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16. Abstract

This report summarizes the findings of a six-year study of moisture damage in asphalt mixtures in Texas. Special emphasis is placed on the evaluation and effectiveness of antistripping agents. The report defines the extent and severity of moisture damage in Texas, methods of minimizing the damage, test procedures for estimating the moisture susceptibility of asphalt mixtures, the effectiveness of antistripping additives, including hydrated lime, and recommendations related to the use of hydrated lime.

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stripping, water damage, Texas Boiling test, Texas Freeze-Thaw Pedestal test, Wet-Dry Indirect Tensile test, antistripping additives, hydrated lime

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TECHNIQUES FOR REDUCING MOISTURE DAMAGE IN ASPHALT MIXTURES

by

Thomas W. Kennedy
James N. Anagnos

Research Report Number 253-9F

Moisture Effects on Asphalt Mixtures

Research Project 3-9-79-253

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH

BUREAU OF ENGINEERING RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

November 1984

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

This is the ninth and final report in a series of reports dealing with the findings of a research project concerned with moisture effects on asphalt mixtures. This report summarizes the findings of the project and presents detailed information related to the effectiveness of various antistripping additives.

The work required to develop this report was provided by many people. Special appreciation is extended to Messrs. Pat Hardeman and Eugene Betts for their assistance in the testing program and to Messrs. R. B. McGennis and C. C. Lin and to Drs. F. L. Roberts, R. B. Machemehl, and K. W. Lee. In addition, the authors would like to express their appreciation to Messrs. Billy R. Neeley and Paul Krugler, of the Texas State Department of Highways and Public Transportation, for their suggestions, encouragement, and assistance in this research effort, and to other district personnel who provided informtion related to their experience. Appreciation is also extended to the Center for Transportation Research staff who assisted in the preparation of the manuscript. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

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November 1984

LIST OF REPORTS

Report No. 253-1, "Stripping and Moisture Damage in Asphalt Mixtures," by Robert B. McGennis, Randy B. Machemehl, and Thomas W. Kennedy, summarizes a study to determine the extent, nature, and severity of moisture related damage to asphalt mixtures used in pavements in Texas.

Report No. 253-2, "An Evaluation of the Asphaltene Settling Test," by Thomas W. Kennedy and Chee-Chong Lin, summarizes a testing program designed to evaluate the Asphaltene Settling Test, the test procedure, factors affecting the test results, and relationships between settling time and asphalt characteristics.

Report No. 253-3, "Texas Freeze-Thaw Pedestal Test for Evaluating Moisture Susceptibility for Asphalt Mixtures," by Thomas W. Kennedy, Freddy L. Roberts, Kang W. Lee, and James N. Anagnos, includes a detailed description of the Texas Freeze-Thaw Pedestal Test and describes how it can be used to distinguish between stripping and nonstripping asphalt concrete mixtures or individual aggregates.

Report No. 253-4, "Lime Treatment of Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos, summarizes information related to stripping of asphalt mixtures and the use of hydrated lime as an antistripping agent and makes recommendations concerning the construction techniques for adding lime.

Report No. 253-5, "Texas Boiling Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," by Thomas W. Kennedy, Freddy L. Roberts, and James N. Anagnos, includes a detailed description and evaluation of the Texas Boiling Test Method and also describes how it can be used to distinguish between stripping and nonstripping asphalt concrete mixtures or individual aggregates.

Report No. 253-6, "A Field Evaluation of Techniques for Treating Asphalt Mixtures with Lime," by Thomas W. Kennedy and James N. Anagnos details a field study to evaluate the use of dry lime and lime slurry in asphalt mixtures.

Report No. 253-7, "Modified Test Procedure for Texas Freeze-Thaw Pedestal Test," by Thomas W. Kennedy and James N. Anagnos updates and alters the test procedures contained in a previously published report, Report No. 253-3, on conducting the Texas freeze-thaw pedestal test.

Report No. 253-8, "Wet-Dry Indirect Tensile Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos includes a detailed description of the wet-dry indirct tensile test for moisture susceptibility and describes its use to distinguish between stripping and nonstripping asphalt mixtures.

Report No. 253-9F, "Techniques for Reducing Moisture Damage in Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos summarizes the findings of the project and presents detailed information related to the effectiveness of various antistripping additives.

ABSTRACT

This report summarizes the findings of a six-year study of moisture damage in asphalt mixtures in Texas. Special emphasis is placed on the evaluation and effectiveness of antistripping agents. The report defines the extent and severity of moisture damage in Texas, methods of minimizing the damage, test procedures for estimating the moisture susceptibility of asphalt mixtures, the effectiveness of antistripping additives, including hydrated lime, and recommendations related to the use of hydrated lime.

KEY WORDS: stripping, water damage, Texas Boiling test, Texas Freeze-Thaw Pedestal test, Wet-Dry Indirect Tensile test, asphalt, asphalt concrete mixtures, stripping aggregates, stripping mixtures, antistripping additives, hydrated lime

SUMMARY

This report summarizes the findings of an extensive study of moisture damage and stripping of asphalt mixtures which was conducted at The University of Texas at Austin over a six-year period. The objectives of the study were to define the nature of the problem of moisture damage in asphalt paving mixtures, develop techniques to identify mixtures which are moisture susceptible, and develop recommendations to eliminate or minimize the problem. While this study has primarily focused on problems and mixtures in Texas, additional mixtures from other areas in North America were evaluated. The study involved an extensive laboratory investigation, including the evaluation of mixtures subsequently used in construction, a field evaluation of methods of introducing hydrated lime into asphalt mixtures for both conventional batch plants and drum mix plants, and an evaluation of actual pavement mixtures which exhibited premature distress to determine the cause of the failure.

Although a number of test methods were reviewed and evaluated, the majority of the work reported in this report utilized the wet-dry indirect tensile test (Lottman, etc.), the Texas freeze-thaw pedestal test, and the Texas boiling test. The advantages and disadvantages of these three test methods are discussed along with an evaluation of their ability to predict moisture susceptibility of asphalt-aggregate mixtures.

In addition, the results obtained for a variety of antistripping agents including hydrated lime and silanes are presented. Initial efforts indicated that generally hydrated lime was the most effective; however, subsequent work indicates that commercially available antistripping agents are being developed which appear to be effective. Nevertheless, all evidence suggests that the effectiveness is dependent on the aggregate and asphalt combination and that testing should be conducted on any proposed mixtures using the aggregates and, if at all possible, the asphalt cement to be used. In addition, quality control tests should be conducted on the actual plant mixtures to determine moisture susceptibility.

A summary of the findings of a field experiment to evaluate methods of introducing lime into asphalt aggregate mixtures is presented.

Finally, recommendations related to methods of alleviating moisture damage, methods of evaluating moisture susceptibility, and methods of treating asphalt aggregate combinations are summarized.

IMPLEMENTATION STATEMENT

The results of this project have determined the extent and severity of stripping and moisture damage of asphalt mixtures in Texas. Methods of minimizing or eliminating this damage have been identified. Three test methods for evaluating the moisture susceptibility have been developed and applied to proposed mixtures and used to evaluate various antistripping additives. Hydrated lime slurry or hydrated dry lime with water was found to be generally very effective as an antistripping additive when applied to the aggregate. At least two of the more recently developed liquid antistripping agents have also been found to be effective for many mixtures. Since the effectiveness of all additives is dependent on the specific asphalt-aggregate combination, each mixture should be tested prior to construction and plant produced field mixtures should be tested during construction to determine whether the selected antistripping additive is providing the desired protection.

Techniques for applying lime during construction were developed and evaluated. Recommended techniques were summarized. All three test methods should be used by the State Department of Highways and Public Transportation to evaluate asphalt-aggregate sources, asphalt-aggregate construction mixtures, and actual field mixtures during construction. The tests, however, should be further evaluated and related to the performance of mixtures placed in the field. It should also be recognized that the tests measure susceptibility to stripping and moisture damage. Poor resistance does not necessarily mean that damage will occur since moisture may not be present or adequate compaction may prevent moisture penetration.

All moisture susceptible mixtures should be treated with an additive which can provide the necessary protection against moisture. If adequate protection cannot be achieved the aggregate, and possibly the asphalt, should not be used. Increased emphasis should be placed on achieving adequate compaction during construction.

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CHAPTER 1. INTRODUCTION

Over the years, a great deal of basic and applied research has been conducted on the problem of moisture damage. This research has involved the identification of aggregates and asphalt-aggregate mixtures which are susceptible to moisture damage, the development of theories related to the mechanism producing damage, and the development of treatments and additives to minimize damage or distress.

Nevertheless, during the past 5 to 10 years, asphalt pavement mixtures have suffered extreme damage due to the adverse effects of moisture. Such damage occurs in two forms, stripping and softening, with stripping being of primary concern. Two major pavement failures occurred in Texas during the summer of 1980 (Refs 1 and 2). While many factors contributed to these failures, moisture damage was a definite contributing factor. In addition, other pavements have exhibited lesser damage which has resulted in shortened pavement life, reduced performance, and increased maintenance costs. In recognition of these problems a research study, Project 3-9-79-253, "Moisture Effects on Asphalt Mixtures," was initiated.

A series of eight previous reports were prepared which provide detailed information on various phases of the study. These reports are:

MOISTURE DAMAGE

- Research Report 253-1, "Stripping and Moisture Damage in Asphalt Mixtures (Ref 3)

TESTS

- Research Report 253-2, "An Evaluation of the Asphaltene Settling Test (Ref 4)
- Research Report 253-3, "Texas Freeze-Thaw Pedestal Test for Evaluating Moisture Susceptibility for Asphalt Mixtures" (Ref 5)
- Research Report 253-5, "Texas Boiling Test for Evaluating Moisture Susceptibility of Asphalt Mixtures" (Ref 7)
- Research Report 253-7, "Modified Test Procedure for Texas Freeze-Thaw Pedestal Test" (Ref 9)

Research Report 253-8, "Wet-Dry Indirect Tensile Test for Evaluating Moisture Susceptibility of Asphalt Mixtures" (Ref 10)

TREATMENT WITH HYDRATED LIME

Research Report 253-4, "Lime Treatment of Asphalt Mixtures" (Ref 6)

Research Report 253-6, "A Field Evaluation of Techniques for Treating Asphalt Mixtures with Lime" (Ref 8)

This report, Research Report 253-9F, is the final report and summarizes the findings, experiences, and information related to moisture damage in asphalt mixtures, evaluates the extent and severity of moisture-related distress in Texas, identifies possible methods of detecting asphalt-aggregate mixtures which are susceptible to moisture damage, and considers potential methods and procedures to alleviate moisture damage. While the project essentially involved a study of moisture damage in Texas, the report also contains information and recommendations acquired as the result of work and interaction with other states. Special emphasis is placed on the evaluation of liquid antistripping agents which has not been covered in previous reports.

Chapter 2 contains a summary of moisture damage in Texas, the phenomenon of stripping, and the factors affecting stripping. Chapter 3 summarizes techniques and procedures to minimize stripping and moisture damage. Chapter 4 discusses test methods and recommends test methods to evaluate moisture susceptibility of asphalt mixtures and the effectiveness of antistripping agents. Chapter 5 provides a detailed evaluation of various antistripping additives. Chapter 6 summarizes the findings and recommendations regarding the use of hydrated lime. Chapter 7 provides general recommendations related to minimizing moisture damage and stripping in asphalt mixtures.

CHAPTER 2. MOISTURE DAMAGE

Moisture damage occurs in two forms, softening and stripping. Softening is characterized by a reduction of cohesion, which produces a reduction in strength and stiffness of the asphalt mixture. Stripping, on the other hand, involves a loss of adhesion and the physical separation of the asphalt cement and aggregate primarily due to the action of moisture (Ref 3). A similar separation can also occur due to surface coatings on the aggregate or to smooth aggregates with minimal surface texture.

Often the terms ravelling and shelling have been and are used interchangeably with stripping. Ravelling is a surface phenomenon and involves the loss of aggregate from the surface downward; shelling is the loss of aggregate used on seal coats. Thus ravelling and shelling involve the loss of bond between aggregate and binder; however, the cause may be due to other factors separately or in conjunction with stripping.

EVIDENCE OF STRIPPING

Preliminary evidence of stripping of asphalt pavement mixtures often occurs as patch bleeding, or flushing, and localized instability. Localized flushing occurs when stripped asphalt cement rises to the surface of the pavement, producing localized shiny areas of asphalt. This bleeding is not necessarily confined to the wheel paths but rather is often distributed randomly across the pavement surface. Deformations in the form of shoving and rutting may also develop due to the loss of structural strength and stiffness and due to instability caused by the excessive amounts of asphalt which accumulate near the surface. Shoving can be expected in areas carrying only moderate traffic and rutting will begin to develop.

In addition, it may be found that cores cannot be obtained due to the lack of cohesion and strength in the lower portion of the pavement layers. Examination of the asphalt-aggregate mixture will often show that the aggregates are essentially clean, with minimal asphalt.

STRIPPING MECHANISMS

No single mechanism of stripping has been universally accepted and it is possible that different mechanisms occur for different conditions and that more than one mechanism may actually produce failure. The more widely proposed mechanisms can be grouped into three types: (1) mechanical, (2) chemical, and (3) thermodynamic.

The mechanical mechanisms suggest that the quality of adhesion is dependent upon how well the asphalt cement intrudes into the pores and irregularities of the surface of an aggregate particle to secure a strong mechanical interlock. Mechanical bond is dependent upon the tensile strength of the asphalt cement and the surface characteristics of the aggregates. The chemical mechanisms involve chemical reactions that take place on the aggregate surface and involve the asphalt, aggregate, and water. The quality of bond that develops between aggregate and binder is assumed to depend on factors such as surface charges and pH of the mixture components.

The thermodynamic mechanisms involve the ability of various asphalts to wet aggregate surfaces. Wetting, which is the ability of a liquid to spread over a solid, is a function of the viscosity and surface tension of the binder. During mixing operations a binder of lower viscosity and surface tension will tend to produce better coating of the aggregate particles.

Because of the number of proposed mechanisms and the lack of agreement, the causes of stripping were categorized as follows:

(1) physical-chemical reactions,

(2) surface coatings, and

(3) smooth surface textures.

Of primary importance is the need to identify the basic cause of the stripping in order to select the best method of treatment. In some cases, two or more of the above causes may be involved and more than one treatment may be required. Physical-chemical reactions are of primary concern. Surface coatings on the aggregate prevent adequate adhesion with the asphalt cement, which often can be eliminated by washing the aggregate prior to use. Smooth aggregates also minimize the ability of the aggregate and asphalt to develop adequate adhesion. Crushing of the aggregate will produce more angular aggregates and, in some cases, will produce fractured surfaces with more texture which in turn may reduce stripping. Nevertheless, it is necessary to consider other treatments to alleviate stripping which results from physical-chemical causes.

It should be noted that work needs to be conducted to determine the actual cause(s) of stripping. Because of the complexity and constantly changing physical-chemical characteristics of asphalt and the large range of aggregates involved, it is felt that such studies will by necessity be long term. Efforts at the Western Research Institute, formerly the Laramie Energy Technology Center, have focused on the physical-chemical nature of asphalts and the surface phenomena at the aggregate-water-asphalt interface. A review of the preliminary results (Refs 11, 12 and 13) and private communication with the researchers indicates potential information related to the mechanism and cause of stripping is being developed.

MOISTURE DAMAGE IN TEXAS

In 1978 and 1979, each Texas highway district was visited and surveyed to assess the severity and extent of moisture damage. After field visits and interviews with highway personnel, the extent and severity of stripping in each district was categorized and is summarized in Figure 1. In addition, project personnel have visited and worked with highway personnel and contractors in 14 other states. As a result, it was concluded that stripping is a major problem throughout the southern portion of the United States and probably in the northern areas.

CAUSATIVE FACTORS

The Texas survey and subsequent experience in Texas and other states indicated that the extent and severity of moisture damage of asphalt mixtures primarily is related to the environment, aggregate, asphalt, and mixture properties.

Environment

As expected, areas with high rainfall and high water tables experienced a much greater amount of moisture damage and stripping. In Texas, the annual rainfall varies significantly, from about 8 inches per year in West Texas to 48 inches per year in East Texas. As shown in Figure 1, most of the problems are located in the eastern and southeastern parts of the state, which have

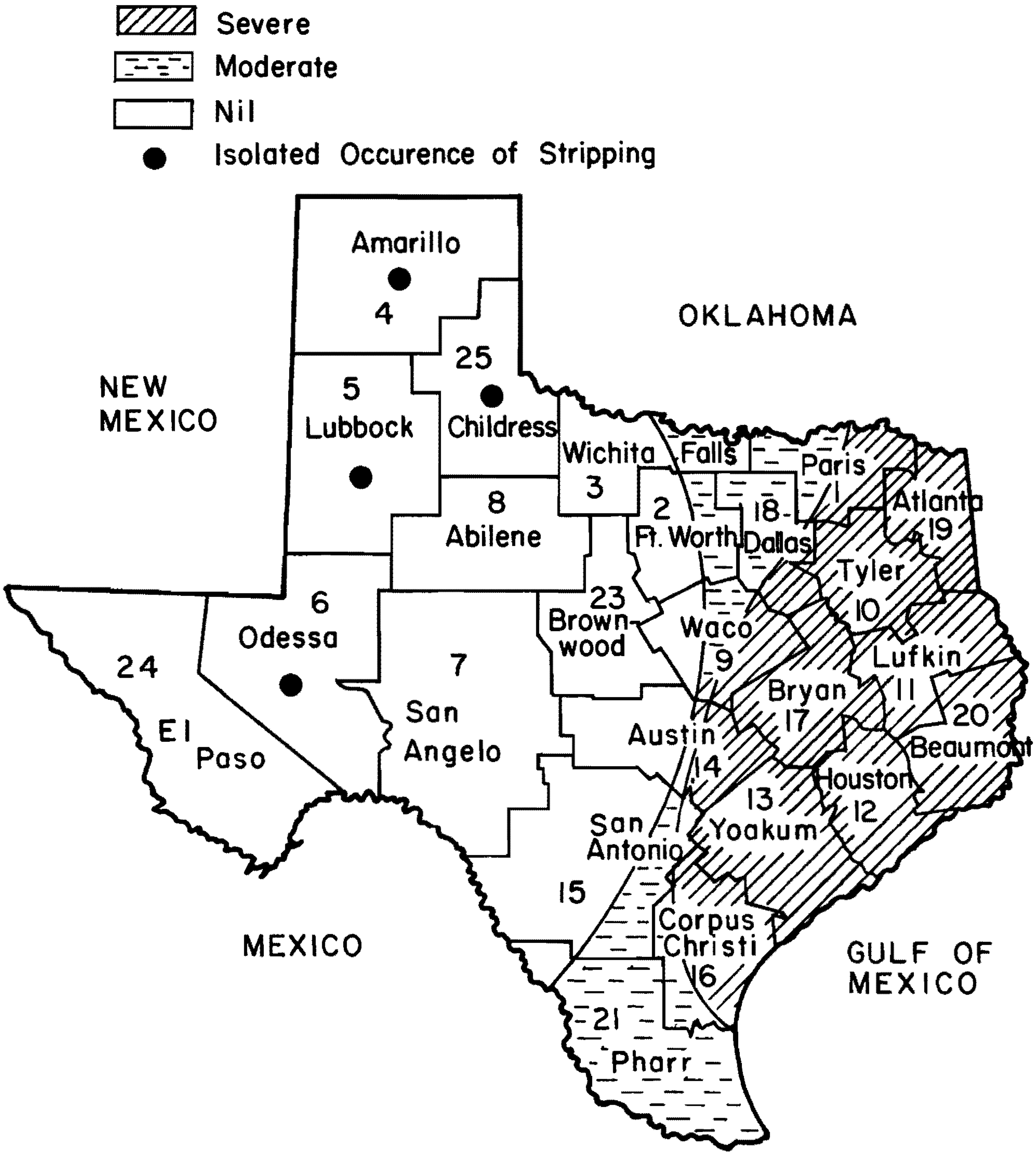


Fig 1. Severity of stripping damage in hot mix, cold mix, and blackbase layers by district (Ref 3).

high rainfall and high water tables. However, isolated cases have occurred in West Texas.

An analysis of these isolated cases showed a general correlation with the high negative values of the Thornthwaite moisture index in West Texas (Ref 3). Soils with a high negative index value have a large potential for attracting moisture (Ref 14). Therefore, moisture from a perched water table, irrigation adjacent to the roadway, or other local source possibly could have caused moisture damage.

Aggregate Type

Another obvious factor is the aggregate type used in mixtures. In Texas, siliceous river aggregates and rhyolite have shown a greater propensity for stripping than other aggregate types. Therefore, districts that both use large quantities of siliceous river aggregates and rhyolite aggregates and have relatively high amounts of rainfall experienced greater moisture-related distress problems. While Texas limestones generally are resistant to stripping, experience indicates that some limestone type aggregates do exhibit stripping. Thus, it is felt that all aggregates should be tested prior to use.

Asphalt Type

The type of asphalt also is important. Certain asphalts used in Texas produce mixtures with a greater resistance to stripping. The actual reasons for the differences are not known; however, work being conducted by Peterson at the Western Research Institute may provide information related to the cause of these observed differences. In addition, it has been shown that higher viscosity asphalts are more resistant to stripping. Thus, it is necessary to test the asphalts which are to be used in asphalt mixtures.

Mixture Properties

The amount and ease with which moisture can enter an asphalt concrete mixture is directly dependent on the density and gradation of the mixture. Dense, well-graded mixtures will more effectively prevent moisture penetration into the mixture (Ref 15). In addition, while the aggregates and asphalts should be tested, it is important to test the actual mixture to be used since stripping is dependent on the asphalt-aggregate combination.

CHAPTER 3. METHODS OF MINIMIZING STRIPPING

The following procedures, treatments, and methods of protection will improve the moisture susceptibility of mixtures and alleviate distress due to stripping (Refs 6 and 16):

(1) provide adequate compaction,

(2) eliminate the use of moisture-susceptible aggregates and asphalts,

(3) provide adequate drainage,

(4) seal the asphalt-aggregate mixture surfaces, and

(5) treat the moisture-susceptible aggregates and asphalt.

PROVIDING ADEQUATE COMPACTION

Adequate compaction will reduce the air voids and the continuity of the air void system. This prevents the penetration of moisture into the mixture, thus reducing the possibility for stripping to occur. The air void content should, ideally, be less than 7 percent. At void contents in excess of 7 percent, water can readily penetrate the mixture. Thus, compaction should achieve a relative density of at least 93 percent of the theoretical maximum density.

Analysis of an overlay project on IH-10 near Columbus, Texas, showed that mixtures compacted to a high density, as determined from cores, experienced no moisture-related distress, whereas mixtures compacted to a lower density experienced significant moisture-related distress (Ref 1).

ELIMINATING MOISTURE-SUSCEPTIBLE MATERIAL

It may be desirable to eliminate the use of certain moisture-susceptible aggregates and, to a lesser extent, certain asphalts. Such an approach may be costly, especially in areas with limited aggregate and asphalt sources. Nevertheless, in view of the long-term maintenance requirements, reduced pavement life and performance, and, in some cases, the rapid and severe failure of the pavement, it may in reality be the most economical solution if adequate protection cannot be achieved or if the mixture cannot be adequately protected.

PROVIDING ADEQUATE DRAINAGE

Drainage should be provided to eliminate moisture, which causes stripping to occur. This involves rapid removal of surface water and prevention of moisture movement into the mixture from the subgrade, subbase, and base by drainage of these layers and by maintaining an adequate pavement elevation above the water table. The use of open-graded friction courses has been found to cause stripping by allowing moisture to enter the underlying layers under the action of traffic, especially if the moisture cannot readily drain laterally.

SEALING MIXTURE SURFACES

Both the top and the bottom surface of the asphalt mixture can be sealed to prevent moisture penetration or may be sealed for other reasons. This approach requires that careful consideration be given to the source of moisture to avoid the possibility of trapping water in the mixture. A number of cases in Texas and other states have been reported in which a surface seal was placed on an existing roadway resulting in subsequent rutting and deterioration due to stripping. Thus, surface sealing may prevent evaporation of moisture from underlying layers which is moving upward through the mixture, and similarly, sealing of the bottom surface may trap surface water by preventing drainage into the underlying layers.

