MONTANA STATE UNIVERSITY

Permanent deformation characteristics of asphalt-aggregate mixtures using varied materials and molding procedures with Marshall method
by Murari Man Pradhan

A thesis submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Civil Engineering
Montana State University
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Abstract:
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Validation of the laboratory findings was made by field performance testing of the materials and methods. The post-construction performance monitoring of polymer-modified, and control sections was conducted by recording the distresses observed in the section. A Rainhart profilograph was used to record the pavement rutting. Other distresses such as transverse and longitudinal cracks and bleeding were recorded according to the SHRP distress manual. The core specimens were investigated for Marshall test properties. Air voids of the cores correlates with the rutting.

An analysis of variance (ANOVA) test was conducted to evaluate the effects of different treatments. A Student-Newman-Keuls range test was then conducted to check the mean values of each treatment for significant differences.

The modifiers significantly improved the high temperature properties and reduced the rutting in the pavement. The low temperature properties were not significantly changed. This also validated the SHRP performance based binder tests. A PG64-46 binder is required to combat temperature extremes. The specification of the Kraton modified binder is only PG64-22. The modifiers should be used in conjunction with the fully crushed aggregate to reduce premature rutting.

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Doctor of Philosophy

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Civil Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

February, 1995

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Murari Man Pradhan

Advisor: Joe D. Armijo, Ph.D., P.E.

Montana State University
1995

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 6/5/95

I dedicate this thesis to my late grandparents, Hiralal and Baba Nani Raj Bhandari, my parents and family, and to my teachers. Their collective contribution through their teachings, experience, knowledge and wisdom has made it possible for me to be what I am today.

VITA

Murari Man Pradhan, son of Raunak Man and Nanda Pradhan, was born in Patan, Nepal on November 10, 1947. He passed the School Leaving Certificate (SLC) examination from Juddhodaya Public High School, Kathmandu, and Intermediate Science from Public (Amrit) Science College, Kathmandu in 1965. He received his Bachelor degree (B.E.) in Mechanical Engineering from Andhra University, India in 1970. He also received a Diploma in Public Administration (DPA) from Tribhuvan University in 1973. After working for seventeen years in the engineering field as a Divisional Engineer to HMG of Nepal, he went back to school and completed his Master of Science (MS) degree in Industrial and Management Engineering from Montana State University in 1989. He continued his education to receive a Master of Science in Civil Engineering in 1990 from Montana State University.

ACKNOWLEDGMENTS

This research was carried out under the supervision of Dr. Joseph D. Armijo. I am indebted to Dr. Armijo for his guidance and valuable insight in several phases of research, both in the laboratory and in the field. I am especially grateful for his constant encouragement and unwavering support at periods of uncertainties and difficulties for the entire duration of this research endeavor.

I am thankful to Dr. Theodore Williams, Dr. Richard Brustkern, Dr. Howard Peavy, Dr. Warren Jones, Dr. Jerry Stephens, and Dr. Calvin Kaya for serving as the committee members. Sincere thanks are due to Dr. Donald W. Boyd for his guidance in data analysis and to Mr. Joseph Leatham of Utah Department of Transportation for correcting my english.

Funding of this research was provided by Montana Department of Transportation (MDT), Montana State University (MSU), and California Department of Transportation (CALTRANS). I wish to express my appreciation to Bob Garber of MDT, John West of CALTRANS, MSU, and Bill Ogle of Kenyon-Noble for crushed aggregates.

I am thankful to my colleagues at MSU: Capt. Bob Tipton, Julia Grenheck, Gayle Maurer, Brian Wacker, Kurt Hafferman, Robert Murray, Matt Strizich, Chris Budesky, Satya Malla, David Johnson, Brian Hensen, Don Graham, John Schwarz, and Molly Schwarz.

Finally, I would like to thank my wife, Mrs. Sandhya Pradhan, for her constant support and understanding. I am especially grateful to her for taking the responsibility of raising our three children. My daughters, Saphu, Inu, and Kumuda also deserve my appreciation for their cooperation with my busy schedule during this period.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Problem Statement

Most highway pavement surfaces are made of asphalt. Extensive infrastructure development was made possible by the use of asphalt as a paving material for the past six decades. Rapid traffic volume growth has brought the need for many innovative changes in the application of asphalt as a highway material. Asphalt is one of the most versatile and economical paving materials available.

Asphalt provides cohesion and durability to the aggregate in an asphalt-aggregate mixture. The physical mixture characteristics that provide the stability to support traffic loadings include: internal friction associated with the bulk density; the shape, size, and roughness of the mineral particles; and the grading of aggregate mix aided by the asphalt cohesion. Mixture stability is a function of the internal resistance due to the real and apparent cohesion and interlocking of the mineral particles. The viscosity of the bituminous mortar (asphalt cement) provides a viscous resistance due to the shear resistance. However, the asphalt contribution to the resistance is a function of its rheological properties which can vary with temperature, time of loading, aging as well as initial hardness. The mass viscosity and cohesion of the asphalt-aggregate mixture are extremely sensitive to changes in these factors.

