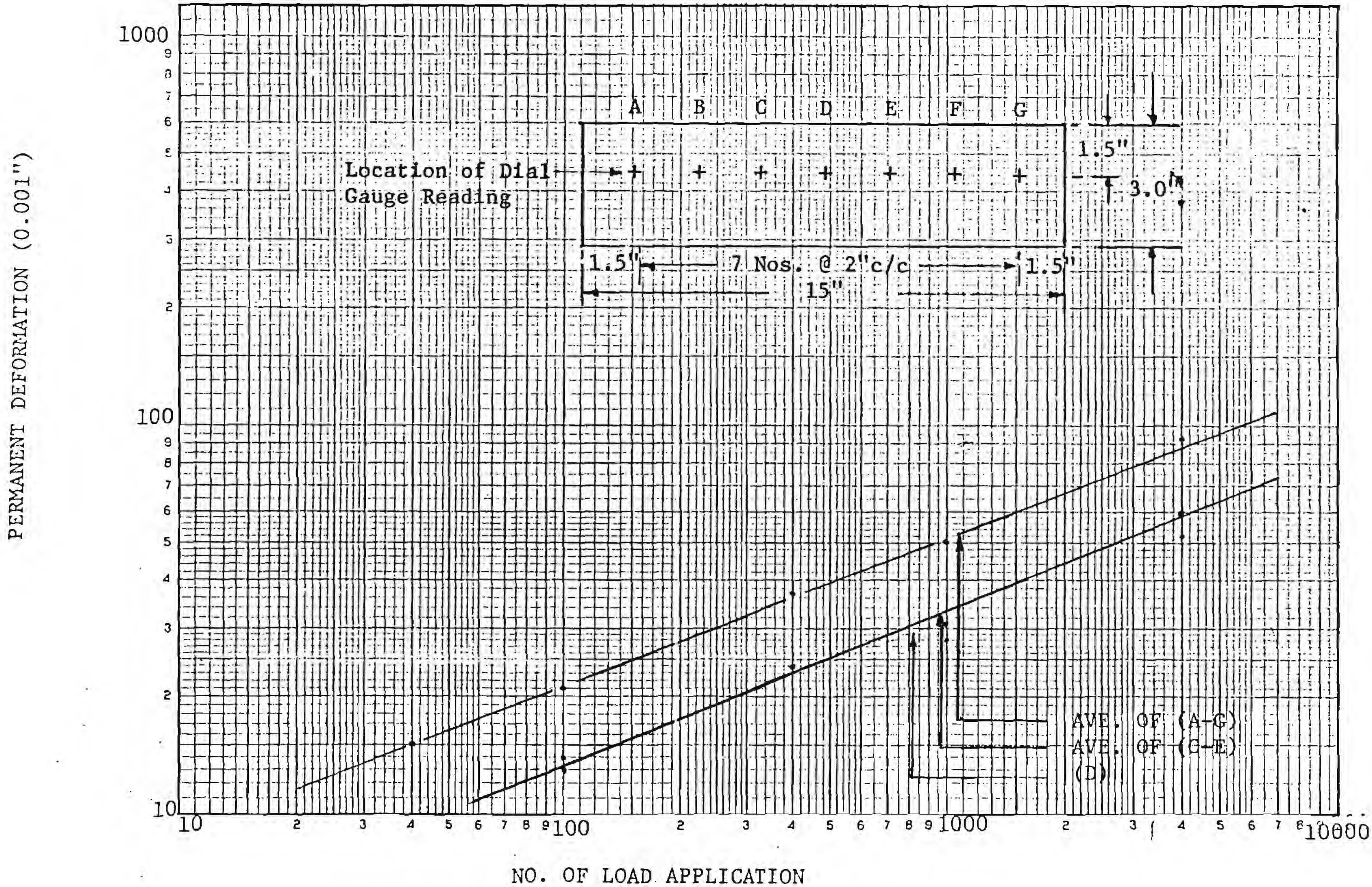


Figure 17. Modified Loaded Wheel Test Results

Sample: D1

Table 6. Modified LWT Rutting Test Results

Sample ID: Mix "A" = IR-20-1(62)
Mix "B" = MPC-401(73) CRISP
Mix "C" = MPC-403(35) Lot 18
Mix "D" = MPC-403(35) Lot 26

Sample ID	Load Condition Load,	Pressure	Amount of Rut (0.001 in.) at N = 40	100	400	1000	4000
A1	100	100	18	27	40	52	80
A6	100	100	18	33	61	73	112
A5	75	100	16	22	31	42	55
A2	75	75	22	29	42	53	70
A3	50	75	11	12	19	25	33
B1	100	100	19	21	31	41	77
B6	100	100	28	36	57	78	124
B4	75	100	22	25	34	44	70
B2	75	75	14	22	33	45	61
B3	50	75	10	15	21	27	47
C1	100	100	17	24	34	45	59
C6	100	100	17	25	37	55	81
C4	75	100	21	26	35	47	68
C2	75	75	18	26	37	48	62
C3	50	75	6	12	20	26	
D1	100	100	9	13	24	31	60
D3	100	100	10	14	20	32	59
D4	75	75	10	16	28	38	55
D5	50	75	17	12	18	24	31

Table 7. Modified LWT Rutting Test Results.

Sample ID: Mix "A" = IR-20-1(62)
Mix "B" = MPC-401(73) CRISP
Mix "C" = MPC-403(35) Lot 18
Mix "D" = MPC-403(35) Lot 26

Sample ID	Load Condition Load,	Pressure	Amount of Rut (0.001 in.) at N = 40	100	400	1000	4000
A1	100	100	18	27	40	52	80
A6	100	100	18	33	61	73	112
	Average =		18	30	50.5	62.5	96
B1	100	100	19	21	31	41	77
B6	100	100	28	36	57	78	124
	Average =		23.5	28.5	44	59.5	100.5
C1	100	100	17	24	34	45	59
C6	100	100	17	25	37	55	81
	Average =		17	24.5	35.5	50	70
D1	100	100	9	13	24	31	60
D3	100	100	10	14	20	32	59
	Average =		9.5	13.5	22	31.5	59.5

