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EVALUATION OF SURFACE TREATMENTS

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**Abstract**

This report describes the installation, evaluation, and performance of surface treatment test sections placed during 1983, 1984, and 1985. The study was initiated because of adhesion problems between asphalt and river gravel in the Fredericksburg District. However, observations by the researchers and complaints from other districts indicated that adhesion problems were also prevalent when crushed stone was used as the cover material. The study was continued through 1985 in order to include crushed stone.

The results of this study indicate that the quality of a surface treatment is greatly influenced by the quantity of aggregate used, its cleanliness, the type and gradation of the aggregate, material adhesion, and construction techniques. It was found that some gravels perform better than others, but none perform as well as crushed stone. It was also learned that steel-wheel rollers embed aggregate better than rubber tire rollers, but because of the irregular cross sections of so many secondary roads, the two should be used together.

The recommendations in this report include the following: material quantities should be determined by a design method; adjustments should be made for road surface characteristics and traffic speeds and volumes; better construction techniques should be employed; river gravels should not be used on roads in traffic groups V and above; and, because of the problems caused by the wide tolerance in gradation on the No. 4 screen of the No. 8 aggregate used in surface treatments, the gradation should be changed to 12 percent + 12 percent passing the No. 4 screen, 2 percent + 2 percent passing the No. 8 screen, and 1 percent + 1 percent passing the No. 16 screen.

# FINAL REPORT

# EVALUATION OF SURFACE TREATMENTS

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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## ABSTRACT

This report describes the installation, evaluation, and performance of surface treatment test sections placed during 1983, 1984, and 1985. The study was initiated because of adhesion problems between asphalt and river gravel in the Fredericksburg District. However, observations by the researchers and complaints from other districts indicated that adhesion problems were also prevalent when crushed stone was used as the cover material. The study was continued through 1985 in order to include crushed stone.

The results of this study indicate that the quality of a surface treatment is greatly influenced by the quantity of aggregate used, its cleanliness, the type and gradation of the aggregate, material adhesion, and construction techniques. It was found that some gravels perform better than others, but none perform as well as crushed stone. It was also learned that steel wheel rollers embed aggregate better than rubber tire rollers, but because of the irregular cross sections of so many secondary roads, the two should be used together.

The recommendations in this report include the following: material quantities should be determined by a design method; adjustments should be made for road surface characteristics and traffic speeds and volumes; better construction techniques should be employed; river gravels should not be used on roads in traffic groups V and above; and, because of the problems caused by the wide tolerance in gradation on the No. 4 screen of the No. 8 aggregate used in surface treatments, the gradation should be changed to 12 percent + 12 percent passing the No. 4 screen, 2 percent + 2 percent passing the No. 8 screen, and 1 percent + 1 percent passing the No. 16 screen.

# FINAL REPORT

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## INTRODUCTION

The majority of the paved secondary roads in Virginia are surface treated. This type of surface adds little or nothing to the structural integrity of the roadway but does reduce the infiltration of water to the underlying portion of the roadway and thus enhances stability.

Surface treatments also eliminate dust problems, provide a skid-resistant surface, and, if properly designed and placed over a reasonably level surface, provide a smooth riding surface. Surface treatments are less expensive than other types of surfaces, especially those that increase the structural integrity of the roadway. In order to keep surface treatments as inexpensive as possible and to stimulate the local economy, the Virginia Department of Transportation (VDOT) permits local materials to be used in these treatments when feasible. In compliance with this policy, the Fredericksburg District has been using local river or pit gravels for a number of years as the cover material in surface treatments.

Although the river gravels have historically presented retention problems in surface treatments, the recent increase in traffic volume and speed has stimulated the public (which now has much higher standards) to complain more about poor surfaces and flying stones, which break windshields. These complaints along with a noticed acceleration in the loss of cover aggregate during placement, immediately after placement, and after a winter's service, prompted the Fredericksburg District to request the Virginia Transportation Research Council (VTRC) to undertake a project designed to improve the quality of surface treatments, especially those that employ river gravel. This report describes the installation and observations of several surface treatments from 1983 to 1986.

## 1983 OBSERVATIONS

In 1983, 32 test sites were designed according to the flakiness index design method (*1*), which is described in Appendix A. One of the requirements of this design procedure is that the aggregate is to be placed only one stone thick. Descriptive information on the sites designed in 1983 can be found in Table 1. Table 2 shows the ratings of these sites several months after placement. The rating system used was developed by Runkle and Mahone (*2*).

In 1983, river gravels were the cover materials used on most sites; however, for comparison, several of the designed sites were covered with crushed stone. All sites placed in 1983 were in the Saluda and Warsaw Residencies, and CRS-2 asphalt emulsions were used as the binder along with No. 8 aggregate from several quarries. No selective treatment was given to the placement practices.

The first study year, 1983, was used to define the scope of the problem and to design the future experiments. Upon careful observation of the placement and periodic observations of the installations, the following were observed:

1. The quantities established by the district were based on tradition.

   - These quantities were as high as 0.42 gal/yd$^2$ of asphalt emulsion and 28 lb of aggregate/yd$^2$. The 32 test sites (see Table 1) that were placed according to design had asphalt quantities from 0.25 to 0.35 gal/yd$^2$ and stone quantities from 17 to 24 lb/yd$^2$. The average asphalt and aggregate quantities for the design sections were 0.31 gal/yd$^2$ and 20 lb/yd$^2$.

   - The high quantities of both asphalt and aggregate placed by the district resulted in much of the cover aggregate never making contact with the asphalt, which resulted in traffic-induced flying stones.

   - During the time the excess stone was being thrown from the road, tires were exposed to the asphalt, which inundated the remaining aggregates. This aggregate inundation was exaggerated since the fine particles were reaching the asphalt prior to the large particles. This phenomenon was the result of two factors: (1) there were excessive fines in many of the cover aggregates and (2) an inadvertent modification of the aggregate spreader that was not detected for several years.

   - The excessive fines were the result of the wide gradation band on the No. 4 sieve in Virginia's No. 8 aggregate specifications. The specification requires 25 percent $\pm$ 15 percent passing the No. 4 sieve, which allows 10 percent to 40 percent passing to be within specifications.

   - Vehicle tires became coated with asphalt and picked up aggregate, which not only rendered a very unsatisfactory surface treatment but produced an asphalt-aggregate undercoating on the vehicles.

