INTERIM REPORT ON THE USE OF EXPANDED SHALE AND PRECOATED LIMESTONE AS COVERSTONE FOR SEAL COATS AND SURFACE TREATMENTS

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Use of Lightweight Aggregates
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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. 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 this particular lightweight aggregate should be accepted as equal to precoated standard weight material for seal coat coverstone. For the materials under study the data show that:

1. The loose unit weight of the expanded shale was in the range 42 to 49 pcf.

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.

5. The steel flat wheel roller caused degradation of both types of coverstone.

6. Laboratory induced windshield damage was severe for the crushed limestone and practically insignificant for the lightweight material.

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 material under study.

8. One hundred cycles of rapid freeze-thaw caused a weighted average loss of 3.1 percent for the Grade 4 lightweight material and 6.5 per-

cent for the Grade 3. These grades are described in Figure 39.

9. These same materials showed a maximum weighted average loss of 1.6 percent when subjected to five cycles of the magnesium sulfate soundness test.

10. Under a variety of construction and service conditions the lightweight material under study has, so far, 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 this particular lightweight aggregate.

12. The lightweight aggregate was favorably accepted by contractors and THD personnel throughout the area in which it was used.

13. The lightweight aggregate under study is considered equal to precoated limestone for seal coat and surface treatment work.

Recommendations

Based on the laboratory and field evaluation work performed during the past fifteen 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. There appears to be no practical need for more than four grades (size-wise) of lightweight aggregate.

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. 4

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.

INTRODUCTION

The following is a progress report on a lightweight single material. It contains no analysis of other than good-to-excellent materials and the findings cannot be considered to be generally applicable. Further, the results set forth are inconclusive and considerable additional research will be performed before final conclusive data are available. Work is continuing with other aggregates.

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.

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. Up grades 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 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 expediency--to effect certain useful needs the most important of which are as follows: (1) Seal the bituminous mat against the entrance of air and water; (2) Absorb the wear of traffic action; (3) Increase the skid resistance of the wearing surface; (4) Reduce the brittleness of the underlying layer of bituminous material; and (5) Increase the night visibility or luminosity of the surface.

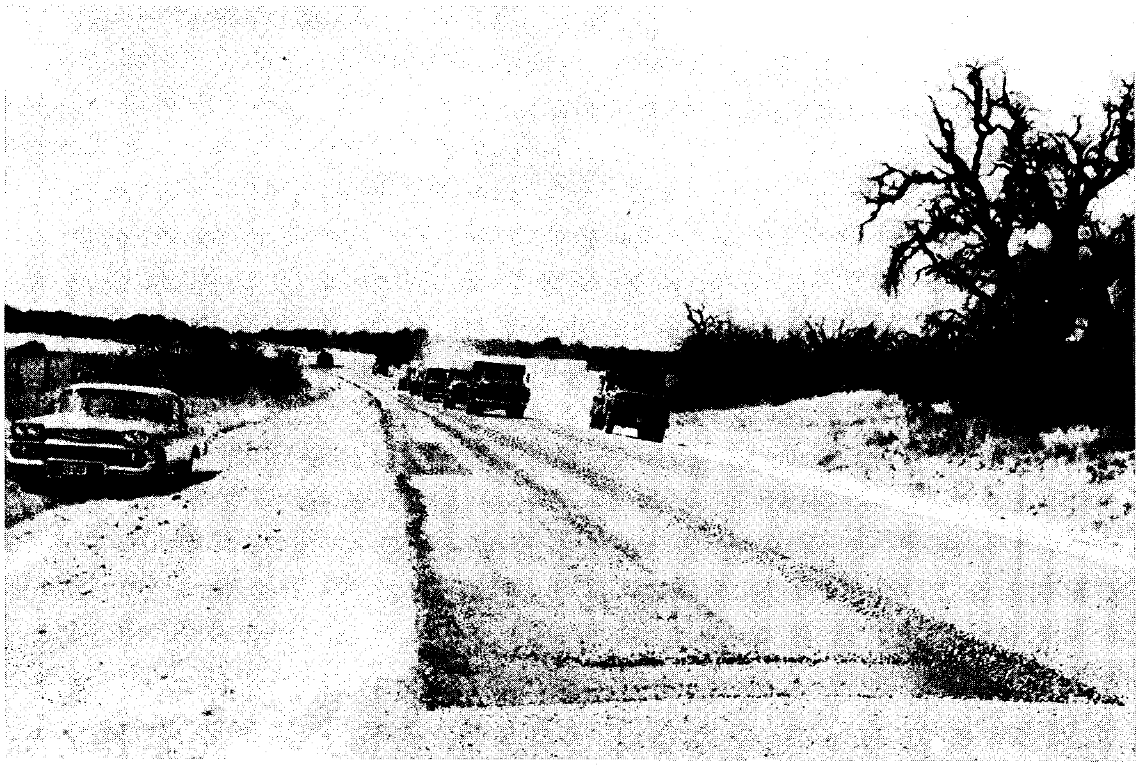


Figure 1. Old surface has variable demand for asphalt from point to point.

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.

OBJECTIVES OF THIS STUDY

The study reported herein is concerned with laboratory and field studies of calcined shale for use as a coverstone for highway seal coats. The aggregate is from a single producer near Ranger, Texas. The primary objective of this study was to determine whether or not this particular lightweight (synthetic) aggregate is 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 project 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 built in Foard County on FM 267 on June 7, 1963. Other jobs were already completed, under construction or planned in other districts in the Ranger, Texas, area. 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. <u>Basic Characteristics of the Aggregate</u>

1. Source and type 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. Abrasion by three methods.

6. Resilience as measured by sulfate soundness.

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 C

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 specification further states that the aggregate shall be predominately 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 following interesting history is quoted from Willson (2).

> "There was an abrupt change in the lightweight industry when the Hayde patents expired in April, 1946. Several plants were under construction in anticipation of this date and several others were awarded immediately after. Two in this category were the first Texas plants. They were the Texas Lightweight Aggregate Company at Eastland, which is now part of the Texas Industries system, and the Featherlite plant at Strawn, Texas. These plants went into production about the same time and both shipped material in December of 1946. The following year construction of two other plants was commenced, one at Converse and the

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

other at Stafford. The Converse plant commenced as an independent operation owned by a group of Austin businessmen but later was taken over by the Featherlite Company. The Stafford plant went into production late in 1948 and in 1950 became part of the Texas Industries system. Construction of of another independent plant at Rosenberg commenced in 1948 and went into production about mid-year in 1949. This operation was also sold to Texas Industries late in 1950, about the same time the Stafford plant was acquired by them. In 1952 it was decided to combine the Rosenberg and Stafford operations and the Stafford plant was tripled in size, using Rosenberg equipment. Incidentally, the first lightweight structural concrete used by the Texas Highway Department came from the Rosenberg plant and was used to replace the timber deck of a bridge across Buffalo Bayou in East Houston.

A year or two later Texas Industries built their Dallas Haydite plant, Barrett Industries built a small plant on the site of their operations in San Antonio and Bill Williams completed his plant at Ranger and it went into production. After approximately one year Featherlite took over the Ranger plant and increased its production, at the same time abandoning the old plant at Strawn. In 1948 an independent plant was built between Corpus Christi and Robstown which failed to survive after about three years of operation. Recent developments are reactivating the old Strawn plant by Bill Williams and construction of the Waco Aggregate Company plant at Waco.

In summation, the rotary kiln lightweight aggregate industry in Texas is 18 years old. Ten plants have been built of which eight are still operating. Five are expanding shale and three are expanding clay, the eight plants having a total capacity of approximately 4,000 cu. yds. per day. While some plants are able to sell their total production capacity, others are not and I estimate the industry in Texas is now operating at from 75% to 80% of capacity."

The introduction of lightweight aggregates in the highway field for bituminous pavement has occurred within about the last six or seven years and in the Texas Highway System only within the last two 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 five years. Test sections were placed in the State of Louisiana on city streets and parish roads and one section, a hot-mix asphaltic concrete surface course was placed on a state highway and has given excellent service for more than five 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 (3), and another double surface treatment was built in this same district in 1962. In 1963, several hundred miles of secondary roads were sealed with 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 or more different districts of the Texas Highway Department. To date lightweight aggregate has been used as cover material on approximately 600 miles of secondary roads on force account and contract maintenance.

The production of this material that 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 the specific material used in this 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 many other plants scattered over the entire United States that produce similar materials in large volumes (4). 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 (5) 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 overburden. 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

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

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 fines produced by the mining and sizing operations may be formed into pellets and processed in much the same manner as that shale produced by the normal operating procedures. The presized or pelleted shale 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 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 other 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 1164 Aggregate for Surface Treatment (lightweight) dated December, 1963.* 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 (6). The early work of Bauer (7) 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.

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 vesicules (for lowest density), and having 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,

* Revised Item 1269 dated November, 1964.

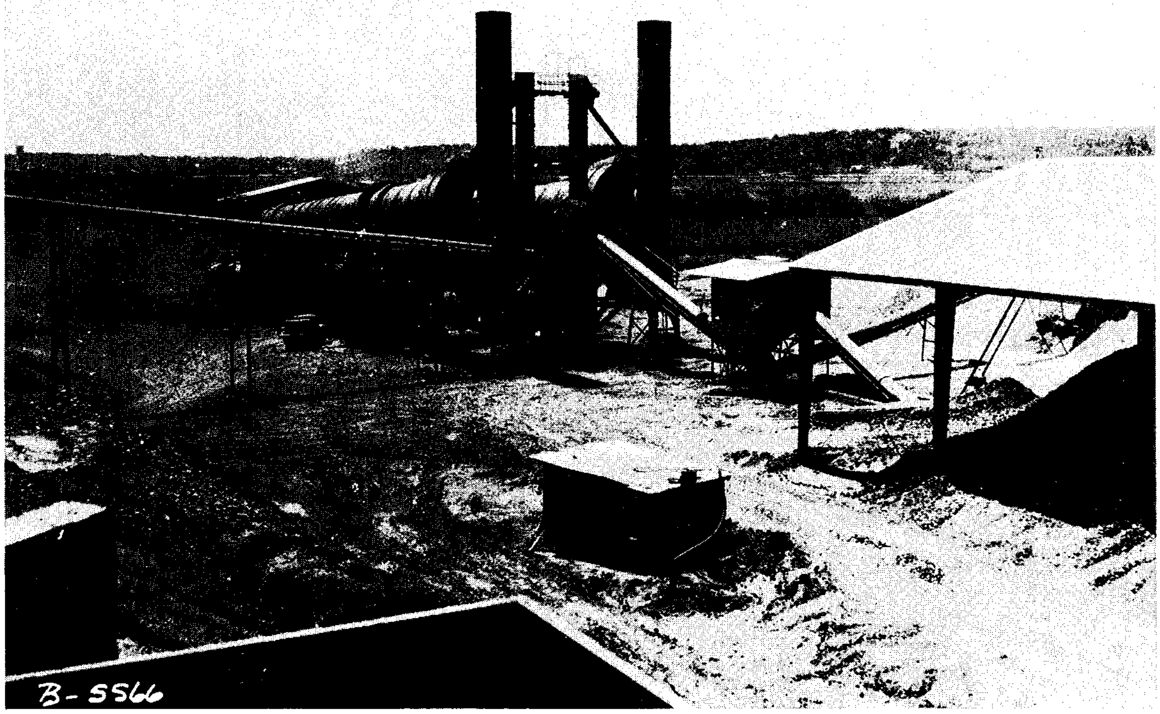


Figure 3. Shale storage and conveyor feed to kilns.
(Photo by Gustafson.)

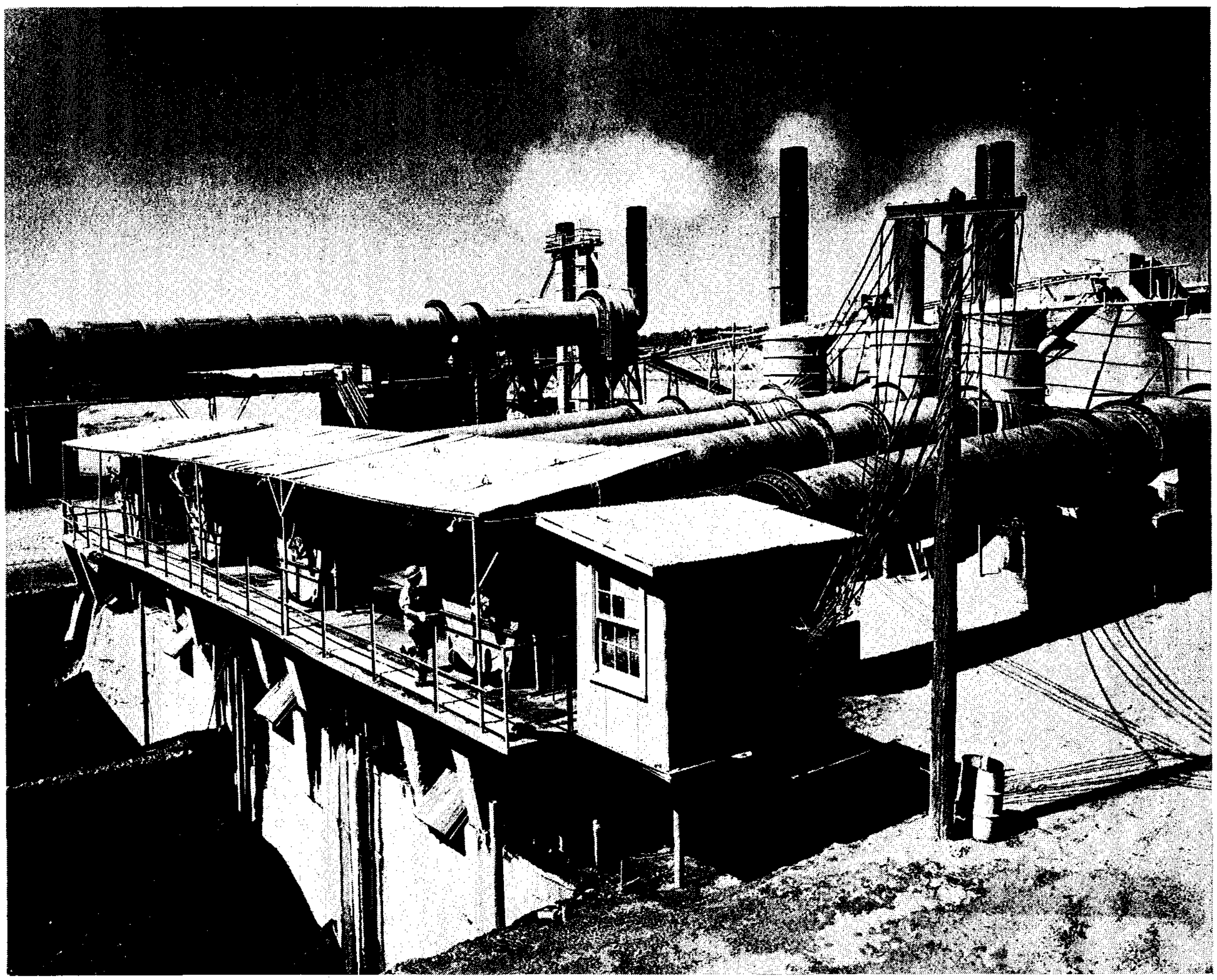


Figure 4. Battery of rotary kilns used to burn shale. (Photo by Richardson.)

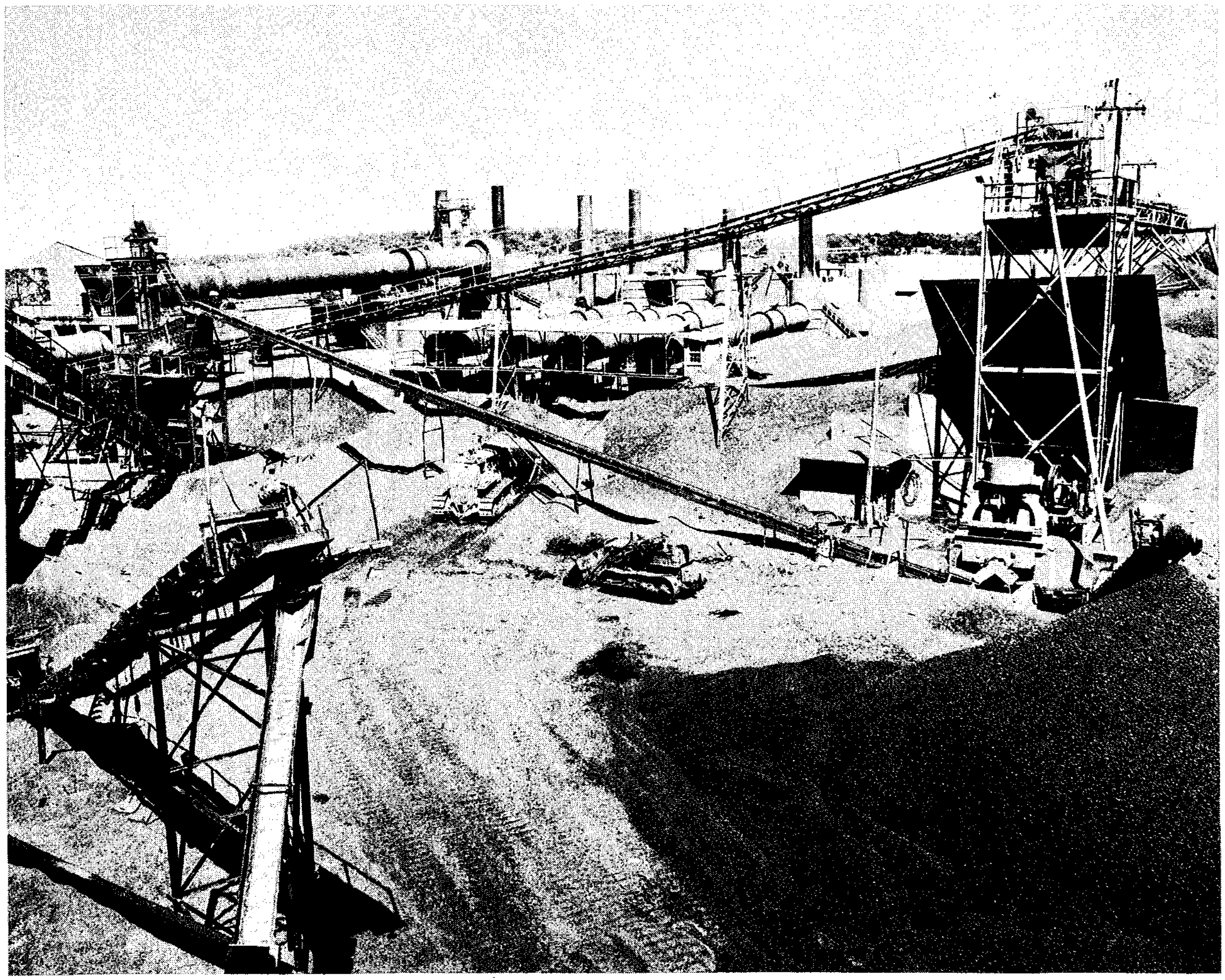


Figure 5. General view of commercial lightweight aggregate plant. Crushing and sieving is in right foreground. (Photo by Richardson.)

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 (7). 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 due 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 these would melt alone.

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

(a) Composition (6).

(b) Density.

(c) Grain size.

(d) Dispersion.

(e) Heating rate.

(f) Heating atomosphere.

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,

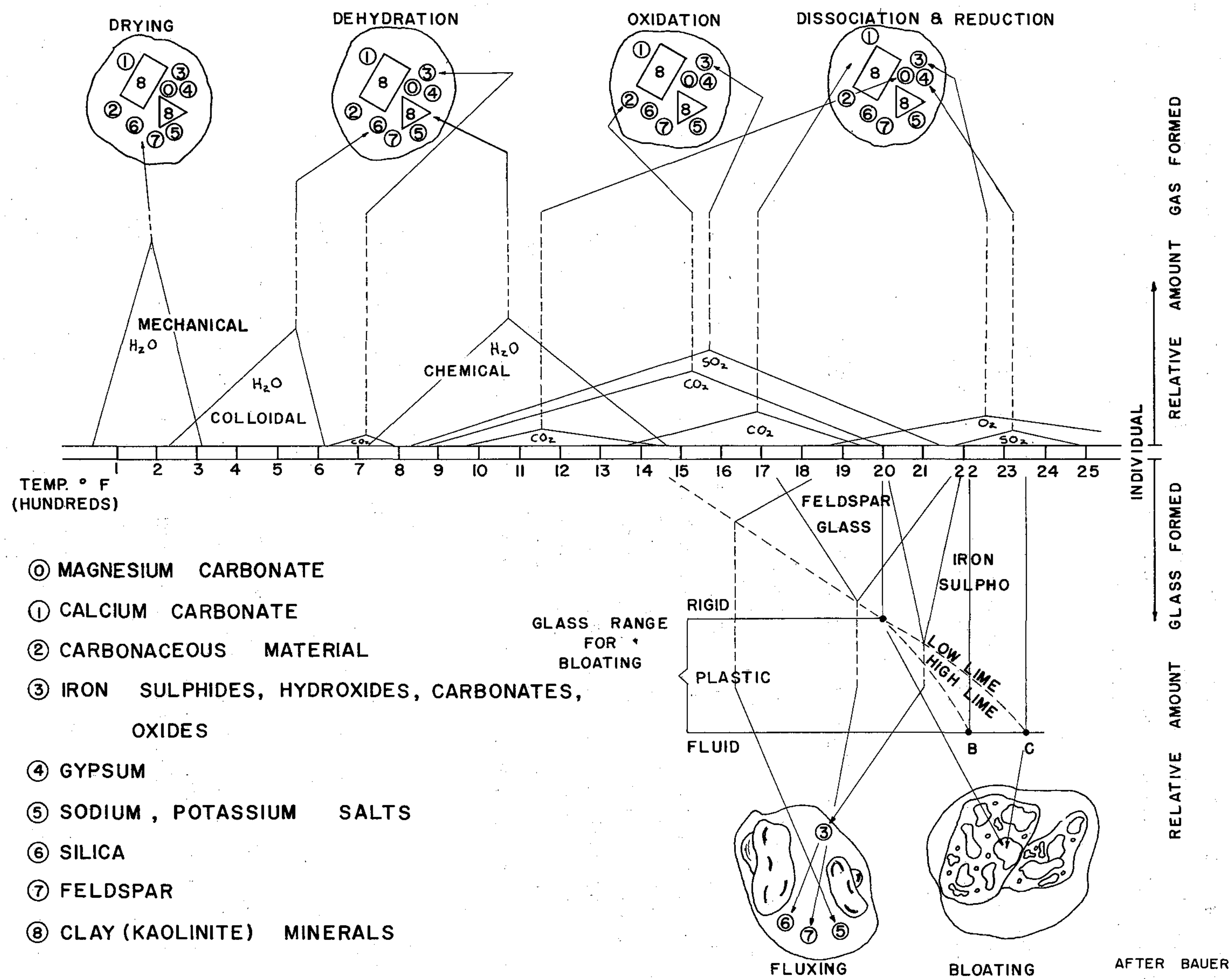


Figure 6. Flow diagram of gas-glass forming versus temperature. (Reference Bauer.)

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 many 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 grades, the materials used in this study were primarily Texas Highway Department Grades 3 and 4 lightweight expanded shale and precoated crushed limestone (8). Gradation requirements for the various grades are listed in Appendix A. Grading curves obtained from producer and field stockpile samplings are shown in Figure 7. The unit weight of the Grade 3 and 4 lightweight aggregate was in the range of 42 to 49 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.

