A study of California kneading compactors ability to optimise angular aggregate particle orientation and interlock of large stone asphalt mixes in Montana
by Robert Alexander Tipton

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
This thesis is prepared as part of phase III of Montana State University's on-going rutting study. This study is in response to the State of Montana's decaying infrastructure due to asphalt pavement rutting. The purpose of phase III is to study the effects of angular large-stone aggregates with asphalt modifiers. This thesis evaluates the effectiveness of the Marshall hammer and California kneading compactor in compacting laboratory asphalt specimens with angular large-stone aggregates. Additionally, since the kneading compactor evaluated in this study is the first ever used in Montana, details on the installation, operation, and maintenance of the compactor are included. The evaluation of the two compactors was conducted in two parts. The first part was to compare the compactors and draw general correlations relating their performances. The second part of the investigation included a detailed analysis on the aggregate sensitivity of the two compactors.

The California kneading compactor demonstrated that it produces a more consistent asphalt test specimen. Standard deviations for kneading compactor stability values were generally lower than those of the Marshall hammer. The kneading compactor and Marshall hammer were found to be very dependent on both aggregate shape and aggregate gradation. The kneading compactor produced samples with higher stabilities when using angular aggregates and a dense gradation. In contrast, the Marshall hammer specimens had higher stabilities when less angular aggregates were used with the same dense gradation. Neither compactor exhibited any specific trends with a less dense gradation. The kneading compactor's ability to provide more work to the sample during the compaction process was found to be a significant factor in the resulting stability values.

The statistical analysis used to evaluate aggregate sensitivity proved to be inconclusive. The analysis did indicate that the kneading compactor is potentially more sensitive. However, additional testing with numerous samples is required to provide conclusive data.

A STUDY OF THE CALIFORNIA KNEADING COMPACTOR'S ABILITY TO OPTIMIZE ANGULAR AGGREGATE PARTICLE ORIENTATION AND INTERLOCK OF LARGE STONE ASPHALT MIXES IN MONTANA

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APPROVAL

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Robert Alexander Tipton

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.

16 FEB 1993 — Date

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16 Feb '93 — Date

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Date 16 February, 1993

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ABSTRACT

This thesis is prepared as part of phase III of Montana State University's on-going rutting study. This study is in response to the State of Montana's decaying infrastructure due to asphalt pavement rutting. The purpose of phase III is to study the effects of angular large-stone aggregates with asphalt modifiers. This thesis evaluates the effectiveness of the Marshall hammer and California kneading compactor in compacting laboratory asphalt specimens with angular large-stone aggregates. Additionally, since the kneading compactor evaluated in this study is the first ever used in Montana, details on the installation, operation, and maintenance of the compactor are included. The evaluation of the two compactors was conducted in two parts. The first part was to compare the compactors and draw general correlations relating their performances. The second part of the investigation included a detailed analysis on the aggregate sensitivity of the two compactors.

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CHAPTER 1

INTRODUCTION

Over the next few years the United States will experience a myriad of changes in asphalt technology. Current field practices reflect technology of the 1930s through the 1950s. This technology served the country well until the late 1960s when traffic volumes and loads began growing at exponential rates. These volumes and loads have seriously damaged the nation's infrastructure. This damage, combined with reduced funding for maintenance in the early 1980s, has put the country in a grave position. To restore the nation's highway infrastructure, improved technology and a dramatic increase in funding is needed.

The passing of the 1991 Federal Highway bill (ISTEA) is long overdue, and is a big step in the right direction. With this increase in financial resources, it is paramount that these funds be spent wisely on promising new technologies. Efforts of the Federal Highway Administration, transportation centers and independent agencies, all coordinated through the Strategic Highway Research Program (SHRP) have yielded many possible solutions to improved asphalt pavements. Much of this research is still being tested at field sites, such as the on-going rutting study at Montana State University.

Asphalt rutting is a failure mechanism present in many of the country's highways. Rutting is a particularly acute problem in regions where temperature extremes are large. Eastern Montana represents an area where this problem is exhibited. Winter time lows reach sub-zero with the summer time highs at more than 100 degrees at the asphalt surface. Designing an asphalt pavement that resists both rutting and thermal cracking is a unique problem facing the Montana Department of Transportation (MDT). The on-going rutting study at Montana State University (MSU), funded by the Montana Department of Transportation is currently testing the effectiveness of large stone aggregates and asphalt modifiers. The purpose of these tests is to evaluate these materials' ability to resist rutting without increasing asphalt viscosity. If viscosity is increased, the pavement is subject to thermal cracking [1]. Of particular interest is the large stone aggregate shape. Phase III of the MSU rutting study is investigating whether angular shaped large stone aggregates provide more stability and thus are more rut resistant than large stone aggregates with rounded surfaces.

Laboratory compaction of asphalt test specimens is extremely important in studying the large stone aggregate characteristics of the test specimen. Obviously, laboratory compaction should simulate compaction as it occurs on the actual roadway. However, it is also of importance to evaluate stabilities that can be obtained by compacting specimens to the most optimum aggregate arrangement possible [2].