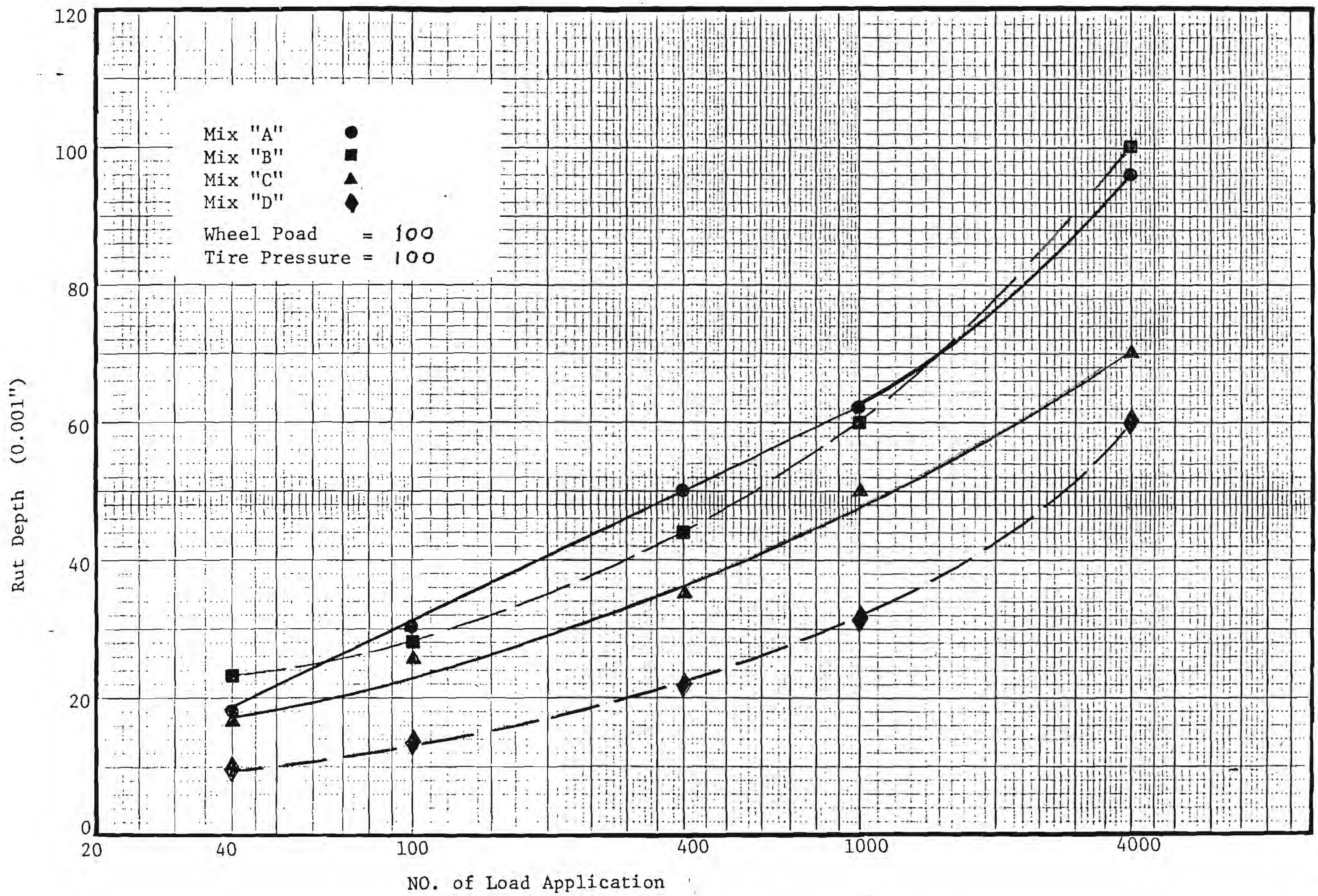


Figure 19. Modified Loaded Wheel Tester Test Results

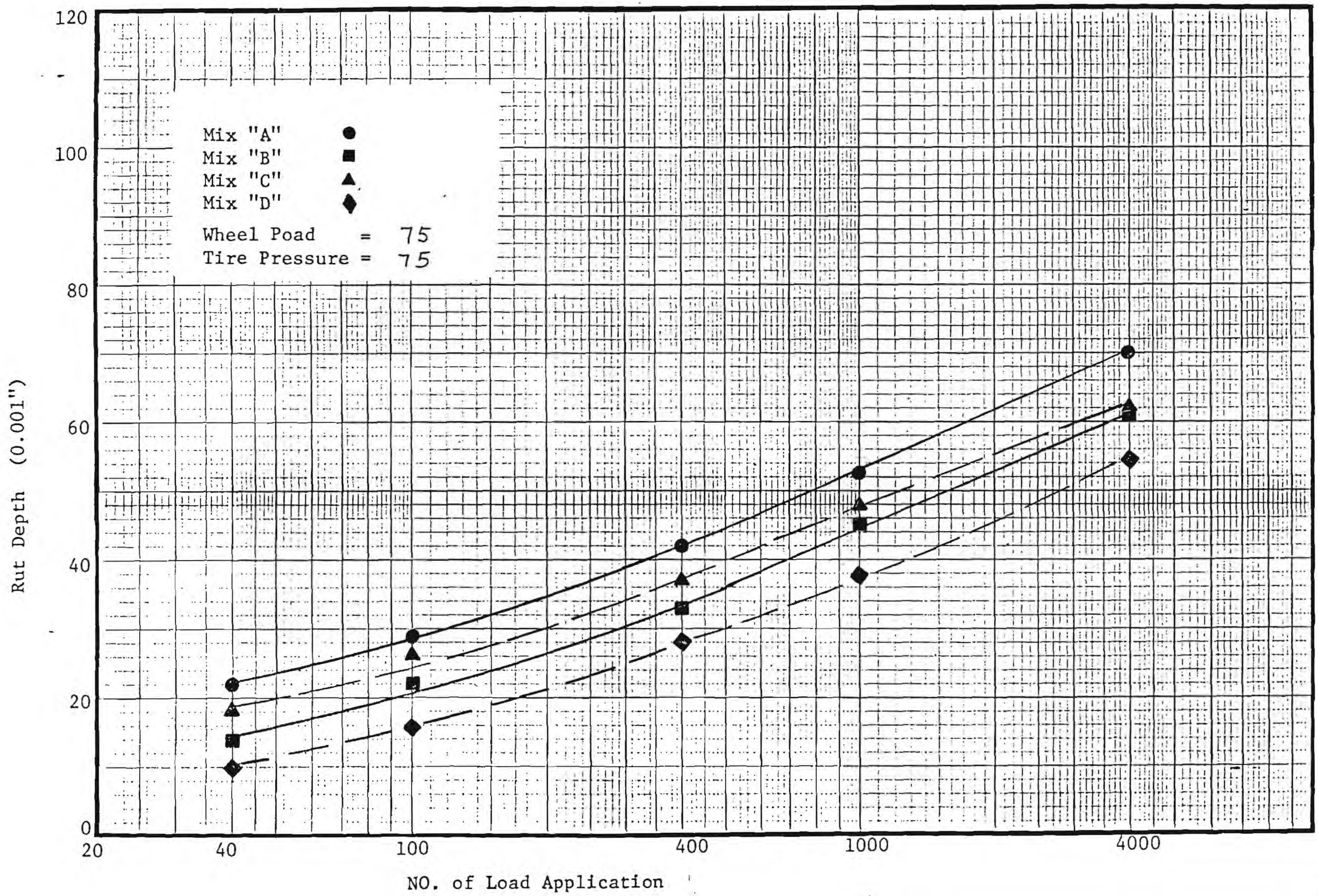


Figure 20. Modified Loaded Wheel Tester Test Results

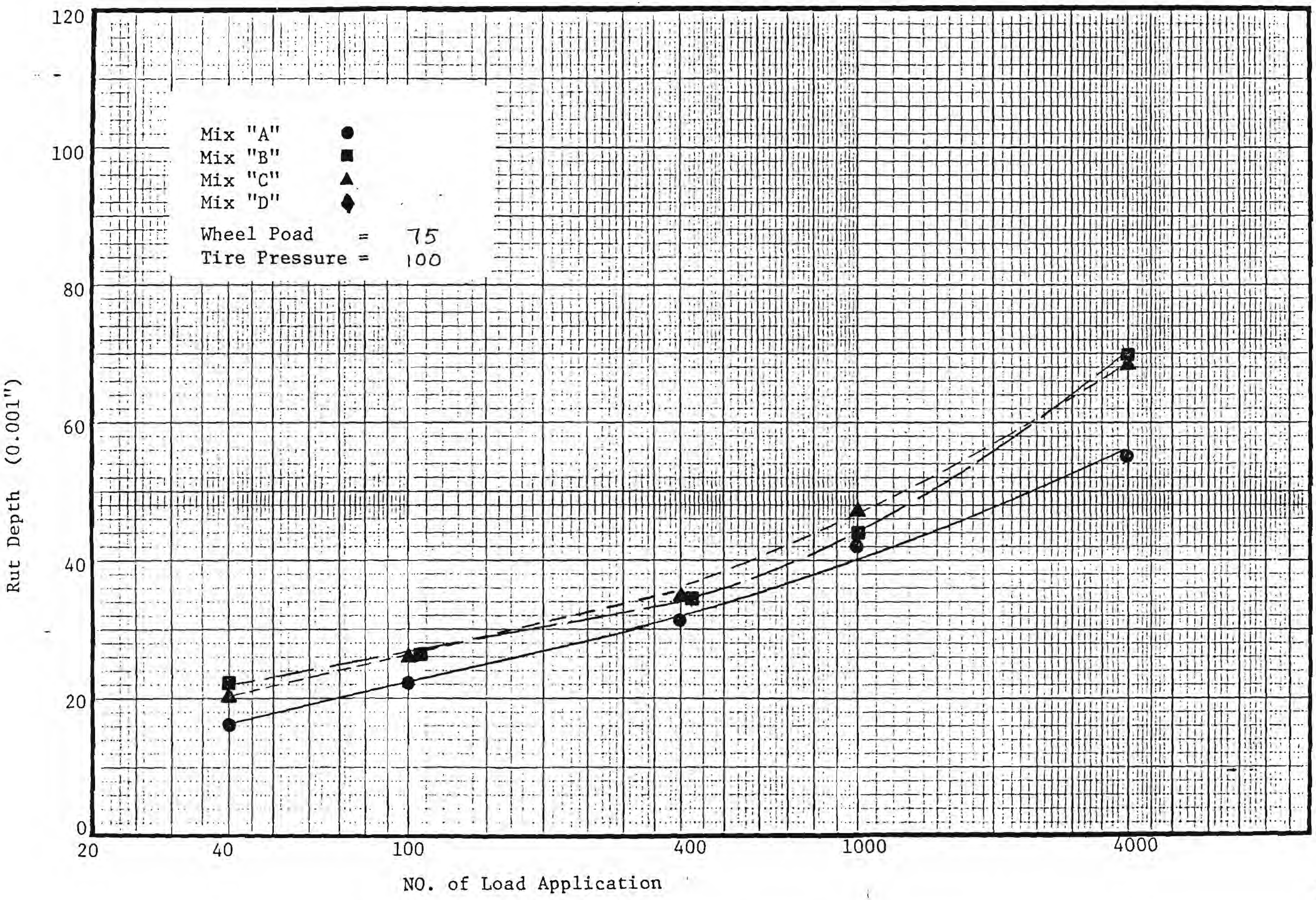


Figure 21. Modified Loaded Wheel Tester Test Results

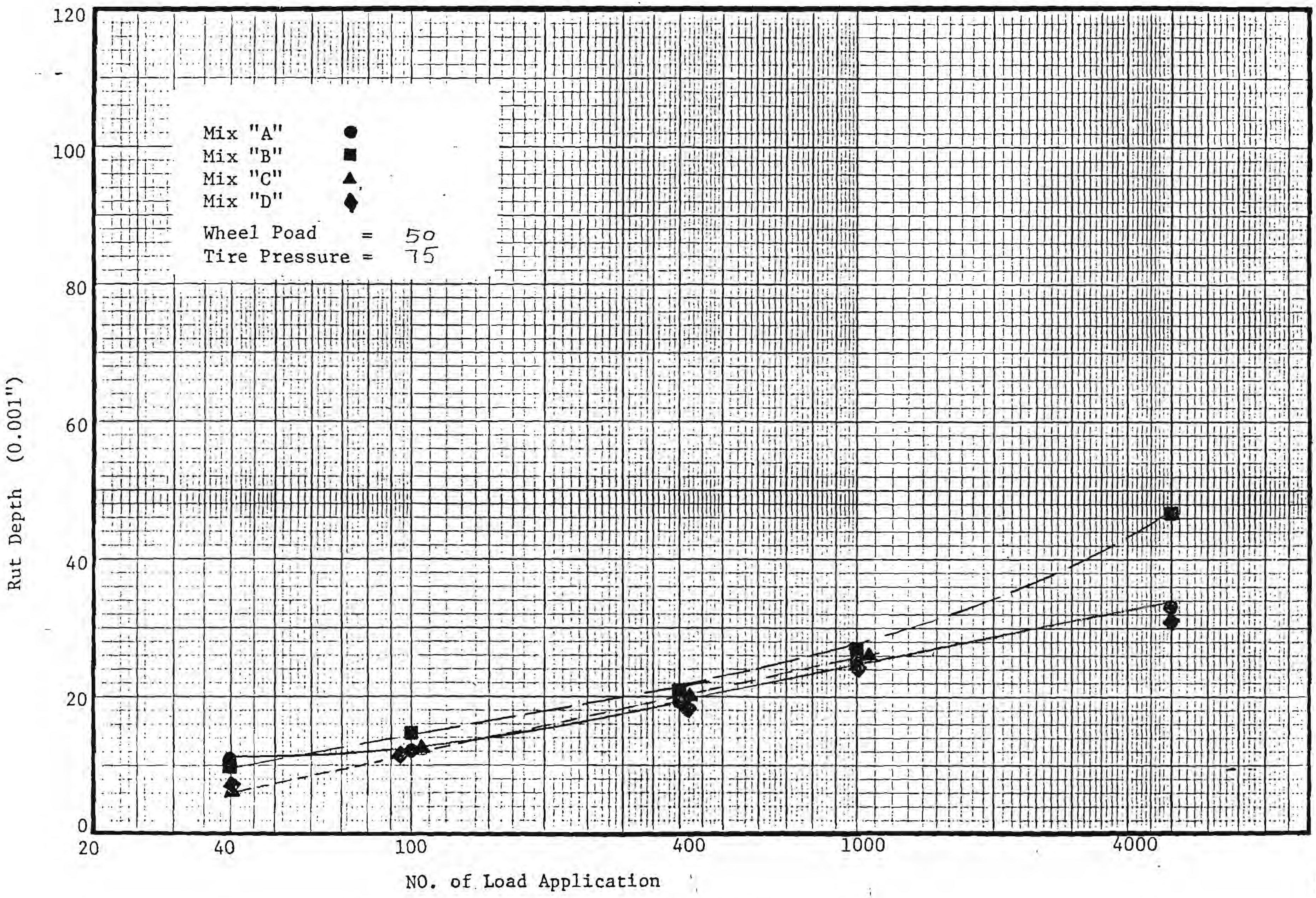


Figure 22. Modified Loaded Wheel TesterTest Results

CHAPTER 7

REPEATED LOAD TRIAXIAL AND CREEP TESTS

Creep and repeated load tests were used in this study to compare qualitatively their results with the results obtained from the modified LWT. The 4" diameter by 8" high cylindrical samples used in the creep and triaxial test were cured for more than two weeks before testing. The apparatus and the testing procedures for the repeated triaxial load test and the creep test used in this research were essentially the same as that employed in the study by Barksdale [5].

7.1 Repeated Load Triaxial Test

The repeated load triaxial testing system is shown in Figures 23 and 24. One sample from each mix was tested in a 6" diameter triaxial cell enclosed in a controlled environmental chamber at 95^{o}F. The test was conducted using a 25 psi deviator stress and 5 psi confining pressure. This stress state has been found in the previous study by Barksdale [5] to be reasonably close to the average stress condition that would occur near the center of an asphalt concrete layer during summer months in central Georgia.

The test procedure used for the repeated load triaxial test was as follows: Each specimen was first carefully examined to assure that it was free from defects such as excessive voids due to presence of large aggregates, and that both ends were flat and parallel. A rubber membrane was then placed around the sides of the specimen. The specimen was positioned on top of the bronze porous stone resting on the bottom loading platen of the triaxial cell. A thin teflon pad was placed between the end of the specimen and the top platen, and the rubber o-rings were used to seal the membrane to the top and bottom platens.