   - On several sites, after multiple trips across the new treatments, state vehicles had such a build up of asphalt and aggregate between the fender and tire that the material acted as a brake. Had this excessive material not been removed, it would have eventually prevented the vehicle from moving.

TABLE 1
1983 DESIGNED SITES

| DATE PLACED | SITE NO. | ROUTE NO. | COUNTY | FROM RT | TO RT | AGGREGATE TYPE AND SOURCE | QUANTITIES EMULSION $(GAl/YD^2)$(1) | QUANTITIES AGGREGATE (LB/YD) |
|---|---|---|---|---|---|---|---|---|
| 9/06 | 1 | 637 | Lancaster | 3 | 1 mi. W. | M.A. Smith (round gravel) | .29 | 23 |
| 9/06 | 2 | 637 | Lancaster | 3+1 mi. | 766 | General (crushed stone) | .34 | 24 |
| 9/06 | 3 | 638 | Lancaster | Whitestone | DE | General (crushed stone) | .34 | 22 |
| 9/06 | 4 | 647 | Lancaster | 646 | Dead end | General (crushed stone | .35 | 24 |
| 9/06 | 5 | 650 | Lancaster | 750 | Dead end | General (crushed stone) | .31 | 23 |
| 9/01 | 6 | 654 | Lancaster | 637 | 637 | Mattaponi (round gravel) | .30 | 19 |
| 8/03 | 7 | 602 | Middlesex | 637 | 17 | General (crushed stone) | .29 | 18 |
| 8/03 | 8 | 602 | Middlesex | 1 | K & Q | Mattaponi (crushed gravel) | .29 | 18 |
| 8/03 | 9 | 603 | Middlesex | 602 | Rt. 17 | Mattaponi (round gravel) | .25 | 17 |
| 8/03 | 10 | 603 | Middlesex | 17 | K & Q | Mattaponi (round gravel) | .25 | 17 |
| 8/03 | 11 | 612 | Middlesex | 602 | Rt. 603 | Mattaponi (round gravel) | .35 | 19 |
| 8/09 | 12 | 676 | Middlesex | 602 | Dead end | Mattaponi (round gravel) | .37 | 21 |
| 8/04 | 13 | 680 | Middlesex | 602 | Dead end | Mattaponi (round gravel) | .35 | 20 |
| 8/04 | 14 | 684 | Middlesex | 602 | Dead end | Mattaponi (round gravel) | .35 | 21 |
| 8/09 | 15 | 691 | Middlesex | 602 | Rt. 602 | Mattaponi (round gravel) | .38 | 17 |
| 8/24 | 16 | 644 | Northumberland | 657 | Rt. 652 | Vulcan (crushed stone) | .31 | 24 |
| 8/24 | 17 | 647 | Northumberland | 360 | Dead end | Mattaponi (round gravel) | .27 | 19 |
| 8/29 | 18 | 650 | Northumberland | 644 | Dead end | Vulcan (crushed stone) | .30 | 19 |
| 8/28 | 19 | 652 | Northumberland | 360 | Rt. 644 | Vulcan (crushed stone) | .29 | 23 |
| 8/29 | 20 | 734 | Northumberland | 647 | Dead end | Mattaponi (round gravel) | .34 | 23 |
| 9/19 | 21 | 614 | Richmond | 615 | 651 | Mattaponi (crushed gravel) | .27 | 19 |
| 9/19 | 22 | 614 | Richmond | 651 | 642 | Mattaponi (crushed gravel) | .33 | 22 |
| 9/19 | 23 | 614 | Richmond | 642 | 655 | Mattaponi (crushed gravel) | .33 | 20 |
| 9/19 | 24 | 615 | Richmond | 614 | Deadend | Mattaponi (crushed gravel) | .30 | 19 |
| 9/27 | 25 | 624 | Richmond | 637 | 638 | Mattaponi (crushed gravel) | .25 | 17 |
| 8/26 | 26 | 624 | Richmond | 635 | 638 | Fredericksburg (round gravel) | .32 | 22 |
| 8/11 | 27 | 600 | Westmoreland | 612 | 615 | Dogue (round gravel) | .25 | 19 |
| 8/11 | 28 | 665 | Westmoreland | 621 | 626 | Dogue (round gravel) | .27 | 19 |
| 8/11 | 29 | 700 | Westmoreland | 618 | 701 | Dogue (round gravel) | .30 | 19 |
| 8/11 | 30 | 701 | Westmoreland | 700 | Deadend | Dogue (round gravel) | .34 | 22 |
| 8/11 | 31 | 724 | Westmoreland | 612 | 750 | Dogue (round gravel) | .27 | 19 |
| 8/12 | 32 | 724 | Westmoreland | 612 | Deadend | Dogue (round gravel) | .33 | 22 |

(1)The emulsion was CRS-2 from Chevron.



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TABLE 2

1983 TEST SECTION RATING DATA

| SITE NO. | AGGREGATE TYPE AND SOURCE | RATING | DATE OF PLACEMENT MONTH | DATE OF PLACEMENT DAY | AIR TEMP. | PRECIPITATION DATE | PRECIPITATION AMOUNT/(IN) |
|---|---|---|---|---|---|---|---|
| 1 | M. A. Smith (crushed gravel) | Fair | 9 | 6 | 85 | 9/13 | 1.32 |
| 2,3,4,5 | General (crushed stone) | Good | 9 | 6 | 85 | 9/13 | 1.32 |
| 6 | Mattaponi (round gravel) | Poor | 9 | 1 | 73 | 9/1 | 0.42 |
| 7 | General (crushed stone) | Excel. | 8 | 3 | 80 | 8/6 & 7 | 0.73 |
| 8 | Mattaponi (crushed gravel) | Fair | 8 | 3 | 80 | 8/6 & 7 | 0.73 |
| 9,10,11 | Mattaponi (round gravel) | Fair | 8 | 3 | 80 | 8/6 & 7 | 0.73 |
| 12 | Mattaponi (round gravel) | Fair | 8 | 9 | 81 | 8/10 | 0.02 |
| 13 | Mattaponi (round gravel) | Fair | 8 | 4 | 72 | 8/6 & 7 | 0.73 |
| 14 | Mattaponi (round gravel) | Good | 8 | 4 | 72 | 8/6 & 7 | 0.73 |
| 15 | Mattaponi (round gravel) | Fair | 8 | 9 | 81 | 8/10 | 0.02 |
| 16 | Vulcan (crushed stone) | Good | 8 | 24 | 76 | 8/28 | 2.25 |
| 17 | Mattaponi (round gravel) | Poor | 8 | 24 | 76 | 8/28 | 2.25 |
| 18 & 19 | Vulcan (crushed stone) | Excel. | 8 | 29 | 76 | 8/31 | 0.78 |
| 20 | Mattaponi (round gravel) | Fair | 8 | 24 | 76 | 8/28 | 2.25 |
| 21,22,23 | Mattaponi (crushed gravel) | Fair | 9 | 19 | 70 | 9/21 | 1.10 |
| 24 | Mattaponi (crushed gravel) | Good | 9 | 19 | 70 | 9/21 | 1.10 |
| 25 | Mattaponi (crushed gravel) | Very Poor | 9 | 27 | 62 | 9/29 & 30 | 0.15 |
| 26 | Fredericksburg (crushed gravel) | Fair | 8 | 26 | 70 | 8/28 | 2.28 |
| 27,28,29,30 | Dogue (crushed gravel) | Good | 8 | 11 | 85 | 8/12 & 13 | 0.29 |
| 31 & 32 | Dogue (crushed gravel) | Good | 8 | 12 | 80 | 8/12 & 13 | 0.29 |