In recent years, highway agencies have experienced premature distresses in the performance of the asphalt concrete pavements, both new construction as well as existing pavements. The most common types of distresses encountered are rutting, thermal cracking, fatigue cracking, raveling, and weathering. While fatigue and thermal cracking are major concerns relative to the performance of the asphalt pavements, rutting of the pavement is assuming more significance (Warburton, Robert G., et al., 1984).

Rutting in the asphalt pavement develops gradually with increasing numbers of load applications, usually appearing as longitudinal depressions in the wheel paths accompanied by small upheavals to the sides. Permanent deformation is usually one of the principal causes of pavement rutting. The repetitive action of traffic loads result in accumulation of permanent deformations in the asphalt pavement. Increase in rut depths may contribute to traffic safety problems. First, when rut depth is about 0.2 inches, the ruts trap water leading to the potential for hydroplaning. Second, as the ruts progress in depth, steering becomes increasingly difficult for trucks and trailers. Therefore, it is important to investigate rutting mechanisms as well as methods to evaluate mixture rutting propensity. The major causes of rutting are:

1) Increased number of heavy trucks in the traffic stream.

2) Increased contact pressure resulting from higher tire pressures due to the use of radial tires as opposed to bias ply tires.

3) Increased axle loads.

4) The presence of asphalt-aggregate mixtures susceptible to excessive permanent deformation under the predominating environmental and traffic conditions.

Conventional asphalt cement used as a binder in asphalt-aggregate concrete mixtures, in some cases, has significant limitations with regard to performance over wide range of temperatures. If softer asphalt is used, cracking may be reduced, but hot summer temperatures bring rutting. Simply stated, some pavements which are too hard and brittle in the cold winter months result in cracks. Temperature susceptibility and resulting pavement distress appear to be inevitable unless something can be done to improve the characteristics of the asphalt.

In recent years, commercially available modifiers have entered the market with claims that their addition to asphalt mixtures will decrease temperature susceptibility. Past studies and manufacturing literatures contain valuable information on selection and use of modifiers. However, because of the diversity of asphalt from one geographical region to another, such information can only give general guidance to the new user of modifiers. There is a vast number of these modifiers available on the market today with different brand names, chemistry and composition. Extensive studies have been conducted to investigate the benefits of using these modifiers, but the results have been inconclusive and in some cases even conflicting for the same modifiers. This, in part, is due to many variables involved in asphalt concrete mix designs using modified asphalts.

During 1988 and 1989, initial research on asphalt modifiers was performed at Montana State University (MSU). It was found that two modifiers, Kraton 4141G from Shell Chemical and Polybilt from Exxon Chemical, improved the asphalt properties to a greater degree than the other modifiers tested. Kraton is a thermoplastic block copolymer rubber, while Polybilt is a copolymer of ethylenevinyl acetate (Pradhan, Armijo, 1993).

One of the primary roles of a modifier is to adjust the temperature susceptibility of the asphalt to the service temperature range. Asphalt modifiers change the binder's rheological characteristics thus improving the asphalt mixture performance in a given service temperature range (Khosla, 1988; Monismith and Tayabali, 1988; Yao and Monismith, 1986; Armijo and Pradhan, 1990; Tayabali, 1990). Asphalt modifiers improve the permanent deformation resistance of asphalt-aggregate mixtures to some extent, and, in some cases, make this solution an economic alternative.

Another component of asphalt pavement is aggregate. The aggregate size, texture, gradation, and composition also contribute greatly to strength, stability, and the resistance to permanent deformation of the pavement. The dense graded material is an aggregate blend that primarily develops strength from aggregate interlock. The introduction of large stone increases the volume concentration of aggregate in the mix which, in turn, improves its bearing capacity. The objective of using large stone mixture is to change the basic structure of the mix so that the traffic load is supported by direct stone-on-stone contact.

In laboratory investigations of asphalt-aggregate mixtures, compaction of asphalt test specimens play an important role, both in large stone and conventional aggregate sizes. Laboratory compaction should simulate compaction as it occurs on the roadway. However, it is also of importance to evaluate stabilities that can be obtained by compacting specimens to the most optimum aggregate arrangement possible.

The existing empirical mix design methodologies based on the Marshall and Hveem tests are the most widely used for conventional asphalt mixtures. These methods need to be employed to evaluate asphalt-aggregate mixtures with modifiers and large stone aggregate mixtures.

The final evaluation of the performance of any material and design method is the actual test section. The validation of the laboratory findings can only be accomplished by field verification of the in-situ performance of the materials. Validation of the laboratory findings is dependent on the close monitoring of the construction methods during installation of the modified asphalt test section and ccareful analysis of the performance testing results from the evaluation period.

Purposes and Objectives

The purpose of this research is to investigate:

1) Variability of the modified asphalt binder of the same grade from one source to another.

2) Consistency of the modified asphalt binder properties from one time period to the next.

3) Effects of the polymer modifiers, Kraton and Polybilt, in the molded specimen using conventional and large-stone aggregates.