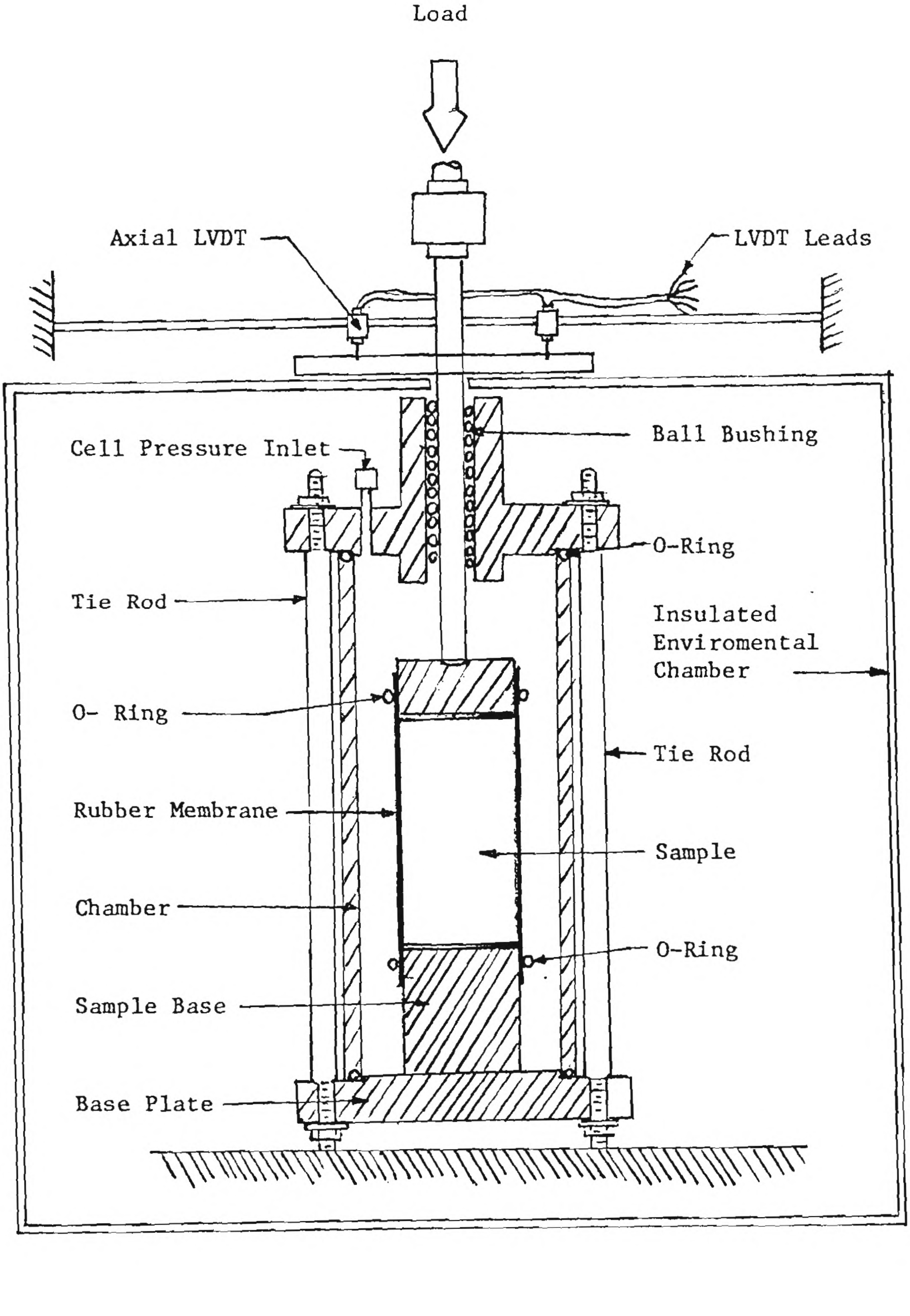


Figure 23. REPEATED LOAD TRIAXIAL TEST APPARATUS

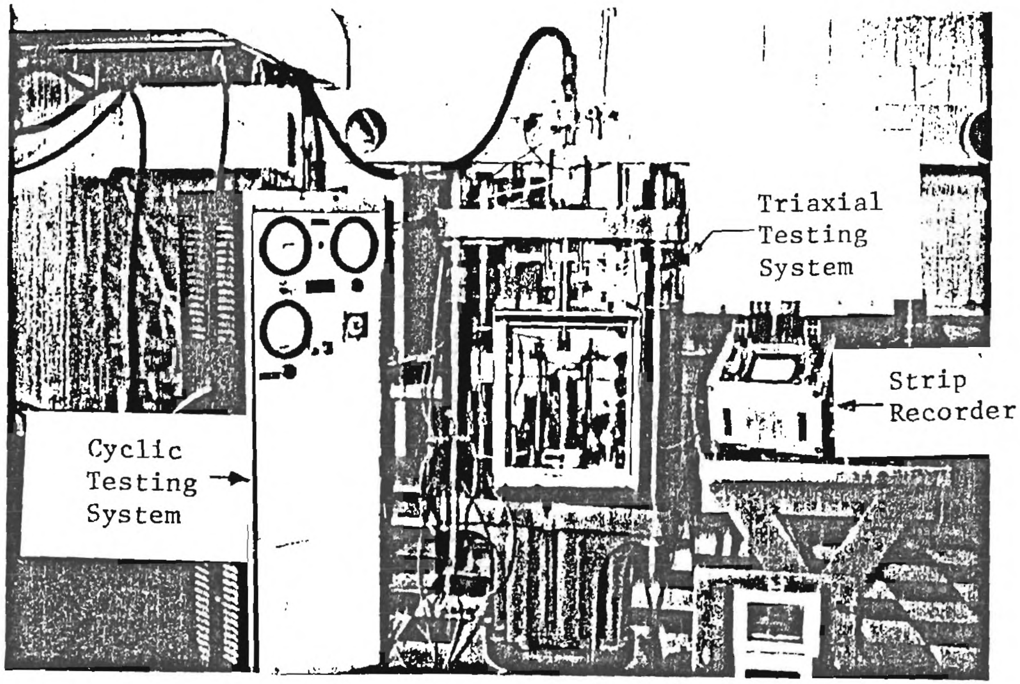


Figure 24.REPEATED LOAD TEST APPARATUS

Once the specimen was in place and adjusted, the triaxial chamber was assembled. The environmental chamber was then placed around the cell, and the loading piston was lowered to the top platen of the specimen. The top cross arm of the loading system was lowered so that a small seating load was applied to the specimen. The triaxial chamber and the enclosed specimen were maintained at the desired testing temperature overnight in order for the specimen to reach the desired temperature.

During the test, loading and unloading of the deviatoric stress for each repetitive cycle were set at 0.1 sec. and 0.9 sec. respectively. The confining pressure was maintained at the constant value of 5 psi throughout the entire testing period. The axial deformation was measured by three DC LVDT's which reacted against a lucite clamp attached to the loading piston outside the enviromental chamber. The output from these transducers was recorded on a HP strip chard recorder.

Specimen deformation was measured continuously for the first ten repetitions, and then at approximately 100, 1000 and 10,000 repetitions. After 10,000 repetitions, the test was terminated. During the test the chamber temperature, cell pressure, pilot valve pressure, deviator stress and load pulse times were observed periodically to ensure proper adjustment.

The permanent deformations as a function of the number of load repetitions were obtained from this test. The test results are shown in Figure 25.

7.2 Creep Test

The creep test equipment (CONBEL System) is shown in Figure 26. It consists of a bellofram cylinder, housed inside a belly like structure, with a ball end loading piston. Also it has a flat platform, directly below the loading piston, for placing the sample. This equipment is a pneumatic

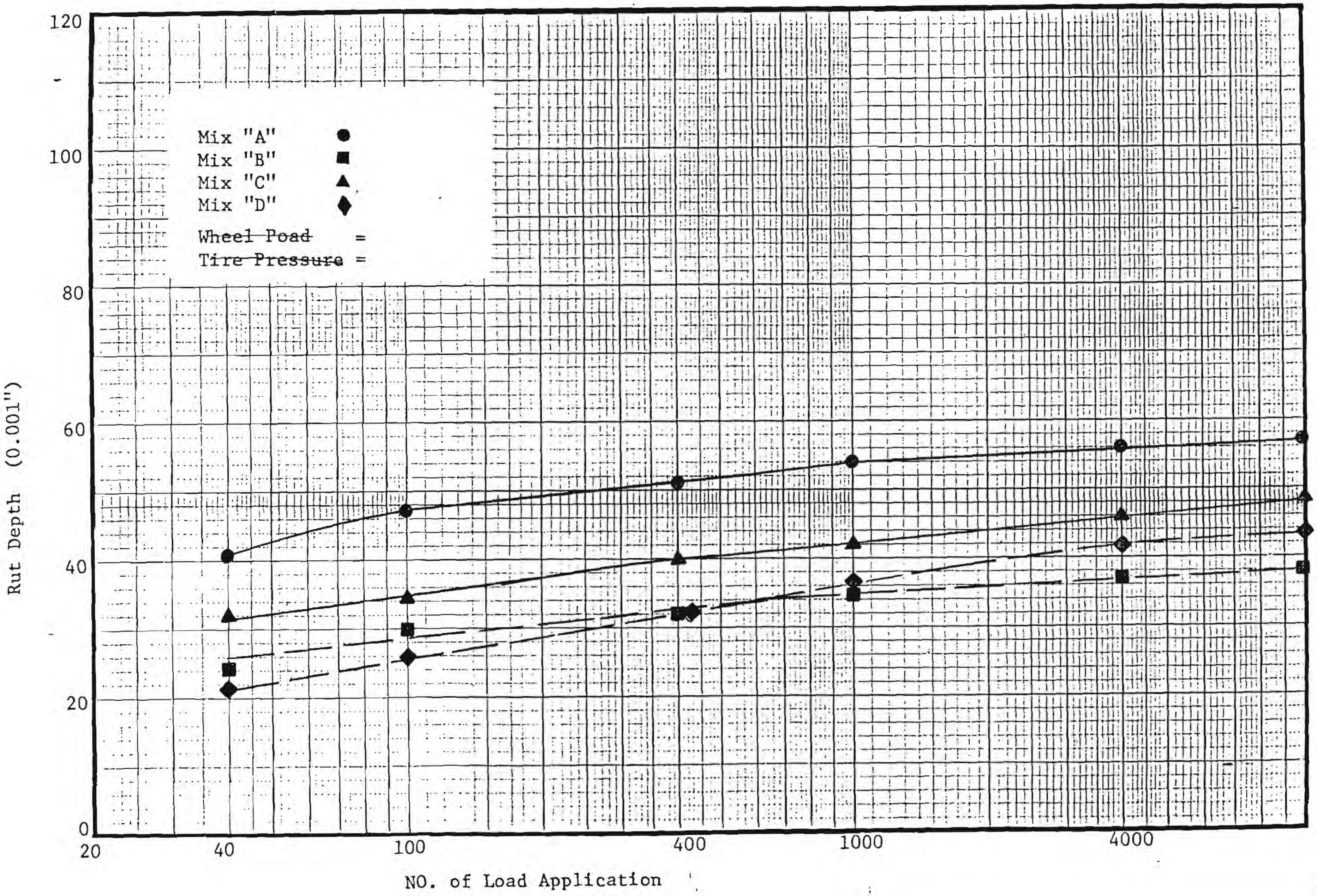


Figure 25. Repeated Load Triaxial Test Results

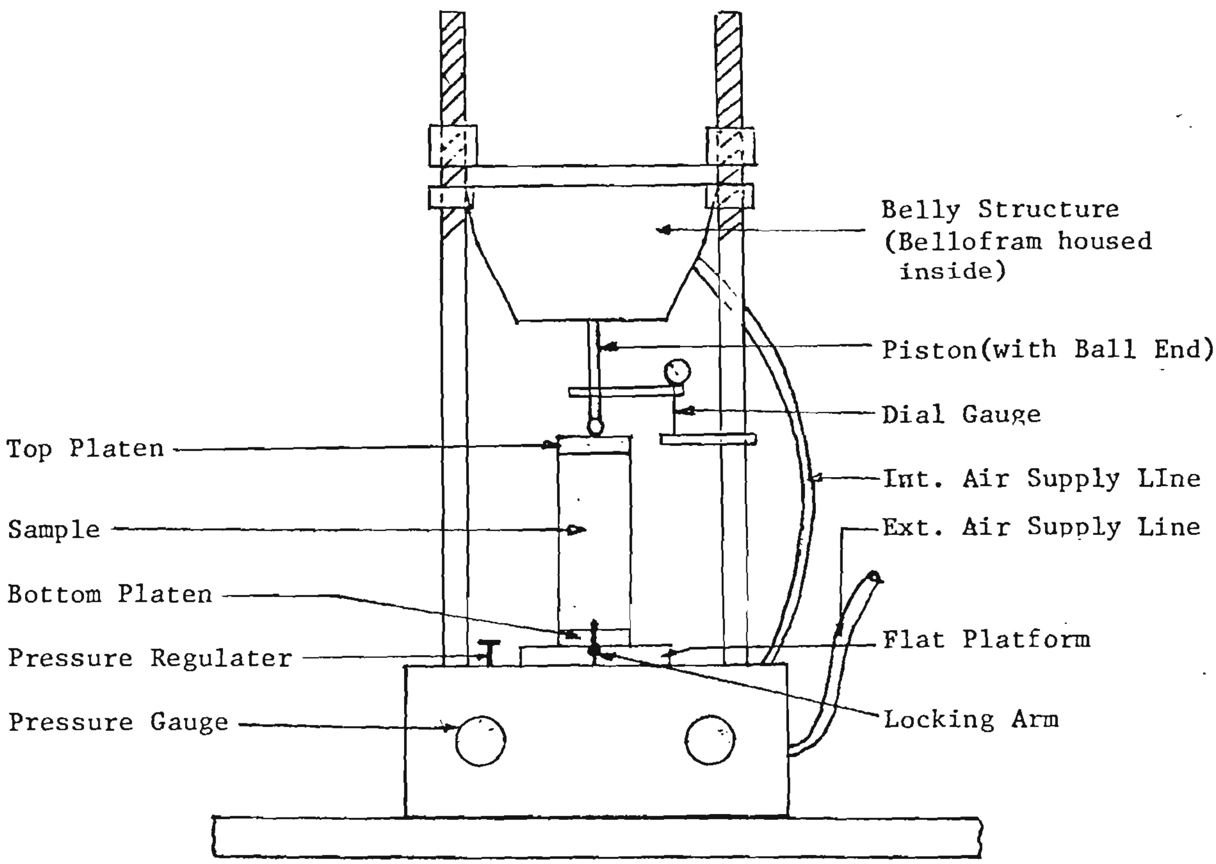


Figure 26. Creep Test Apparatus

constant stress loading system with a pressure gauge for regulating the load. The equipment was installed in a temperature controlled room where the temperature was maintained at 95^{o}F. The testing procedure used was as follows:

The sample was placed between two end platens. To minimize friction, two thin polyethylene sheets were placed between the end platens and the sample. The whole assembly was mounted on the flat platform directly below the loading piston.