Retention 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 material 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 probable need for altering the test procedure 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 change in the volume of the sample changes

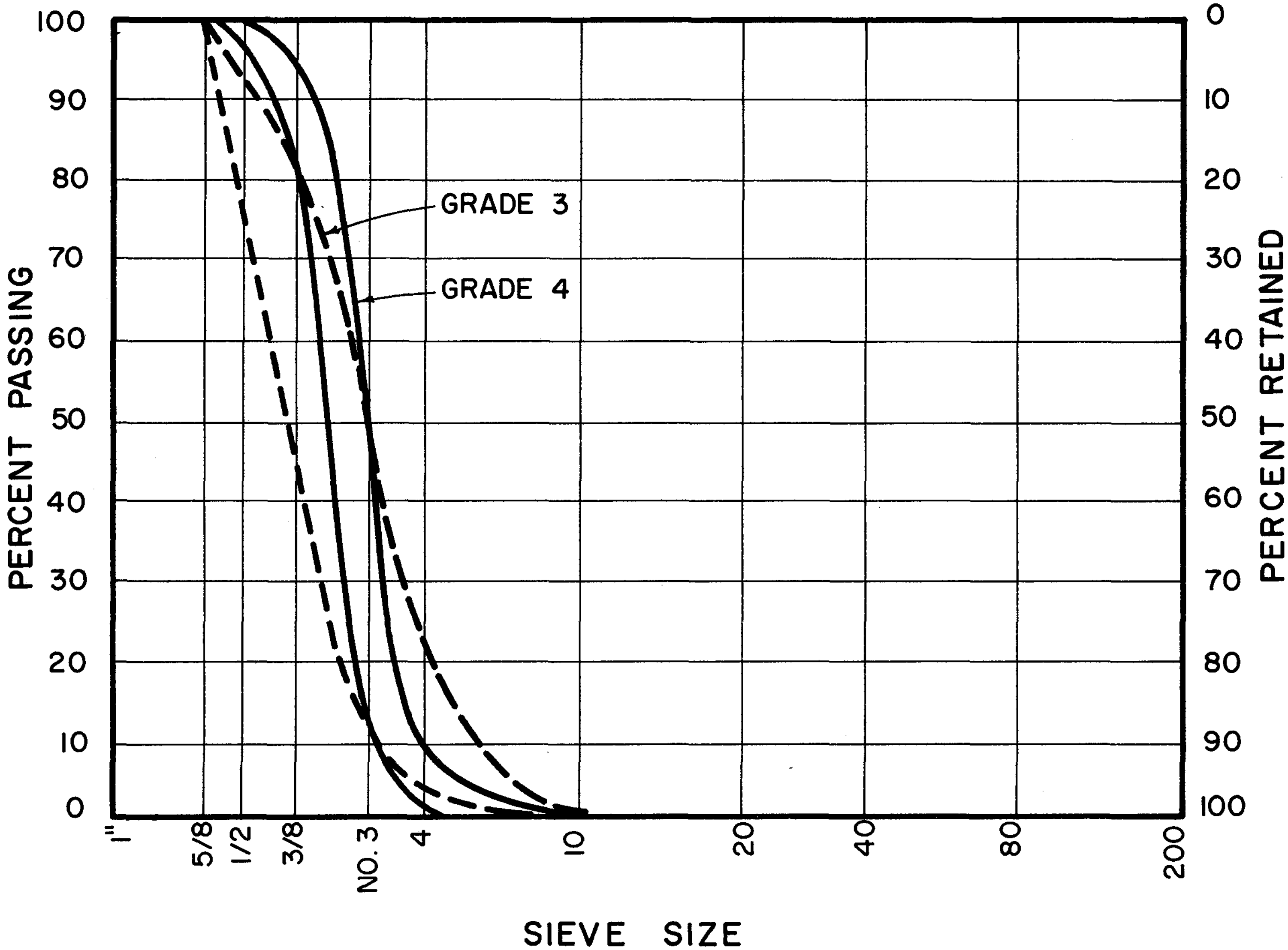


FIGURE 7 GRADING OF STOCKPILE AND PRODUCTION RUN TYPE F GRADES 3 & 4 MATERIAL

the crushing and abrasion characteristics of the testing equipment for given testing procedures. The TDH modification of ASTM designation C-131-55(1) possibly represents a more realistic approach to the measurement of resistance to abrasion of such materials. Further modifications may be required as service data are collected and evaluated. This, or course, may require several years. It is also quite possible that the maximum wear of 35 percent as set by Item 1164 and determined by Test Method Tex-410-A (Part II) is unnecessarily restrictive. Earlier work by Woolf (9) indicated that a wear value of 40 percent maximum for surface treatments would be satisfactory.

It was anticipated by some that the freeze-thaw damage to lightweight aggregate might be severe; however, for the materials and conditions of the test this was not found to be true. Even for 100 cycles of rapid freezing to 0°F or lower caused only limited degradation. The same finding resulted from the magnesium sulfate soundness test.

LABORATORY RETENTION STUDIES

The laboratory design of seal coats and surface treatments was based on previous work done by Kearby (10), Benson and Gallaway (11), and Hank and Brown (12). 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 dessribed 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

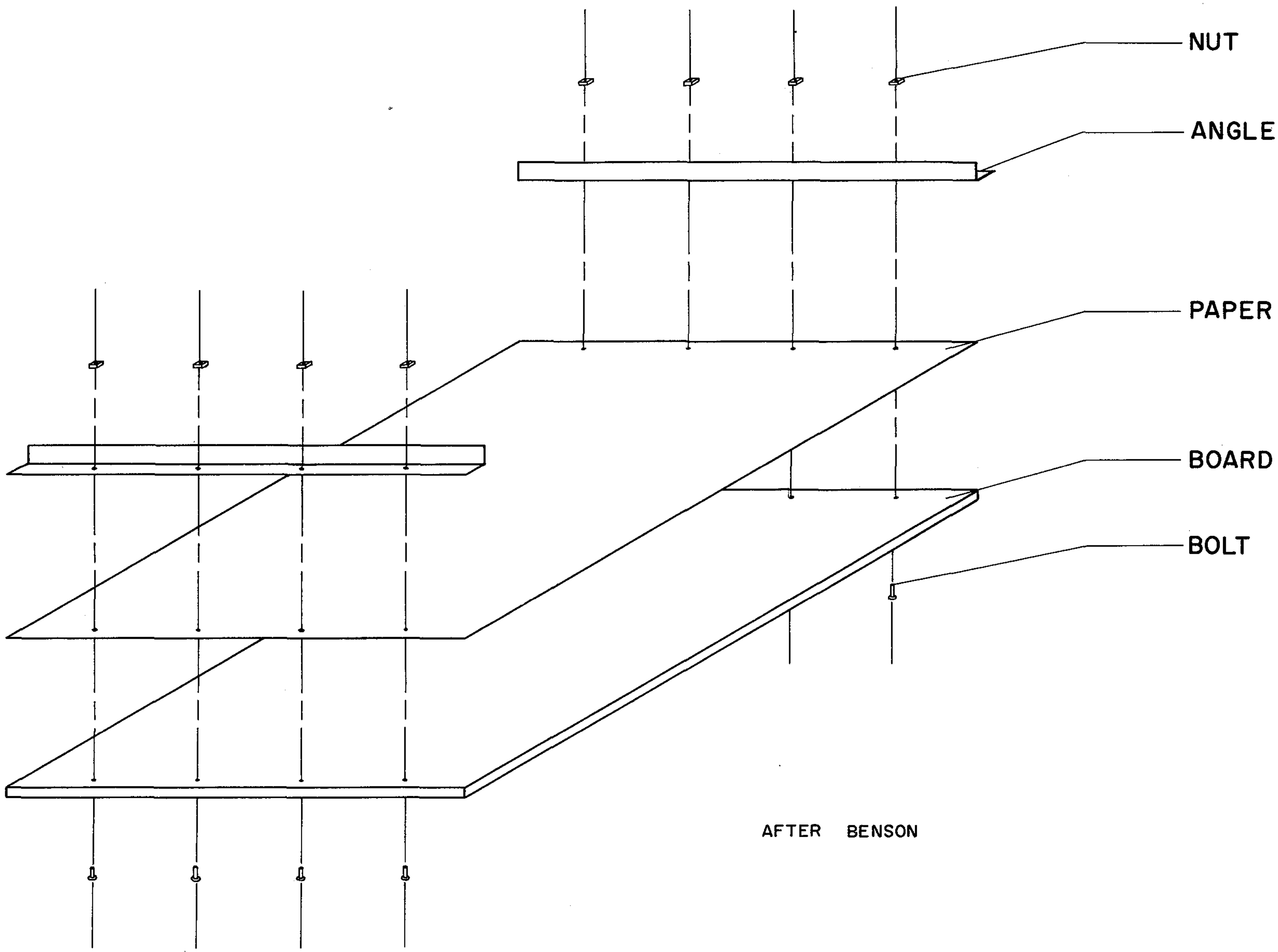


FIGURE 8 "EXPLODED" ASSEMBLY OF BOARD, PAPER AND ANGLES

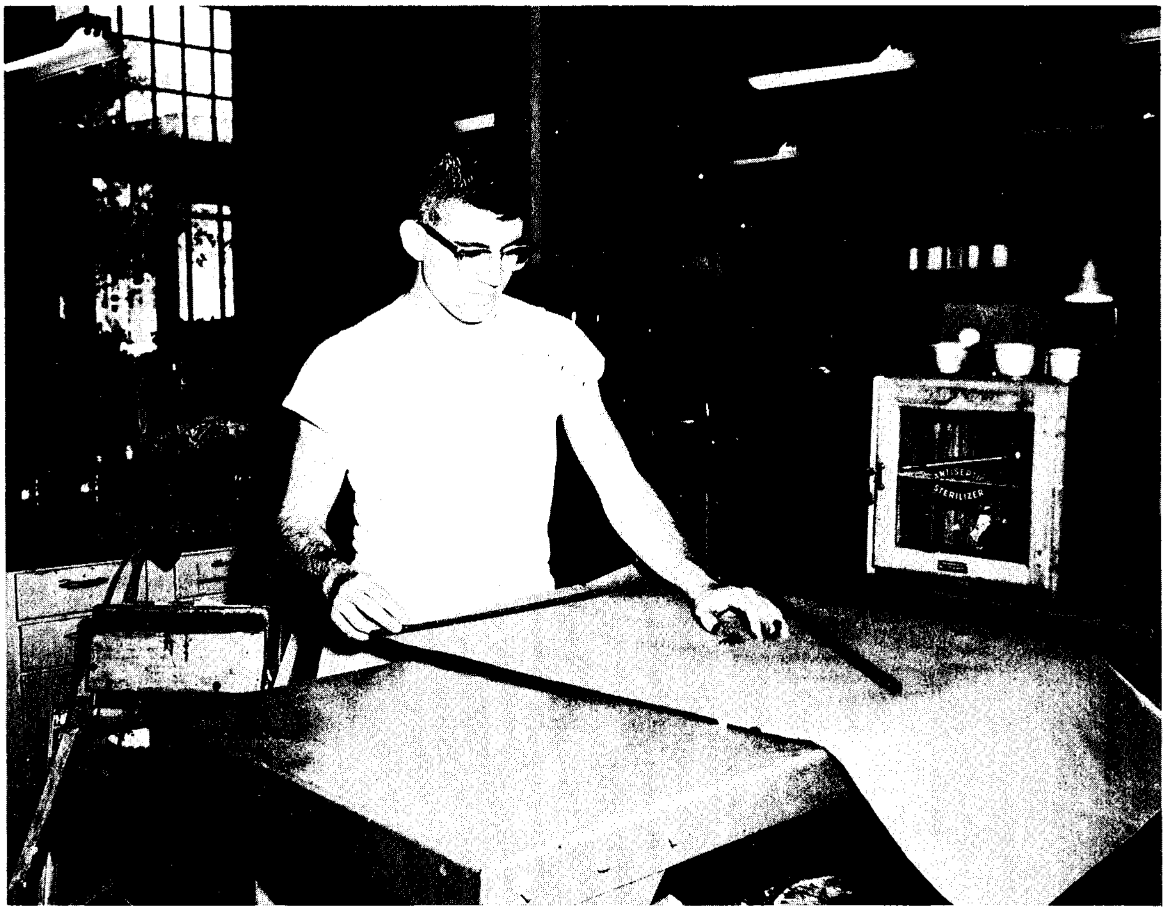


Figure 9. Laboratory surface treatment board being covered with paper

Figure 10. Boards in line for asphalt shot.

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 a temperature that produces a Saybolt Fural 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.

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 500 lb. pneumatic roller shown in Figure 15. The pneumatic tires were inflated to 30 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 1164 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

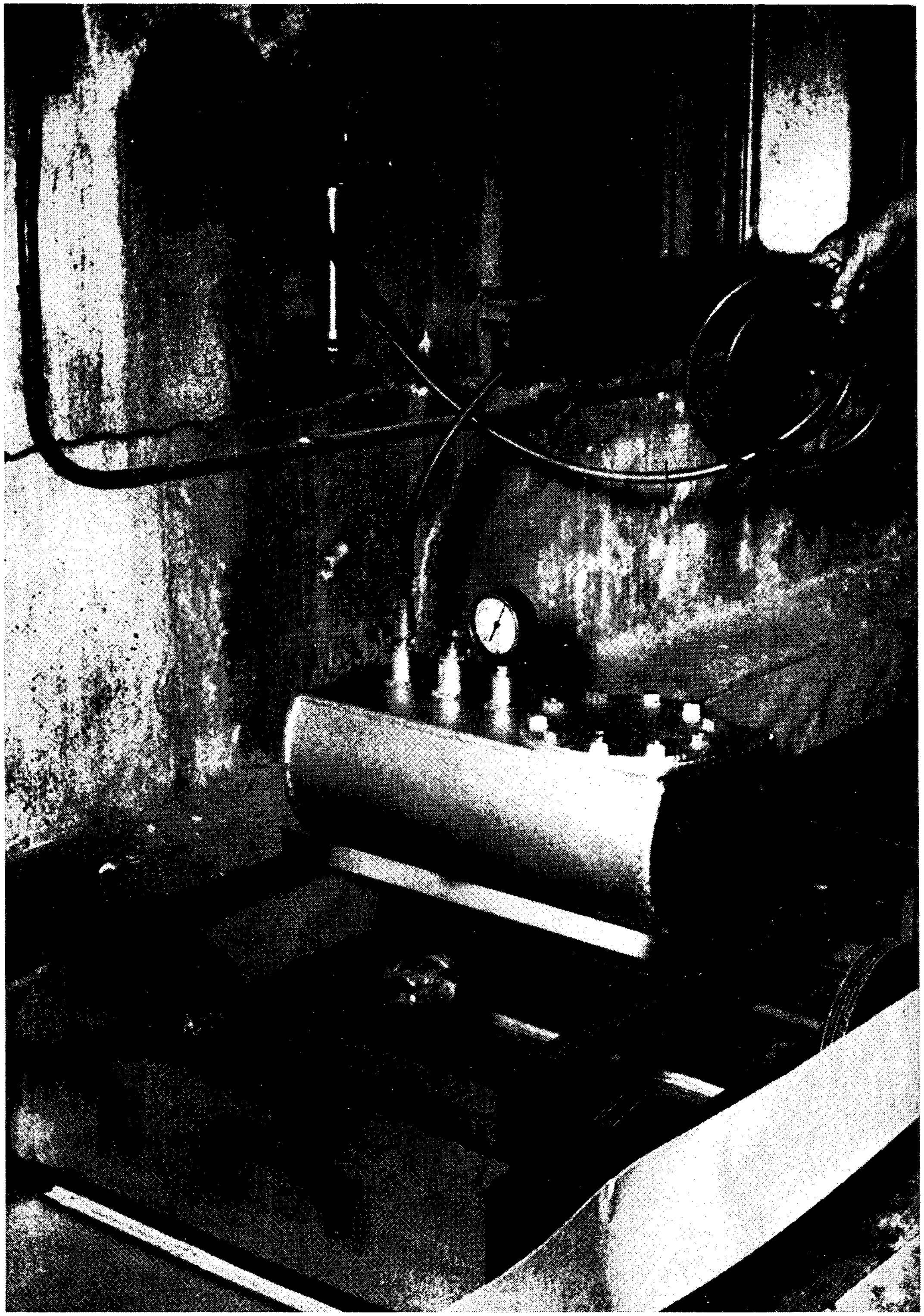


Figure 11. Asphalt distributor used for laboratory retention studies.

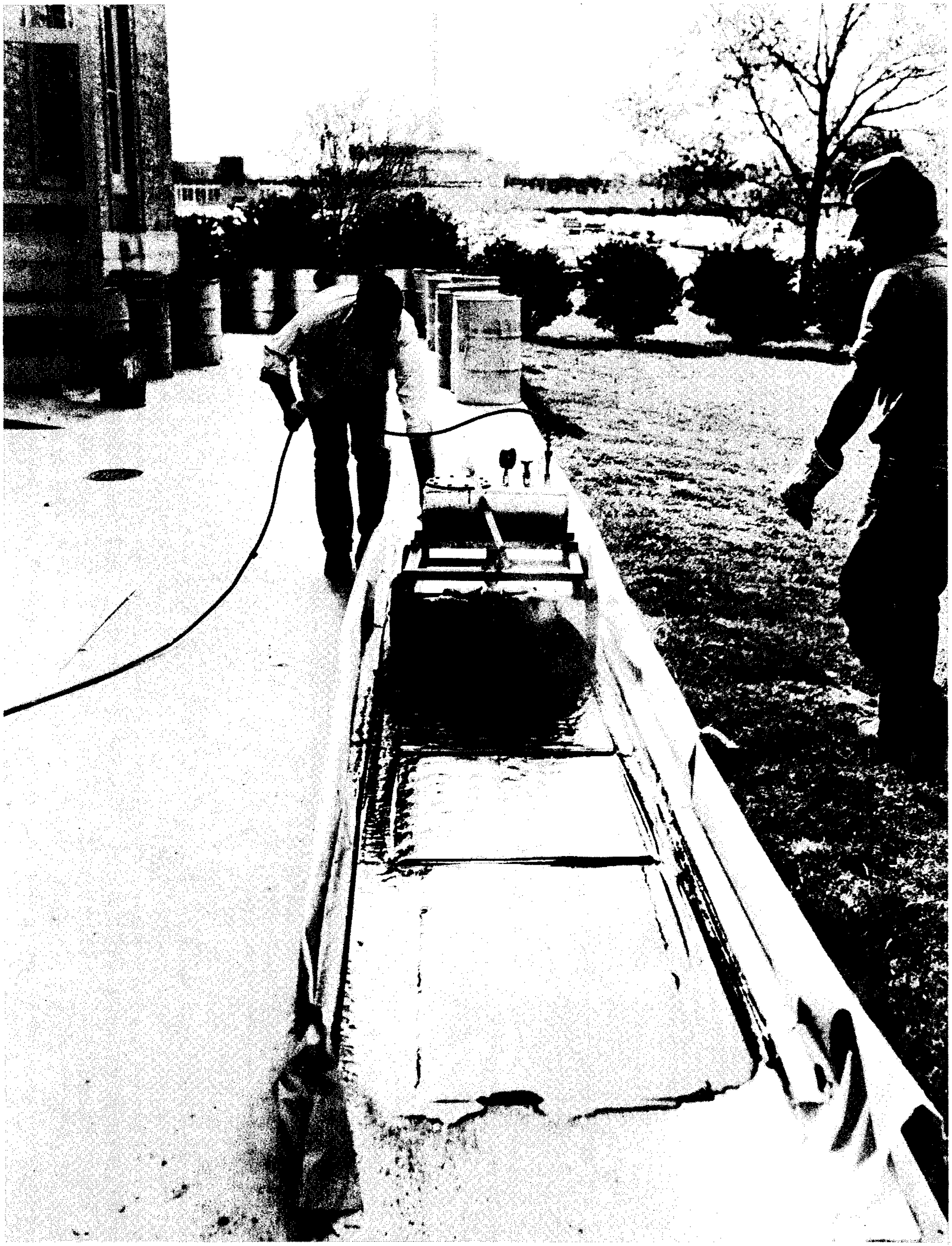


Figure 12. Hot asphalt cement being sprayed from small distributor.

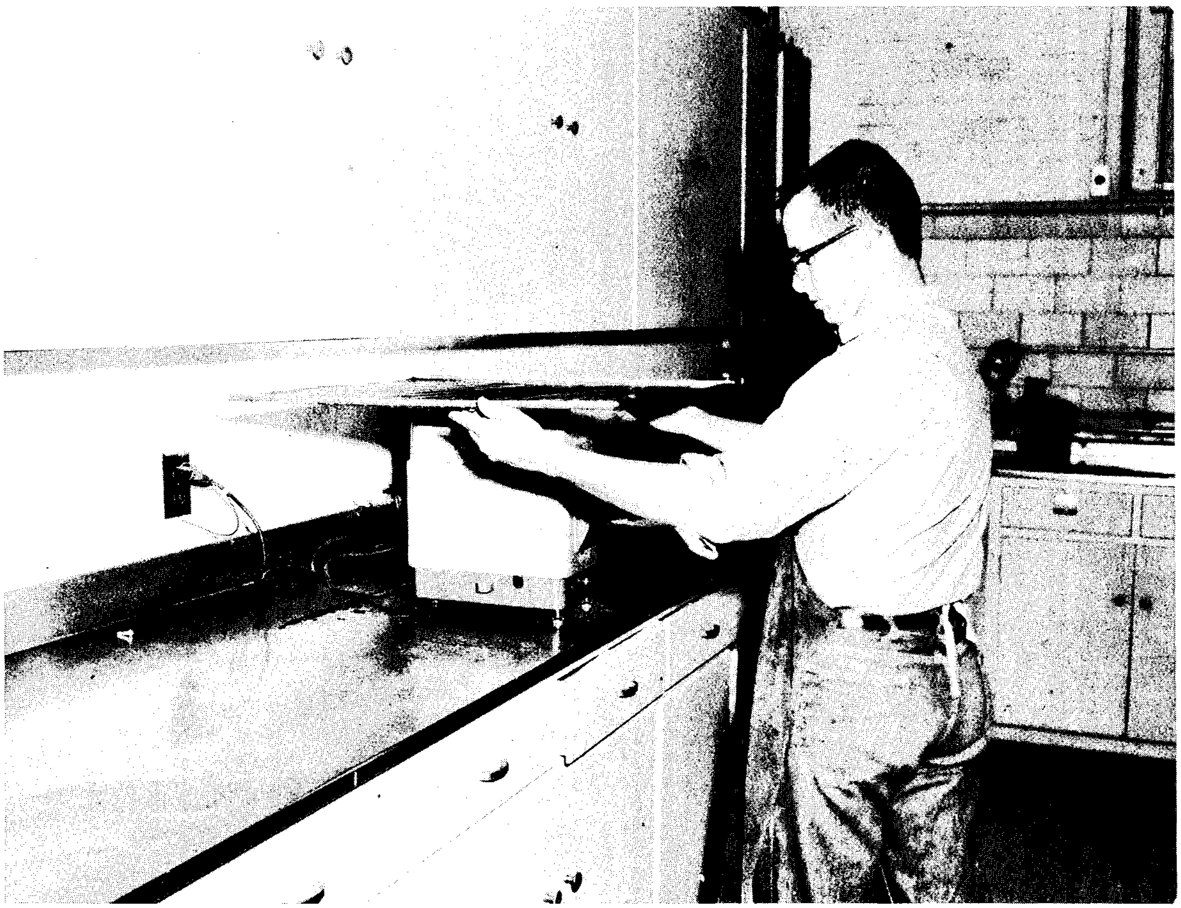


Figure 13. Asphalt coated board being weighed to measure application rate.

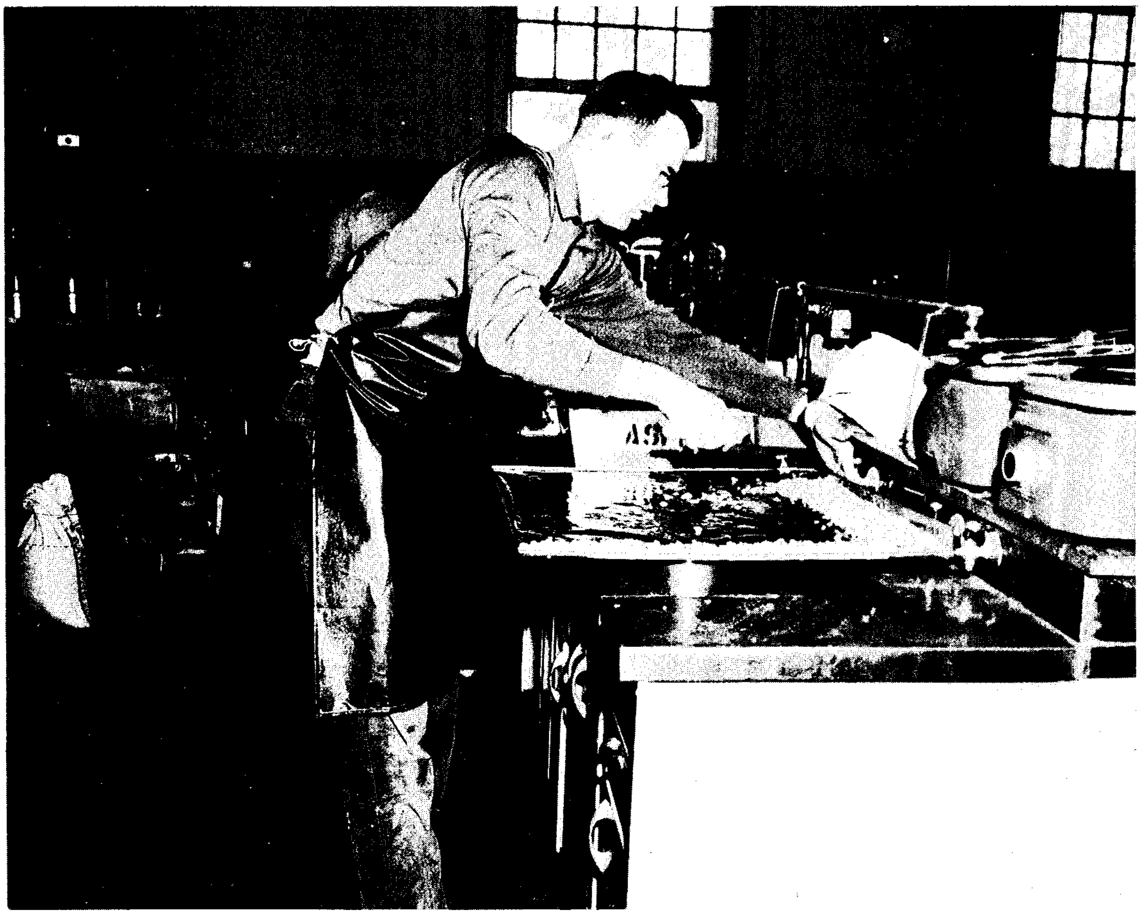


Figure 14. Aggregate being spread by hand on asphalt coated board.