- The excess quantities of aggregate and emulsion resulted in flying stones and broken windshields.

- On the day after many of the installations, the excess quantities of aggregate were recovered and weighed. These wasted quantities were as high as 10 lb/yd$^2$.

2. The following adverse construction practices were observed:

- Even though specifications stated that the asphalt emulsion application temperature should be between 140°F and 175°F, the temperature at which the asphalt was received was normally between 140°F and 150°F. This resulted in streaking or alternate strips of too much and too little asphalt. Streaking caused loss of cover material where the quantity of asphalt emulsion was inadequate and flushing of asphalt through the cover aggregate when there was too much asphalt.

- Another cause of streaking and loss of cover aggregate was from a lack of calibrated asphalt distributors. A calibrated distributor provides a good uniform spray pattern. Once a distributor is delivering the desired quantity of asphalt, two key adjustments need to be made: (1) the angle of the slot in the nozzle with respect to the spray bar and (2) the height of the spray bar. Frequently, distributors on which these two adjustments had not been made were observed. Not adjusting the spray bar resulted in compounding the streaking problem. To the credit of the crews that were observed in 1983, the distributor operator made proper use of the shot calculator and therefore set the appropriate pump pressure to correspond to the distributor's speeds. This has not always been true of crews observed previous to or after 1983.

- To achieve the desired one-stone coverage with an aggregate spreader, it is essential that the aggregate spreader be calibrated and in good working condition. The crews that worked in 1983 had their equipment calibrated and in good working condition, but again this has not always been true with crews observed prior to and after 1983. Two key elements to calibrating a spreader are (1) the proper chip-spreader speed for specific gate openings and (2) homogeneous gate openings across the spreader box. To ensure compliance, samples can be collected on a piece of canvas and weighed. Careful observation will determine whether a homogeneous pattern is being obtained.

- The spreader is designed to drop the larger aggregate to the pavement surface first to prevent the smaller aggregate and fines from covering the asphalt prior to the larger aggregate making contact with the asphalt. The mechanism that was designed to ensure distribution of the large aggregate first is a detachable screen, which unbeknownst to the researchers had been removed by all contractors from their spreaders. The knowledge of this removal was not gained until recently. One of the recommendations of this report is for the VDOT to require that all contractors replace the portion of the equipment that regulates the discharge of the aggregate sizes.

- When placing surface treatments, it is imperative to place aggregate on the asphalt emulsion mat immediately after the asphalt has been sprayed. The crews observed in 1983 were diligent with regard to early application of the cover material, which has not always been the case with crews observed prior to and after 1983. The two conditions that most often caused delayed placement of aggregate were poor coordination between the distributor and spreader operators and insufficient quantities of aggregate being transported to the job site because of stockpile problems or an insufficient number of haul trucks assigned to the operation.

- Aggregate embedment is greatly affected by roller speed. In 1983, state specifications required a maximum speed of 3 mph for the steel wheel and 5 mph for the rubber tired rollers. This practice was observed by one of the crews; however, no other crew rolled at specified speeds and, in fact, some were clocked at speeds in excess of 20 mph. This excessive roller speed dislodges aggregate the same way a vehicle does traveling at excessive speeds. If the roller speed is fast enough to dislodge aggregate, it is doing more damage than good.

- At several locations, a pneumatic roller was used on one side of the road and a tandem steel wheel roller was used on the other side. Not only did it appear that the steel wheel roller was doing a better job of embedding the aggregate, but less whip-off occurred where the steel wheel roller was employed.

- In 1983, traffic control consisted only of signs and flaggers at each end of the job site. It is very important to employ whatever traffic control is necessary to ensure adequate curing time, especially for treatments that have aggregates and asphalts with poor early compatibility. Some of the treatments that failed in 1983 would probably have been successful if a pilot vehicle had been employed to permit sufficient curing time.

- Ambient temperature has a marked effect on the quality of surface treatments. Cool weather reduces the adhesion characteristics of asphalt, which promotes extensive aggregate loss. In 1983, VDOT required that the air temperature be 60°F prior to placing surface treatment. Neither of the 1983 crews always observed this temperature requirement.

- Inspection of surface treatment placements greatly affects success or failure. The inspector needs to have an extensive knowledge of surface treatment procedures. Three inspection practices are imperative: (1) stay with the paving operation at all times, (2) make periodic checks on quantities of asphalt and aggregates and their homogeneity of distributions both perpendicular and parallel to the center line, and (3) if unfamiliar problems arise, contact someone who can help solve the problem. In 1983, inspectors were always on the job but did not have expertise in surface treatment work.

3. The quality of the 32 sites that were placed by the flakiness index method performed better that those placed according to existing Fredericksburg practices. However, because of poor construction techniques and existing flushed pavements, the 32 test sites did not remain quality surfaces for their expected life of 4 to 7 years.