4) Effects of the aggregate texture and shape, rounded and fractured, in molded specimens using large-stone aggregates.

5) Effects of the compactors, (Marshall hammer and California Kneading) utilizing modified and unmodified asphalt binders to form molded specimens with conventional and large-stone aggregates.

6) Effects of specimen preparation methods, Marshall and Hveem, on conventional aggregates mixes.

7) Effects of the compactive effort, 75 and 112 blows of the Marshall hammer, to specimens prepared with modified binder and large-stone aggregates.

8) Effect of moisture induced damage on modified asphalt and conventional aggregate mixes.

9) Effect of mineral filler on large-stone aggregates mixes with modified asphalts.

10) The relationship between the test properties of the conventional and large-stone aggregates.

11) Experimental test section using the polymer-modified asphalts and conventional aggregates.

12) The relationship between the field performances and laboratory test results including performance based Strategic Highway Research Program (SHRP) tests.

13) The basis for comparing modified binders, selection of modifiers, and amount of modified asphalts to be used for mitigating the propensity for permanent deformation in conventional and large-stone aggregate mixtures.

14) Possibilities for further research programs.

Particular emphasis is placed on the development of the laboratory specimen preparation of large-stone aggregates using the modified asphalt and on the measurements of distresses of field experimental test sections.

Scope of this Study

The purpose of this research is to study the applicability of the Marshall test properties to the polymer-modified asphalt binder and large-stone aggregates specimen prepared with different methods and compactors. The behavior of asphalt-aggregate mixtures, under different specification, preparation methods, and different compactors should provide a basis for evaluation and comparison with asphalt concrete pavement performance. The experimental field test will require constant monitoring for several years to provide meaningful results. One can identify material properties associated with a distress mechanism (performance criteria) as it occurs in the field. This can be accomplished by reviewing records obtained in the process of periodical monitoring. An attempt has been made to associate or correlate the laboratory test results with the pavement performance.

Among the several performance criteria (distress mechanisms) associated with asphalt concrete pavement, only permanent deformation (rutting) and thermal cracking characteristics of asphalt concrete pavements are addressed in this study. Also, records of several other distresses are made as they occurred in the test section.

There are numerous asphalts, modifiers and aggregate types and combinations. The variables associated with the asphalt concrete pavement are; temperature, asphalt content, specimen preparation methods, compaction effort, test conditions, aggregate size, gradations, shape, and texture, and mineral filler. The permutation and combination of these factors to be studied leads to an astronomical number. This study tries to account for each of these factors in appropriate numbers of asphalt and modifier combinations and aggregate size, gradations and textures to reflect their effects to the statistical significance. A statistical experiment is designed for a set of combinations of the factors concerned. An ANOVA test was conducted to evaluate the effects of different treatments. A Student-Newman-Keuls range test was then conducted to check the mean values of each treatment for significant differences. The details of experimental design and ANOVA for the combination of variables is explained in Chapter 6.

Research Approach and Organization

The research work spanned over three years in three phases. Each phase consisted of a set of variables, asphalts, modifiers, aggregate size, shape and gradation, specimen preparation methods, and compactors used.

The Marshall design parameters were sensitive to the shape and texture of both the conventional and large-stone aggregates. Two types of large-stone aggregates were investigated, one with at least four fractured faces and another with at least two broken faces. The aggregate with at least four broken faces was prepared by crushing the large boulders in a commercial impact crusher that yielded a cubical shape and sharp texture. The test results compared with the results of aggregates with at least two broken faces gave us the effects of shape and texture on aggregate-asphalt mixtures. Two gradations of large-stone aggregates were investigated.

The specimens produced from the California Kneading compactor were known to simulate pavement conditions better than those produced from the Marshall hammer. An attempt was made to distinguish variations in the test properties between the specimens prepared with the Marshall hammer and the California Kneading compactor. Also, the variations of the Marshall test properties between the Hveem and Marshall methods of specimen preparation were investigated.

All four Montana asphalts (Cenex, Conoco, Exxon, and Montana Refining) were used with and without modifiers. Two polymer modifiers were used. They were identified by their commercial brand names, Kraton and Polybilt.

This thesis is organized into several chapters according to the sequence of the research. Chapter 2 presents summary of literature review concerning permanent deformation in asphalt mixtures and recent research on the use of polymer modified asphalts and aggregate characteristics. The flow diagram in Figure 1.1 shows the overall scheme of the laboratory testings and field investigations. The Marshall mix design procedure for conventional aggregate and asphalt has already been established, and the behavior of asphalt cement is well known. The modified asphalt and large stone aggregates are relatively new to the user agencies and contractors and both are skeptical about it. Conventional physical tests were conducted to observe the consistency in the physical properties of the asphalts and modified asphalts from different time periods. The same grade and source of asphalts and modified asphalts were used. The conventional asphalt test program is shown in Figure 1.2 and discussed in Chapter 3.