The loading piston was lowered slowly by regulating the pressure gauge, until it rested firmly on the top platen. The piston was then locked into position using the locking arm, and the initial dial gauge reading was taken. With the piston held in position, the pressure gauge was adjusted to 15 psi axial stress. This axial stress was found in a previous study by Barksdale [5] to cause the asphalt concrete to develop significant amounts of creep while the material is still within linear range. After this pressure was set, the piston was then slowly unlocked and the specimen subjected to a constant stress. The deformation of the specimen was recorded at 1, 4, 10, 40, 100, 400, 1000, 4000 and 10,000 seconds. Load and temperature were maintained constant throughout the test to ensure proper testing conditions.

The creep test data are shown in Figure 27.

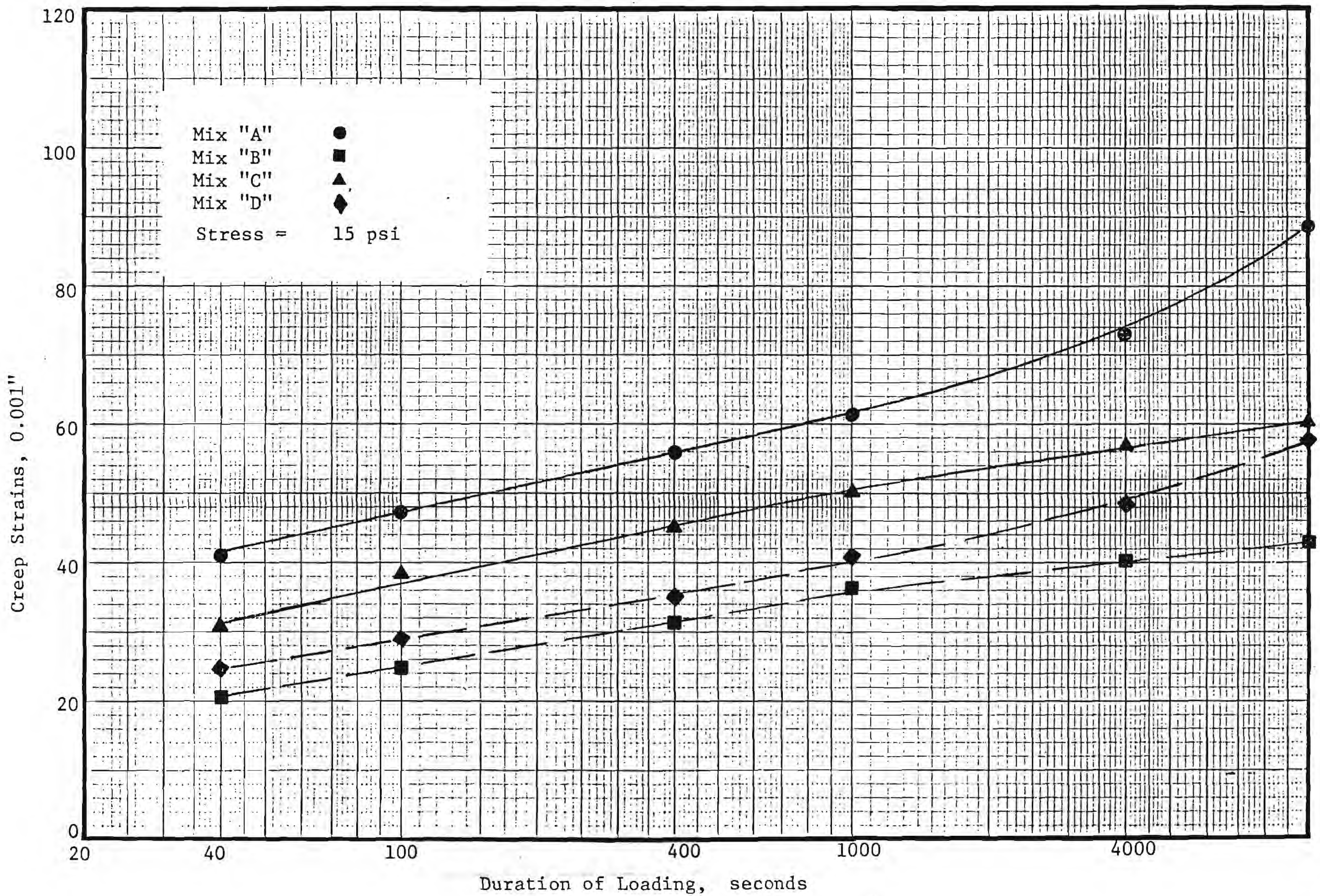


Figure 27. Creep Test Results

CHAPTER 8

ANALYSIS AND DISCUSSION OF TEST RESULTS

In this chapter the results from loaded wheel tester on the four asphalt mixes were analyzed and compared with the results from the repeated load triaxial tests and the creep tests. The analysis was aimed toward assessing the feasibility of using the loaded wheel test results as a means of predicting the rutting potential of asphalt mixes.

8.1 Analysis of LWT Results

Table 6 in Chapter 6 summarizes the accumulated rut-depth developed on the asphalt concrete beams versus the number of repetitions. These results were also plotted as shown in Figures 28-31. Figures 28 to 31 show the effects of the magnitude of wheel load and the tire pressure on the development of rutting. As expected, higher wheel load and tire pressure generally resulted in more severe rutting. The extent of the effects were different for the four different mixes. The effects of wheel load and tire pressure were most significant for Mix A and Mix B where the magnitudes of rutting were increased with increasing of wheel load (from 50 lbs. to 75 lbs. to 100 lbs.). The effect of tire pressure (100 psi vs. 75 psi) was not as consistent. For Mix C and D, rutting due to 100 lb. and 75 lb. wheel loads was about the same while at 50 lb. wheel load the rutting was substantially lower for both mixes.

The effects of mix types on the rutting could be seen from Figures 19 to 22. As shown in Figure 19, at 100 lbs. wheel load and 100 psi tire pressure, significant differences in rutting were observed among the four mixes with Mix A and B showing the highest rut while Mix D showed the least rut. At 75 lbs. wheel load and 100 psi tire pressure, the differences in