## 1984 EXPERIMENTS

With knowledge gained in 1983, experiments were planned for 1984. The experiments included the installation of 54 test sites on three highways employing two asphalts and nine types of cover stone. The goal of the 1984 study was to determine whether some combinations of aggregates and asphalts are more compatible than others. In addition to placing test sites, laboratory tests were performed to see if compatibility could be predetermined.

The 54 test sites were placed on Routes 645, 646, and 721 in Caroline County. Arrangements were made to obtain CRS-2 from Central Oil and Chevron Oil and a special formulated CRS-2 from Central. Nine types of aggregate were used: seven river gravels and two crushed stones.

In addition to the 54 test sites, 8 routes were selected in Northumberland County to test a vibratory roller equipped with a 1 1/2-inch rubber sleeve on the front drum to see whether it would embed the aggregate in the asphalt more securely than the combination of the tandem drum and pneumatic tire rollers or either of the two rollers used separately.

The test sites were located on roads in traffic groups I (under 100 VPD) through IX (1,000-9,999 VPD) and were selected by district personnel.

As previously discussed, the Fredericksburg District has determined quantities of asphalt and aggregate from past experience; however, the quantities for all of the 1984 test sections were determined by design methods. In 1983, design quantities for 32 sites were determined by the flakiness index design method found in the *Asphalt Surface Treatment Handbook* MS-13 (*1*). This method was developed by Hanson in New Zealand and has been modified and adopted by the *Asphalt Institute* and can be found in their *Asphalt Emulsion Manual*(MS-19)(*3*). This same design method was used in 1984 along with two other methods. The quantities derived from these design procedures and a description of the procedures are shown in Appendices A, B, C, and D.

## Materials

### Emulsions: Laboratory Tests

The 1983 test sites employed CRS-2 emulsions supplied by Central and Chevron. In 1984, CRS-2 emulsions were furnished by both companies, and CRS-2H was supplied by Central. Central Oil provided samples of different formulations to the VDOT so they could be tested prior to selecting the asphalts to be used on the 1984 test sections. Laboratory tests were performed by the Materials Division to determine residual asphalt content, penetration, solubility, and ductility values and are shown in Table 3.

In addition, two other tests were performed by the VTRC to determine which asphalts were more compatible with the aggregates being used. These two tests were the centrifuge whip-off test and the immersion test, which are described by Arnold (*4*). Both tests require that samples be placed on metal plates. The plates are preheated to between 100°F and 120°F to simulate road conditions and then weighed on an electronic scale. About 25 square inches of the plate is covered uniformly with 14 to 16 grams of emulsion at 175°F. Forty stones are then placed on each plate within the coated square. The stones are randomly picked from a sample retained on the +3/8-inch sieve.

### Centrifuge Test

The centrifuging system consists of a centrifuge head designed to allow two 6-by-6-in metal plates to be fastened at an angle of 15° from the horizontal. As the head rotates, stone particles are dislodged. Figure 1 shows the centrifuge, with sample mounted.

Because of the short time between receiving the asphalt and placing test sections, only one plate was made for each binder aggregate combination. After curing for 24 hours, two sample plates of different asphalt aggregate combinations were attached to the centrifuge head and centrifuged for 2 minutes at 700 rpm. The plates were then removed and weighed to determine the percentage of loss. These data can be found in Table 4. Because asphalt No. 3, which was CRS-2 high formula with an AC-20 base, and No. 5, which was a CRS-2H high acid with an AC-20 base, had the lowest penetrations and the least whip-off, they were selected as the asphalts that would be furnished by Central. These data can be seen in Tables 3 and 4.

Chevron did not furnish samples for pre-evaluation.

### Immersion Test

In addition to the centrifuge test, an immersion test was performed on the two asphalts that had the highest retention rate in the centrifuge test. In the immersion test, prepared plates are hung vertically from the sides of a large tub of water as shown in Figure 2. The water and gravity induce adhesion failure. The plates were

Figure 1. Centrifuge with sample mounted.

Figure 2. Immersion plate test.

## TABLE 3

## EMULSION TEST RESULTS FOR 1984

| ASPHALT No. | EMULSION TYPE & FORMULATION | ASPHALT(%) | PENETRATION | SOLUBILITY | DUCTILITY |
|---|---|---|---|---|---|
| 1 | CRS-2 Regular with High Acid | 65.7 | 113.3 | 99.8 | 50% |
| 2 | CRS-2 High Formula - Base | 67.2 | 118.3 | 99.8 | 50% |
| 3 | CRS-2 High Formula - AC-20 Base with Hard Pen | 66.8 | 93.0 | 97.2 | 50% |
| 4 | CRS-2H Low Formula - Emulsion Base | 69.0 | 110.2 | 99.8 | 50% |
| 5 | CRS-2H High Acid - AC-20 Base | 67.9 | 68.0 | 99.8 | 50% |

## TABLE 4

## CENTRIFUGE WHIP-OFF TESTS[1]

| | % LOSS BY EMULSION NUMBER | | | | |
|---|---|---|---|---|---|
| AGGREGATE SOURCE & TYPE | 1[2] | 2[3] | 3[4] | 4[5] | 5[6] |
| Dogue (uncrushed gravel) | 53.7 | 37.3 | 0 | 62.6 | 4.2 |
| Fredericksburg (uncrushed gravel) | 55.3 | 32.5 | 2.5 | 69.9 | 0.9 |
| Massaponax (uncrushed gravel) | 52.7 | 42.7 | 3.6 | 22.4 | 12.5 |
| Massaponax (crushed gravel) | 46.9 | 52.2 | 11.3 | 29.5 | 9.3 |
| Mattaponi (crushed gravel) | 55.2 | 50.8 | 1.8 | 59.9 | 4.7 |
| Mattaponi (uncrushed gravel) | 51.4 | 38.1 | 2.2 | 43.2 | 5.2 |
| M. A. Smith (uncrushed gravel) | 38.7 | 23.6 | 3.5 | 19.5 | 0 |
| General (crushed stone) | 70.1 | 61.3 | 14.6 | 50.1 | 8.4 |
| Vulcan (crushed stone) | 66.8 | 58.9 | 13.9 | 29.3 | 2.3 |
| AVERAGE: | 54.5 | 44.2 | 5.9 | 42.9 | 5.3 |

(1) Only one test was performed for each asphalt aggregate combination.
(2) Emulsion No. 1-CRS-2 Regular With High Acid.
(3) Emulsion No. 2-CRS-2 High Formula Base.
(4) Emulsion No. 3-CRS-2 High Formula AC-20 Base With Hard Pen.
(5) Emulsion No. 4-CRS-2H Low Formula-Emulsion Base.
(6) Emulsion No. 5-CRS-2H High Acid with AC-20 Base.

allowed to cure for 24 hours after they were prepared before being immersed for 24 hours. They were removed, dried, and weighed to determine the percentage of loss. These data can be found in Table 5.