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.

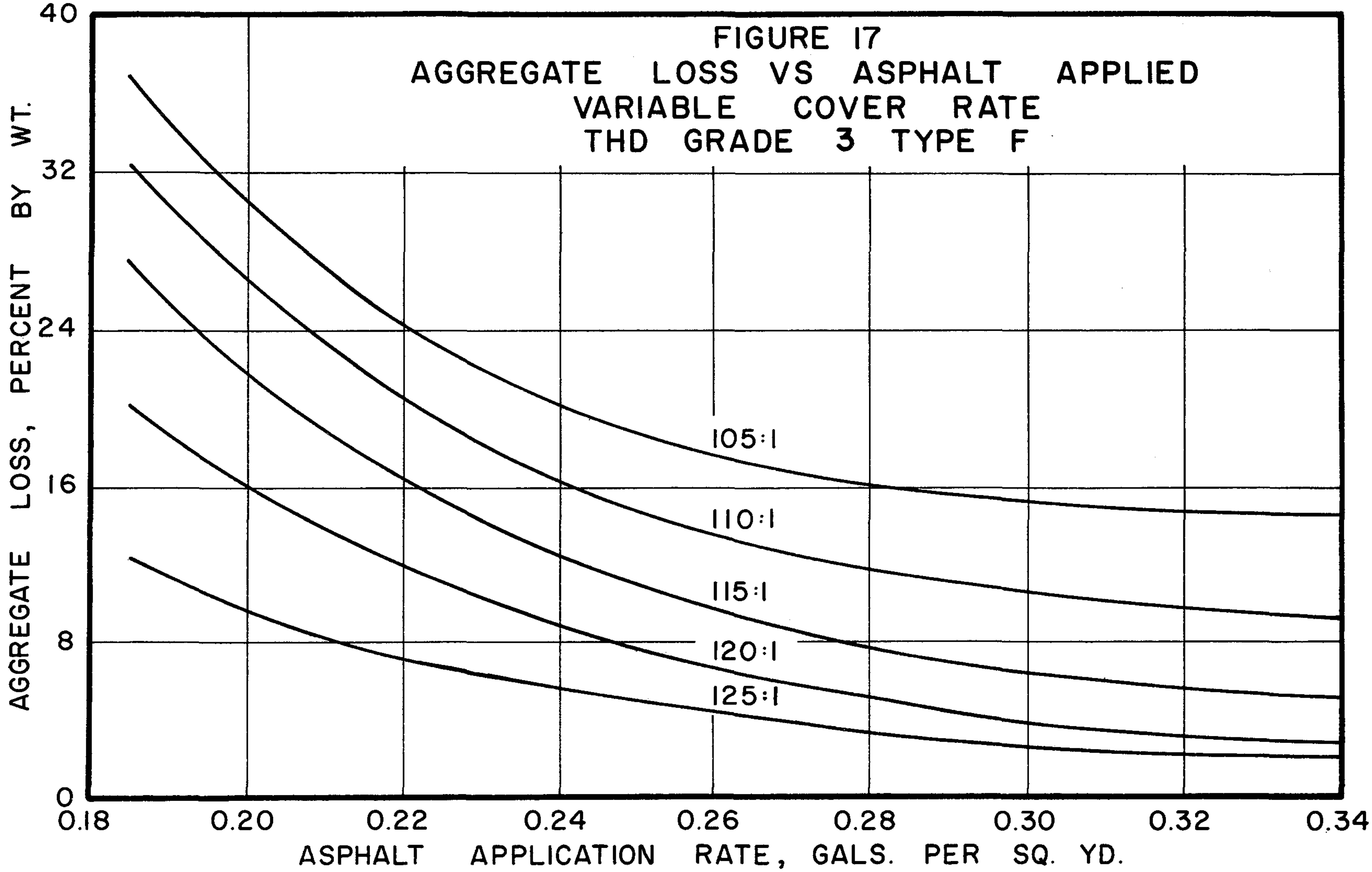


FIGURE 17
AGGREGATE LOSS VS ASPHALT APPLIED
VARIABLE COVER RATE
THD GRADE 3 TYPE F
AGGREGATE LOSS, PERCENT BY WT.
40
32
24
16
8
0
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
ASPHALT APPLICATION RATE, GALS. PER SQ. YD.
105:1
110:1
115:1
120:1
125:1

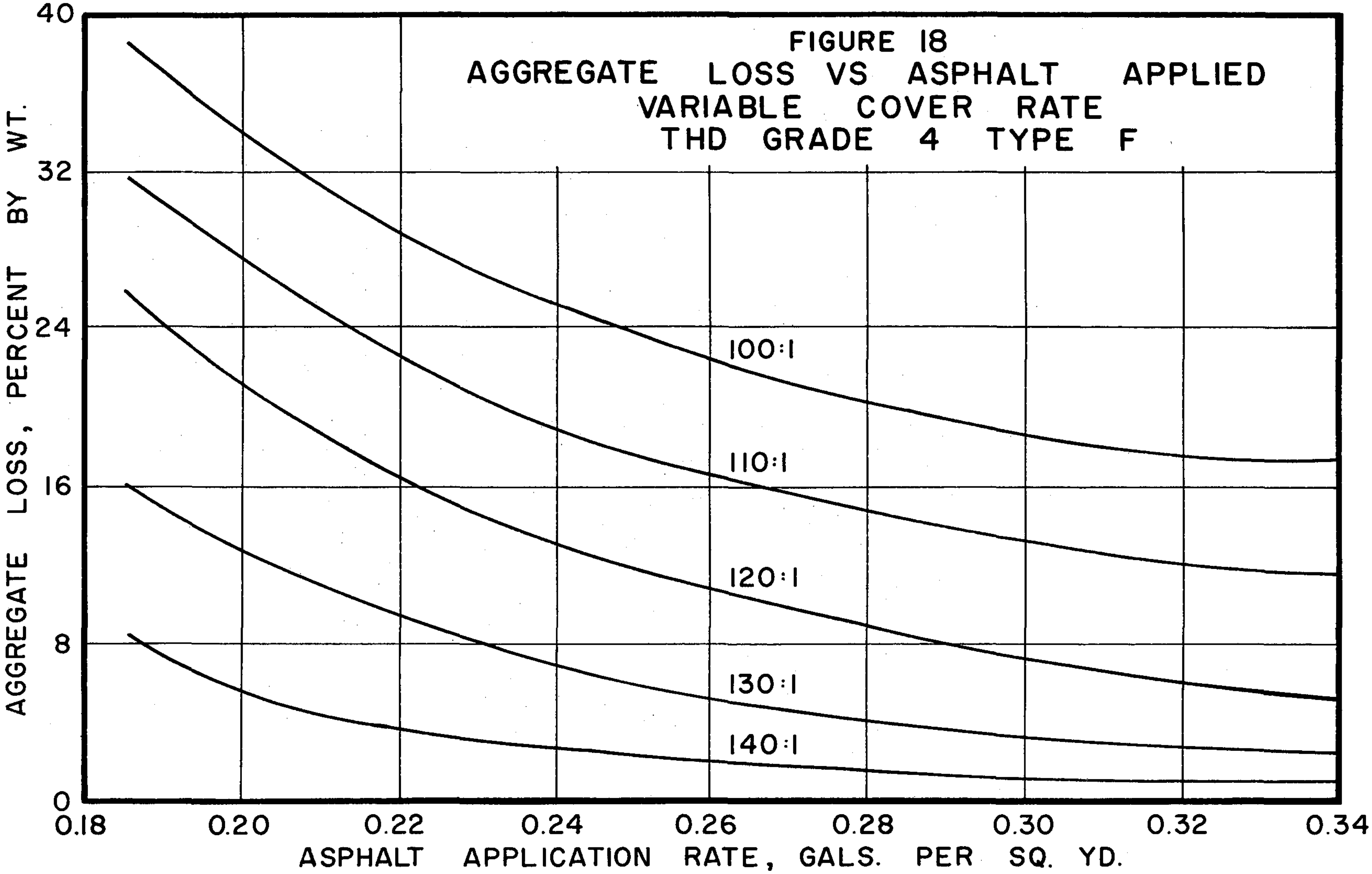


FIGURE 18
AGGREGATE LOSS VS ASPHALT APPLIED
VARIABLE COVER RATE
THD GRADE 4 TYPE F
AGGREGATE LOSS, PERCENT BY WT.
40
32
24
16
8
0
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
ASPHALT APPLICATION RATE, GALS. PER SQ. YD.
100:1
110:1
120:1
130:1
140:1

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 (13) unit weight, if both materials were equally uniform in grading.

Due to the somewhat greater average particle size for Grade 3 stone 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 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 have been extended beyond the 0.34 asphalt application rate. It should not be assumed that rates above this might not be warranted; however, it should be observed 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.

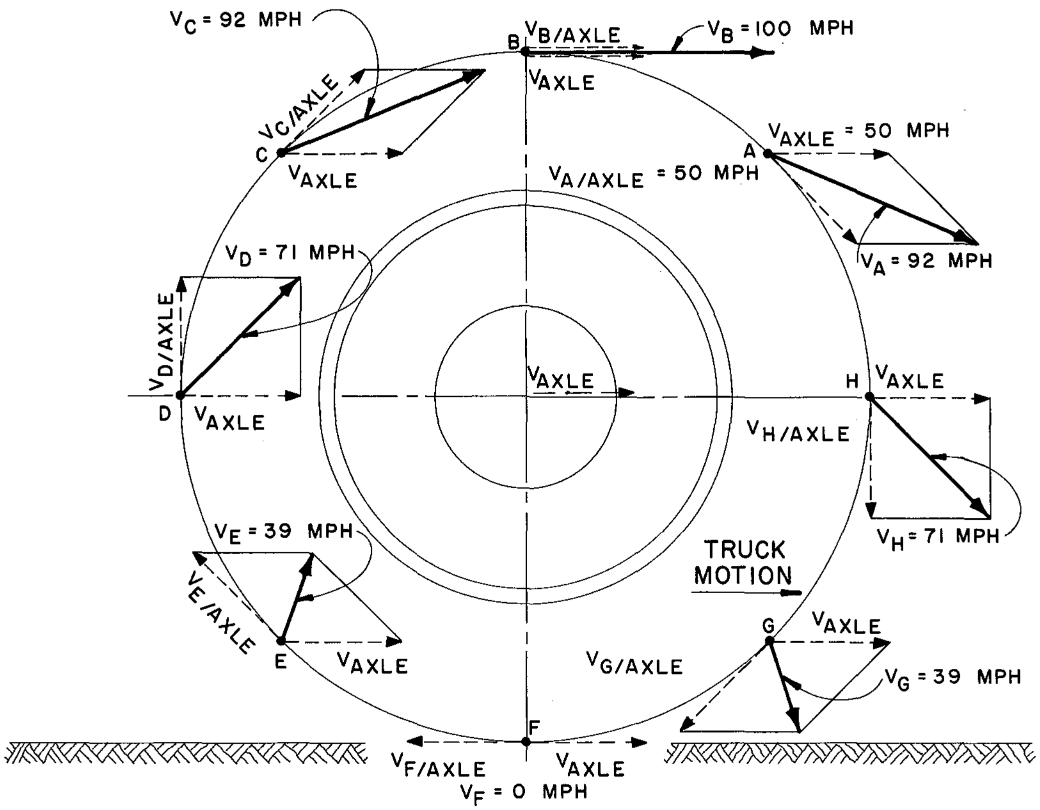
In 1957, Downey (14) reported on a study of the mechanics of stone damage to windshields. This report showed that 57 percent of the windshields examined revealed damage of some type, presumably from flying objects. A questionnaire indicated that almost half of the 415 cases of damage reported were caused 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) (14). 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 92 + 50 or 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.

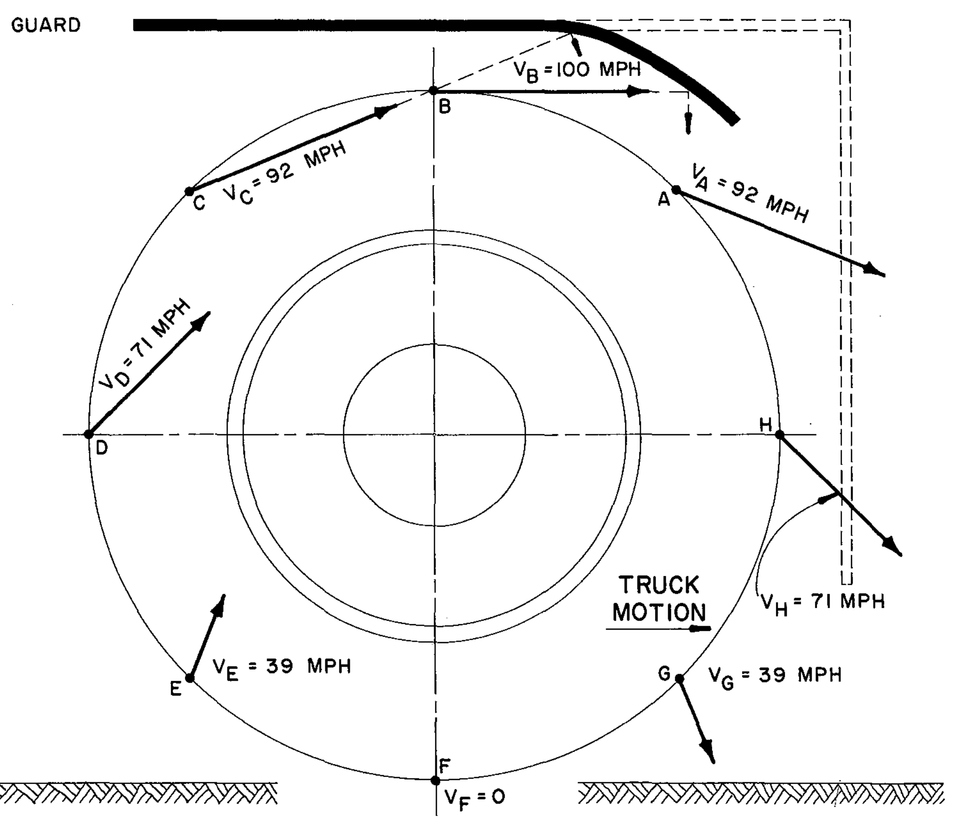
Shown in Figure 20 is a schematic illustration showing the path a stone might take from an open truck's wheels to an oncoming vehicle (14). A simple truck wheel guard suggested by Downey is shown in Figure 19 (b) (14). The dotted lines represent a flap which should be completely effective in stopping 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.

Producers of lightweight aggregates 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.



(a) UNPROTECTED WHEEL



(b) PROTECTED WHEEL

AFTER DOWNEY

FIGURE 19 STONE MOTION AS IT LEAVES A TRUCK WHEEL

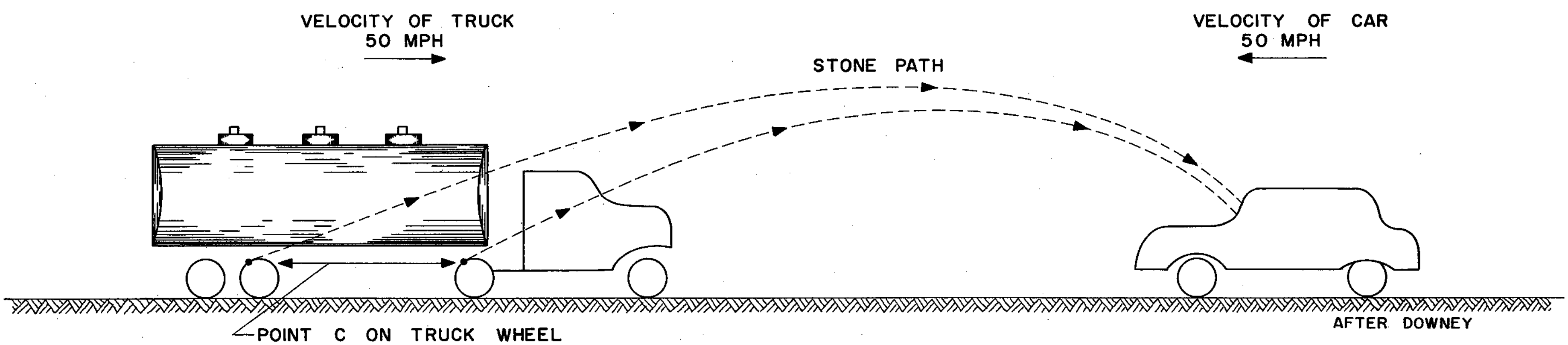


FIGURE 20 RELATIONSHIP OF CAR AND STONES THROWN FROM OPEN TRUCK WHEELS

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 (15). 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 barrell 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 stone is then brought in contact with the wadding. The selected air pressure is set on the air regulator and the air 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 24 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 name of Herculite (16).

The light weight 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 semiautomatic analytical balance. From these data, histograms were prepared and the stones were selected from each of the families of stone making up the histogram. 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.

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 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. More than 1800 stones were prepared and approximately 600 of these were shot, 300 lightweight and 300 precoated stones.

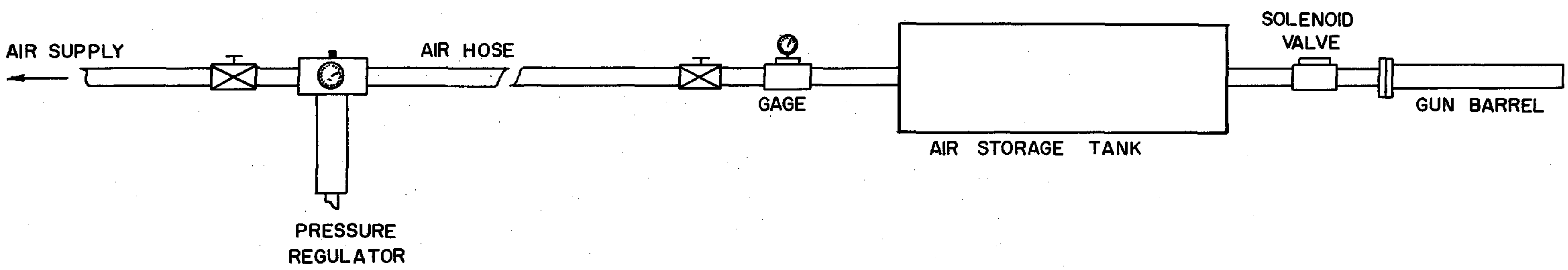


FIGURE 21 AIR GUN FOR SHOOTING STONES

Figure 22. Air powered gun for shooting stones.

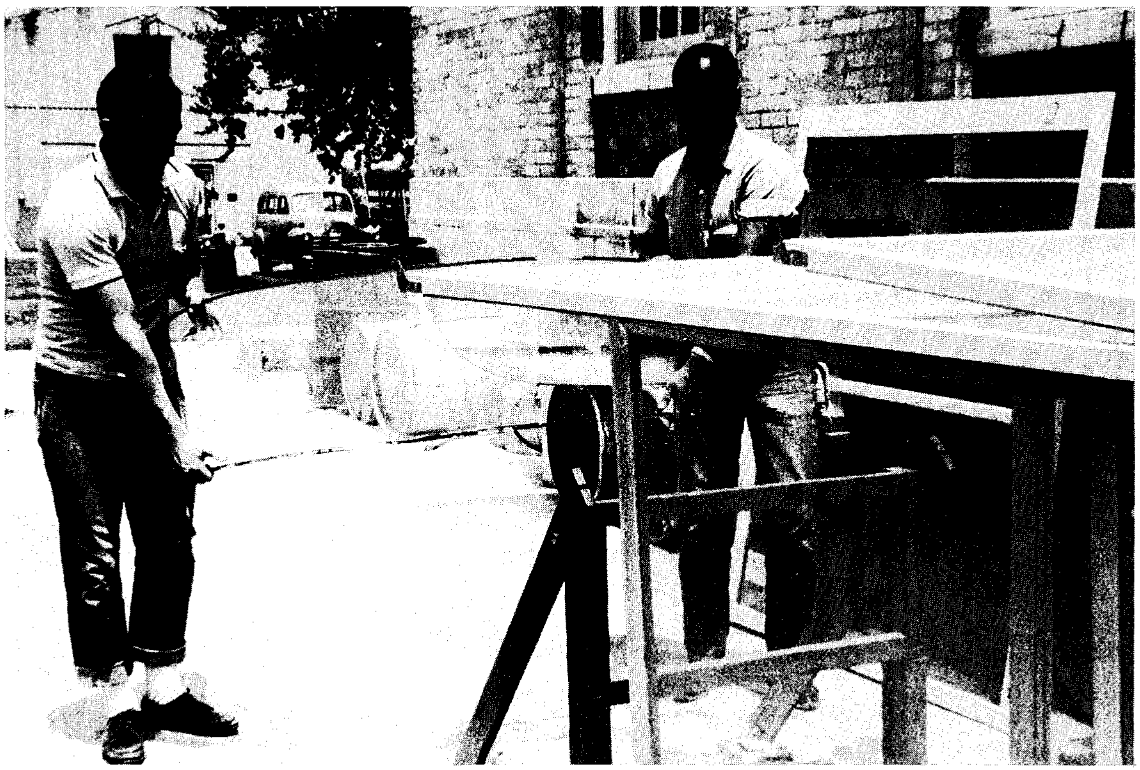


Figure 23. Windshield being placed into position for "flying stone" study.

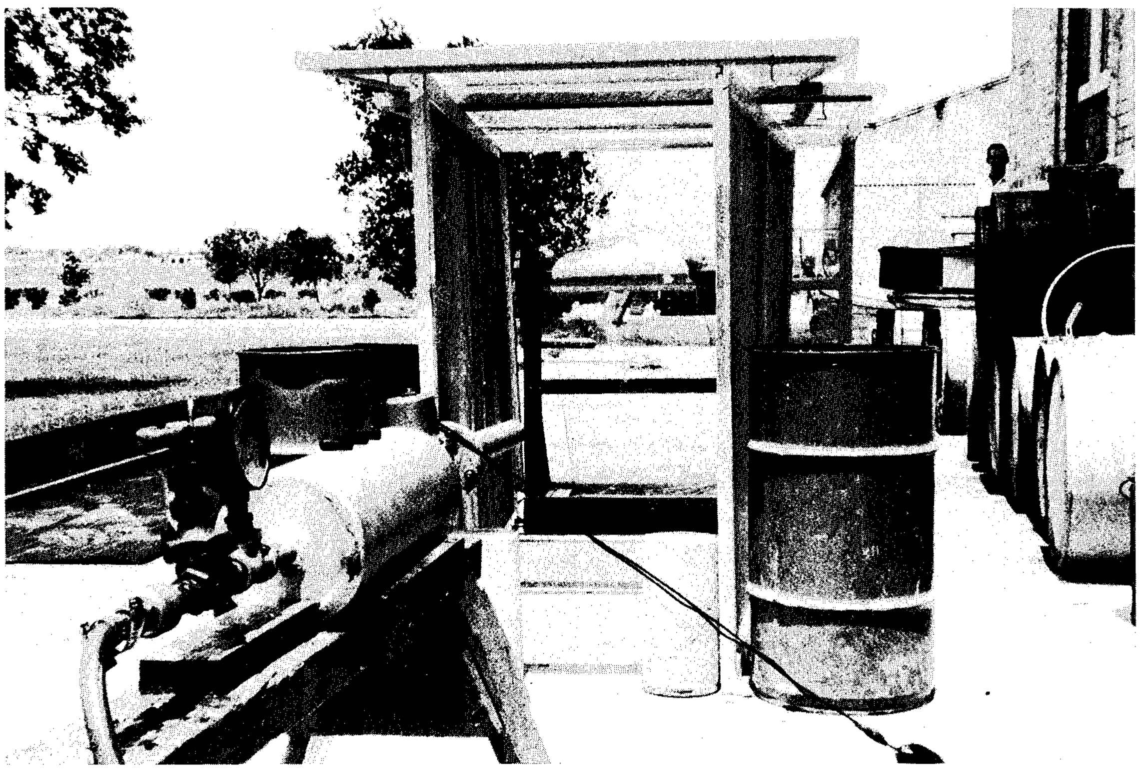
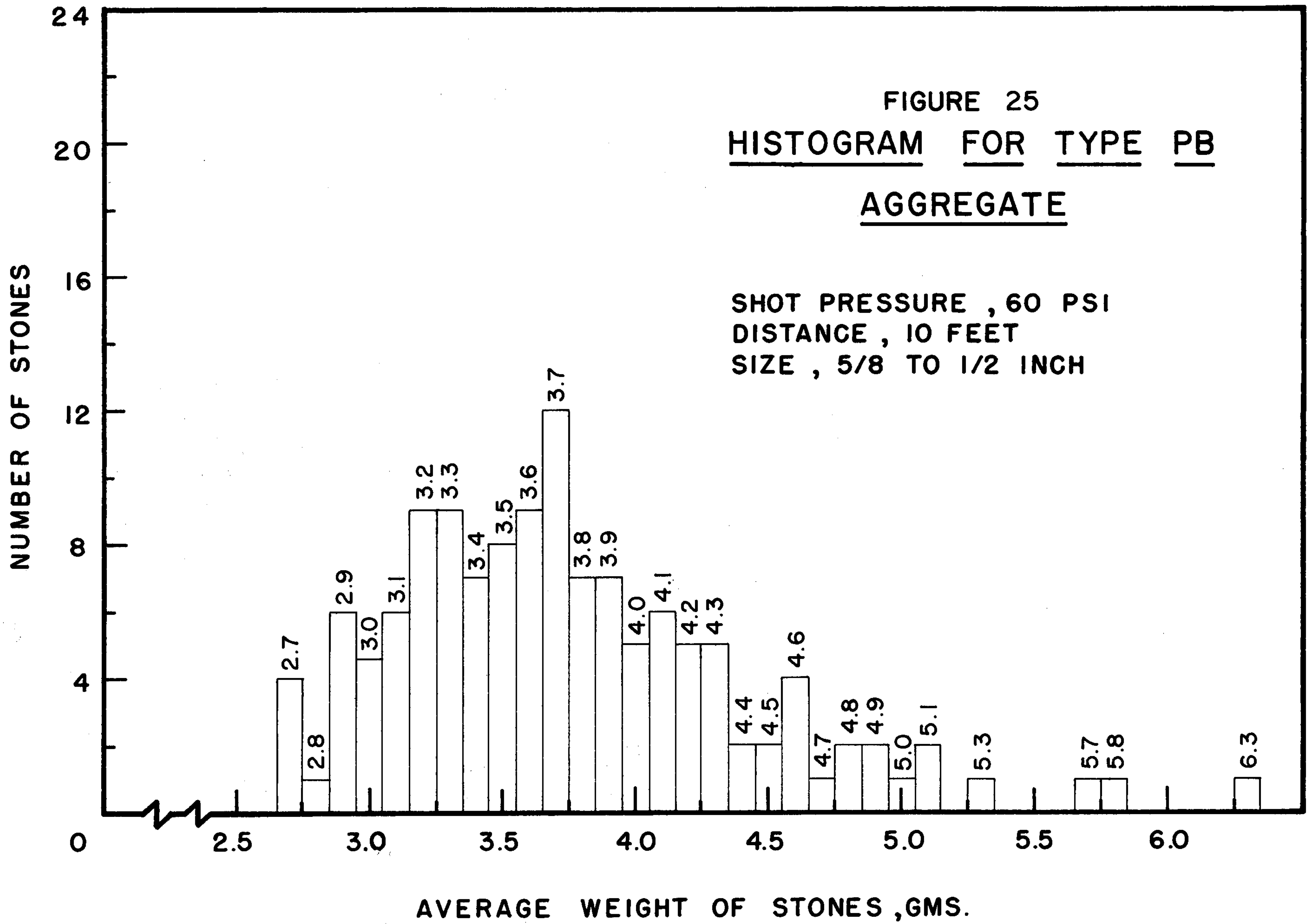


Figure 24. Windshield (target) in screened tunnel from gunner's view.

