SULFUR EXTENDED ASPHALT
PAVEMENT EVALUATION

by

Joe P. Mahoney

Prepared by the
University of Washington

for the

Washington State Transportation Commission
Department of Transportation
and in Cooperation with
U.S. Department of Transportation
Federal Highway Administration

WSDOT Contract Y-2229

September 1982

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. WA-RD 53.3

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Sulfur Extended Asphalt Pavement Evaluation

5. Report Date
September 1982

6. Performing Organization Code

7. Author(s)
Joe P. Mahoney

8. Performing Organization Report No.

9. Performing Organization Name and Address
University of Washington
Department of Civil Engineering
Seattle, Washington 98195

10. Work Unit No.

11. Contract or Grant No. WSDOT Y-2229

12. Sponsoring Agency Name and Address
Washington State Department of Transportation
Highway Administration Building
Olympia, WA 98504

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Contract Manager - Mr. Art Peters

16. Abstract

This summary report overviews two previously issued study reports. One report assesses the availability and pricing of sulfur with resepct to sulfur extended asphalt (SEA) paving mixtures. The second study report concerned a laboratory oriented testing program which was principally used to examine the durability and aging characteristics of SEA paving mixtures.

17. Key Words
Sulfur, asphalt, sulfur extended asphalt, pavement, mixture, performance, stiffness durability, aging, supply, demand.

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)

21. No. of Pages
17

22. Price

Form DOT F 1700.7 (8-69)
HWY FORM 341-004
6/72

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENT

The author gratefully acknowledges the Washington State Department of Transportation and the Federal Highway Administration for their sponsorship of the study.

INTRODUCTION

The current sulfur related research in the State of Washington is being used to examine the potential of using sulfur for partially replacing or extending the asphalt cement in asphalt concrete. The first experimental work was accomplished in a Washington State Department of Transportation (WSDOT) sponsored study entitled "Sulfur Extended Asphalt Binder Evaluation". This project was a cooperative effort between WSDOT, the University of Washington (UW), Washington State University (WSU), the Federal Highway Administration (FHWA), the Sulphur Development Institute of Canada (SUDIC) and the Asphalt Paving Association of Washington. The study involved the placement during August 1979 of sulfur extended asphalt (SEA) paving mixtures at two test sites near Pullman, Washington [1]. One site is on an existing state highway (SR 270) and the other was the WSU Test Track. Evaluation of the SR 270 test site continued through July 1982.

Because of the initial findings from the first SEA project, a second study (summarized herein) was initiated by WSDOT with UW entitled "Sulfur Extended Asphalt Laboratory Investigation". The stated goals of this study were:

1. Further evaluate the applicability and desirability of using SEA paving mixtures in the State of Washington.
2. Develop design criteria which will improve the utilization of SEA mixtures.
3. Assess the availability and pricing of sulfur in the State of Washington.

This executive summary provides an overview of the study and the two major study reports [1, 2]. These reports are briefly summarized as follows:

1. Availability of Sulfur: This report provides background regarding the uses of sulfur, types of sulfur deposits, identified sulfur reserves, current sulfur recovery technology, and the importance of price in maintaining an adequate future supply of sulfur. The report is concluded with projected sulfur supply and demand trends for the world, the United States, and the State of Washington.
2. An Examination of Fundamental Mixture Characteristics: This report provides a summary of a laboratory oriented investigation of SEA paving mixtures. The following major features are included:
    (a) Design of laboratory experiment which included the use of mixtures which contained various amounts of sulfur, two

viscosity levels of asphalt cement, and two types of aggregate (basalt and granite).

(b) Evaluation of mixture design methods (Hveem and Marshall).

(c) Determination of optimum binder contents.

(d) Evaluation of mixture durability and aging characteristics.

(f) Development of revised mixture design criteria.

In the sections which follow, a more detailed overview of the study results will be presented.

AVAILABILITY OF SULFUR

Sulfur, one of the world's most important industrial raw materials, is distributed throughout the world. More than half of the world's sulfur output is in the elemental form, nearly all of which is obtained from native sulfur deposits and natural gas. Fertilizer manufacture accounts for approximately 60 percent of all sulfur consumed, followed by chemicals, pigments, and pulp and paper.