The large-stone aggregates in dense-graded mixtures increase the volume concentration of aggregates in the mix which enhances the ability of the mix to resist permanent deformation under anticipated load conditions. This also improves the stability and load bearing structural capacity of the pavement. The Marshall test properties of specimens with two fractured face large-stone aggregates mixes using several compactors, compactive efforts, temperatures, gradations with and without mineral fillers, and unmodified and modified asphalts are shown in the flow diagram in Figure 1.3 and are discussed in Chapters 7 and 8 for 75 and 112 blows of Marshall hammer respectively.

It was found that the Marshall design parameters were sensitive to the shape and texture of the large stone aggregates. Investigation in this phase probed the extent of the

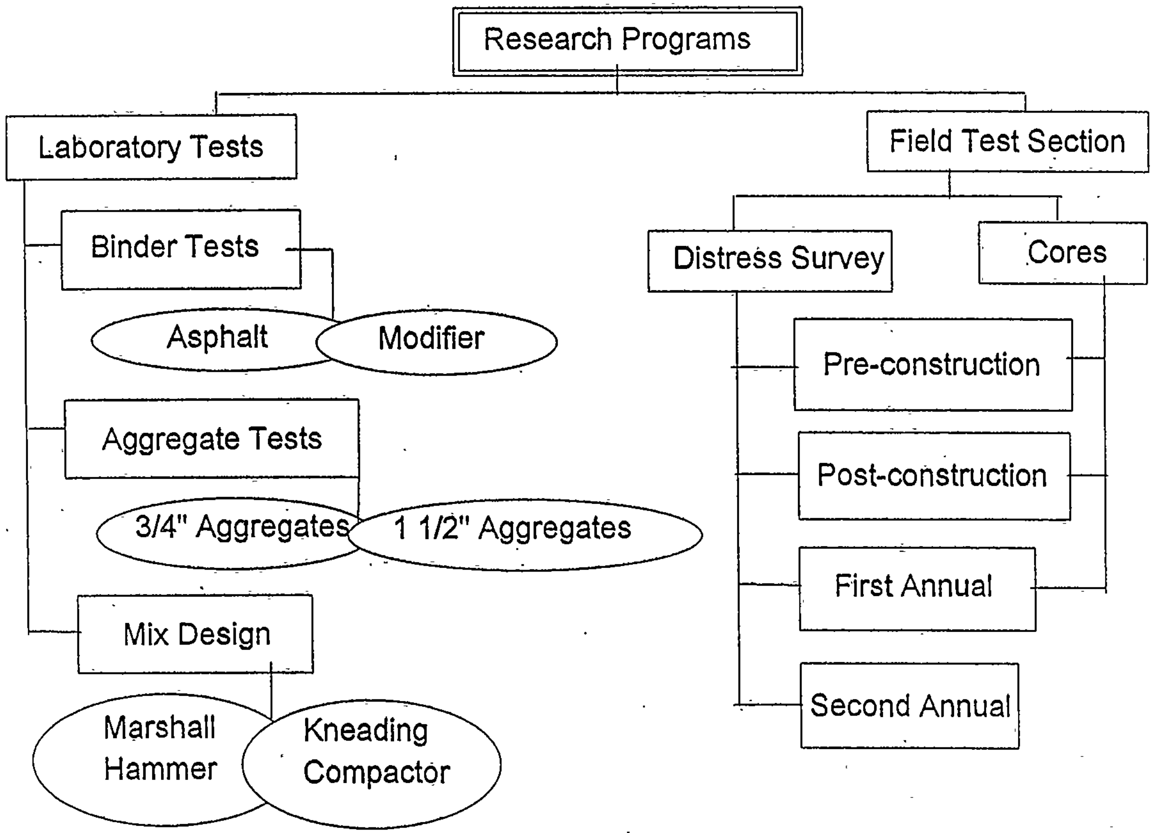

Figure 1.1. Flow Diagram of Laboratory and Field Investigations.