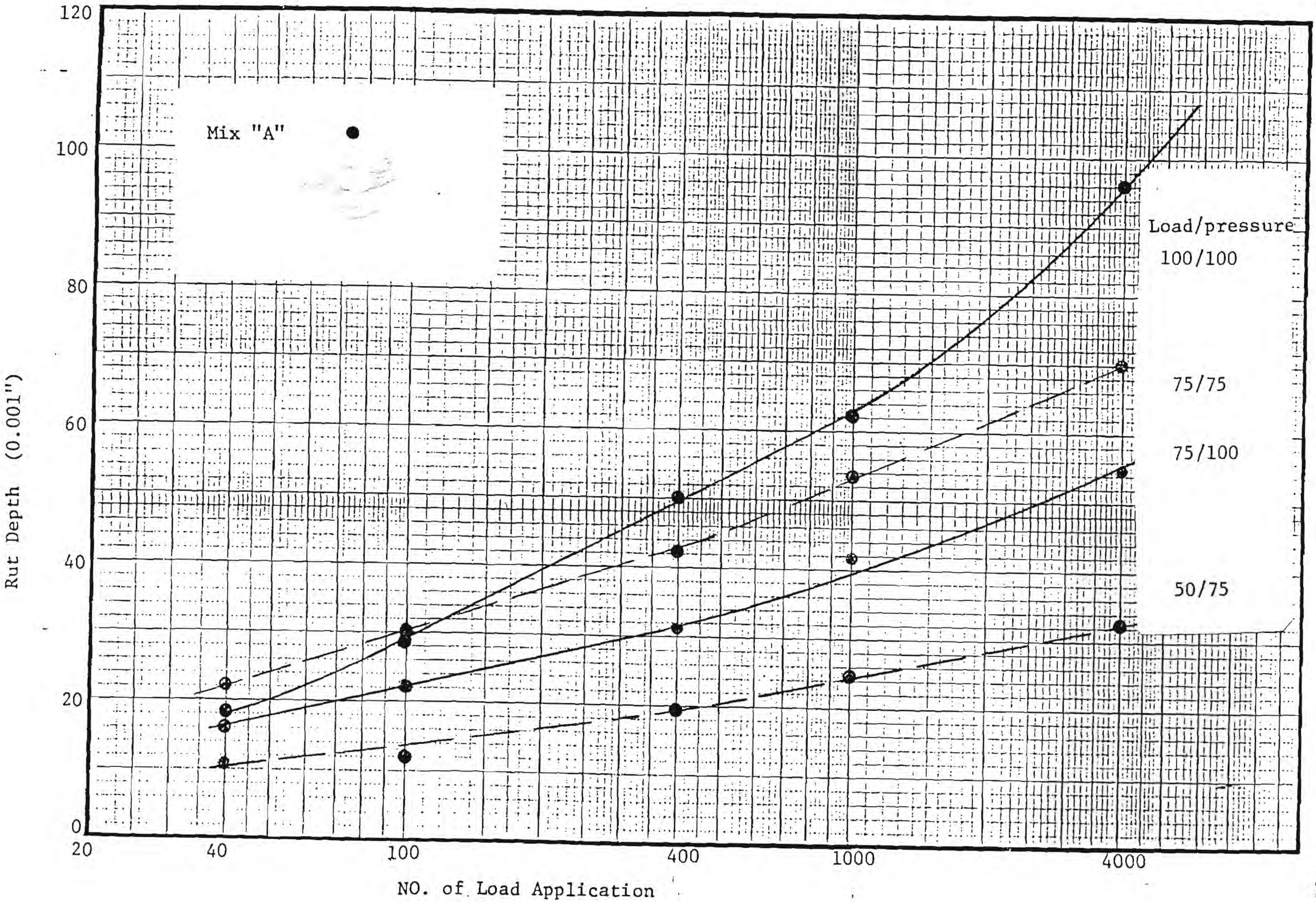


Figure 28. Modified Loaded Wheel Test Results, Mix A

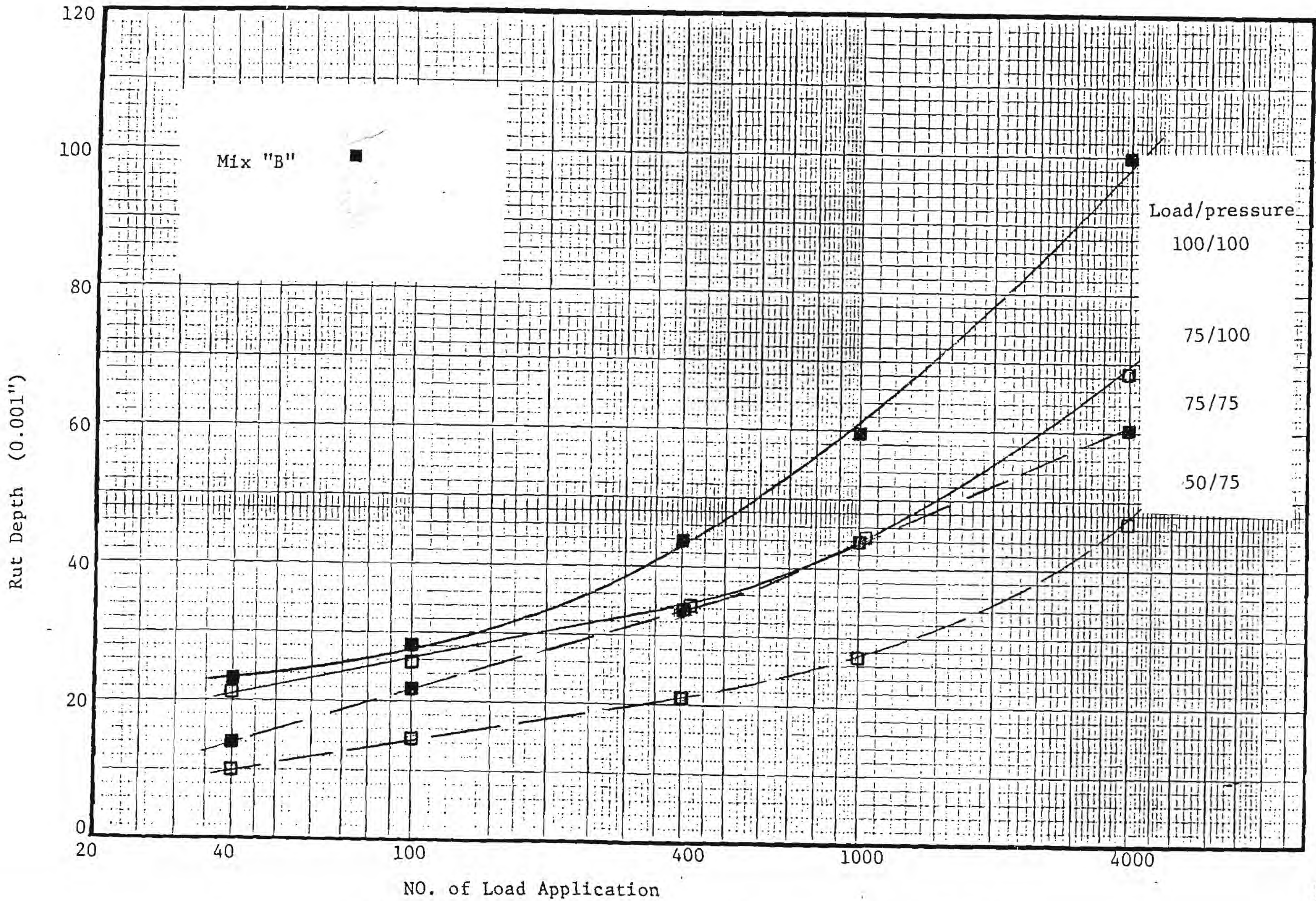


Figure 29. Modified Loaded Wheel Test Results, Mix B

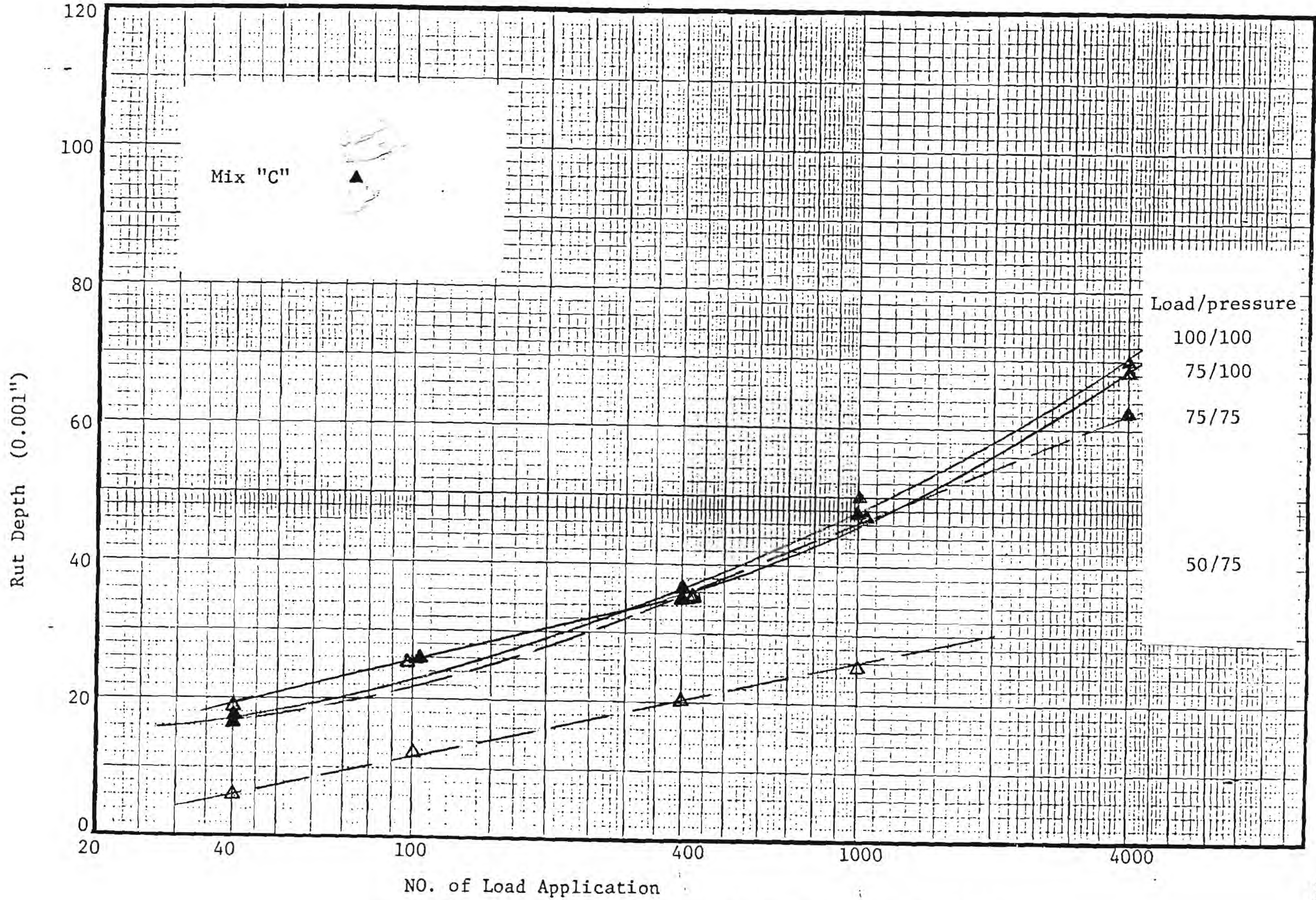


Figure 30. Modified Loaded Wheel Test Results, Mix C

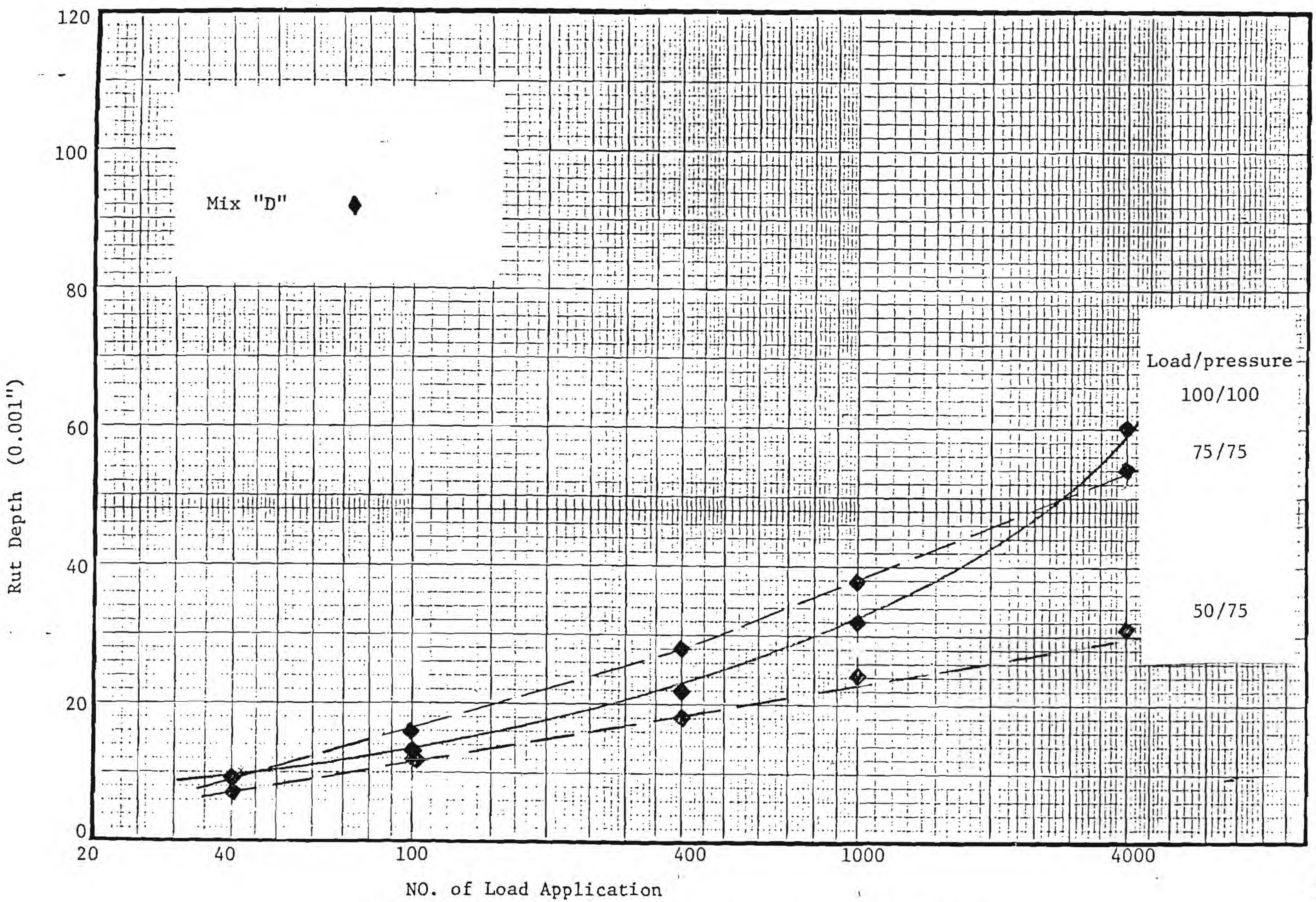


Figure 31. Modified Loaded Wheel Test Results, Mix D

rutting among the four mixes was quite small. At 50 lb. wheel load and 75 psi pressure the effects of mix types on rutting became almost indistinguishable. This suggested that under the present testing conditions, 100 lb. wheel load and at about 75 psi to 100 psi tire pressure probably would produce the best usable results in so far as assessing rutting potential of asphalt mixtures was concerned.

It is important to point out the variability of the test results. Two tests were performed at the same magnitude of wheel load (100 lb.) and tire pessure (100 psi) for Mix A, B and C. The results presented in Tables 6 and 7 indicated a high degree of variability between replicates. In view of the potential sources of errors due to sample preparations and testing, the magnitudes of the variations among the test results shown in Table 7 did not seem unreasonable. Therefore, discussions and conclusions made in this study should always bear in mind that they were presented with a certain degree of uncertainty due to the variabilities mentioned above.

8.2 Analysis of Repeated Triaxial Test Results and Creep Test Results

As mentioned earlier, these two types of tests have been used in several studies [1-5] to predict rutting tendency of asphalt concrete mix. These tests were performed in this study in an attempt to qualitatively compare their results with that obtained from the modified LWT. The results of the triaxial repeated load tests and the creep tests are shown in figure 25 and 27, respectively.