Sulfur production is categorized as either voluntary or involuntary, depending on whether it is the primary product or a by-product from other sources. Voluntary sources include pyrite, native sulfur, and gypsum. Native sulfur is usually recovered either by conventional mechanical mining or the Frasch process. Involuntary sulfur is essentially a by-product arising from abatement of sulfurous emissions associated with processing or combustion of fossil fuels and the roasting and smelting of base metal ores. Involuntary sources include coal, oil shale, natural gas, petroleum, tar sands, and metal ore processing.

Until the 1960's, the majority of the world's sulfur supply was the result of the voluntary sulfur production. However, the advent of sour gas production in Alberta, Canada resulted in the production of large quantities of involuntary sulfur and entry into the world marketplace. By 1968, an oversupply developed, sulfur prices weakened, and a retrenchment in the fertilizer sector occurred. This led to a decline in the price of sulfur which continued through 1973. Figures 1 and 2 illustrate the above trends in that demand has exceeded production since about 1973-74 and has resulted in recent and steady price increases through 1981. Also in the early 1970's renewed interest in sulfur extended asphalt paving mixtures occurred.

Currently, the supply and demand situation for sulfur is about balanced both worldwide and in the United States; a tight supply situation has however resulted in significantly increased prices. The trend of approximately balanced supply and demand for sulfur is expected to continue to the year 2000, but a number of factors could change this