FIGURE 25

HISTOGRAM FOR TYPE PB AGGREGATE



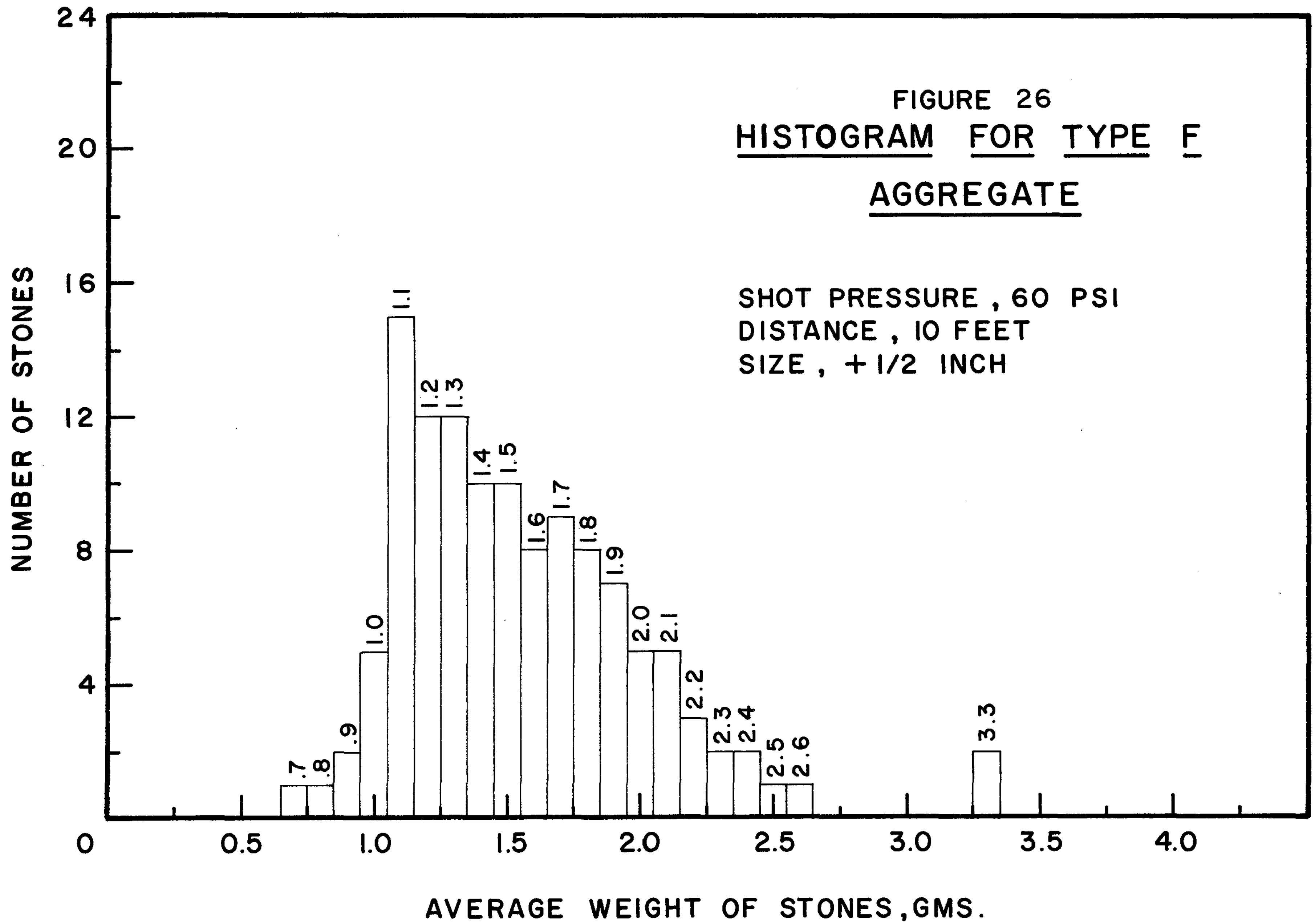


FIGURE 26
HISTOGRAM FOR TYPE F AGGREGATE
SHOT PRESSURE, 60 PSI
DISTANCE, 10 FEET
SIZE, +1/2 INCH
NUMBER OF STONES
AVERAGE WEIGHT OF STONES, GMS.
0
4
8
12
16
20
24
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
3.3

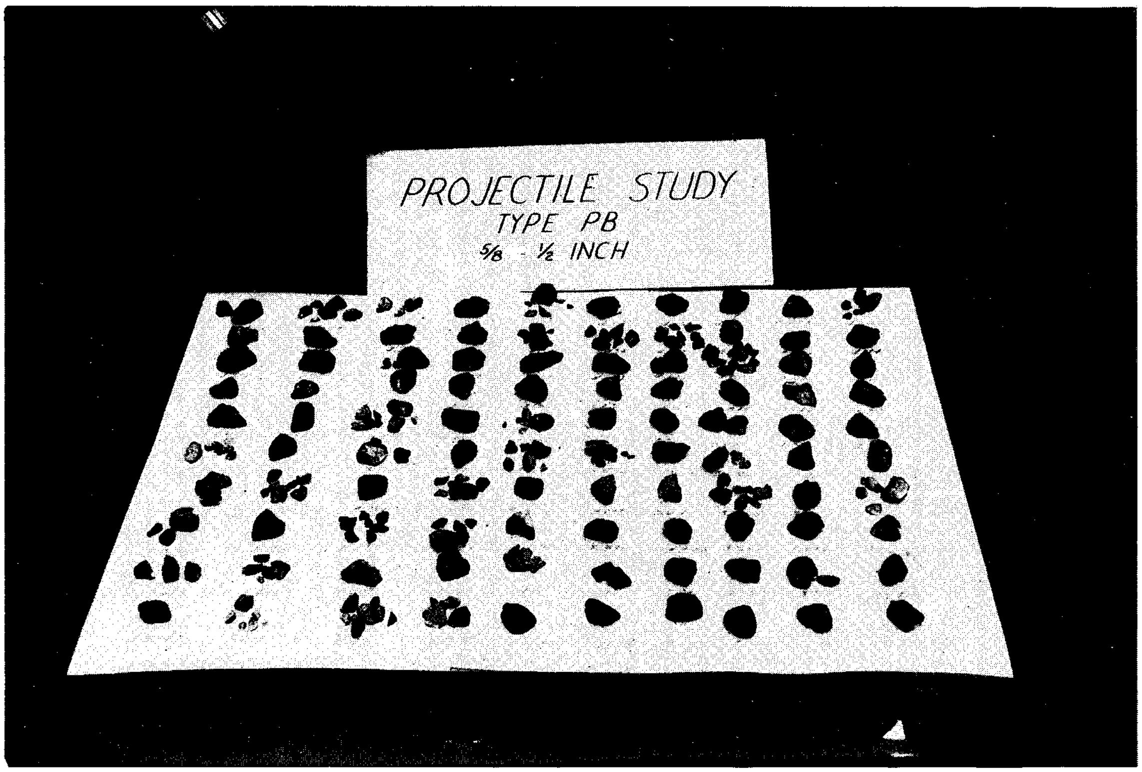


Figure 27. Type PB family of 5/8 to 1/2 inch stones after shooting.

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 one caused by the lightweight aggregate, is shown in Figure 28. The diagonal crack to the right of the "star" crack existed in the glass before test. One other noticeable break was caused by the lightweight material but it was minor compared to the one shown. The crack shown in Figure 28 was caused by a stone weighing 3.78 grams, the heaviest lightweight stone out of the 900 considered for shooting. 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.

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 27. The stones shot out of this family were selected from the histogram 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

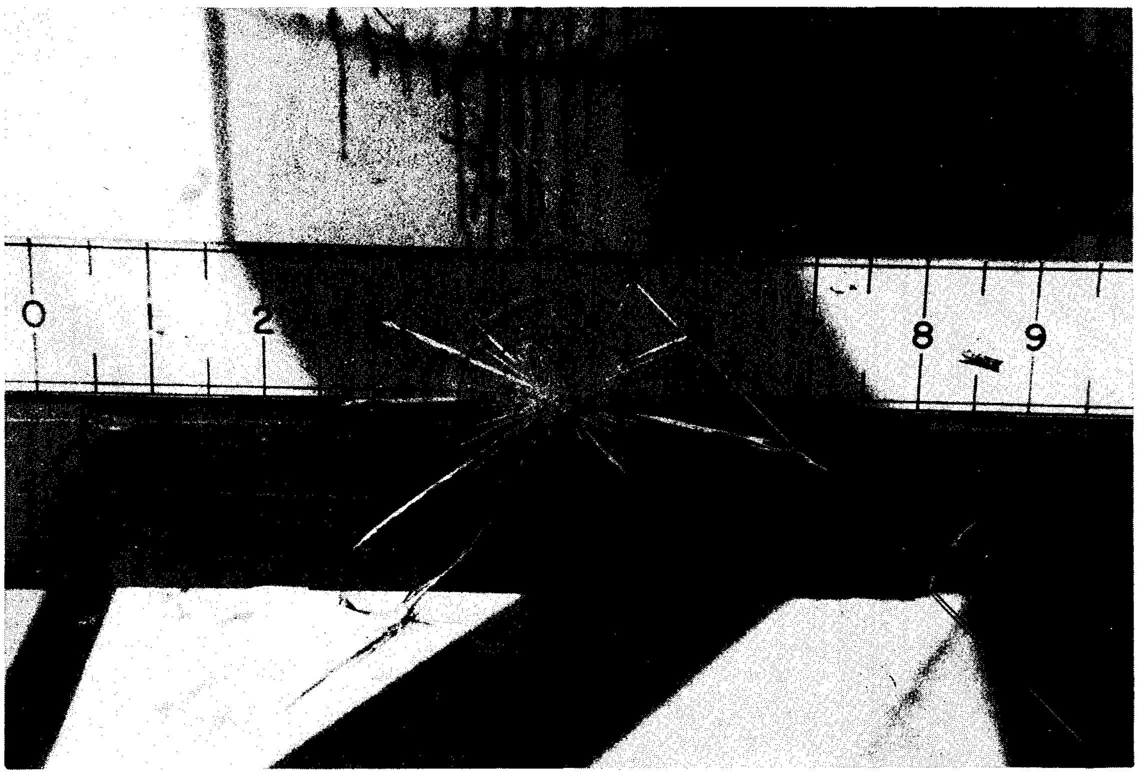


Figure 28. Most severe windshield damage caused by type F material.

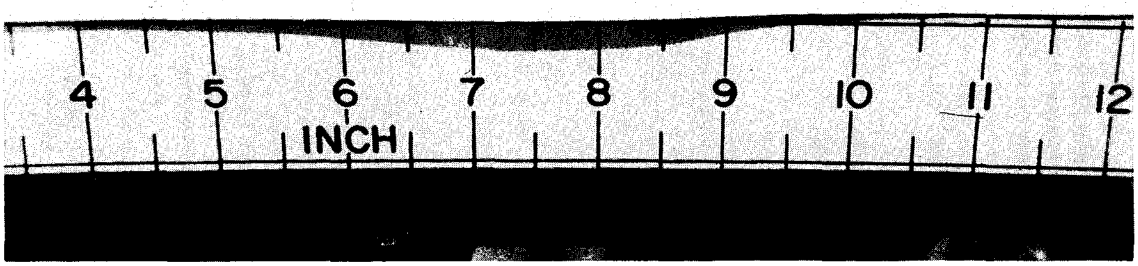


Figure 29. Typical "powder burn" of lightweight aggregate on impact into laminated glass windshield.

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

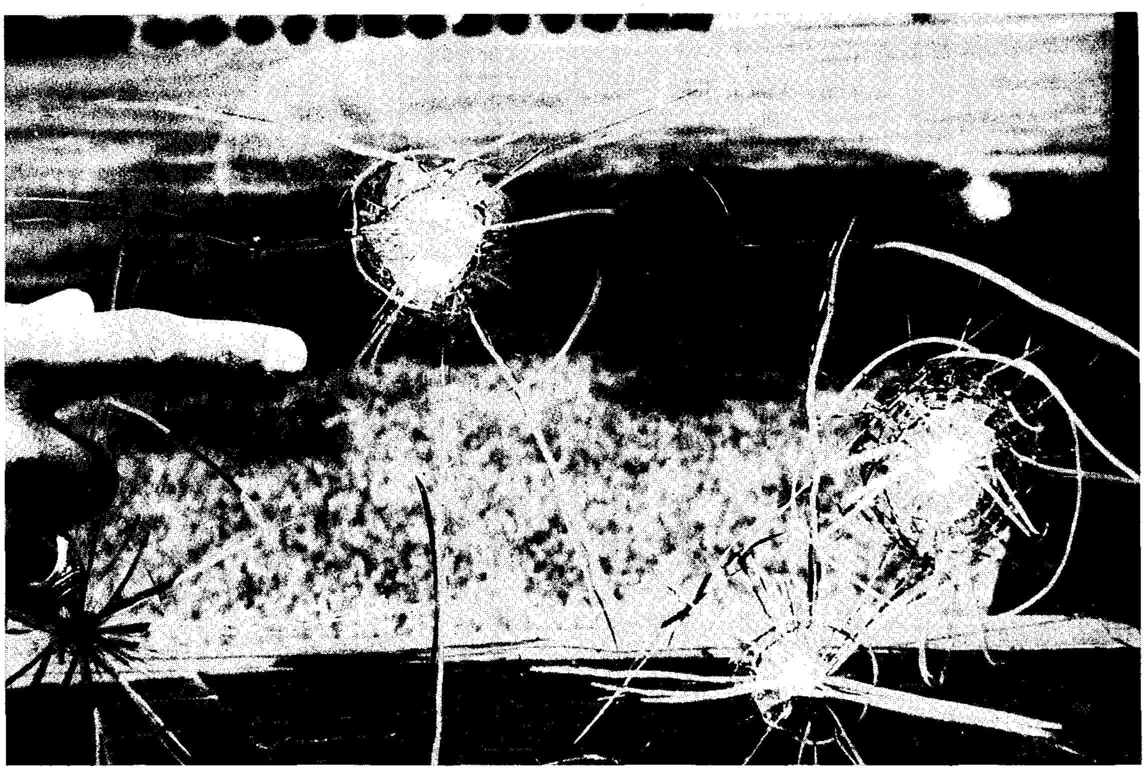


Figure 31. Laboratory windshield damage caused by Type PB material. (Same windshield as Figure 30.)

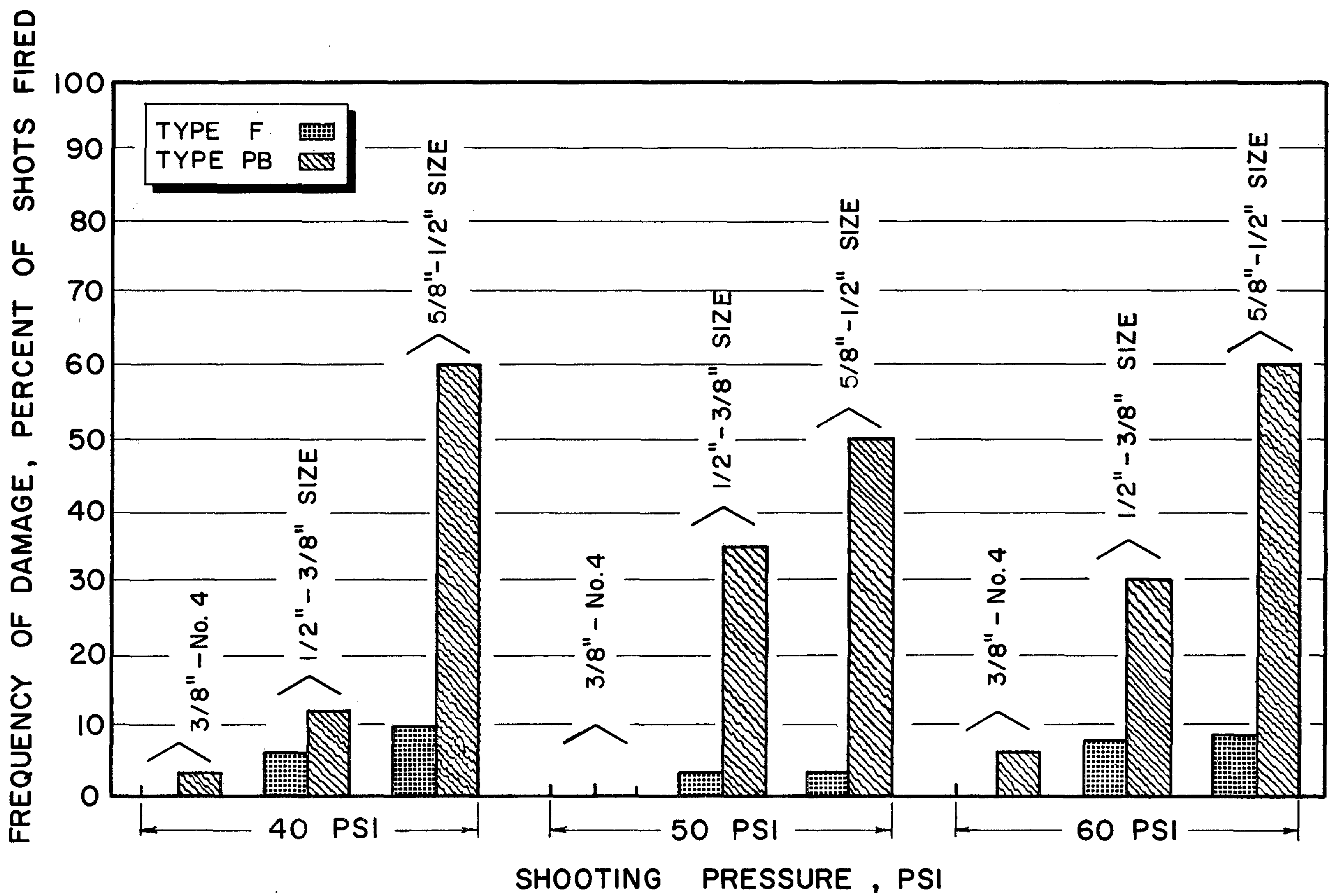


FIGURE 32 COMPARATIVE DAMAGE TO WINDSHIELDS FOR TYPE F AND TYPE PB AGGREGATE SHOT AT DIFFERENT PRESSURES

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 over-all results from the shooting of both lightweight and standard weight materials 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.

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 variable involved is the weight of the stones that were shot.

Modified Los Angeles Abrasion Tests

An abrasion study of lightweight aggregates was carried out by Rushing (17) 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 (AASHO Designation T4-35) (18) 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, (19) made a somewhat similar modification of ASTM's Designation: C 131-55. 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 Table I. The materials after test are shown in Figure 33.

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 complete data of Table II for comparative rates of wear for the lightweight aggregate used in this study, when these materials were 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 limited data given that the regular ASTM Test is more restrictive than either of the other two modifications. The Louisiana method which approximates the severity of the ASTM method is quicker and easier to run since it requires only 100 revolutions of the drum and the separation is made on the No. 4 sieve rather than the No. 12. 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 (13) 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 records 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.

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

TABLE I

A Comparison of Los Angeles Wear of Lightweight Aggregate by Three Methods

Grade	ASTM	Texas	Louisiana
B	28.6	21.6	21.0
BC	--	15.5	23.2
C	23.9	17.8	25.1

Table II

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

Size Range	Sample Weight, Gms	Abrasive Charge, Gms	Test Method	Percent Loss
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

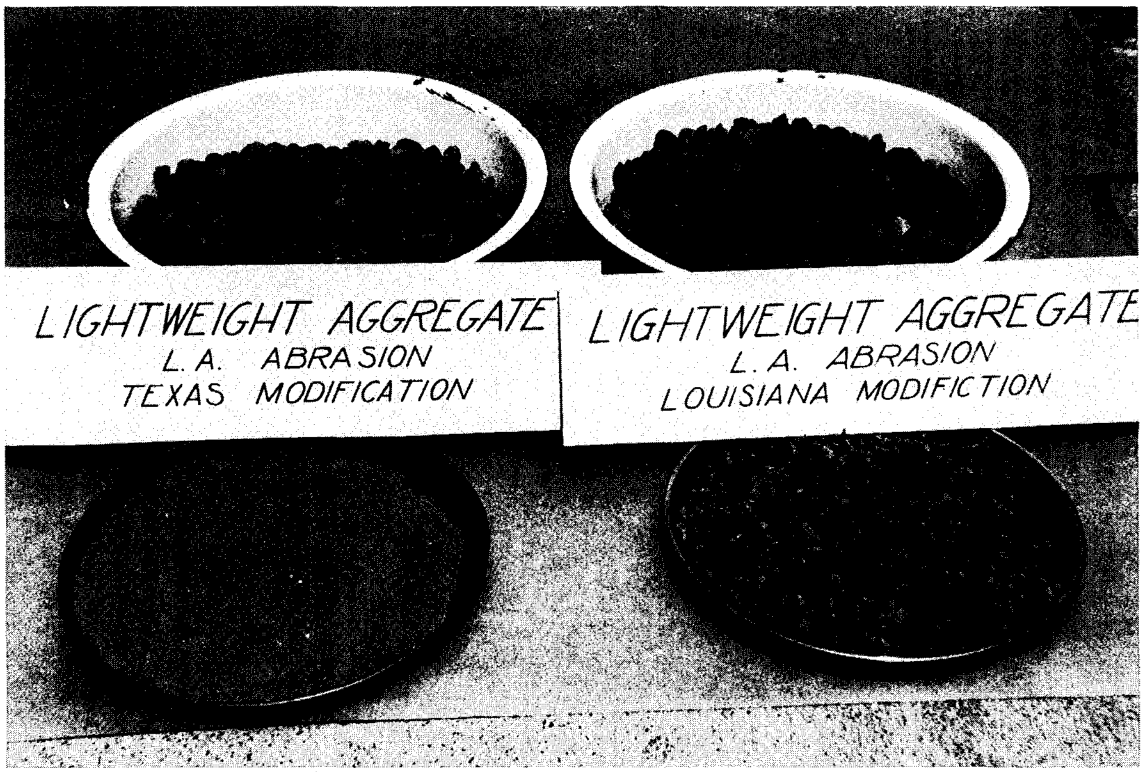


Figure 33. Type F materials after testing by Texas and Louisiana methods for L. A. wear.