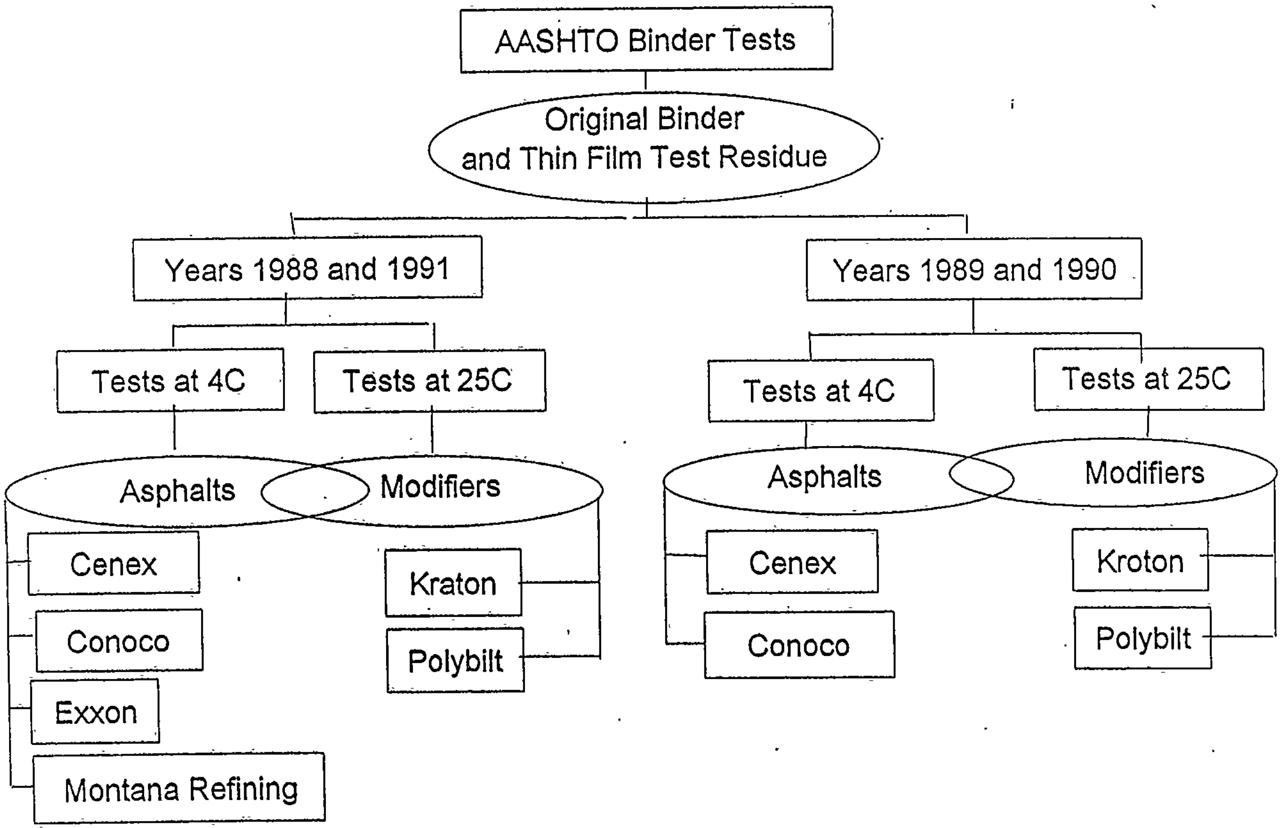

Figure 1.2. Flow Diagram of Binder Tests.

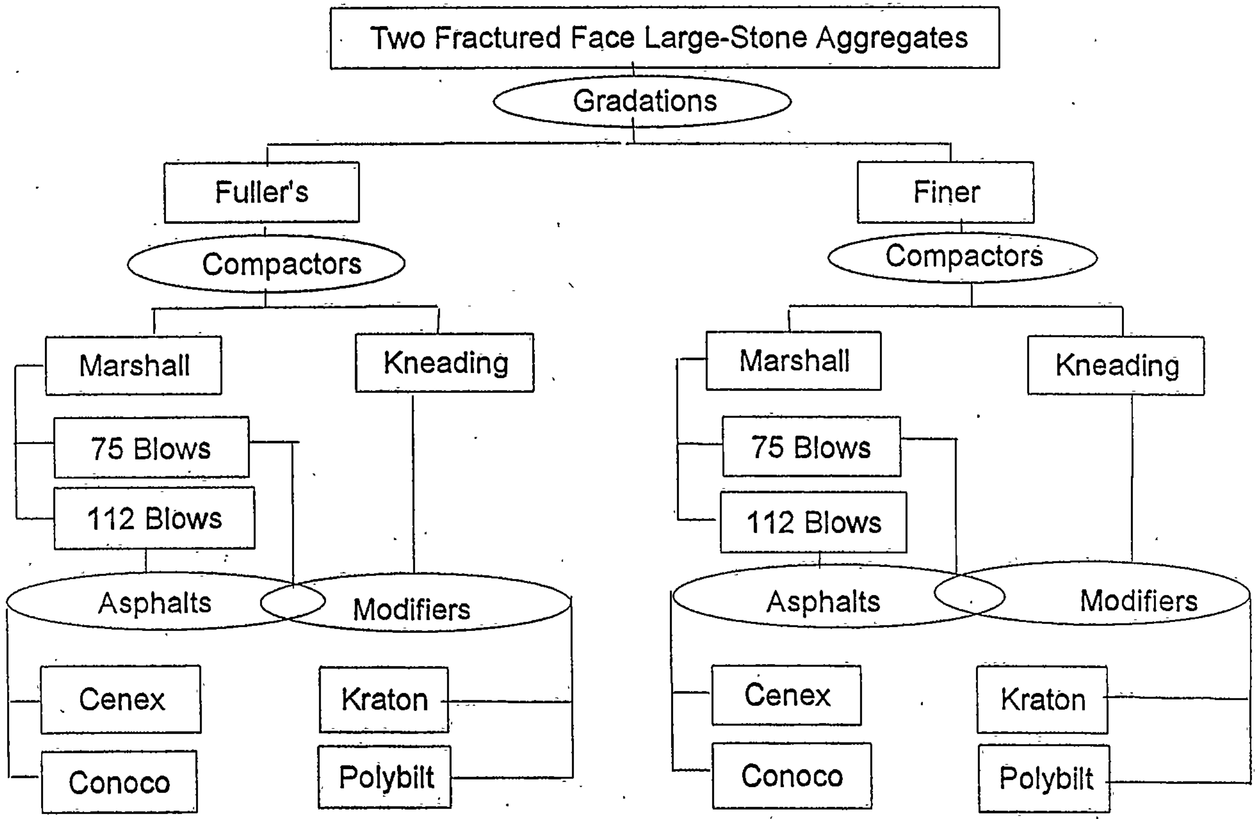

Figure 1.3 Flow Diagram of Two Fractured Face Large-Stone Aggregates.