### Test Results

The average loss in the centrifuge test for the nine combinations of asphalt and aggregate was 5.9 percent for No. 3 and 5.3 percent for No. 5, whereas the other three asphalts averaged 40 percent or greater. However, when looking at the immersion test results in Table 5, it can be seen that CRS-2 emulsion No. 3 did not perform as well as the CRS-2H emulsion No. 5. The average loss for No. 5 is about 12 percent and for No. 3 is 36 percent. This is probably the result of the lower penetration value of the CRS-2H emulsion. The lower pen emulsion sets faster and thus can provide better early adhesion.

### Aggregates

Aggregate types and gradations of the No. 8 aggregates used on the test sites in 1983, 1984, and 1985 are shown in Tables 6, 7, and 8, respectively. It can be seen in Tables 6 and 7 that 9 of the 18 aggregate sources had more than 25 percent passing the No. 4 sieve.

TABLE 5

IMMERSION TEST RESULTS(1)

| AGGREGATE SOURCE AND TYPE | % LOSS EMULSION NO. 3(2) | % LOSS EMULSION NO. 5(3) |
|---|---|---|
| Dogue (uncrushed gravel) | 37.8 | 10.9 |
| Fredericksburg (uncrushed gravel) | 43.4 | 11.1 |
| Massaponax (uncrushed gravel) | 38.3 | 1.1 |
| Massaponax (crushed gravel) | 44.3 | 18.4 |
| Mattaponi (crushed gravel) | 30.2 | 18.8 |
| Mattaponi (uncrushed gravel) | 55.0 | 14.6 |
| M. A. Smith (uncrushed gravel) | 31.5 | 2.6 |
| General (crushed stone) | 33.2 | 24.5 |
| Vulcan (crushed stone) | 9.4 | 2.3 |
| AVERAGE: | 35.9 | 11.6 |

(1) Only one test was performed for each asphalt/aggregate combination.

(2) Emulsion No. 3: CRS-2 High Formula Base With Hard Pen.

(3) Emulsion No. 5: CRS-2H High Acid Wih AC-20 Base.

## TABLE 6

### SIEVE ANALYSIS IN PERCENTAGE PASSING INDICATED SIEVES FOR 1983

| AGGREGATE SOURCE & TYPE | 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
|---|---|---|---|---|---|
| Dogue (uncrushed gravel) | 100 | 93.1 | 21.4 | 2.0 | 1.0 |
| Fredericksburg (uncrushed gravel) | 100 | 87.8 | 22.8 | 2.8 | 3.0 |
| Mattaponi (crushed gravel) | 100 | 93.9 | 17.2 | 1.6 | 0.3 |
| Mattaponi (uncrushed gravel) | 100 | 92.2 | 15.3 | 1.6 | 0.6 |
| M. A. Smith (uncrushed gravel) | 100 | 92.6 | 13.2 | 2.4 | 0.4 |
| General (crushed stone) | 100 | 93.7 | 19.5 | 2.6 | 1.7 |
| Vulcan (crushed stone) | 100 | 91.6 | 27.9 | 5.3 | 1.8 |
| Massaponax (uncrushed gravel) | 99.9 | 91.6 | 25.6 | 0.5 | 0.3 |
| Massaponax (crushed gravel) | 99.9 | 90.9 | 32.8 | 5.4 | 1.9 |

## TABLE 7

### SIEVE ANALYSIS IN PERCENTAGE PASSING INDICATED SIEVES FOR 1984

| AGGREGATE SOURCE & TYPE | 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
|---|---|---|---|---|---|
| Dogue (uncrushed gravel) | 100 | 93.3 | 24.5 | 1.7 | 1.0 |
| Fredericksburg (uncrushed gravel) | 100 | 75.7 | 17.4 | 4.4 | 3.0 |
| Massaponax (uncrushed gravel) | 99.9 | 96.9 | 25.6 | 0.5 | 0.3 |
| Massaponax (crushed gravel) | 99.9 | 90.9 | 32.8 | 5.4 | 1.9 |
| Mattaponi (crushed gravel) | 98.7 | 77.8 | 24.2 | 2.0 | 0.3 |
| Mattaponi (uncrushed gravel) | 100 | 91.5 | 38.5 | 4.2 | 0.6 |
| M. A. Smith (uncrushed gravel) | 99.9 | 94.1 | 30.0 | 3.2 | 0.4 |
| General (crushed stone) | 100 | 84.3 | 8.0 | 2.4 | 1.7 |
| Vulcan (crushed stone) | 100 | 81.3 | 8.4 | 2.5 | 1.8 |

TABLE 8

SIEVE ANALYSIS IN PERCENTAGE PASSING INDICATED SIEVES FOR 1985

| AGGREGATE SOURCE & TYPE | 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
|---|---|---|---|---|---|
| Mattaponi (uncrushed gravel) | | | | | |
| Regular gradation | 100 | 82.7 | 12.1 | 1.9 | 1.4 |
| Special gradation | 100 | 72.6 | 10.4 | 0.8 | 0.2 |
| M. A. Smith (uncrushed gravel) | | | | | |
| Regular gradation | 100 | 81.8 | 8.1 | 0.7 | 0.7 |
| Special gradation | 100 | 85.1 | 11.0 | 0.3 | 0.1 |
| Vulcan (crushed stone) | | | | | |
| Regular gradation | 100 | 91.8 | 16.2 | 1.0 | 0.6 |
| Special gradation | 100 | 91.1 | 15.0 | 0.5 | 0.2 |
| Trego (crushed stone) | | | | | |
| Regular gradation | 100 | 87.3 | 24.6 | 3.5 | 0.6 |
| Special gradation | 99.8 | 86.4 | 18.4 | 0.5 | 0.2 |
| West (uncrushed gravel) | | | | | |
| Regular gradation | 100 | 70.4 | 3.1 | 0.7 | 0.2 |
| Special gradation | 100 | 90.7 | 8.8 | 0.7 | 0.4 |

## Methodology for Determining Quantities

The quantities of materials used in surface treatments should be determined through a design procedure and adjusted to accommodate traffic speed, volume, and surface condition. In addition to providing the inspector with target quantities, the design quantities give the contractors information that assists them in bids.