In Figure 25 all four curves from the repeated triaxial tests exhibited a very slow accumulation of the permament deformation, approximately 0.01 in. from the 40th cycle to 400th cycle; and 0.005 in. from 400 cycles to 4000 cycles. Actualy the accumulation of the permament deformations from 40 cycles to 4000 cycles for all four mixes were nearly the same. The differences in the total permanent deformations among the four mixes occured in the first 40 cycles. Based on the trends exhibited on these figures, this very slow rate of accumulation of permanent deformations would continue if the repeated triaxial load tests were to continue from 10,000 cycles to 100,000 cycles and, perhaps, beyond. Therefore the effects of load repetition on the development of permanent deformation for different mixes could not be accurately assessed by this test with the testing conditions used in this study. An increase of deviatoric stress would increase the rate of permanent deformation on the test specimens so that differences in the responses among the different mixes could be revealed.

In Figure 27 the rates of the total deformation under 15 psi unconfined creep loading among the four mixes were much faster than that of under the repeated load triaxial loading conditions. Judging from the magnitude of the total formations, the magnitude of the applied stress was about right. Among the four mixes, Mix A and Mix B exhibited the highest and next to the highest total deformation, and Mix C had the lowest total deformation. The total deformation during the initial loading period for Mix D was quite close to that of Mix C, and the rate was steadily increased faster than that of Mix C as the duration of the loading increased.

It is to be noted that the deformation obtained from the creep tests described above were the "total deformation" and not the permanent deformation. Figure 32 illustrates the total deformation (in solid line) under a constant stress and two delay recovery curves and the associated permanent deformations if the applied stress were removed at time T1 and T2 respectively. The only way to obtain the permanent deformation experimentally is to apply loading-unloading type creep test and to measure the entire creep and recovery strain history through the test period.

