

A LABORATORY AND FIELD EVALUATION OF LIGHTWEIGHT
AGGREGATES AS COVERSTONE FOR SEAL COATS
AND SURFACE TREATMENTS

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Research Report Number 51-2

Use of Lightweight Aggregates
Research Project Number 2-14-63-51

Sponsored by

The Texas Highway Department
In Cooperation with the
U. S. Department of Commerce, Bureau of Public Roads

April, 1966

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

TABLE OF CONTENTS

SUMMARY AND RECOMMENDATIONS-----	1
INTRODUCTION-----	4
OBJECTIVES OF THIS STUDY-----	7
RESEARCH PLAN-----	8
AGGREGATE HISTORY AND PRODUCTION METHODS-----	10
LABORATORY EVALUATIONS - GENERAL-----	20
LABORATORY RETENTION STUDIES-----	23
WINDSHIELD DAMAGE STUDIES-----	37
MODIFIED LOS ANGELES ABRASION TESTS-----	57
FREEZE-THAW TESTS-----	66
SOUNDNESS TEST-----	72
FIELD-PERFORMANCE OF SEAL COATS-----	76
PICTORIAL DATA OF CONSTRUCTION AND FINISHED PAVEMENTS-----	97
REFERENCES-----	109
TEXAS HIGHWAY DEPARTMENT SPECIAL SPECIFICATION, Item 1969, AGGREGATE FOR SURFACE TREATMENTS-----	111
APPENDIX A-----	113
ABRASION OF CONVENTIONAL AND LIGHTWEIGHT COARSE AGGREGATE BY THE USE OF THE LOS ANGELES MACHINE-----	114
COMMENTS ON THE HANDLING, CONSTRUCTION AND SERVICE OF LIGHTWEIGHT AGGREGATE COMPARED TO PRECOAT-----	117

SUMMARY AND RECOMMENDATIONS

Summary

The use of one producer's lightweight aggregate (expanded shale) as a coverstone for seal coats and surface treatments was introduced experimentally on Texas highways in 1961 and 1962. During 1963 and 1964 more than ten million square yards of this material were placed as an alternate to precoated limestone in five northwest districts of the Texas Highway Department. Considerable additional material from the same source was placed in 1965 on an optional basis. Lightweight aggregate has been used primarily in the secondary road system; however, limited but successful use of the material as a surfacing in the primary system is a proven fact.

Laboratory tests and field evaluations were effected to determine whether or not lightweight aggregate should be accepted as equal to precoated standard weight material for seal coat coverstone. For the materials under study the data suggest the following conclusions and recommendations. It should be emphasized that any findings pertaining to actual field performance are based on evaluations as a lightweight material from a single source, therefore, these findings cannot be considered to be generally applicable.

1. The loose unit weight of the lightweight materials under study was in the range 38 to 50 pcf. For seal coats and surface treatments a minimum as well as a maximum unit weight is recommended.
2. Laboratory design and evaluation of seal coats, preparatory to construction, results in improved over-all economy.
3. Laboratory studies and field observations showed that the lightweight material had a strong affinity for all the asphalt cements used in the project. This was a qualitative observation.
4. Crushing of coverstone is minimized when the pneumatic roller alone is used to seat the cover material and it is therefore recommended that only pneumatic rolling of lightweight aggregate be practiced.
5. The steel flat wheel roller caused degradation of both types of coverstone, particularly in areas of irregular cross section.
6. Laboratory induced windshield damage was severe for the crushed limestone and practically insignificant for the lightweight materials.

7. The Texas and Louisiana modifications of the Los Angeles abrasion test were found to be less severe than the ASTM standard test when used to measure the abrasion resistance of the lightweight materials under study.
8. One hundred cycles of rapid freeze-thaw caused a significant loss for some Grade 3 and Grade 4 lightweight materials.
9. Lightweight aggregate "A" showed a maximum weighted average loss of 1.56 percent when subjected to five cycles of the magnesium sulfate soundness test. This compared to 3.07 percent loss for the same material after 100 cycles of rapid freeze-thaw.
10. Under a variety of construction and service conditions, lightweight aggregate "A" has, after one to four years of service, proved to be a highly successful cover aggregate for seals and surface treatments.
11. Volume of vehicular service appears to have no measurable effect on the degradation of lightweight aggregate "A".
12. The lightweight aggregate was favorably accepted by contractors and Texas Highway Department personnel throughout the area in which it was used.
13. Lightweight aggregate "A" is considered equal to precast limestone for seal coat and surface treatment work. Laboratory results indicate that several of the other lightweight aggregates under study are also acceptable for this and similar service.

Recommendations

Based on the laboratory and field evaluation work performed during the past twenty-six months and considering only those materials involved in these studies, the following recommendations are submitted:

1. Consideration should be given to setting a minimum as well as a maximum unit weight for lightweight aggregate used in seals and surface treatments. This minimum could be a set figure or it could be provisionally based on service records and/or laboratory data from an abrasion test and rapid freeze-thaw results.

2. The very definite advantages of clean uniform graded materials were emphasized in the study. Improved construction control and extended service would result from further restrictions of range of particle size presently permitted. Grades 1 through 5 permit two percent of the material to pass the No. 10 sieve. Of this minus No. 10 material not more than one half of one percent (based on the total aggregate) should pass the No. 80 sieve.
3. Only pneumatic rolling of lightweight aggregate coverstone is recommended'.
4. It is suggested that consideration be given to adopting the Louisiana modification of the L. A. abrasion test with washing of the plus No. 5 material* after test as provisional.
5. Considering availability of equipment, a rapid freeze-thaw test might be substituted for or made optional to a sulfate soundness test. Fifty cycles and eight percent maximum loss are tentatively suggested.
6. New lightweight materials or lightweight materials produced from unproven sources of raw materials should be subjected to and pass acceptable field service trials before final acceptance and general use.
7. The use of synthetic aggregates in paving systems of all types should be encouraged where these materials meet service requirements. No maximum unit weight restriction should be imposed on materials of this general type unless some definite purpose is served by the restriction, for example, the minimizing of windshield damage in seal coat and surface treatment work.
8. To establish realistic quality boundaries on the many lightweight aggregates that might be used for seal coats and surface treatments, it would be advisable to evaluate these materials in the laboratory before controlled field serviceability tests are made.
9. Finally, general specifications should be prepared which would place the various synthetic aggregates in use categories. Three or four categories would be required.

*Analysis for wear should be made by use of the No. 5 sieve rather than the No. 4.

INTRODUCTION

The recent introduction of lightweight aggregate as a coverstone for seal coats and surface treatments was prompted by predicted improved construction and service characteristics of the material. The Texas Highway Department during 1963 and 1964 accepted synthetic (lightweight) aggregate as an alternate to precoated crushed limestone as a cover material for seals and surface treatments placed in Districts 2, 8, 18, 23, and 25. In 1965 it was accepted as optional.

This report includes the laboratory evaluation of lightweight aggregates from seven sources - six in Texas and one in Louisiana. Two of these materials have been field tested on an extensive scale, although the field evaluations reported herein are limited to one source of material.

The use of seal coats with and without cover aggregate dates back many years in the maintenance programs of highways and city streets of the United States and many other countries. Construction procedures vary widely with the many different groups who are responsible for the use of this maintenance tool. Some of these are rather simple while others are quite detailed; however, as a general statement it has not been possible to eliminate the need for experience and good judgment in the successful design and construction of this type of surface.

Due to the very widespread use of this maintenance tool and the many variables that may exist with respect to its successful use, it is not surprising that errors are made although these errors are not readily apparent at the time of construction. And indeed, in certain instances it is not practical to eliminate potential errors in limited segments of a given road. For example, it is a well known fact that many farm-to-market roads have numerous sharp curves for which it is not practical to make adjustments in asphalt application rates. Upgrades present similar problems. Natural variations in the precise nature of the surface being repaired is another case in point. Many roads, when they finally receive a seal coat, have been patched as shown in Figure 1 and in some cases sections have been completely rebuilt. This presents wide variations in the demanded rate of asphalt and/or coverstone application; yet, the normal construction procedures do not take these variations into account.

It is however, usually wise and practical to design a seal coat - and all seal coats should be designed and not simply constructed as an expedient - to effect certain useful needs the most important of which are as follows:

- a. Seal the bituminous mat against the entrance of air and water.
- b. Absorb the wear of traffic action.
- c. Increase the skid resistance of the wearing surface.
- d. Reduce the brittleness of the underlying layer of bituminous material.
- e. Increase the night visibility or luminosity of the surface.

In these respects the idea of using lightweight aggregates as coverstone involves no differences from those for precoated material or regular aggregates. The fact that precoated aggregate and lightweight have been and are now being included in specifications as alternates infers that the materials are equal, at least to the desired end points of construction and service.



Figure 1. Old surface has variable demand for asphalt from point to point.

OBJECTIVES OF THIS STUDY

The study reported herein is concerned with laboratory and field evaluations of expanded clay and shale for use as a coverstone for highway seal coats. The aggregates are from six producers in Texas and one from Louisiana. The primary objective of this study was to determine whether or not these lightweight (synthetic) aggregates are acceptable as equal to precoated limestone available in the same general market area. In order that the researcher might be able to compare the physical characteristics of the lightweight aggregate under study with the accepted serviceability of precoated stone, it was necessary to design and carry out a rather extensive and intensive laboratory study on the lightweight material. These necessary evaluation measurements then became a part of the primary objectives.

Since no study of a construction material is complete without actual field trials, a large number of seal coat and surface treatment jobs built under regular Texas Highway Department specifications were included for study in the program. Field evaluations on both lightweight aggregate and precoated crushed limestone seals were included for comparison purposes.

RESEARCH PLAN

Research on this project began in 1963 in both the laboratory and the field with the first designated test section being build in Foard County on FM 267 on June 7, 1963. Other jobs were already completed, under construction or planned in other districts in northwestern Texas. In those areas where it was expedient to work with the contractor and/or Texas Highway Department personnel, additional designated test sections were set up. Because of the delay in getting the research program under way a major part of the 1963 seal program was already completed or under way before arrangements could be made for setting up test sections. It was therefore necessary to take road samples from completed projects. Within such projects no changes in materials, application rates or construction procedures were effected. However, due to differences in these factors from job to job and district to district, this was not considered a particularly important disadvantage.

Outlined below are the specific items of research planned in the program.

A. Basic Characteristics of the Aggregate

1. Source and type clay or shale used.
2. Bloating agent used, if any.
3. Method of presizing and necessary crushing and sizing after manufacture.
4. Burning time and exit temperature of kiln.
5. Nature of storage, handling and shipping.

B. Laboratory Evaluations

1. Coverstone retention as affected by application rate of asphalt.
2. Windshield damage.
3. Freeze-thaw effects on soundness.
4. Grading variations.

5. Asphalt absorption.

6. Resilience.

C. Construction and Service Evaluations

1. Windshield damage in the field.

2. Design cover rates and asphalt content.

3. Handling methods.

4. Coverstone retention and bond tenacity as affected by road layout.

5. Aggregate degradation due to construction and traffic.

6. Effects of weather.

7. Acceptance evaluations.

AGGREGATE HISTORY AND PRODUCTION METHODS

Lightweight inorganic aggregates may be said to fall into two categories, namely, man-made and natural lightweight materials. Man-made aggregates may be further subdivided into two more groups. According to ASTM Designation C331-59T, (1)* the general types of lightweight inorganic aggregates are as follows:

"Aggregates prepared by expanding, calcining or sintering products such as blast furnace slag, clay, diatomite, fly ash, perlite, shale, slate or vermiculite.

Aggregates prepared by processing natural materials such as pumice, scoria or tuff.

Aggregates consisting of cinders derived from the combustion of coal, (lignite) or coke."

The specifications further states that the aggregate shall be predominantly composed of lightweight cellular and granular inorganic particles with a maximum unit weight of 55 pounds per cubic foot for the coarse fraction.

Lightweight aggregates of various types have been used for many years in a variety of services from high strength structural concrete units to acoustical plaster and insulating materials.

During World War I a number of cargo ships were constructed of structural grade reinforced lightweight aggregate concrete and one of these vessels, the Selma, lies awash in Galveston Bay today. Recent cores taken from the hull of this ship tested more than 10,000 psi in compression revealing the fine durability of concrete made from lightweight aggregates. The Haydite patent covering the production of expanded shales and clays was granted to Hayde in 1918 and numerous other patents in this field were granted in the 1920's.

The introduction of lightweight aggregates in the highway field of bituminous pavements has occurred within about the last seven or eight years and in the Texas Highway System only within the last three years. Personnel of the Texas Transportation Institute have worked with industry on the design and application of lightweight aggregate in bituminous pavements for more than six years. Test sections were placed in the State of Louisiana on city streets and parish roads and

*Numbers in parentheses refer to references at end of report.

one section, a hot-mix asphaltic surface course was placed on a state highway and has given excellent service for more than six years under heavy traffic.

The use of lightweight aggregate as a coverstone for seal coats in Texas began in the Abilene District of the Texas Highway Department in 1962. A section about 1000 feet in length was placed on the inbound lanes of Interstate Highway 20 near the west city limits of Abilene. A double surface treatment was constructed in the Brownwood District in 1961 (2), and another double surface treatment was built in this same district in 1962. In 1963, several hundred miles of secondary roads were sealed with hot asphalt cement and lightweight aggregate was used as the coverstone. Again in 1964, use was made of lightweight aggregate as a coverstone for seal coats constructed in five of more different districts of the Texas Highway Department. To date lightweight aggregate has been used as cover material on approximately 700 miles of secondary roads on force account and contract maintenance.

The production of this material which has found a new use in the State of Texas should be of interest to the reader of this report; therefore, a section on this aspect of the over-all story follows. It is important to point out at this time that the description that follows applies to the production of Aggregate "A" which was used in the first phase of the over-all program on the characteristics and uses of this general type of material. It should also be noted that there are several Texas plants representing separate industrial interests that produce synthetic or man-made aggregates and further that there are many other plants scattered over the entire United States that produce similar materials in large volumes (3). However, little has been done and even less published on the use of synthetic aggregates in bituminous pavements. The potential in this field is tremendous.

The production of the lightweight aggregate (4) used in this study consists of the phases listed below.

1. Pit operations.
2. Burning or calcining.
3. Crushing and grading.
4. Testing and shipping.

The raw shale, which geologically speaking is a part of the Pennsylvania system, is mined from open pits after removal of the over-



Figure 2. Open pit mining of shale. (Photo by Richardson.)

burden. This operation is shown in Figure 2. It is to be noted that the shale is mined from a vertical bank with a power shovel. This method is used to insure a uniform material of reasonably constant moisture content.

The raw shale is transported from the open pit by truck to a roll crusher where it is crushed, sized and conveyed to covered storage. At this point the moisture content of the shale is in the range of 10 to 12 percent. The material is taken from storage by an underground conveyor system and fed into the kilns. These operations are shown in Figure 3. The feed consists of shale sized from 5/16-inch to 3-inch particles. Presizing of the feed makes possible a more nearly uniform final product of consistently high quality.

The raw shale or clay fines produced by the mining and sizing operations may be formed into pellets and processed in much the same manner as that produced by the normal operating procedures. The presized or pelleted material is then burned or calcined for approximately one hour at temperatures in excess of 2000°F in large rotary kilns such as those shown in Figure 4. After the clay or shale is heat-processed, it is gravity fed into large rotary coolers and then conveyed to a screening system for removal of certain specified sizes of aggregate. A general view of this operation is shown in Figure 5. The oversize is sent by conveyors to crushers. The crushed aggregate is then passed through an additional screening system where it is separated into the proper sizes for the market.

The processed and sized aggregate is then tested for compliance with buyer specifications. In the case of the Texas Highway Department, this is Special Specification Item 1269 Aggregate for Surface Treatments (lightweight) dated November, 1964. A copy of this specification appears in Appendix A of this report. Comments will be made on these specifications in appropriate sections of this report.

Possibly of general interest to the reader is some additional background on the subject of burning or calcining shales and clays (5). The early work of Bauer (6) covers in five articles most of the basic concepts involved in the bloating and heat stabilization of shales and clays. According to Bauer the raw material requirements are:

- "1. The material must develop sufficient glassy phase under heat to entrap evolving gases.
2. The material must contain gas-forming ingredients of sufficient quantity to bloat the glass so formed.
3. The gas-forming constituents must release a sufficient amount of their volatile constituents at an optimum rate, and at a temperature and time which coincides with the optimum pyro-plastic conditions of the clay.



Figure 3. Shale storage and conveyor feed to kilns.
(Photo by Gustafson.)

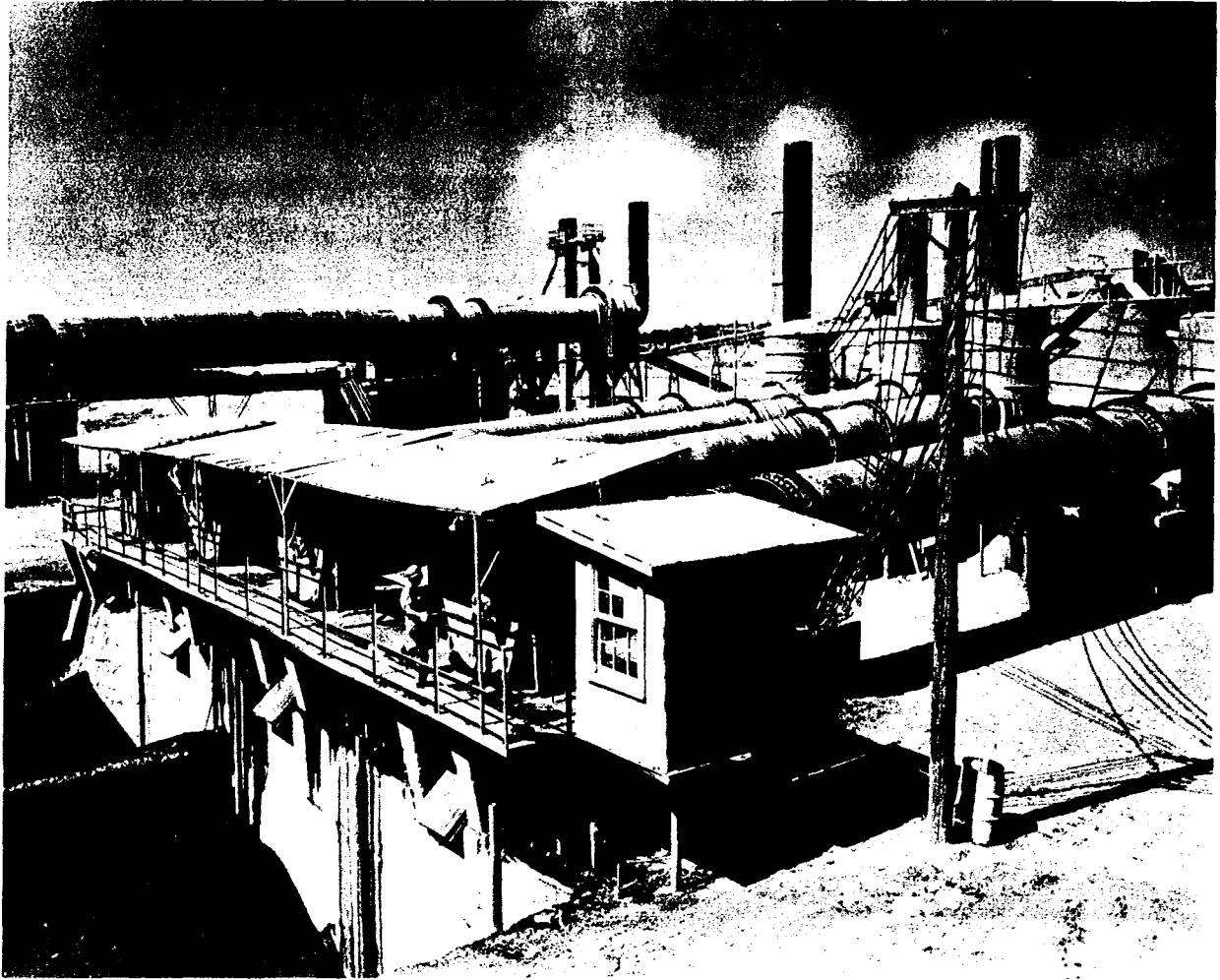


Figure 4. Battery of rotary kilns used to burn shale. (Photo by Richardson.)



Figure 5. General view of commercial lightweight aggregate plant. Crushing and sieving is in right foreground. (Photo by Richardson.)

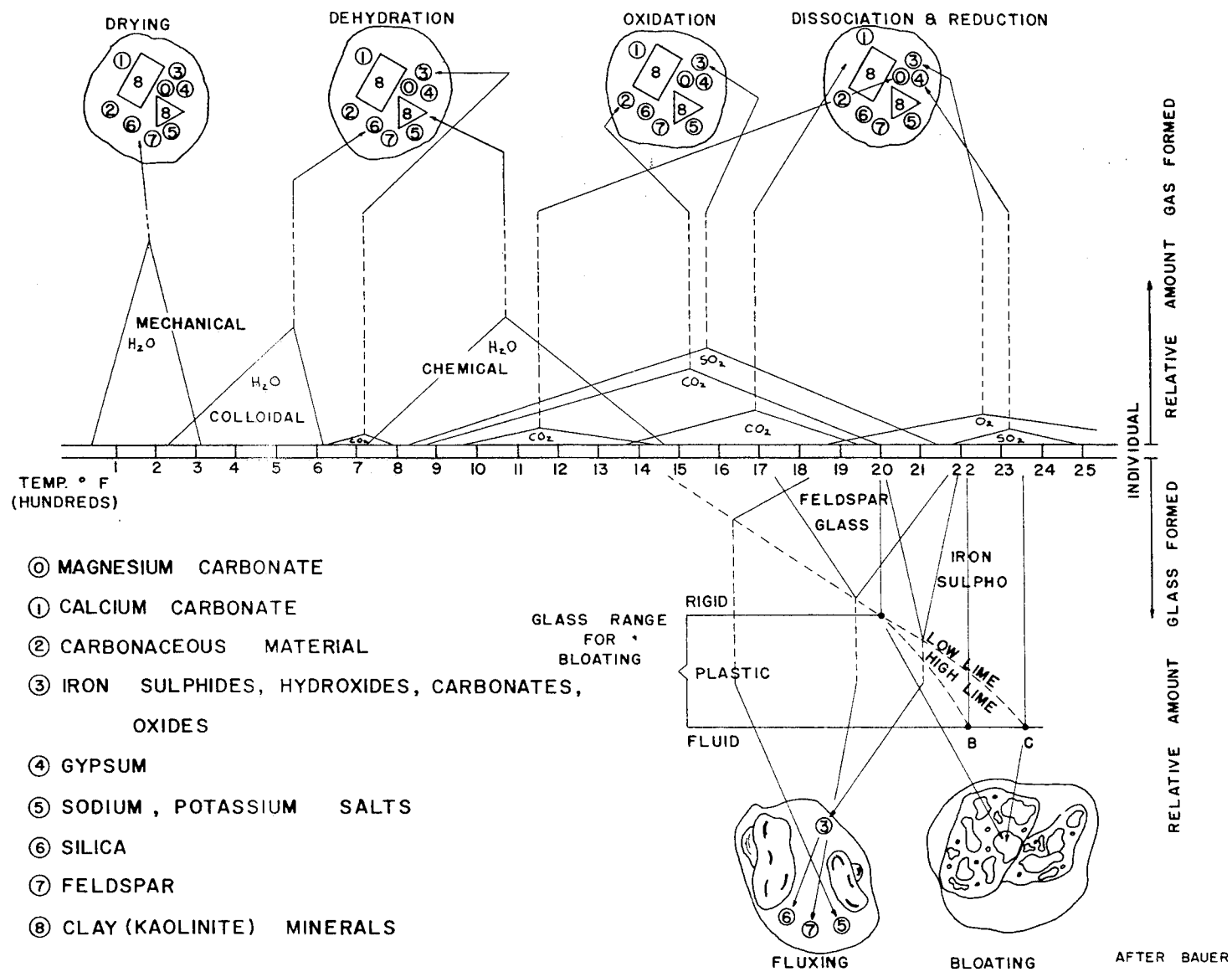


Figure 6. Flow diagram of gas-glass forming versus temperature. (Reference Bauer.)

4. At these optimum time-temperature glass-forming conditions, the glass must be of a viscosity which will allow formation of suitably-sized blebs or vesicles (for lowest density), and have bleb wall thicknesses that reflect in maximum glass strength.
5. The material should bloat into a vesicular structure at the lowest temperatures for reasons of process economics. On the other hand, such low temperatures must not be the results of alkali or salt flux action causing soluble salts to break down in the final concrete body."

Figure 6 is a chart showing the principal stages of gas-forming reactions and in turn relates these to the glass-forming reactions along the temperature scale (6). It is evident that most of the reaction periods overlap on the time temperature scale and as the chemistry of the clay or shales changes from one deposit to another many and varied shades of differences may occur. The possible variations multiply as a chemically complex material passes through a rotary kiln where it is subjected to changing conditions from entry to exit of the kiln.

The glass forming phase is particularly important to lightweight aggregate producers interested in changing the absorption characteristics of a given material. Bauer points out the importance of the fluxing action of minerals melting at the lower temperatures. Feldspar, for example, has a fluxing action that extends over a considerable temperature range. Such fluxing will lead to the melting of such refractory minerals as lime, magnesium, zinc and various oxides at temperatures lower than at which these would melt alone.

It is further pointed out that the melting of clays and shales is strongly influenced by:

- (a) Composition (5).
- (b) Density.
- (c) Grain size.
- (d) Dispersion.
- (e) Heating rate.
- (f) Heating atmosphere.

When the clay or shale reaches that temperature corresponding to the principal gaseous state in commercial kilns, it is important to remember that time, temperature and the partial pressure of the combustion gas, excess air and gasses from the burned material have their effects on the final results. To form the desired amount and quality of bubbles or blebs in the finished lightweight material, expansion of the heated clay or shale is necessary. This expansion is controlled primarily by gas density and glass viscosity properly timed in the reactions involved.

For uniform quality of finished product, appreciable changes in kiln temperature must be avoided if the proper glass viscosity is to be maintained during bleb formation. Theoretically, very little gas forming material is required, less than 0.1 percent of sulfur, for example, is sufficient.

It is beyond the scope of this report to go into much detail on the main facets of the lightweight aggregate production business. It should be pointed out that for a business of this type, requiring rather large investments in equipment, radical changes in manufacturing processes will not be made rapidly. One may hope that the best use be made of equipment and the most efficient techniques be utilized to maintain a uniformly high quality end product to lessen the problems of the user.

Coated aggregates, that is aggregates with fused outer shells, are possible today and this would do much to solve the absorption problem and at the same time this coating would increase the effective strength of products incorporating the aggregate.

LABORATORY EVALUATIONS - GENERAL

Although limited use was made of other gradations, the materials used in this study were primarily Texas Highway Department Grades 3 and 4 lightweight aggregate and precoated crushed limestone (7). Gradation requirements for the various size ranges are listed in Appendix A. Grading curves obtained from producer and field stock-pile samplings are shown in Figure 7. The unit weight of the Grades 3 and 4 lightweight aggregate was in the range of 38 to 50 pounds per cubic foot with the higher values generally associated with the Grade 3 material. The generally higher unit weight value for the Grade 3 material may be explained by a greater variation in the range of particle size. The Grade 4 material was consistently more uniform in grading and therefore had a higher void content.

Rentention studies indicated a general need for preparatory design work in the laboratory to determine asphalt and coverstone application rates. Laboratory and field tests rule out the practical use of a steel flat wheel roller for seating lightweight aggregates. The pneumatic roller is highly effective for this use.

The experimental work of damage to windshields from "flying stones" proved that the likelihood of windshield breakage is rather remote for the lightweight materials under study. The work further showed that crushed limestone would cause severe damage at the impact energies included in the experimental work. The frequency of damage was high for the plus 1/2-inch size material.

The suggested need for altering the test procedure (present THD modification) to determine laboratory abrasion of lightweight aggregate is based on the fact that the volume of lightweight aggregate may be as much as three times that of an equal weight of conventional aggregate. Any appreciable changes in the volume of the sample might be expected to affect the crushing and abrasion characteristics caused by the testing equipment for given testing procedures. However, the data (presented later) indicate that test method ASTM Designation C-131-55 (1) was the most severe test and the crushing and abrasion characteristics were not altered appreciably. Modifications may be required as service data are collected and evaluated, but this may require several years. Hence, it is quite possible that the maximum wear of 35 percent as set by Texas Highway Department Special Specification Item 1269 and determined by Test Method Tex-410-A (Part II) is not a restrictive requirement. Earlier work by Woolf (8) indicates that a wear value of 40 percent maximum for surface treatments would be satisfactory. This assumes natural aggregates and ASTM standard evaluations.