TABLE III - AVERAGE VALUES FOR PHYSICAL PROPERTIES OF ROCK[a]

Kind of Rock	Toughness		Hardness		Loss by Abrasion			
					Deval Test		Los Angeles Test	
	Number of Tests	Average	Number of Tests	Average	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

[a]From "Results of Physical Tests of Road-Building Aggregate"
[b]Including andecite, dacite, rhyolite, and trachyte
[c]Including granodiorite, pegmatite, and unakite

After Woolf

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 require that cover aggregate be subjected to a freeze-thaw test. Neither ASTM nor AASHO 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 34. 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 two grades 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 Table IV.

It is interesting to note in Table IV that the material became progressively more resistant to freezing and thawing as the average particle size decreased. 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. This correction is shown in Tables V and 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 5/8 to 1/2-inch material in the original samples caused this difference.

As previously mentioned, this lightweight aggregate is 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

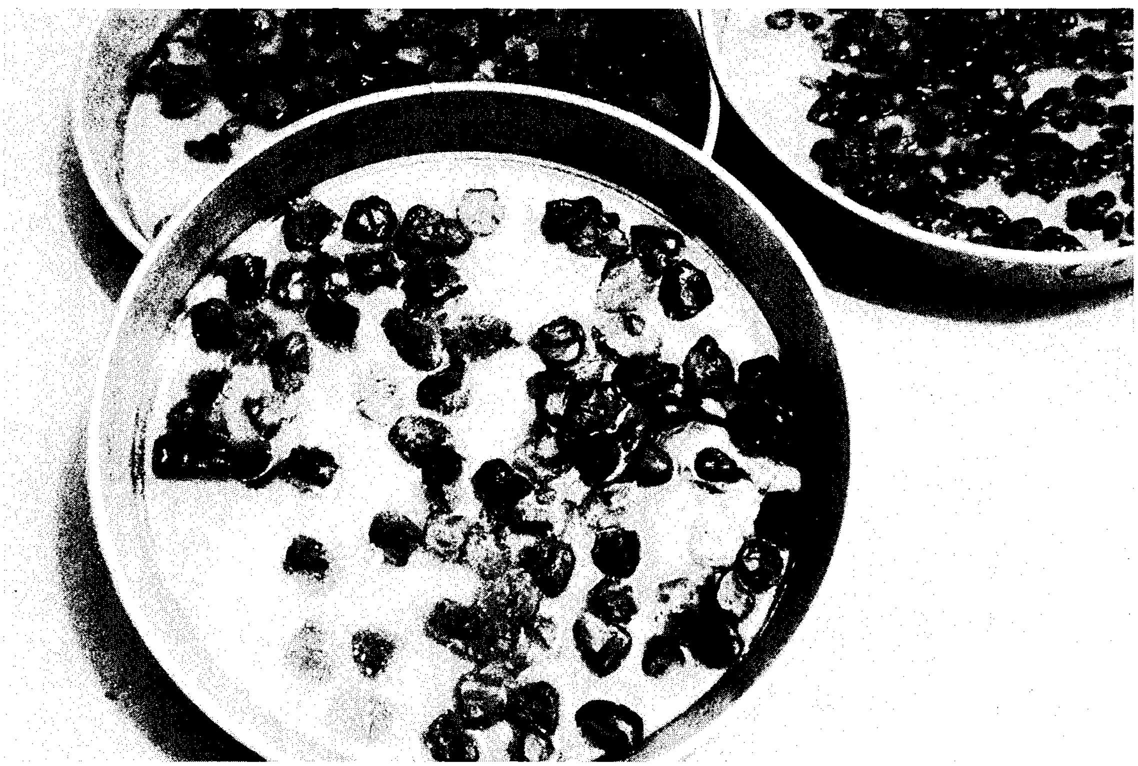


Figure 34. Type F material after freezing in water.

TABLE IV

Rapid Freeze-Thaw of Lightweight Aggregate

Sample	Size Range	No. of Particles	Wt. Before Test, Gms	Wt. After 50 Cycle, Gms	Wt. After 100 Cycles, Gms
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

Corrected Percentage Loss After
50 Cycles of Freezing and Thawing

Type F Grade 4

Sieve Size	Grading of Orig. Sample	Actual Loss, Pct.	Weighed Loss, Pct.
5/8 - 1/2 inch	1	17.4	0.17
1/2 - 3/8 inch	14	8.3	1.16
3/8 inch-No. 4	76	1.3	0.99
		Total loss ------	2.32

Type F Grade 3

Sieve Size	Grading of Orig. Sample	Actual Loss, Pct.	Weighed Loss, Pct.
5/8 - 1/2 inch	12	17.4	2.09
1/2 - 3/8 inch	22	8.3	1.91
3/8 inch-No.4	55	1.3	0.71
		Total loss -----	4.71

TABLE VI

Corrected Percentage Loss After 100 Cycles
of Freezing and Thawing

Type F Grade 4

Sieve Size	Grading of Original Sample	Actual Loss, Pct.	Weighted, Loss, Pct.
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	1.40
		Total Loss--------	3.07

Type F Grade 3

Sieve Size	Grading of Original Sample	Actual Loss, Pct.	Weighted Loss, Pct.
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	.83
		Total Loss--------	6.46

along these or similar planes of weakness thus making the smaller particles comparatively stronger. The Grade 4 material contained very little of the weaker plus 1/2-inch size and lots of the 3/8-inch to No. 4 stronger material; so, it is easy to see why the loss suffered by the Grade 4 material is much lower.

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 the state 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 $0^{o} \pm 5^{o}$ F.

Soundness Tests

The lightweight aggregate under study was subjected to five cycles of the soundness test, ASTM Designation C 88-61T, using magnesium sulfate solution.

Results of these tests are shown in Tables VII and VIII. 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. 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 35 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.

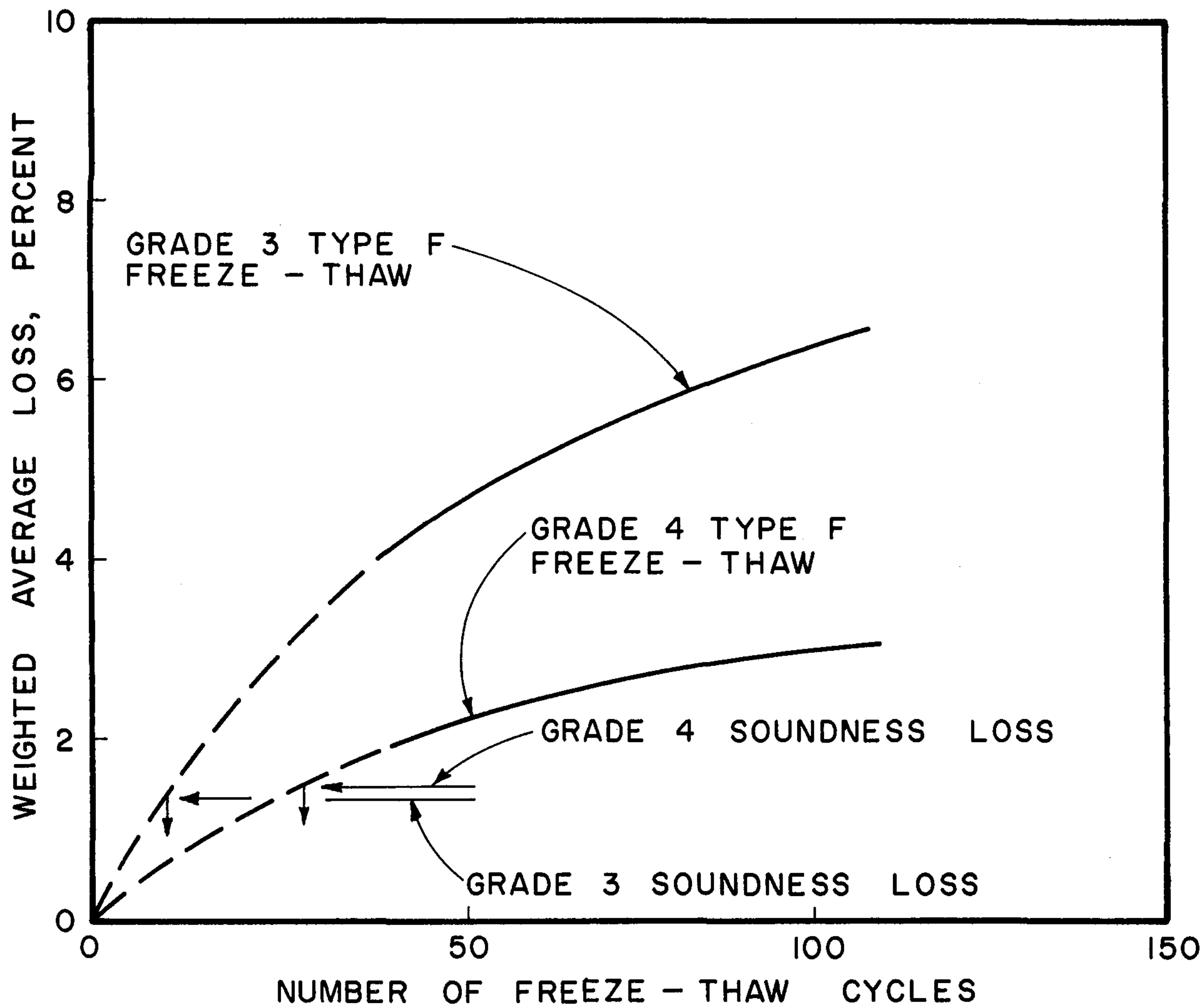


FIGURE 35 COMPARATIVE FREEZE - THAW AND SOUNDNESS LOSSES

TABLE VII

Soundness Test No. 1 Sample A

Type F Grade 4

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.14
		Total Loss-----	1.56

Type F Grade 3

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.14
		Total Loss-----	1.47

Soundness Test No. 1 Sample B

Type F Grade 4

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.22
		Total Loss-----	1.41

Type F Grade 3

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
5/8-1/2 inch	12	0.60	0.07
1/2-3/8 inch	22	0.99	0.22
3/8 inch-No. 4	55	1.37	0.75
No. 4-No. 8	5	4.40	0.22
		Total Loss------	1.26

TABLE VIII

Soundness Test No. 2 Sample A

Type F Grade 4

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.13
		Total Loss	1.55

Type F Grade 3

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.13
		Total Loss	1.41

Soundness Test No. 2 Sample B

Type F Grade 4

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.23
		Total Loss	1.26

Type F Grade 3

Sieve Size	Grading Orig. Sample	Actual Loss, %	Weighted Loss, %
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	0.23
		Total Loss	1.13

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 overall 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.

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 was possible by prior aggreement 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 Table IX and X.

It is to be noted that for those roads listed in Table IX some material application rate or 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 X 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.

TABLE IX

Designated Precoat and Lightweight Aggregate Field Test Sections

Highway	County & District	Length of Sec. ft.	Coverstone Type & Grade	Rolling Hrs. per Mi.	Asphalt Gals. per S.Y.	Coverstone C.Y. per S.Y.	Traffic vpd
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
FM1715	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	1-110	150

Highway	County & District	Length of Sec. ft.	Coverstone Type & Grade	Rolling Hrs. per Mi.	Asphalt Gals. per S.Y.	Coverstone C.Y. per S.Y.	Traffic vpd
FM 1884	Parker-2	1980	PB-4	Steel-1 Pnu-4	0.29	1-110	100
FM 1884	Parker-2	1980	PB-4	Steel-1 Pnu-4	0.27	1-110	100
FM 1884	Parker-2	1980	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

TABLE X

Undesignated Precoat and Lightweight Aggregate Field Test Sections

Highway	County & District	Date of Construction	Coverstone Type & Grade	Rolling Hrs. per Mi.	Asphalt Gals. per S.Y.	Coverstone C.Y. per S.Y.	Traffic vpd
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

Highway	County & District	Date of Construction	Coverstone Type & Grade	Rolling Hrs. per Mi.	Asphalt Gals. per S.Y.	Coverstone C.Y. per S.Y.	Traffic vpd
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	1-100	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

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 came 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 36 and 37. 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 37, 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 (21) 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 38. 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

Figure 36. Cutting a field sample with a portable saw.

Figure 37. Cutting a field sample with an ax.

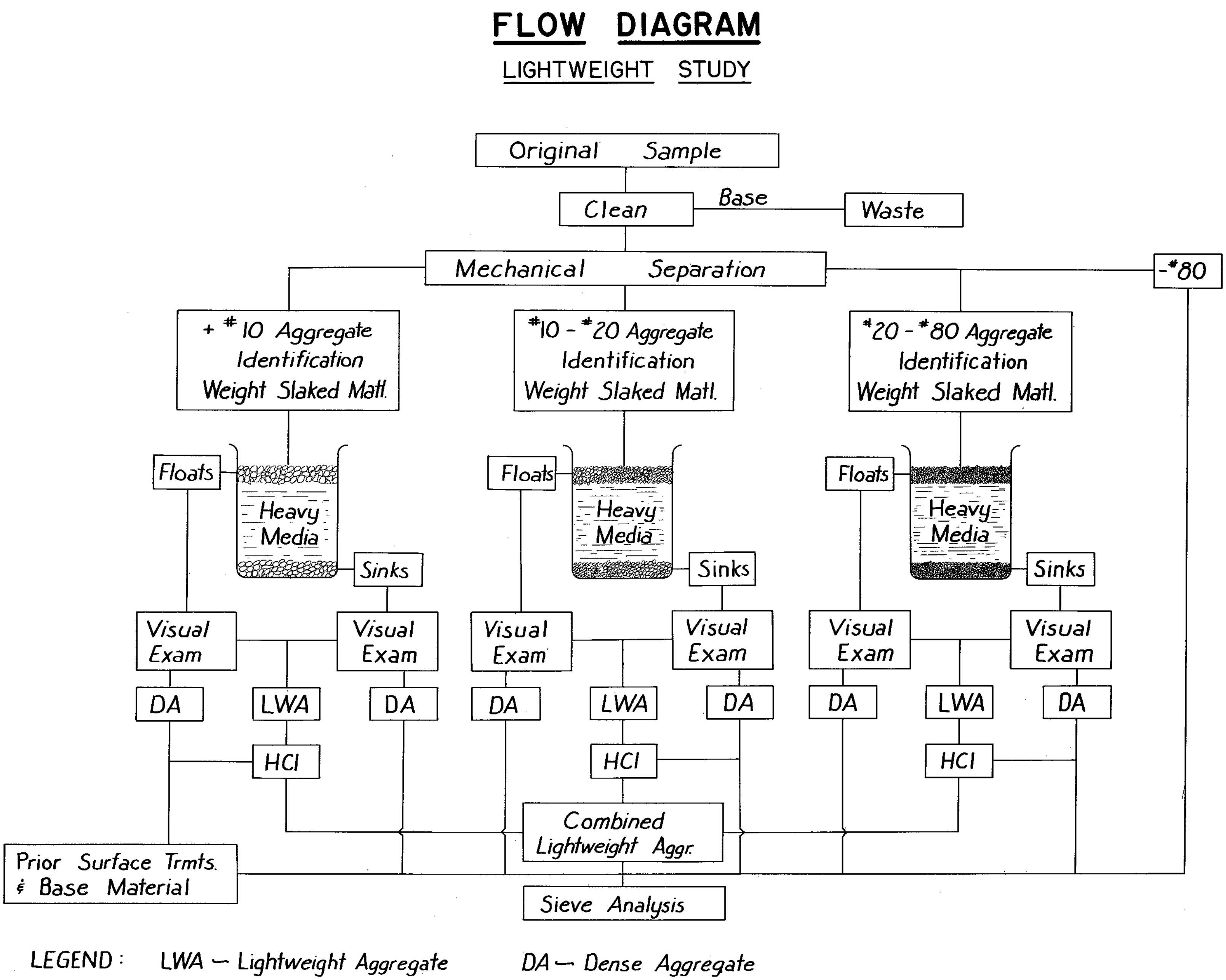


Figure 38. Flow diagram for heavy media separation of lightweight aggregates from field samples.

to make a satisfactory separation of the lightweight material from the contaminated composite.

Following the cleaning and separating procedures the individual fractions were recombined and analysed 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 39. The range in the grading of typical field stockpile samples of Grade 4 stone is shown in Figure 40. 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 40. Field samples of these same materials were taken from the road surface and recovered according to the flow diagram of Figure 38. The grading of these 25 pavement samples fell within the bounds indicated on Figure 40.

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 41. By comparing the "after" curve with the range of "after" gradings shown in Figure 40, 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 42 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.