The state of Montana uses the Marshall method of mix design with the Marshall hammer to compact test specimens. Many other states use the California Kneading Compactor to compact test specimens. Within the asphalt field, no single laboratory compaction method has been shown to be the absolute best. Recent studies [3,4,5] indicate that the U.S. Army

Corps of Engineers' gyratory compactor and California Kneading Compactor produce a more representative sample than other compactors [4]. However, the National Center for Asphalt Technology has modified its Marshall hammer by angling the hammer head and has achieved results consistent with the kneading compactor [3]. Historically Montana has only used the Marshall Hammer to compact specimens in its asphalt pavement design.

Purposes and Problem Statement

The purpose of this investigation was to evaluate the effectiveness of the Marshall Hammer and the California Kneading Compactor in producing an asphalt test specimen that best demonstrates the optimum aggregate characteristics of Montana large stone aggregates.

This study provides the first research in Montana using the kneading compactor with Montana produced asphalt and aggregates. An additional goal of this report is to provide a guide to the Montana Department of Transportation on how to install and operate the California Kneading compactor.

This study also attempts to provide general correlations between the Marshall Hammer and the California Kneading compactor. Results from this thesis are to be used to support or refute the overall findings of the MSU Rutting Study [1] with particular emphasis on the value of angular large stone aggregates versus semi-rounded large stone aggregates found in Eastern Montana.

CHAPTER 2

HISTORICAL BACKGROUND

Asphalt

The first uses of asphalt pavement in road construction in the United States began in the late 1800s. These pavements used either tar, which is actually a distilled coal, or naturally occurring asphalt. One of the major sources of this naturally occurring asphalt came from Lake Trinidad on Trinidad Island in the Gulf of Mexico. Asphalt from Lake Trinidad was used to pave Pennsylvania Avenue in Washington D.C for the first time in 1876. By the early 1900s the petroleum industry evolved and a more uniform asphalt was produced as a by-product of the oil refining process. To this date, asphalt produced in these refineries is the major source of asphalt for asphalt pavement. While many improvements in this refining process have taken place, there is still variance from refinery to refinery.

The asphalt acts as a binder for the aggregate in asphalt pavement. It holds the aggregate together through an adhesive layer between the aggregate particles. Resistance to shear of any binder film between surfaces is proportional to the area of the film and inversely proportional to its thickness [6]. Thus, the larger the surface area in contact and the thinner the thickness of binder between those two surfaces, the stronger the bond and the greater the resistance to shear.

Asphalt also acts as a lubricant to allow some give in the pavement structure. The thicker the film, the more the pavement is allowed to move and the less strong the bond between aggregates. With this in mind, it is apparent that in asphalt pavement, it is desirable to avoid particle arrangement as shown in Figure 1(a). In this figure it can be seen that the contact area "I" is low. The arrangement shown in Figure 1(b) where contact area "I" is maximized is the most desirable. Figure 1(c) demonstrates that the contact area "I" in rounded aggregate is limited regardless of particle arrangement.

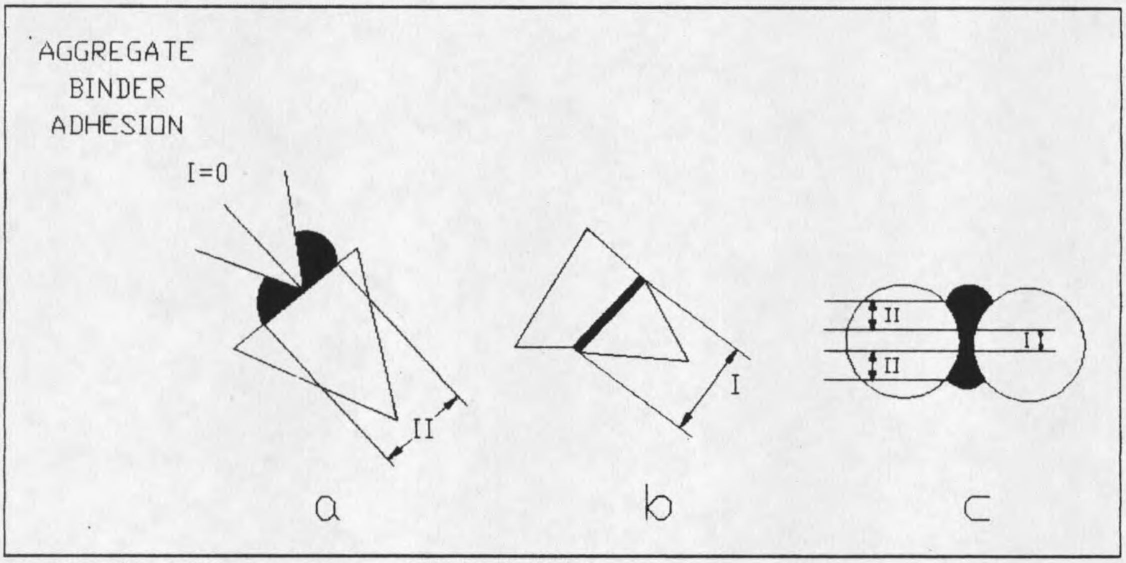

Figure 1. Adhesion Properties of Aggregates.