effects of the shape and texture of the aggregates. The large stone aggregates with at least four fractured faces were prepared by crushing the large boulders in a commercial impact crusher. These specially produced aggregates had a cubical shape and a sharp texture. The aggregates from a single source, Yellowstone river, were used in all phases of the research. The variables considered in this phase were two compactors, the California Kneading and the Marshall hammer with two different compactive efforts. Figure 1.4 shows the flow diagram of the materials and test variables. The discussions are presented in Chapter 7, 8, and 9 for 75 and 112 blows of the Marshall hammer and kneading compactor respectively.

The effects of the mixing methods of specimen preparation, Marshall and Hveem methods, temperatures, and modifiers on Marshall test properties were investigated using conventional aggregate. The schematic flow diagram of the test program is shown in Figure 1.5 and discussed in Chapter 10. The maximum size of 3/4-inches with at least four fractured face aggregates was used to evaluate the sensitivity of the conventional test methods and to differentiate performance among asphalt mixtures containing unmodified and modified asphalts and specimen preparation methods.

The final phase of the research work is the construction and performance monitoring of the experimental test section of about six linear miles. Construction data of the polymer modified asphalt was taken and analyzed. The post-construction performance monitoring of polymer-modified section and control section were conducted by recording the distresses observed on the section. A Rainhart profilograph was used to record the pavement rutting. Other distresses such as transverse and longitudinal cracks and bleeding were recorded according to the SHRP distress manual. In addition, cores were taken from pre-

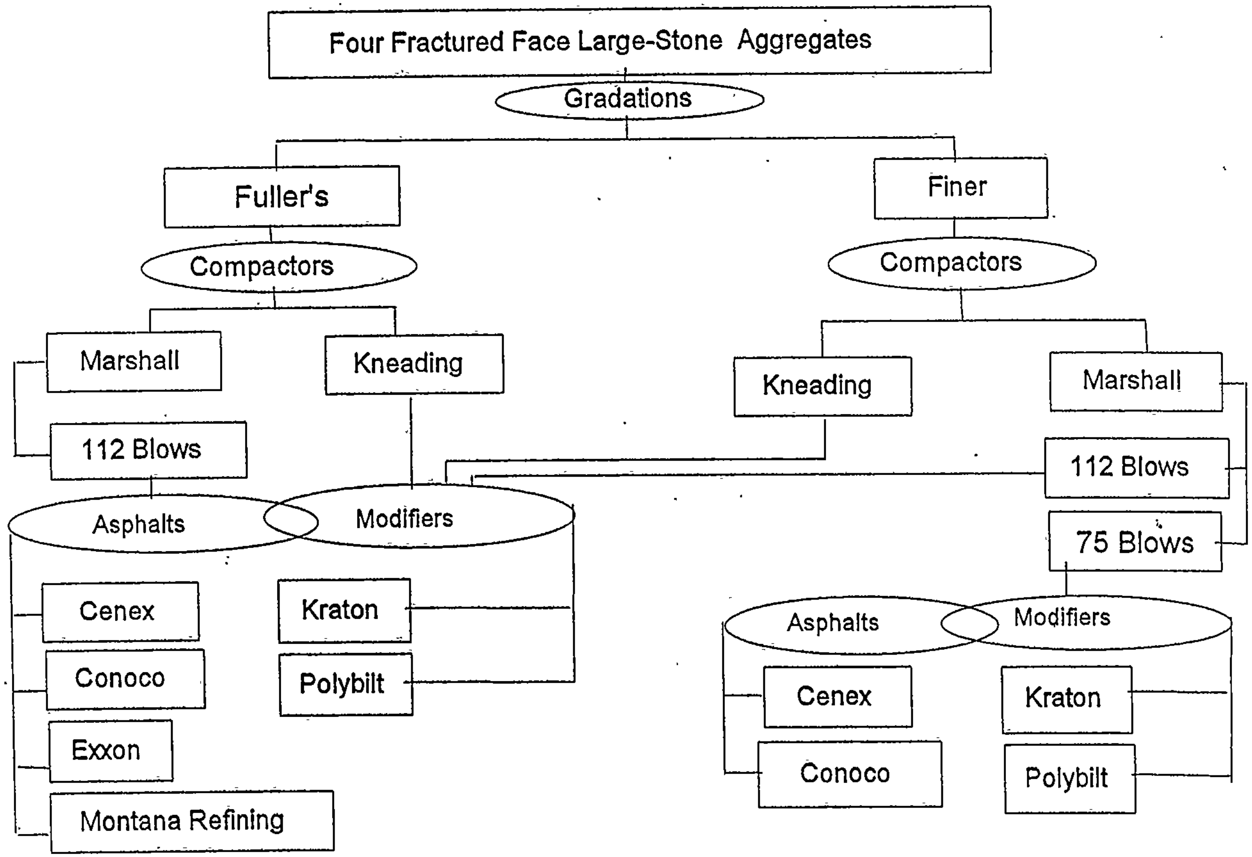

Figure 1.4. Flow Diagram of Four Fractured Face Large-Stone Aggregates.