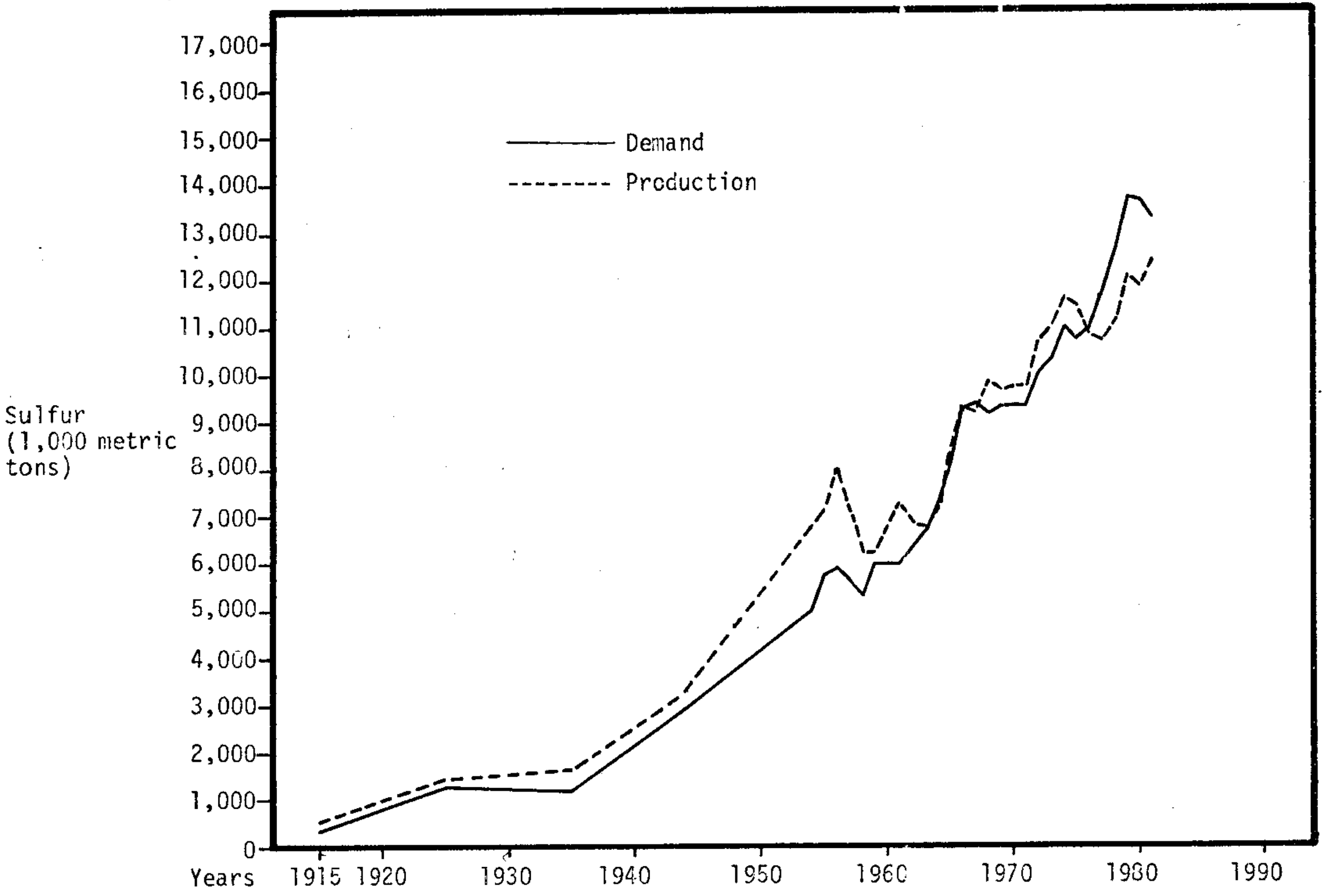

Figure 1. Domestic Sulfur Production and Demand, 1915 - 1981

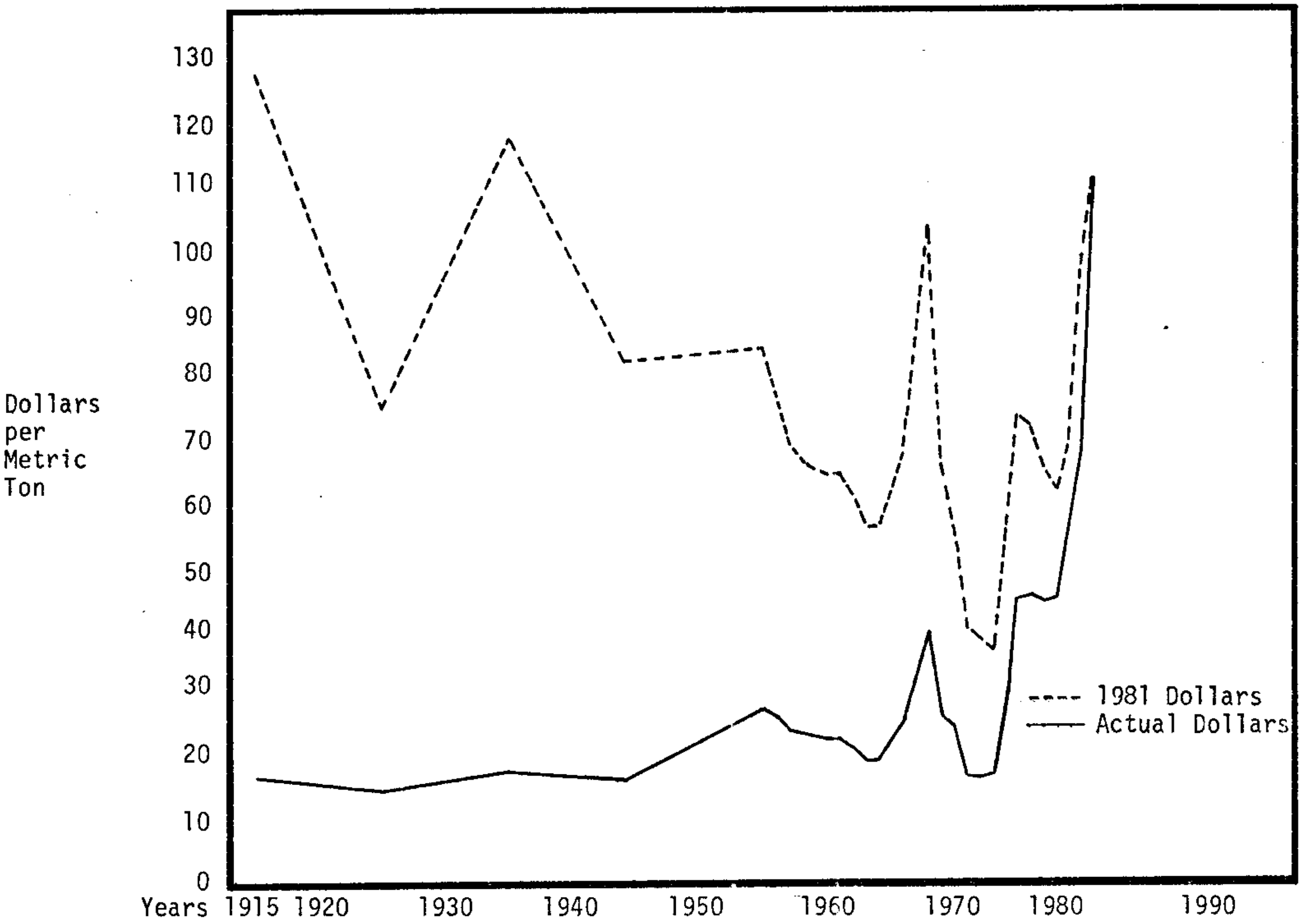

Figure 2. Time Price Relationship for Sulfur, 1915-1981.

balanced situation in either direction (increased recovery of sulfur from coal and increased use of sulfur in agriculture to identify two of the more uncertain, major factors).

The break even price of sulfur in SEA paving mixtures as compared to conventional asphalt concrete mixtures is influenced by the cost of the principal ingredients in hot-mix (asphalt cement and aggregate). Essentially the maximum allowable price for sulfur is primarily related to the price of asphalt cement by a factor of about 1.7 to 1.8, i.e., the market price for asphalt cement can be no less than about 1.7 to 1.8 times larger than the market price for sulfur.

SEA MIXTURE CHARACTERISTICS

The laboratory evaluation of the paving mixtures studied included the following major variables in the experimental design:

1. SEA ratios:
    - (a) 0/100 (conventional asphalt concrete).
    - (b) 20/80 (20 percent added sulfur, 80 percent asphalt cement by weight).
    - (c) 30/70 (30 percent added sulfur, 70 percent asphalt cement by weight).
    - (d) 40/60 (40 percent added sulfur, 60 percent asphalt cement by weight).
    - (e) 50/50 (50 percent added sulfur, 50 percent asphalt cement by weight).
2. Aggregates:
    - (a) Eastern Washington crushed basalt.
    - (b) Western Washington crushed gravel.
3. Asphalt cements:
    - (a) Chevron AR-4000W.
    - (b) Chevron AR-2000.
4. Mixture compaction methods:
    - (a) Kneading compaction (Hveem).
    - (b) Marshall compaction.

These mixture variables represent a wide range of mixture conditions for the types of paving materials commonly used throughout the State of Washington.

The types of tests conducted on the laboratory prepared binders and mixtures included:

1. Binder tests:
    - (a) Viscosity (Sliding Plate @ 77°F (25°C)).
    - (b) Penetration @ 77°F (25°C) @ 100 g., 5 sec, ASTM D5
    - (c) Scanning electron microscope with photographic and X-ray scans.
    - (d) Determination of "natural" sulfur content in asphalt cements.
2. Mixture tests:
    - (a) Kneading compaction (WSDOT Test Method 701).
        - (i) Stabilometer values (WSDOT Test Method 703).
        - (ii) Bulk specific gravity (WSDOT Test Method 704).
        - (iii) Maximum specific gravity (WSDOT Test Method 705).
        - (iv) Marshall stability and flow (ASTM D1559).
    - (b) Marshall compaction (ASTM D1559).
        - (i) Marshall stability and flow (ASTM D1559).
        - (ii) Bulk specific gravity (WSDOT Test Method 704).
        - (iii) Maximum specific gravity (WSDOT Test Method 705).
    - (c) Tests common to all compacted mixtures.
        - (i) Resilient Modulus (ASTM "Indirect Tensile Test Method for Resilient Modulus of Bituminous Mixtures").
        - (ii) Conditioning tests - mixture durability and aging.
        - (iii) Scanning electron microscope with photographic and X-ray scans.