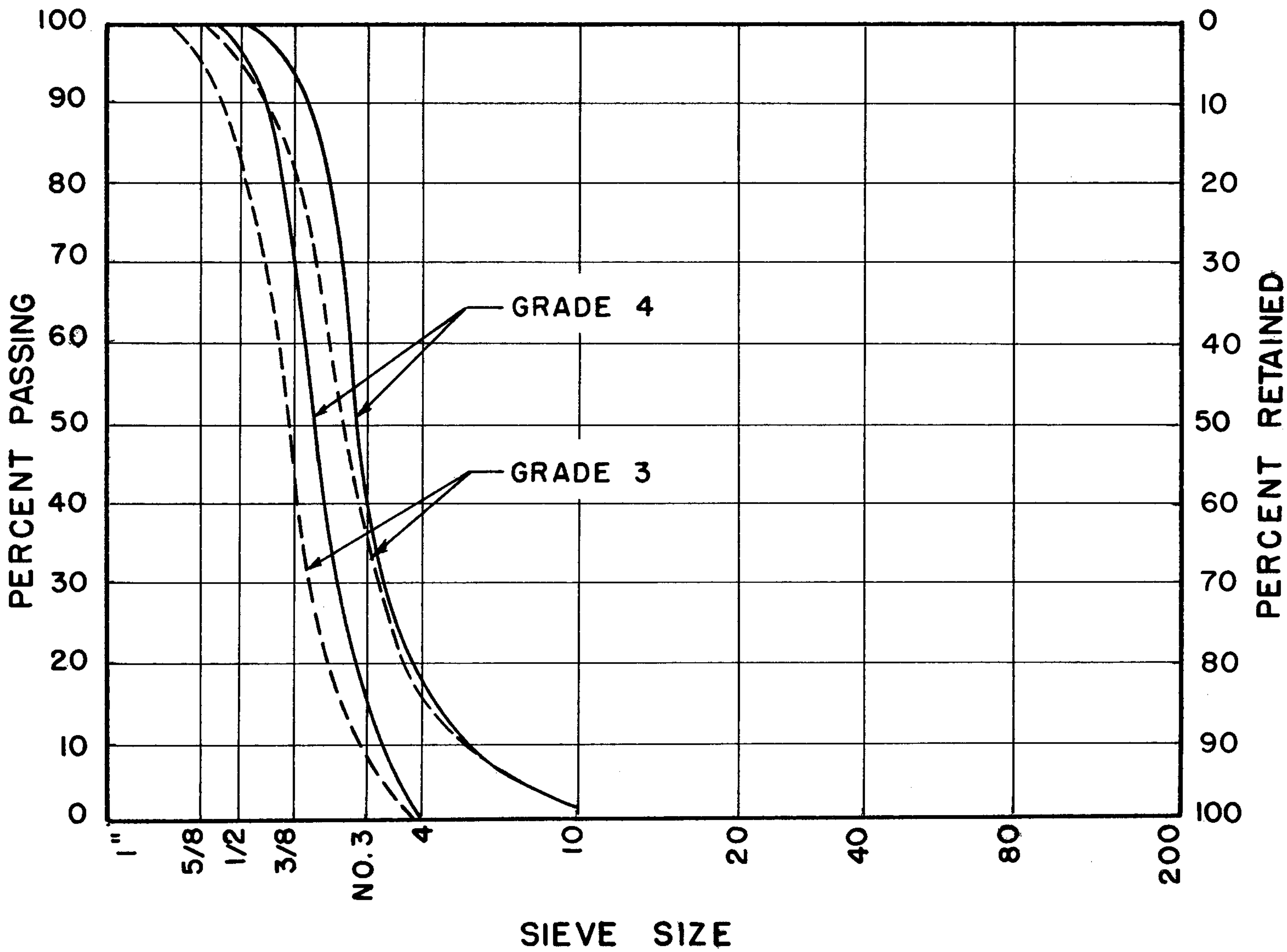


FIGURE 39 GRADATION REQUIREMENTS OF THD ITEM 302 COVERSTONE, GRADES 3 & 4

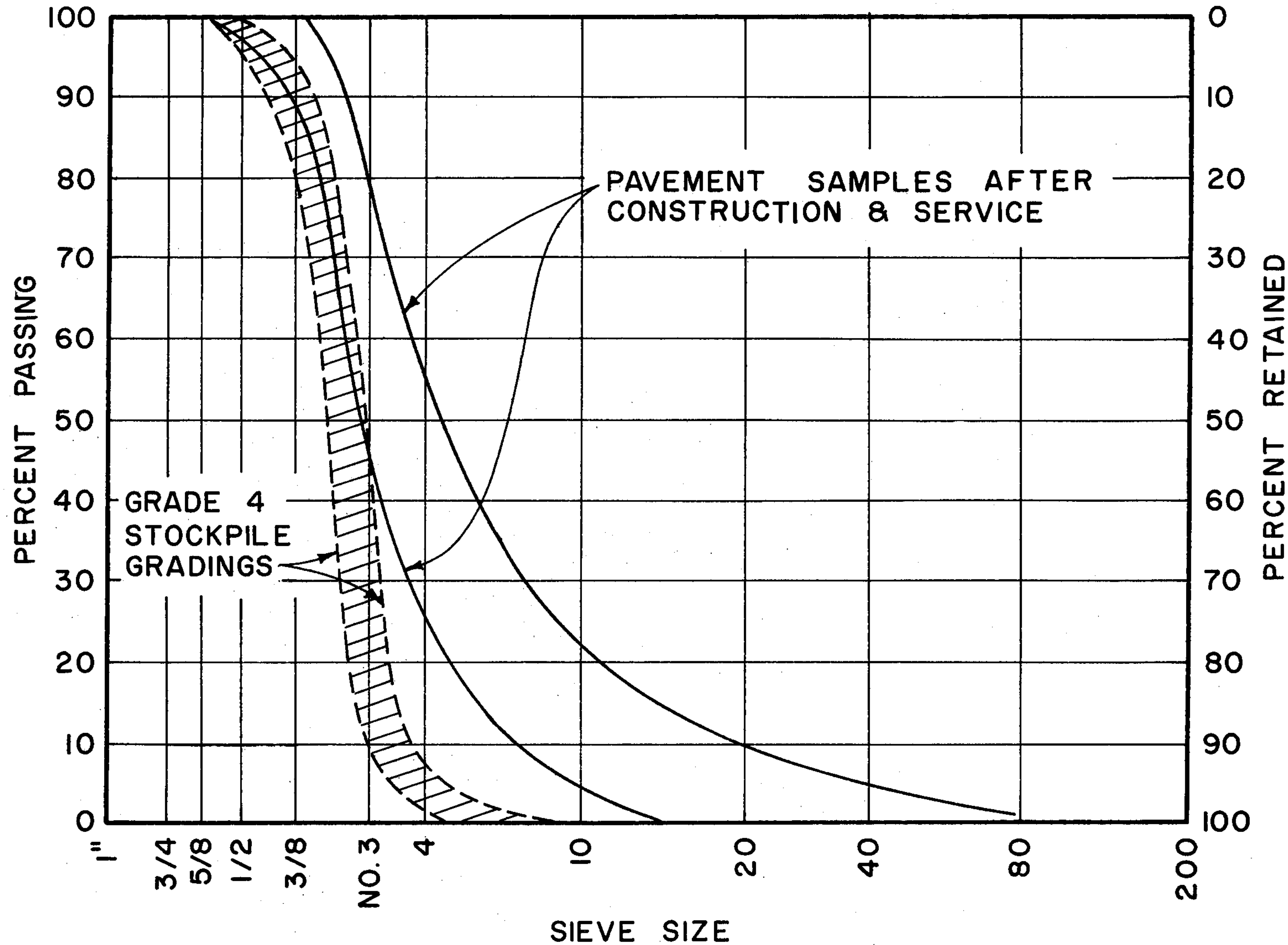


FIGURE 40 COMPARATIVE DEGRADATION OF LIGHT-WEIGHT AGGREGATE DUE TO CONSTRUCTION AND SERVICE

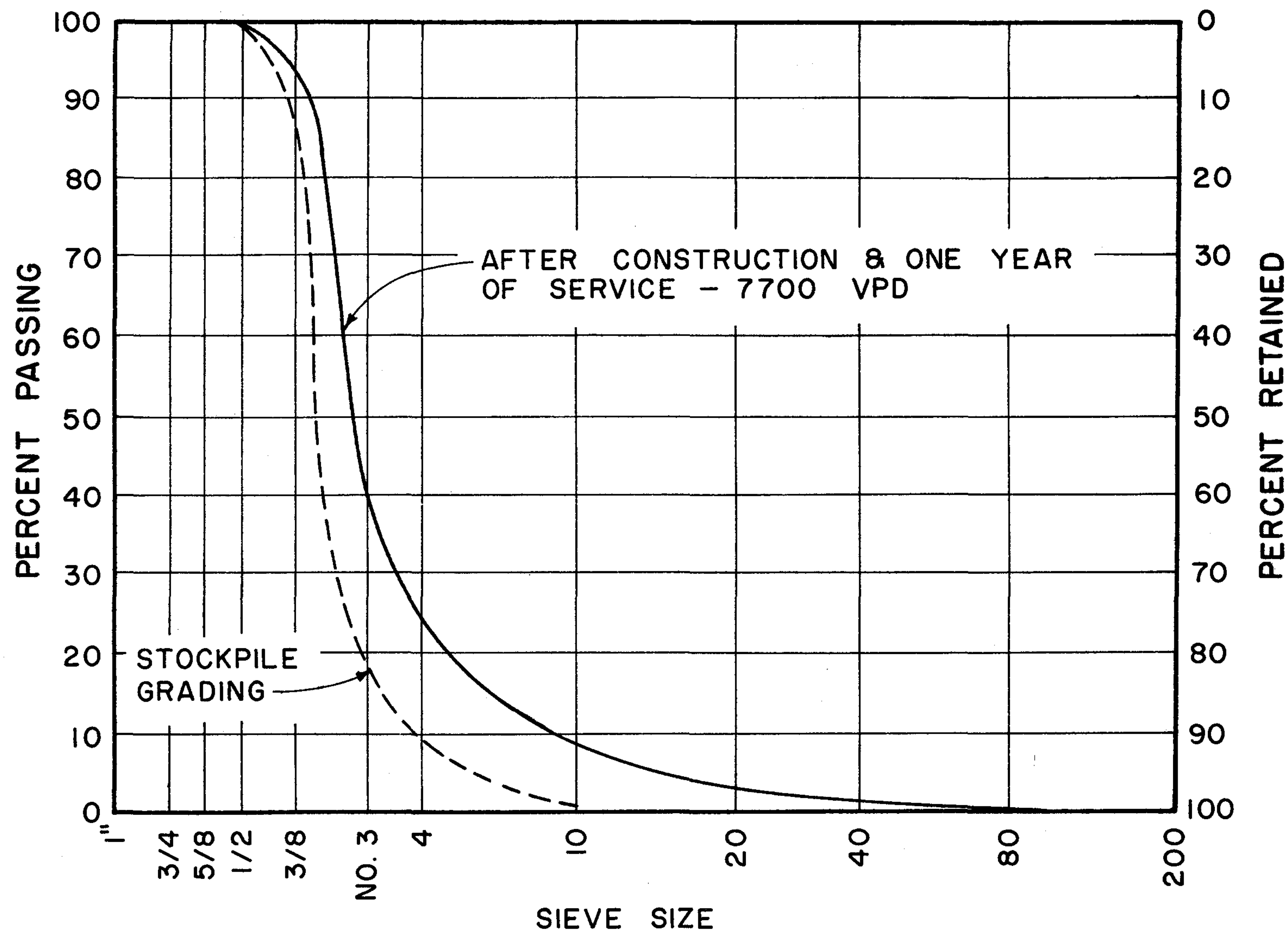


FIGURE 41 TIME AND LEVEL OF SERVICE A MINOR FACTOR IN DEGRADATION OF TYPE F COVERSTONE

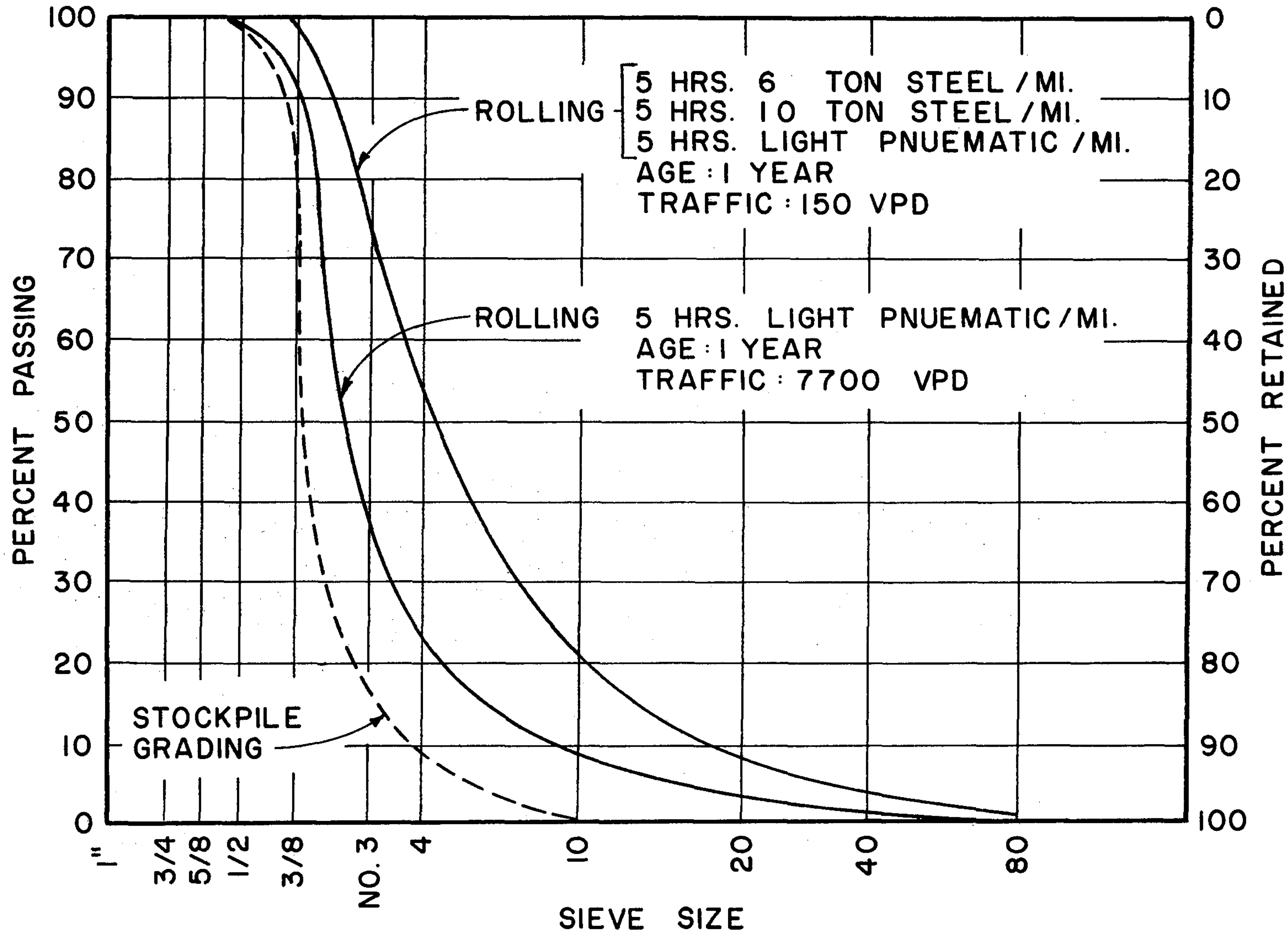


FIGURE 42 DEGRADATION OF TYPE F AGGREGATE DUE TO CONSTRUCTION AND SERVICE

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 nine precoated limestone sections are shown in Figure 43. 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 39 and 40) overlap but this, of course, incorporates a number of variables that have their individual effects on the grading of a given material.

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 44. This surface is two years old and carries 7700 vpd. A close-up of this surface is shown in Figure 45. 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 46 shows the roadside stockpile of Type F material and the contractor's loading operation. In Figure 47 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 48 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 it 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 men-

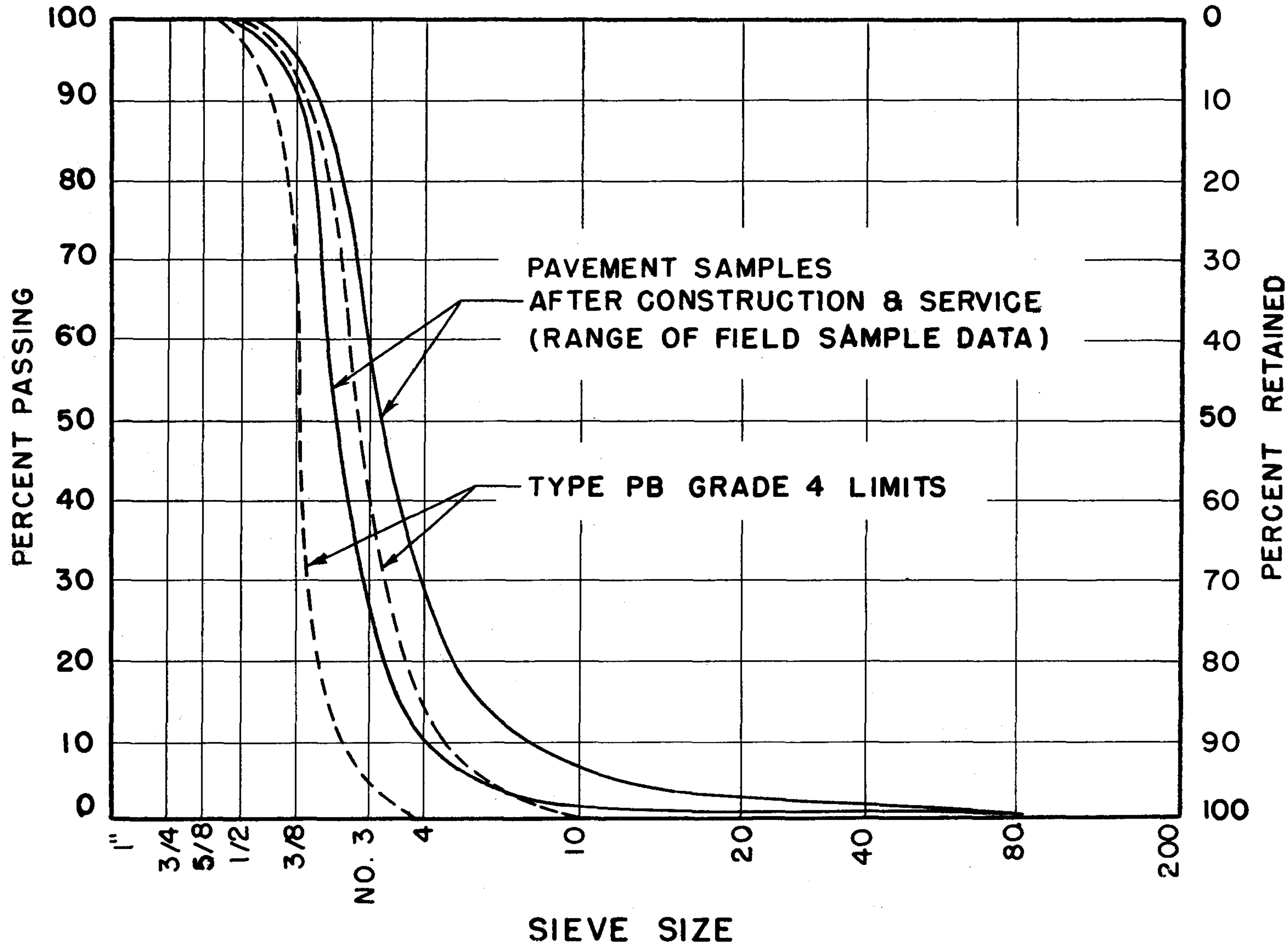


FIGURE 43 COMPARATIVE DEGRADATION OF PRECOATED LIMESTONE DUE TO CONSTRUCTION AND SERVICE

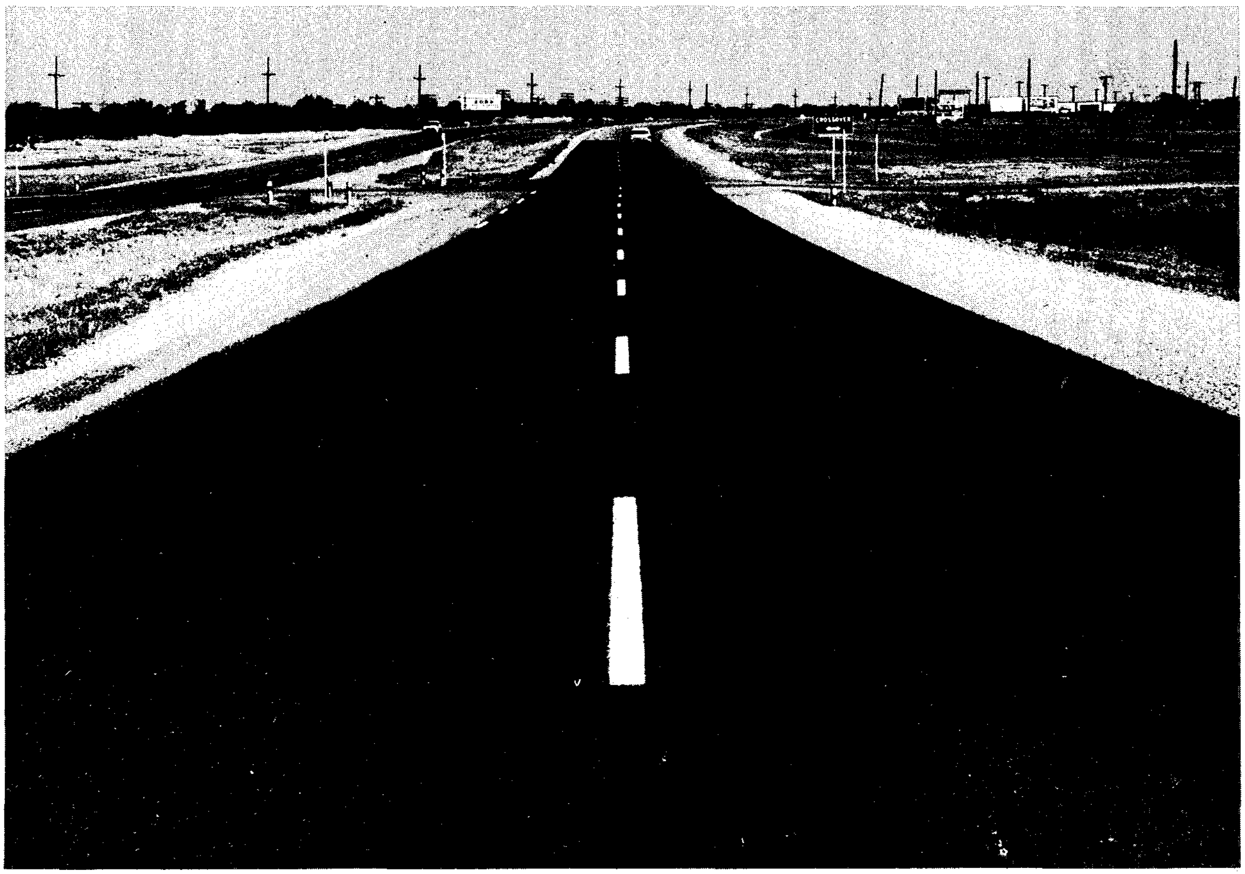


Figure 44. Type F seal two years old with 7700 vpd. (Photo by Billingsley and Plumlee.)

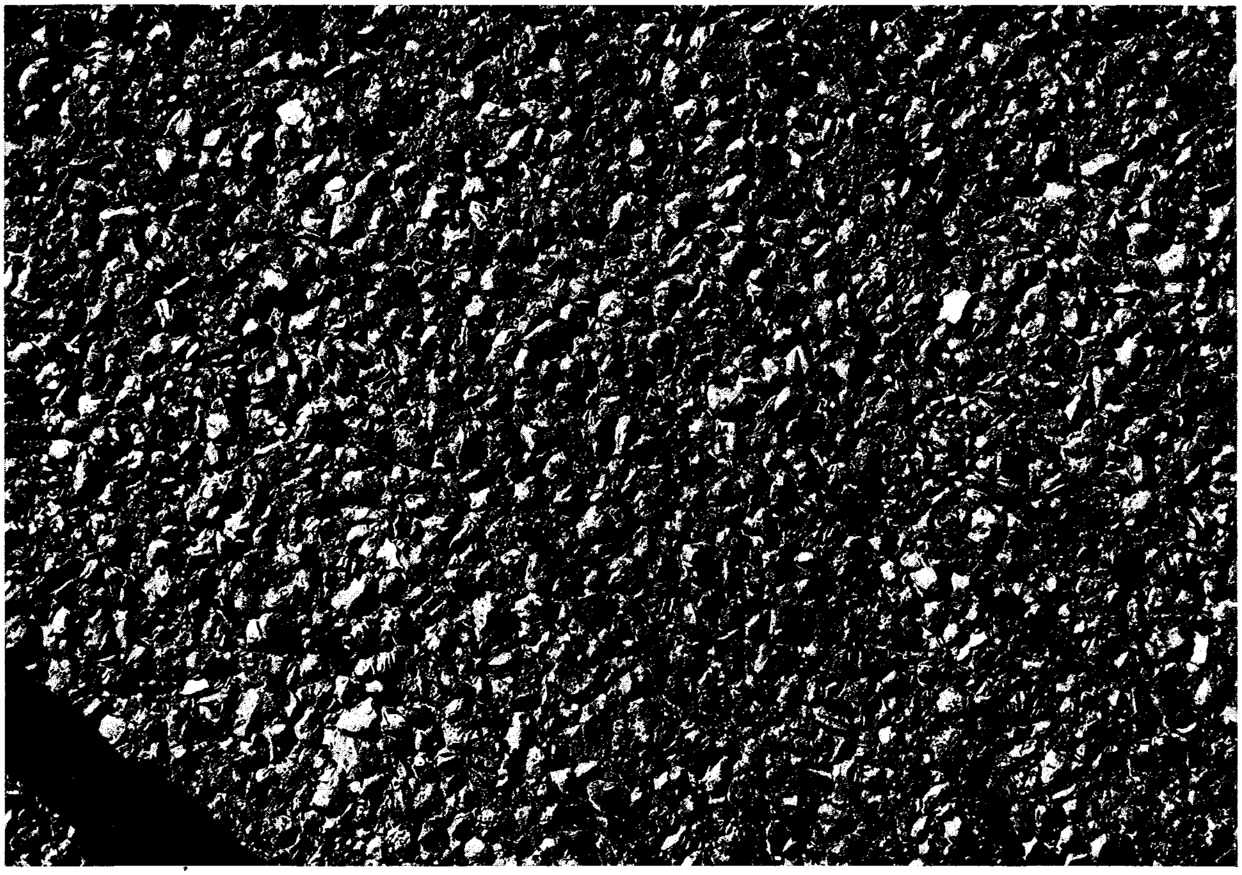


Figure 45. Close-ups in the wheel path showing excellent condition of Type F cover aggregate after two years' service.

Figure 46. Stockpile and loading operation of Type F material.

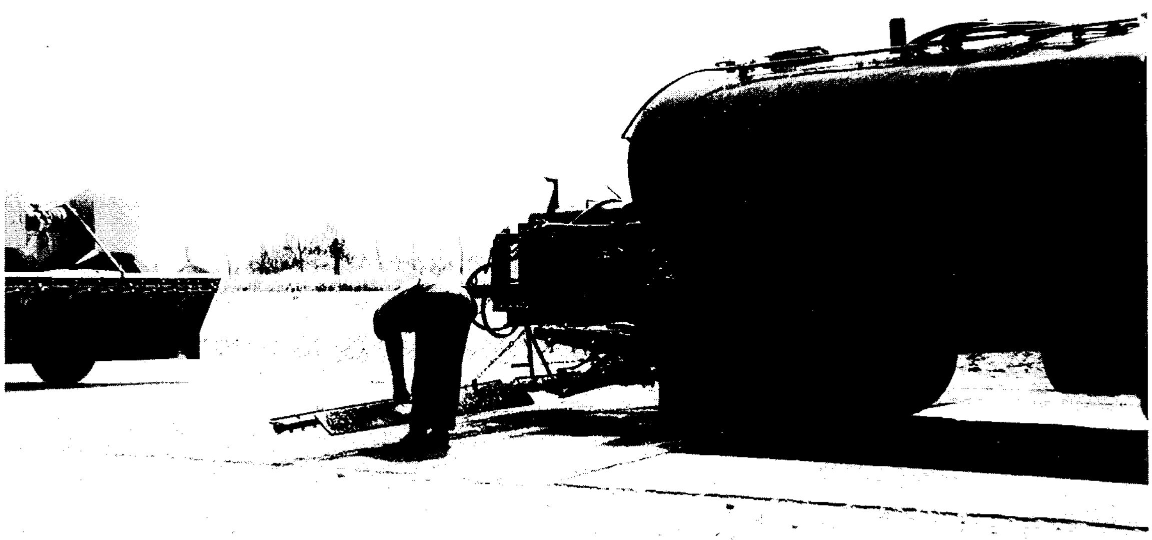


Figure 47. Distributor operator placing wind guard on spray bar.

Figure 48. Patches create variations in asphalt demand of surface.

tioned this is a variable difficult to take into practical consideration. Another picture in this series is Figure 49. 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 50 and 51 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.

FM 1192 in Johnson County was constructed with Type F cover aggregate and Figures 52 and 53 indicate above average application of asphalt. 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 52. 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 to 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 54. This picture of a Type F coverstone job was taken six weeks after construction. A close-up, Figure 55, 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 56.

The use of a blade broom is shown in Figure 57. 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 58. 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 59. 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 for the stone being used.

Shown in Figure 60 is an experimental section of hot-mix asphaltic concrete made with burned clay and field sand as the aggregates. This is

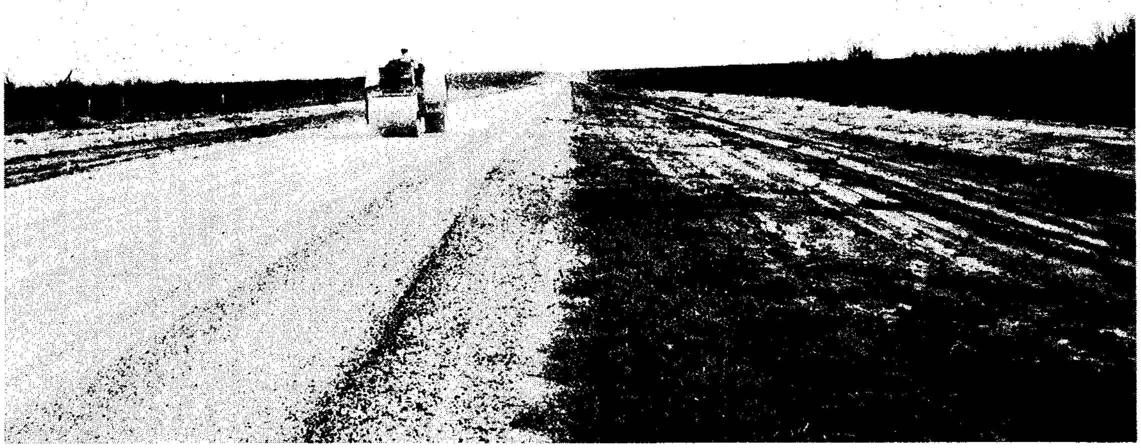


Figure 49. Experimental section proves that the use of steel flat wheel roller is not advisable.

Figure 50. Type F material after one year of light traffic.

Figure 51. Type F material presents a pleasing contrast for center stripe.

Figure 52. No center stripe concentrates traffic in center third of FM 1192. (Photo by Gustafson.)

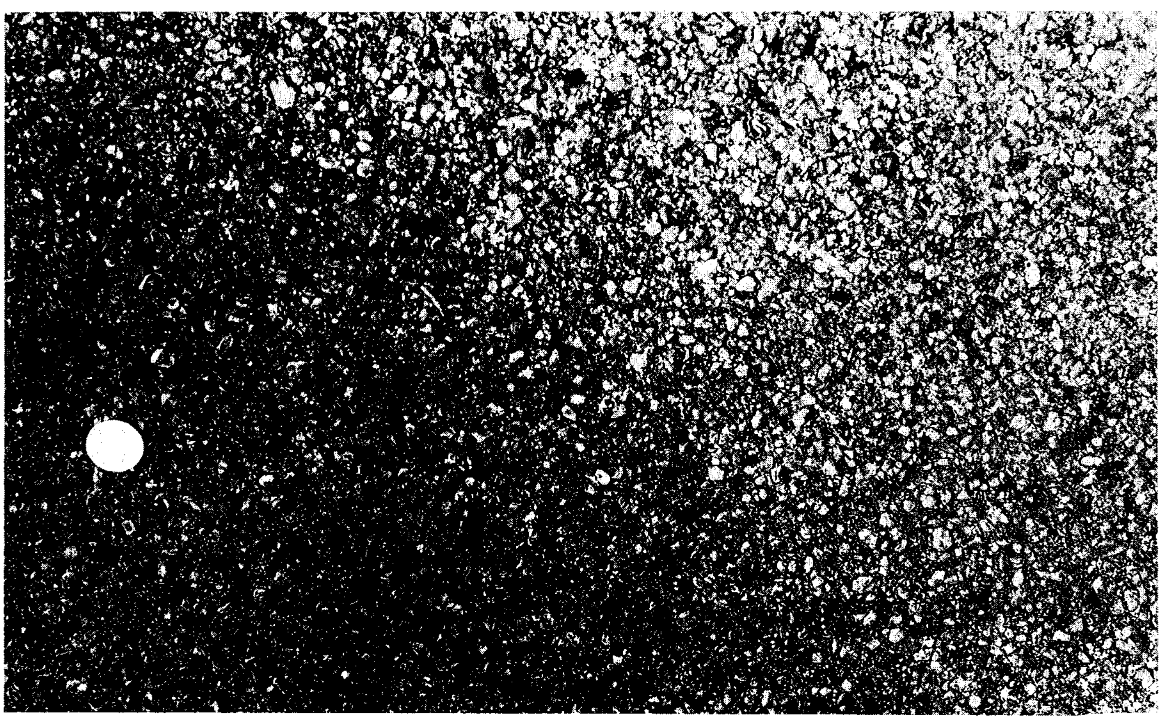


Figure 53. Close-up of center third of above road. Surface not flushed. (Photo by Gustafson.)