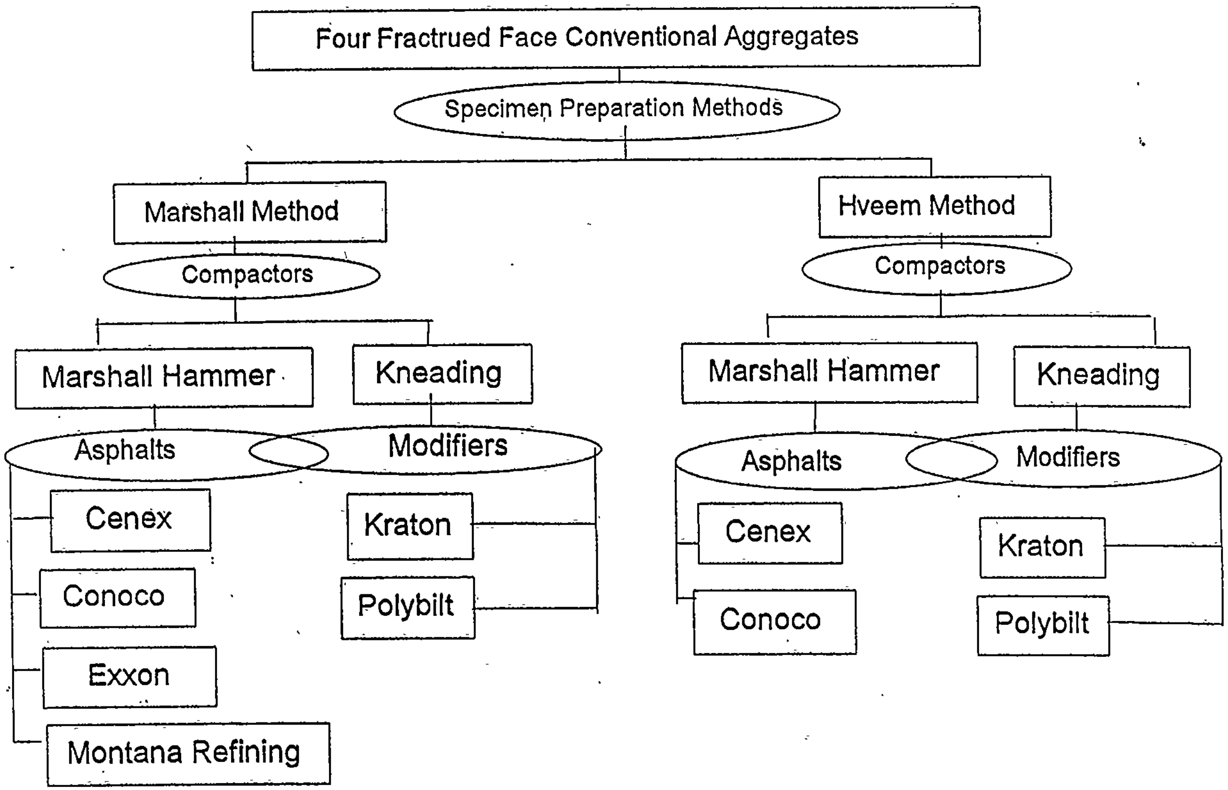

Figure 1.5. Flow Diagram of Conventional Aggregates.

construction, post-construction, and one year old pavements. The Marshall test properties of these cores were analyzed. The variables considered in this phase of research are shown in Figure 1.6 and discussed in Chapter 11.