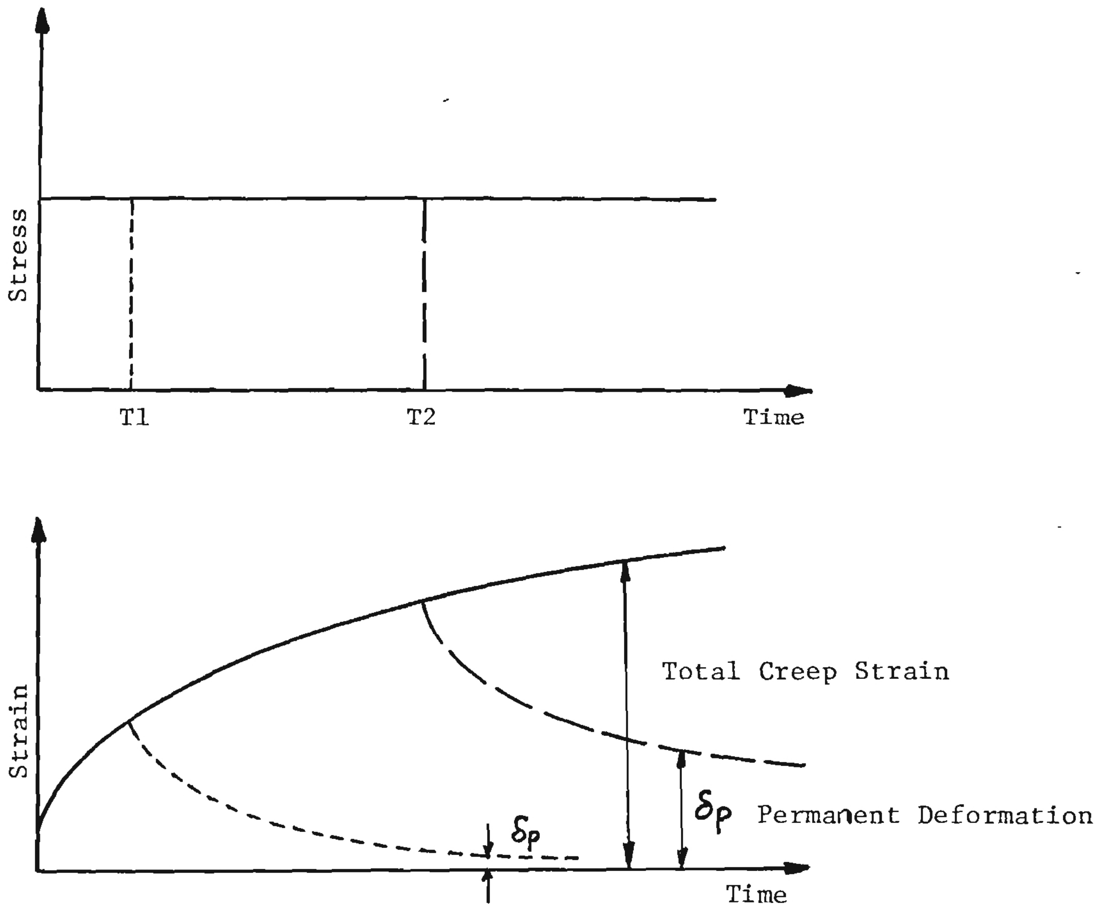


Figure 32. Creep and Recovery Behavior of Viscoelastic Materials

Results in Figure 25 and Figure 27 showed a similar pattern. The order of permament deformation developed from the repeated load tests and the total deformation from the creep tests among the four mixes was the same with only exception being Mix C and D at the initial period of loading. It was interesting to note that in both tests Mix D exhibited higher rate of deformation than that of Mix B and Mix C. Based on the limited test results presented in Figure 25 and Figure 27, it seems that both types of tests can generated deformatiion characteristics of asphalt concrete, provided a proper set of testing conditiond is used. For a viscoelastic material, such as an asphalt mix, a creep test can basically measure the quasi-static time-dependent (including permanent deformation) behavior of the material, while a repeated load test measures the resilient behavior and the cumulative permanent deformation under a repetitive load-unload-reload pattern. These two types of deformation, although they were obtained from two different tests, are related and one can be predicted from the other, if the material is strictly following the linear viscoelastic behavior [31]. Unfortunately, an asphalt mix is not strictly a linear viscoelastoc material and therefore strictly speaking the permanent deformation of asphalt pavement under repetitive wheel loads cannot be predicted accurately from either one of the test results due to the complex stresses induced in a pavement under a moving wheel load. Either one of these two tests is no more accurate than the other in predicting or assessing the pavement rutting behavior.

The question as to the relevency of the results of the deformation from either one of these tests to the potential rutting of the same asphalt mix placed on a highway pavement is a difficult one to answer. Extensive research works performed in the past, see references cited in this report, on predicting asphalt pavement rutting from creep and/or repetitive load tests have met only a limited degree of success. Differences in material preparation of the laboratory samples versus the field compaction, differences in loading conditions and of the boundry conditions as well as the enviromental effects are just a few of the variables that could hinder the predictability.

8.3 Comparision of LWT Results with Creep Test Results

Since the characteristics of the creep test results and that from the repeated triaxial load tests are similar, the results from the creep tests only will be used to compare with the LWT test results in the following. Comparsions of Figure 19 and Figure 27 show some interesting differences in the permament deformation characteristics of the four miixes.

Figure 19 shows that the rut-depth increased from about 0.01 to 0.02 in. at 40 cycles of repetitions to about 0.06 to 0.1 in. at 4000 cycles, an increase of about five times. Figure 27 shows that the total deformation increased from about 0.02 to 0.04 in. at 40 seconds of load duration to about 0.04 to 0.08 in. at 4000 seconds of load duration. That is the total creep strain developed in the first 40 seconds was about the same as the additional creep strain developed from 40 to 4000 seconds. If the recoverable strain can be separated from the total creep strain, then the rate of accumulated permament strain versus the duration may be more reasonable. It would be difficult experimentally to separate these two components. The trends of the accumulated rut-depth versus the number of repetitions applied from LWT tests seem more comparable with the characteristics of the rut-depth versus the number of wheel loads in an actual pavement.

Among four mixes used in this study, Mix A exhibited high rutting in LWT tests and high creep strains in the creep tests, Mix C exhibited moderate rutting and creep strains in both tests, Mix D exhibited low rutting and low creep strains, although the rates in both tests had the tendency to increase. Mix B was the one which exhibited very different responses between these two tests. In the LWT tests, Mix B exhibited a very high rutting tendency, about as high as that of Mix A. On the other hand, the same mix exhibited the lowest creep strain in the creep tests. There is no apparent explanations as why this particular type of mix exhibit such a different responses in these two tests.

Based on the characteristics of the results from the LWT tests and creep tests, and for that matter the repeated load triaxial tests, the LWT test results seem to have produced the results more in line with the rutting characteristics experienced on asphalt pavements. Origionally these four mixes were chosen for this study with each mix exhibited different degree of rutting tendency in four different pavement projects. Comparision between the field rutting characteristics and the magnitude of rutting from LWT tests of each mix would provide a means to assess the applicability of the LWT tests in predicting the rutting potential of asphalt mixes. Unfortunately, there were many variables which could hinder this effort. The differences in the bulk density and the air voids of the origional Marshall mix designs for the projects and that obtained in the study, as well as other variables such as the differences in the field compaction efforts among the origional projects, and their subsequent traffic conditionsns are some of the variables that may contribute to the differences in the rutting characteristics of the four mixes in the field and in this study. Therefore attempts to draw conclusion on the correlation, if any, and the validity of the correlation among these four mixes in terms of the rutting observed in the field versus that from the LWT tests should be made with great cautions.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusion

The modified loaded wheel tester used in this study has demonstrated its capability in evaluating the rutting characteristics of asphalt concrete samples. Results of the rutting characteristics of the asphalt mixes tested with this apparatus were more compatible with the rutting characteristics normally experienced in asphalt pavements under vehicular loading. Other laboratory testing methods, the quasi-static creep test and repeated load triaxial test were performed. The characteristics of the total creep strain from the creep test and the permanent deformation from the repeated load test were less compatible with the rutting characteristics of asphalt pavement under traffic.

The present study has shown that the modified loaded wheel tester is relatively simple to perform in a laboratory enviroment and the results obtained from the test has the potential for being used to assess the rutting characteristics of asphalt mixes. It is suggested that further research be conducted to develop a refined testing apparatus based on the loaded wheel principle and to conduct a test program for the purpose of establishing positive correlation between the laboratory and fielf performance of rutting tendency of asphalt mixes.

9.2 Recommendations

The rutting tests performed using the modified loaded wheel tester have shown that the concept of the loaded wheel as a simplified rut predicting apparatus is workable. From the observations made in this study, the following suggestions are made for further research in this area:

Modification of Apparatus

A) The reciprocative action of the moving wheel causes longer duration of loading at the ends of the beam sample. Also, the momentum gained by the wheel causes it to skid at the ends of each stroke. As a consequence of these, excessive deformation occurs at the sample ends. If the load and the wheel can be held stationary while the beam is subjected to a forward-backward motion under the loaded wheel, the above mentioned problems can be minimized. A double stroke bellofram cylinder can be used to move the sample under the loaded wheel. Ideally, a test sample subjected to an one-directional loading is preferred. This could better simulate the loading conditions of a pavement under the vehicular loading. Construction of a low cost machine which can generate this type of loading condtion may not be feasible, however.

B) The sagging action of the Linear Tube is likely to cause an uneven distribution of pressure on the sample. Also the Linear Tube is not of a durable nature. It wears out fast. In this study it was observed that the Linear Tube had to be replaced after about 20,000 load applications. Furthermore, the stiffness of the Linear Tube was suspected to vary with increasing rut depth or due to the loosening of the end clamps. Considerable amount of time was lost in temporily removing and reinstalling the Linear Tube for readings to be taken. To alleviate these problem, the Linear Tube mechanism should be replacecd with a wheel such as a bicycle wheel to which pressure of about 120 psi can be applied.

C) The temporary removal and reinstallation of the load between readings is likely to cause a variation in the load applied. A double stroke bellofram cylinderr can be used to load the stationary wheel and unload it by liftinng the wheel above the beam samples when the readings need to be taken.

D) Using the Channel Section for rutting measurements took about 10 minutes to record the profile readings after each predetermined number of cycles. A better device should be developed to save time in recording the readings and also to provide more accurate readings. For example, An LVDT with a strip chart recorder may be used to accurately and rapidly measure the profile.

E) For this study, the whole room had to be heated up to 95 degrees. This is not practical for routine test purposes. A temperature controlled enviromental chamber similar to the one used for the repeated load triaxial tests will be useful for storing and testing the samples at the required temperature.

Test Program

F) It is suggesteed that a comprehensive test program be planned and carried out after the apparatus has been modified as mentioned above. The objectives of this test program are i) to establish the most ideal laboratory test conditions including the test temperature, magnitude of load and the tire pressure, characteristics of the flexible base and the side confinement; ii) to develop and carry out an statistically based test program for the purpose of establishing the correlation between the laboratory test results and the field performance of asphalt mixes. The ultimate objective of this proposed test program is to develop the test procedures and to establish the acceptance criteria based on the concept of the loaded wheel testing to be used as a supplement to the Marshall mix design criteria for the purpose of minimizing the rutting potential of asphalt mixes.

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APPENDIX A

GaDOT Mix Design Worksheets

Marshall Mix Design Data

Sample Preparation Data