MIXTURE DURABILITY

One of the most important features of this study was the investigation of SEA mixture aging and other environmentally induced mixture deterioration. The reason for this emphasis area is at least twofold. First, the Pullman test pavements (SR 270 sections) have shown that the SEA paved sections experienced greater amounts of surface aggregate loss than did the conventional asphalt concrete sections. Even though the differences were small, the matter required further examination. Second, a review of various construction materials which contained added sulfur generally revealed susceptibility to moisture and/or freeze-thaw damage.

The conditioning tests selected for use in the study included the following:

1. Accelerated aging conditioning @140°F (60°C).
2. Wet freeze-thaw conditioning ("Lottman" procedure).

The "aging" conditioning was conducted in order to study the physiochemical aging phenomenon and its effect on mixture resilient modulus properties. This in effect accelerated the sulfur recrystallization process thus providing estimates of long-term mixture stiffness values.

The general trend for all samples subjected to the aging conditioning procedure was an increase in resilient modulus with time (typical example shown in Figure 3).

The wet freeze-thaw conditioning was patterned after the procedures developed by Lottman at the University of Idaho [3]. The objective of this conditioning process was to determine the mechanical properties of a given mixture due to the combined effects of moisture and freeze-thaw cycling. This information was then compared to the same properties obtained from pre-conditioning testing. The resulting ratios can be used as a relative index of environmental susceptibility.

In general, it was found that mixture moisture susceptibility increases when increasing amounts of sulfur are added to the binder (i.e., increasing SEA ratio). A summary of these test results is shown in Figure 4.

To determine the effects of adding an anti-strip binder additive on the strength characteristics of samples before and after moisture conditioning, mixtures were prepared using two percentages (by total weight of binder) of a commonly used anti-strip additive. The general trend observed for samples containing the anti-strip additive agreed with those without anti-strip, namely that moisture susceptibility appears to increase with increasing sulfur content in the binder.