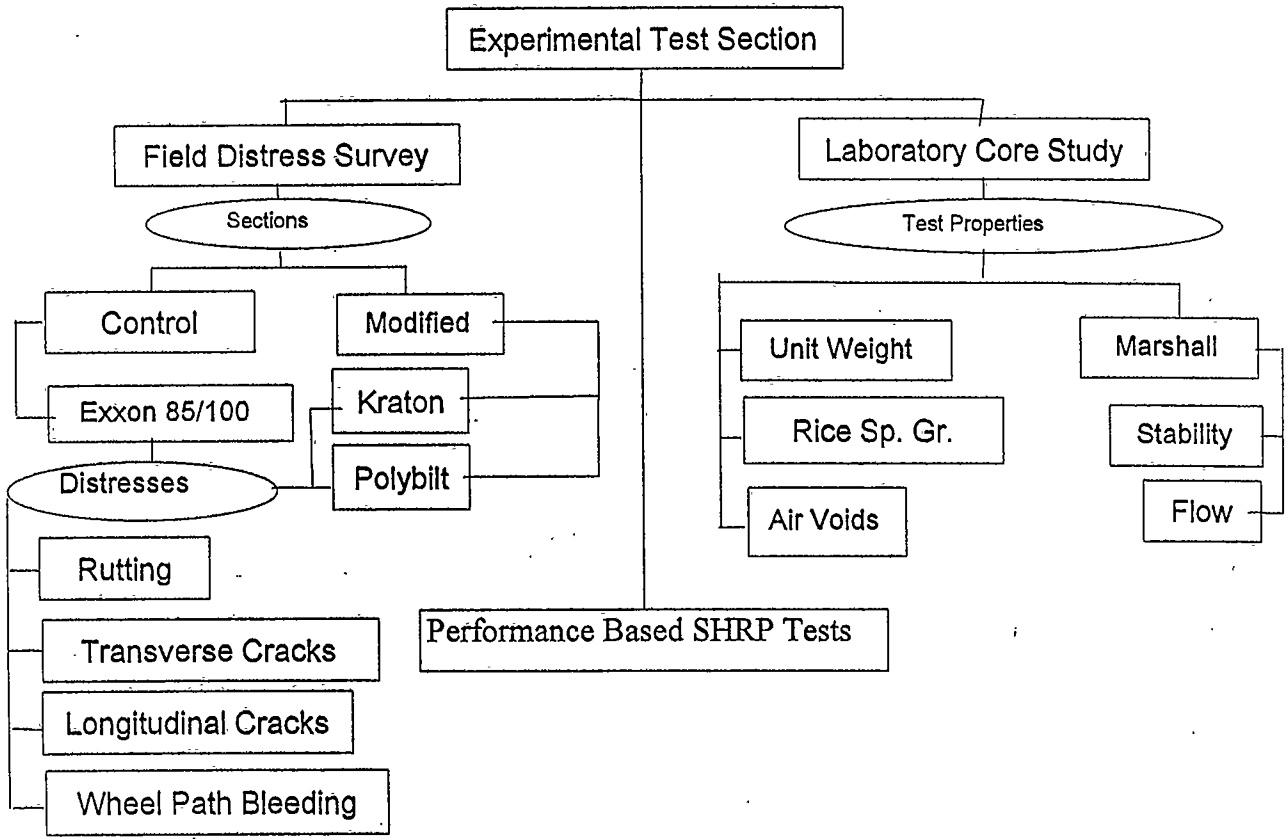

Figure 1.6. Flow Diagram of Field Test Sections.

CHAPTER 2

BACKGROUND

Introduction

Asphalt is a mixture of bituminous materials with a small amount of minerals in a variety of sizes and chemical compositions. Asphalt's tensile and adhesive strength makes it a flexible, plastic-like material. Asphalt has no melting point, it simply becomes softer and softer until it liquifies. It is a rheological material. Asphalt cement is the least expensive, most versatile material available for most applications in highway construction.

When asphalt is a solid at low temperatures, it is as brittle as glass and cracks under a heavy load. As it becomes warmer, it becomes increasingly shear sensitive, so that above 24°C (75°F), most asphalts flow under pressure and are prone to shove and rut.

Longitudinal depression along the wheel paths of the asphalt concrete pavement is the result of permanent deformation. These depressions are called "ruts" and the distress phenomenon associated with them is "rutting". Exogenous factors including load magnitude, contact stress, load repetition, and temperature are important factors affecting pavement rutting.

The rutting problem identified in the western states, for the most part, falls into two categories: 1) Excessive traffic consolidation in the upper portion of the pavement. 2) Plastic deformation due to insufficient stability or instability caused by the stripping of asphalt below the riding surface. In general the problem is not associated with subgrade deformation or failure (Warburton, Robert G., et al., 1984).

Rutting affects road users in two ways: 1) It increases the operating costs and 2) decreases the general safety of traffic flow. Previous studies (Watanatada et al., 1987) have demonstrated that pavement roughness, including rutting, can significantly affect truck operating costs. If rutting progresses past a certain threshold, i.e. rutting depths of about 0.2 inches, water is likely to accumulate in the ruts. The presence of water in the ruts can result in vehicle hydroplaning and consequent loss of traffic safety.

Mechanism of Rutting

Rutting can occur at different times in the service life of the pavement. The rutting that occurs early on its service life is most likely be associated with densification by the application of heavy traffic. The rutting associated with load and environmental conditions are a result of the shear deformation and can occur anytime throughout the life of the pavement.

One mechanism of rutting, permanent deformation, is densification (decrease in volume and increase in density) of the pavement. Another is shear deformation (plastic flow with no change in volume). Figure 2.1 illustrates two mechanisms of rutting. Trenching studies performed at the AASHTO Road Test (1962) and also results of test track studies reported at the Third International Conference in 1972 by Hofstra and Klomp (1973)