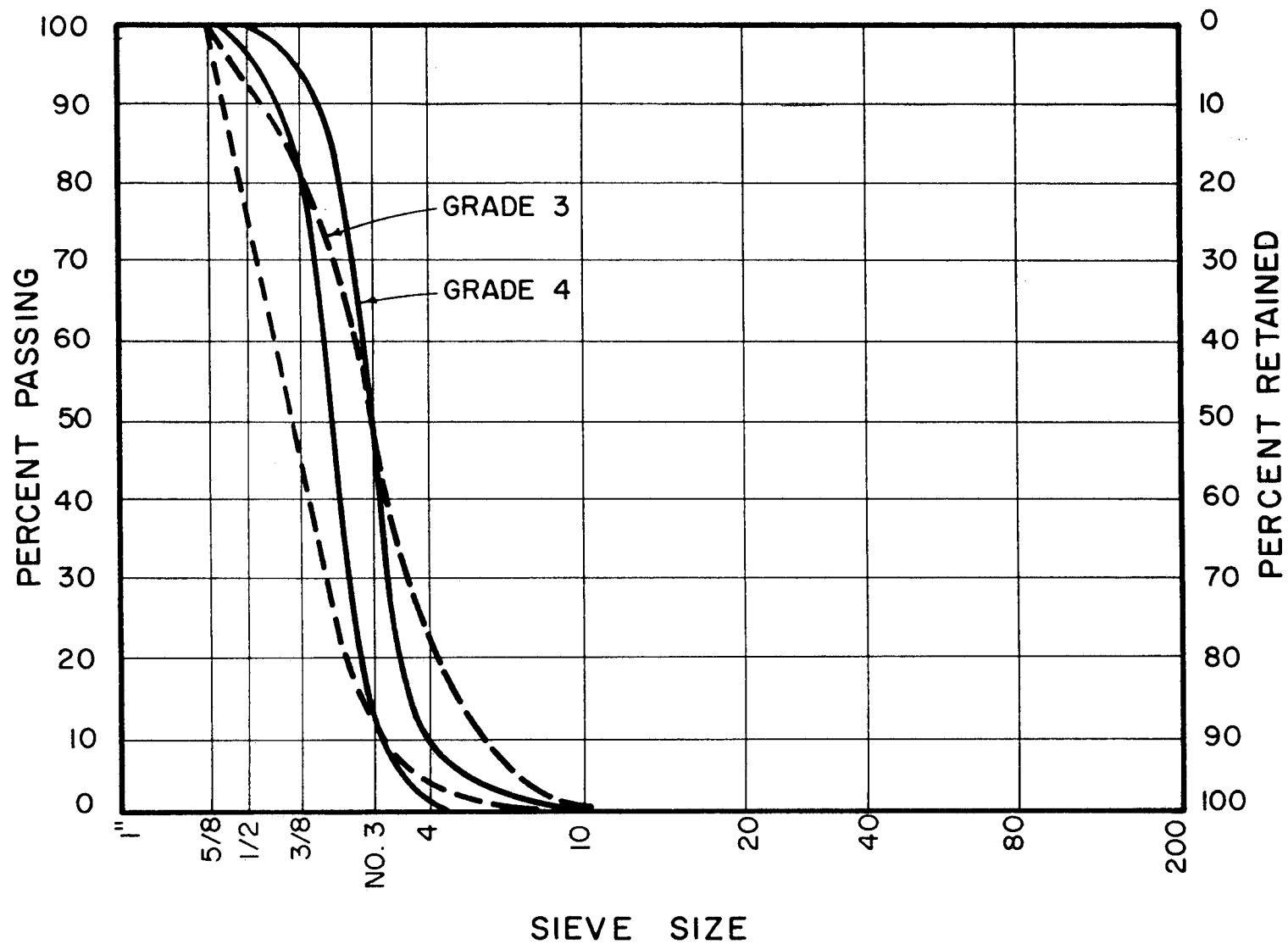


FIGURE 7 GRADING OF STOCKPILE AND PRODUCTION
RUN TYPE F GRADES 3 & 4 MATERIAL

It was anticipated by some that the freeze-thaw damage to light-weight aggregate might be severe; however, for the materials and conditions of the test, this was not generally true. But 50 cycles of rapid freezing to 0° F or lower caused appreciable degradation to aggregates "B" and "F". The same finding resulted for the magnesium sulfate soundness for aggregate "A".

LABORATORY RETENTION STUDIES

The laboratory design of seal coats and surface treatments was based on previous work done by Kearby (9), Benson and Gallaway (10) and Hank and Brown (11). According to these researchers, the optimum quantity of coverstone required is the amount necessary to cover the area in question one stone deep. The proper amount of asphalt cement is a function of the average mat thickness and the embedment depth. Careful laboratory measurements revealed that the cover rate for the Grade 3 stone should be in the range of 115 to 125. Under average laboratory conditions it was not possible to retain these optimum amounts of stone even though the asphalt application was changed over a considerable range. It was also found that for rates lower than these amounts it was not possible to stick all of the stone applied. Other types of stone react in the same manner. There appears to be some double decking of stone even at very low application rates.

It is felt that the reader will have a better appreciation of the data to follow if the procedures used to obtain these data are described in some detail.

Shown in Figure 8 is an "exploded" pictorial drawing of the board, paper, angles and bolts. In Figure 9 the actual assembly of these items is taking place. These boards are one half square yard in surface area and are covered with heavy brown wrapping paper. After a shot is made and all data obtained the paper-asphalt-stone composite is easily removed and discarded. The remainder of the assembly with minor cleaning is then ready for reuse. After the boards are covered with paper, the exposed upper surface of the angle is covered with masking tape and the covered boards are then placed in the "run" as shown in Figure 10. The boards are centered in the run which is also covered with paper. Side boards about one foot high prevent splatter during the application of the hot asphalt cement. Masking tape is used to cover the abutting ends of the boards. This is also shown in Figure 10. Removal of this tape after the asphalt is applied exposes a clean surface which simplifies removal of the boards from the run.

The laboratory distributor used in the study is shown in Figure 11. The unit is designed to contain about five gallons of asphaltic material and can be operated at pressures up to 100 psi and temperatures up to 400°F. Pressure is supplied by compressed air through a regulator and filter. Care should be exercised to never allow water to enter with the air. The asphaltic material is heated with gas burners and distributed under pressure through standard Etnyre nozzles at temperature that produces a Saybolt Furol viscosity of 50 seconds \pm 10. For the 120-150 penetration asphalt cement used, this required a temperature of about 310°F. Application of the asphalt is shown in Figure 12.

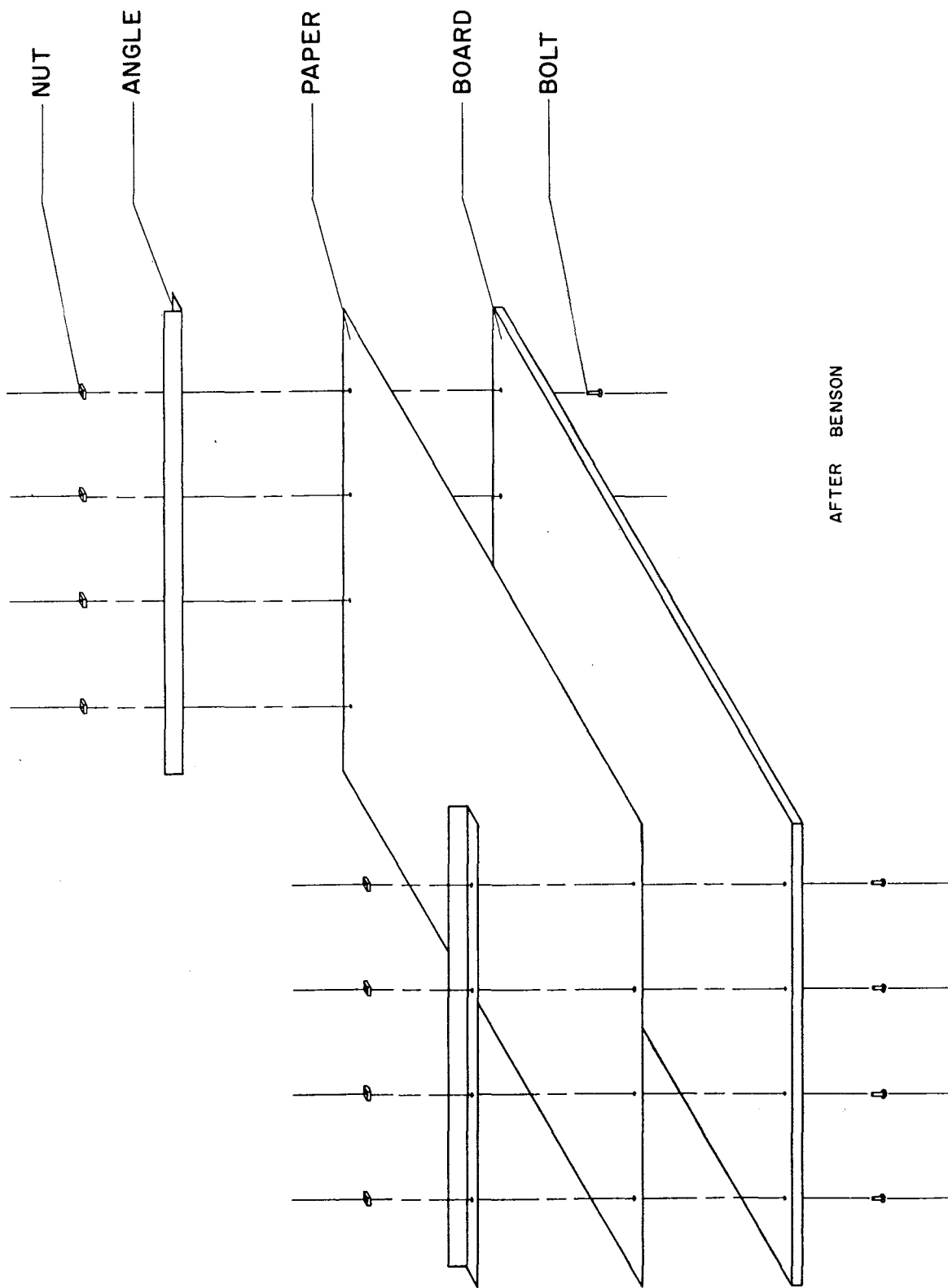


FIGURE 8 "EXPLODED" ASSEMBLY OF BOARD, PAPER AND ANGLES

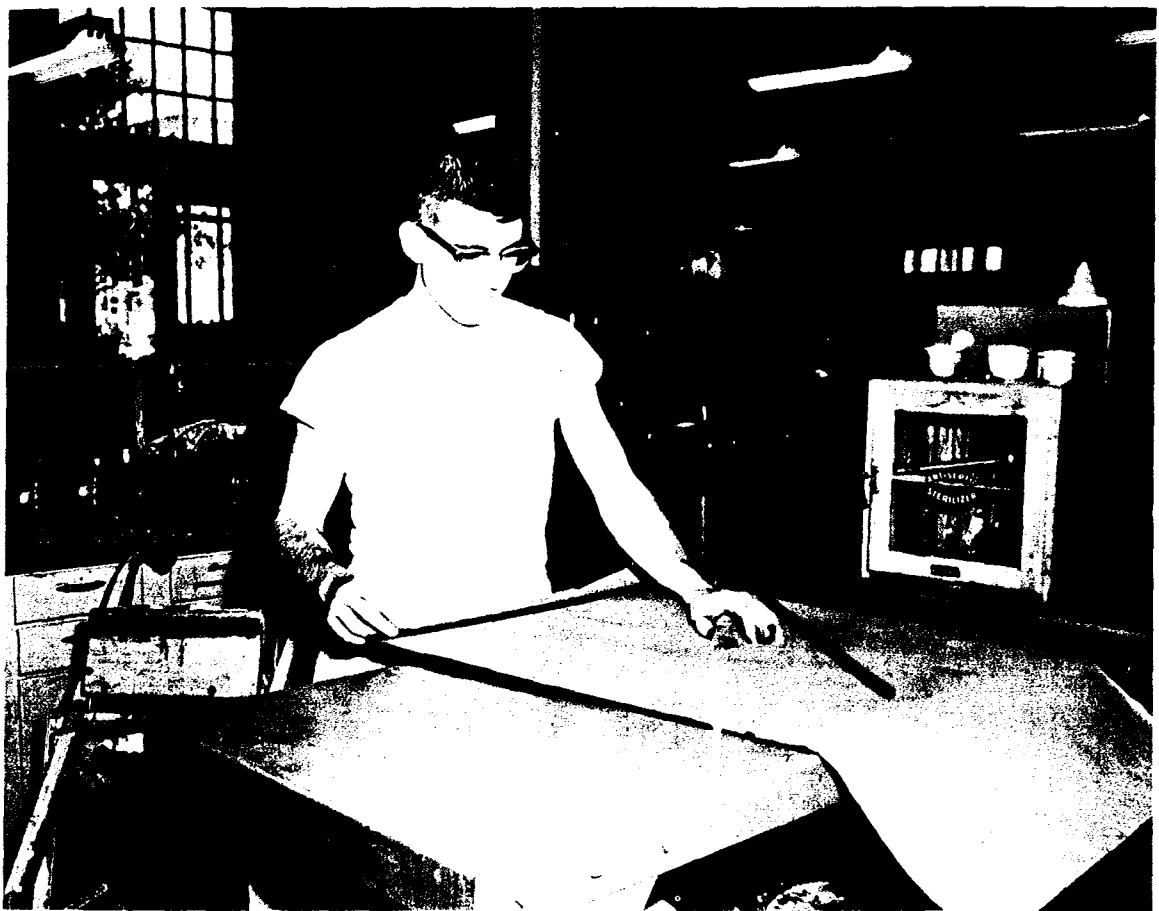


Figure 9. Laboratory surface treatment board being covered with paper

After the asphalt was applied, the exact amount of cement on each board was determined by weighing the board assembly as shown in Figure 13. Following this operation, a weighed quantity of stone was applied as shown in Figure 14. The aggregate was usually applied beginning five minutes after the asphalt was sprayed on the board and this operation was completed in an additional five minutes or less.

The aggregate covered boards were then placed on heavy paper for the rolling operation. This is shown in Figure 15. During the application of the asphaltic material, the boards were arranged with metal angles abutting each other; whereas, when these same boards are arranged for the rolling operation, the boards are rotated so the angle is at the outside as may be observed in Figure 15. This prevents the angle from being damaged by the roller.

The stone was seated by use of the pneumatic roller shown in Figure 15. The pneumatic tires were inflated to 50 psi and twelve coverages of the roller were used. After rolling was completed, the boards were tilted at an angle of 75° with the horizontal and brushed lightly as shown in Figure 16. Loosely attached and unstuck stone was dislodged in this manner and this material was collected and weighed. Data collection and analysis completed a given test.

A complete series of tests was run for both Grades 3 and 4 material in which coverstone and asphalt application rates were varied. Results of these tests are shown graphically in Figures 17 and 18. In the analysis and use of the data presented in these figures, several items should be taken into consideration. Texas Highway Department Specifications in Item 1269 allow Grades 3 and 4 to be very nearly the same in particle size distribution if one takes, say, the fine side of the specification on Grade 3 and the coarse side of the specification on Grade 4. The producer is also allowed by these specifications to vary the unit weight of the material supplied but this does not appear to be a disadvantage in this area of application, at least in the field. It does, however, present a problem in a laboratory study of the type being reported where the materials being analyzed come from several different lots of production. Actual measurements showed that for some shipments Grade 3 had a lower unit weight than Grade 4 from other shipments. Other samples revealed the reverse. Normally it is expected that Grade 4 would have a lower (12) unit weight, if both materials were equally uniform in grading.

Due to the somewhat greater average particle size for Grade 3 material more stone (weight wise) is required to cover a given unit of surface area. It will be noted from Figure 17 that the rate of application of the coverstone is given on the individual curves as a ratio. This ratio is the number of square yards of surface covered by one cubic yard of aggregate. For example, the uppermost curve in Figure 17 is labeled 105:1 which simply

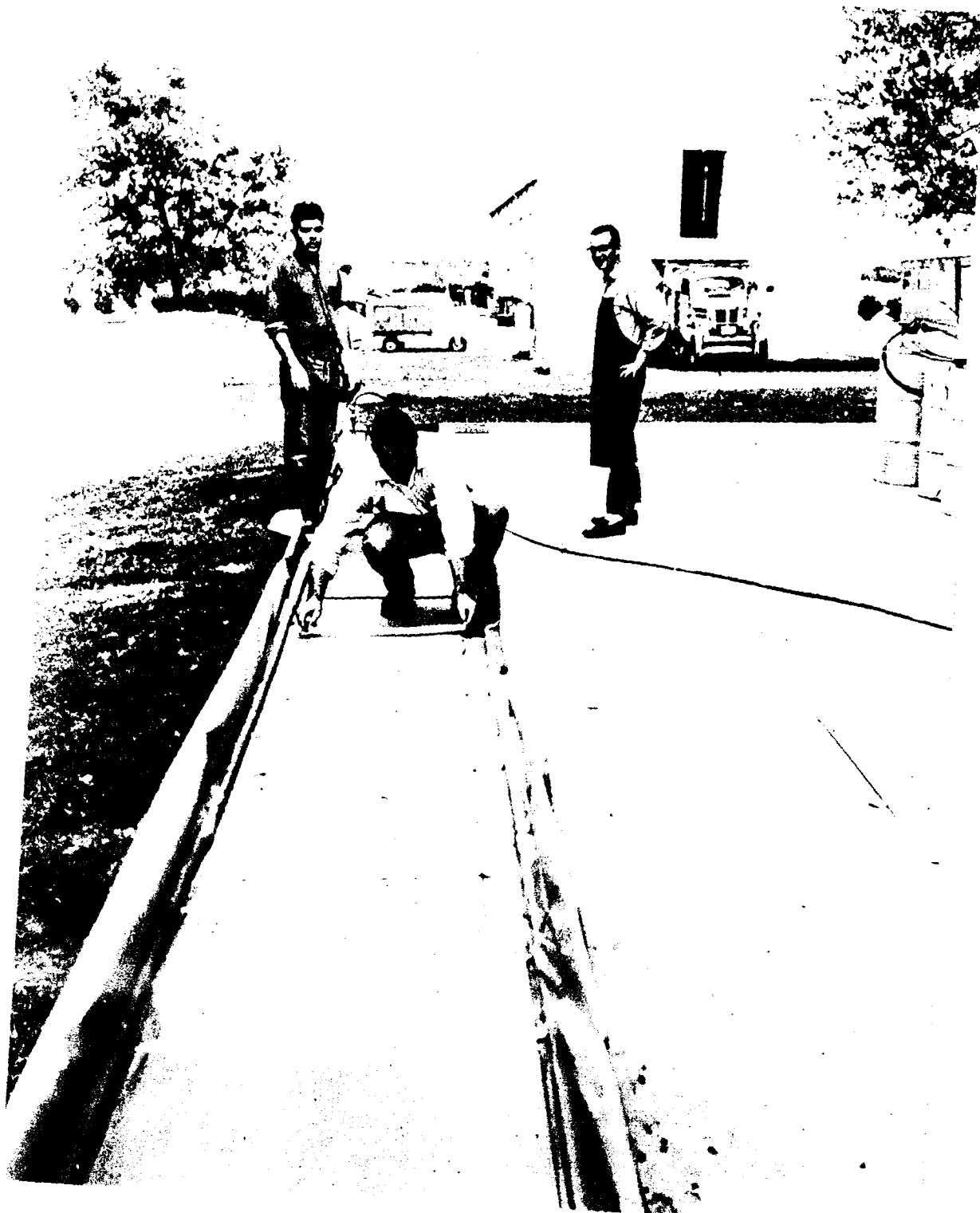


Figure 10. Boards in line for asphalt shot.

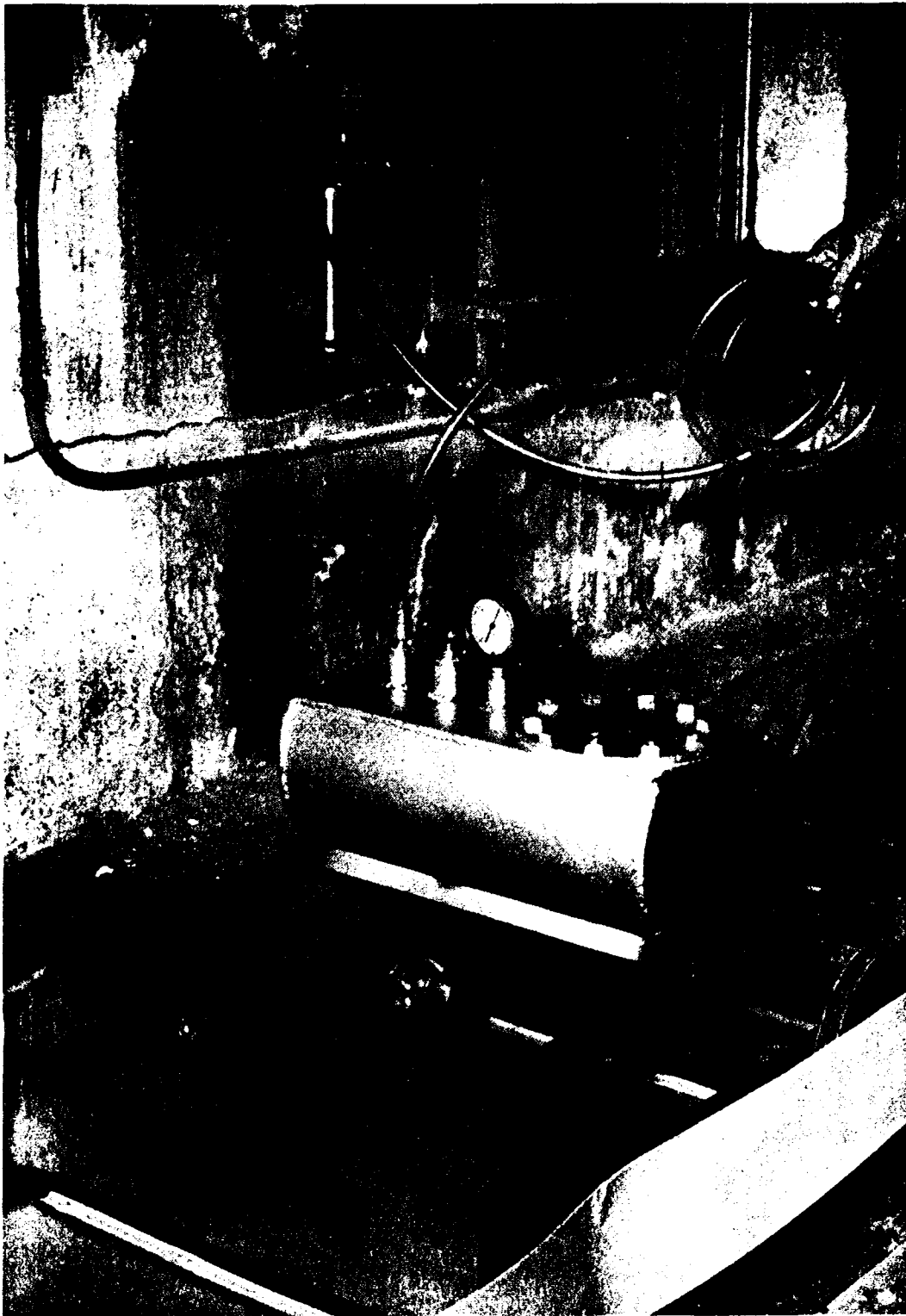


Figure 11. Asphalt distributor used for laboratory retention studies.

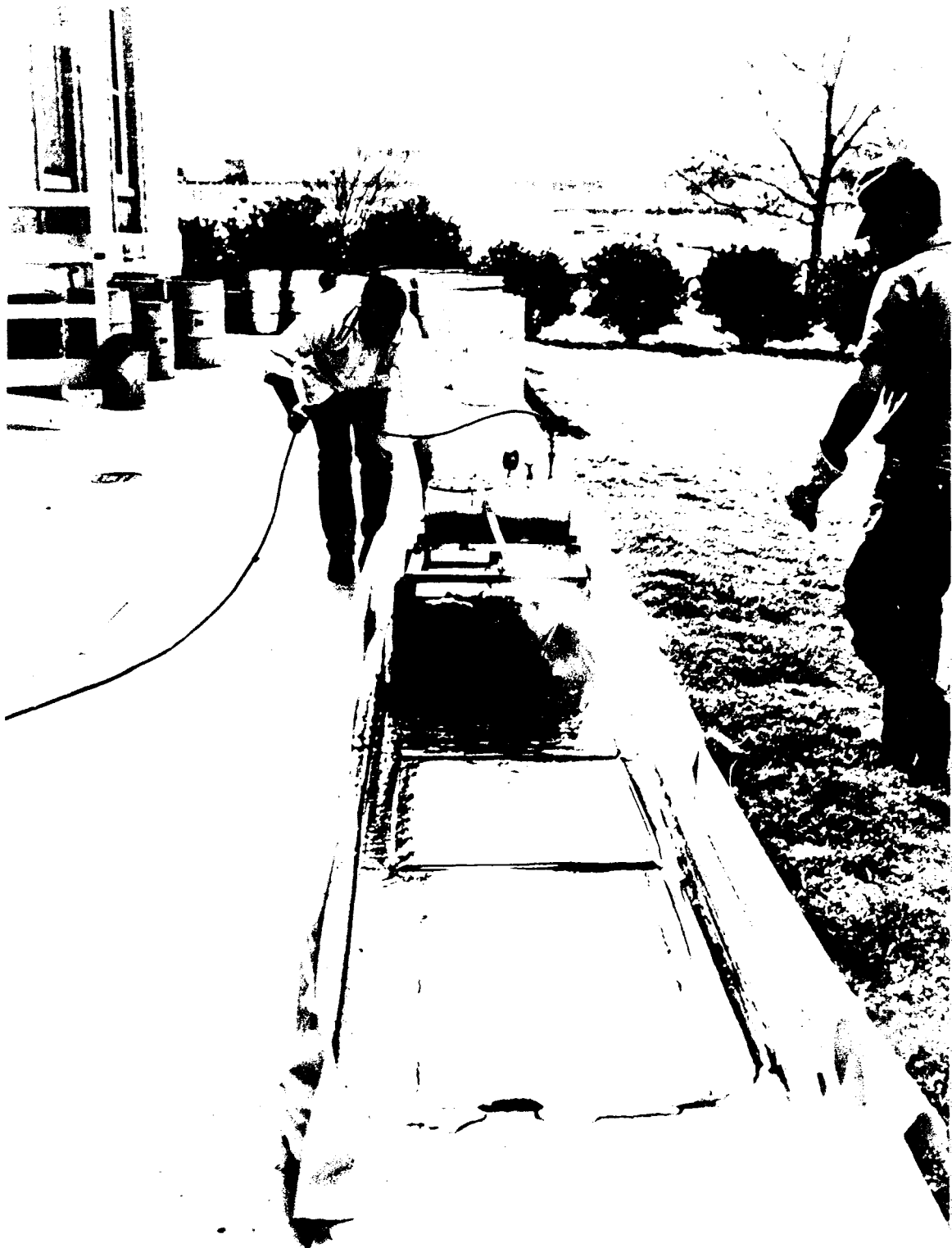


Figure 12. Hot asphalt cement being sprayed from small distributor.