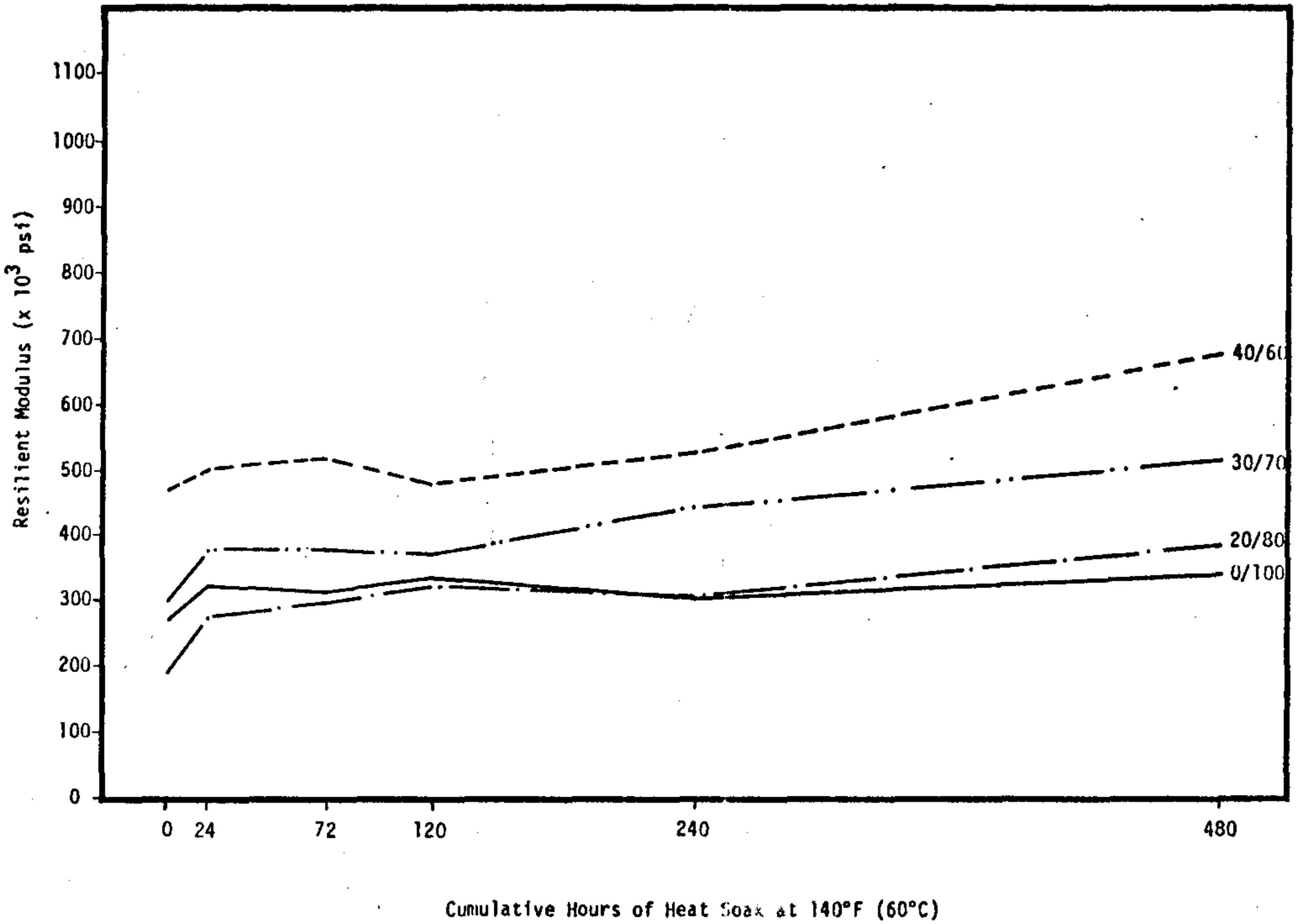

Figure 3. Resilient Modulus After Heat Soaking (AR-4000, crushed basalt, kneading compaction, test temp: 77°F (25°C))