The surface factor that influences the adjustment to the designed quantity is the condition of the existing surface with respect to the amount of asphalt present. If the surface is flushed, the quantity of asphalt applied should be slightly reduced, and if the surface has a dry appearance, the quantity of asphalt should be slightly increased.

As previously mentioned, three design procedures were used in determining emulsion and aggregate quantities in 1984 and 1985. These design procedures were (1) the flakiness index, which is described in the *Asphalt Surface Treatment Handbook* MS-13 (*1*) (which is out of publication), (2) graded aggregate, which is described in the *Asphalt Emulsion Manual* MS-19 (*3*), and (3) *U.S. Customary*, which can also be found in MS-19 (*4*). All three are shown in Appendices A, B, and C. The average of the three designs was used to set the estimated quantities that are shown in Appendix D.

## Installations

The 1984 surface treatment test sections were placed by Whitehurst Paving Co., Inc. Normal surface treatment practices, such as brooming, applying the emulsion with calibrated distributors, and using self-propelled chip spreaders, were employed. Two rollers were used, a three-wheel steel wheel roller and a pneumatic tire roller with the steel wheel roller following the pneumatic tire roller on all sites. In addition, a vibratory roller with a 1 1/2-inch rubber sleeve on the compaction drum was used on 8 test sites that were in addition to the 54 designed sites. The normal practice of making three passes was employed by each of the rollers. Rolling immediately followed the placement of the treatment, and the rollers were kept close to the chip spreader.

To ensure proper quantities of emulsion and aggregate, periodic checks were made. Metal plates and scales were used for quantity determinations. Two plates were placed on the pavement. The first plate was removed after the distributor passed, and the second after both the distributor and aggregate spreader had passed. After weights were recorded, calculations were made to determine the amount of asphalt and aggregate being placed.

Table 9 contains descriptive information on the 1984 test sections and the quantities of materials placed.

TABLE 9

1984 TEST SECTION DATA

| DATE PLCD. | SITE NO. | ROUTE NO. | COUNTY | FROM RT | TO RT | AGGREGATE TYPE AND SOURCE | EMULSION TYPE & SOURCE | QUANTITIES EMULSION ($GAl/YD^2$) | QUANTITIES AGGREGATE (LB/YD) |
|---|---|---|---|---|---|---|---|---|---|
| 8/20 | 33 | 721 | Caroline | K & Q(1) | .3Mi.W | Dogue (round gravel | CRS-2H Central | .20 | 15 |
| 8/20 | 34 | 721 | Caroline | .3Mi.W | .6Mi.W | Fredericksburg (round gravel) | CRS-2H Central | .27 | 20 |
| 8/20 | 35 | 721 | Caroline | .6Mi.W | 1Mi.W | Massaponax (round gravel) | CRS-2H Central | .25 | 19 |
| 8/20 | 36 | 721 | Caroline | 1Mi.W | 1.3Mi.W | Massaponax (crushed gravel) | CRS-2H Central | .25 | 25 |
| 8/20 | 37 | 721 | Caroline | 1.3Mi.W | 1.6Mi.W | Mattaponi (crushed gravel) | CRS-2H Central | .25 | 22 |
| 8/20 | 38 | 721 | Caroline | 1.6Mi.W | 1.9Mi.W | Mattaponi (round gravel) | CRS-2H Chevron | .20 | 20 |
| 8/20 | 39 | 721 | Caroline | 1.9Mi.W | 2.2Mi.W | M. A. Smith (round gravel) | CRS-2H Chevron | .24 | 17 |
| 8/20 | 40 | 721 | Caroline | 2.2Mi.W | 2.6Mi.W | General (crushed stone) | CRS-2H Chevron | .28 | 19 |
| 8/20 | 41 | 721 | Caroline | 2.6Mi.W | 2.9Mi.W | Vulcan (crushed stone) | CRS-2H Chevron | .28 | 19 |
| 8/21 | 42 | 721 | Caroline | 2.9Mi.W | 3.2Mi.W | Dogue (round gravel) | CRS-2 Chevron | .24 | 17 |
| 8/21 | 43 | 721 | Caroline | 3.2Mi.W | 2.6Mi.W | Fredericksburg (round gravel) | CRS-2 Chevron | .28 | 20 |
| 8/21 | 44 | 721 | Caroline | 3.6Mi.W | 3.6Mi.W | Massaponax (round gravel) | CRS-2 Chevron | .27 | 21 |
| 8/21 | 45 | 721 | Caroline | 3.9Mi.W | 4.2Mi.W | Massaponax (crushed gravel) | CRS-2 Chevron | .27 | 19 |
| 8/21 | 46 | 721 | Caroline | 4.2Mi.W | Rt. 630 | Mattaponi (crushed gravel) | CRS-2 Chevron | .27 | 25 |
| 8/21 | 47 | 721 | Caroline | .2Mi.E | Rt.630-5Mi.E | Mattaponi (round gravel) | CRS-2 Chevron | .23 | 17 |
| 8/21 | 48 | 721 | Caroline | .5Mi.E | .8Mi.E | M. A. Smith (round gravel) | CRS-2 Chevron | .24 | 18 |
| 8/21 | 49 | 721 | Caroline | .82MI.E | 1.1MI.E | Genearl (crushed stone) | CRS-2 Chevron | .27 | 19 |
| 8/21 | 50 | 721 | Carloine | 1.1MI.E | 1.5MI.E | Vulcan (crushed stone) | CRS-2 Chevron | .27 | 19 |
| 8/21 | 51 | 721 | Caroline | 1.5MI.E | 1.8MI.E | General (crushed stone) | CRS-2 Central | .27 | 19 |
| 8/21 | 52 | 721 | Caroline | 1.8MI.E | 2.1MI.E | General (crushed stone) | CRS-2 Central | .27 | 19 |
| 8/21 | 53 | 721 | Caroline | 2.1MI.E | 2.4MI.E | M. A. Smith (round gravel) | CRS-2 Central | .24 | 17 |
| 8/21 | 54 | 721 | Caroline | 2.4MI.E | 2.7MI.E | Mattaponi (round gravel) | CRS-2 Central | .29 | 21 |
| 8/21 | 55 | 721 | Caroline | 2.7MI.E | 3.1MI.E | Mattaponi (crushed gravel) | CRS-2 Central | .25 | 22 |
| 8/21 | 56 | 721 | Caroline | 3.1MI.E | 3.6MI.E | Massaponax (crushed gravel) | CRS-2 Central | .30 | 21 |
| 8/22 | 57 | 721 | Caroline | 3.6MI.E | 3.7MI.E | Massaponax (round gravel) | CRS-2 Central | .25 | 19 |
| 8/22 | 58 | 721 | Caroline | 3.7MI.E | 4MI.E | Fredericksburg (round gravel) | CRS-2 Central | .30 | 24 |
| 8/22 | 59 | 721 | Caroline | 4MI.E | K & Q(1) | Dogue (round gravel) | CRS-2 Central | .24 | 17 |
| 8/22 | 60 | 645 | Caroline | 721 | .4MI.N | Dogue (round gravel) | CRS-2 Chevron | .27 | 17 |
| 8/22 | 61 | 645 | Caroline | .4I.N | .7MI.N | Fredericksburg (round gravel) | CRS-2 Chevron | .29 | 24 |
| 8/22 | 62 | 645 | Caroline | .7MI.N | 1.1MI.N | Massaponax (round gravel) | CRS-2 Chevron | .25 | 25 |
| 8/22 | 63 | 645 | Caroline | 1.1MI.N | 1.5MI.N | Massaponax (crushed gravel) | CRS-2 Chevron | .26 | 19 |