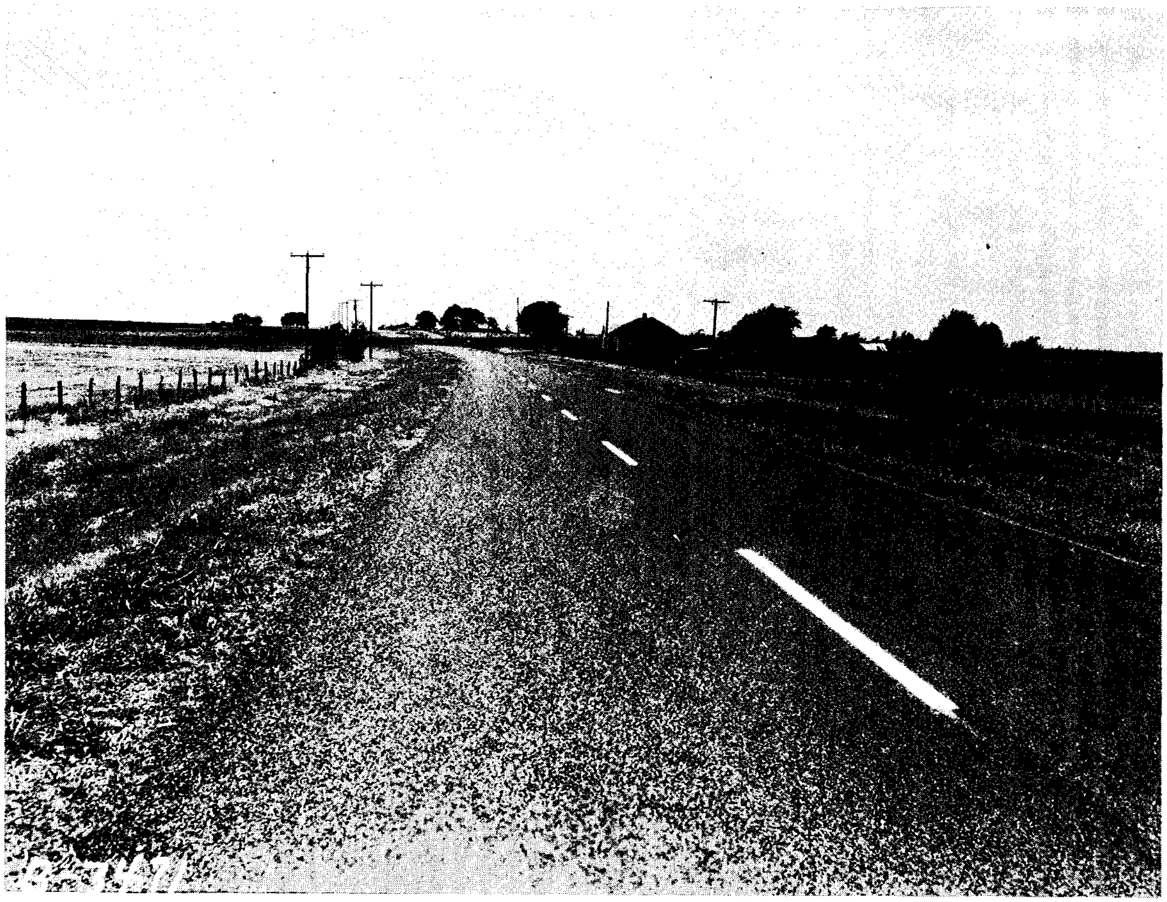


Figure 54. Typical form-to-market road surfaced with Type F material. (Photo by Gustafson.)

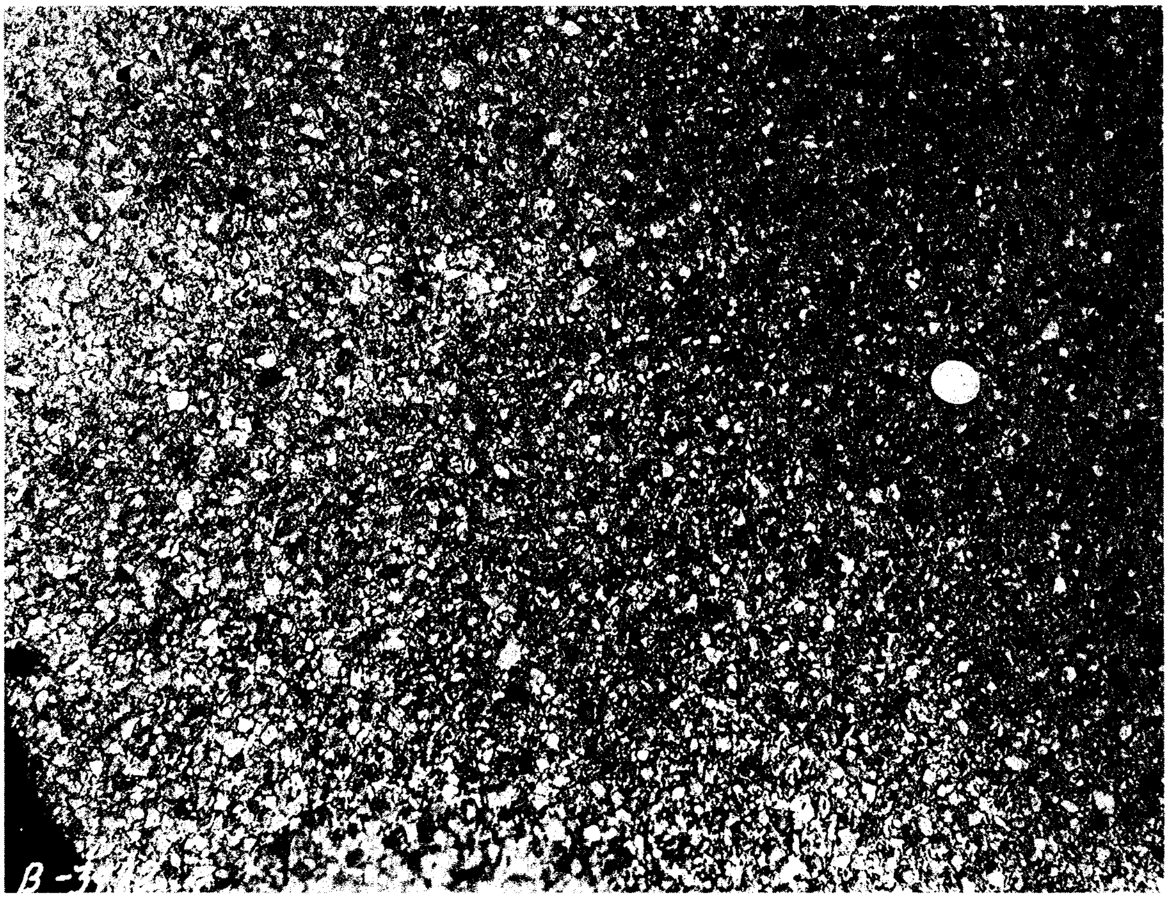


Figure 55. Type F Grade 4 coverstone three months after construction FM 744. (Photo by Gustafson.)

Figure 56. Type F cover aggregate in service three months, 1500 vpd, U S 190. (Photo by Gustafson.)

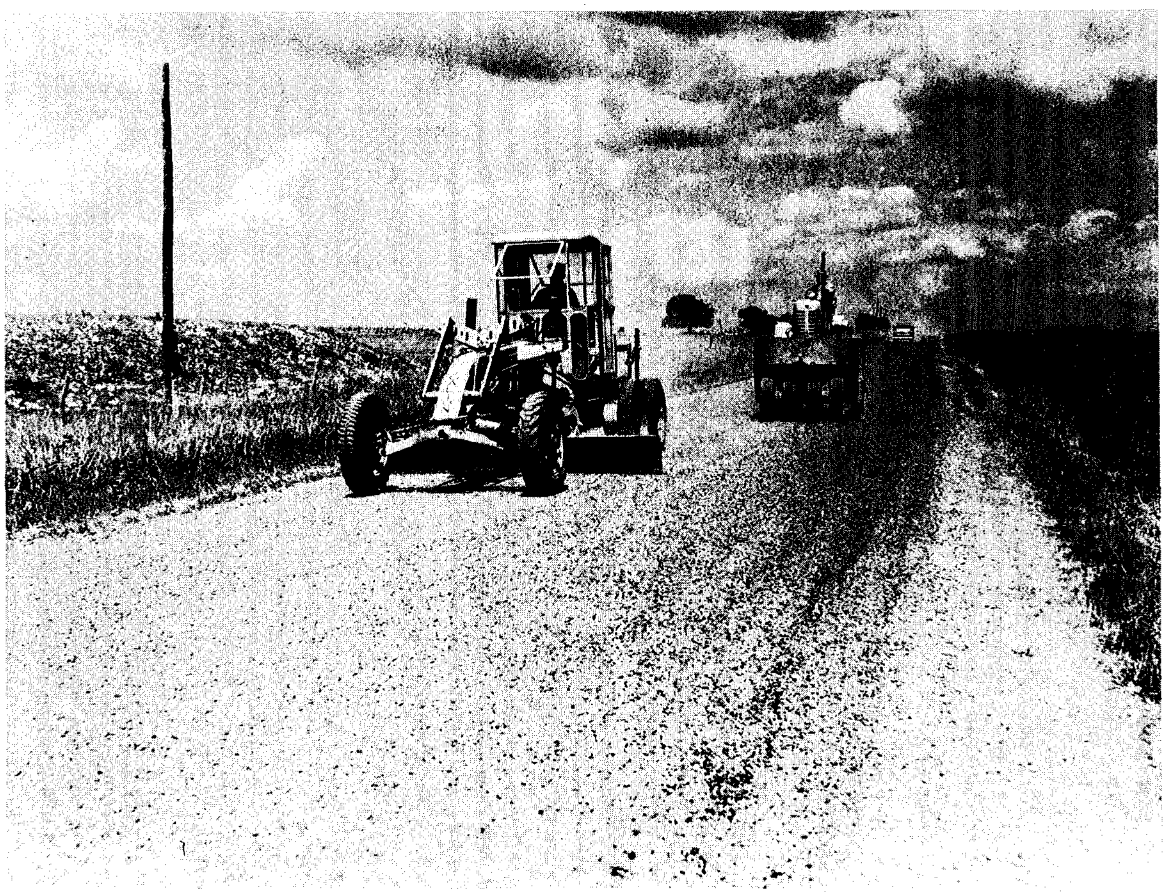


Figure 57. Blade broom successfully used on Type F coverstone. (Photo by Gustafson.)

Figure 58. Adhesion of asphalt to Type F material is very good.

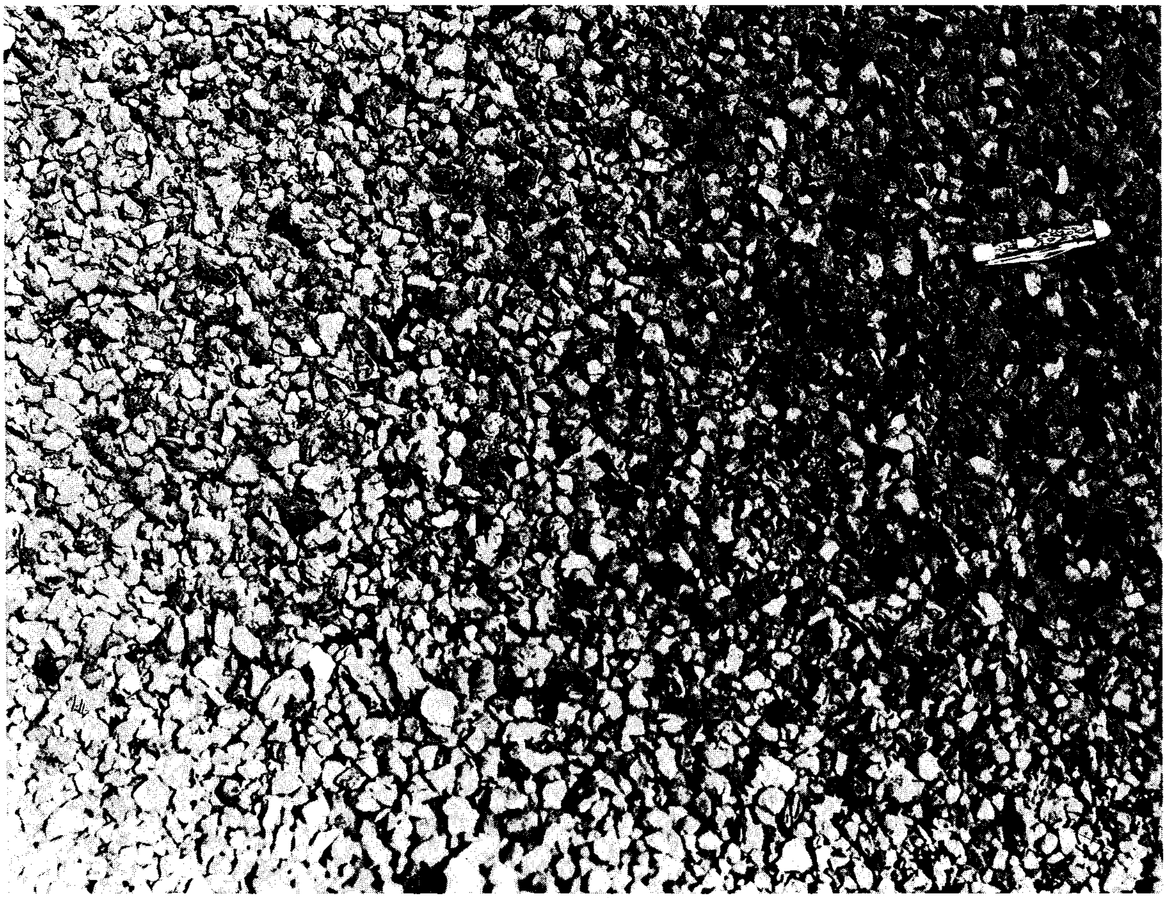


Figure 59. Type F Grade 3 after brooming. Spread rate -- 130 square yards per cubic yard. (Photo by Gustafson.)

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 a 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.

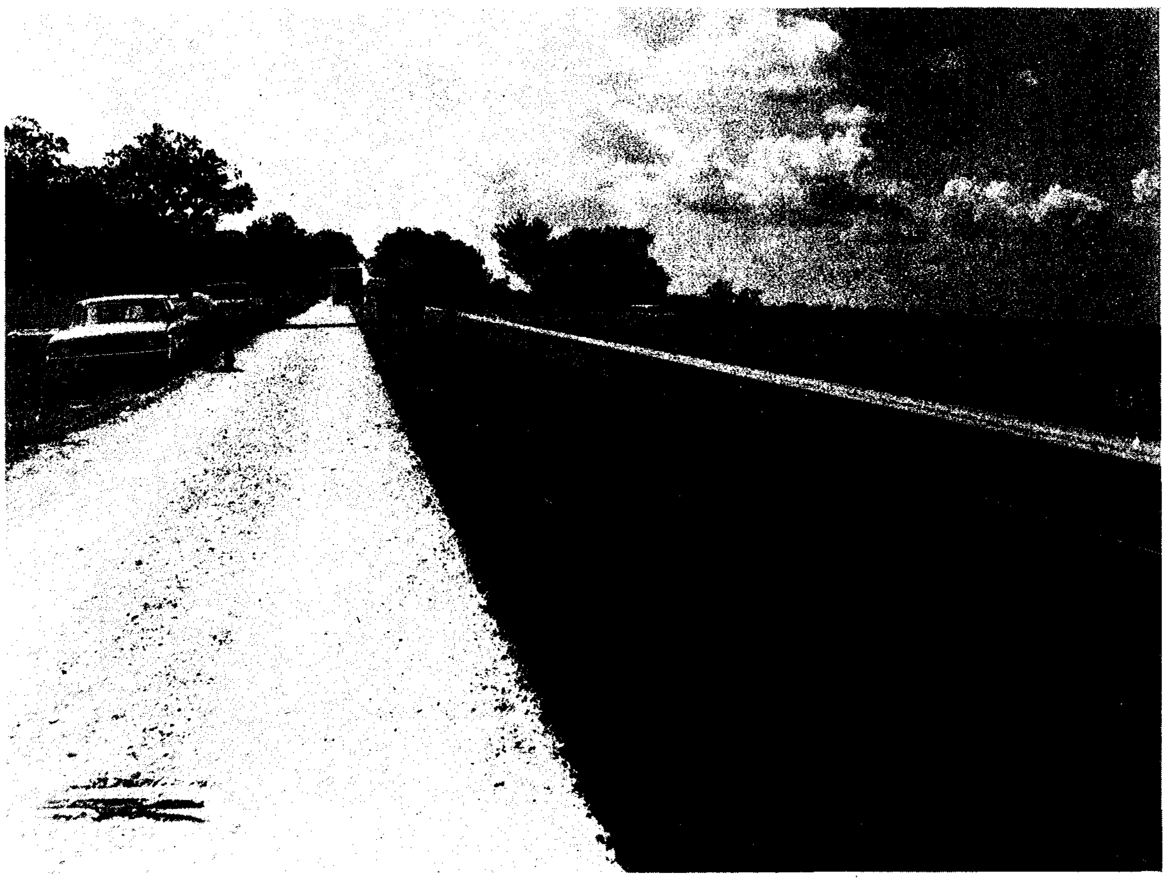


Figure 60. Hot-mix with burned clay aggregate placed on SH 6. (Photo by Gustafson.)

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 do not create a 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 observations 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.

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21. 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.

APPENDIX A

TEXAS HIGHWAY DEPARTMENT

SPECIAL SPECIFICATION

Item 1164

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 maximum dry loose unit weight of coarse lightweight aggregates shall not exceed 55 pounds per cu.ft. If the unit weight of any shipment of lightweight aggregate differs by more than 6 percent from that of the sample submitted for acceptance tests, the aggregates in the shipment may be rejected. Tests shall be in accordance with Test Method Tex-404-A, except that the aggregates 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
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
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 1/2" 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.

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 the 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:

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

$$X_1 = \frac{(C_L)\ (U_L)}{97.0}$$

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_1 = 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.

APPENDIX B

BIBLIOGRAPHY ON LIGHTWEIGHT AGGREGATE

1. Surface Treatments - Summary of Existing Literature, M. Herrin, K. Majidzadeh, C. Marek. The Engineering Experiment Station, University of Illinois in cooperation with Illinois Division of Highways and U.S. Bureau of Public Roads, August, 1963.

The first section of the report (Chapters II-VIII) contains the results of a comprehensive "library study." It is, in effect, a summary of the status of existing, published knowledge of seal coats and surface treatments. In this section, the basic constituents of a surface treatment, the aggregate and binder, and factors influencing their behavior in a finished treatment are discussed in detail. In Chapter IV, several known, current methods of design are discussed and the limitations of each noted. In addition, an Appendix is attached in which each design method is presented in detail and an example design given when possible. Also included is a summary and a chapter on areas of needed research as suggested in the literature. The authors believe that the information summarized in Chapters II through VIII and the Appendix is a valuable contribution to this field of study and may help in arriving at a more universally accepted method of design and proper construction techniques that will lead to better performing seal coats and surface treatments.

The second section of this report consists of a bibliography on seal coats and surface treatments. It too is the result of a comprehensive library study. In this study, all pertinent articles, either available at the University of Illinois Library or listed in other articles, were referenced. In addition, several articles not readily available at the university library were obtained in order that they might be included in the study.

The bibliography is divided into two groups. In one group (Chapter IX) articles are included that provide definite, valuable information related to the design and construction of surface treatments. Because of their importance, these articles were annotated to give a better understanding of the contents of the contents of each reference. The other group (Chapter X) contains articles that have only general information dealing with surface treatments. Since this latter groups contributed little to increasing the knowledge of this type of construction, the articles were not annotated and were placed in the separate chapter.

All information included in this report, including the bibliography, has been prepared from literature published prior to January, 1963. The reader should be aware of this terminal date since information published after this time may add to the technical knowledge on seal coats and surface treatments presented herein.

2. Bituminous Stabilization of Wyoming Heat-Altered Shale, Larry S. Slotta. Highway Research Board Bulletin No 282 - Influence of Stabilizers on Properties of Soils and Soil-Aggregates Mixtures, pp. 84-97, 1961.

Wyoming has future highway projects that will pass through areas lacking first-class aggregates, but containing a quantity of unproven heat-altered shale aggregate. Considering the possible transportation savings if the shale were to be used, research was undertaken to explore the possibility of improving the utility of asphalt as a stabilizer for heat-altered shale by the use of trace quantities of chemical additives known to react with asphalt, or with soil-mineral surfaces. Resulting Marshall design control methods (ASTM D 1559-58T) and effective weathering tests were used to evaluate the materials used. Various asphalts and/or additives were well above the minimum design criteria for roads receiving heavy traffic. Thus, constructing roads of heat-altered shale would be justified.

3. Suitability of Lightweight Aggregate for Bituminous Plant Mix, John C. Wycoff. ASTM Bulletin No 235, pp. 33-36, January 1959.

Using a reasonably well-graded 0 to 3/8-in. lightweight aggregate, Hubbard-Field tests as described by the Asphalt Institute and compressive strength tests as specified in ASTM Method D 1074 - 58 T, were performed at varying asphalt content. The results of these tests were highly satisfactory. Hubbard-Field tests of over 3,500 lb and compressive strength of over 350 psi were obtained using 11.0 to 11.5 percent 85-100 penetration asphalt. The second consideration was the effect of water on bituminous mixtures using this type of aggregate. Mixes tested in accordance with ASTM Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures (D 1075 - 54) showed an index of retained strength to be 89.1 percent. A field test strip four lanes wide and 200 ft long was placed on route 360 in Richmond, Va., November 19, 1957. This strip was placed using standard manufacturing and laying equipment without encountering difficulty. Between the dates of November 19, 1957, and May 23. 1958, this pavement was exposed to very severe weather conditions.

4. Use of Expanded Clay Aggregate in Bituminous Construction, H. L. Lehmann and Verdi Adam.
Highway Research Board Proc. 38: pp 398-407. (1959)

5. Cinder as heat insulating material and lightweight aggregate in cement mortar, I. S. Uppal, S. R. Bahadur.
Indian Concrete J 33: n5, p 167-8, May 1959.

Use of ground and screened cinder in cement-sand mortars, in various proportions was tested in India; chemical analysis of cinder and sand used; effects of proportions of mixing on reduction of heat conductivity and on tensile strength; other tests showed that waterproofing by soap treatment is successful also in presence of cinder in mixture.

6. Bloated clay aggregate--its production and marketing potential in Florida, M. J. Roberts.
<u>Florida Univ--Eng & Indus Experiment Station</u>-- Bul n 98, v 12, n 6, June 1958, 51 p.
Survey of Florida's lightweight concrete aggregates; types, limiting factor; production costs; mining, preparation of material, and bloating are described; use of traveling grate and rotary kiln methods; crushing, screening, and storage.

7. Mineral Aggregates: 1958 Revision--Annotated Bibliography, J. F. McLaughlin.
<u>Highway Research Board Bibliography</u> 23, No. 631, pp 1-111, 1958.
This revision includes and brings up to date a prior "Annotated Bibliography on Mineral Aggregates" (HRB Bibliography 6) published in 1949. The earlier work was compiled and annotated for the HRB Committee on Correlation of Research in Mineral Aggregates by Fulton K. Fears, of the Joint Highway Research Project at Purdue University.
The current revision was compiled and annotated by J. F. McLaughlin, also of the Joint Highway Research Project at Purdue University, for the HRB Committee on Mineral Aggregates. It comprises a chronologically arranged, annotated bibliography on mineral aggregates, including everything available up through 1956. Complete indexing both by subject and by author, makes for easy location of a specific reference.
Also included is the supplementary listing of references on Distribution of Mineral Aggregates, arranged by states, as included in the original Bibliography 6. Although not brought up to date in the current revision because of the diversity of available publication sources and the lack of time, it is included because of its value to those seeking this type of information on sources of engineering aggregates.