In recent years, asphalt modifiers have been developed. Many improve the asphalt characteristics when added. Some researchers may be putting too much stock in the benefits of modifiers in combating rutting. Asphalt modifiers can increase the binding characteristic of the asphalt which assists in resisting rutting. However, if not used with a suitable aggregate, the modified asphalt can fail as easily as an unmodified asphalt [3]. According to Robert L. Dunning, President of Petroleum

Sciences, Inc., "Rutting is caused by insufficient bearing strength of the aggregate, not a deficiency in the asphalt" [7]. The National Institute for Asphalt Technology insists that asphalt pavements must have a minimum amount of air voids to properly combat rutting [3]. Compaction, aggregate shape and gradation are key factors in the amount of air voids present in road pavements.

Aggregates

Aggregates, in asphaltic pavement, provide the actual strength and carry the majority of the loads in the pavement. " The function of the asphalt is to glue the rocks together, not carry the load, and its most important property is its ability to stress/relax by viscous flow, not its stiffness" [7]. Typically aggregate produced from an igneous rock such as basalt and dolomite are suited for use in asphalt pavement and produce pavement that is stable [3]. Phase III of MSU's rutting study is focussing on aggregate shape and its contribution to asphalt pavement's stability [1].

In the early 1900s, Frederick Warren obtained a patent for use of large stone aggregates in hot asphalt mix pavements. This patent included aggregates with an upper limit size of 3/4" to 1-1/4". This patent expired in 1920; however, due to its existence, fine grained aggregates were widely developed (1/2" or less) to avoid infringement of Warren's patent. As a result, even after Warren's patent expired, large stone mixes still were not used. The fine grained or conventional aggregate mixes exhibited excellent workability and proved to be adequate under the low tire pressures of the time. Not until the late 1960s, when tire pressures began to increase, did asphalt mix designers start considering the use of large stone mixes to counter the rutting produced by these larger tire pressures. When using large stone aggregates, aggregate shape and gradation become increasingly more important to the asphalt pavement mix design [3,6].

Professor W.S. Housel has provided an excellent analysis of the structural effects of particles [8]. His analysis, combined with V.A. Endersby and B.A. Vallerga's article on "laboratory compaction methods and their effects on mechanical stability tests for asphaltic pavements" [6], is used in the following discussion. Referring to the spherical particles in Figure 2(a), any load applied will cause the top sphere to slip down and the others to move out. Any resistance to movement, either vertically or horizontally is provided by friction only. Comparing this to Figure 2(b) it can be seen that the vertical load is resisted by geometry, while any horizontal resistance is still a result of friction only. Finally, Figure 2(c) shows that angular particles arranged properly resist both vertical and horizontal loads through geometry. While it is understood

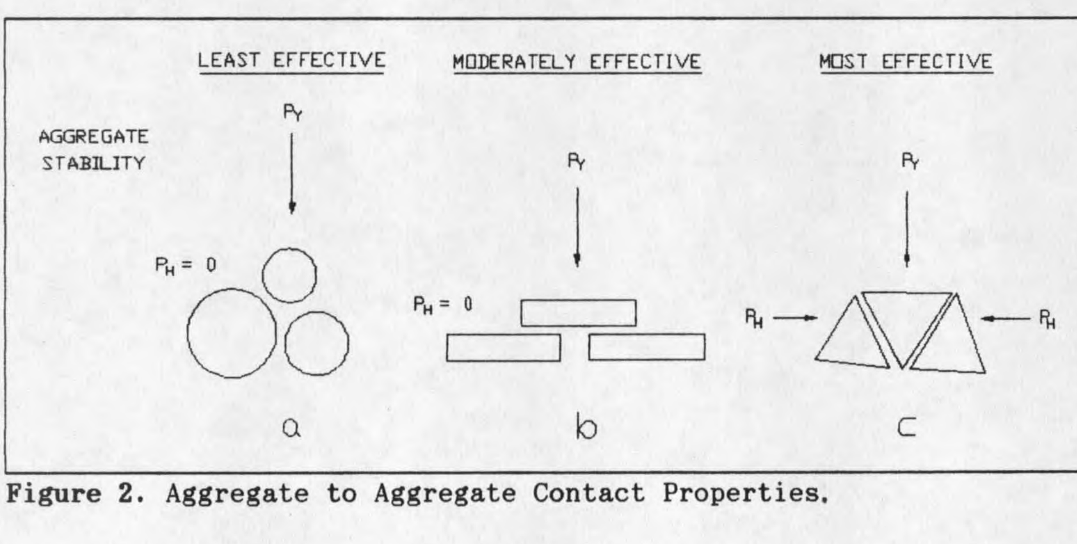

Figure 2. Aggregate to Aggregate Contact Properties.