It should also be noted that surface sealing is generally only a temporary preventative measure since cracks will ultimately reflect through the seal. Highly moisture susceptible mixtures will tend to fail rapidly along the cracks. Thus, sealing is, at best, a temporary method of controlling moisture damage and may in fact cause the pavement to fail if moisture is entering the mixture from underlying layers.

TREATING MATERIALS

A number of additives have been proposed for treating the aggregate and the asphalt, with the primary emphasis placed on treatment of the aggregate. These additives are

(1) commercial liquid antistripping agents,
(2) portland cement, and
(3) hydrated lime.

While some of the earlier additives appeared to work with certain combinations of aggregate and asphalt, hydrated lime generally was found to be the most effective method for treating Texas aggregates (Refs 3, 5, and 6). Nevertheless, new liquid additives have been and are being developed, some of which appear to be effective antistripping agents. Regardless of the method of treatment selected, moisture susceptibility tests should be conducted for each combination of asphalt, aggregate, and antistripping agent.

CHAPTER 4. TEST METHODS

Numerous tests and test variations have been proposed and are being used to evaluate the moisture susceptibility of asphalt-aggregate mixtures, with and without additives. These tests included

(1) ASTM Stripping Test,
(2) California Swell Test,
(3) Texas Film Stripping Test,
(4) Texas Freeze-Thaw Pedestal Test,
(5) Boiling Test,
(6) Thin-Layer Chromotography Test,
(7) Immersion Compression Test, and
(8) Wet-Dry Indirect Tensile Test.

After a thorough review and evaluation of these various tests, the following three tests were recommended and adopted for use in the project:

(1) Wet-Dry Indirect Tensile Test (Ref 10)
(2) Texas Freeze-Thaw Pedestal Test (Refs 5, 9, and 16)
(3) Texas Boiling Test (Refs 7 and 16)

Other tests which commonly are being used are:

(4) Immersion Compression Test (Ref 17)
(5) Other Boil Tests (Refs 18, 19, 20, and 21)

INDIRECT TENSILE TEST ON DRY AND WET SPECIMENS

The indirect tensile test subjects a cylindrical specimen to compressive loads, distributed along two opposite generators, which create a relatively uniform tensile stress perpendicular to and along the diametral plane which contains the applied load and causes a splitting failure (Fig 2). Estimates of the tensile strength, modulus of elasticity, and Poisson's ratio can be calculated from the applied load and corresponding vertical and horizontal deformations.

Prior to and during this project, an extensive study was conducted by Lottman (Ref 23) which led to a laboratory test to predict moisture damage in

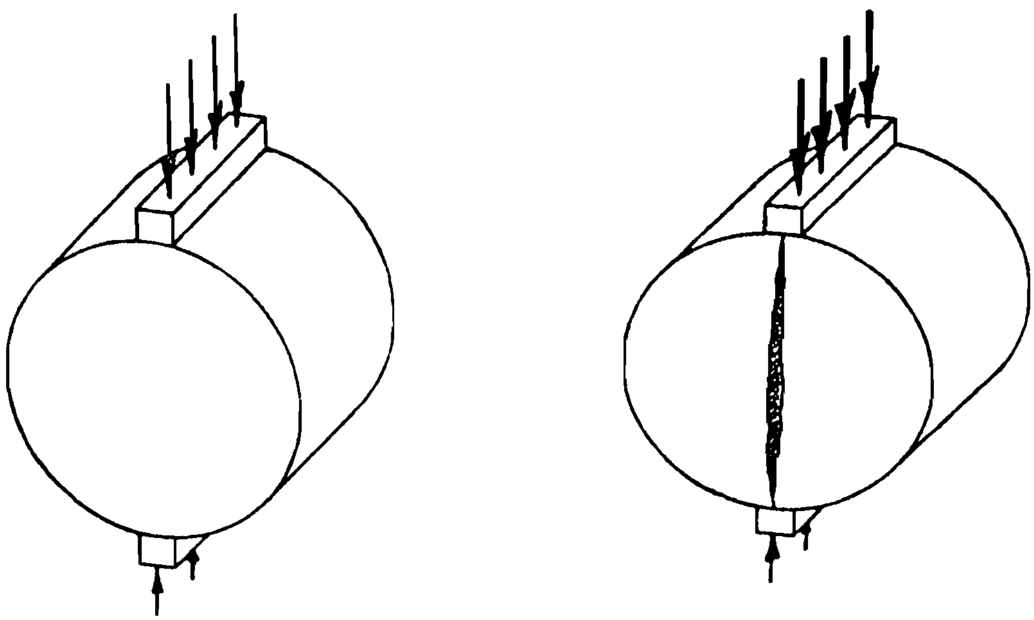


Fig 2. Indirect tensile test loading and failure.

asphalt mixtures. This procedure includes a conditioning procedure for the specimens after which the specimens are tested using the static or repeated-load indirect tensile test (Refs 22, 24, and 25). Schmidt (26) also used the repeated-load indirect tensile test to evaluate the effects of moisture. Kennedy et al (Refs 27 and 28) investigated the effects of moisture on blackbase mixtures using the same test method.

For proper evaluation based on project findings and experience, mixtures should have about 7 percent air voids and it is tentatively recommended that compacted specimens should be conditioned to produce a constant degree of saturation in the range of 60 to 75 percent*, rather than by following a specified procedure. Moisture conditioning is provided by subjecting submerged samples to a vacuum equivalent to 26 inches of mercury. Moisture susceptibility is determined by the ratio of tensile strength in a wet condition to the tensile strength in a dry condition, which is called the tensile strength ratio. Currently it is felt that mixtures with tensile strength ratios less than 70 percent are moisture susceptible and mixtures with ratios greater than 70 percent are relatively resistant to moisture damage. However, mixtures with ratios between 70 and 85 percent would probably benefit by treating the aggregate or asphalt with an effective antistripping additive. In addition, consideration should be given to the absolute values of the retained strength.

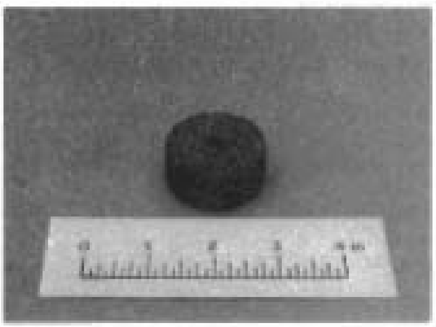
The test procedure used to evaluate the mixtures is described in Reference 10. Since the time period when most of the laboratory testing took place, the Texas State Department of Highways and Public Transportation has adopted a very similar procedure which is outlined in Test Method Tex-531-C.

TEXAS FREEZE-THAW PEDESTAL TEST

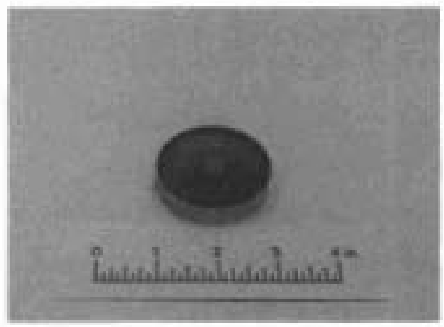
The pedestal test (Refs 5, 9, and 16), which is based on a water susceptibility test developed at the Laramie Energy Technology Center (Ref 29), involves subjecting miniature asphalt-aggregate briquets to repeated freeze-thaw cycles (15 hours at 10°F and 9 hours at 120°F) while submerged in distilled water (Fig 3). The specimens, which are approximately 1.6 inches in diameter and 0.75 inches high, contain a uniform aggregate size, are highly permeable, allow easy penetration of water, and minimize

* Work should be conducted to establish a recommended degree of saturation.

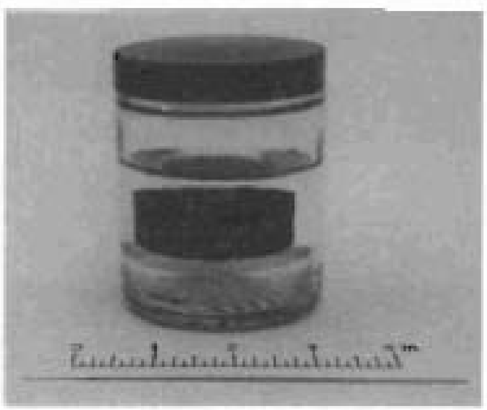
(a) Compaction mold, base plate, and ram, from left to right.



(b) Specimen.



(c) Stress pedestal.



(d) Specimen in water.

Fig 3. Texas freeze-thaw pedestal test.

mechanical interlocking of the aggregate particles. Thus, the mixture properties are largely determined by the asphalt-aggregate bond and, to a lesser extent, the cohesion provided by the asphalt. Moisture susceptibility of an asphalt concrete mixture is evaluated by determining the number of freeze-thaw cycles required to crack a briquet seated on a beveled pedestal. Mixtures requiring less than 10 cycles are considered to be very moisture susceptible while mixtures with values in excess of 25 to 35 are relatively resistant. Details of the test procedure are described in References 9 and 16.

TEXAS BOILING TEST

In this test, which is based on a review and evaluation of boiling tests that have been performed by various agencies, a visual observation is made of the extent of stripping of the asphalt from aggregate surfaces after the mixture has been subjected to the boiling action of water for a specified time. To perform this test an asphalt mixture is prepared at 325°F and boiled in distilled water for 10 minutes. After boiling, the mixture is allowed to cool, the water is drained, and the contents are emptied on paper and allowed to dry. The extent of stripping is rated visually and compared to a standard set of mixtures (Fig 4), which vary from 0 to 100 percent of the asphalt cement retained. Based on field performance, mixtures which retain less than 70 percent of the asphalt cement are considered to be moisture susceptible. Details of the test procedure are described in References 7 and 16. The Texas Department of Highways and Public Transportation has approved a procedure very similar to that described above. This procedure is designated Tex-530-C.

APPLICATION OF TESTS

The wet-dry indirect tensile test provides an evaluation of the mixture with the proper proportions of aggregates and asphalt and in a density configuration intended to simulate the constructed asphalt aggregate mixture. The test is relatively easy but requires a few days to conduct. The results, however, are sensitive to differences in moisture content. The Texas pedestal test can be used to evaluate the moisture susceptibility of the combined aggregates and asphalt or the individual aggregate components and

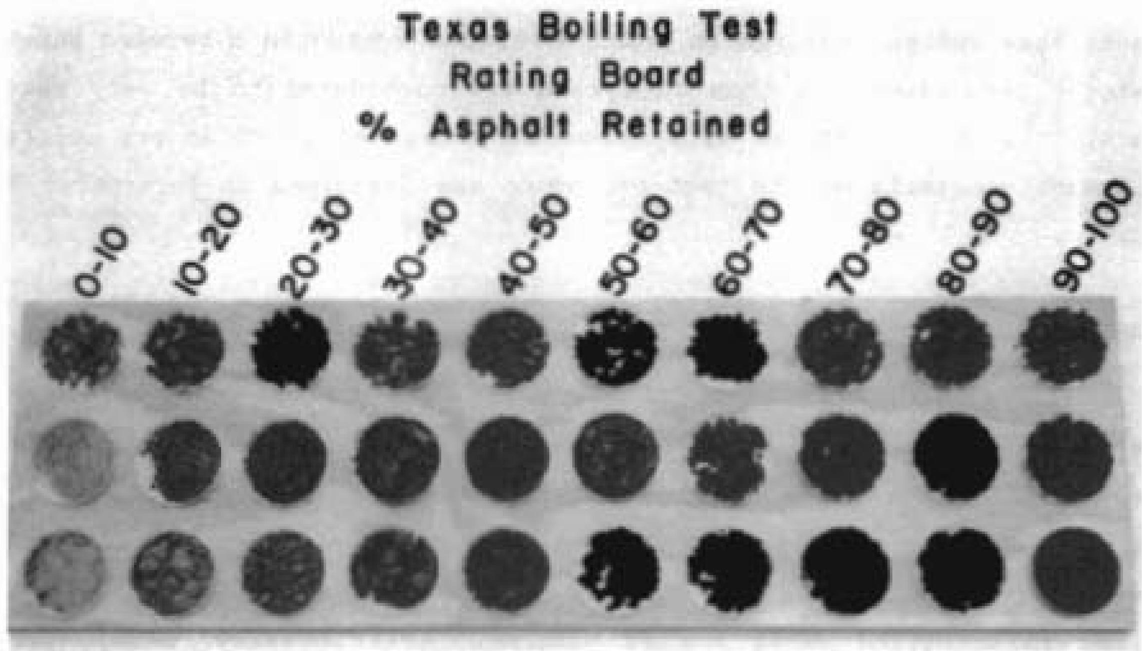


Fig 4. Texas Boiling Test Rating Board.

asphalt. Experience in Texas would indicate that the test is relatively accurate; however, the testing procedure is time consuming and thus is more applicable to preconstruction evaluations. The Texas boiling test, while probably not as accurate, is a very quick test to conduct and thus can be used during construction. In addition, the combined aggregates and asphalt or the individual aggregate components and asphalt can be evaluated.

Experience indicates that while there is a general correlation between test results obtained using the three tests, differences do occur which in some cases can be significant. Generally it has been found that liquid additives perform better with the boiling test while lime performs better with the pedestal and indirect tensile tests. Thus, whenever possible, more than one test probably should be used.

Testing should be conducted on mixtures containing the aggregates and, to the extent possible, the asphalt cement to be used. The indirect tensile test and the boiling test can and should be conducted on the mixtures produced during construction by sampling the mixtures at the plant. In addition, even though the tests were established with respect to known field performance of asphalt-aggregate mixtures, a long-term monitoring program should be conducted to determine the ability of these tests to predict field performance.

CHAPTER 5. EVALUATION OF ANTISTRIPPING ADDITIVES

A number of additives have been proposed and used for treating the aggregates and asphalts for mixtures which were susceptible to stripping. These additives commonly have included:

(1) Liquid Antistripping Agents

These materials, which are commercially available under various trade names and designations, are normally added to the asphalt cement and have been used extensively over the past few years.

(2) Portland Cement

Portland cement is added to the aggregate and has been reported to be generally effective; however, except for certain states or regions, it has not been used widely in the United States.

(3) Hydrated Lime

Hydrated lime, normally calcitic, is added to the aggregate and has been used widely in portions of the United States during various time periods.

While at the beginning of the study these various antistripping additives were being used in many states, moisture damage in the form of stripping was still occurring. Thus, a study of various liquid antistripping additives and hydrated lime was undertaken. Portland cement was not evaluated because of its limited use. Test methods were the wet-dry indirect tensile test, Texas freeze-thaw pedestal test, and the Texas boiling test.

Since a great deal of effort has been focused on developing improved liquid antistripping additives during the period of the study, the following discussion has been subdivided into initial studies and later studies. It should be noted that the earlier work involved the pedestal test as the primary evaluation test, while later evaluations made greater use of the Texas Boiling Test.

INITIAL EVALUATIONS

The early evaluations consisted of a formalized test program and a number of small case study experiments conducted on selected aggregate-asphalt combinations which were scheduled for use on actual highway construction projects. The antistripping agents evaluated in these case studies often were selected by the district highway personnel responsible for construction and materials evaluations.

In the formal program, a moisture-susceptible aggregate and two asphalt cements (AC-20) from two different Texas refineries were evaluated (Ref 30). These mixtures were treated with 25 liquid additives and lime slurry. The liquid additives were added to the asphalts at a rate of 1 percent by weight of the asphalt cement; lime slurry was added to the aggregate at an approximate rate of 1 percent by weight of the aggregate.

Using the Texas freeze-thaw pedestal test, five mixtures, which had not been treated with an additive, were tested to provide the basis for evaluating the additives. Four replicate specimens were tested for each combination of asphalt, aggregate, and additive. The test results for the various additives were grouped by the classification provided by the producer (Figs 5 and 6).

As shown, only liquid additive N and lime slurry were effective in improving moisture resistance as measured by the pedestal tests. Similar results were obtained with the boiling test. However, test results for the individual case study evaluations involving a range of aggregates suggested that certain liquid additives were effective with specific combinations of asphalt and aggregate (Figs 7 through 11).

As a result of these tests and field experiences, it was concluded that treatment with hydrated lime generally could be expected to improve resistance to stripping. Thus. Texas, as well as other states, began to use hydrated lime added to the aggregate in dry, slurry, and wet conditions.

LATER STUDIES

As hydrated lime gained popularity as an antistripping additive, there was renewed interest in developing new or improved liquid antistripping additives. Thus a limited test program was conducted and two of these additives (P and Q) were evaluated for possible use on actual construction projects. The results of the test program and typical results of the project evaluations are summarized in Figures 12 through 18. As shown, a number of these additives appeared to provide adequate protection and in some cases were better than hydrated lime. A test series involving the boiling test was conducted on a given mixture treated with a series of additives including additives P and Q (Fig 18). As shown, a number of the additives appeared to produce significant improvements which suggest that the boiling test produces more favorable results for mixtures treated with liquid antistripping additives.

SUMMARY

One very important finding was that each combination of asphalt, aggregate, and antistripping additive must be evaluated to determine whether the combination is resistant to stripping. In addition, it was apparent that certain asphalts are more resistant to stripping than others. Thus, stripping is not an aggregate problem alone. Subjectively, it is estimated that 80 percent of the problem is aggregate related and 20 percent is asphalt related. Equally important is the fact that the effectiveness of antistripping additives is dependent on the specific combination of aggregate and asphalt.

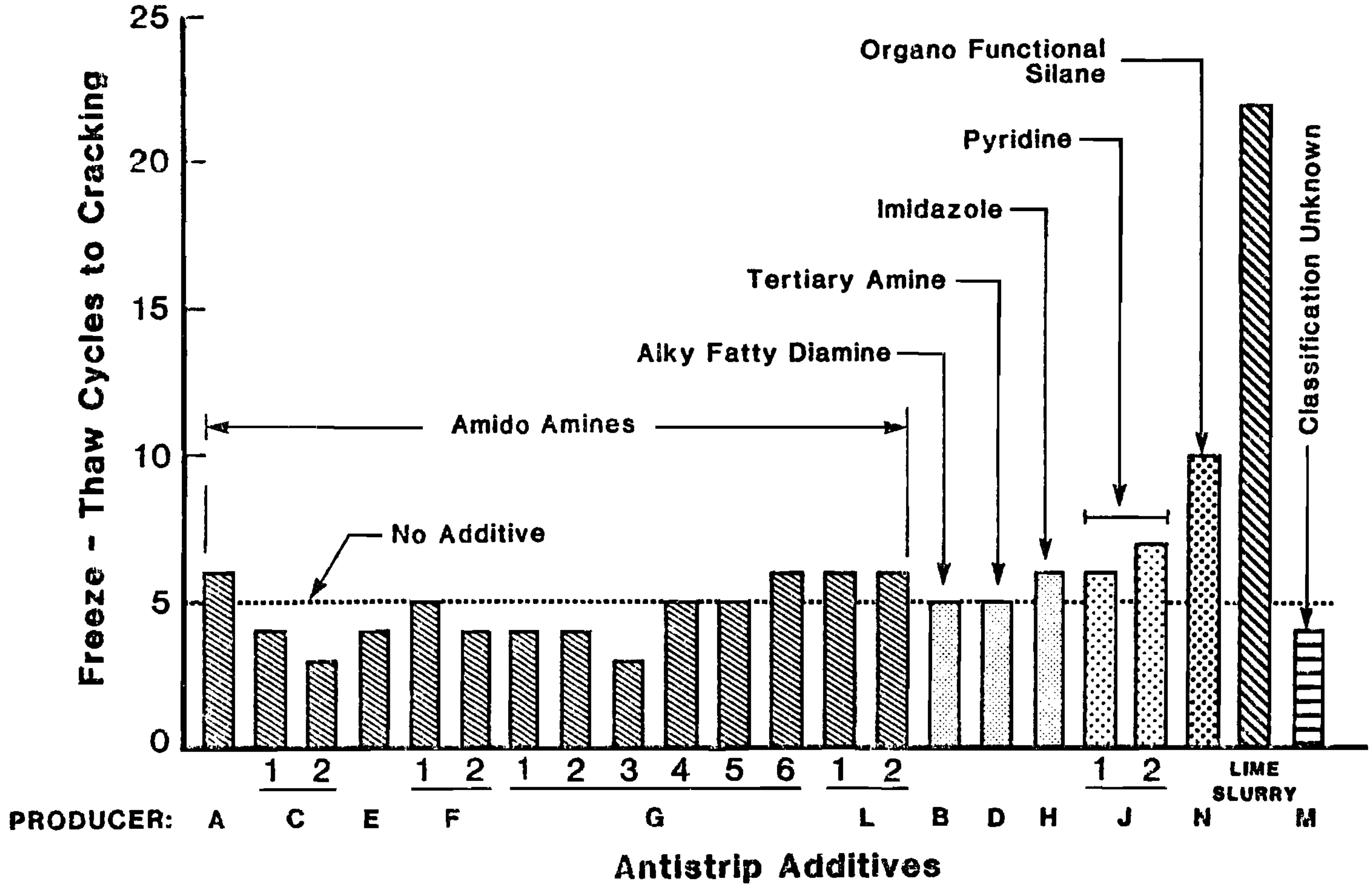


Fig 5. Effect of antistripping additives on the stripping resistance of asphalt mixtures with Asphalt E.

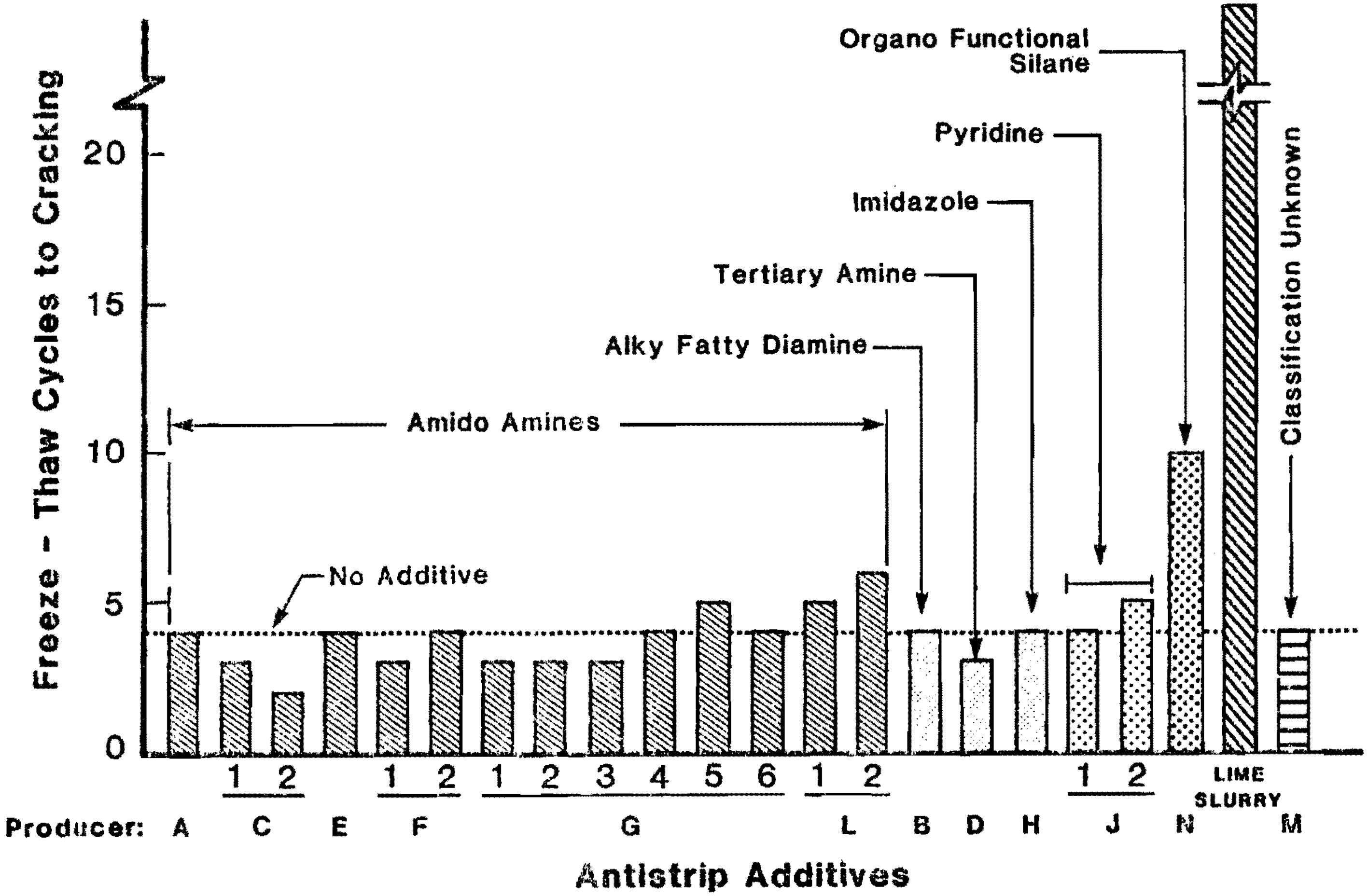


Fig 6. Effect of antistripping additives on the stripping resistance of an asphalt mixture with Asphalt A.