8. The Influence of Chemical Additives on the Adhesion of Bitumens to Minerals, R. A. Ambros.
<u>Cond. Bitumen, Teere, Asph</u>. 8: June, 1957, 208p.
The effect of shale tar phenolates, tall oil, pine tar, stearic acid, or lime additions on the adhesion of bitumen to various hydrophilic mineral (0.6-0.2mm) and 28% bitumen (Kraemer-Sarnow softening point 28°-29°C.) premixed with 2% of the additive at 120°C and 0.5 g. of each mixture was boiled with 6 cc. of 1/256-1 M. sodium carbonate for 1 min. For granite, the "degree of suitability" for use in asphalt concrete rose from 2-3 to 4-5 upon addition of calcium phenolate or kilned lime, pine tar raised that of limestone from 5-6 to 10 (-100% coverage) while burned-shale ash (Kukermit) was rated 10 even without additive. The softening point of the bitumen was lowered upon addition of 2% tall oil but calcium phenolate although it did not change the softening point markedly improved the strength of the asphalt concrete.

9. Fly ash sintering, A. J. Kantor.
<u>Pit & Quarry</u> 49: n 12, June 1957, p 88-90.
Research and development of process as carried out by Koppers Co.; basic equipment required for sintering plant; estimate of cost of producing 1 cu yd of fly ash aggregate based on 1900 cu yd per day plant.

10. Production of lightweight aggregate by sinter-hearth process, F. Catchpole. Brit Cer Soc--Trans 56: n 10, Oct 1957, p 519-26 (discussion) 526-8, 2 plates.

Description of first endless grate continuous sintering machine installed in Great Britain for making expanded clay aggregate on industrial scale; raw materials and processing methods; operation of plant when sintering carbonaceous shale; aggregate produced has low bulk density and is shown to be suitable for production of concrete of high strength weight ratio.

11. Use of Finely Ground Lightweight Aggregate as a Mineral Filler in Hot Mix Hot Laid Asphltic Concrete Construction, H. L. Lehmann and Verdi Adam. Paper presented at 41st Annual Meeting, American Association of State Highway Officials, New Orleans, December 7, 1955. 14 pp. Highway Research Abstracts, February 1956.

In an effort to find a solution to the shortage of mineral filler, for use in hot-mix asphaltic concrete, Louisiana Department of Highways initiated an investigation. The purpose being to explore new sources that were suitable for use. Among the materials tested were fine silts, by products, waste products as well as materials that would be produced in case they were acceptable. During this investigation a filler prepared by pulverizing lightweight aggregate was found suitable for use. The observations made during this project and the results of tests of the finished mixture indicate that: 1. Reasonable variations in the bitumen content do not considerably effect the stability values. 2. Having a high affinity for bitumen the lightweight filler permits the use of more asphalt in the mixture, hence, possibly complementing the durability of the pavement. 3. This material does not cause any difficulties at the plant that can be attributed to its use. 4. The placement and compaction of the mixture is satisfactory. 5. The increased stability values, due to the use of lightweight filler, do not decrease the workability of the mixture. The required roadway densities can be obtained with the same number of passes of the roller as is obtained in compacting a mixture made with limestone filler.

12. Clay mineralogy techniques, M. F. Auklund. Ohio Geol. Survey--Information Cir n 20, 1956, 31 p.

Classification and nomenclature of clay and clay minerals; physical properties, such a particle size and composition, bonding strength, firing properties, differential thermal analysis, X-ray diffraction, and optical properties; origin and occurrence; structural mineralogy of clays.

13. New method of preparing clay samples for differential thermal analysis, J. D. Walton, Jr. Am Cer Soc--J 38: n 12, Dec 1955, p 438-43.

Method which permits analysis to be made with test and reference samples freely exposed to furnace atmosphere; data for samples thus heated and when Inconel block was used to contain clay.

14. Quantitative differential thermal analyses of clay and other minerals, H. W. van der Marel.
Am. Mineralogist 41: n 3-4, Mar-Apr 1956, p 222-44.
Shape and intensity of thermal curve of minerals, when analyzed by DTA method, are strongly influenced by amorphous coatings and disordered structures on surface of particles (Beilby layer), and furthermore by differences in particle and/or crystallite size, degree of crystallinity of crystallites and ion substitutions in crystal structure; examples. Bibliography.

15. Carolina tuff-lita triples production, plans expansion.
Brick & Clay Rec 129: n 3, Sept 1956, p 62-5.
Procedures for raw material preparation and sintering operation in manufacture of lightweight aggregates; aggregate and coarse material handling; loading set-up; equipment list.

16. Raw materials for lightweight aggregate production in New Jersey, W. Lodding.
Rutgers University--Bur Mineral Research--Bul n 7, 1956, 160 p, 2 maps.
Physical and chemical properties; preparing sinter charge and sintering tests; properties of sintered aggregate; kiln expansion tests and procedure for concrete testing.

17. Sintering and lightweight aggregates, A. F. Leitner.
Pit & Quarry 48: n 8, 9, Feb 1956, p 94-6, 105, Mar p 104-6, 110.
Feb: Essentials of sintering. Mar: Planning commercial sintered lightweight aggregate manufacturing operation.

18. Fundamental study of clay: XIII, W. D. Kingery, J. Francl.
Am Cer Soc--J 37: n 12, Dec 1954, p 596-602.
Drying behavior and plastic properties; effects of nonionic, anionic, and cationic surface active agents on yield point, plasticity, drying, and firing shrinkage, dry and fired density, and rate of drying. Bibliography.

19. Kinetics of thermal dehydration of clays--1,2,3,4,P. Murray, J. White.
Brit Cer Soc--Trans 54: n 3, 4, Mar 1955, p 137-87, Apr p 189-238.
Pt. 1: Dehydration characteristics of clay minerals; continuation of kinetic investigation of breakdown characteristics of china and ball clays, plastic fire clays and montmorillonites upon heating. Pt. 2: Isothermal decomposition of clay minerals; from velocity constants, arrhenius parameters have been determined for kaolinites, secondary micas, halloysites and montmorillonites. Pt. 3: Analysis of mixtures of clay minerals; method for kaolinites and secondary mica clays. Pt. 4: Interpretation of differential thermal analysis of clay minerals; to test correctness, constants have been applied to obtain; analogous differential heating curves, information on relative life of clay bonds in molding sands, and 3-hr dehydration curves. Bibliography.

20. Use sintering process to make lightweight aggregate.
Rock Products 58: n 6, June 1955, p 76-7.
Onondaga Brick Corp, Warners, NY, has remodeled and enlarged its plant for production of expanded shale lightweight aggregate; annual production is 200,000 cu yd; process employs Dwight-Lloyd sintering machine and involves proportioning of raw materials, mixing materials, burning out fuel to cause shale to coalesce into hard spongy mass, and primary crushing of resultant mass.

21. Estudio sobre propiedades de las puzolanas, A. Ochoa Rivera.
Ingenieria (Mexico) 31: n 2, Apr 1961, p 52-5.
Testing of pozzolan properties; study of diatomite, bentonite, burned clay, perlite, pumica sand, pumicitye, and fly ash; method for determination of index of activity; testing of expansion and contraction capacity during drying; data on chemical and physical tests.

22. Verwendbarkeit von Hochofenschlacke als bituminoeses Heissmischgut fuer den Strassenbau, A. Send, G. Gelsdorf, H. Kaiser.
Stahl u Eisen 80: n 5, Mar 3, 1960, p 290-6.
Use of blast furnace slag as aggregate for hot bituminous mixtures used in road building; laboratory comparison of blast furnace slag vs natural rock gravel; ratio of under-size pieces after heating at 150-800 C, and effect of compression and impact; field tests; slag gravel is found in no way inferior to rock.

23. Kornformbeurteilung von aufbereiteten Hochofenschlacken-Splitten, H. Kahlhoefer, A. Send, H. Kaiser.
Stahl u Eisen 76: n 15, July 26, 1956, p 957-64.
Evaluation of grain shape of processed blast furnace slag as road aggregate, with special reference to different types of crushers; investigations carried out by Mannesmann-Huettenwerke; effect of crusher type of quality of aggregates; correlation between grain form, weight per cubic meter, and resistance to compression.

24. Investigation of some North Dakota clays and shales, O. E. Manz.
North Dakota Geol Survey--Report Investigations n 13, 1953, 36 p.
Survey of unfired and fired properties of clays and shales from various outcrops and commercial deposits; screen analyses with microscopic examination; determination of linear drying shrinkage and water of plasticity of handmade specimens; slaking test of dried specimens; determination of fired linear shrinkage, apparent porosity and water adsorption of fired specimens.

25. Rehydration of fired clay and associated minerals, R. D. Hill.
Brit Cer Soc--Trans 52: n 11, Nov 1953, p 589-613.
Durability of fired clay materials as function of firing temperature; kaolinite, illite, montmorillonite, vermiculite, bauxite, and limonite were fired at temperatures between 500 and 1150 C and then rehydrated in saturated steam at 200 C for periods up to 96 hr; products were examined by X-ray and differential thermal analysis.

26. Roanoke Webster develops highly integrated operation.
<u>Brick & Clay Rec</u> 124: n 5, May 1954, p 35-8, 71.
Methods employed at plant in Roanoke, Va., to produce quality face brick, light weight clay aggregate and top quality concrete block; brick is produced on stiff mud machines; light weight aggregate is made on sintering hearth; operation consists of two brick plants manufacturing stiff mud and molded brick, and concrete building block plant manufacturing both light weight and heavy units.

27. Weight loss and oxidation behavior of structural bodies during firing, R. R. Van Der Beck, J. O. Everheart.
<u>Am Der Soc--J</u> 36: n 11, Nov 1953, p 383-8.
Twenty materials, including clays and shales and mixtures, were investigated to study factors which affect firing behavior of structural clay materials; methods included differential thermal analyses, oxidation rate determinations, and length change determinations; method for application resultant data to firing schedules.

28. Clays and shales of New York State.
Published by <u>New York State Dept of Commerce</u>, Albany, NY. 1951, 349 p.
Geology of clays and shales; results of analyzing and testing; economic uses; data on unfired properties and pyrometric cone equivalent, percent linear firing shrinkage, fired strength, percent fired absorption, colors of fired specimens, efflorescence tendencies of fired specimens, mineralogical and chemical analyses.

29. Differential thermal analysis, R. C. Patterson.
<u>Am Cer Soc--Bul</u> 32: n 4, Apr 1953m p 117-18.
Basic factors concerned with existence of differential temperature; application of study of clay minerals showed this was dependent upon amount and kind of material used, heat capacity of holder, and rate of heating.

30. Effect of high temperatures on strength of roadmaking aggregates, F. A. Shergold.
<u>Roads and Road Construction</u> 31: n 366, June 1953, p 161-3.
Object of work described was to determine what temperatures and for what periods aggregates must be exposed to reduce their strength; eleven different aggregates were investigated; description of each; experimental work described; results.

31. Field practice in lightweight concrete, J. A. Murlin and C. Willson.
<u>Am Concrete Inst--J</u> 24: n 1, Sept 1952, p 21-36.
Properties of expanded shale and clay aggregates produced in Texas; economy of light weight structural concrete members as compared to heavy concrete; design and control of light weight structural concrete, both ready and job mixed; methods of mixing, placing, finishing and use of admixtures; economy of expanded clay or shale structural concrete.

32. Sources of lightweight aggregates in Colorado, A. L. Bush.
Colorado Scientific Society--Proc. 15: n 8, 1951, 368 p, 6 supp plates.
Materials in Colorado suitable for use as light weight aggregates are pumic, scoria, perlite, obsidian, vermiculite, welded tuff, clay shale, slate, diatomite, fullers' earth, slag, and cinders; deposits of suitable aggregates shown on maps; characteristics. Bibliography. Paper prepared as part of program of Interior Dept for Development of Missouri River Basin.

33. Mineral products company lightweight aggregate plant, B. J. Moats, Jr.
Min Congress J 38: n 4, Apr 1952, p 68-9.
Plant located in Kansas City, Kans, capable of producing 600 cu yd of structural aggregate daily; coal and clay used as raw materials; process of coal and clay preparation and sinterization described.

34. Proper pelletizing technique key to efficient sintering of aggregate, W. C. Bell.
Brick and Clay Rec 120: n 1, Jan 1952, p 46, 49, 52.
Pelletizing problems presented by characteristics of different materials; proper methods allowing use of almost all types of clay to produce light weight aggregate; pelletizing equipment; sintering characteristics of various clays; use of sintered clay aggregate in concrete block.

35. Sintering Ray Clay and shale into lightweight aggregate, T. Brown.
Rock Products 55: n 3, Mar 1952, p 94-6.
Manufactured product produced by expansively sintering clay and shale at 2400 F until it is vitrified; flowsheet of light weight aggregate plant; plant and operation described.

36. Sintering clay into lightweight aggregates, W. B. Lenhart.
Rock Products 54: n 8, Aug, 1951, p 108-11.
Application of Dwight-Lloyd sintering process to manufacture of light weight aggregate from clay at plant in Salisbury, NC; data on raw material, tests and test results.

37. Colloid chemistry of silicate minerals (Agronomy, Series of Monographs, Vol 1), C. E. Marshall.
Academic Press, New York, 1949, 195 p, illus, diagrs, charts, tables.
Monograph clarifies fundamentals of colloid chemistry of clays; following historical material, structure, properties, sizes and shapes of clay particles are discussed; adsorption by clays, clay acids, ionic exchange reactions, and electro-kinetic properties of clays considered, as well as mechanical properties of suspensions and properties of aggregates and films. Eng Soc Lib, NY.

38. Crystalline phases in fired shale products, W. E. Brownell.
Am Cer Soc --J 33: n 10, Oct 1, 1950, p 309-13.
Development of crystalline and glassy phases traced in shale specimens fired over range of temperatures; two raw materials of different compositions selected for study, namely, high lime shale and argillaceous shale; mechanical separations and X-ray analyses were used to isolate and identify crystalline phases; development of glass was observed petrographically; identification of phases at various heat treatments was helpful in explaining properties of fired shale products.

39. First aglite plant, W. M. Avery.
Pit & Quarry 42: n 5, Nov 1949, p 182-5, 191.
Illustrated description of plant of Marietta Concrete Corp., Marietta, Ohio, for manufacture of light weight (expanded clay) aggregate, Aglite, made by sintering mixture of finely crushed clay or shale and coal; data on Leftwich sintering machine and other equipment; 5000 masonry units and 6000 silo staves are produced in 8 hr.

40. In light weight aggregate production select proper burning equipment, E. P. Flint.
Brick & Clay Rec 116: n 4, Apr 1950, p 65-6, 69.
Report on study made by Armour Research Foundation concerning relative performances of rotary kiln and of various types of sintering machines for manufacture of light weight clay aggregate; sintering machines appear to be more adaptable, aggregate from them tends to give harsher concrete and has higher water absorption; rotary kilns give particles with glazed surfaces and resulting low water absorption.

41. Lightweight aggregate from expanded slag.
Rock Products 52: n 10, Oct 1949, p 154-5.
Caldwell B sintering machine used at Lone Star Steel Co, at Lone Star, Tex, for production of slag having capacity of 50 ton per hr; it is rotor type with water cooled side plates, table and cone and driven by 100-hp motor; data on crushing, screening and storing; process is so flexible that neither furnace shutdown nor crusher breakdown will affect operation.

42. Lightweight aggregate from phosphate slimes, R. C. Specht and W. E. Herron, Jr.
Rock Products 53: n 5, May 1950, p 96-7.
Commercial uses developed in Florida for finely divided phosphatic clay; wasted during mining and processing of pebble phosphate; requirements for light weight aggregates; description of deposits; chemical analysis of dried phosphate slime; tests and results; mechanical drying of slimes.

43. North Carolina concern sinters clay to produce lightweight aggregate, W. M. Avery.
Pit & Quarry 43: n 2, Aug 1950, p 87.
Dwight-Lloyd process applied at Salisbury, NC, to produce light weight aggregate from clay at 45 cu yd per hr rate; sintering machine is 42 in. wide and 66 ft long over windbox section, driven by 15-hp U S Vari-Drive; data on hammermill, screens, drum type pelletizer mixer and sintering machine.

44. Producing aggregate from expanded clay by sintering process, L. D. Minsk.
Rock Products 52: n 11, Nov 1949, p 105-7, 116.
Marietta Concrete Corp, Marietta, Ohio, produces 30 to 35 cu yd per hr of Aglite by unique sintering process which involves mixing raw clay with pulverized coal and feeding this mixture onto grate traveling through gas fired ignition chamber; flow sheet of aggregate processing facilities; illustrated description of sintering machine, grinder, crusher and belt conveyor.

45. Recent developments in manufacture of lightweight aggregates, J. E. Conley and J. A. Ruppert.
Min Eng 187: n 4, Apr 1950 (Trans) p 479-85, (discussion) n 11, Nov, p 1170.
In search for sources of light weight aggregate, various clays, shales, slates and natural occurring light weight rocks such as pumice, scoria and volcanic ash have received special attention; methods and equipment for producing suitable light weight aggregates; in addition to expanded use of rotary kiln, traveling grate and continuous sintering machines are being installed in many localities. Bibliography.

46. Rotary kiln L-W aggregate plant.
Brick & Clay Rec 117: n 2, Aug 1950, p 44-5.
Typical plan layout for light weight aggregate plant using rotary kiln; for 250 cu yd production from clay or shale material which expands approximately 40%, two rotary kilns are suggested; triple screen series divides crushed aggregate product into fines for mortar, medium sizes for roof and floor fill, and larger sizes for structural usage; flowsheet of equipment.

47. Sintered L-W aggregate plant.
Brick & Clay Rec 117: n 3, Sept 1950, p. 51.
Basic plan for aggregate plant utilizing moving grate sintering machine which produces 250 cu yd per day, and can be operated intermittently or continuously; it is adaptable to wide variety of clays and shales; sintering process requires only simple crushing and mixing of clay with coal or coke breeze, miltiple screening for size distribution, and storage facilities, in addition to actual sintering machinery; typical plan layout shown in diagram.

48. Southeastern research progress report: Sintering lightweight aggregate, R. L. Crouch and W. C. Bell.
<u>Brick & Clay Rec</u> 116: n 2, Feb 1950, p 45, 48.
Results of research program, sponsored by group of Southeastern structural clay products manufacturers, to develop and produce light weight clay aggregates and light weight fired clay building units; main production unit used for making aggregate is 12 x 48-in. Dwight-Lloyd type of sintering machine.

49. For aggregate production consider several manufacturing processes.
<u>Brick & Clay Rec</u> 117: n 1, July 1950, p 56.
Variety of methods have been successfully used in production of light weight clay aggregates; manufacturers contemplating aggregate production should consider merits of all processes before selecting plant equipment; brief summary of those light weight aggregates which can be made by industry; description of processes for manufacturing Haydite, Aglite and lighter aggregate; sizing aggregate; note on pellets made from clay.

50. Mechanics, techniques and economics of expanded clay-shale aggregate production, W. G. Bauer.
<u>Pit & Quarry</u> 42: n 5, Nov 1949, p 119-21.
Kiln burner requirements; behavior of material in kiln depends on kiln speed, flame temperature and material grading; oil, pulverized coal, and gas burners; burner location.

51. Testing of clays for lightweight aggregate, T. A. Klinefelter, R. T. Hancock and H. P. Hamlin.
<u>Am Cer Soc--J</u> 32: n 9, Sept 1 1949, p 294-6.
Method of testing and evaluating clays suitable for production of lightweight aggregate; procedures to be used with both laboratory furnace and pilot plant rotary kiln are outlined; determinations and tests necessary for relative comparisons of products are described.

52. Lightweight aggregate concrete, R. W. Kluge, M. M. Sparks, and E. C. Tuma.
<u>Am Concrete Inst--J</u> 20: n 9, May 1949, p 625-42, (discussion) v 21: n 4, pt 2, Dec, p 644 (4 p): see also <u>Ice & Refrig</u> 117: n 3 Sept 1949, p 24-6.
Studies made by Nat Bureau of Standards; aggregates studied were expanded clay, shale and slate, expanded blast furnace slag, expanded vermiculite and perlite, sintered diatomite, fly ash and pumice; test results summarized.

53. Lightweight aggregate from mine shale.
<u>Utilization</u> 3: n 4, Apr 1949, p 27-9.
Utilization breaker slate reject from anthracite preparation plants, Lehigh Navigation Coal Co has developed process from which light weight aggregate of special quality is manufactured at its new plant at Tamaqua, Pa.

54. Expanded blast furnace slag for use as light weight concrete aggregate, R. W. Miller.
Blast Furnace & Steel Plant 41: n 6, June 1953, p 634-8, 645.
Operation of Brosius and Caldwell machines used in producing expanded slags; other methods and devices indicated; principal use of expanded slag as aggregate in manufacture of concrete masonry units; relationship of expanded, air cooled, and granulated slag with respect to tonnage produced and dollar value per ton.

55. Lightweight aggregates--expanded shale, J. W. Shaver.
Concrete 61: n 10, Oct 1953, p 3-6, 41.
Estimate of demand for lightweight aggregates for current annual production of concrete units is 20 million cu yd; to make up ever increasing deficit, method was developed consisting of bloating of local clays and shales through burning them in rotary kilns or by sintering on grates; burning to 2000 F. shale begins to become plastic; bloated material is cooled, then crushed and graded; data on Buildex plant, Ottawa, Kan.

56. Lightweight aggregates from blast furnace slag, J. R. Wallace.
Conference on Industrial Minerals Sponsored by Nova Scotia Dept Mines & Research Foundation June 20-22, 1951, p 62-72 (discussion) 72-7.
Production of foamed slag and its properties; comparison of chemical composition of Portland cement and foamed slag; properties of foamed slag concrete; uses of foamed slag concrete in masonry units and monolithic structure.

57. Preliminary report on coated lightweight concrete aggregate from Canadian clays and shales-- 5: Quebec, H. S. Wilson.
Canada Dept Mines & Tech Surveys--Memo Series n 126, Aug 1953, 36 p.
Definition of light weight aggregate; types of clay and shale lightweight aggregate and their desirable properties; test methods; relation of chemical properties to bloating of clays and shales; application of chemical analyses to problem of producing coated aggregate; distribution of clays and shales in Quebec.

58. Basalt rock makes pelletized aggregates.
Concrete 61: n 4, Apr 1953, p 3-5, 54.
Manufacture of light weight aggregates from local materials, by burning local clays and shales and mixtures of them either in rotary kilns or by employment of traveling grates; new plant at Napa, Calif, utilizes rotary kiln process of burning local material at 1900 F; no crushing and sizing of material after shale has been burned is necessary.

59. New lightweight aggregate, W. M. Avery.
Pit & Quarry 41: n 11, May 1949, p 158-60.
Lelite is produced by expanding metamorphic, carbonaceous shale, which is mined along with anthracite coal at plant near Lansford, Pa: manufacturing process; about 360 tons are produced daily.

60 . Production of lightweight concrete aggregates from clays, shales, slates, and other materials, J. E. Conley, H. Wilson, T. A. Klinefelter and others.
U. S. Bur Mines--Report Investigations n 4401, Nov 1948, 121 p, supp plates.
Industrial Research and Development Division of Office of Technical Services, U S Department of Commerce, has entered into contract with Bureau of Mines to assist in research aimed at stimulations of industrial production of larger quantities of light weight concrete aggregates; results of investigation under contract to date. Bibliography.

61 . Mechanics, Techniques and economics of expanded clay-shale aggregate production, W. G. Bauer.
Pit & Quarry 41: n 6, 12, Dec 1948, p 91-5, June 1949, p 87-90, Dec 1948:
Factors which affect clay handling; mining, transportation, crushing, sizing, conditioning and clay drying; diagram gives list of equipment for raw material preparation. June 1949: Use of rotary kiln in sintering and floating process of gas containing clays and shales; kiln design factor; shortcomings of present installations; mechanical and thermal kiln capacity factors, heat exchange and draft factors; heat requirements and role of moisture.

62 . Modified differential thermal analysis apparatus, P. G. Herold and T. J. Planje.
Am Cer Soc--J 31: n 1, Jan 1, 1948, p 20-2.
In apparatus described, clay sample and standard holder are arranged so that thermocouples become both holder and differential temperature measuring device; this arrangement permits easy removal of sample and also permits investigation of exothermic and endothermic reactions at much higher temperatures without damage to thermocouples. Bibliography.

63 . Lightweight aggregates win new attention.
Arch Rec 104: n 1, July 1948, p 143-5.
Examples of use in recent building construction; physical properties, formation and mode of occurrence of volcanic aggregates, including pumice, vesicular glass and perlite; vermiculite; clay, shale aggregates including Airox, Rocklite and diatomite; byproduct aggregates such as expanded slag, cinders and fibers.

64 . Haydite-light-weight aggregate, P. E. Cox.
Cer Age 49: n 3, Mar 1947, p 109-10.
Aggregate developed by S. Hayde is made by heating clay containing small percentage of carbon; swelling tendency, which made such clays unsuitable for brick manufacture, is utilized to make desirable product; description of kiln; suggested procedure for converting brick to Haydite; original patent expire Apr 1946.

65. Differential thermal analysis of clays and shales, control and prospecting method, R. E. Grim and R. A. Rowland.
Am Cer Soc --J 27: n 3, Mar 1, 1944, p 65-76.
Paper records differential thermal analyses for clay-mineral and non-clay mineral components of clays as well as natural and synthetic mixtures of these minerals; thermal analysis for variety of clay materials; attempts made to show how such analyses may be used practically to evaluate properties of clays.