*continues*

TABLE 9 (*continued*)

| DATE PLCD. | SITE NO. | ROUTE NO. | COUNTY | FROM RT | TO RT | AGGREGATE TYPE AND SOURCE | EMULSION TYPE & SOURCE | QUANTITIES EMULSION (GAl/YD²) | QUANTITIES AGGREGATE (LB/YD) |
|---|---|---|---|---|---|---|---|---|---|
| 8/22 | 64 | 645 | Caroline | 1.5MI.N | 1.7MI.N | Mattaponi (round gravel) | CRS-2 Chevron | .25 | 17 |
| 8/22 | 65 | 645 | Caroline | 1.5MI.N | 1.1MI.N | Mattaponi (crushed gravel) | CRS-2 Chevron | .24 | 20 |
| 8/22 | 66 | 645 | Caroline | 1.1MI.N | 0.7MI.N | M. A. Smith (round gravel) | CRS-2 Chevron | .27 | 17 |
| 8/22 | 67 | 645 | Caroline | .7MI.N | .4MI.N | General (crushed stone) | CRS-2 Chevron | .27 | 18 |
| 8/22 | 68 | 645 | Caroline | .4MI.N | 721 | Vulcan (crushed stone) | CRS-2 Chevron | .26 | 21 |
| 8/23 | 69 | 646 | Caroline | 627 | .4MI.N | Dogue (round gravel) | CRS-2 Chevron | .27 | 17 |
| 8/23 | 70 | 646 | Caroline | .4MI.N | .8MI.N | Fredericksburg (round gravel) | CRS-2 Chevron | .31 | 20 |
| 8/23 | 71 | 646 | Caroline | .8Mi.N | 1.2Mi.N | Massaponax (round gravel)) | CRS-2 Central | .29 | 21 |
| 8/23 | 72 | 646 | Caroline | 1.2Mi.N | 1.6Mi.N | Massaponax (crushed gravel) | CRS-2 Central | .29 | 19 |
| 8/23 | 73 | 646 | Caroline | 1.6Mi.N | 2Mi.N | Mattaponi (crushed gravel) | CRS-2 Central | .25 | 19 |
| 8/23 | 74 | 646 | Caroline | 2Mi.N | 2.3Mi.N | Mattaponi (round gravel) | CRS-2 Central | .24 | 24 |
| 8/23 | 75 | 646 | Caroline | 2.4Mi.N | 2.8Mi.N | M. A. Smith (round gravel) | CRS-2 Central | .27 | 17 |
| 8/23 | 76 | 646 | Caroline | 2.8Mi.N | 3.2Mi.N | General (crushed stone) | CRS-2 Central | .29 | 17 |
| 8/23 | 77 | 646 | Caroline | 3.2Mi.N | 721 | Vulcan (crushed stone) | CRS-2 Central | .29 | 19 |
| 8/23 | 78 | 646 | Caroline | 721 | .4Mi.S | Vulcan (crushed stone) | CRS-2 Central | .30 | 19 |
| 8/23 | 79 | 646 | Caroline | .4Mi.S | .8Mi.S | General (crushed stone) | CRS-2 Central | .31 | 19 |
| 8/23 | 80 | 646 | Caroline | .8Mi.S | 1.2Mi.S | M. A. Smith (round gravel) | CRS-2H Central | .28 | 19 |
| 8/23 | 81 | 646 | Caroline | 1.2Mi.S | 1.6Mi.S | Mattaponi (round gravel) | CRS-2H Central | .32 | 25 |
| 8/23 | 82 | 646 | Caroline | 1.6Mi.S | 2Mi.S | Mattaponi (crushed gravel) | CRS-2H Central | .26 | 22 |
| 8/23 | 83 | 646 | Caroline | 2Mi.S | 2.3Mi.S | Massaponax (crushed gravel) | CRS-2H Central | .31 | 19 |
| 8/23 | 84 | 646 | Caroline | 2.3Mi.S | 2.8Mi.S | Massaponax (round gravel) | CRS-2H Central | .28 | 19 |
| 8/23 | 85 | 646 | Caroline | 2.8Mi.S | 3.2Mi.S | Fredericksburg (round gravel) | CRS-2H Central | .31 | 20 |
| 8/23 | 86 | 646 | Caroline | 3.2Mi.S | 627 | Dogue (round gravel) | CRS-2H Central | .27 | 17 |
| 9/6 | 87 | 662 | Lancaster | 354 | dead end(NBL) | Mattaponi (crushed gravel) | CRS-2 Central | .24 | 16 |
| 9/6 | 88 | 662 | Lancaster | 354 | dead end(SBL) | Mattaponi (crushed gravel) | CRS-2 Central | .24 | 16 |
| 9/5 | 89 | 681 | Lancaster | 354 | dead end(NBL) | Mattaponi (crushed gravel) | CRS-2 Central | .29 | 19 |
| 9/5 | 90 | 681 | Lancaster | 354 | dead end(SBL) | Mattaponi (crushed gravel) | CRS-2 Central | .29 | 19 |
| 9/7 | 91 | 682 | Lancaster | 354 | dead end(NBL) | General (crushed stone) | CRS-2 Central | .38 | 25 |
| 9/7 | 92 | 682 | Lancaster | 354 | dead end(SBL) | General (crushed stone) | CRS-2 Central | .38 | 25 |
| 9/7 | 93 | 794 | Lancaster | 620 | dead end(NBL) | Mattaponi (crushed gravel) | CRS-2 Central | .26 | 21 |
| 9/7 | 94 | 794 | Lancaster | 620 | dead end(SBL) | Mattaponi (crushed gravel) | CRS-2 Central | .26 | 21 |