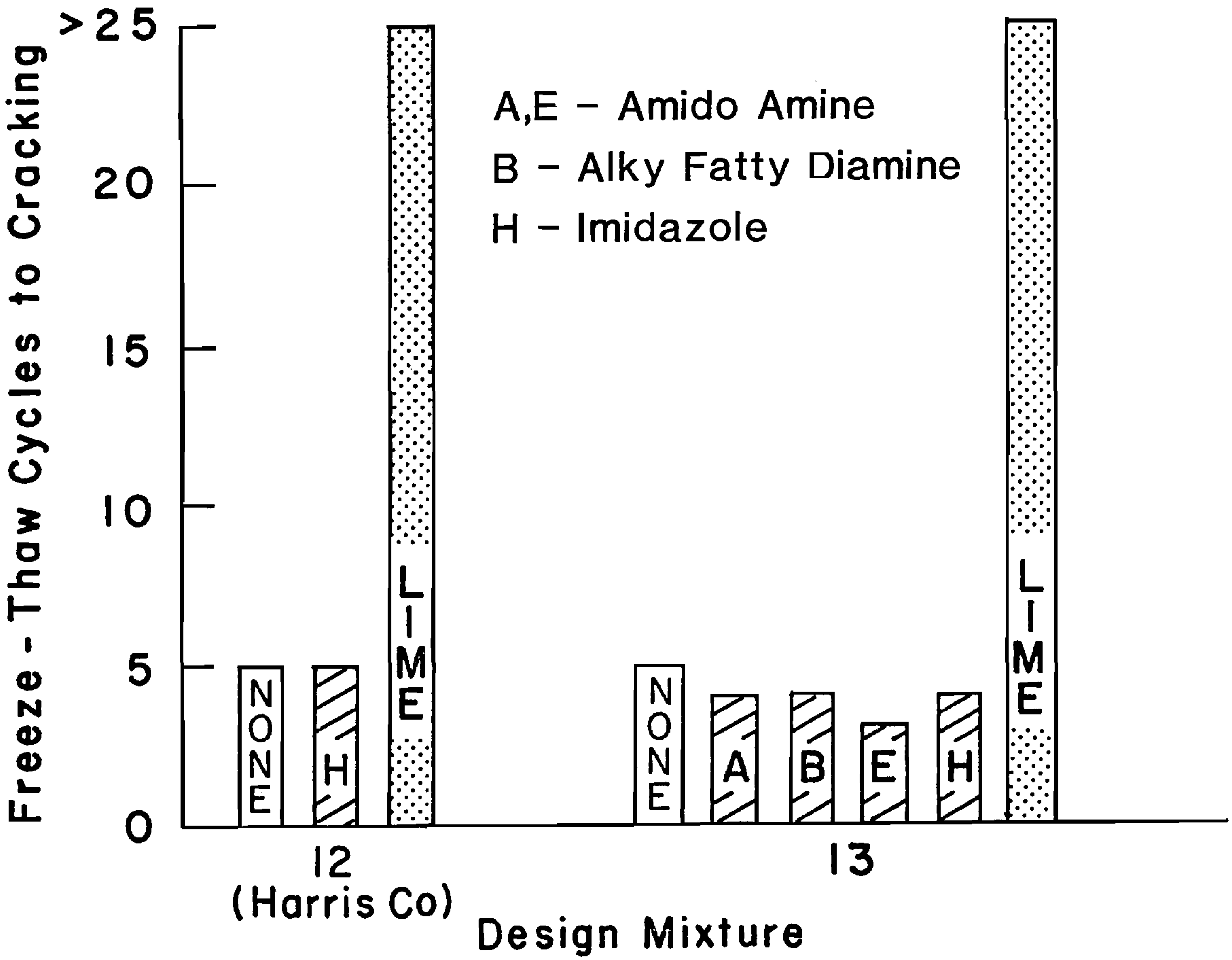


Fig 7. Effect of antistripping additives on the stripping resistance of asphalt mixtures proposed for construction.

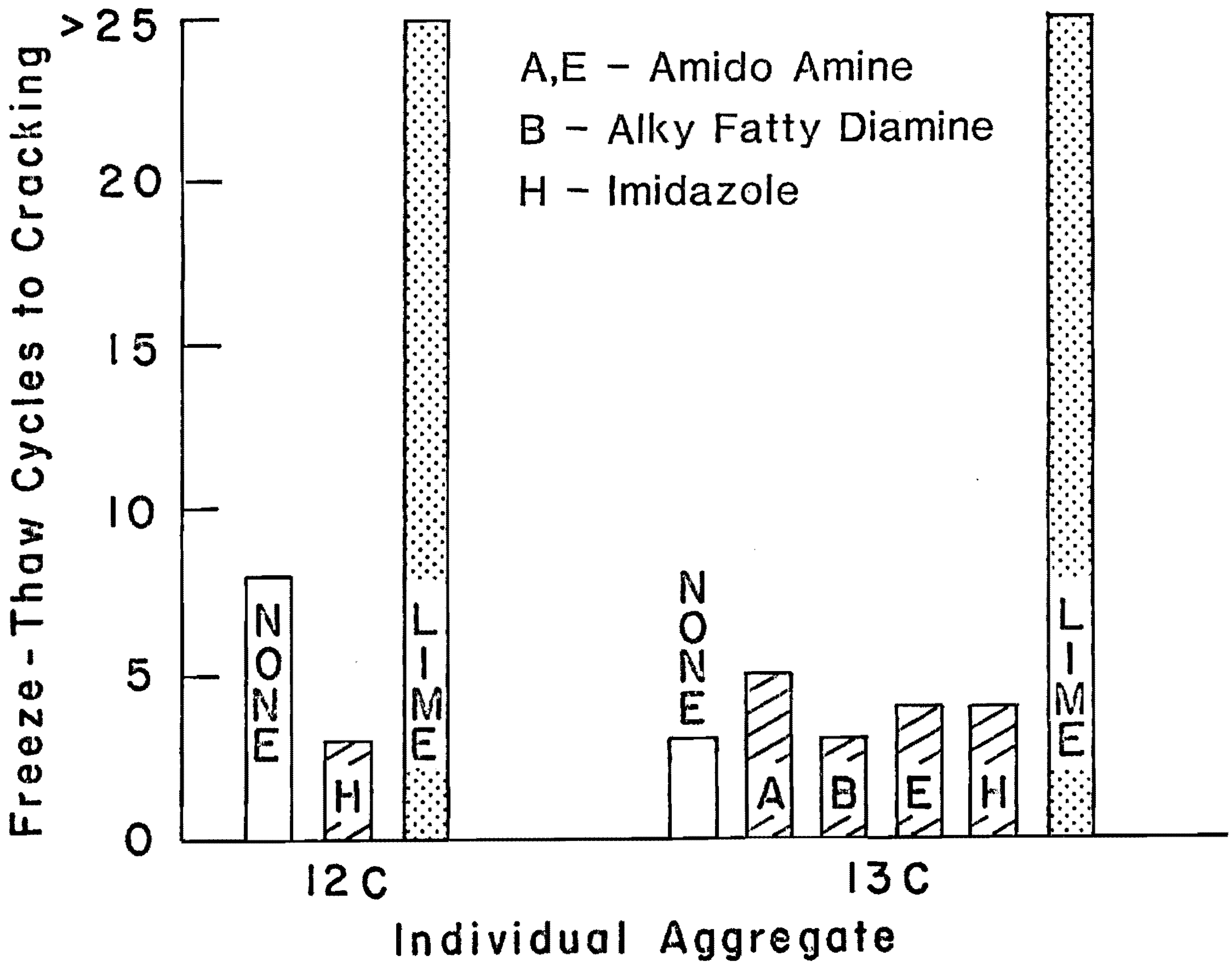


Fig 8. Effect of antistripping additives on the stripping resistance of asphalt mixtures proposed for construction.

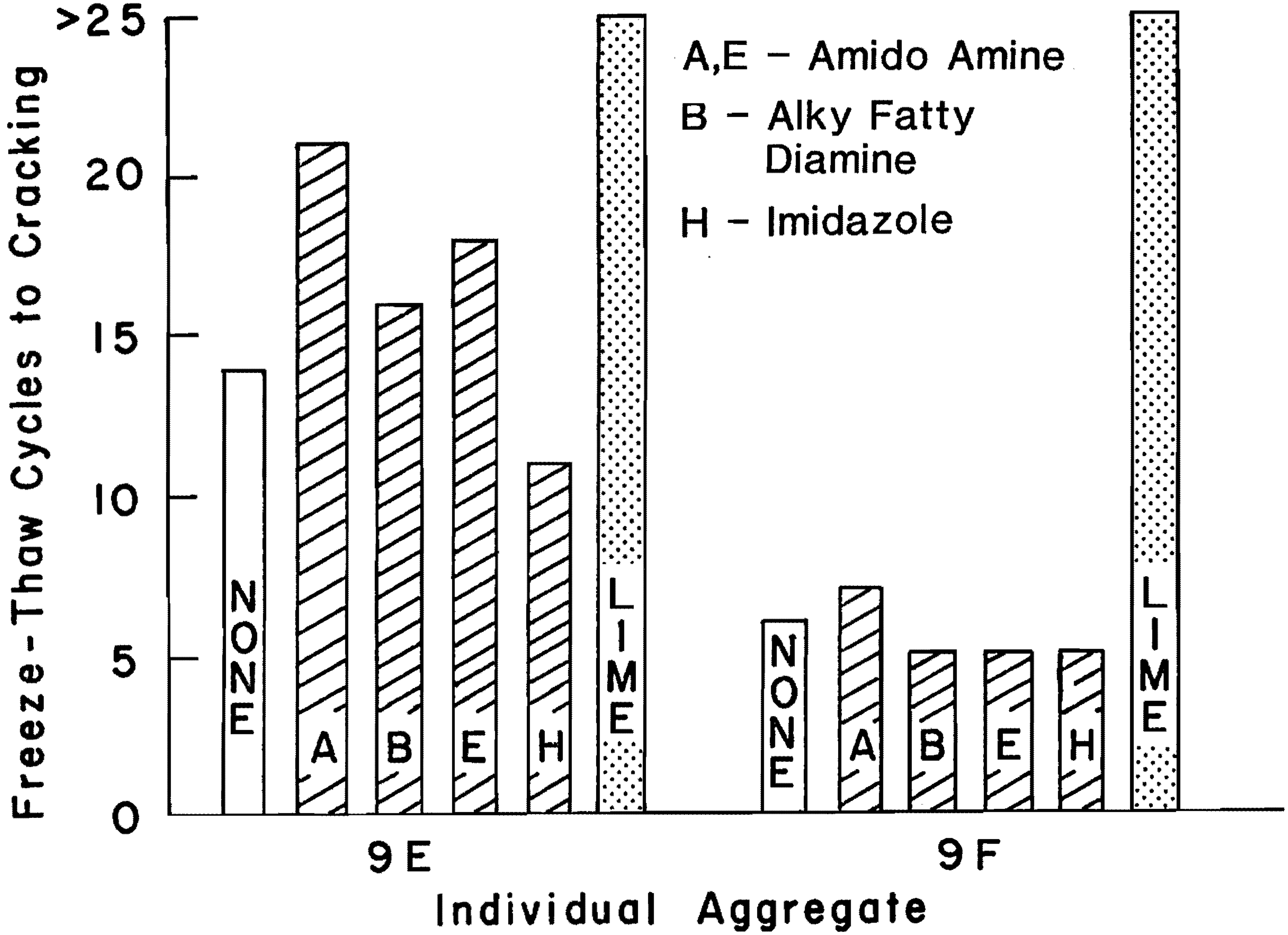


Fig 9. Effects of antistripping additives on the stripping resistance of asphalt mixtures proposed for construction.

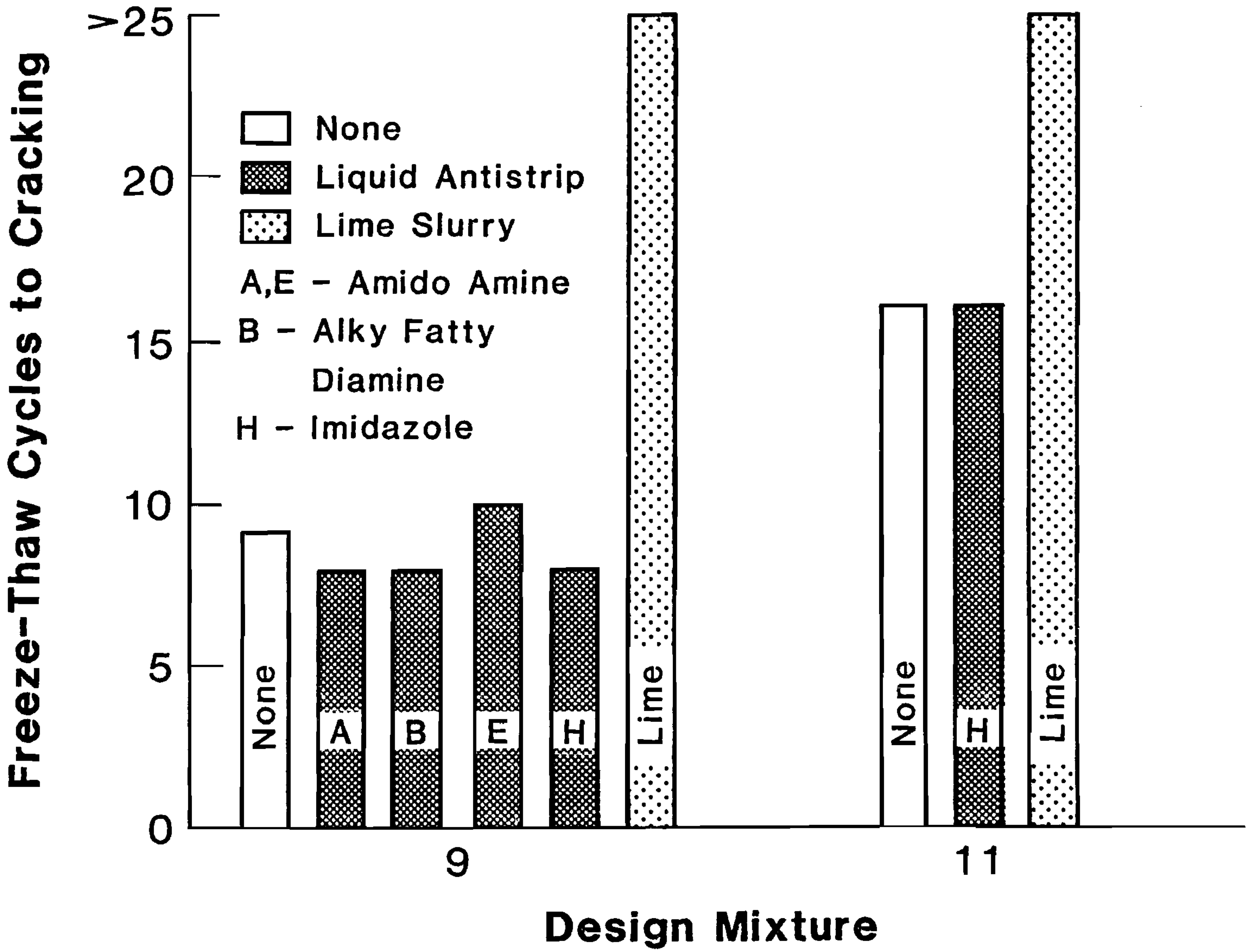


Fig 10. Effects of antistripping additives on the stripping resistance of asphalt mixtures proposed for construction.

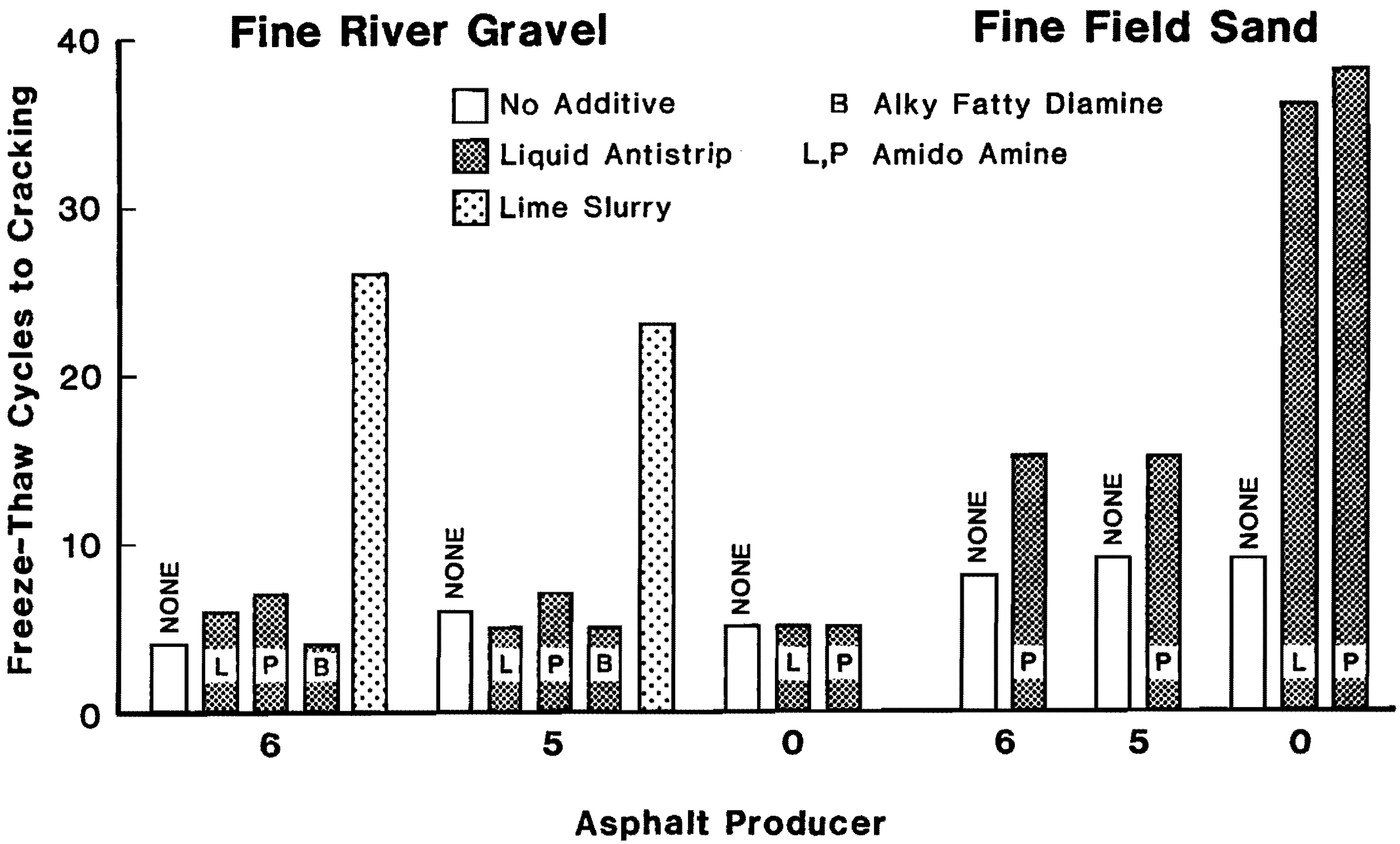


Fig 11. Effects of antistripping additives on the stripping resistance of asphalt mixtures involving two aggregates and three asphalt producers.

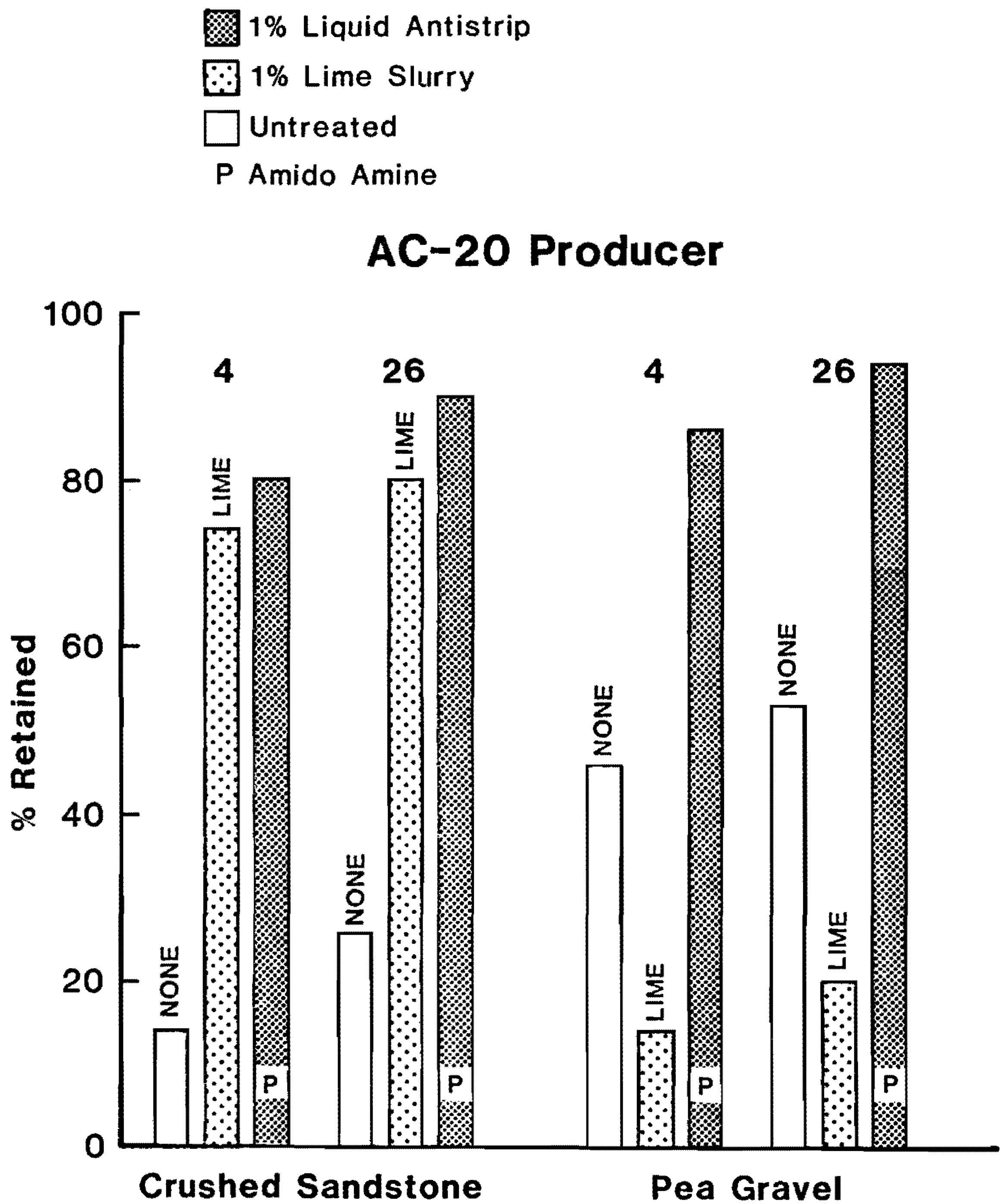


Fig 12. Effect of new antistripping additive on the moisture resistance of asphalt mixtures involving two Texas aggregates and two asphalts.