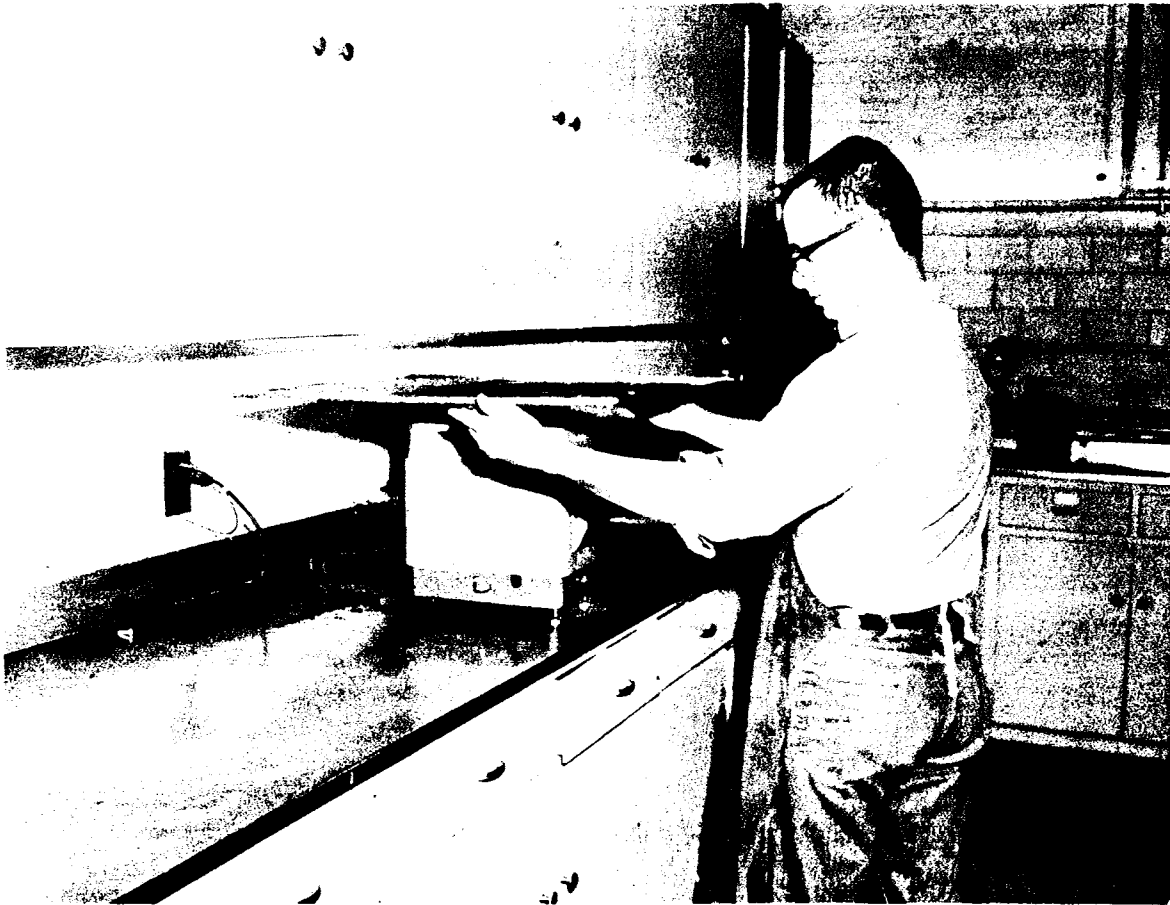


Figure 13. Asphalt coated board being weighed to measure application rate.

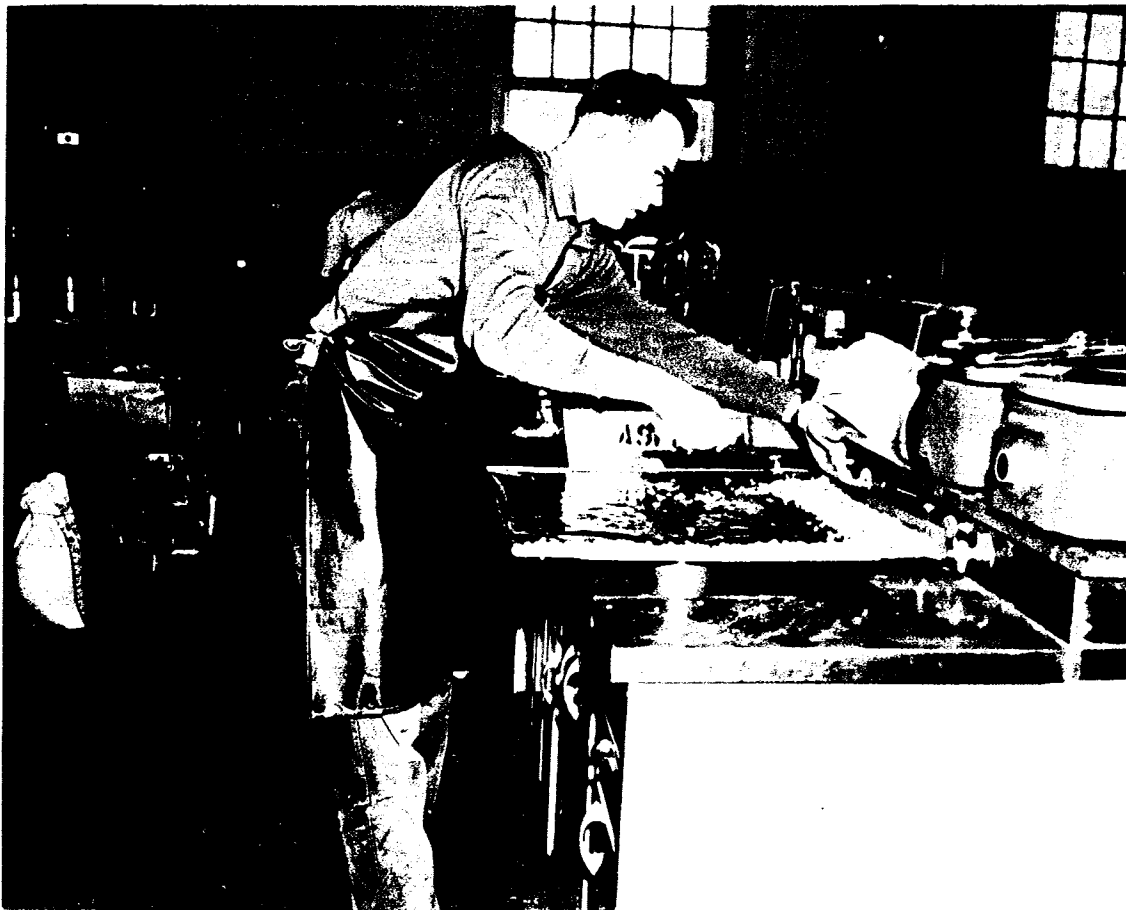


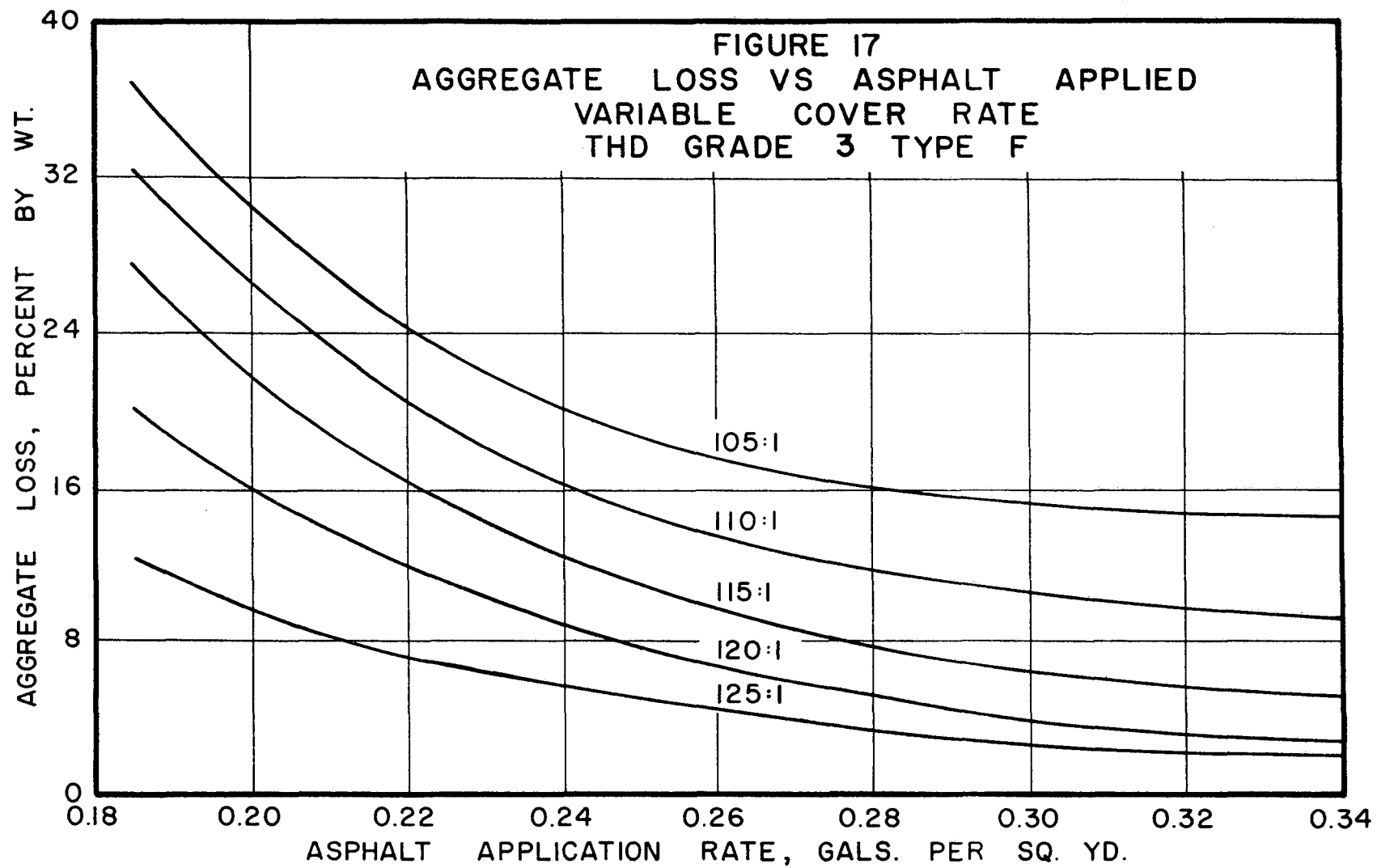
Figure 14. Aggregate being spread by hand on asphalt coated board.

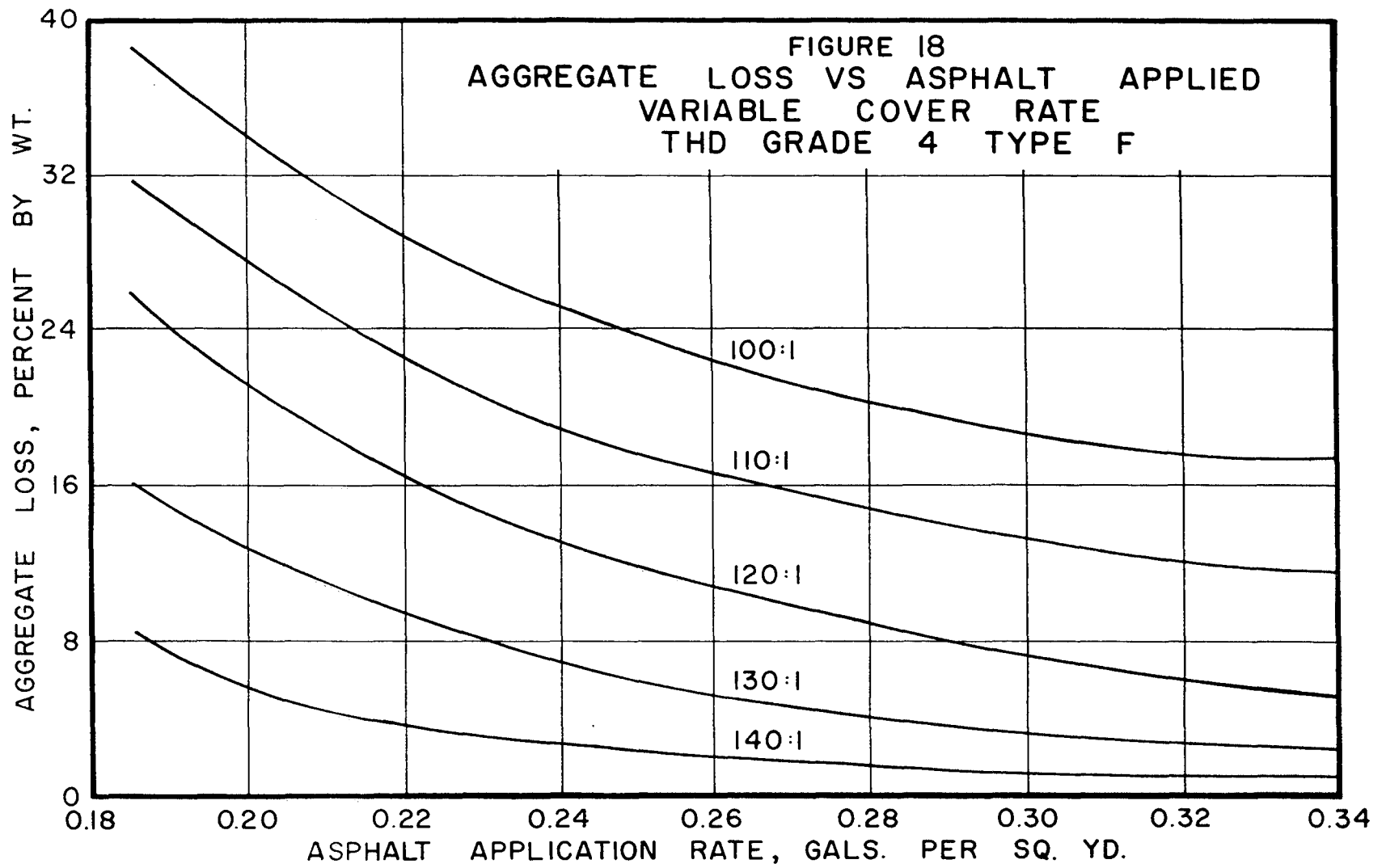


Figure 15. Pneumatic roller used to seat stone on laboratory surface treatments.



Figure 16. Completed surface is tilted at 75° and brushed to remove loose stone.





means that one cubic yard was applied at such a rate as to cover 105 square yards of surface. If it is assumed that this material weighs 43 pcf, then the cover rate would be eleven pounds per square yard. Taking this analysis a bit further, one might assume that asphalt cement is applied at the rate of 0.30 gallons per square yard and find from this curve that about 15 percent by weight of the stone would not be retained under the conditions of the test. On the other hand if the stone is applied at the rate of 120:1 then the loss would be four percent by weight. For the average Grade 3 material tested and for asphalt cement application rates in the range 0.28 to 0.32 the coverstone should be applied at the ratio of 120:1 or there about. Even then not all the stone is retained in the laboratory experiments; although, separate tests on the stone alone indicated that this amount would be retained.

For the segments of the curves to the left of asphalt application rates of about 0.23, the data were quite erratic. However, it is felt that the curves presented are logically located, and too, it is not likely that rates this low and lower would be used in seal coat work for this size and grading of aggregate. It is also to be noted that none of the curves has been extended beyond the 0.34 asphalt application rate. It should not be assumed that for rates above about 0.28 to 0.30 all the curves become rather flat. This is an indication that under the conditions of the test it was difficult to increase the coverstone retention rate by increasing the amount of asphalt applied. There is some small gain in the amount of stone retained as the stone application rate is increased but the excess that is applied is, for all practical purposes, wasted. This aspect of the problem will be further discussed in this report under field operations.

The reader is reminded that the above remarks are relegated to single shots of asphalt and single applications of coverstone with operations done under laboratory controlled conditions. It has, however, been found that with good equipment properly operated under adequate supervision similar results can be obtained in the field. Normally, seal coat work does not require more than a single application of asphalt and coverstone. Should it be considered necessary to place a double application, changes in the design, the details of which will not be given here, are necessary. Further, the trends indicated in the curves of Figures 17 and 18 do not apply to doubles in all their details.

WINDSHIELD DAMAGE STUDIES

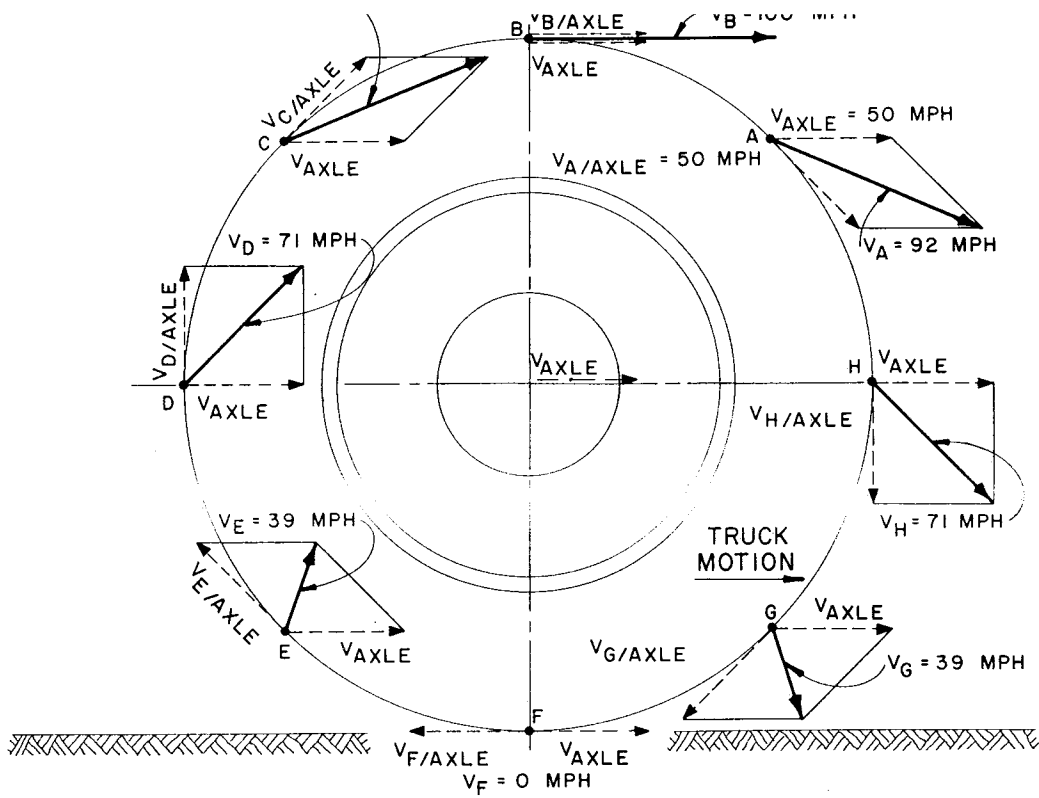
For many years in the past and even today newly constructed seal coats and surface treatments using cover aggregate of any appreciable size have caused some damage to the glass and finish of vehicles using the roads. Even at relatively low vehicular speeds some stone will be plucked from the road surface and thrown into the path of another vehicle. "Loose Gravel" caution signs are not uncommon during the asphalt construction season and may appear throughout the year on various maintenance jobs.

In 1957, Downey (13) reported on a study of the mechanics of stone damage to windshields. This report showed that 57 percent of the windshields examined revealed damage of some type, presumably from flying objects. A questionnaire indicated that almost half of the 415 cases of damage reported were caused while meeting another vehicle. The article further reported that approximately 80 percent of the damage occurring on the open paved road was caused by trucks.

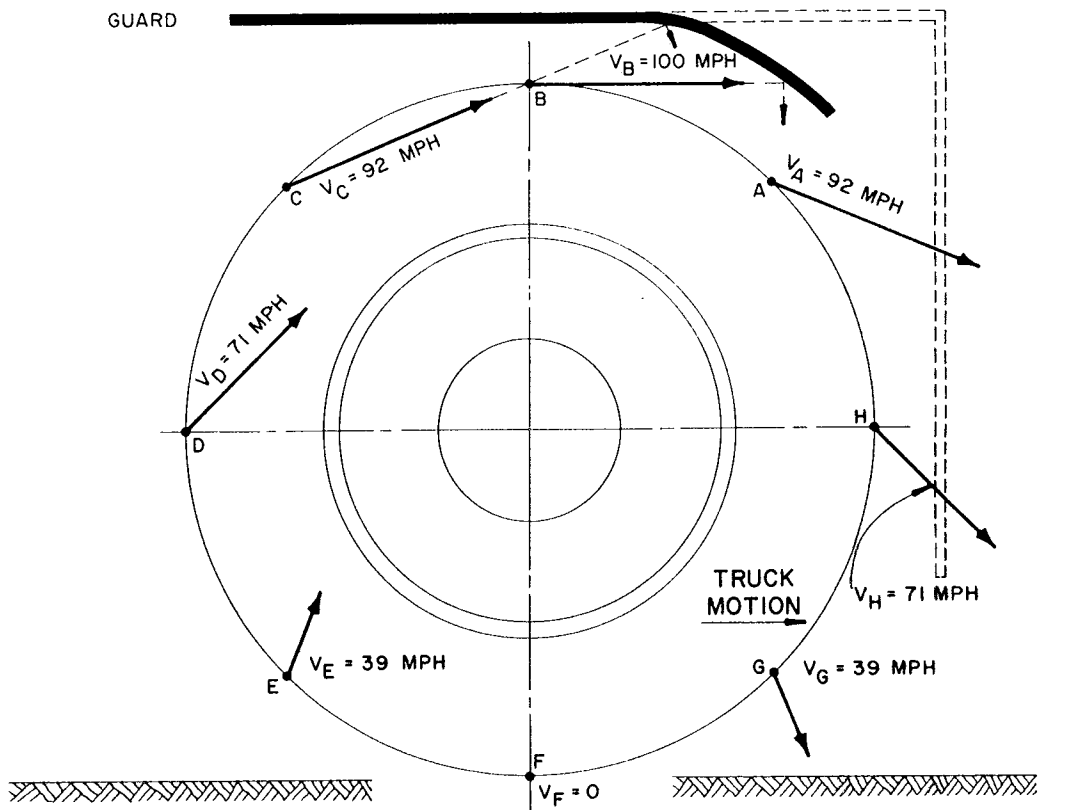
An analysis of the mechanics of the motion of a stone as it leaves a truck wheel is shown in Figure 19 (a) and (b) (13). It will be noticed that for an axle motion of 50 mph and no slip between the tire and the road surface a stone leaving the tire tread at point C will have a theoretical velocity of 92 mph. If no loss is suffered from wind resistance this stone would strike an oncoming vehicle (traveling in the opposite direction at 50 mph) at a relative speed of 142 mph. Naturally, there is a reduction in the velocity of the stone as it moves through the air from the truck tire to the windshield of the oncoming vehicle and the velocity at impact will be less than 142 mph but still would never be less than 50 mph.

Shown in Figure 20 is a schematic illustration showing the path a stone might take from an open truck's wheels to an oncoming vehicle (13). A simple truck wheel guard suggested by Downey is shown in Figure 19 (b) (13). The dotted lines represent a flap which should be completely effective in stopping any flying stone. With this summarized background the reader should now be better prepared for the following material on further laboratory studies of the flying stone problem.

In an effort to reduce or eliminate the damage caused by flying stone, Texas producers of gravel and crushed stone began the production of what is referred to as precoated aggregates for seals and surface treatments. This practice began about ten years ago. The Texas Highway Department revised its grading requirements for all the materials used in this type construction. The net result of these changes was to materially reduce the "fly stone" hazard.

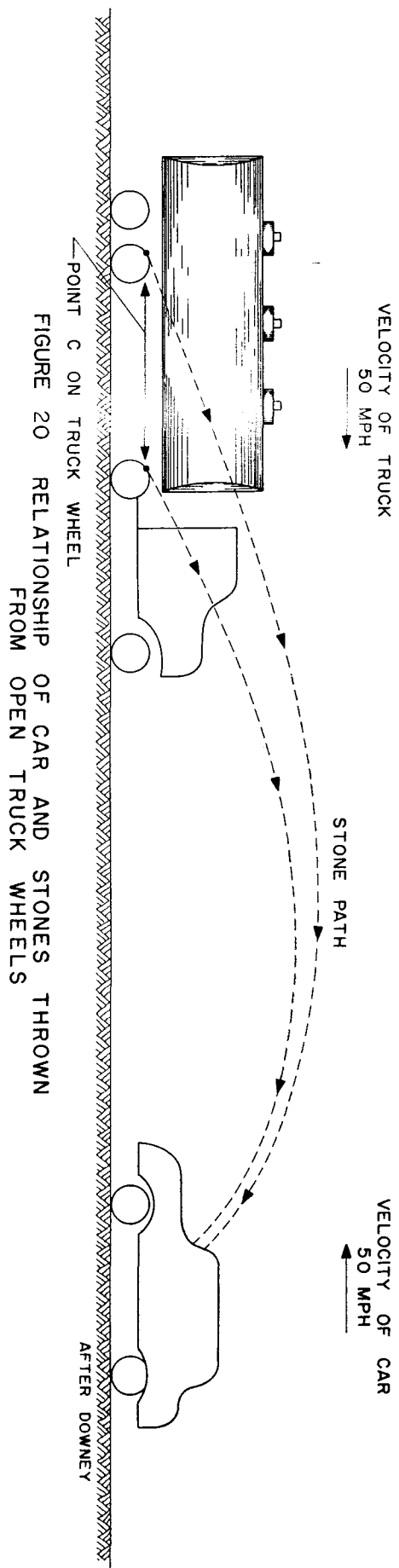


(a) UNPROTECTED WHEEL



(b) PROTECTED WHEEL

FIGURE 19 STONE MOTION AS IT LEAVES A TRUCK WHEEL



Producers of lightweight aggregate suggested that if their product were used as coverstone, no windshield damage would be caused. This, they reasoned, could be explained on the basis of the much lower weight of their produce compared to standard precoated limestone.

An air gun for shooting the stone was fabricated in the local shop and is shown as a line drawing in Figure 21. This gun is based on a design furnished by Monsanto Company (14). The unit is composed primarily of an air pressure regulator, an air storage tank made from a piece of 4-inch steel pipe, a solenoid valve and the gun barrel which is a 15-inch segment of 1-inch steel pipe. A photograph of the actual gun is shown in Figure 22. The gun is operated by inserting two felt or sponge rubber wads into the barrel and the projectile to be fired is brought in contact with the wadding. The selected air pressure is set on the air regulator and the storage tank is pressurized by opening the gate valve between the regulator and the gage. A shot is then fired by action of the solenoid valve with the aid of an electrical switch.

A windshield is being installed on an adjustable rack in Figure 23. These windshields were obtained from local auto glass repair shops and were already damaged in some way. Those that were used in the tests were carefully selected and positioned in testing assembly so damaged areas would not be in the impact area. The gun-muzzle-to-glass distance was set at ten feet and a fly screen enclosure as shown in Figure 25 was built to catch broken stone and glass. This served as a safety precaution and made it possible to recover and examine broken stone. The gun operator was required to wear a face guard or fire the gun while facing away from the windshield. Both safety laminated sheet and safety (tempered) plate glass were tested. The safety plate glass used is sold under the trade number of Herculite (15).

The lightweight aggregate used in the study fell in the size range 5/8-inch to No. 4 sieve size; so, the stone was divided into three sizes by sieving. These three groups were composed of 5/8-inch to 1/2-inch, 1/2-inch to 3/8-inch, and 3/8-inch to No. 4 material. Each size range was analyzed by taking representative samples and weighing each stone on a semi-automatic analytical balance. From these data, histograms were prepared and the stones were selected from each of the families of stone making up the histogram. Table I shows the average weight and standard deviation computed from the histogram data for each of the materials used in this study. The number of stones selected and shot from a given family was a function of the frequency of occurrence of size and weight. Typical histograms are shown in Figure 25 and 26. An actual photograph of a family of stones is shown in Figure 27.

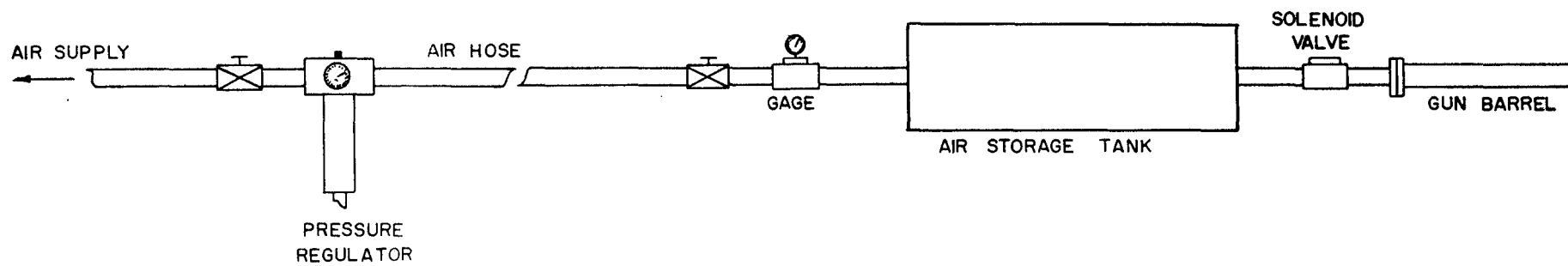


FIGURE 21 AIR GUN FOR SHOOTING STONES



Figure 22. Air powered gun for shooting stones.