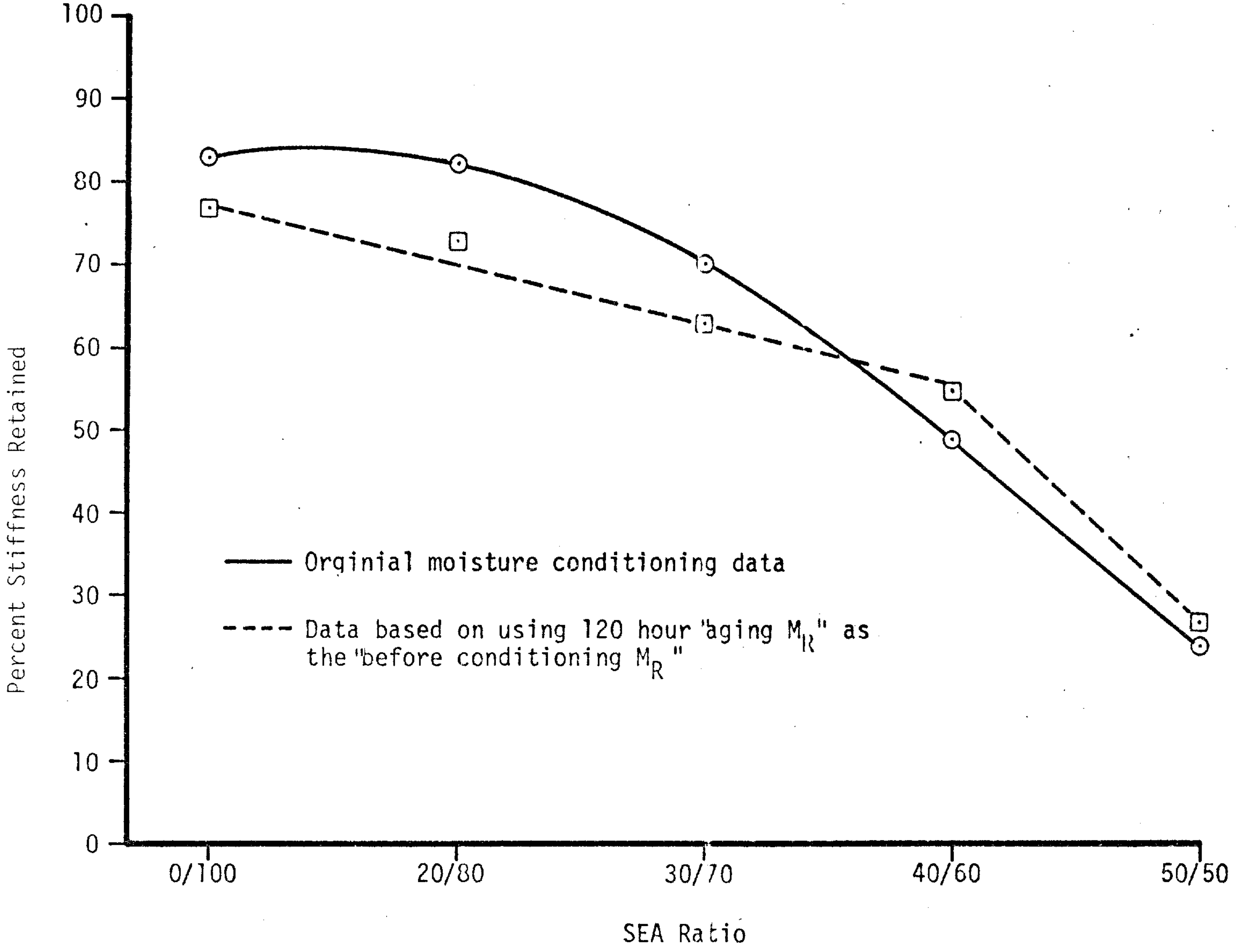

Figure 4. Percent Strength Retained as a Function of SEA Ratio

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following principal conclusions are appropriate:

1. The current and anticipated future production of sulfur in the State of Washington is modest and probably not sufficient to provide substantial quantities of elemental sulfur for SEA paving mixtures.

2. Unless the price of asphalt cement rises substantially with respect to the price of elemental sulfur, the production of SEA paving mixtures is not currently economical in the State of Washington. This conclusion is based in part on the assumption that SEA mixtures are not superior to conventional asphalt concrete and in part on the assumption that current and future price levels of sulfur will remain above the break even price with asphalt cement.

3. Increasing amounts of added sulfur results in increased mixture stiffness.

4. Increasing amounts of added sulfur generally result in increased mixture stiffness loss following the moisture and freeze-thaw conditioning process developed by Lottman. However, the stiffness loss is not necessarily permanent. Some stiffness recovery can occur after drying of the mixture.

RECOMMENDATIONS

1. A minimum SEA binder content equivalent to the volume of an optimum amount of asphalt cement should be used in SEA mixtures.

2. SEA mixtures should have lower than normal air void contents in order to minimize full crystalline sulfur growth.

3. The time dependency of SEA mixture strength must be recognized in the mix design process in order to use design criteria properly.

4. Future SEA mixture designs should be evaluated in the laboratory by use of the moisture conditioning procedure as developed by Lottman.

5. Based on the results of this and the Pullman studies, SEA surface course mixtures are not recommended in areas which experience the combined effects of wet freeze-thaw cycles and significant amounts of studded or chained tire wear. However, SEA mixtures should be effective in all climate and traffic areas as a structural base.

6. Future use of SEA paving mixtures should be based strictly on economic considerations since SEA mixtures do not appear to exhibit superior performance for Washington climate and traffic conditions.

REFERENCES

1. Mahoney, J.P., M.K. Loose and J.A. Lary, "Sulfur Extended Asphalt Pavement Evaluation in the State of Washington: Availability of Sulfur," Final Report, Contract Y-2229, Washington State Department of Transportation, April 1982.

2. Mahoney, J.P., J.A. Lary, F. Balgunaim and T.C. Lee, "Sulfur Extended Asphalt Pavement Evaluation in the State of Washington: An Examination of Fundamental Mixture Characteristics," Final Report, Contract Y-2229, Washington State Department of Transportation, June 1982.