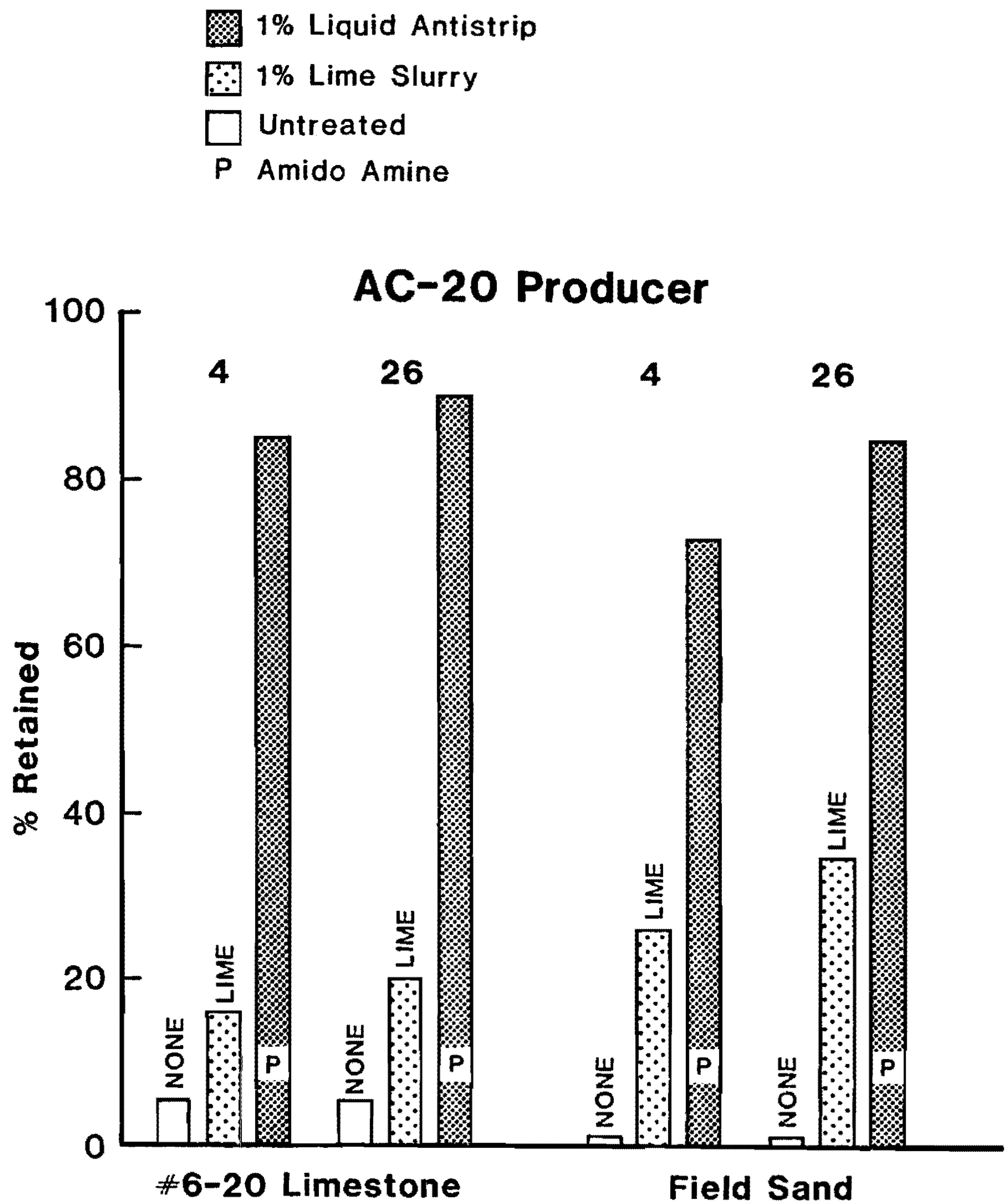


Fig 13. Effect of new antistripping additive on the moisture resistance of asphalt mixtures involving two Texas aggregates and two asphalts.

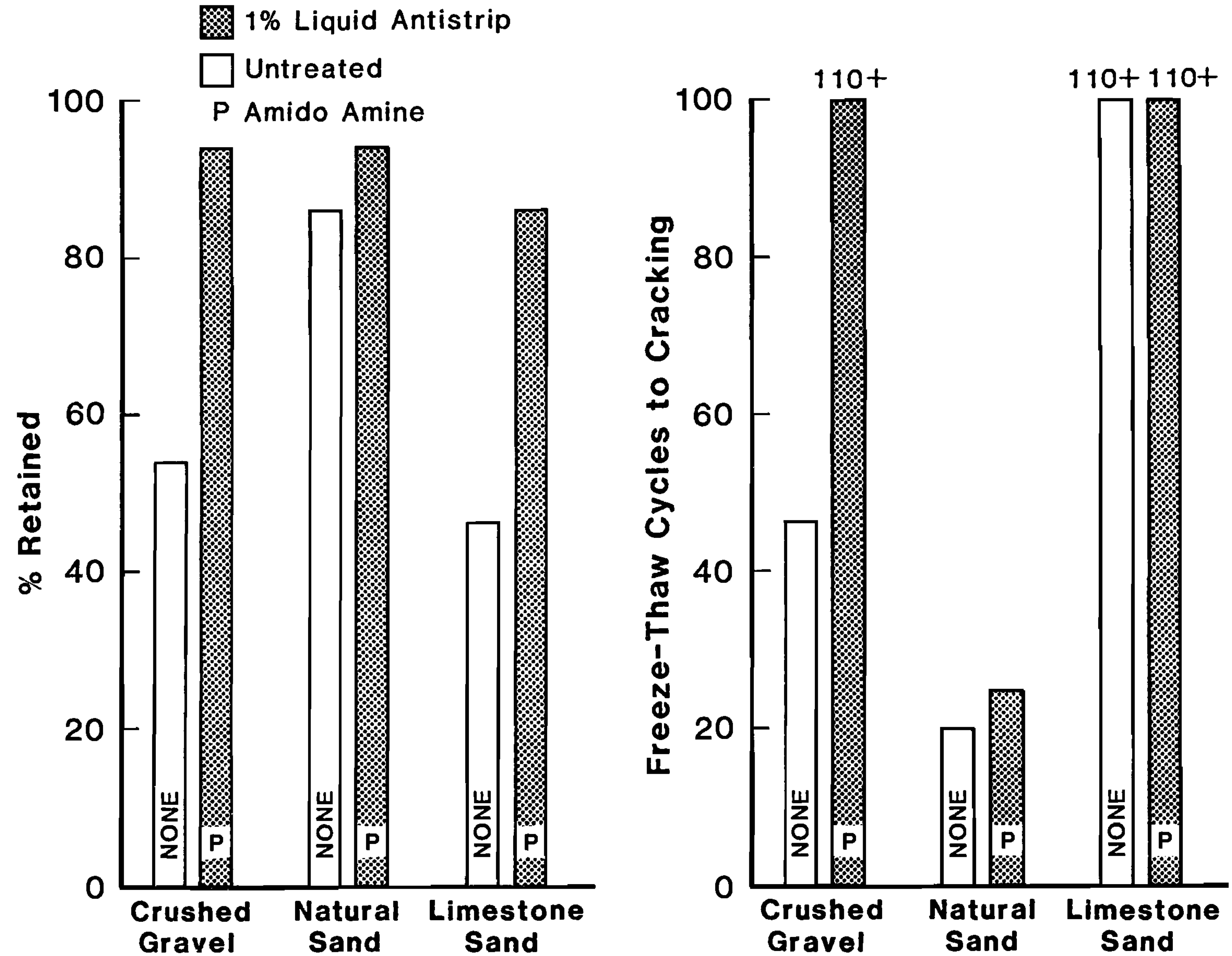


Fig 14. Effect of new antistripping additive on the moisture resistance of three Texas asphalt-aggregate mixtures.

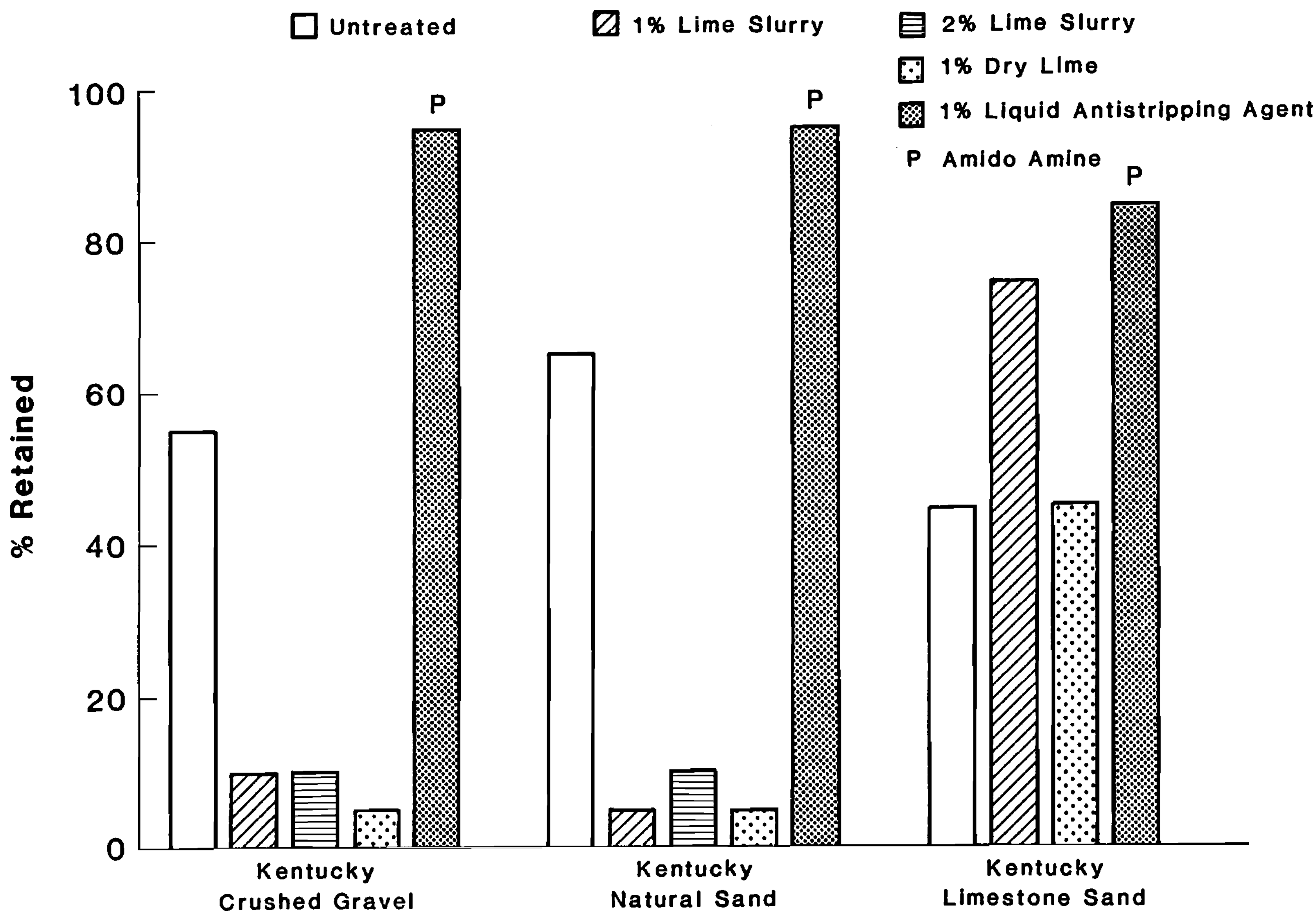


Fig 15. Effect of new antistripping additive on the moisture resistance of three Kentucky asphalt-aggregate mixtures.

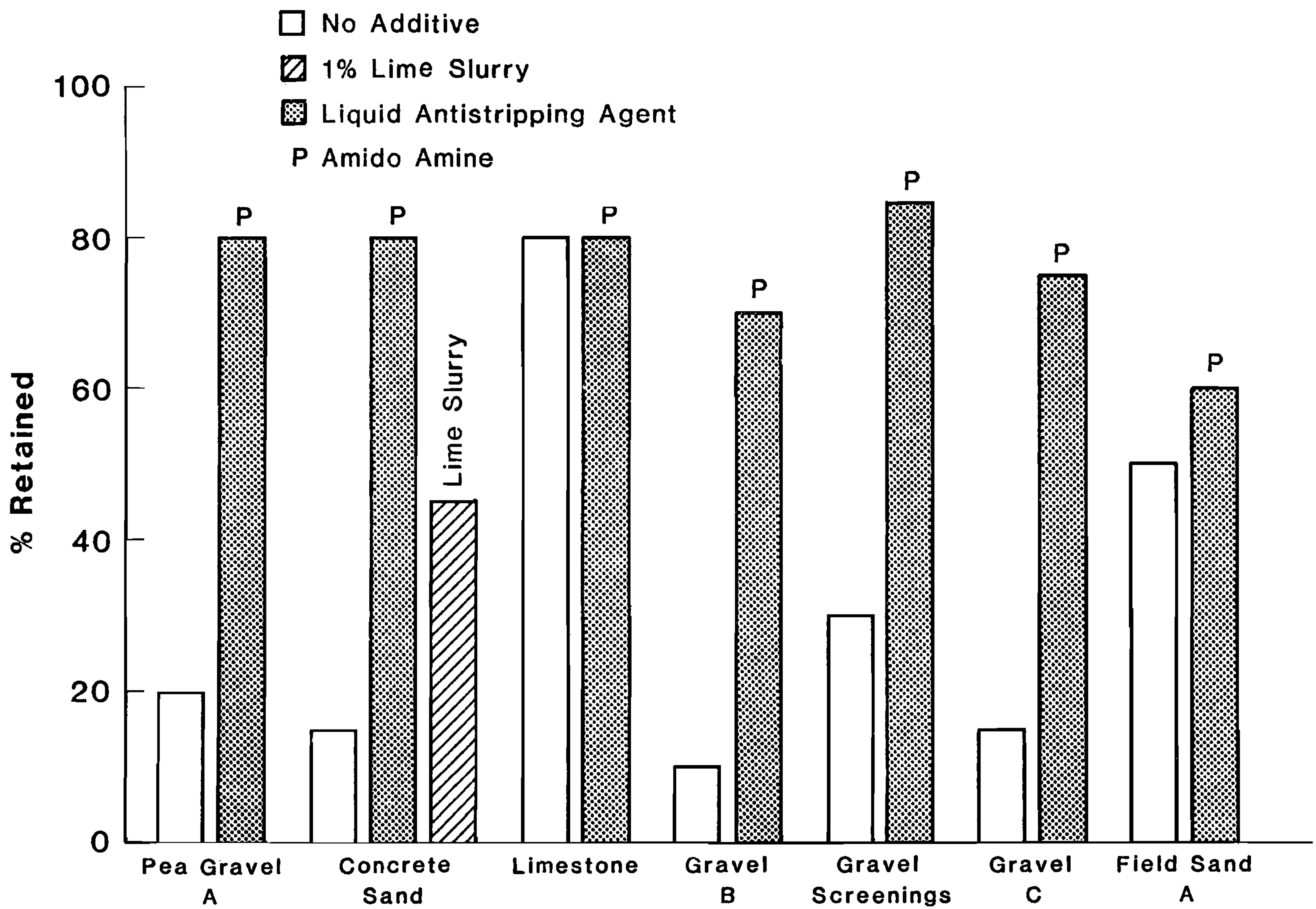


Fig 16. Effect of new antistripping additive P on the moisture resistance of seven Texas asphalt-aggregate mixtures.

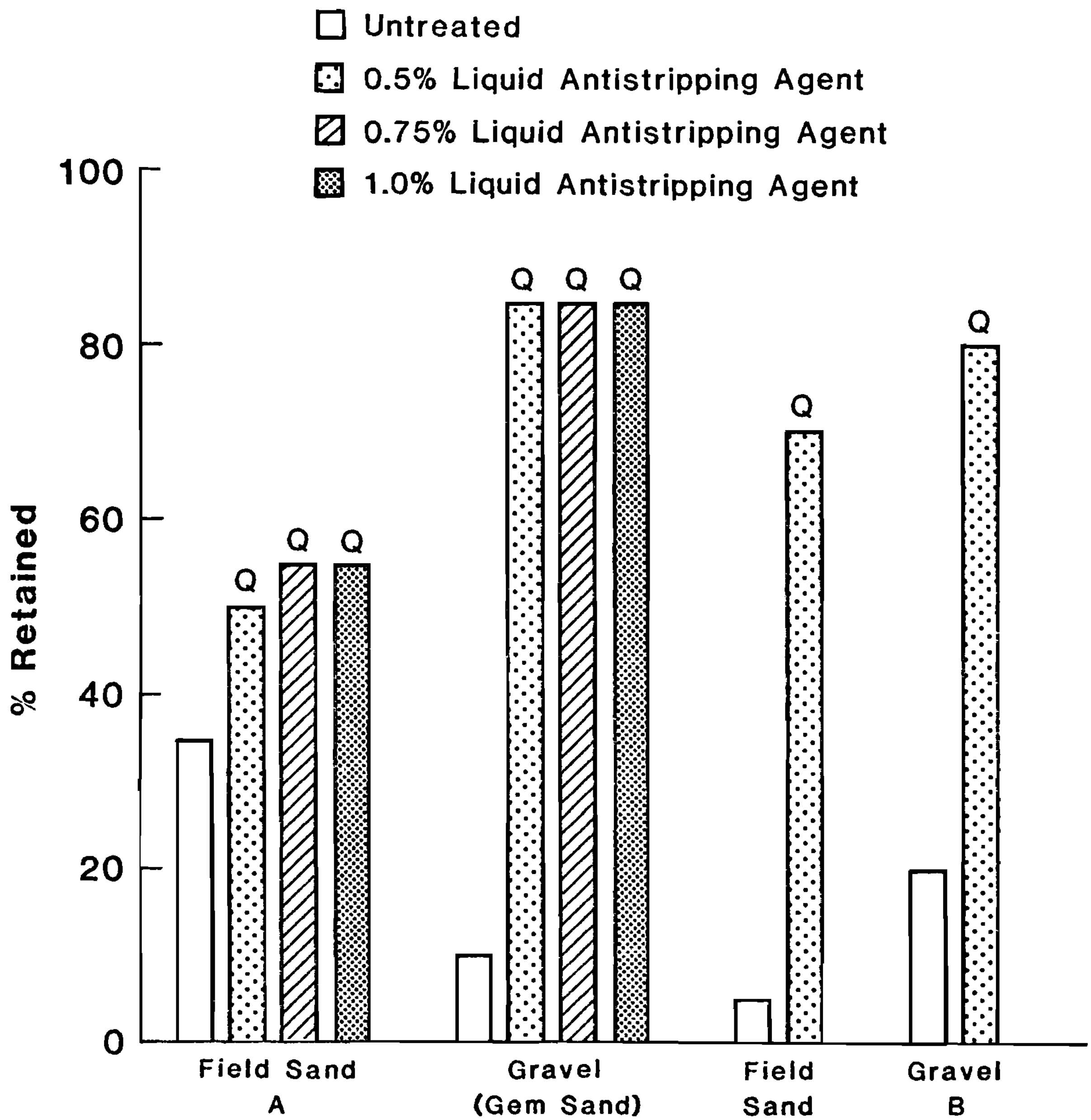


Fig 17. Effect of new antistripping additive Q at three application rates on the moisture resistance of four Texas asphalt-aggregate mixtures.

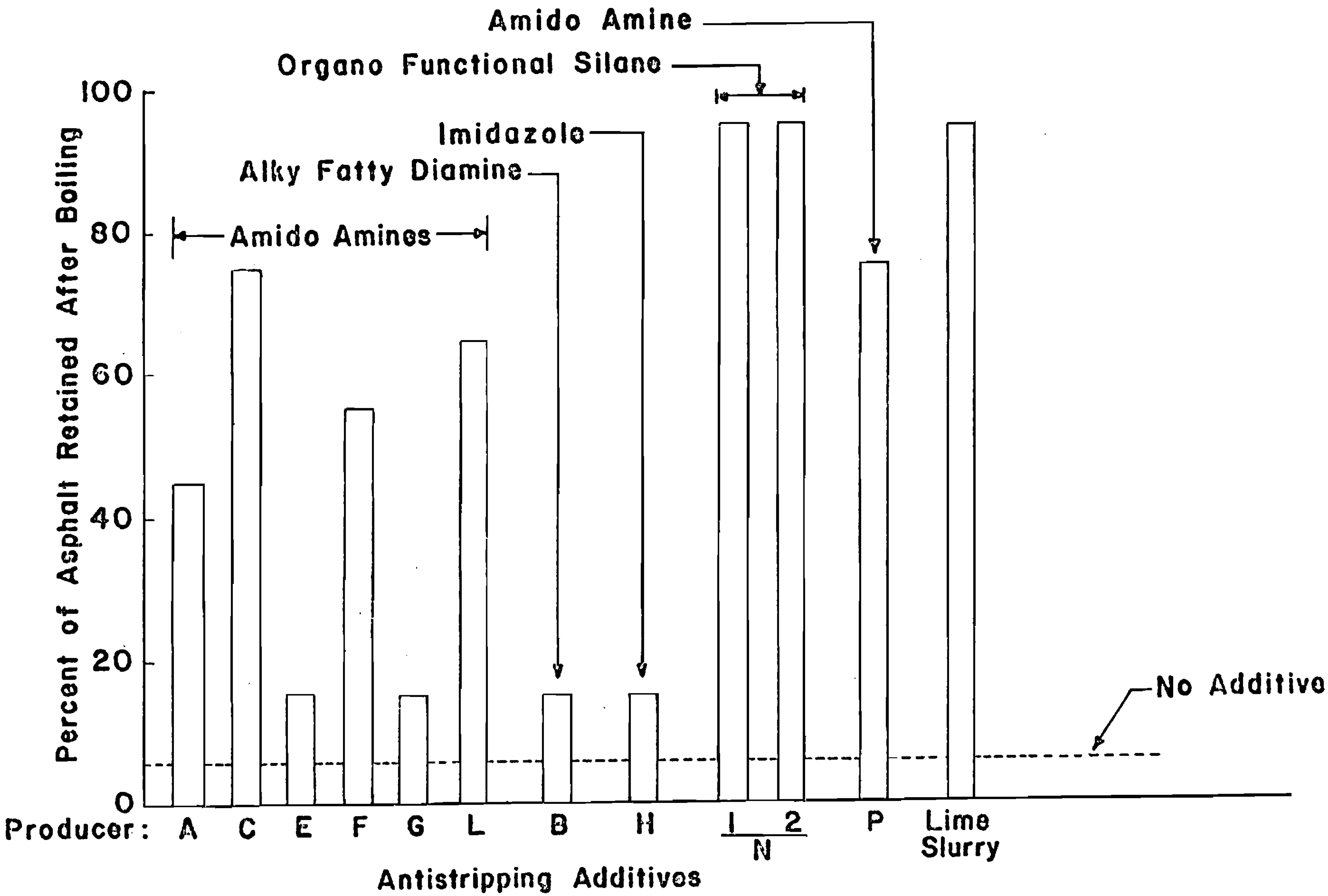


Fig 18. Effect of antistripping additives on the moisture resistance of asphalt mixtures.

CHAPTER 6. LIME TREATMENT

As a result of the early tests, which indicated the general effectiveness of hydrated lime, many states began to specify or encourage the use of hydrated lime in asphalt mixtures. Thus, both laboratory and field studies were conducted to evaluate the use of hydrated lime and the techniques and construction procedures for utilizing lime.

LABORATORY STUDIES

The laboratory study included an evaluation of methods of adding lime, the effect of curing conditions and time, and a limited comparison of calcitic and dolomitic lime to determine relative effectiveness.

Evaluation of Treatment and Curing

Laboratory studies were conducted to evaluate the relative effectiveness of using dry lime, lime slurry, and hot lime slurry. In addition, tests were conducted using lime slurry to determine the effects of curing time.