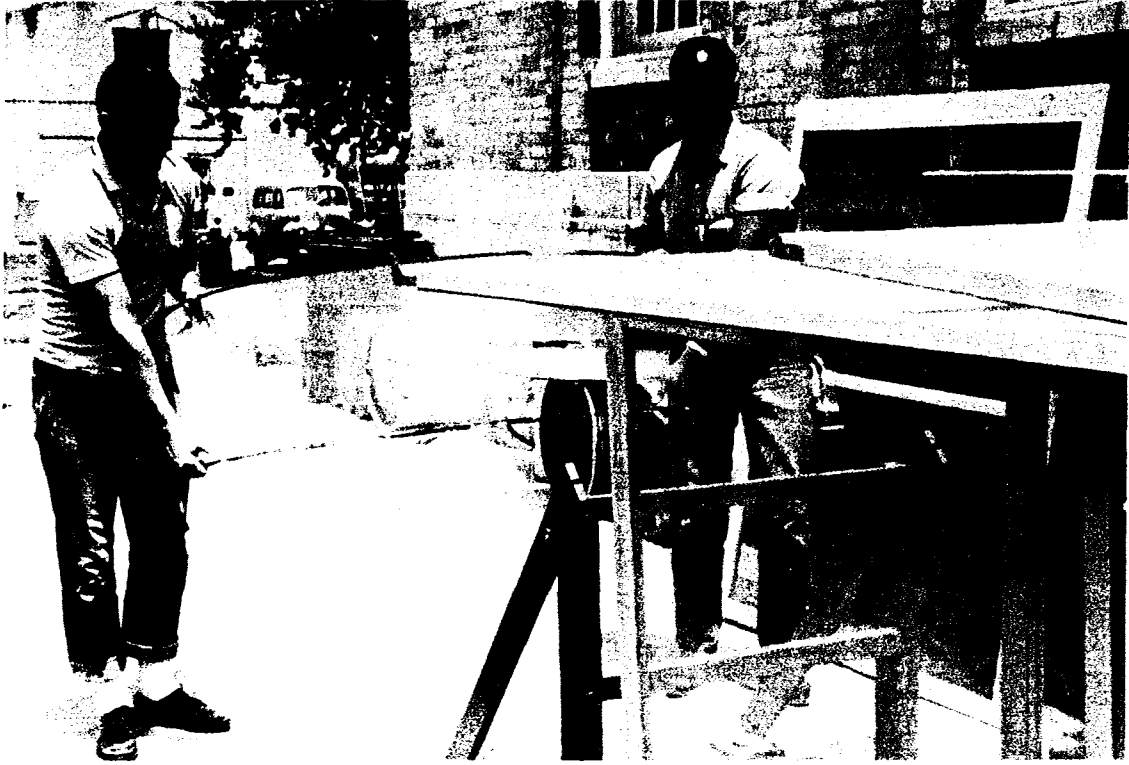


Figure 23. Windshield being placed into position for "flying stone" study.

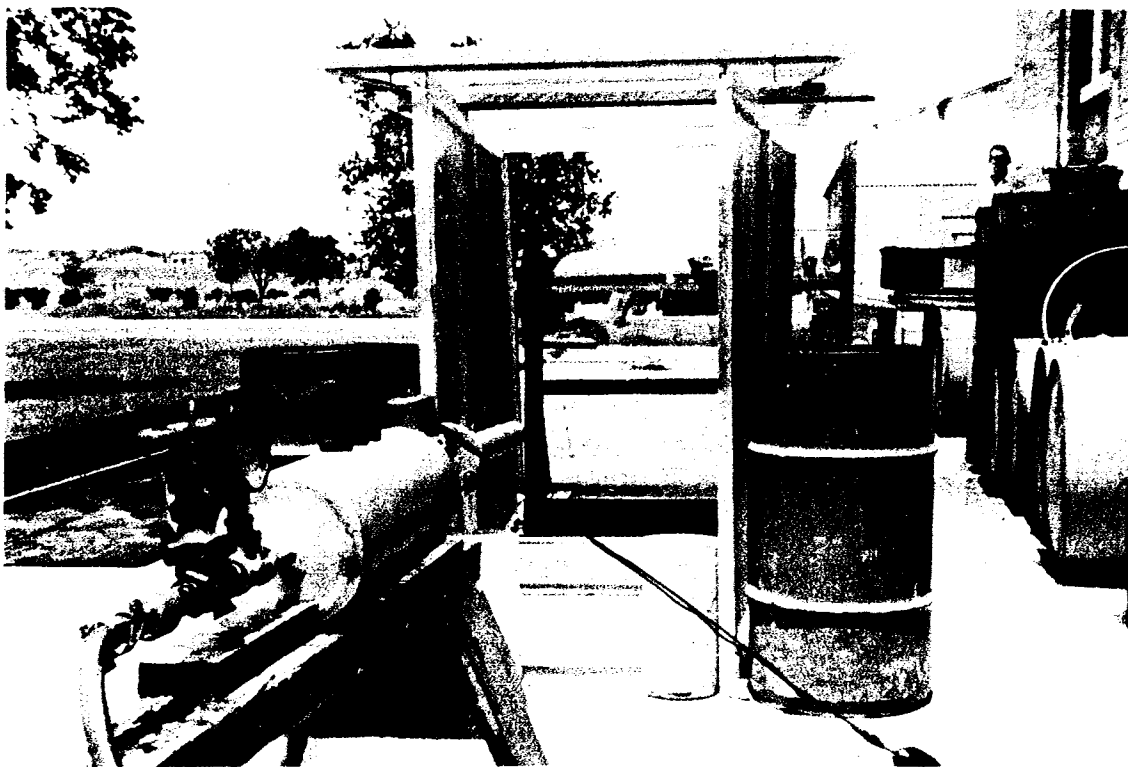


Figure 24. Windshield (target) in screened tunnel from gunner's view.

FIGURE 25
HISTOGRAM FOR TYPE PB
AGGREGATE

SHOT PRESSURE, 60 PSI
 DISTANCE, 10 FEET
 SIZE, 5/8 TO 1/2 INCH

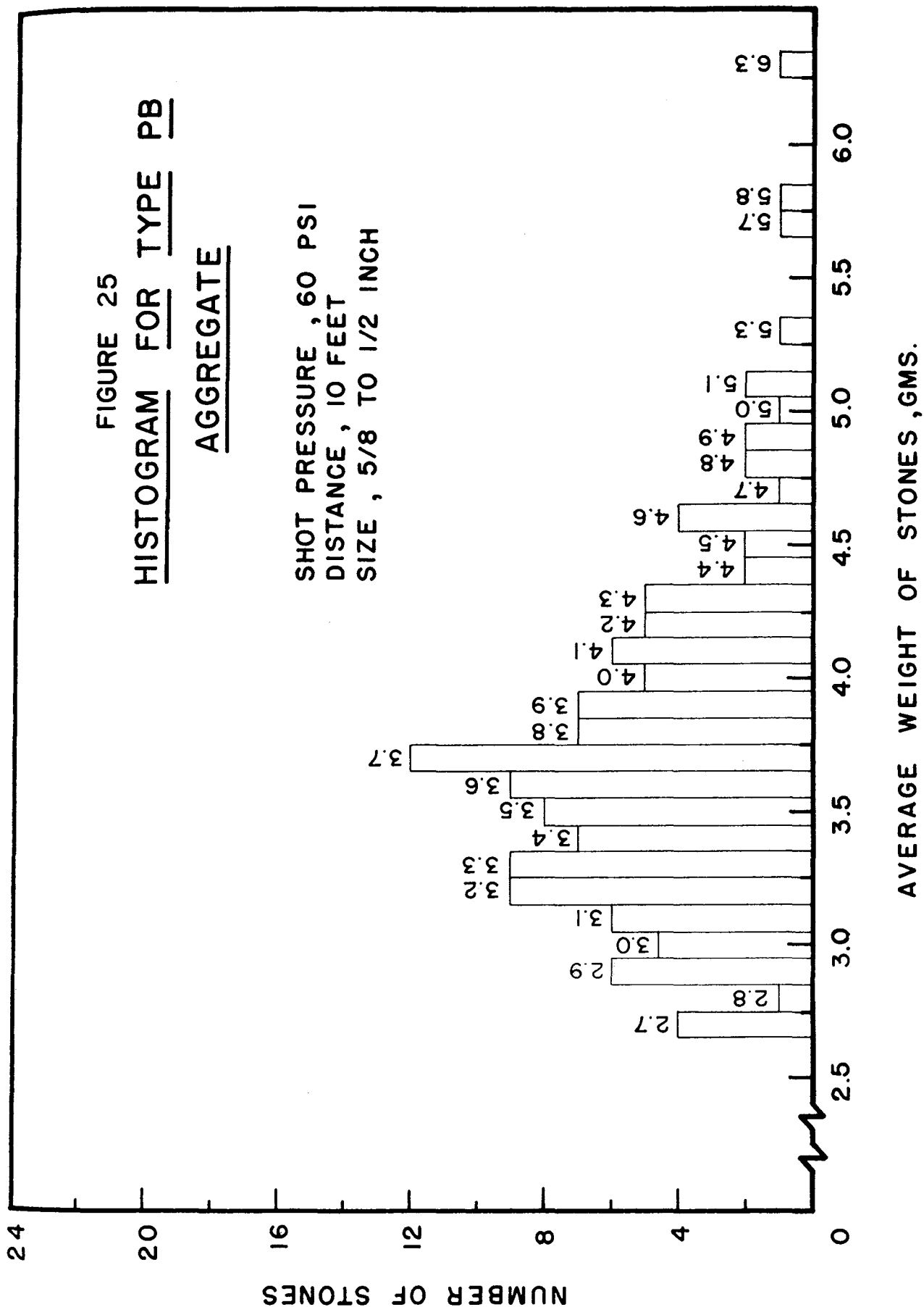


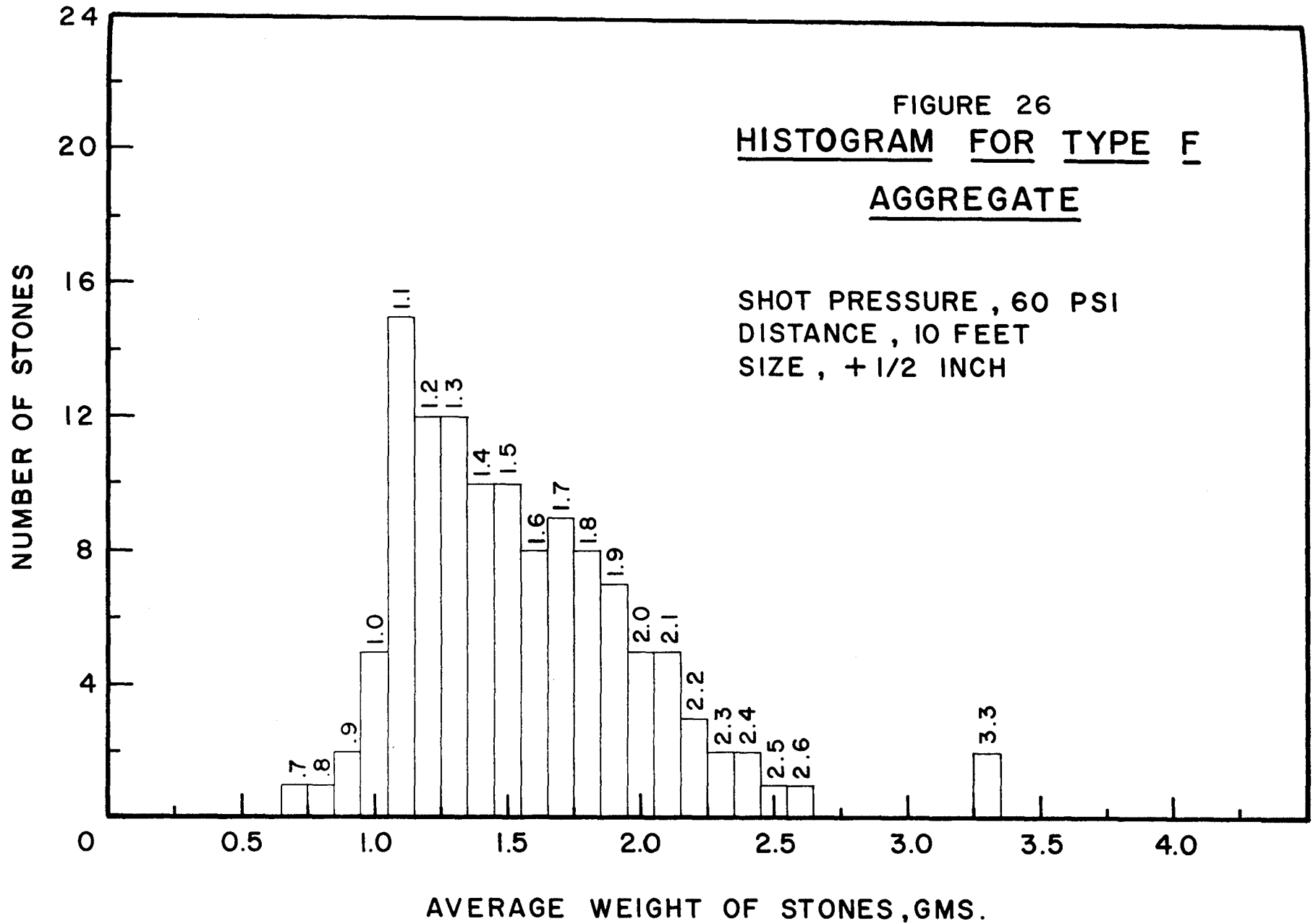
TABLE I

Average Weight and Standard Deviation of Stones

Material Source	Aggregate Size					
	5/8" to 1/2"		1/2" to 3/8"		3/8" to No. 4	
	Avg wt, gms	σ , gms	Avg wt, gms	σ , gms	Avg wt, gms	σ , gms
A	1.576	0.556	0.852	0.346	0.415	1.197
B	-	-	0.850	0.274	0.329	0.144
C	1.629	0.516	0.895	0.345	0.270	0.165
D	2.478	0.882	1.039	0.341	0.568	0.237
E	2.452	1.128	1.025	0.350	0.325	0.102
F	2.772	1.005	1.220	0.437	0.394	0.105
G	2.034	0.771	1.107	0.433	0.473	0.207
H	3.790	0.780	1.889	0.325	0.778	0.372

FIGURE 26
HISTOGRAM FOR TYPE F
AGGREGATE

SHOT PRESSURE , 60 PSI
DISTANCE , 10 FEET
SIZE , + 1/2 INCH



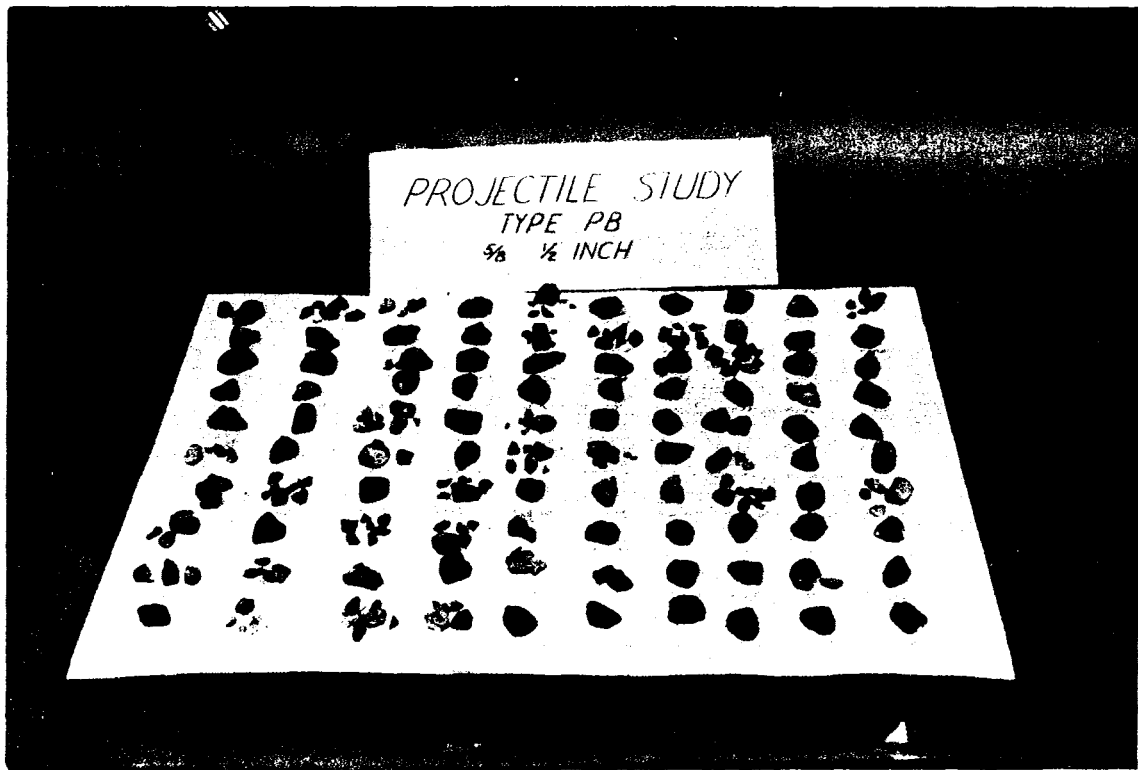


Figure 27. Type PB family of 5/8 to 1/2 inch stones after shooting.



Figure 28. Most severe windshield damage caused by type F material.

As previously mentioned, the muzzle-to-glass distance was ten feet. This distance was selected for two reasons. First, the directional accuracy of the gun was more dependable at this or a shorter distance and, second, the lightweight stones lost elevation quite rapidly at shooting pressures below 30 psi, particularly those of the least weight in a given family. For the arrangement used a distance much less than ten feet was considered hazardous.

Representative stones were initially shot at 40, 50 and 60 psi air pressure from nine families of stone for the lightweight and nine families of stone for the precoated material. After the initial portion of the study was completed, an analysis of the data indicated that it would not be necessary to "shoot" at all three pressures to determine the relative damage to the windshields. Therefore, the remainder of the lightweight aggregates were shot at pressures of 40 and 60 psi. More than 5000 stones were prepared and approximately 1200 of these were shot, 900 lightweight and 300 precoated stones.

As a general rule little glass damage was caused by the lightweight material. It was, however, found possible to break a laminated windshield with the lightweight stones. One such break, the most severe caused by any of the lightweight aggregates, is shown in Figure 28. The diagonal crack to the right of the "star" crack existed in the glass before test. Other noticeable breaks were caused by the lightweight materials, but they were minor compared to the one shown. The crack shown in Figure 28 was caused by a stone from aggregate A which weighed 3.78 grams. This stone is one of the heaviest lightweight particles shot, and it is approximately the same weight as the average PB stone. It was shot at a pressure of 50 psi and was estimated to be traveling in excess of 100 mph on impact.

The most common result observed was similar to that shown in Figure 29. Here the stone has been "powdered" on impact and some of the shattered material would usually remain on the glass. In this particular photograph, the scale and sheet of white paper are behind the glass. Also included within the bounds of the picture are numerous invisible points of stone impact. The glass was cleaned by scrapping it with a razor blade and washing it with a glass cleaning liquid after each shot. Usually no visible evidence of the shot remained after the cleaning operation.

The shooting of the precoated limestone was scheduled to follow the work done with the lightweight material because it was anticipated that the damage done to the windshields would be more severe with the heavier stones. To further conserve the supply of windshields the work plan included shooting stones from the families with the smallest stones first. Naturally the early shots were made beginning with the lowest pressure.

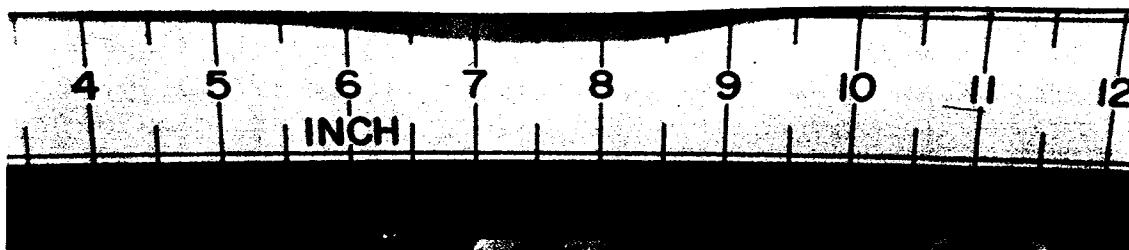


Figure 29. Typical "powder burn" of lightweight aggregate on impact into laminated glass windshield.

The 3/8-inch to No. 4 precoated limestone shot at 40 psi caused only minor damage to the laminated windshield used; however, as the pressure was increased to 60 psi on the gun, small cracks were formed and some chips of glass were broken from the impact side of the glass.

When the largest stones were shot, severe damage to the windshield was a frequent occurrence. One family of stones made up from the 5/8 to 1/2-inch precoated limestone is shown in Figure 25. The number of shots was in keeping with the frequency of occurrence of the different weights in the family. Of the 100 stones in the family about 30 were shot and the pieces were gathered up and returned to the display board. These may be observed in the photograph (Figure 27).

One of the "used" windshields obtained for a target, by chance, was already damaged by flying stone. The damaged area is shown in Figure 30. Another area of this same windshield with laboratory induced damage is shown in Figure 31. It is suggested that the reader compare the damage in the upper center of the latter photograph with damaged areas of the preceding photograph (Figure 30). Very careful examination will reveal striking similarity in the "Real McCoy" and the experimental damage shown in these pictures. Other "breaks" on other windshields not shown included similar damage done in the experiments. It therefore seems reasonable to conclude that the damage in both cases was caused by impacts of similar magnitude although the stones causing the original damage might have been smaller or larger than those included in the study.

A summary of the results from the shooting of lightweight aggregate "A" and a standard weight material is shown in Figure 32. The frequency of damage to the glass is shown as a percent of the shots fired and this percentage includes only those shots that caused actual cracks of such size as to be visible to the naked eye. Not included in this summary are numerous very small scratches many of which were discernible only by softly passing one's fingernail over the imperfection on the glass.

The lightweight material described in the previous figure was aggregate "A" which appeared to cause a little more damage than the other lightweight aggregates. A comparison of the breakage created by the larger particles of the lightweight material is presented in Figure 33. The smaller sizes, 1/2-inch to 3/8-inch and 3/8-inch to No. 4, cause no appreciable damage. Only aggregate "A" and "F" caused damage in the middle size range; whereas, aggregate "A" was the only one causing breakage in the small size range.

It is interesting to note that most of the damage was caused by stones whose weight was greater than a unit standard deviation from the mean. For instance, aggregate "A" had 10.3 percent breaks at 40



Figure 30. Actual in-service windshield damage caused by a flying object.



Figure 31. Laboratory windshield damage caused by Type PB material. (Same windshield as Figure 30.)

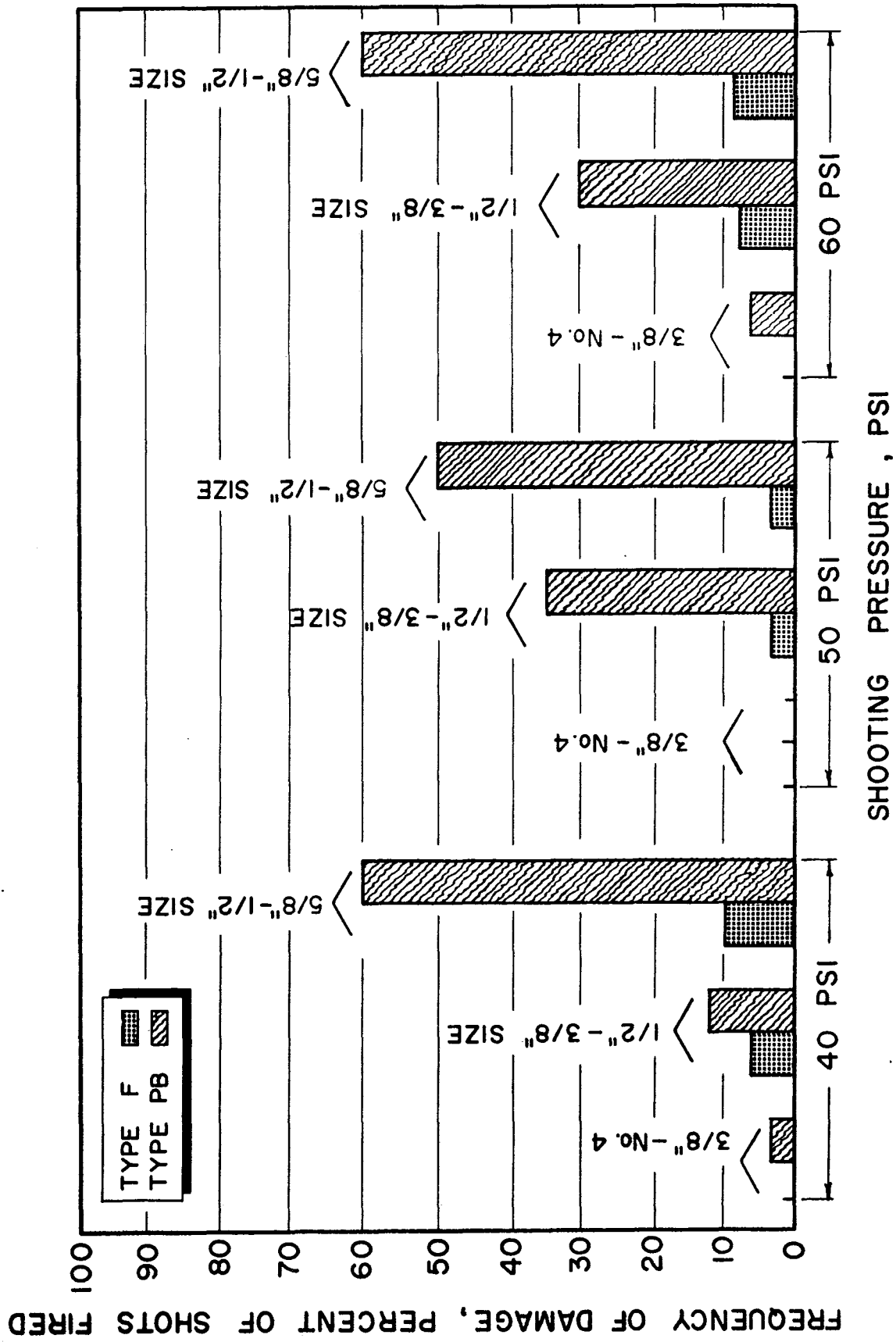
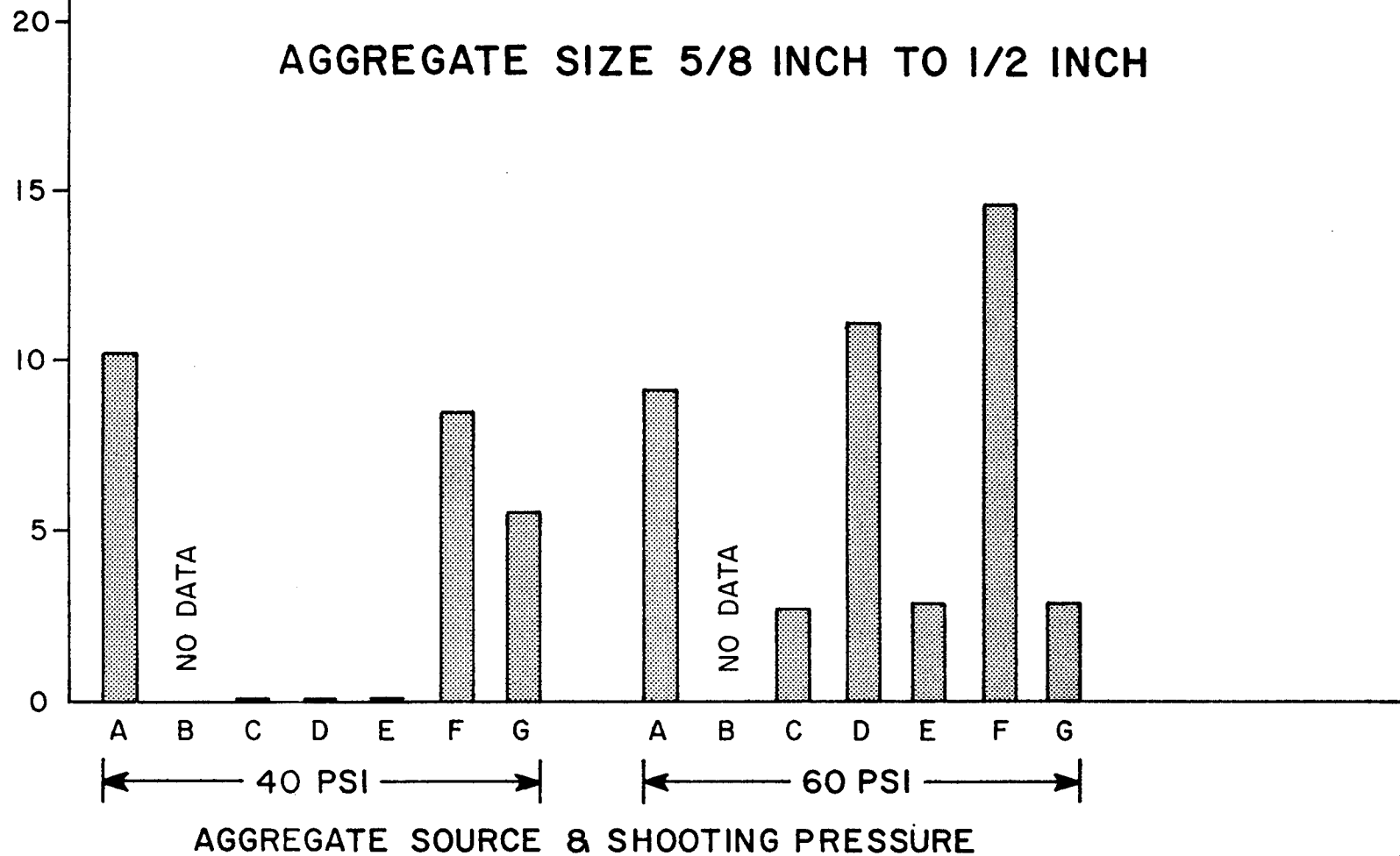


FIGURE 32 COMPARATIVE DAMAGE TO WINDSHIELDS FOR TYPE F AND TYPE PB AGGREGATE SHOT AT DIFFERENT PRESSURES

FREQUENCY OF DAMAGE, PERCENT OF SHOTS FIRED

FIGURE 33 COMPARITIVE DAMAGE TO WINDSHIELDS FOR
TYPE F AGGREGATE FROM DIFFERENT SOURCES
SHOT AT DIFFERENT PRESSURES

AGGREGATE SIZE 5/8 INCH TO 1/2 INCH



psi for the 5/8-inch to 1/2-inch stone. Of this 10.3 percent, 3.4 percent was caused by stone weights within a standard deviation of the mean and 6.9 percent was caused by stone weights greater than a standard deviation. In keeping with the frequency dictated by the histogram, only 5.6 percent of the stones actually shot within the standard deviation group caused damage; whereas, 33.3 percent of the stones shot in the greater than this unit standard deviation group caused damage. In the same vein, if the precoated stone is considered, the total damage was 66.6 percent with 45.5 percent in the unit standard deviation group, and 21.1 percent fell in the group of stones whose weight was greater than the unit standard deviation from the mean. However, 68.2 percent of the shots fired in the unit standard deviation group caused damage, and 87.5 percent of the shots fired in the group whose weight was greater than a unit standard deviation caused damage.

It must be admitted that the damage picture is not as awesome as it may appear for it is to be remembered that to create damage the stone must first be thrown and then it must be made to travel in the right direction and have sufficient energy on impact to damage the target. The results presented serve to show what happens under controlled laboratory conditions when the variables involved are the weight and velocity of the stones that were shot.

MODIFIED LOS ANGELES ABRASION TESTS

An abrasion study of lightweight aggregates was carried out by Rushing (16) at the Louisiana Department of Highways in cooperation with the Bureau of Public Roads. Results of this study are summarized in his report dated February, 1963. The author concluded that the Deval Abrasion Test (AASHTO Designation T4-35) (17) with certain modifications would give better results than the Los Angeles Abrasion Test. However, due to the extensive time (about 5 hours) required for the Deval Test, Rushing suggested the use of the Los Angeles Abrasion Test modified as follows:

- "a. A No. 4 sieve should be used for the determination of the loss.
- b. One hundred revolutions be used in lieu of 500.
- c. The dry aggregate sample be determined by using the same volume of lightweight aggregate as is used for gravel and stone."

The Texas Highway Department, under Test Method Tex-410-A Part II, (18) made a somewhat similar modification of ASTM's Designation: C131-55. Test Method Tex-410-A Part II in its entirety will be found in Appendix A. In summary the modification calls for reducing the weight of the lightweight aggregate test sample so it will have the same volume as the regular stone or gravel sample, the unit weight of which is assumed to be 97 pcf. The abrasive charge is reduced in the same ratio as the sample weights. No change is made in the number of revolutions of the drum nor is the method of analysis of the loss changed.

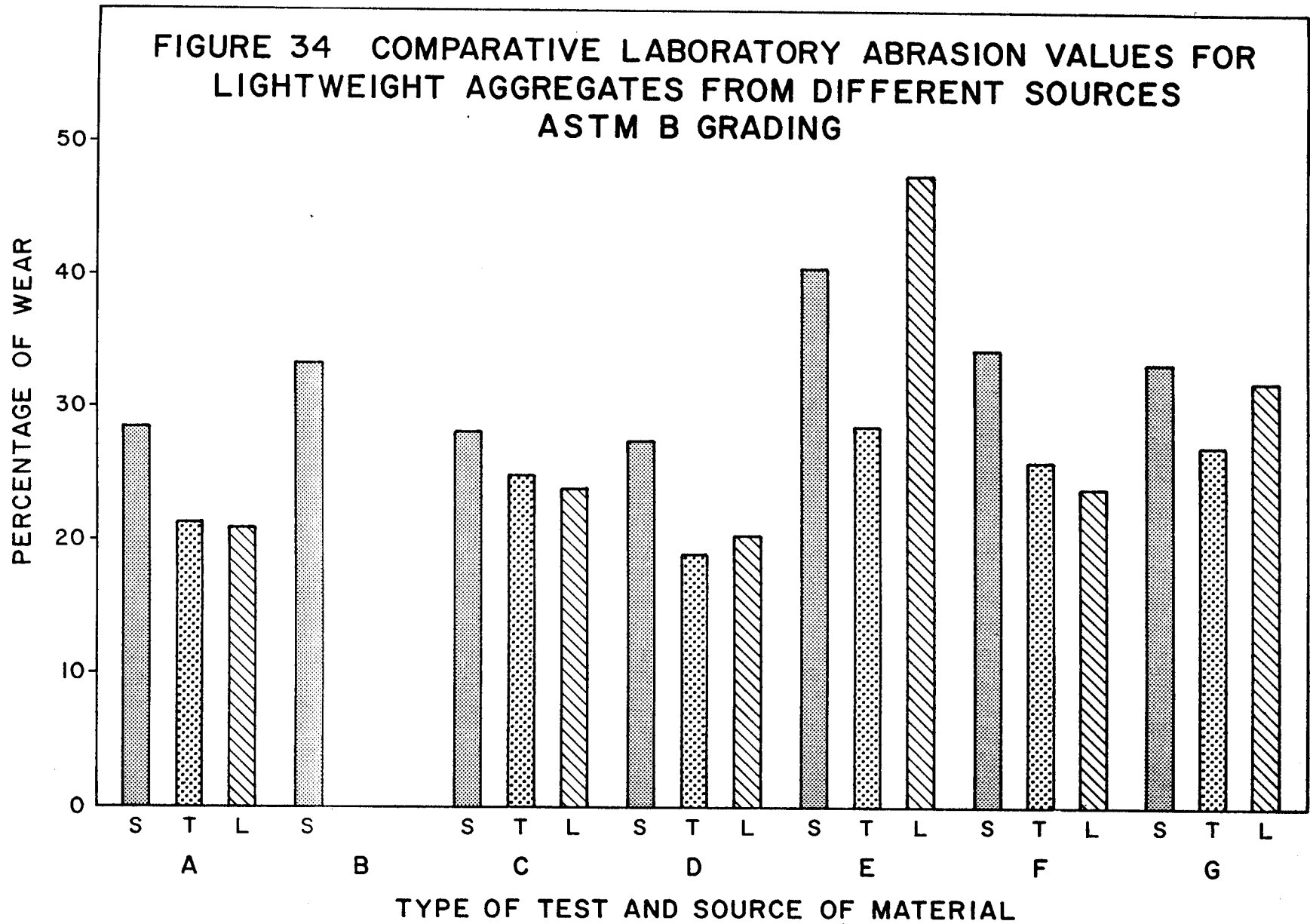
Three methods for evaluating the wear characteristics of the lightweight aggregate under study were used and the average results are compared in Figures 34-36. The materials after test are shown in Figure 37.

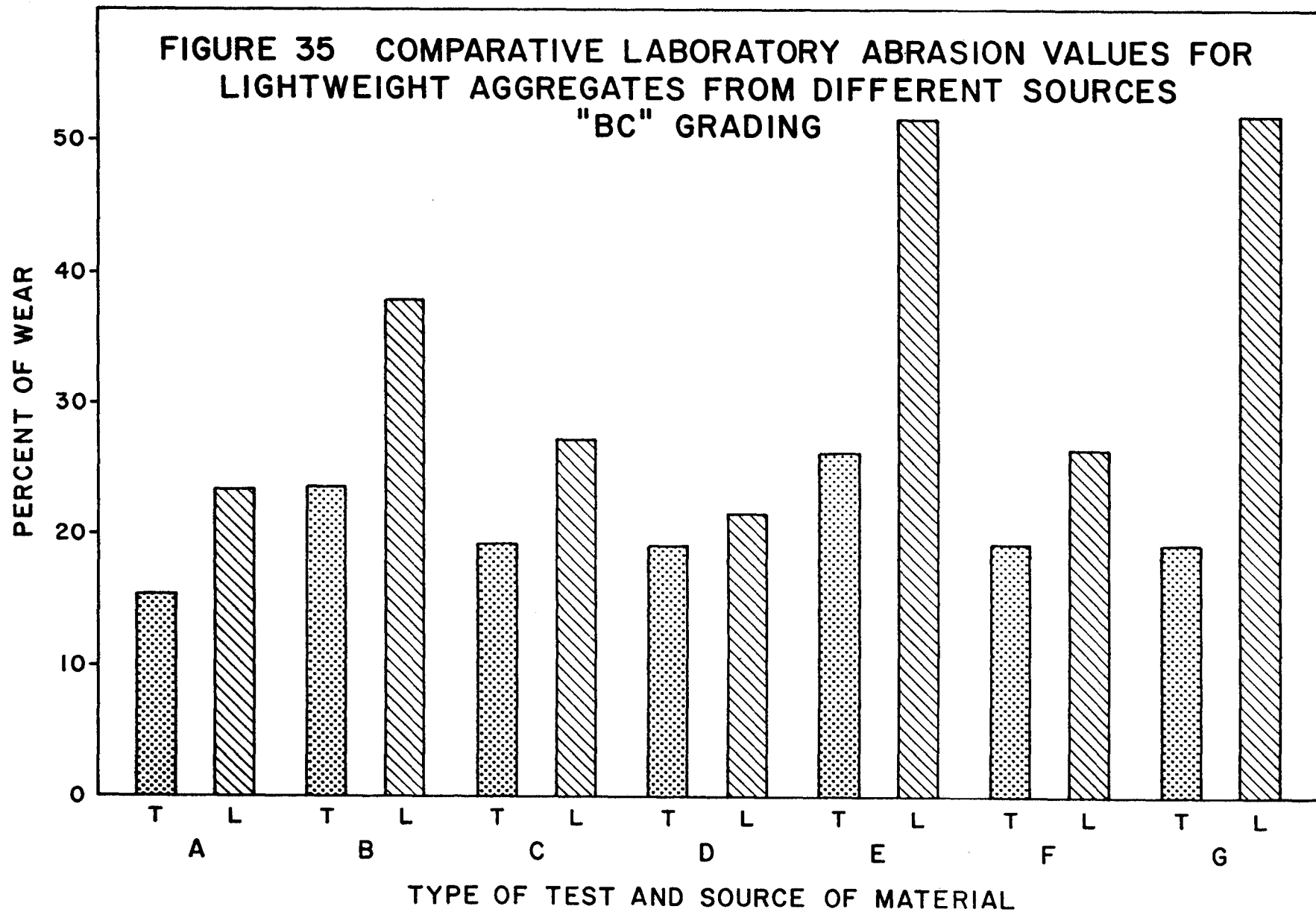
Since the aggregates studied were primarily in the size range 5/8-inch to No. 4 sieve, it was considered advisable to select samples fitting both the "B" and "C" gradings of ASTM's C 131. Actually the materials studied were made up of sizes that straddled "B" and "C" grading; so, another group of abrasion tests was run using samples designated as "BC" grading.

The reader is referred to the data of Table II for an example of comparative rates of wear for lightweight aggregate "A" tested by the three different methods listed. Details on the grading and weights of

the samples as well as the weight of the abrasive charge are given in this table. It would appear from the data given that the regular ASTM Test are more restrictive than either of the other two modifications for the coarser "B" grading, but the Louisiana method is the more severe test for the finer "C" grading. This is attributed to the difference in method of evaluation. The "C" grading contains 50 percent of a 3/8-inch to No. 4 material, and if the evaluation is to be made on the No. 4 sieve, it would not require much breakage to accumulate high percentages of loss. However, the Louisiana method is quicker and easier to run, since it requires only 100 revolutions of the drum. Too, the variability of the individual tests is such as to suggest that in the interest of saving laboratory testing time the washing and drying of the retained material could be an optional requirement.

Shown in Table III are data from Woolf (12) giving the average values for the physical properties of rock. If the results obtained from testing the lightweight aggregate of this project were compared to the values in this table, it would be apparent that none of the test procedures used give a true picture of the impact and abrasion resistance of the lightweight material. Many of the lightweight particles may be individually crushed by foot pressure; yet, the service record to date on the material are good. And, after all, it is the service record that really counts. Still, some means of specifying and evaluating a material preparatory to its use is needed and acceptance based on such tests could be made conditional until sufficient proof from the field is available.





**FIGURE 36 COMPARATIVE LABORATORY ABRASION VALUES FOR
LIGHTWEIGHT AGGREGATES FROM DIFFERENT SOURCES
ASTM C GRADING**

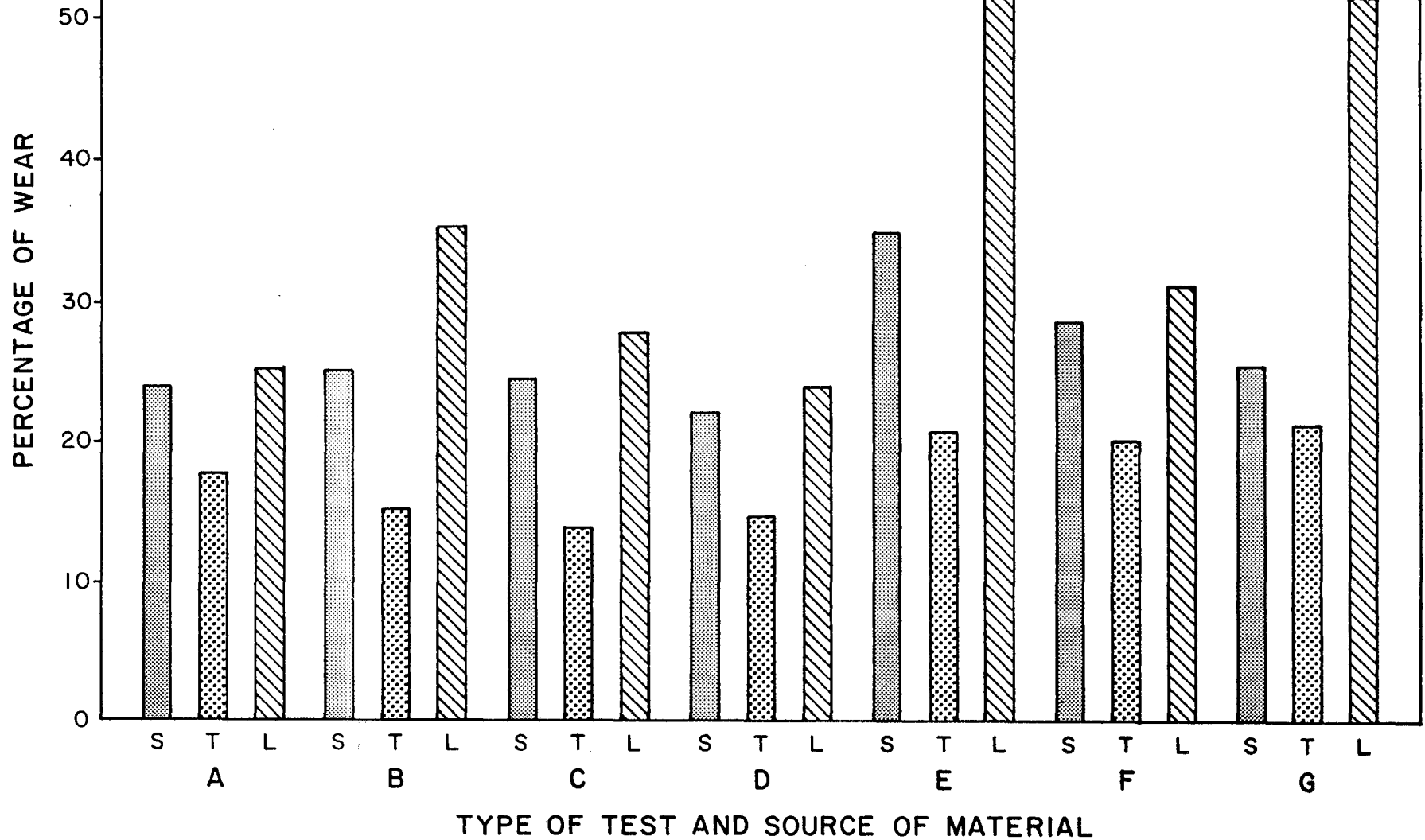


TABLE II

Results of L. A. Abrasion Test on Lightweight Aggregate "A"
by Three Methods

<u>Size Range</u>	<u>Sample Weight, Gms</u>	<u>Abrasive Charge, Gms</u>	<u>Test Method</u>	<u>Percent Loss</u>
3/4-3/8 inch	5000	4574	ASTM	28.2
3/4-3/8 inch	5000	4569	ASTM	28.2
3/4-3/8 inch	5000	4574	ASTM	29.6
3/8 inch-No. 4	5000	3335	ASTM	24.1
3/8 inch-No. 4	5000	3344	ASTM	23.5
3/8 inch-No. 4	5000	3344	ASTM	23.8
3/4-3/8 inch	2280	2083	Texas	22.6
3/4-3/8 inch	2280	2090	Texas	21.8
3/4-3/8 inch	2280	2090	Texas	20.5
1/2-1/4 inch	2090	1666	Texas	16.3
1/2-1/4 inch	2090	1676	Texas	15.2
1/2-1/4 inch	2090	1676	Texas	15.1
3/8 inch-No. 4	2510	1665	Texas	17.9
3/8 inch-No. 4	2510	1665	Texas	18.2
3/8 inch-No. 4	2510	1673	Texas	17.3
3/4-3/8 inch	2214	4579	Louisiana	21.0
3/4-3/8 inch	2214	4574	Louisiana	20.3
3/4-3/8 inch	2214	4579	Louisiana	21.8
1/2-1/4 inch	2214	4160	Louisiana	22.0
1/2-1/4 inch	2214	4162	Louisiana	20.8
1/2-1/4 inch	2214	4160	Louisiana	26.8
3/8 inch-No. 4	2214	3329	Louisiana	29.3
3/8 inch-No. 4	2214	3346	Louisiana	21.1
3/8 inch-No. 4	2214	3330	Louisiana	26.9
3/8 inch-No. 4	2214	3346	Louisiana	23.3

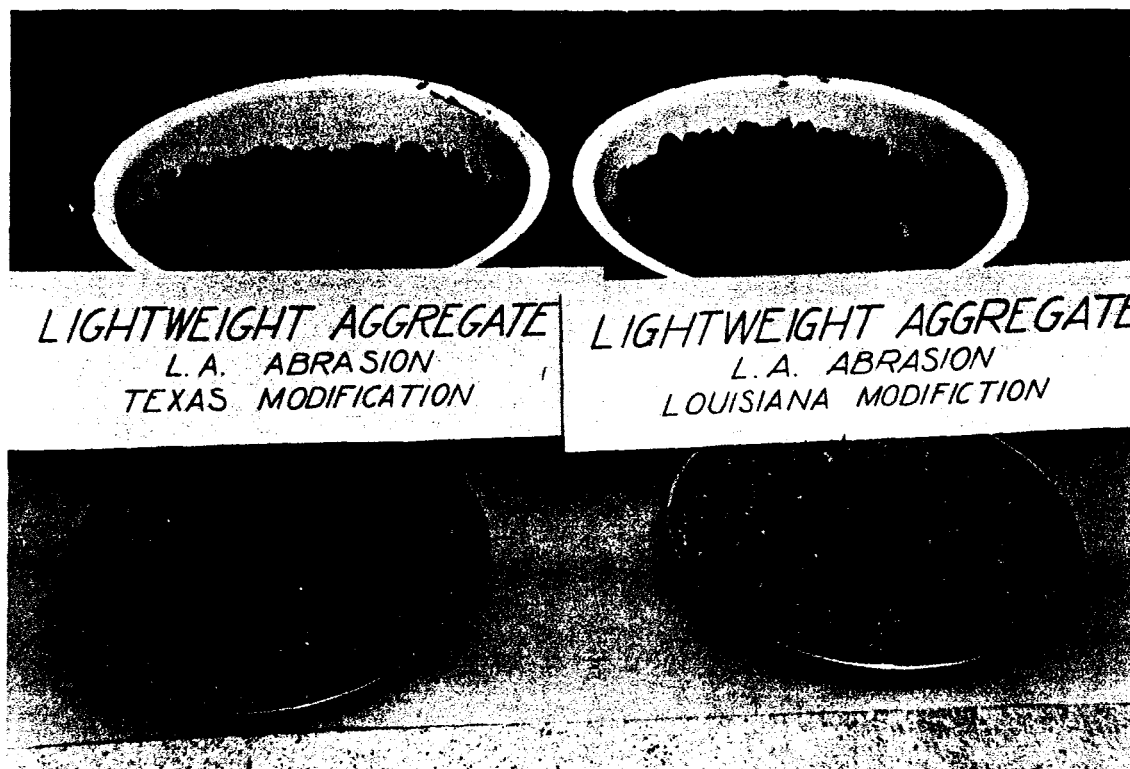


FIGURE 37 Type F materials after testing by Texas and Louisiana methods for L. A. wear.

Kind of Rock	Toughness		Hardness		Loss by Abrasion			
	Number of Tests	Average	Number of Tests	Average	Deval Test		Los Angeles Test	
					Number of Tests	Average, per cent	Number of Tests	Average, per cent
Amphibolite	70	14	56	16	87	3.9	30	35
Basalt	203	19	192	17	203	3.1	24	14
Chert	29	12	29	19	78	8.5	6	26
Diabase	285	20	253	18	340	2.6	63	18
Diorite	48	15	45	18	60	3.1	--	--
Dolomite	612	9	586	14	708	5.5	134	25
Felsite ^b	127	17	118	18	150	3.8	9	18
Gabbro	42	14	38	18	45	3.0	4	18
Gneiss	386	9	365	18	602	5.9	293	45
Granite ^c	703	9	589	18	718	4.3	174	38
Limestone	1315	8	1209	14	1677	5.7	350	26
Marble	188	6	162	13	175	6.3	41	47
Quartzite	161	16	146	19	233	3.3	119	28
Sandstone	681	11	613	15	699	7.0	95	38
Schist	212	12	180	17	314	5.5	136	38
Syenite	32	14	26	18	31	4.1	14	24

^aFrom "Results of Physical Tests of Road-Building Aggregate."

^bIncluding andesite, dacite, rhyolite, and trachyte.

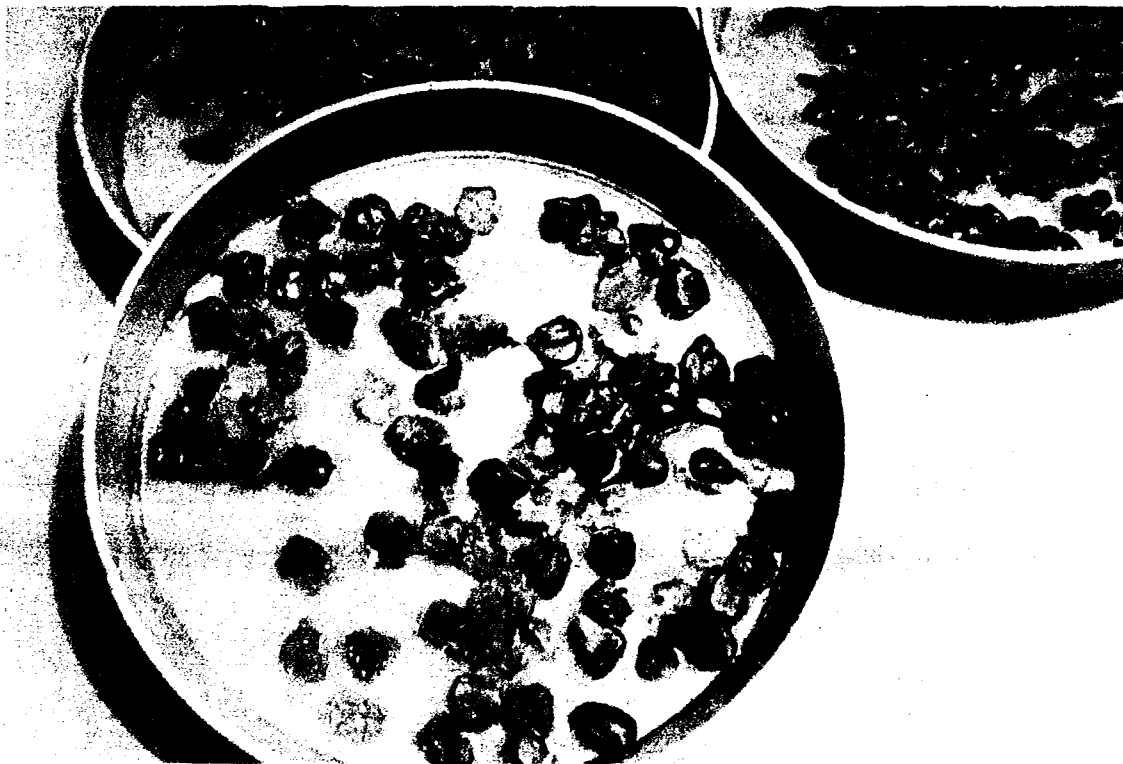


FIGURE 38 Type F material after freezing in water.

FREEZE - THAW TESTS

Since lightweight aggregate was introduced as a coverstone, some question has arisen concerning the resistance of such materials to freezing and thawing in the presence of water. It is reasonable to suspect that a material with a relatively high absorption capacity might be damaged appreciably if saturated and cooled to low temperatures of, say 0°F or colder. Neither present standard nor special specifications of the Texas Highway Department requires that cover aggregate be subjected to a freeze-thaw test. Neither ASTM nor AASHTO lists a test procedure specifically designed for testing aggregates of this type. It was therefore necessary to design a freeze-thaw test for the lightweight used in this study to approximate the nature of the exposure experienced in the field. Such a test was designed and will be described.

A chest type freezer was used as the freezing chamber and the prepared samples were exposed to a freezing atmosphere in shallow metal pans. Before the first cycle began, distilled water was added to the pans to bring the level up to a point about half the depth of the stone. A close-up photograph of the frozen material is shown in Figure 38. As the test progressed from cycle to cycle, distilled water was added when necessary to maintain this level. A freeze-thaw cycle consisted of about two hours and fifteen minutes of quick freezing and about thirty minutes of thawing at 75 ± 3°F. The freezing chamber temperature was in the range -14 to +4°F through 100 cycles of freezing.

Of the seven sources of lightweight aggregate under study most of the material would pass a 5/8-inch sieve and be retained on a No. 4 sieve. For test purposes the material was therefore divided into three fractions in accordance with the data shown in Table IV. The number of stones selected for test in each size range was the approximate number required to cover the pan one stone deep.

After the first 50 cycles, the samples were dried and weighed and any particles passing the sieve on which they were retained before the test began were removed. The remaining stones, those retained on the sieve, were then subjected to an additional 50 cycles of rapid freezing and thawing. The loss was again checked by sieving. Any particles passing the sieve upon which they were retained before the test were reported as loss. These weight losses are shown in Tables IV and V. It is interesting to note that the greater losses occur in the two larger aggregate sizes. There are two reasons for this behavior. First, the loss was created by a spalling action or breaking of the corners of the rocks. In the larger sizes a broken corner may have caused sufficient size reduction to allow the aggregate particle to pass the sieve, but

in the smaller size (3/8-inch to No. 4) a particle just passing the 3/8-inch sieve could be broken into half by the freeze-thaw action and still be retained on the No. 4 sieve, thus showing no loss. Secondly, the small particles may actually be stronger. As previously mentioned, some of these lightweight aggregate particles are produced from shale which presents planes of weakness parallel to the bedding plane. In the crushing operation of the burned shale, the smaller particles were often created by fracture along these or similar planes of weakness thus making these small pieces comparatively stronger.