Generally the use of lime was found to be effective in laboratory studies; however, the use of lime slurry or lime in the presence of moisture was more effective than the use of dry lime. In addition, hot lime slurry, which is produced by slaking lime and then adding additional water to produce a slurry, was found to be as effective as normal lime slurry (Fig 19). While a part of this benefit may be due to an improved interaction between the lime and aggregate, it is felt that most of the benefit is due to the fact that the lime is held on the surface of the aggregate until coated with asphalt. Since the loss of lime can be minimized in the laboratory it is felt that the differences in relative effectiveness will be greater in field applications.

Additional tests involving the addition of lime slurry were conducted to evaluate curing. Treatment levels were 0.5, 1.0, and 1.5 percent hydrated calcitic lime. The treated aggregates were cured from 0 to 90 days prior to mixing with asphalt. Curing was at 75°F under both dry and wet conditions. After curing, the treated aggregates were either immediately mixed with asphalt or were washed and then mixed with aggregate.

The level of protection increased with increased lime; however, for dry curing the effectiveness gradually decreased (Fig 20) with increased curing time. This decrease was attributed to carbonation. Washing of the aggregate prior to mixing with asphalt greatly reduced the effectiveness of the lime.

For wet curing the decrease was quite rapid (Fig 21), possibly due to an increased rate of carbonation but also because the high humidity in the moisture room caused the lime to be removed. Washing of the moist cured lime eliminated essentially all beneficial effects of the lime (Fig 22).

These laboratory studies as well as field experience indicate that the beneficial effects of lime are instantaneous and do not require curing in the stockpile. The improved moisture resistance requires that the lime be on the surface of the aggregate at the time the aggregate is coated with asphalt. In addition, the lime is not effective if it carbonates prior to mixing with the asphalt.

Comparison of Type of Lime

A study involving one asphalt and two aggregates, one of which was moisture susceptible, was conducted, using both a hydrated dolomitic lime (Type N) and a hydrated calcitic lime for treatment. The mixtures were treated with 1 percent hydrated lime slurry and subsequently tested using the Texas Boiling Test. As shown in Figure 23, both the hydrated calcitic and hydrated dolomitic limes were effective in providing increased stripping resistance for the mixture containing the moisture-susceptible river gravel. Tests on the mixture containing the limestone aggregate which was not moisture susceptible showed no adverse effects of the lime treatment.

FIELD STUDY

A field study was performed on a pavement widening project in Bryan, Texas. Testing and evaluation were performed by the Texas State Department of Highways and Public Transportation District 17, The University of Texas at Austin, and Texas A&M University. The results obtained are summarized in four reports (Refs 8, 31, 32, and 33).

The primary objectives of the study were to 1) determine the effectiveness of lime as an antistrip additive when added either dry or in slurry, 2) investigate the effect of time delay after lime treatment of

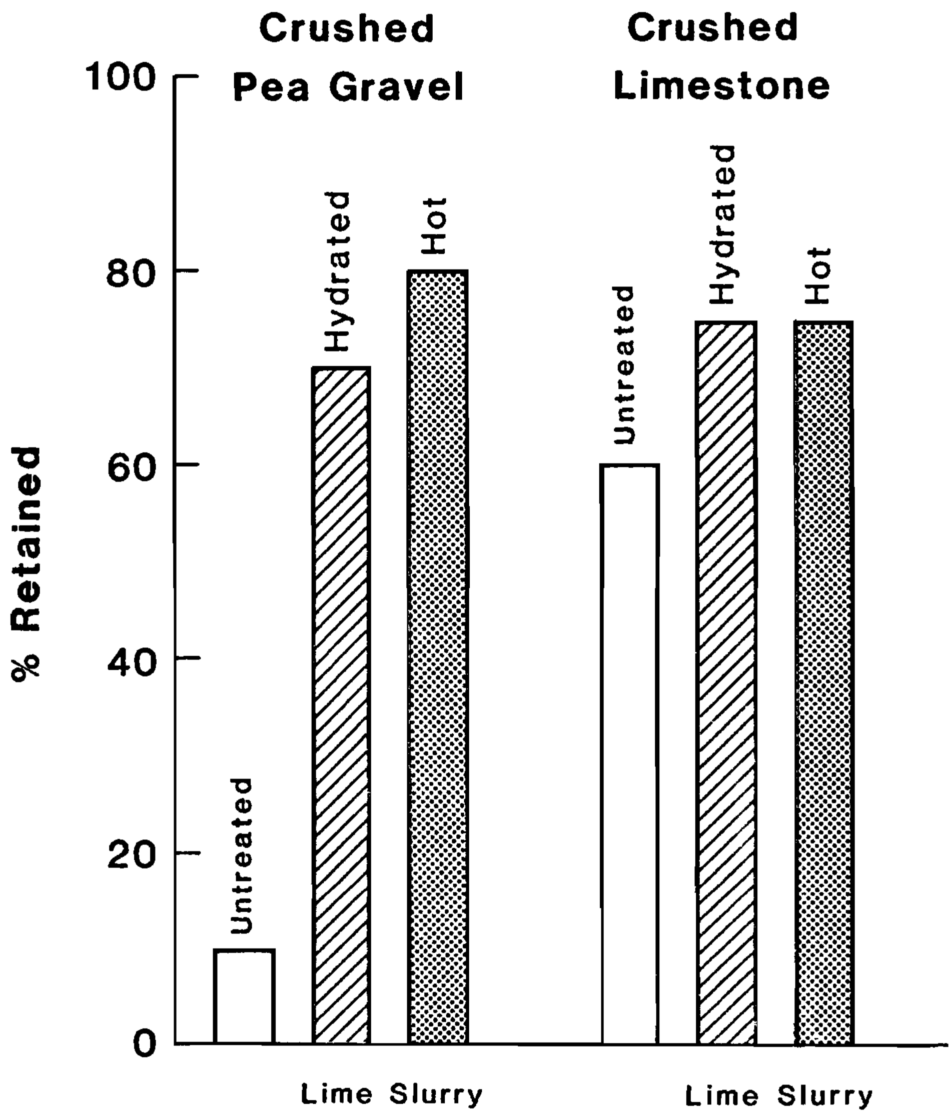


Fig 19. Effect of lime slurry and hot lime slurry on the moisture resistance of two Texas asphalt-aggregate mixtures.

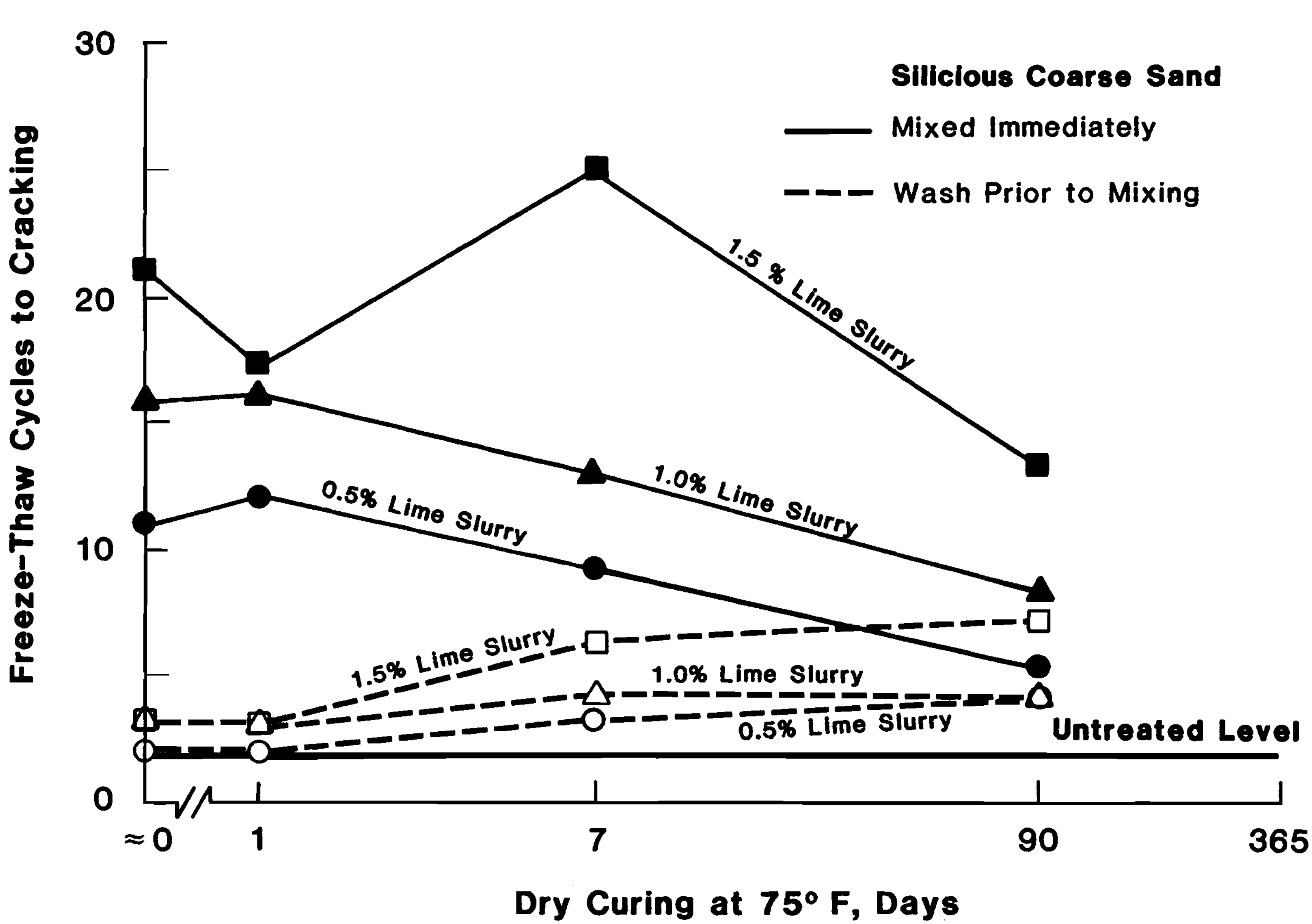


Fig 20. Effect of dry curing time on the moisture resistance of asphalt mixtures containing lime treated aggregates.

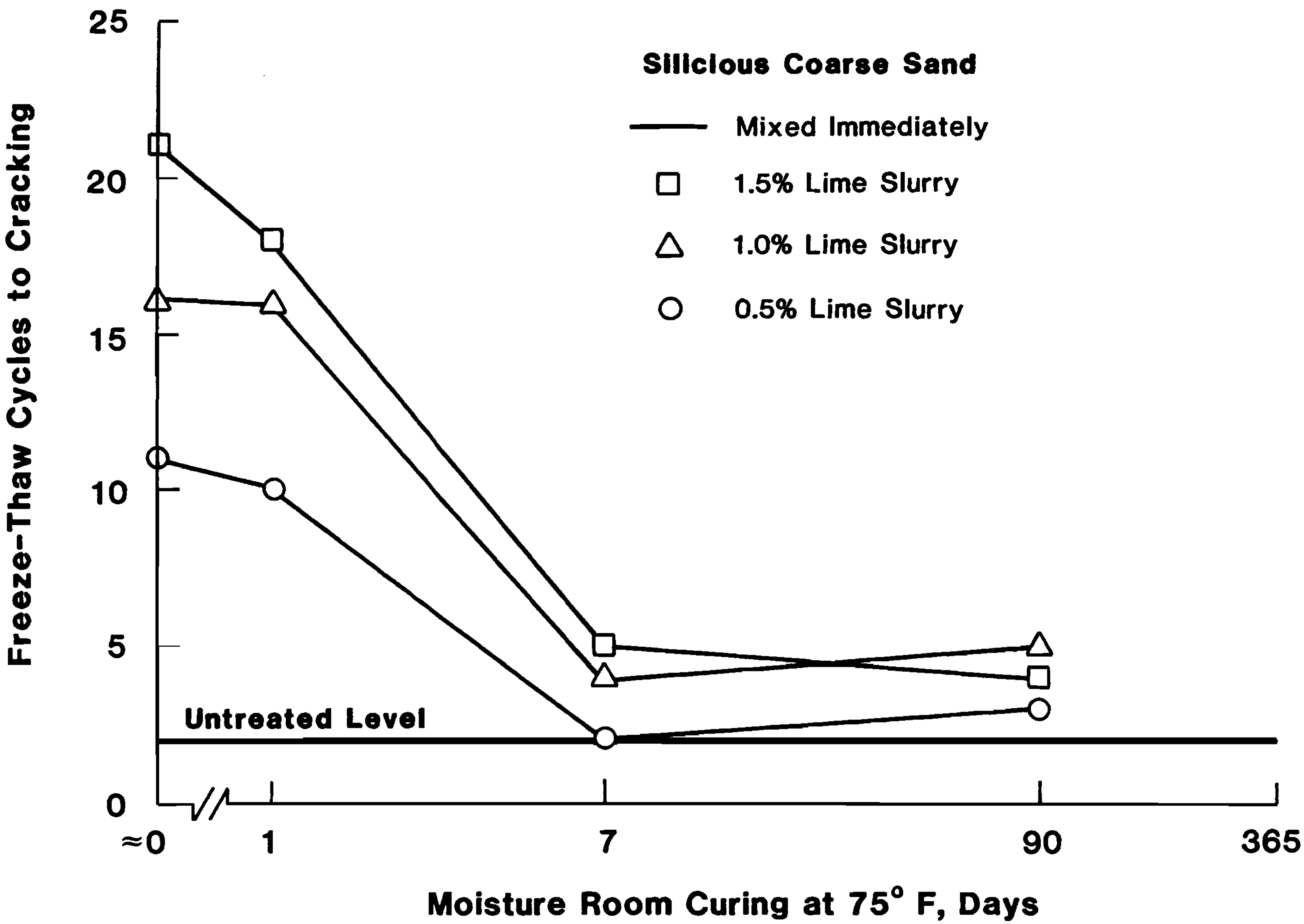


Fig 21. Effect of wet curing time and washing lime treated aggregates prior to mixing with asphalt.

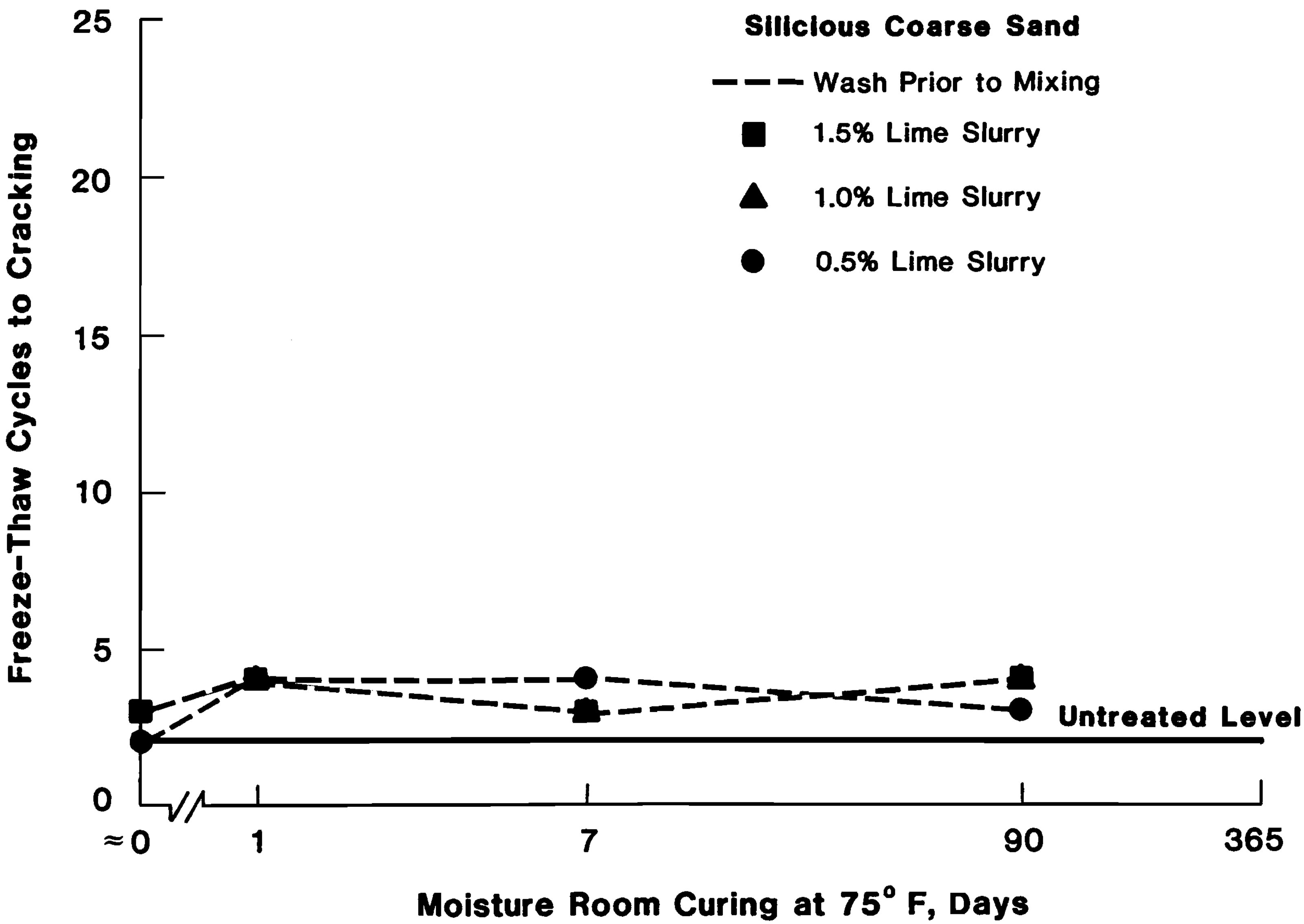


Fig 22. Effect of wet curing time on the moisture resistance of asphalt mixtures containing lime treated aggregates.

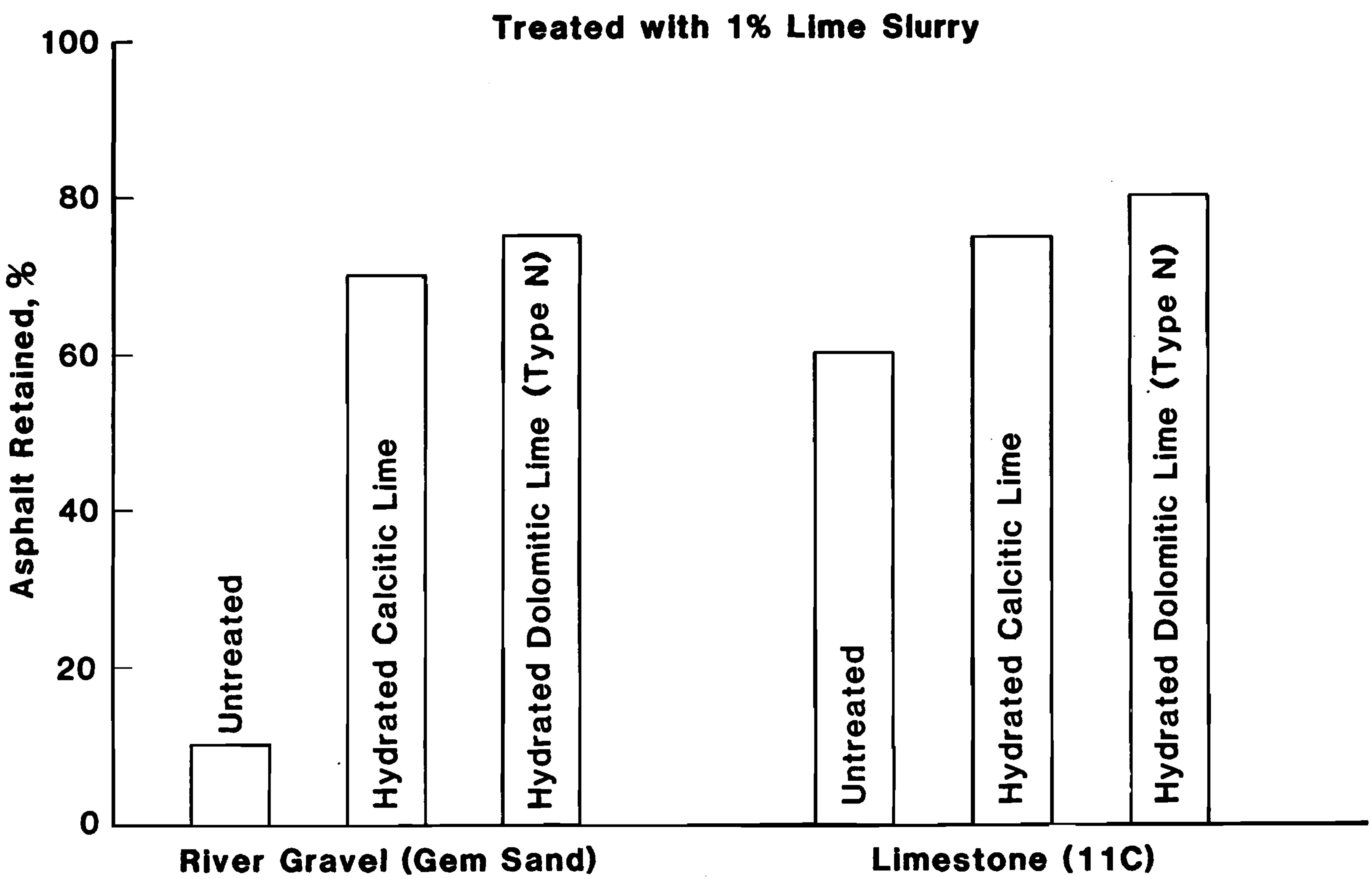


Fig 23. Comparison of the effect of calcitric and dolomitic hydrated lime as an antistripping additive for asphalt mixtures.

aggregate, and 3) evaluate the point of entry of lime in the production system.

Materials and Paving Mixture

An AC-20 asphalt cement and siliceous pea gravel, washed sand, and field sand were used to produce an asphalt mixture which met the Texas State Department of Highways and Public Transportation (SDHPT) specifications of Item 340, Type D (Modified) fine graded surface course (Ref 34). The mixture was designed without hydrated lime; however, in practice the mixture should be designed using aggregates which have been treated with hydrated lime. Laboratory design test values for the mixture design were:

Asphalt Content - 5 percent
Average Density - 95.5 percent of theoretical maximum
Air Void Content - 4.5 percent
Hveem Stability - 41
Cohesiometer Value - 164

Dry hydrated lime was supplied in bags. When used as a slurry, it was mixed in a slurry mixer at a 70-30 weight ratio of water to lime. Dry or slurry lime was added at a rate of 1.5 percent of dry hydrated lime by weight of the dry aggregate treated.

Pavement Test Sections

A major urban arterial test pavement was constructed in August, 1982, and involved reconstruction and widening to four lanes. Each test section was approximately three inches thick, 12 feet wide, and 600 feet long and contained approximately 150 tons of the experimental asphalt concrete. Cores will be obtained over a period of time to evaluate the relative effectiveness of the treatments. This information currently is not available.

Field Procedures

Batch and drum mix plants, located at the same site, were used to prepare asphalt mixtures containing dry or slurried lime. Methods of adding the hydrated lime to the aggregates are summarized below.

Dry Lime. Three methods were used for the addition of dry lime and varied depending on plant type.

a. Batch Plant

Dry lime was manually placed in the pugmill after an initial 15-second dry mixing and was mixed with the aggregate for about 15 seconds prior to the addition of the asphalt cement; mixing then continued for an additional 20 seconds.

b. Drum Plant

Two methods were utilized to introduce dry lime into the mixtures produced in the drum plant. One method employed the fines feeder from the baghouse. The lime was blown into the drum just ahead of the asphalt stream. This location was selected so that the dry lime would immediately encounter the asphalt cement and minimize the loss of lime into the baghouse. The second method involved adding the dry lime directly to the aggregates on the cold feed belt.

Slurried Lime. Lime slurry was added to the individual aggregates immediately after being discharged from the cold feed bins on the cold feed belt. This allowed individual aggregates or combined aggregates to be treated. For aggregates which were stockpiled the individual aggregates were treated using the same system and stockpiled separately.

a. Batch Plant

The only procedure utilized for the batch plant involved treating all aggregates and stockpiling for 2 days prior to mixing with asphalt.

b. Drum Plant

The addition of slurried lime involved 1) treatment of all aggregates and 2) treatment of individual aggregates with the other two aggregates untreated followed by immediate mixing and stockpiling for 2 days prior to mixing. A third procedure involved treatment of all aggregates and stockpiling for 30 days prior to mixing.

It should be noted that when lime slurry was introduced on the cold feed belt and mixed immediately, minimal mixing occurred until the lime-treated aggregate passed through the scalping screen. When lime slurry was added to a given aggregate (field sand, washed sand, or pea gravel) at a rate of 1.5

percent by weight of that particular aggregate, the net effect was to simply reduce the lime content of the final paving mixture.

Testing

Tests were performed on mixtures 1) mixed and compacted in the laboratory, and 2) mixed in the field and compacted in the laboratory.

Laboratory Mixed/Laboratory Compacted Mixtures. Samples of the project asphalt cement, aggregates, and lime were obtained. These materials were mixed and compacted in the laboratory in accordance with the established mixture design. Lime was introduced in a manner similar to that used in the field. Selected specimens were compacted at a reduced compactive effort to produce a higher air void content and thus provide a more severe test of moisture susceptibility.

Field Mixed/Laboratory Compacted Mixtures. Samples of the field mixtures were obtained at the asphalt mixing plant. They were immediately transported to the laboratory and compacted to fabricate 4-inch diameter specimens. Reheating was necessary to maintain a compaction temperature of 250°F; but reheating was kept to a minimum in order to minimize any changes in mixture properties.

Test Results

Presentation of test results is limited to those performed on laboratory-mixed and field-mixed mixtures. In addition, because of the extensive number of tests performed in the investigation, only selected, typical data are presented. Complete test results can be found in References 8, 31, 32, and 33.

Untreated Aggregates. Based on boiling and pedestal tests conducted on the combined and individual aggregates (washed and unwashed), all untreated aggregates were susceptible to moisture damage. Results obtained by UT and by Highway District 17 generally were comparable. Washing of the aggregate did not consistently improve susceptibility to moisture damage.

Laboratory Mixtures. The results of pedestal tests and indirect tensile tests for combinations of all aggregates and individual aggregates which were treated with dry lime and lime slurry are shown in Figures 24 through 27. The moisture resistance of the treated aggregates was significantly improved and it appeared that the improvement was greater for lime slurry treatment than for treatment with dry lime.

Figure 24 illustrates the pedestal test results which show significant improvements in moisture susceptibility for both dry lime and lime slurry. No differences in the two techniques were apparent, nor was there any effect produced by cure time. Figure 25 illustrates a similar trend for mixtures in which individual aggregate components were treated with lime slurry and cured for two days prior to mixing with asphalt. When only the field sand and washed sand were treated, the specimens failed. This was probably because the amount of lime incorporated in the mixture was not sufficient to protect all of the aggregates since the field sand and washed sand represented only 23 and 15 percent of the total aggregate, respectively. When the entire mixture and the pea gravel (62 percent) were treated, the mixture exhibited significant improvements.

Figures 26 and 27 illustrate the wet-dry indirect tensile test results for specimens compacted using standard procedures (≅3% air voids) and modified procedures (≅7% air voids). Figure 26 indicates that both dry lime and lime slurry were beneficial to improving the moisture susceptibility of specimens compacted using the standard procedure. It was also found that the treatment of individual components was beneficial but that the treatment of only the field sand or washed sand did not produce as much benefit as the treatment of the pea gravel or the total aggregate.

Similar results were also observed for specimens produced using the modified compaction procedure (Fig 27). The improvements, however, were not as great as with standard compaction because of the higher void content which allowed more water to enter the specimens.

Field Mixtures. The results for mixtures which were processed through the two plants and then compacted in the laboratory are shown in Figures 28 through 31. Boiling tests are summarized in Figure 28 and indirect tensile tests are summarized in Figures 29 through 31.

Boiling test results for field mixtures indicated that lime improved the resistance to stripping, with the lime slurry generally being more effective. Dry lime, introduced in the drum just prior to the asphalt, was relatively ineffective, presumably because the lime was removed and deposited in the bag house and/or mixed with the asphalt cement, serving more as a filler (Fig 28). In contrast with the laboratory mixtures, treatment of only certain individual aggregates was effective in improving the resistance to stripping and moisture damage. It should also be noted that aggregates which were stockpiled produced favorable results while previous laboratory tests on other stockpiled aggregates have indicated a loss of effectiveness, presumably because of carbonation of the lime. This can be explained by the fact that the stockpiles used on this project were relatively impermeable to air and environmental conditions were dry.

Dry and wet indirect tensile strengths and the tensile strength ratios, i.e., the ratios of wet strengths to dry strengths, are shown in Figures 29 through 31. For batch plants the lime slurry was more effective, especially for specimens with modified compaction (Fig 29). Similarly, for drum plants the lime slurry tended to be more effective, especially in comparison to the procedure in which dry lime was introduced into the drums (Figs 30 and 31). Standard compaction also produced higher resistance to moisture damage. Slurry treatment of only a given aggregate component provided satisfactory mixtures; however, for modified compaction the resistance to moisture change was greater when the pea gravel was treated, presumably because of the higher overall lime content.

Indirect test results indicate that both dry lime and lime slurry were effective in reducing stripping and moisture damage; however, lime slurry tended to be more effective, especially for drum mixers. This is attributed to the loss of the dry lime which can be more readily removed and either deposited in the bag house or mixed with the asphalt cement where it acts more as a filler. The importance of adequate compaction is also evident by comparing mixtures with about 3 percent air voids (standard compaction) with mixtures with 7 percent air voids (modified compaction).

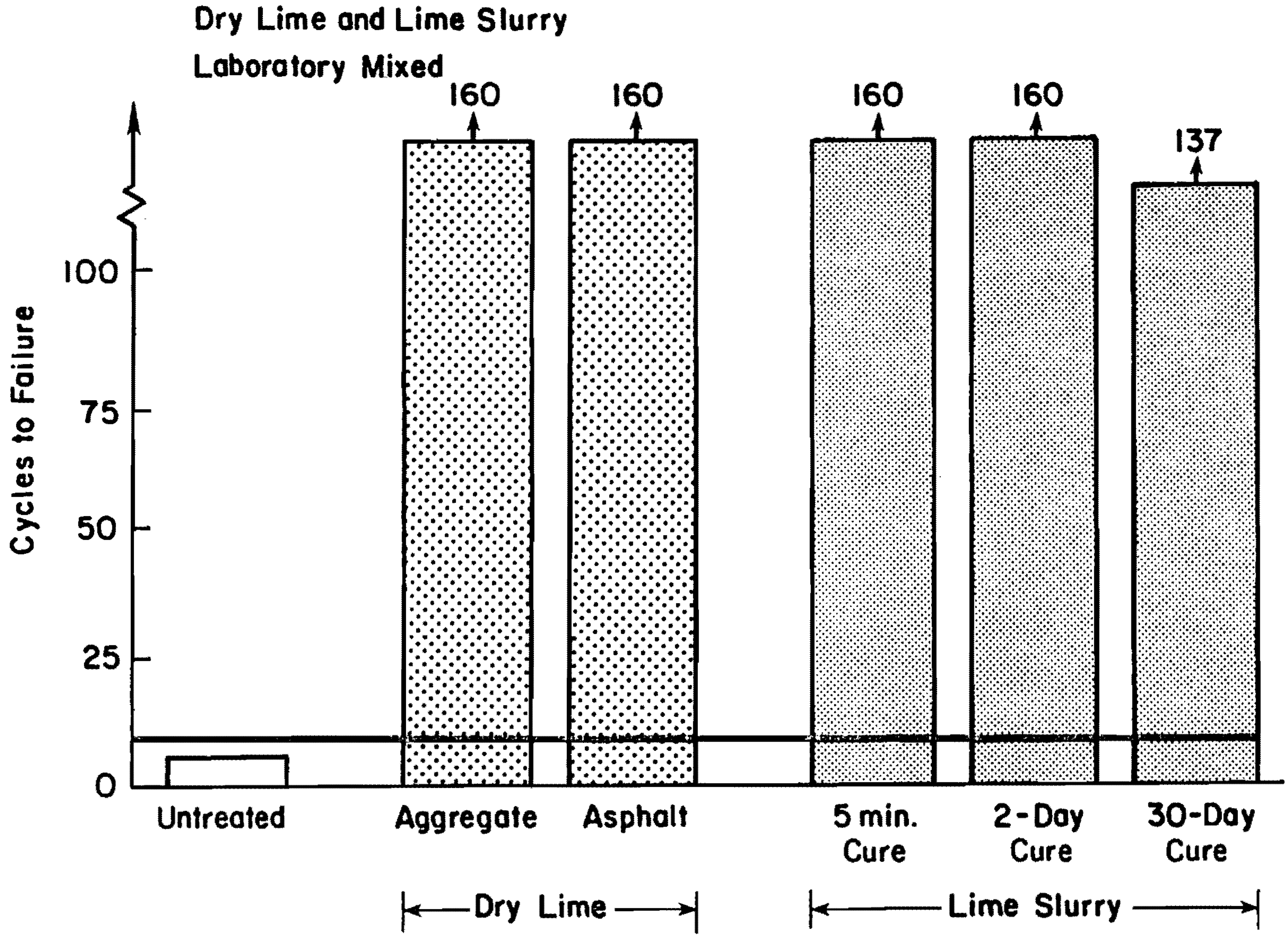


Figure 24. Pedestal test results for laboratory prepared mixtures with dry lime and slurry lime

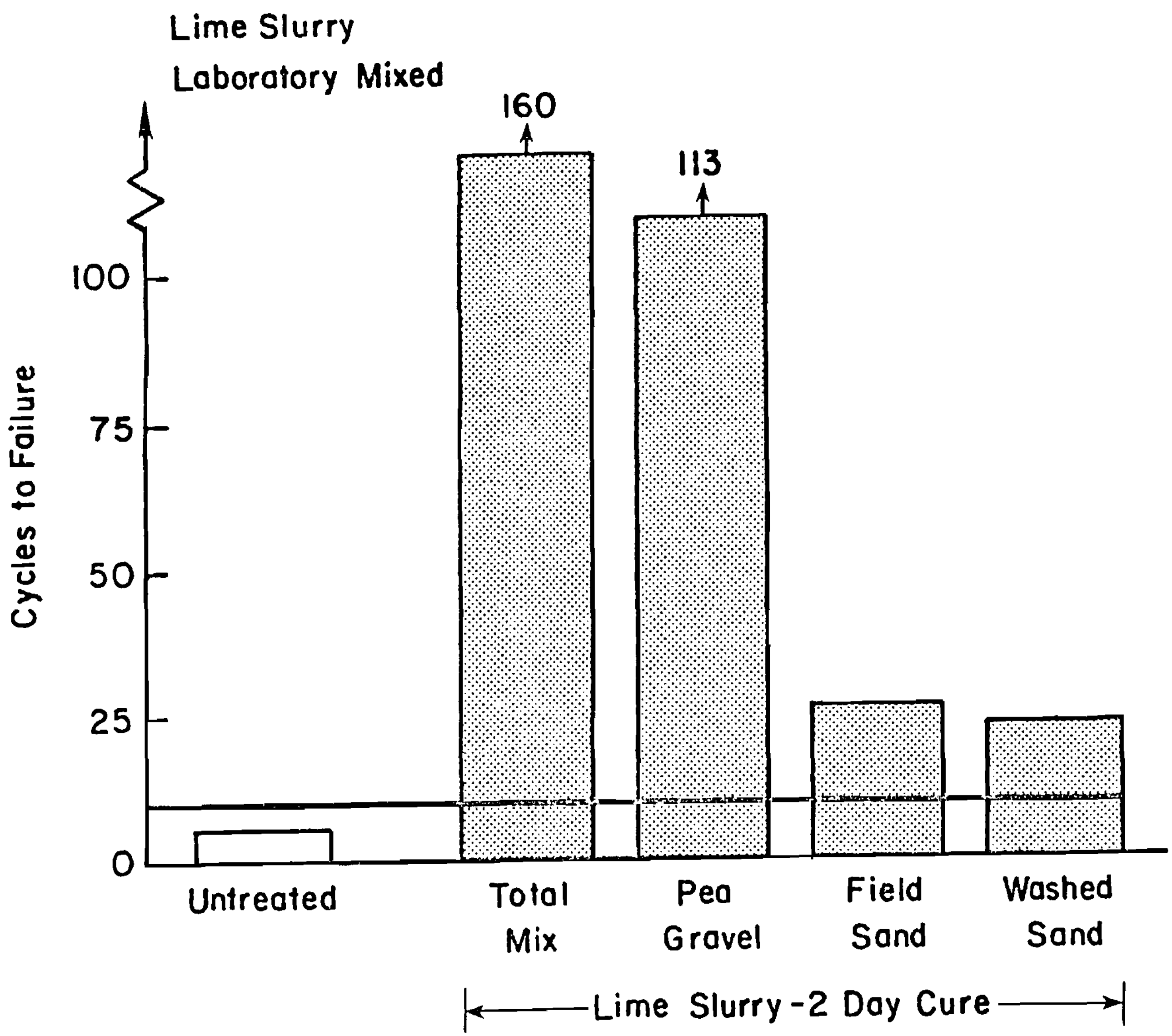


Figure 25. Pedestal test results for laboratory prepared mixtures with individual aggregate components treated with lime slurry

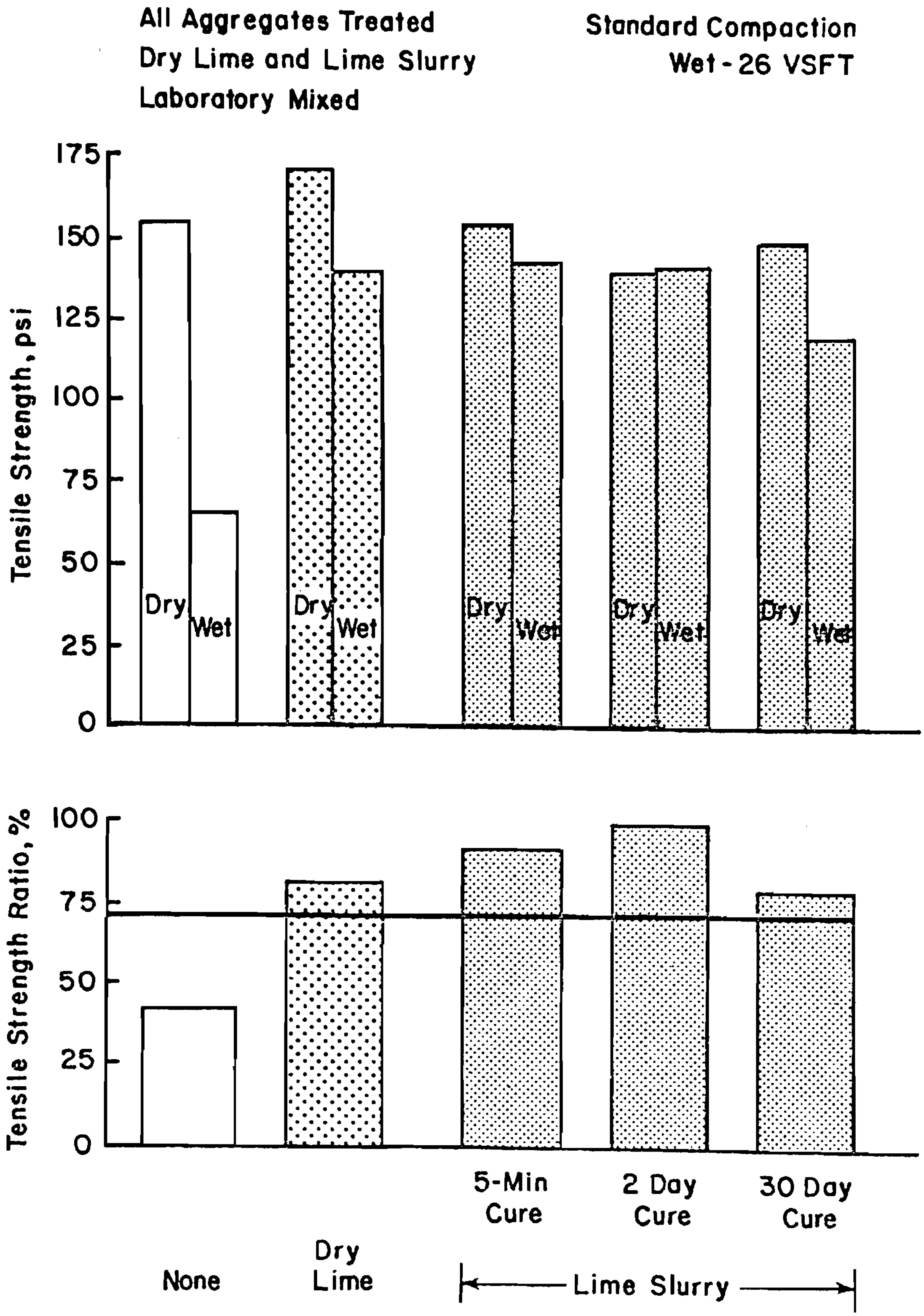


Figure 26. Indirect tensile test results for laboratory prepared mixture with dry and slurry lime using standard compaction

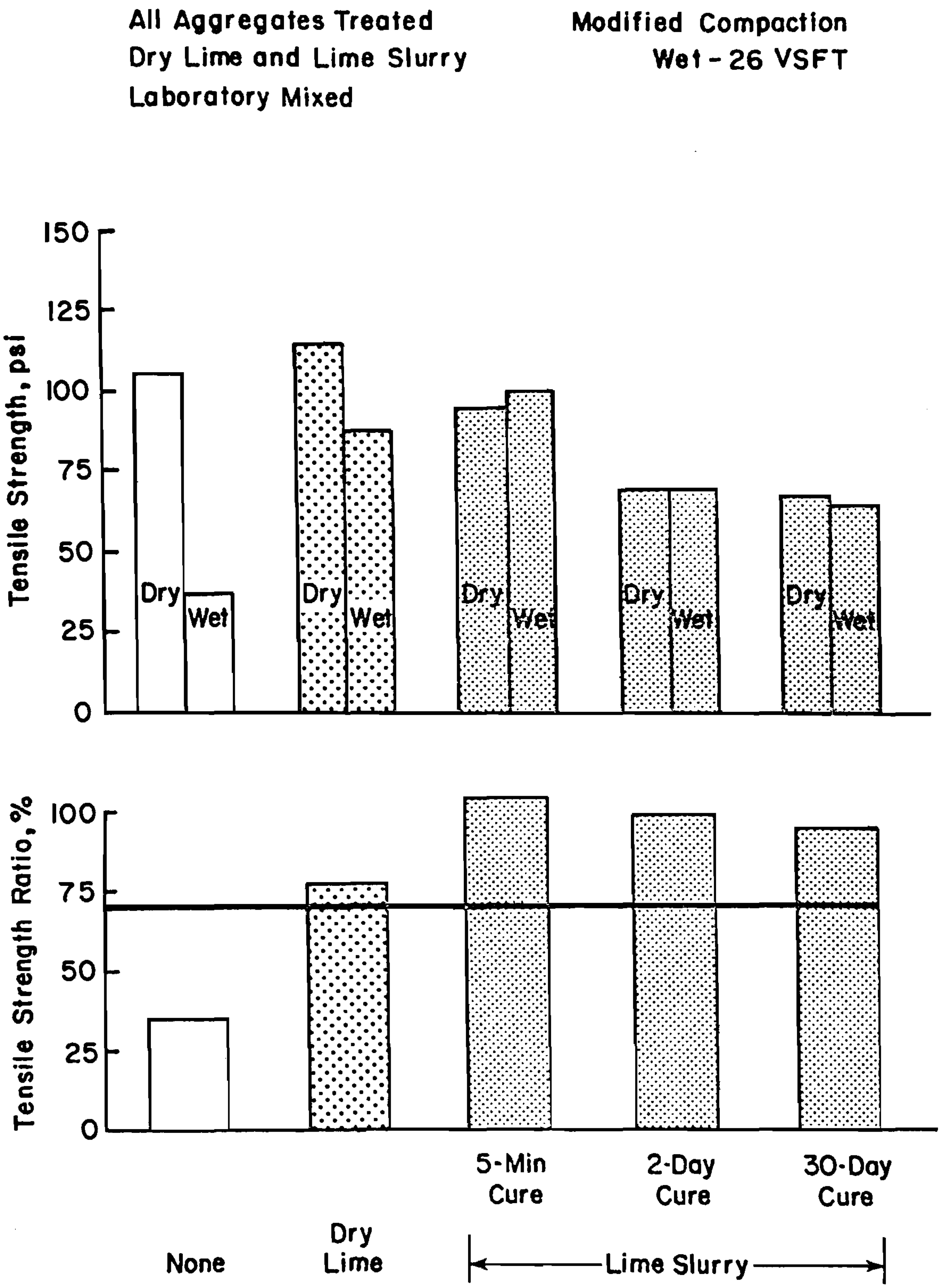


Figure 27. Indirect tensile test results for laboratory prepared mixtures with dry and slurry lime using modified compaction

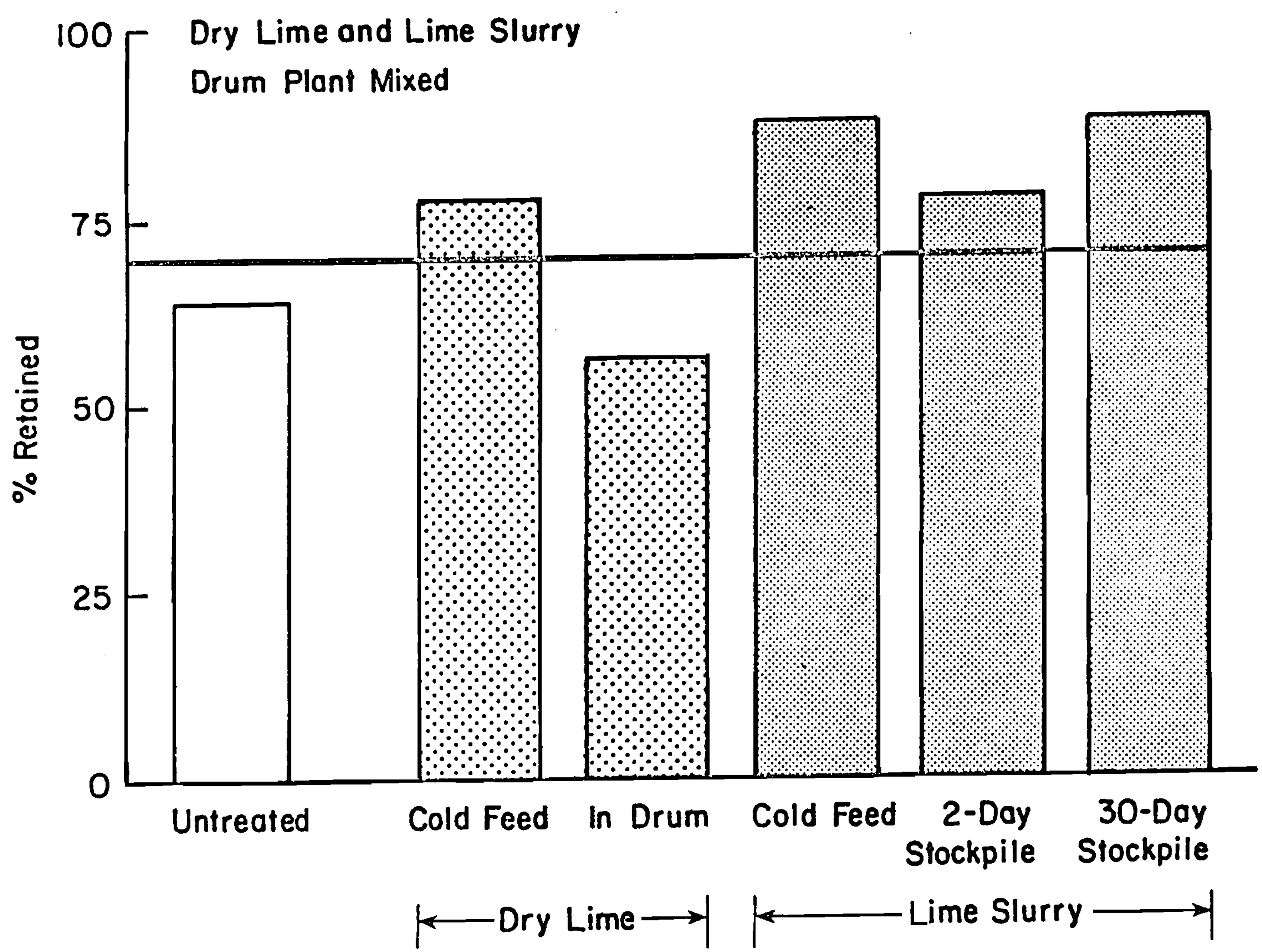


Figure 28. Boiling test results for drum plant mixtures treated with dry and slurry lime