Due to the difference in the amounts of the different sizes in the two grades of aggregate tested, it was considered advisable to correct the actual measured losses in accordance with the original sieve analysis of the two grades of lightweight aggregate. An example of this correction is shown in Table VI. The Grade 4 stone showed a corrected loss of 3.07 percent compared to 6.46 for the Grade 3 material for 100 cycles of exposure. The variation in the amounts of each size material in the original samples caused this difference. The corrected percent losses for all of the lightweight aggregates studied are shown in Table VII.

Normally a seal coat would be expected to last about four years although some jobs may have a much longer life. In the colder areas of the state, it is possible that a road would be subjected to ten or more cycles of zero weather but it is considered unlikely that any part of Texas would be subject to more than 25 cycles of zero weather in one winter. Nevertheless, in setting up the test conditions, 100 cycles were chosen for evaluating this material. Further study and more field data may well indicate the need for a change in the test procedure.

A tentative recommendation would be to restrict the weighted total loss to 8 percent after 50 cycles of rapid freezing and thawing in presence of distilled water. The freezing should be done at $0^{\circ} \pm 5^{\circ}\text{F}$.

TABLE IV

Rapid Freeze-Thaw of Lightweight Aggregate

<u>Sample</u>	<u>Size Range</u>	<u>No. of Particles</u>	<u>Wt. Before Test, Gms</u>	<u>Wt. After 50 Cycles, Gms</u>	<u>Wt. After 100 Cycles, Gms</u>
A	5/8-1/2 inch	100	163.1	140.0	125.8
A'	5/8-1/2 inch	100	171.1	135.9	111.9
B	1/2-3/8 inch	200	189.8	174.8	171.6
B'	1/2-3/8 inch	200	199.1	181.9	178.8
C	3/8 inch-No. 4	300	95.9	94.3	94.2
C'	3/8 inch-No. 4	300	104.1	103.1	102.8

TABLE V

Actual Percent Loss Due to Freezing and Thawing
of Lightweight Aggregates

Material Source	50 Cycle			100 Cycle		
	5/8-1/2	1/2-3/8	3/8-#4	5/8-1/2	1/2-3/8	3/8-#4
A	17.4	8.3	1.3	28.8	9.9	1.5
B	42.8	45.2	16.0	71.5	68.7	30.7
C	6.0	14.8	2.6	17.0	22.4	6.2
D	5.2	9.3	2.2	10.8	15.2	2.5
E	3.3	8.8	4.0	11.5	18.0	7.5
F	12.5	14.5	5.3	26.8	27.7	14.3
G	29.0	28.6	3.9	39.1	35.8	7.3

TABLE VI

Corrected Percentage Loss After 100 Cycles
of Freezing and Thawing

Type F Grade 4

<u>Sieve Size</u>	<u>Grading of Original Sample</u>	<u>Actual Loss, Pct.</u>	<u>Weighted, Loss, Pct.</u>
5/8-1/2 inch	1	28.8	.28
1/2-3/8 inch	14	9.9	1.39
3/8 inch-No. 4	76	1.5	<u>1.40</u>
Total Loss-----			3.07

Type F Grade 3

<u>Sieve Size</u>	<u>Original Sample</u>	<u>Actual Loss, Pct.</u>	<u>Weighted Loss, Pct.</u>
5/8-1/2 inch	12	28.8	3.45
1/2-3/8 inch	22	9.9	2.18
3/8 inch-No. 4	55	1.5	<u>.83</u>
Total Loss-----			6.46

TABLE VII

Freezing and Thawing
Corrected Percentage Loss

Material Source	Grade 3		Grade 4	
	50 cycles	100 cycles	50 cycles	100 cycles
A	4.7	6.5	2.3	3.1
B	24.8	41.9	20.9	36.6
C	5.7	10.3	3.0	6.5
D	5.4	8.2	2.6	3.4
E	6.6	13.4	3.7	6.9
F	8.5	18.8	5.0	12.8
G	12.5	17.8	5.8	9.0

SOUNDNESS TESTS

Lightweight aggregate "A" was subjected to five cycles of the soundness test, ASTM Designation C88-61T, using magnesium sulfate solution.

Results of these tests are shown in Tables VIII and IX. An examination of the aggregate sizes listed in these tables reveals differences in the fractions making up the sample when these are compared to ASTM requirements. Modifications made in the samples tested were considered necessary due to the original grading of the materials under study. It is evident from the data that the losses are rather low but it should be pointed out that the difference in loss of similar fractions was high in certain instances. This, no doubt, may be explained by differences in the original samples from which these fractions were selected. But not to be neglected is the difference in actual particle size within a given range before test. Because the losses were small, any difference is revealed as a large change in the actual loss where these losses are reported as percentages.

If the weighted average loss caused by five cycles of the magnesium sulfate soundness test is compared to the loss caused by fifty cycles of the freeze-thaw test, it is readily evident that the freeze-thaw test is much more severe at least for the number of cycles involved in this study. It may be concluded then that 50 cycles and 8 percent loss of rapid freeze-thaw in water may be unduly severe as a requirement for an aggregate of this type. In Figure 39 the results of the 50 and 100 cycle freeze-thaw tests are plotted and extrapolated to zero loss then superimposed on this graph are the soundness test losses on corresponding THD grades of lightweight material. It appears that to get approximately equal losses for this particular material, Grade 3 should be subjected about ten freeze-thaw cycles and Grade 4 about twenty-five.

Three problems were encountered in the soundness test. The coarse lightweight aggregate absorbed a large quantity of the salt solution and this in turn made it necessary to extend the drying period and consequently the over-all time of the test. After each cycle it was necessary to re-establish the correct specific gravity of the sulfate solution by heating, stirring and cooling it. After the last cycle was completed it was difficult to wash the aggregate free of the salt. Some 36 to 48 hours of continuous washing was required. These problems extended the over-all test time to eight or nine days for any given sample. Normally, it was possible to effect five freeze-thaw cycles in one day and this would mean about six days total for a 25-cycle test, or about three days for the 10-cycle test. More work must be done on both tests before firm recommendations can be made.

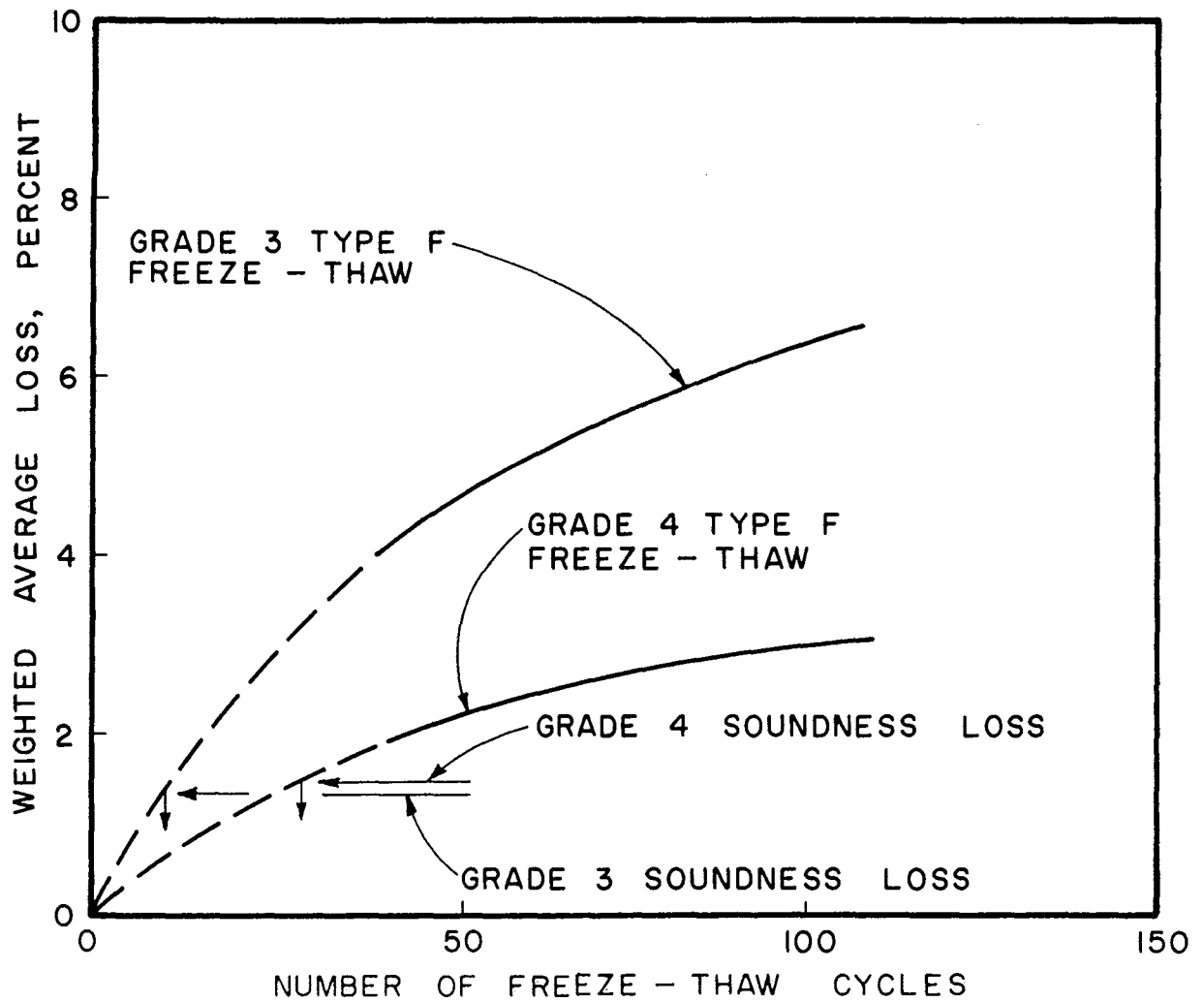


FIGURE 39 COMPARATIVE FREEZE-THAW AND SOUNDNESS LOSSES FOR AGGREGATE "A"

TABLE VIII

Soundness Test No. 1 Sample A

Type F Grade 4

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	1	0.70	0.01
1/2-3/8 inch	14	1.92	0.27
3/8 inch-No. 4	76	1.50	1.14
No. 4-No. 8	5	2.70	<u>0.14</u>
		Total Loss-----	1.56

Type F Grade 3

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	12	0.70	0.08
1/2-3/8 inch	22	1.92	0.42
3/8 inch-No. 4	55	1.50	0.83
No. 4-No. 8	5	2.70	<u>0.14</u>
		Total Loss-----	1.47

Soundness Test No. 1 Sample B

Type F Grade 4

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	1	0.60	0.01
1/2-3/8 inch	14	0.99	0.14
3/8 inch-No. 4	76	1.37	1.04
No. 4-No. 8	5	4.40	<u>0.22</u>
		Total Loss-----	1.41

Type F Grade 3

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
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TABLE IX

Soundness Test No. 2 Sample A

Type F Grade 4

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	1	1.00	0.01
1/2-3/8 inch	14	1.20	0.17
3/8 inch-No. 4	76	1.63	1.24
No. 4-No. 8	5	2.50	<u>0.13</u>
Total Loss-----			1.55

Type F Grade 3

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	12	1.00	0.12
1/2-3/8 inch	22	1.20	0.26
3/8 inch-No. 4	55	1.63	0.90
No. 4-No. 8	5	2.50	<u>0.13</u>
Total Loss-----			1.41

Soundness Test No. 2 Sample B

Type F Grade 4

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	1	0.50	0.01
1/2-3/8 inch	14	0.90	0.13
3/8 inch-No. 4	76	1.17	0.89
No. 4-No. 8	5	4.50	<u>0.23</u>
Total Loss-----			1.26

Type F Grade 3

<u>Sieve Size</u>	<u>Grading Orig. Sample</u>	<u>Actual Loss, %</u>	<u>Weighted Loss, %</u>
5/8-1/2 inch	12	0.50	0.06
1/2-3/8 inch	22	0.90	0.20
3/8 inch-No. 4	55	1.17	0.64
No. 4-No. 8	5	4.50	<u>0.23</u>
Total Loss-----			1.13

FIELD-PERFORMANCE OF SEAL COATS

Although there are many control problems associated with the study of actual field samples, few studies of highway materials are considered complete without going to the field and observing performances of the material in service. In this study of the comparative merits of lightweight and precoated dense rock aggregates a rather comprehensive field evaluation program was carried out.

Data collected from the field were obtained through the District Engineers of those districts in which lightweight aggregates were used as coverstone for seal coats constructed in 1963 and 1964. One exception to this occurred in the Abilene District where an experimental section using lightweight was constructed in 1962. All other seal coat jobs from which field samples were taken were constructed by contractors who followed the normal procedure of bidding from a set of plans and specifications.

Where it was practical, arrangements were made with the contractor through the Texas Highway Department supervising personnel for incorporating selected design and construction variables in limited sections of several different jobs. However, for most of the sections which were sampled and tested, no changes were made in the plans or construction procedures. The roads were simply sampled at selected spots and field observations and records were made. Numerous photographs were also taken.

Because several different districts were involved and because of the wide variations in original road condition and level of service, a number of variables in design, construction and service were naturally incorporated into the study.

Field Variables

An idealized simplification of all the problems associated with seal coat design and specifications would be the availability of a single adhesive and a single companion coverstone that could be universally and successfully used in fixed amounts on any and all road surfaces. No such materials are economically available today; therefore, in the design and construction of seal coats the engineer is faced with a number of variables and he should take into account as many of these as is economically practical. The more important of the variables are included in the following list.

1. Existing condition of the road.

2. The amount of traffic handled.
3. Construction procedures and controls.
4. Whether the road is urban or rural.
5. Horizontal and vertical alignment.
6. Weather conditions during construction and immediately thereafter.
7. Climate of the area.

A detailed discussion of these factors is beyond the scope of this report; however, some of these factors will be considered in a limited way as they bear upon this study. It should be pointed out that the above list of variables is encountered in all seal coat work regardless of the type of cover aggregate used; however, the magnitude of the effect of the different factors may change somewhat for different combinations of materials.

Field Test Sections

For any selected test section, it would possible be prior agreement with the contractor and the Texas Highway Department to vary, within reasonable limits, the application rates of the asphalt cement and/or coverstone and the type and amount of rolling. The first three sections for study were selected in District 25 in Foard County on FM 267. Construction was completed in late July 1963. Details on this road and many others are shown in Tables X and XI.

It is to be noted that for those roads listed in Table X some material application rate of construction procedure variation was included in each of the different sections. These sections varied in length from 1220 to 2250 feet with these lengths being set by construction procedures and not by design.

The roads listed in Table XI do not incorporate any variables other than those normally produced by construction procedures. They were selected at random for field sampling, observation and analysis and will be more fully described in the sections to follow.

Field samples were taken from a point beginning 30 inches from the outside edge of the pavement and included a section two feet square. As a general rule this meant that the sample come from an area falling in the outside wheel path of a two-lane pavement.

Two different methods were used in taking these samples and these are shown in Figure 40 and 41. Sawing the sample is the preferred method; however, equipment of this type is not always readily available. In taking road samples of this type with an ax and grubbing hoe as shown in Figure 41, care must be exercised to prevent damage to the coverstone within the bounds of the area to be analyzed. It is, however, not recommended that one use an ax and a sledge hammer due to the hazards involved.

After the samples were taken from the roadway surface, they were transported in bags to the laboratory for evaluating.

The precoated surfaces were treated in a different manner from the lightweight aggregate samples. The precoated coverstone was removed stone by stone from the sampled area with the aid of heat and tongs. That is, the surface was heated to soften the asphalt and then the stones were plucked from the surface and placed in a pan of solvent for cleaning and further analysis. The lightweight material, on the other hand, was subjected to an entirely different recovery procedure.

Solvent was used to slake the lightweight coverstone from the field samples; however, it was found that in this slaking process some of the previously placed material, an old seal, surface treatment or hot-mix, would be removed with the lightweight aggregate. It was found necessary to go to heavy media (20) separation as a means of separating the lightweight aggregate, since sieve analysis was used to analyze for changes in grading caused by construction and/or traffic.

A flow diagram of the heavy media separation procedure used in this study is shown in Figure 42. The samples, after slaking, were cleaned essentially free of asphalt and then air dried preparatory to heavy media separation. These samples were then placed in a large beaker containing a mixture of carbon tetrachloride and acetylene tetrabromide. By trial-and-error adjustment of the specific gravity of this mixture, satisfactory separation of the lightweight material could be effected. It will be noticed from the flow diagram that the materials were separated into different sizes. This was a necessary expediency since the specific gravity of the lightweight material increased somewhat with decreasing particle size. An acid wash of the fine material was used to remove some of the very fine particles of limestone material. All fractions were visually examined after separation to assure that the recovered material was all lightweight aggregate. In some cases it was necessary to visually inspect and hand separate "foreign material" from the lightweight stone. The entire procedure was much more tedious and time consuming than was anticipated. Nevertheless, it was possible to make a satisfactory separation of the lightweight material from the contaminated composite.

TABLE X

Designated Precoat and Lightweight Aggregate Field Test Sections

<u>Highway</u>	<u>County & District</u>	<u>Length of Sec. ft.</u>	<u>Coverstone Type & Grade</u>	<u>Rolling Hrs. per Mi.</u>	<u>Asphalt Gals. per S.Y.</u>	<u>Coverstone C.Y. per S.Y.</u>	<u>Traffic vpd</u>
FM 267	Foard-25	2250	F-4	Steel-15	0.30	1-105	150
FM 267	Foard-25	2250	F-4	Pnu-12	0.30	1-105	150
FM 267	Foard-25	1640	F-4	Pnu-12	0.36	1-105	150
FM 1192	Johnson-2	1680	F-3	Pnu-4	0.29	1-105	100
FM 1192	Johnson-2	1560	F-3	Steel & Pnu-5	0.30	1-130	100
FM 1192	Johnson-2	2100	F-3	Steel & Pnu-5	0.28	1-105	100
FM 1192	Johnson-2	1680	F-3	Steel & Pnu-5	0.29	1-105	100
FM 1192	Johnson-2	1920	F-3	Pnu-5	0.28	1-120	100
FM 1715	Erath-2	1980	F-4	Steel-1 Pnu-4	0.29	1-110	150
FM 1715	Erath-2	1980	F-4	Pnu-4	0.28	1-110	150
FM 1715	Erath-2	1980	F-4	Steel-1 Pnu-4	0.27	1-110	150
FM 1715	Erath-2	1980	F-4	Pnu-4	0.28	1-110	150
FM 1715	Erath-2	1980	F-4	Steel-1 Pnu-4	0.32	1-110	150
FM 1715	Erath-2	1980	F-4	Pnu-4	0.32	1-1	150

<u>Highway</u>	<u>County & District</u>	<u>Length of Sec. ft.</u>	<u>Coverstone Type & Grade</u>	<u>Rolling Hrs. per Mi.</u>	<u>Asphalt Gals. per S.Y.</u>	<u>Coverstone C.Y. per S.Y.</u>	<u>Traffic vpd</u>
FM 1884	Parker-2	19 80	PB-4	Steel-1 Pnu-4	0.29	1-110	100
FM 1884	Parker-2	19 80	PB-4	Steel-1 Pnu-4	0.27	1-110	100
FM 1884	Parker-2	19 80	PB-4	Pnu-4	0.25	1-110	100
FM 1884	Parker-2	1220	PB-4	Pnu-4	0.25	1-110N 1-125S	100



FIGURE 50 Stockpile and loading operation of Type F material.

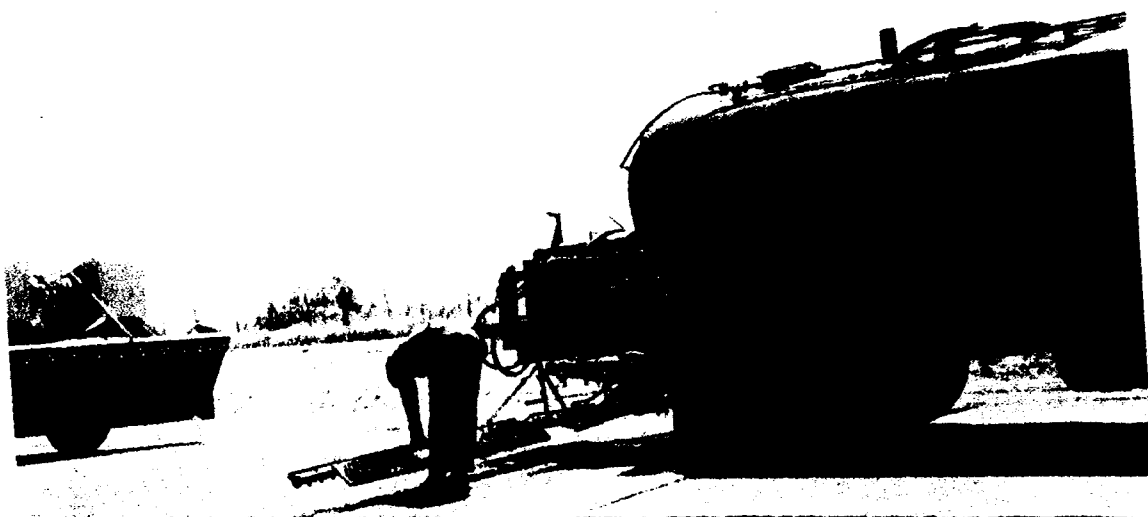


FIGURE 51 Distributor operator placing wind guard on spray bar.



FIGURE 52 Patches create variations in asphalt demand of surface.



FIGURE 53 Experimental section proves that the use of steel flat wheel roller is not advisable.



FIGURE 54 Type F material after one year of light traffic.



FIGURE 55 Type F material presents a pleasing contrast for center stripe.



FIGURE 56 No center stripe concentrates traffic in center third of FM 1192. (Photo by Gustafson.)

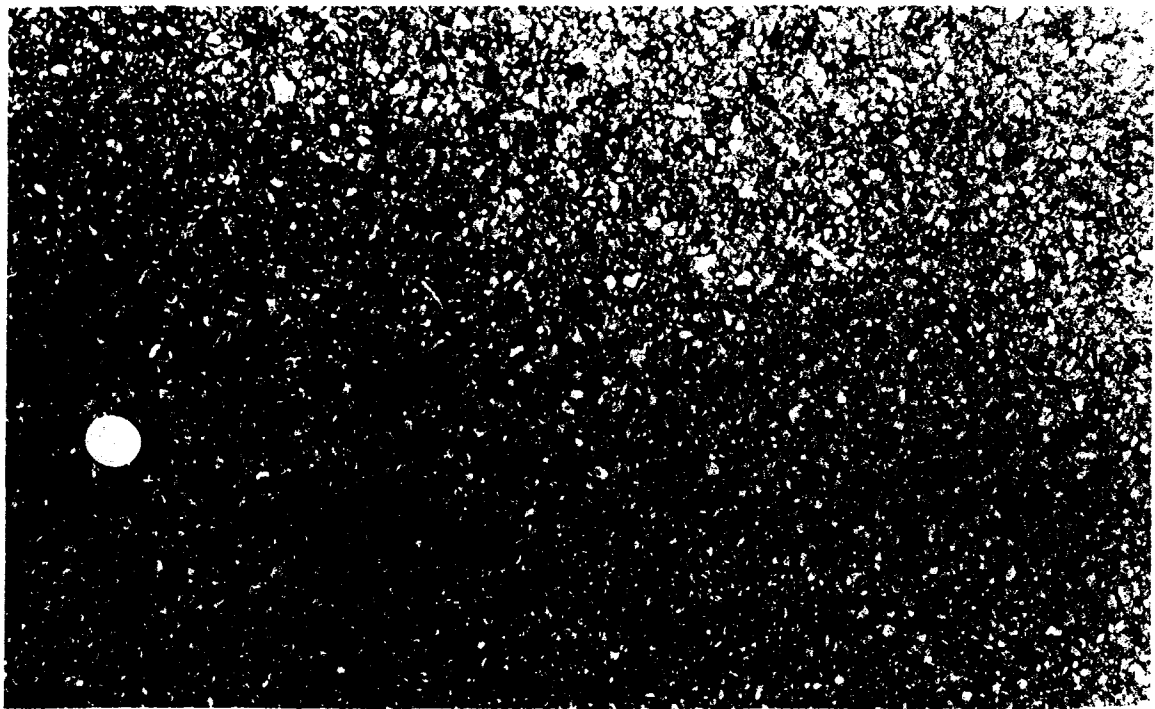


FIGURE 57 Close-up of center third of above road. Surface not flushed. (Photo by Gustafson.)



FIGURE 58 Typical farm-to-market road surfaced with Type F material. (Photo by Gustafson.)

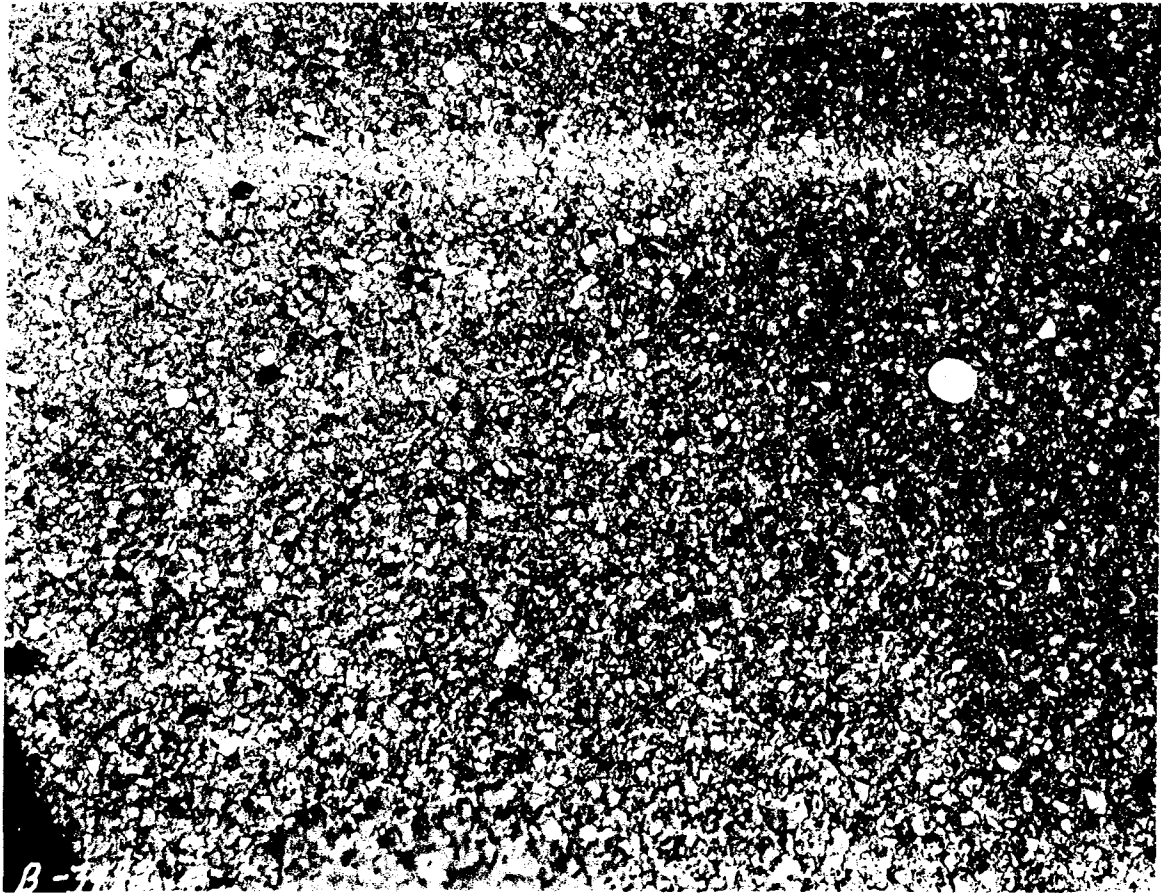


FIGURE 59 Type F Grade 4 coverstone three months after construction FM 744. (Photo by Gustafson.)