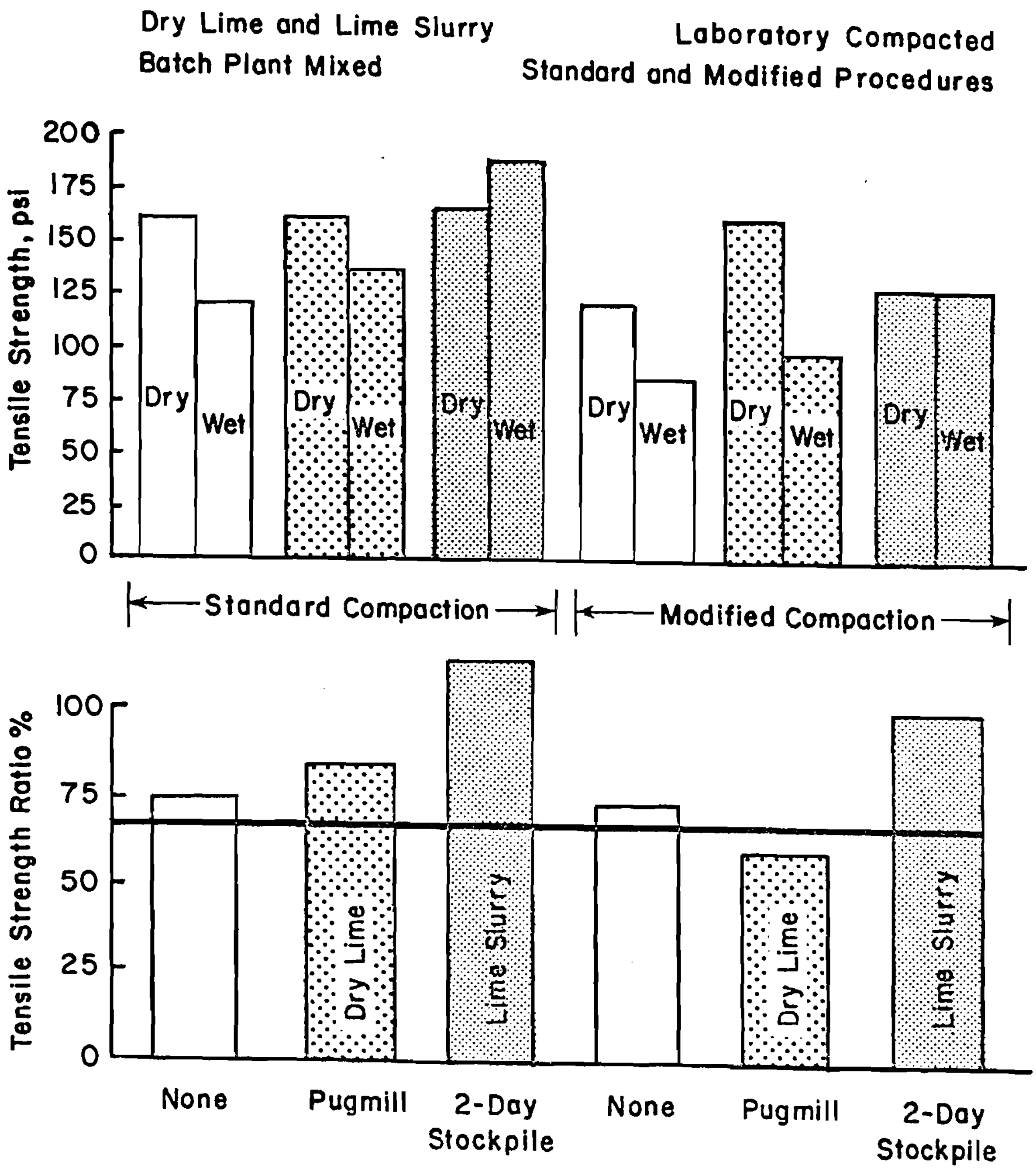


Figure 29. Indirect tensile test results for batch plant mixtures treated with dry and slurry lime

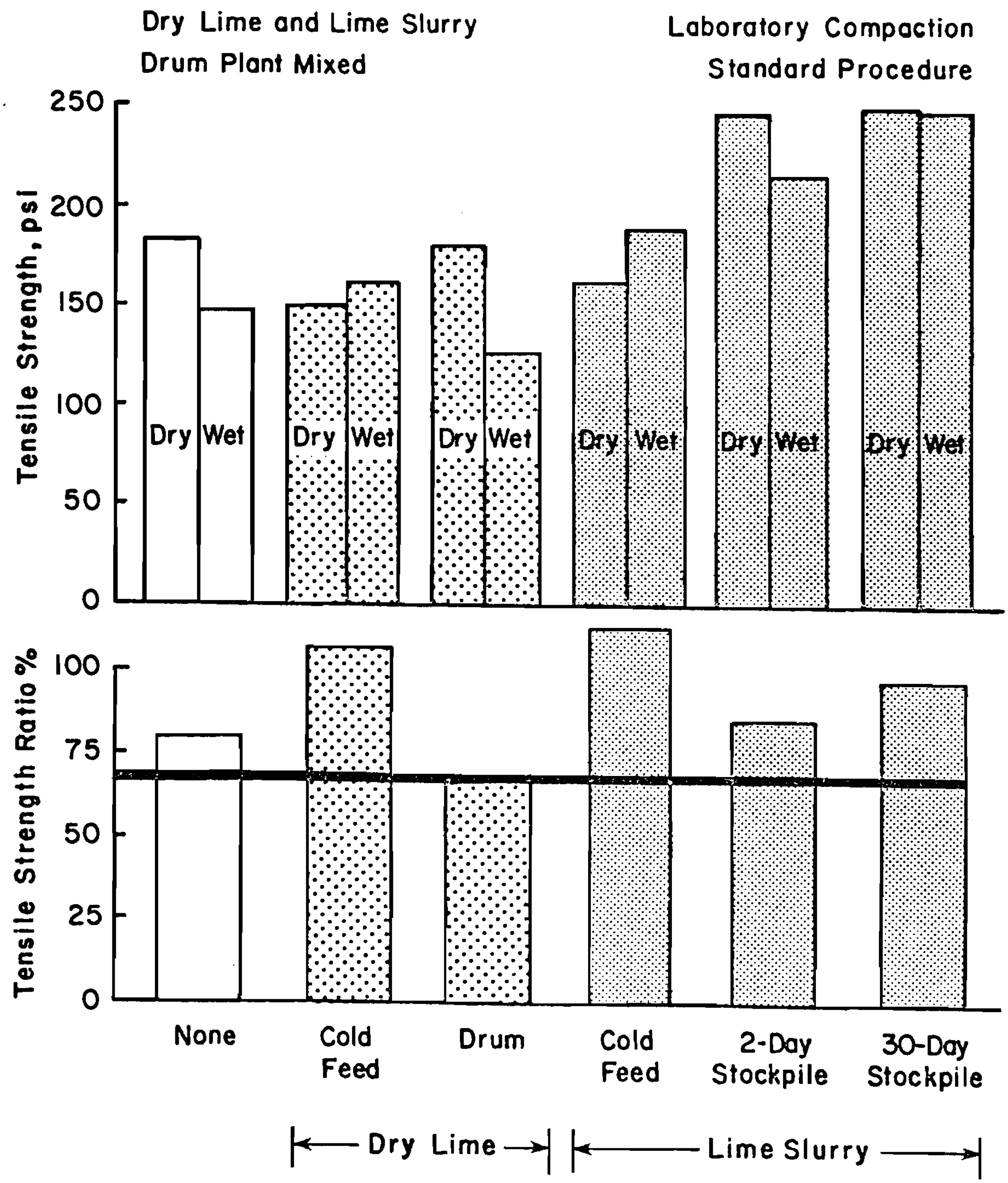


Figure 30. Indirect tensile test results for drum mixtures (standard compaction) treated with dry and slurry lime

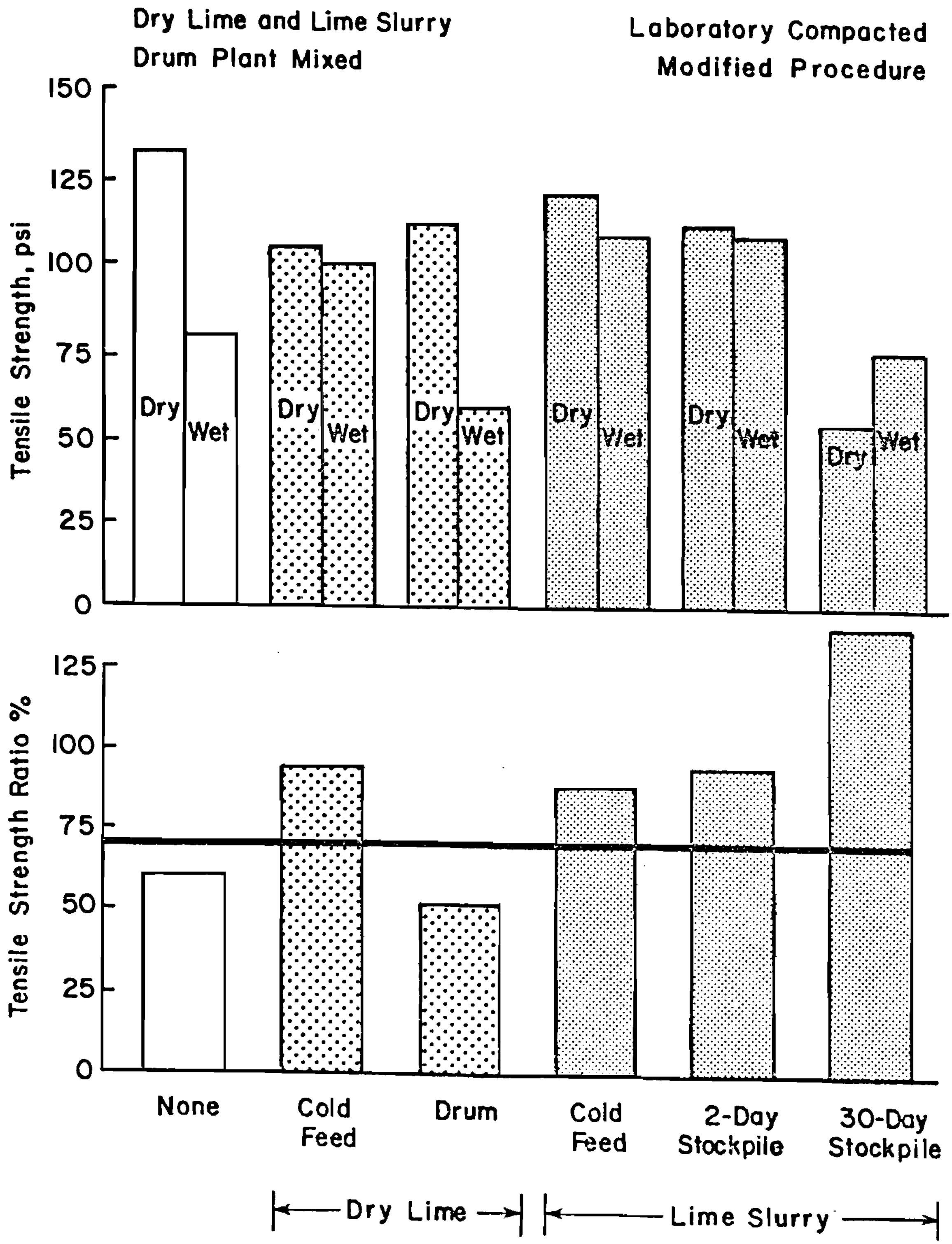


Figure 31. Indirect tensile test results for drum plant mixtures (modified compaction) treated with dry and slurry lime

RECOMMENDATIONS FOR FIELD APPLICATION OF HYDRATED LIME

Both dry lime and hydrated lime slurry have been shown to be effective antistripping additives although lime slurry or, at least, lime in the presence of water is the most effective. It should be noted that stiffening of the mixture may occur for cooler conditions, long haul distances, and delayed placing. This may occur as surface crusting or as stiffening of the entire mixture. Generally it will be difficult to treat only one aggregate component since mixing will occur with the lime being transferred from the treated aggregate to the untreated aggregate.

The following summarizes the various techniques which can be used.

Dry Lime

The primary problem with the addition of dry lime is holding the lime on the surface of the aggregate until it is coated with asphalt even though there is some indication that lime in the presence of water gives a better reaction with the surface of some aggregates. The loss of lime will be greater in drum mixers, which tend to pick up the lime in the gas flow. In addition, a portion of the dry lime may be mixed into the asphalt, thus acting as a filler.

Aggregates can be treated by adding dry hydrated lime to the aggregates as follows; however, none of these procedures are recommended.

(1) Batch and Drum Mix Plants

a. On the aggregate cold feed

Mixing and coating of the aggregates will be minimized. Passing the aggregate and lime through a scalping screen can improve mixing but at the same time may produce dusting and the loss of lime.

b. In a premixing pugmill

This technique will maximize the coating of the aggregates, but lime may be lost due to dusting.

c. Prior to stockpiling

This technique probably requires that the lime be added prior to construction of the stockpile, either by pugmilling at the plant site or by having the aggregate supplier add the lime. A large portion of the lime will probably be lost prior to construction due to segregation, dusting, rainfall, etc. This method is not recommended.

(2) Batch Plants

In the plant's pugmill prior to adding asphalt

This technique probably maximizes mixing and coating of the aggregates and minimizes losses due to dusting. A portion of the lime, however, may be lost in the asphalt cement.

(3) Drum Mix Plants

In the drum prior to adding asphalt

This technique is definitely not recommended unless new equipment and techniques can be developed which will insure that the lime is not removed from the aggregate. Georgia has reported successful use of dry lime in drum mixers which have been modified to reduce the loss of lime. Figure 32 shows an example of such a modification. Lime enters from the cone shaped head in the foreground; liquid asphalt cement and baghouse fines enter from the cylindrical head in the background. Baffles were added at the point of lime injection to promote mixing of the lime and aggregate. Dust loss is minimized by modification of the flights which prevents the mixture from being thrown into the air stream.

Lime Slurry

The primary problem with the use of lime slurry is that the water added to the aggregates must be removed by drying, thus increasing fuel costs and reducing production rates. Application techniques should minimize the amount of water which must be removed when the aggregate enters the dryer or the drum mixer.

The lime slurry should be prepared with an approximate minimum of 30 percent lime and a maximum of 70 percent water by weight in order to minimize

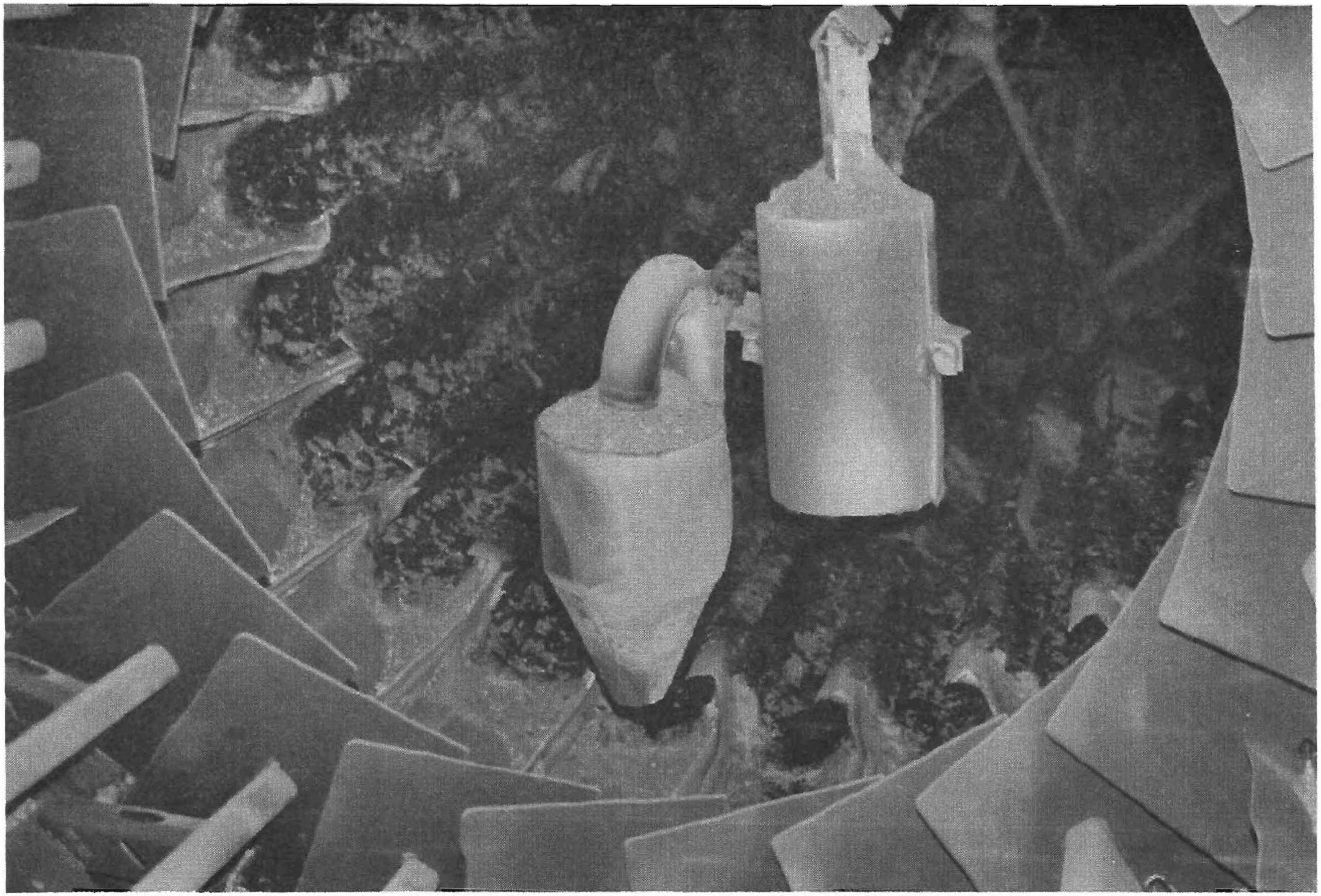


Fig 32. Application of dry lime to aggregate in feed end of drum mixer (Georgia plant).

the amount of water added to the aggregate. Aggregates can be treated by adding the lime slurry as follows:

(1) Batch and Drum Mix Plants

a. On the cold feed (Figs 33 and 34)

Mixing and coating of the aggregates are minimized. Passage through a scalping screen may improve aggregate coating, but the mixture may foul the screens. Since mixing is minimized, it may be possible to treat only certain aggregates by arranging the cold feed bins to place the aggregate to be treated on top of the cold feed or by treating the aggregate under the cold feed bins immediately after it is placed on the cold feed belt.

b. In a premixing pugmill (Fig 35)

This method provides better coverage of the aggregate and allows a portion of the water to drain.

c. Prior to stockpiling (Fig 36)

This method allows much of the water to drain, thus minimizing required drying. However, it maximizes the chances of carbonation and the loss of lime. Preliminary indications are that hydrated lime applied in slurry form to aggregates is difficult to remove. Nevertheless, the length of time permitted in the stockpile is not well established. This technique would allow only certain aggregates to be treated. Tentatively, until more experience is acquired, it is recommended that stockpiling be limited to 10 days or less depending on the environmental conditions.

(2) Drum Mix Plants

On the slinger belt

This method minimizes the amount of mixing and coating of the aggregates and maximizes the amount of moisture which must be removed.

Dry Lime With Water

Another technique involves adding dry hydrated lime to wet aggregates

(Fig 37) or adding dry lime to dry aggregates and then spraying a small quantity of water onto the mixture.

All techniques and recommendations pertaining to lime slurry also pertain to the application of dry lime and water. In general, it is felt that the water should be added to the aggregate before the dry lime is added, to prevent washing the lime off the aggregate surface. The exception is in a premixing pugmill where probably the water can be added after the lime is introduced.

Hot Lime Slurry

The use of quick lime which is slaked and slurried at the job site (Fig 38) offers a number of advantages. First, quick lime normally costs about the same as the cost of hydrated lime, but when slaked it will result in about 25 percent more hydrated lime. In addition, slaking with excess moisture will produce a slurry with a temperature of about 180°F, which may maximize evaporation losses and the reactivity of the hydrated lime. In addition, the elevated temperature should produce a hydrated lime with smaller particle sizes, which in turn may maximize the reactivity of the hydrated lime. Thus, a more reactive lime possibly can be obtained at a lower cost, which will partially offset drying costs.

All techniques and recommendations pertaining to lime slurry also pertain to the use of hot lime slurry.

Summary

The final decision as to how lime should be added should, for the most part, be left to the contractor in order to minimize costs and disruptions to the production cycle, providing that tests of the produced mixture indicate that the desired resistance to stripping can be achieved. It is recommended that the lime be added as a slurry or at least with a small amount of water. However, dry lime can be used if proper precautions are taken to prevent loss of the lime prior to mixing with the asphalt cement. The use of a pugmill in the cold feed system is recommended since it will maximize coverage. Nevertheless, the final decision should be based on relative effectiveness and cost. In addition, the effectiveness of the procedure chosen should be monitored during production.

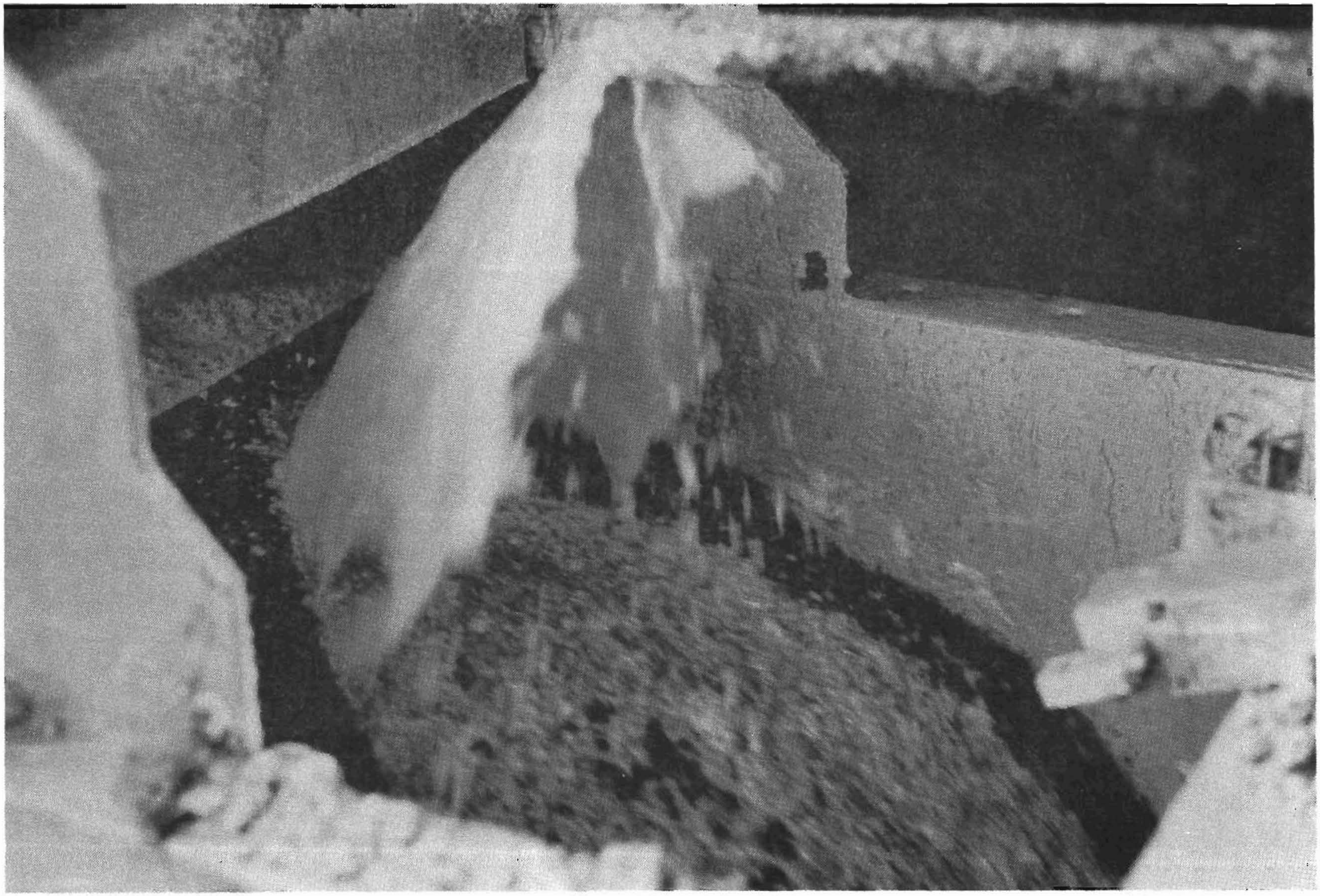


Fig 33. Lime slurry being applied to the cold feed (Texas plant).