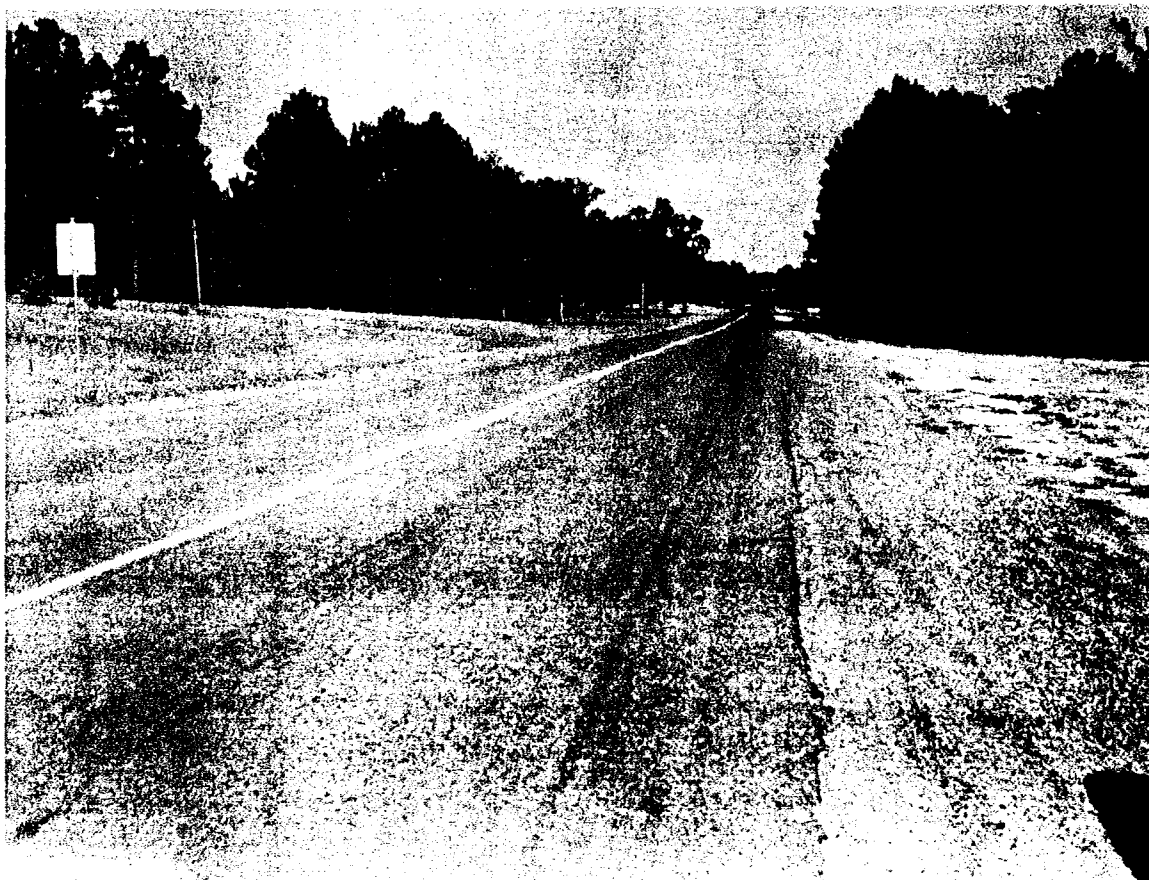


FIGURE 60 Type F cover aggregate in service three months,
1500 vpd, U S 190. (Photo by Gustafson.)



FIGURE 61 Blade broom successfully used on Type F coverstone. (Photo by Gustafson.)

FM 1192 in Johnson County was constructed with Type F cover aggregate and presents somewhat similar conditions in Figures 56 and 57. This pavement, however, will not give any trouble, mainly due to a low traffic volume of about 100 vpd. An interesting factor exists in Figure 56. Notice the center third of the road is darkened by asphalt being near the surface. The road has no center stripe and the traffic tends to ride near the center of the road. Horizontal curves accentuate this tendency; so, if a surface bleeds, this bleeding will often start at or be more severe in the curves. Not be neglected as an added factor is the kneading action of the vehicular compaction on curves and the possible difference in distributor performance.

A general view of FM 1603 in Navarro County appears in Figure 58. This picture of a Type F coverstone job was taken six weeks after construction. A close-up, Figure 59, taken on FM 744 in Navarro County shows the excellent uniform surface made with Type F grade 4 material. A view of U. S. 190 in Polk County shows Type F material in service for three months and carrying 1500 vpd. This is Figure 60.

The use of a blade broom is shown in Figure 61. This picture was taken during construction on FM 1192 in Johnson County where Type F Grade 3 material was used. A close-up of this sample surface appears in Figure 62. Note the good adhesion. Also on FM 1192 one experimental section used Grade 3 stone at the rate of 130 square yards per cubic yard. A close-up of this section is shown in Figure 63. The coverage is adequate. Inspection of this section the following day revealed no loose stones. It is true that a little asphalt may be seen through the voids in the stone but this is only evidence of the proper distribution rate or the stone being used.

Shown in Figure 64 is an experimental section of hot-mix asphaltic concrete made with burned clay and field sand as the aggregates. This is a section of SH 6 in Ft. Bend County constructed in August of 1963. The hot-mix was placed on a flexible base made with burned clay and sandy clay binder. Limited laboratory tests on the hot-mix from this section indicated that the surface course mix has limited fatigue life. The compacted mix was high in voids and had low flexural strength. A short life is predicted for the surface.



FIGURE 62 Adhesion of asphalt to Type F material is very good.



FIGURE 63 Type F Grade 3 after brooming. Spread rate --
130 square yards per cubic yard. (Photo by
Gustafson.)

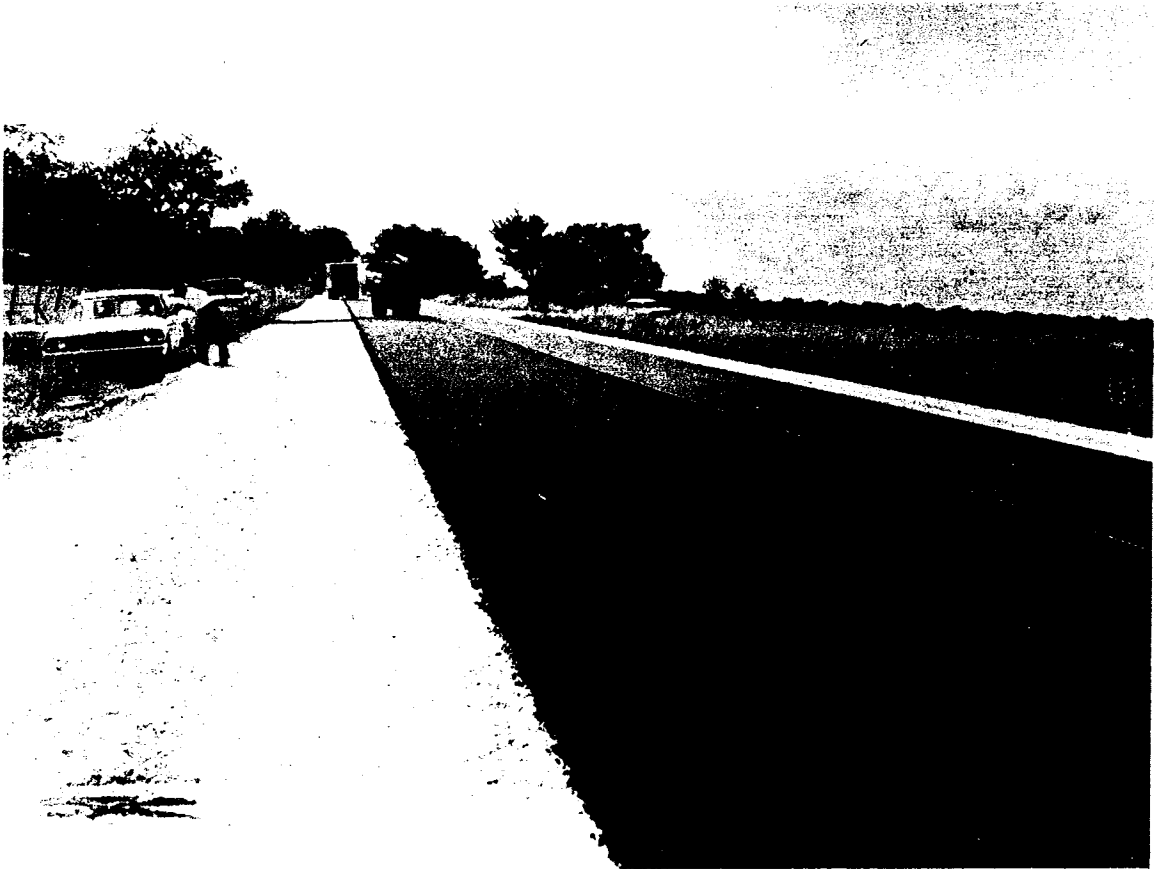


FIGURE 64 Hot-mix with burned clay aggregate placed on
SH 6. (Photo by Gustafson.)

REFERENCES

1. _____, 1961 Book of ASTM Standards Including Tentatives, Part 4, American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pennsylvania, 1961.
2. Haun, R. P., "Tar and Feather Highways," Texas Highways, Vol. 10, No. 3, p. 7, April, 1963.
3. Mueller, J. I., Riley, R. P., Shapero, H. L., "Lightweight Aggregate from Pacific Northwest Clays and Shales," The Trend in Engineering, University of Washington, Volume 5, No. 2, p. 5-9, April, 1953.
4. Marslender, W. H., Featherlite Corporation, Ranger, Texas, (Private Communication).
5. Riley, C. M., "Relation of Chemical Properties of the Bloating of Clays," Journal American Cer. Soc., Volume 34, No. 4, pp. 121-128, April, 1951.
6. Bauer, W. G., "Mechanics, Techniques and Economics of Expanded Clay-Shale Aggregate Production," Pit and Quarry, Volume 41, No. 1, pp. 71-73, July, 1948, No. 3, pp. 93-96, September, 1948, No. 6, pp. 91-95, December, 1948, No. 12, pp. 87-89, June, 1949.
7. _____, "Standard Specifications for Road and Bridge Construction," Adopted by the State Highway Department of Texas, Items 302 and 304, pp. 207-216, January 2, 1962.
8. Woolf, D. O., "The Relation Between Los Angeles Abrasion Test Results and the Service Records of Coarse Aggregate," Highway Research Board Proceedings, Vol. 17, pp. 350-359, 1937.
9. Kearby, J. P. "Thoughts and Theories on Penetration Surfaces," Texas Highway Department Construction and Maintenance Bulletin No. 11, pp. 43-65, 1952.
10. Benson, F. J., Gallaway, B. M., "Retention of Coverstone by Asphalt Surface Treatment," Texas Engineering Experiment Station Bulletin 133, September, 1953.
11. Hank, R. J., Brown, M., "Aggregate Retention Studies of Seal Coats," Proceedings, Association of Asphalt Paving Technologists, Volume 18, pp. 261-272, 1949.

12. Richart, F. E. Jenses, V. P., "Tests of Plain and Reinforced Concrete Made With Haydite Aggregates," Engineering Experiment Station, University of Illinois, Bulletin No. 237, October, 1931.
13. Downey, G. L., "The Mechanics of Stone Damage to Automobile Windshields," Highway Research Board Abstracts, Volume 27, No. 4, pp. 29-32, April, 1957.
14. Buckley, F. T., Nelson, J. S., Monsanto Company, Research Department, Plastics Division, Springfield, Massachusetts, (Private Communication dated September, 1963).
15. Bowen, G., Hamblet, C. H., "Du Pont Research on the Safety Performance of Tempered Glass," October, 1957 (Private Communication).
16. Rushing, H. B., "Lightweight Aggregate Abrasion Study," Research Project 61-7C, HPS 1 (18) U. S. Department of Commerce, Bureau of Public Roads and Louisiana Department of Highway, February, 1963.
17. Standard Specifications for Highway Materials and Methods of Sampling and Testing, Part II. Adopted by the American Association of State Highway Officials, Eighth Edition, 1961.
18. _____, "Manual of Testing Procedures," of the Texas Highway Department, Volumes 1 and 2, Revised February, 1963.
19. Woolf, D. O., "Toughness, Hardness, Abrasion, Strength and Elastic Properties," American Society for Testing and Materials, Special Technical Publication No. 169, p. 314-324, 1956.
20. Higgenson, E. C. and Wallace, G. B., "Control Testing for Separation of Lightweight Material from Aggregate," ASTM Bulletin, (TP15), No. 243, pp. 60-68, January, 1960.

TEXAS HIGHWAY DEPARTMENT

SPECIAL SPECIFICATION

Item 1269

AGGREGATE FOR SURFACE TREATMENTS

(LIGHTWEIGHT)

1. DESCRIPTION. This item establishes the requirements for lightweight aggregates to be used in the construction of surface treatments.

2. MATERIALS. Aggregates shall be composed predominately of lightweight cellular and granular inorganic material prepared by expanding, calcining, or sintering products such as clay or shale.

The aggregate shall contain not more than 1 percent of organic matter, impurities or objectionable matter when tested in accordance with Test Method Tex-217-F.

The dry loose unit weight of course lightweight aggregates shall not be less than 40 and shall not exceed 60 pounds per cubic foot. If the unit weight of any shipment of lightweight aggregate differs by more than 6 percent from that of the sample submitted for acceptance test, the aggregates in the shipment may be rejected. Tests shall be in accordance with Test Method Tex-404-A, except that the aggregate shall be tested in an oven-dry condition. The percent of wear, as determined by Test Method Tex-410-A (Part II), shall not exceed 35 percent.

The aggregate, when tested in accordance with Test Method Tex-411-A, shall show a loss of not more than 12 percent after five cycles of the sodium sulfate soundness test or 18 percent after five cycles of the magnesium sulfate soundness test.

3. GRADES. When tested by Test Method Tex-200-F, the gradation requirements for the several grades of aggregate shall be as follows:

	Percent by Weight
Grade 1: Retained on 1" sieve	0
Retained on 7/8" sieve	0-2
Retained on 5/8" sieve	15-45
Retained on 3/8" sieve	85-100
Retained on No. 4 sieve	95-100
Retained on No. 10 sieve	98-100

TABLE X 1

Undersignated Precoat and Lightweight Aggregate Field Test Sections

<u>Highway</u>	<u>County & District</u>	<u>Date of Construction</u>	<u>Coverstone Type & Grade</u>	<u>Rolling Hrs. per Mi.</u>	<u>Asphalt Gals. per S.Y.</u>	<u>Coverstone C.Y. per S.Y.</u>	<u>Traffic vpd</u>
SH 352	Dallas-18	6-4-63	F-4	Pnu 3.9	0.28	1-127	1390
FM 55	Ellis-18	5-29-63	F-4	Pnu 3.1	0.27	1-125	370
FM 987	Kaufman-18	6-3-63	F-4	Pnu 4.6	0.27	1-125	870
FM 1390	Kaufman-18	5-31-63	F-4	Pnu 3.7	0.27	1-125	160
FM 1603	Navarro-18	5-29-63	F-4	Pnu 4.7	0.28	1-125	310
FM 1838	Navarro-18	5-27-63	F-4	Pnu 4.1 Steel 0.4	0.28	1-130	280
FM 740	Rockwall-18	6-4-63	F-4	Pnu 3.4	0.28	1-127	370
FM 548	Rockwall-18	6-7-63	F-4	Pnu 4.0	0.27	1-127	420
SH 78	Collin-18	7-23-63	PB-4	Pnu 3.8 Steel 1.6	0.23	1-124	790
FM 540	Collin-18	7-24-63	PB-4	Pnu 3.2 Steel 1.4	0.23	1-125	1230
FM 2478	Collin-18	7-31-63	PB-4	Pnu 3.9 Steel 1.4	0.23	1-123	430
FM 156	Denton-18	8-12-63	PB-4	Pnu 4.2 Steel 1.4	0.23	1-123	1210
FM 1830	Denton-18	8-2-63	PB-4	Pnu 3.9 Steel 1.6	0.23	1-122	850

<u>Highway</u>	<u>County & District</u>	<u>Date of Construction</u>	<u>Coverstone Type & Grade</u>	<u>Rolling Hrs. per Mi.</u>	<u>Asphalt Gals. per S.Y.</u>	<u>Coverstone C.Y. per S.Y.</u>	<u>Traffic vpd</u>
US 83	Taylor-8	5-19-64	F-4M	Pnu 5	0.35	1-104	1580
SH 16	Palo Pinto-2	8-9-63	F-4	Steel 1.5 Pnu 4.5	0.31	1-110	160
FM 218	Mills-23	8-2-63	F-4	Steel 1.7 Pnu 5.0	0.29	1-110	260
FM 2731	Eastland-23	9-3-63	F-4	Steel 2.5 Pnu 2.5	0.35	1-90	100
FM 570	Eastland-23	7-27-63	F-4	Steel 1.7 Pnu 5.0	0.27	1-100	710
SH 6	Eastland-23	7-29-63	F-4	Steel 1.7 Pnu 5.0	0.27	1-100	710
FM 2214	Eastland-23	5-10-61	F-3 F-4	Steel 4.2 Steel 4.2	0.32 0.25	1-100 1-120	500
FM 2689	Eastland-23	4-17-62	F-3 F-5	Steel 4.6 Steel 4.6	0.31 0.37	1-90 1-120	200
IH 20	Taylor-8	---62	F-3	Pnu 5.0	0.30	1-100	7700
FM 572	Mills-23	8-7-63	F-4	Steel 1.7 Pnu 5.0	0.30	1-100	250



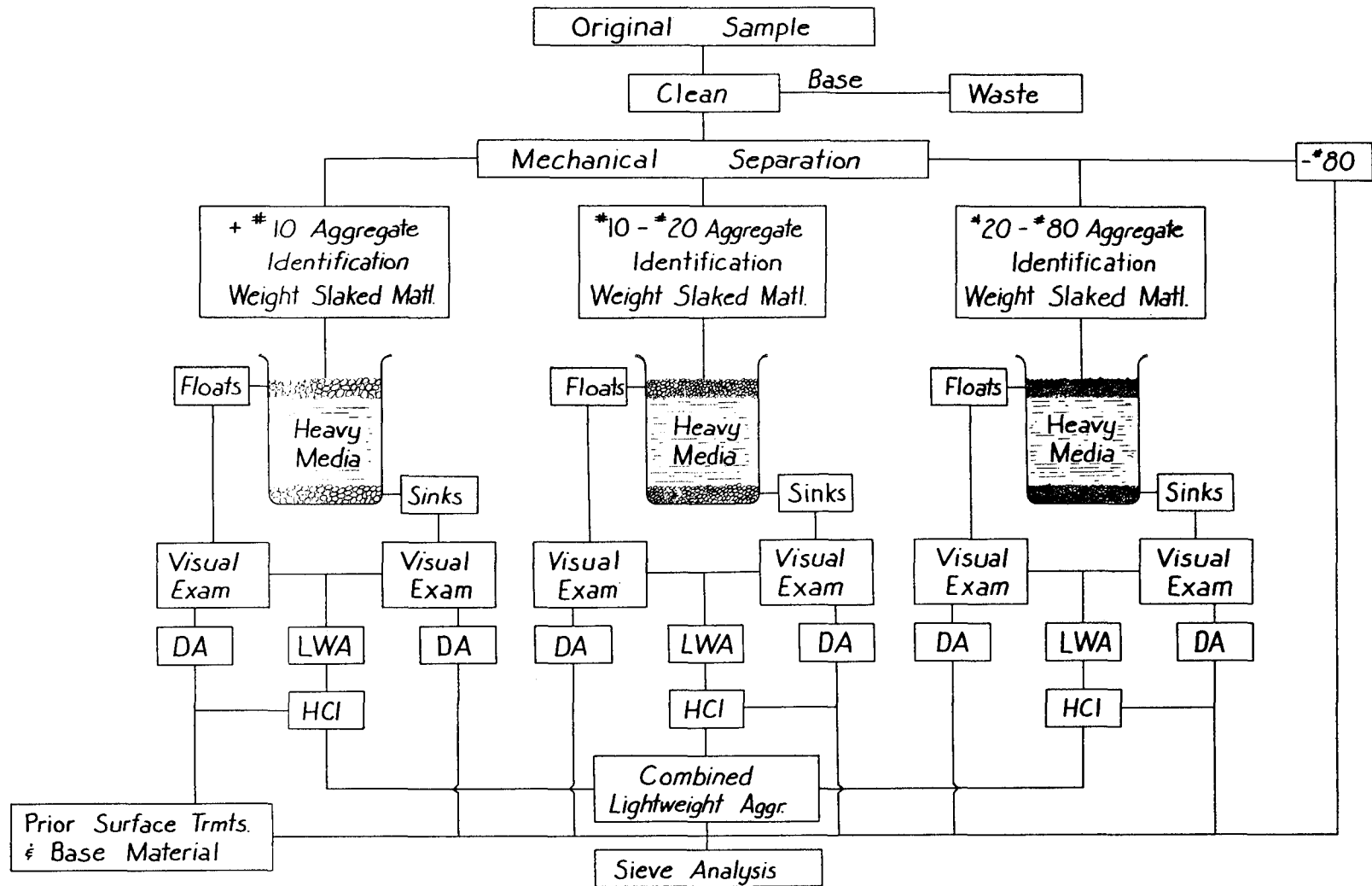
FIGURE 40 Cutting a field sample with a portable saw.



FIGURE 41 Cutting a field sample with an ax.

FLOW DIAGRAM

LIGHTWEIGHT STUDY



LEGEND: LWA — Lightweight Aggregate DA — Dense Aggregate

FIGURE 42 Flow diagram for heavy media separation of lightweight aggregates from field samples.