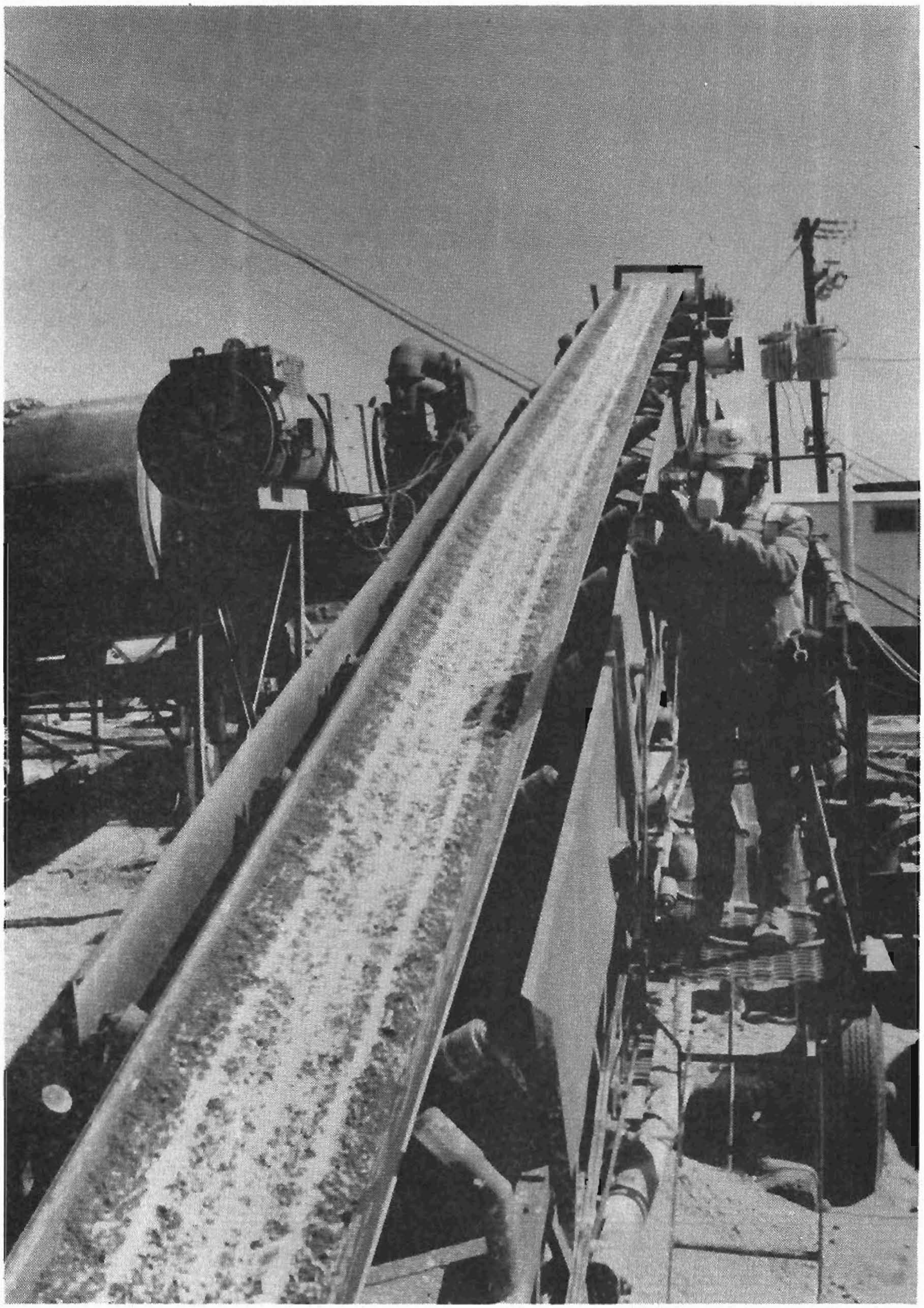


Fig 34. Application of lime slurry to aggregate on the cold feed belt.

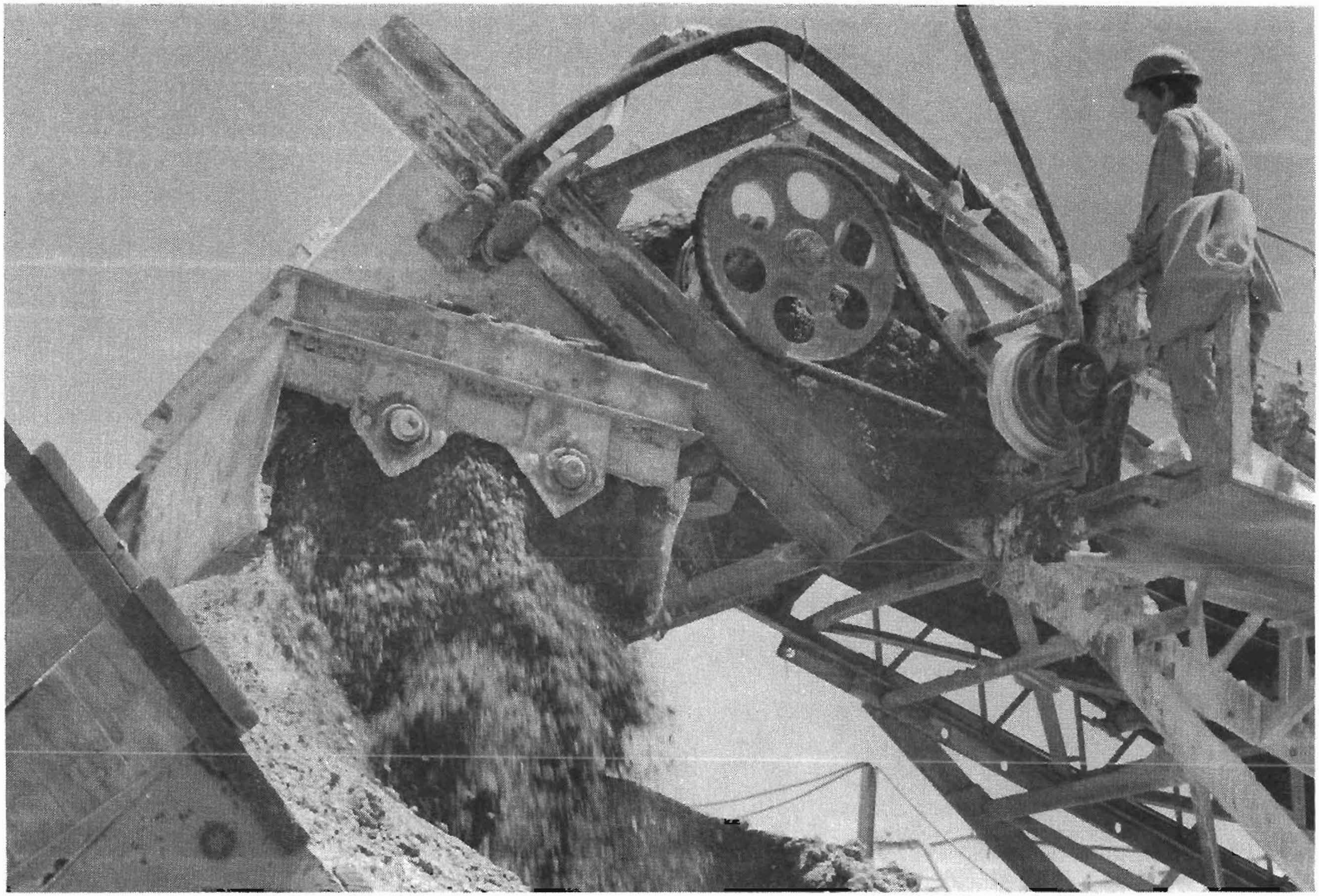


Fig 35. Lime slurry added to aggregate in twin pugmill.

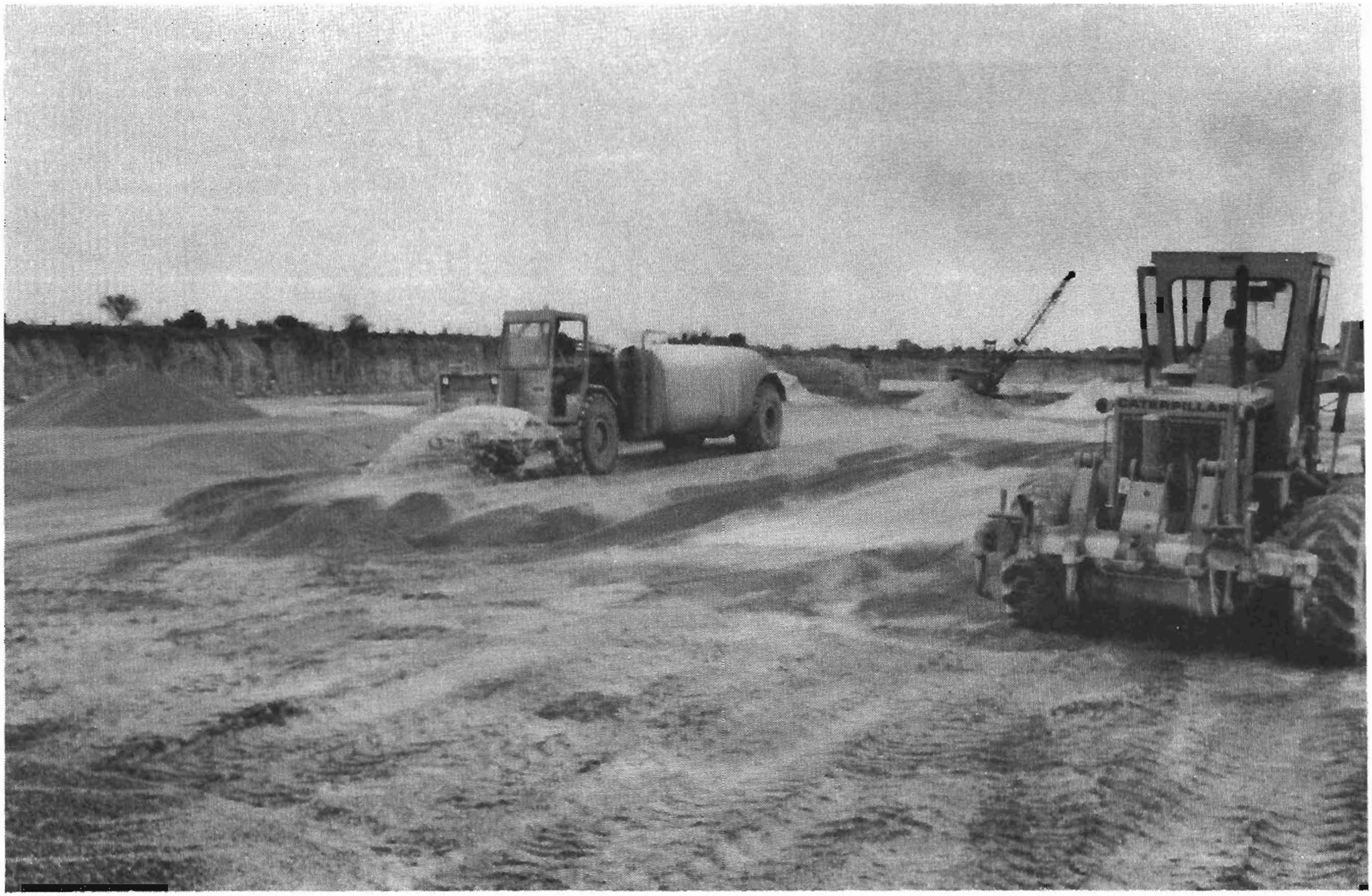


Fig 36. Application of lime slurry to aggregate during building of stockpile.

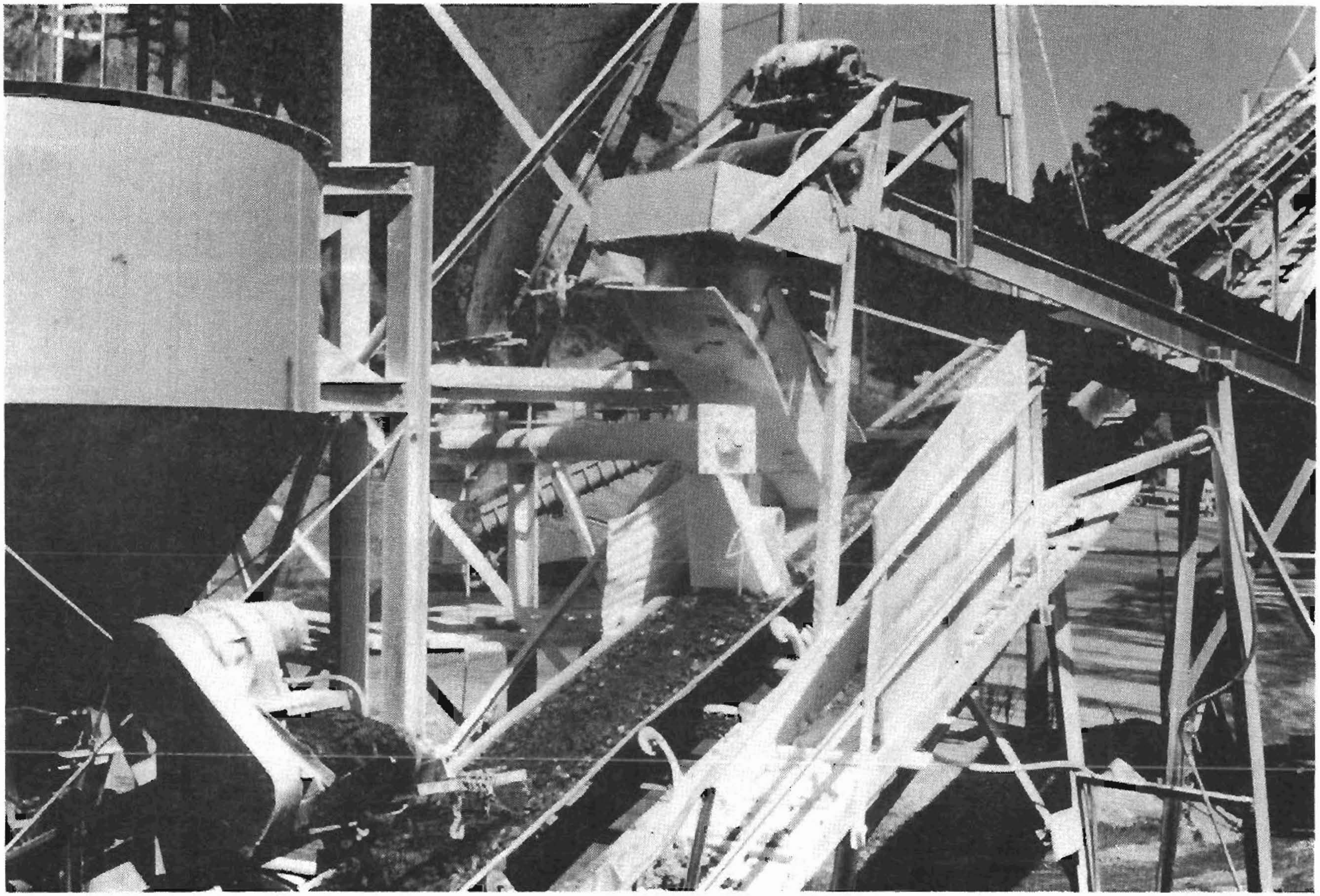


Fig 37. Adding lime from screw conveyor (center of photo) to damp aggregate.

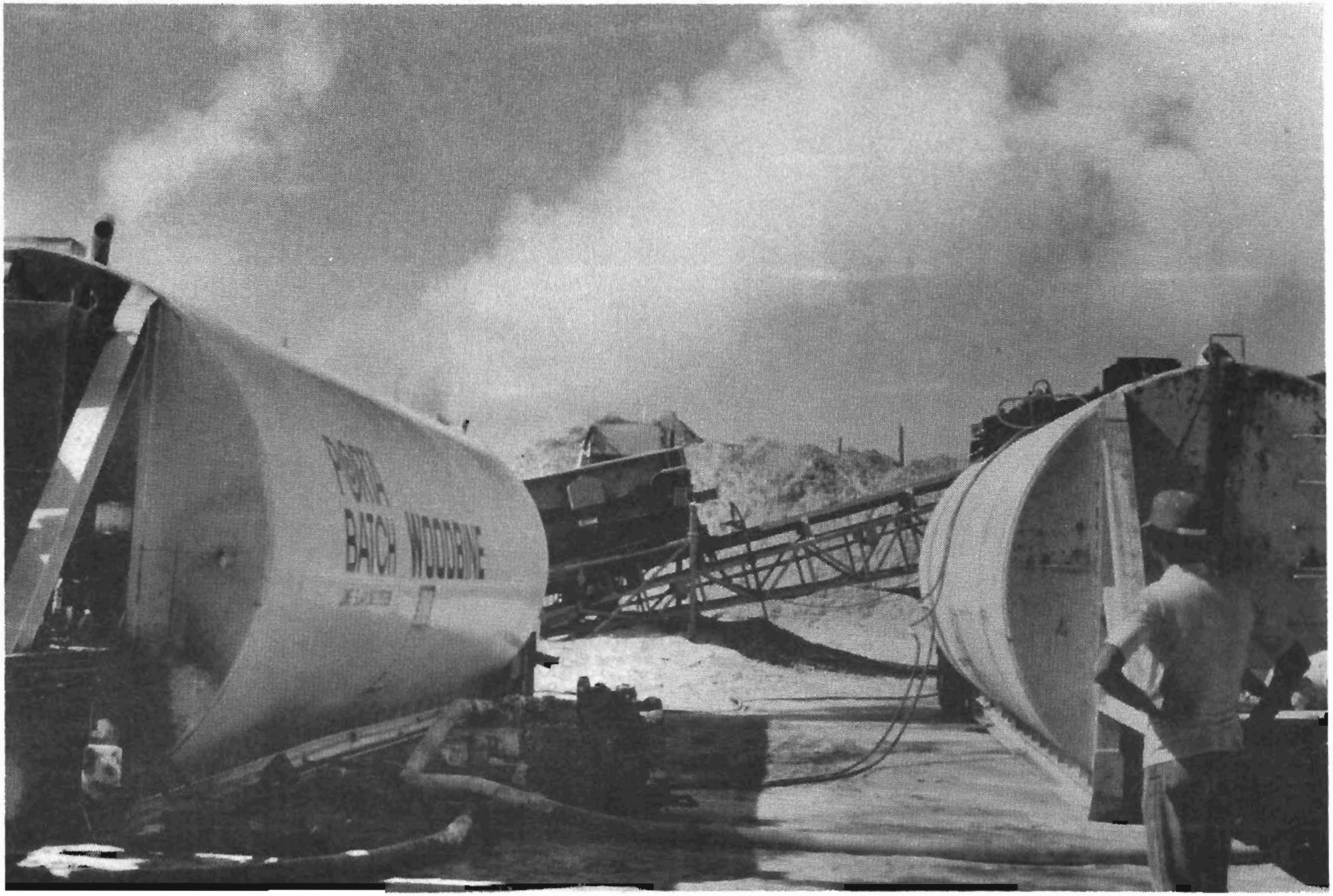


Fig 38. Portable batch slaker on left for producing lime slurry from quicklime.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The report summarizes the results and experience of a six-year research project conducted at The University of Texas at Austin but also contains information obtained through interactions with 14 other states. The report describes the problem of moisture damage, recommends procedures to minimize stipping, recommends test procedures to identify moisture susceptible mixtures and evaluate antistripping additives, reviews the relative effectiveness of various additives, and provides recommendations related to the use of hydrated lime. General conclusions and research recommendations are summarized below. Detailed information can be obtained from the individual reports shown in the List of Reports.

SEVERITY AND EXTENT

Stripping and moisture damage of asphalt mixtures is primarily concentrated in the eastern and southeastern parts of the state; however, mixtures in other parts of the state are susceptible to damage. The extent of the damage is primarily related to the amount of moisture which penetrates the mixture.

AGGREGATES AND ASPHALTS

Approximately 80 percent of the stripping problem is related to the aggregate and 20 percent to the asphalt. In addition, the severity of damage is dependent on the specific combination of aggregate and asphalt. Siliceous river gravels, sands, and rhyolite have been found to be the primary moisture susceptible aggregate. Limestone aggregates generally are resistant to moisture but certain limestones have shown a tendency to strip. Certain asphalts also have a greater tendency to strip.

PROCEDURES TO MINIMIZE MOISTURE DAMAGE

Moisture damage can be eliminated or minimized by achieving adequate compaction, providing drainage or sealing the pavement mixture surfaces, eliminating the use of moisture susceptible aggregate, or treating the asphalt aggregate mixtures with hydrated lime or a liquid antistripping additive.

TESTING

All mixtures should be tested using the wet-dry indirect tensile test, Texas boiling test, and Texas Freeze-Thaw Pedestal test. Generally, these tests provide comparable results; however, in some cases it has been found that significantly different results have been obtained. The wet-dry indirect tensile test and the pedestal tests tend to give results which are more favorable to the use of hydrated lime. The boiling test tends to provide more favorable results for liquid antistripping additives. Thus, the use of all three tests is probably desirable when time permits.

LIQUID ANTISTRIPPING ADDITIVES

Generally, liquid antistripping additives which are added to the asphalt have been relatively ineffective. At least two recently developed additives have been shown to be effective with selected mixtures and it is anticipated that additional additives which are effective will be developed. In addition, the possibility of adding these additives to the aggregate should be considered.

HYDRATED LIME

Both dolomitic and calcitic hydrated lime has been found to be a very effective antistripping additive. It is recommended that the lime be added to the aggregate in combination with water, i.e., lime slurry, dry lime with water, or hot lime slurry. Dry lime is effective if the lime can be held on the aggregate surface until coated with asphalt. Definite recommendations related to construction procedures for adding lime were developed and are contained in Research Report 253-4 (Ref 6).

RESEARCH RECOMMENDATIONS

(1) A study to relate field performance with laboratory test results should be conducted to determine which of the recommended tests

provide the best estimate of field behavior and to possibly improve on the tests and test procedures.

(2) A field study should be conducted using various antistripping additives, including hydrated lime, to determine the actual effectiveness of these additives on moisture and stripping resistance of asphalt-aggregate mixtures under field conditions. Such a study would require careful control of construction procedures. In addition, a minimum of 5 years of performance data would need to be obtained.

(3) Work should be conducted to determine the cause(s) or mechanism(s) which produce moisture damage or stripping on asphalt mixtures. This study should also consider the mechanisms by which various additives provide protection. In view of the amount of work which has already been conducted on this subject, the complexity of asphalt chemistry, the constantly changing properties of the asphalts being produced, and the wide variety of aggregates being used, it is felt that a long term study will be required and that the chances of success are small. Nevertheless an understanding of the problem is definitely needed and work should be conducted. Ideally the research effort should involve asphalt chemists, aggregate mineralogists, and pavement materials engineers.

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