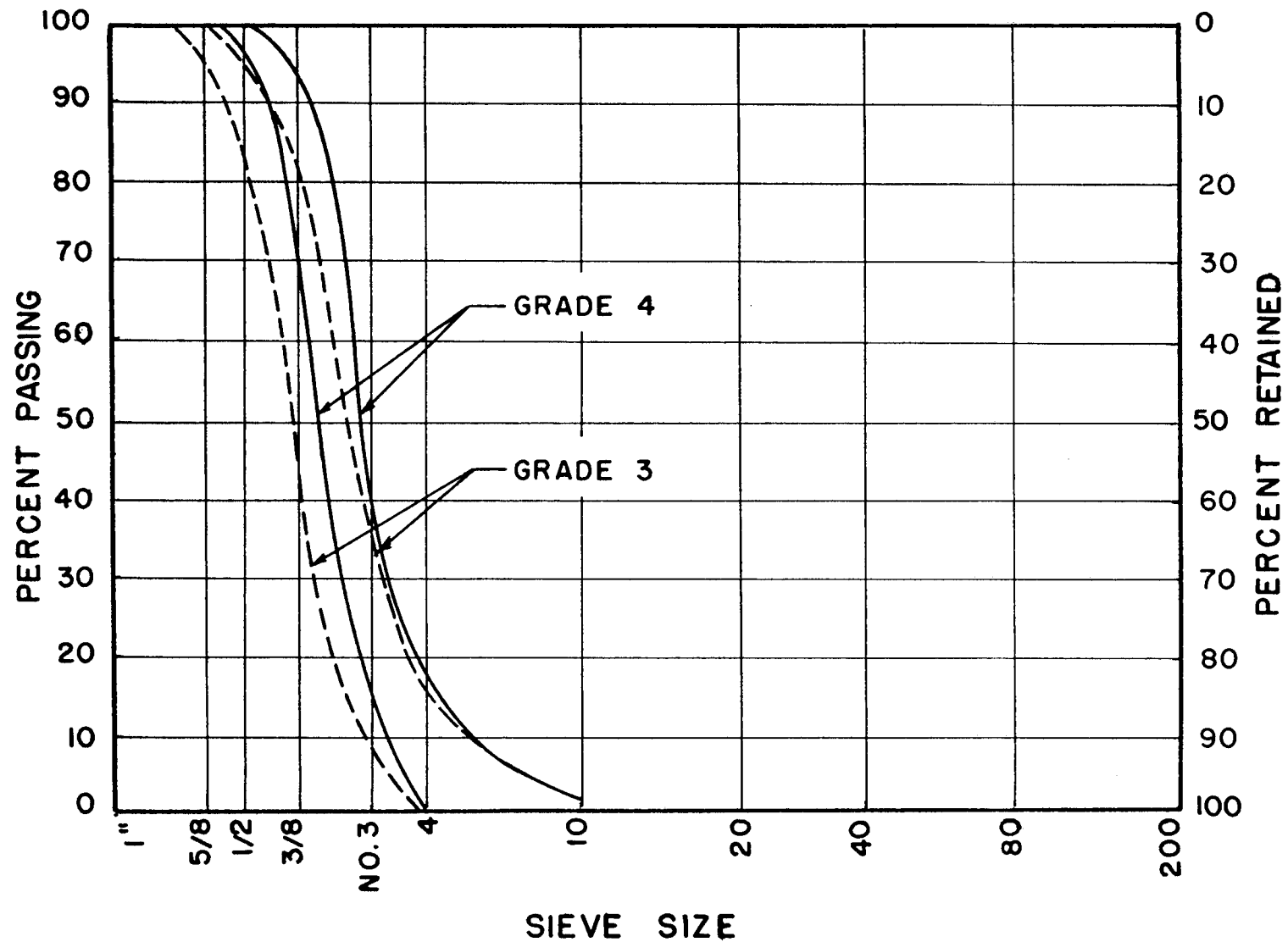


FIGURE 43 GRADATION REQUIREMENTS OF THD
ITEM 302 COVERSTONE, GRADES 3 & 4

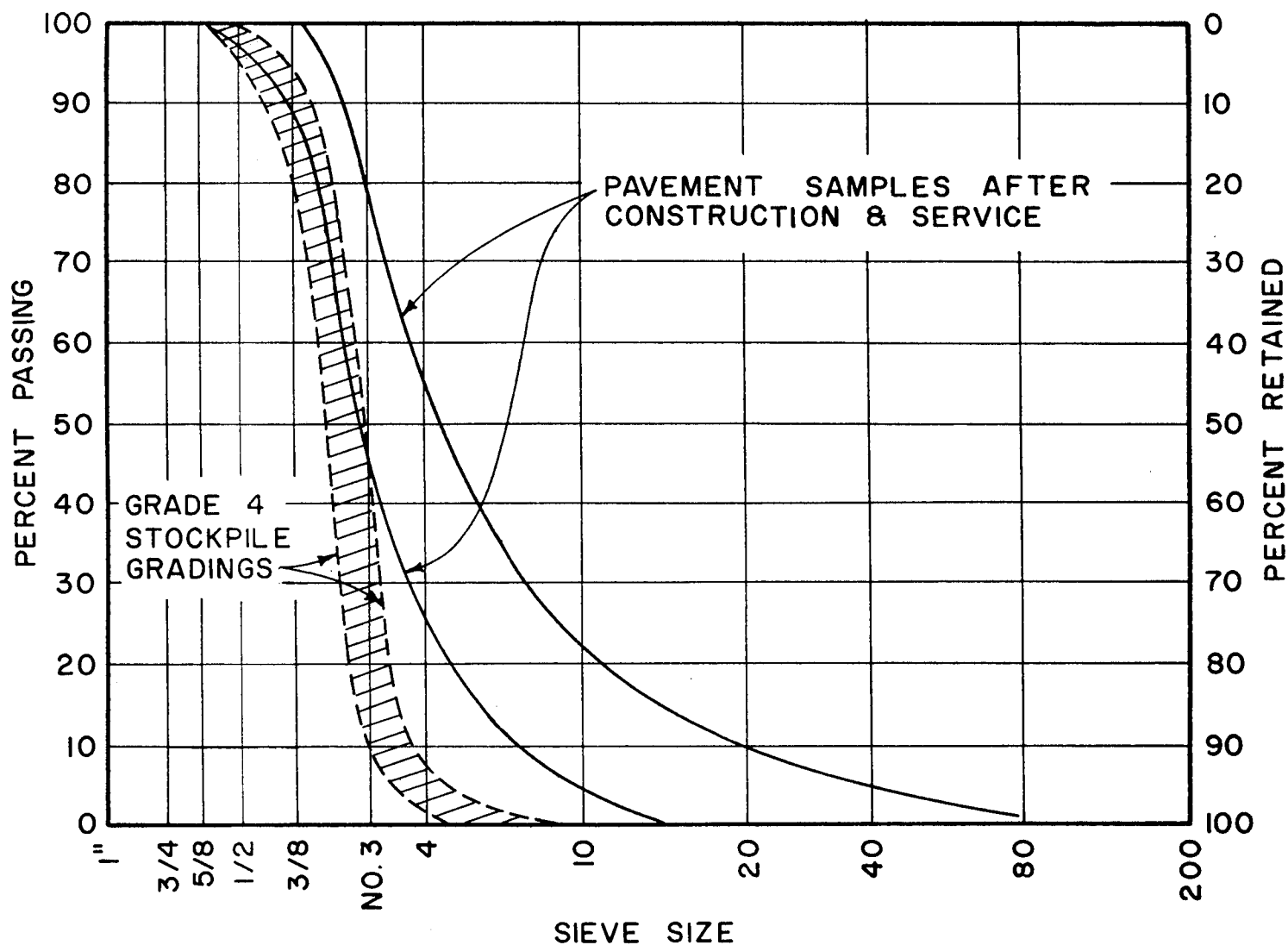


FIGURE 44 COMPARATIVE DEGRADATION OF LIGHT-WEIGHT AGGREGATE DUE TO CONSTRUCTION AND SERVICE

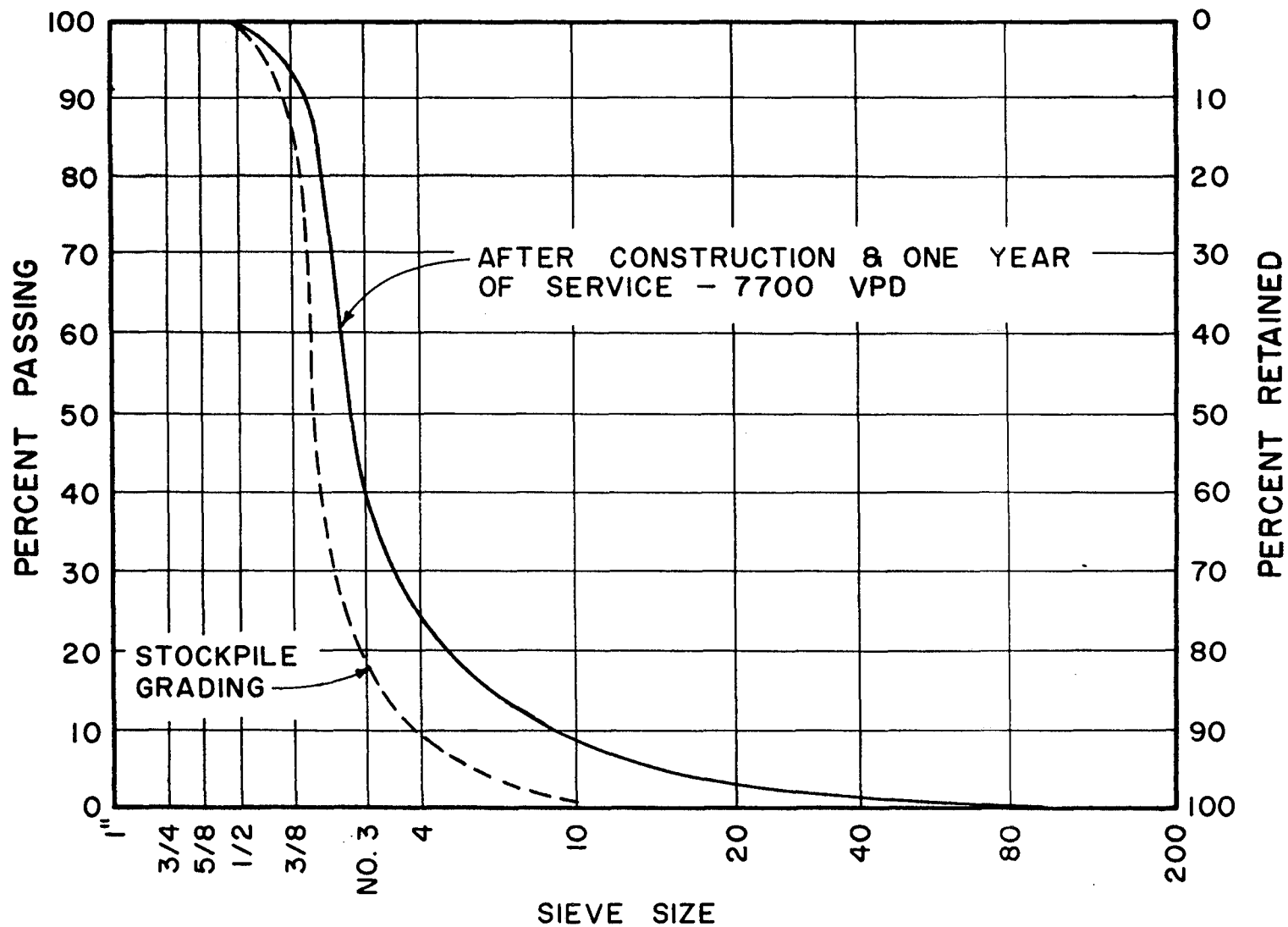


FIGURE 45 TIME AND LEVEL OF SERVICE A MINOR FACTOR IN DEGRADATION OF TYPE F COVERSTONE

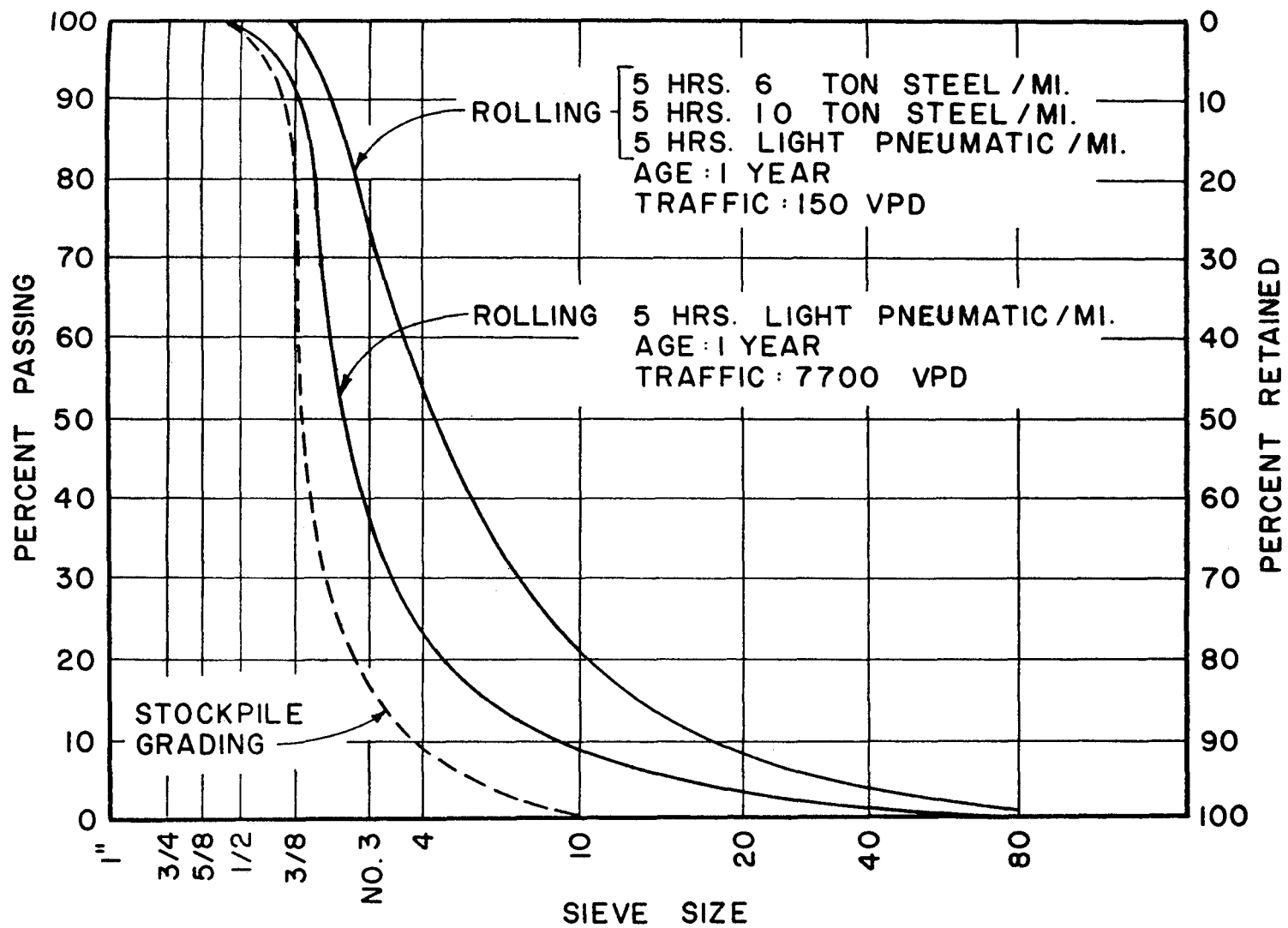


FIGURE 46 DEGRADATION OF TYPE F AGGREGATE
DUE TO CONSTRUCTION AND SERVICE

Following the cleaning and separating procedures the individual fractions were recombined and analyzed for grading to determine the extent of degradation.

Specification requirements for grading of the various sizes of coverstone under THD Item 302 are shown in Appendix A. Specification grading curves for Grades 3 and 4 are shown in Figure 43. The range in the grading of typical field stockpile samples of Grade 4 stone is shown in Figure 44. It is evident from this figure that the grading of this material does not vary appreciably from sample to sample and further that most of the material passes the 3/8-inch sieve and is retained on the No. 4 sieve. Similar analyses on the Grade 3 aggregates showed that it was predominately 1/2-inch to No. 4 material.

The extent of degradation caused by construction is graphically shown in Figure 44. Field samples of these same materials were taken from the road surface and recovered according to the flow diagram of Figure 42. The grading of these pavement samples fell within the bounds indicated on Figure 44.

The data showed that time in service was not a significant factor in changing the grading of the cover material. It was also observed that there was no major difference in the "after-construction" grading of Grade 3 and Grade 4 Type F material. Some discussion of these two points is in order and shall be included. The majority of the field samples giving dependable data had not been in service more than four to six months when the samples were taken. Two of the test areas under study included double surface treatments one of which was two years old but the nature of the base and type of construction of these jobs differ to such an extent that data from these samples are of questionable value. However, the road sample from I. H. 20 at the western city limits of Abilene tells a clear story. The "before and after" gradings of the lightweight material that went into this surface are shown in Figure 45. By comparing the "after" curve with the range of "after" gradings shown in Figure 44, it is evident that heavy traffic (7700 vpd), had a very minor effect on the material. It is further pointed out that only pneumatic rollers were used for rolling the Abilene sample during construction.

The data presented in Figure 46 clearly indicate that the type and amount of construction rolling has a decided effect on the degradation of the coverstone. Admittedly this is no new finding but proper rolling of lightweight (Type F) aggregates is quite important and further it is evident from these data that if additional fines were desired, these fines can be produced on the road surface during construction. It must be pointed out that it seems foolish, however, to specify a uniform graded material provided at extra cost and then

unnecessarily degrade this same material at additional cost to a net disadvantage in both service and cost.

The data clearly show that the Type F cover aggregate under study is highly suitable for seal coat and surface treatment work when the job is properly designed and constructed. Based on the service records to date traffic density appears to have a very minor effect on this material as measured by degradation of aggregate recovered from the road surface.

Comparative data on the construction degradation of precoated limestone are shown in Figure 47. It is to be noted from this figure that there is some crushing of the cover material during construction but it is not quite as severe as that for the Type F material subjected to similar rolling equipment. None of the precoated material under study was subjected to the severe steel flat wheel rolling used on some of the test sections involving Type F material so precise comparisons are not made. The range of values for the two materials (shown in Figure 43 and 44) overlap but this, of course, incorporates a number of variables that have their individual effects on the grading of a given material.

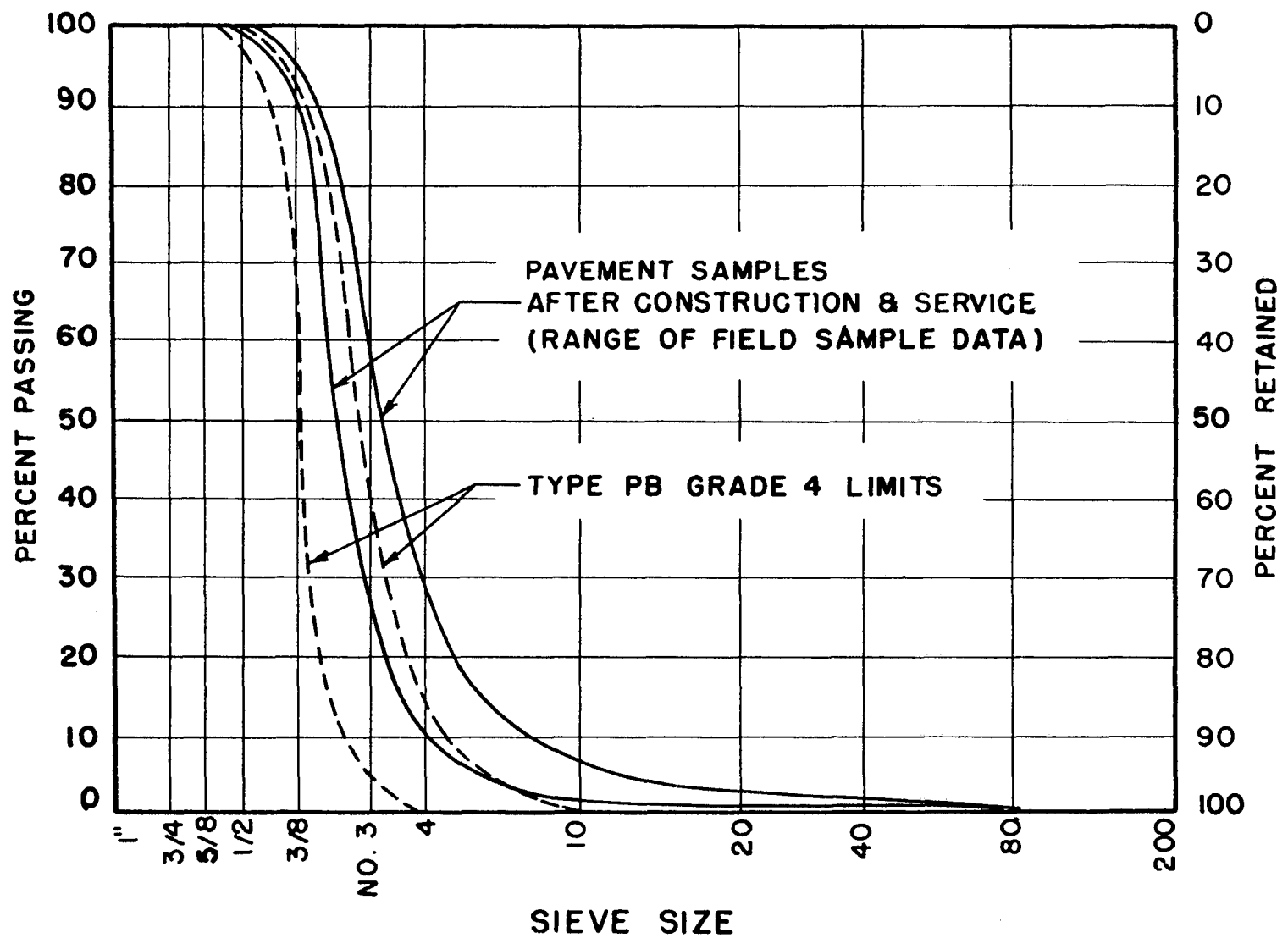


FIGURE 47 COMPARATIVE DEGRADATION OF PRECOATED LIMESTONE DUE TO CONSTRUCTION AND SERVICE

PICTORIAL DATA OF CONSTRUCTION AND FINISHED PAVEMENTS

In order that the reader may get a better picture of the construction operations and service performance of the materials under discussion, a pictorial review of selected projects is presented in the following pages. Where it is necessary to amplify on the photographic data, appropriate discussions will be included.

One of the first experimental lightweight aggregate seal coat jobs in the state is shown in Figure 48. This surface is two years old and carries 7700 vpd. A close-up of this surface is shown in Figure 49. It is clearly evident that the heavy traffic carried by this pavement has caused no noticeable wear on the surface aggregate.

A series of pictures was made on FM 267 in Foard County covering a one-year time interval. Figure 50 shows that roadside stockpile of Type F material and the contractor's loading operation. In Figure 51 the use of a wind guard on the spray bar of the distributor is shown; also to be noted is the use of paper at the construction joint. This minimizes overlap. To the left in this same picture is a self-propelled aggregate spreader ready to apply the coverstone immediately behind the asphalt distributor.

Two items of interest appear in Figure 52 where the asphalt cement has been applied and half of the road has been covered with Type F material. These items are the newly patched area at the left edge of the pavement and the striations in the asphalted surface. Striations are caused by poor distribution of asphalt and probably in this case they occurred in a previous application creating a difference in the asphalt absorption demand across the surface. Reasonable proof of this is demonstrated by the dull appearance of the patched area. Here, due to lack of densification, the asphalt demand was high and unsatisfied. As previously mentioned this is a variable difficult to take into practical consideration. Another picture in this series is Figure 53. Here a steel roller is used to "seat the stone." Laboratory and field data strongly indicate that the steel flat wheel roller should not be used on Type F aggregate. Crushing of the aggregate was excessive here in this experimental strip. One year after FM 267 was constructed the pictures appearing as Figure 54 and 55 were taken. This was not in a designated experimental section but represents regular construction control. The excellent appearance of the surface is evident and apparently is also pleasing to the horned toad that has stopped on the highly contrasting white center stripe.



FIGURE 48 Type F seal two years old with 7700 vpd.
(Photo by Billingsley and Plumlee.)

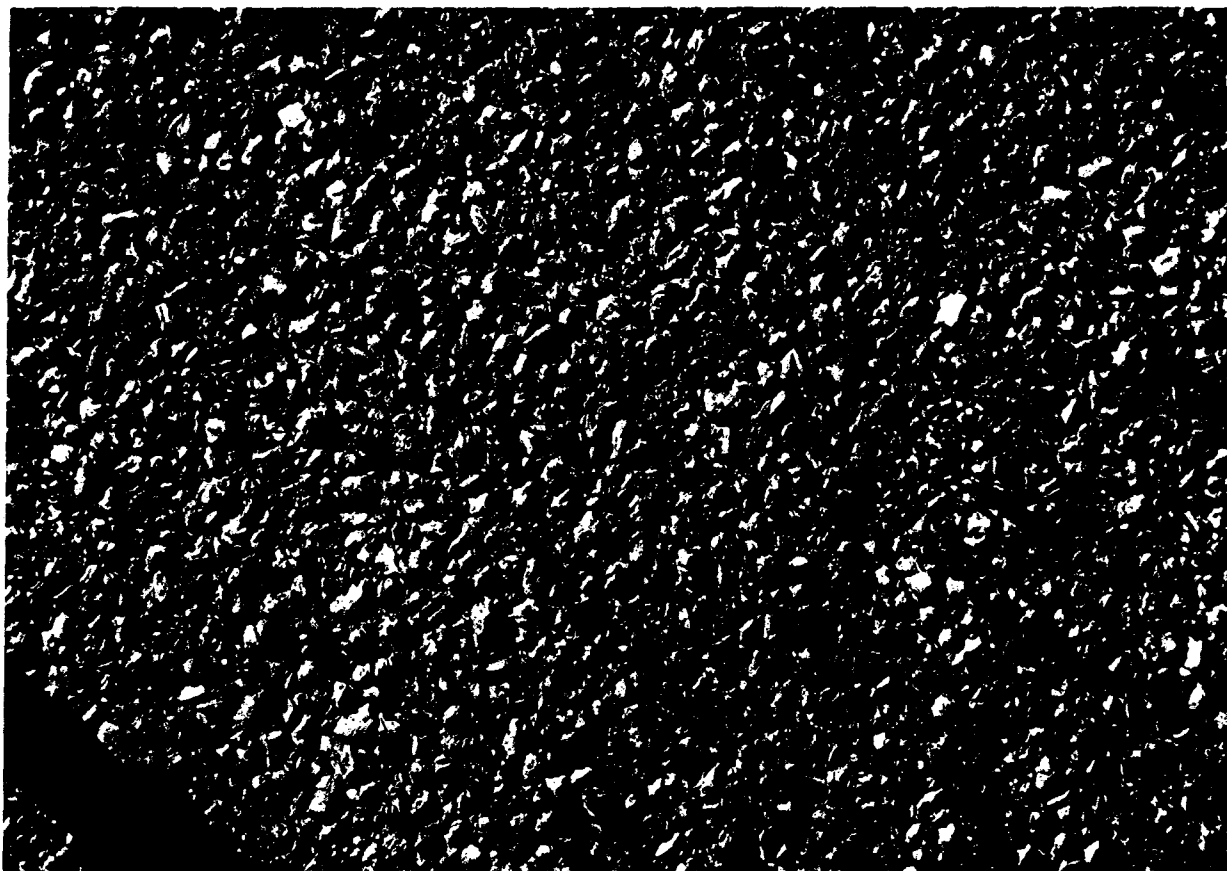


FIGURE 49 Close-ups in the wheel path showing excellent condition of Type F cover aggregate after two years' service.

Grade 2: Retained on 7/8" sieve	0
Retained on 3/4" sieve	0-2
Retained on 1/2" sieve	20-35
Retained on No. 4 sieve	85-100
Retained on No. 10 sieve	98-100

Grade 3: Retained on 3/4" sieve	0
Retained on 5/8" sieve	0-2
Retained on 1/2" sieve	5-20
Retained on No. 4 sieve	85-100
Retained on No. 10 sieve	98-100

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Grade 4: Retained on 5/8" sieve	0
Retained on 1/2" sieve	0-2
Retained on 3/8" sieve	5-25
Retained on No. 4 sieve	85-100
Retained on No. 10 sieve	98-100

Grade 5: Retained on 1/2" sieve	0
Retained on 3/8" sieve	0-2
Retained on No. 4 sieve	40-85
Retained on No. 10 sieve	98-100

Grade 6: Retained on 1/2" sieve	0
Retained on 3/8" sieve	0-2
Retained on No. 4 sieve	5-40
Retained on No. 10 sieve	70-100
Retained on No. 20 sieve	99-100

Grade 7: Retained on 1/4" sieve	0
Retained on No. 4 sieve	0-10
Retained on No. 20 sieve	25-55

Grade 8: Retained on No. 4 sieve	0
Retained on No. 10 sieve	0-10
Retained on No. 20 sieve	10-55

4. MEASUREMENT AND PAYMENT. Aggregates will be measured and paid for in accordance with the governing specifications for the items of construction in which these materials are used.

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APPENDIX A

ABRASION OF CONVENTIONAL AND LIGHTWEIGHT COARSE AGGREGATE
BY THE USE OF THE LOS ANGELES MACHINE
(Test Method Tex-410-A
Rev: November 1963)

Scope

This Test Method covers the procedure for testing conventional and lightweight coarse aggregate for resistance to abrasion in the Los Angeles testing machine with an abrasive charge. The apparatus and procedure used in this test are identical with ASTM Designation: C 131 with the exceptions noted under Part II of this method.

PART I

ABRASION OF CONVENTIONAL COARSE AGGREGATE

Procedure

Use the apparatus specified to prepare and test the required gradings of aggregate in accordance with the procedure described in ASTM Designation: C 131.

PART II

ABRASION OF LIGHTWEIGHT COARSE AGGREGATE

Procedure

To avoid the excessive volume of material in the testing machine which will occur when the lightweight aggregate sample is prepared according to ASTM Designation C 131, it is necessary to reduce the weight proportionately to obtain an equal volume of lightweight aggregate comparable to that normally obtained with a conventional aggregate sample.

The abrasive charge must also be reduced in a similar manner

1. Determine the unit weight (U_L) of the lightweight aggregate by Test Method Tex-404-A.

2. Assume an average unit weight of conventional aggregate to be 97.0 lbs. per cu. ft.
3. Reduce the lightweight aggregate sample.

$$\frac{U_L}{97.0} = \frac{X}{C}$$

$$X = \frac{(C) (U_L)}{97.0}$$

Where:

U_L = Unit weight of lightweight aggregate sample (lbs. per cu. ft.)

C = Weight of conventional aggregate required for grading in ASTM 131

X = Reduced lightweight aggregate sample charge

4. Reduce the abrasive charge:

$$\frac{U_L}{97.0} = \frac{X_L}{C_L}$$

$$X_L = \frac{(C_L) (U_L)}{97.0}$$

Where:

U_L = Unit weight of lightweight aggregate (lbs. per cu. ft.)

C_L = Weight of abrasive charge required for grading in ASTM 131

X_L = Reduced abrasive charge for lightweight aggregate

5. Remainder of procedure as set forth in ASTM 131.

NOTE:

It is sometimes impossible to obtain the exact abrasive charge with the steel balls available. In this case, obtain the closest abrasive charge possible to the reduced value and then adjust the weight of the sample in proportion to the new abrasive charge.

Reporting Test Results

Report the test data and type grading and the wear to the nearest 0.1 percent on Form No. 272.

COMMENTS ON THE HANDLING, CONSTRUCTION AND SERVICE OF LIGHTWEIGHT AGGREGATE COMPARED TO PRECOAT

The following comments represent a cross section of those received in interviews with THD personnel and contractors who used these materials in Districts 2, 8, 18, 23 and 25.

I. State and District Personnel

- A. Within its area of competitive haul, the Type F expanded shale aggregate is an important alternate to other materials because of reduction in windshield breakage alone. The material is dark in color which reduces glare and it appears to have a natural affinity for asphalt. The material is not degraded appreciably under normal surface rolling.
- B. The hard freezes during the winter of 1963 did not damage the lightweight. It performs as well as precoat and has less flying particles immediately after construction. Lightweight dusts a little but the grading is good and it is a valuable material for seal coat and surface treatment work.
- C. After two years of service we are still pleased with the performance of Type F aggregate. The color contrast produced by lightweight is maintained throughout the life of the surface whereas precoat fades out in a few months.
- D. Of all the stone available for seal coat and surface treatment I prefer the over-all characteristics of precoated rock asphalt with lightweight running a close second. The contractor's men prefer the handling ease afforded by lightweight aggregate and it bonds well to the asphalt.
- E. We had one job, a double surface treatment, (lightweight) that bled severely but this was in the early trial stages and was caused by a fault in design. We have had some trouble with variation in amount of oil used on our precoated material. However, both materials do a good job when properly designed and constructed.
- F. High speed traffic on new surfaces of lightweight does not create flying stone hazard. Loose stone is thrown but is carried only a short way from the vehicle wheel. It is not necessary to sweep loose stone back on a new surface made with lightweight. Initial adhesion is good with both precoat and lightweight.

G. Where lightweight is used the reduced gross loads of equipment during construction minimize damage to shoulders on low traffic roads.

H. Retention of lightweight aggregate is as good as that of precoated aggregate when placed under identical conditions. Lightweight aggregate is naturally dust free and has an inherent affinity for asphalt. This material has produced excellent results on high-traffic roads when placed under favorable weather conditions.

II. Resident Engineer and Contractor Personnel

A. Some dusting was experienced on one surface one to four days after construction. (This lightweight aggregate seal was rolled with steel and pneumatic rollers.) At speeds up to 60 mph some stone was thrown by traffic. Stones were airborne for a distance of 20 to 40 feet. No windshield damage was observed or reported on this lightweight aggregate section.

B. Lightweight aggregate adheres well to the asphalt. The grading is uniform and the material is clean when delivered. Due to its lightweight and good bond, it can be broomed effectively with a blade broom.

C. In-place crushing (of lightweight) helps key in the coverstone. A nonglare surface is produced.

D. The material (lightweight) is easy to handle and easy on equipment. Job progress is more rapid and laborers handling the hand touch-up work find their job easier.

E. Without special modification of hauling equipment, overloading is eliminated and this extends equipment life.

Summarizing these observation on Type F and Type PB aggregate we find:

A. Retention is comparable for like designs and service conditions.

B. Bleeding, where observed, was about the same and could not, for either material, be definitely attributed to any characteristic of the materials involved.

C. Serious raveling was encountered on one precoat job and this was attributed to improper design. Minor raveling was observed on several other sections but there was no great difference in degree of raveling for the two materials. As a general rule where minor raveling occurred this took place between the wheel paths, possibly,

indicating the need for a slight increase in asphalt application rate.

- D. Degradation during construction rolling was comparable except where the Type F material was rolled excessively with steel flat wheel rollers.
- E. General appearance of the two types of material is good. Type PB material used for contrast purposes often fades or loses color within a few months.
- F. Contractors prefer the lightweight material due to ease of handling and increased production rate of finished road surface. Wear and tear on equipment is reduced materially.
- G. No broken windshields attributable to either material were reported from any of the sections under observation.
- H. Some Engineers and Maintenance Personnel indicated a preference for the Type F material. No one contacted objected to its use and all were satisfied with its performance.