(1) County Line
(2) NBL (NORTHBOUND LANE)
(3) SBL (SOUTHBOUND LANE

**Climatological Data**

Temperature data were recorded on an hourly basis throughout the day during placement of the test sites. The high, low, and average daily temperatures are shown in Table 10. Some of the low temperatures fell below the suggested minimum temperature of 60°F; however, placement was not allowed until the 60°F temperature was reached.

Precipitation data were also obtained and are shown in Appendix E.

TABLE 10

TEMPERATURE DATA (DEGREES FAHRENHEIT)

| DATE | LOW | HIGH | AVERAGE DAILY TEMPERATURE |
|---|---|---|---|
| 8/20/84 | 76 | 88 | 80 |
| 8/21/84 | 54 | 84 | 76 |
| 8/22/84 | 62 | 89 | 80 |
| 8/23/84 | 69 | 80 | 75 |
| 9/05/84 | 59 | 76 | 68 |
| 9/06/84 | 51 | 72 | 62 |
| 9/07/84 | 44 | 73 | 59 |

**1984 Evaluation**

Prior to placement of the test sites, the roads were evaluated to determine their condition and to make final adjustments to asphalt quantities. The majority of the roads were rated poor to very poor. This was the result of the application of too much asphalt on previous treatments and to other poor construction practices.

After the placement of these test sites, they were evaluated periodically. Table 11 shows the data for the first two evaluations (November 1984 and February 1985). Table 11 shows that the deterioration of the river gravel treatments is more significant than with the crushed stones. When the next evaluations were made, six months to one year later, most of the river gravels had deteriorated to poor and very poor whereas the crushed stone sites were fair to excellent.

After a year, distinguishing differences in test sites became more difficult as pre-existing flushed conditions were reflecting through and distorting the surface appearance. Even though the crushed stone sites were performing well after the first six months, they too began to deteriorate during the second six months after placement.

# TABLE 11

## NUMBER OF TEST SITES WITH INDICATED RATINGS IN 1984 AND 1985

| Stone Source | Asphalt | Excellent(1) 11/84 | Excellent(1) 2/85 | Good(2) 11/84 | Good(2) 2/85 | Fair(3) 11/84 | Fair(3) 2/85 | Poor(4) 11/84 | Poor(4) 2/85 | Very Good(5) 11/84 | Very Good(5) 2/85 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dogue (round gravel) | 5** | | | 1 | 1 | 1 | | | 1 | | |
| | 6** | 1 | | 1 | 2 | | | | | | |
| | 3*** | | | 1 | 2 | 1 | | | | | |
| Fredericksburg (round gravel) | 5 | 1 | | | | | 1 | 1 | 1 | | |
| | 6 | 1 | | 1 | 2 | | | | | | |
| | 3 | 1 | | | 1 | | | 1 | 1 | | |
| Massaponax (round gravel) | 5 | 2 | | | 1 | | 1 | | | | |
| | 6 | 1 | | 1 | 2 | | | | | | |
| | 3 | | | | 1 | 2 | | | 1 | | |
| Massaponax (crushed gravel) | 5 | 2 | | | 1 | | | | 1 | | |
| | 6 | 1 | | | | | | 1 | | | |
| | 3 | | 1 | 1 | | | | 1 | | | |
| Mattaponi (crushed gravel) | 5 | | | 1 | 2 | | | 1 | | | |
| | 6 | | | 1 | | | | 1 | 2 | | |
| | 3 | | | 1 | | | | 1 | 2 | | |
| Mattaponi (round gravel) | 5 | 1 | | | | 1 | 1 | | 1 | | |
| | 6 | | | 1 | 2 | 1 | | | | | |
| | 3 | 1 | | | | 1 | 1 | | 1 | | |
| M. A. Smith (round gravel) | 5 | | | 1 | | 1 | 2 | | | | |
| | 6 | 2 | | | 1 | | 1 | | | | |
| | 3 | | | | 1 | | 2 | 1 | | | |
| General (crushed stone) | 5 | 1 | 1 | 1 | 1 | | | | | | |
| | 6 | | 1 | 2 | 1 | | | | | | |
| | 3 | 1 | 1 | 1 | 1 | | | | | | |
| Vulcan (crushed stone) | 5 | 1 | 1 | | 1 | | | | | | |
| | 6 | | 1 | 2 | 1 | | | | | | |
| | 3 | 1 | 1 | 1 | 1 | | | | | | |

*5 - CRS-2H (Central) **6 - CRS-2 (Chevron) ***3 - CRS-2 (Central

(1) EXCELLENT - 90 TO 100% AGGREGATE RETENTION.

(2) GOOD - 80 TO 90% AGGREGATE RETENTION.

(3) FAIR - 70 TO 80% AGGREGATE RETENTION.

(4) POOR - 50 TO 60% AGGREGATE RETENTION.

(5) VERY POOR - 0 TO 50% AGGREGATE RETENTION.

As previously mentioned, quantities were determined by design test and adjusted according to surface condition and traffic speeds and volumes. However, pre-existing bleeding or flushing cannot always be eliminated after making adjustments on one surface treatment. Adjustments need to be made for several surface treatment applications. Thus a number of years are usually required to eliminate severely flushed surfaces.

In addition to placing and observing the 54 test sites in the Fredericksburg District, observations were made on many other surface treatments placed statewide during 1984. From these observations, it was apparent that crushed stone performed better than river gravel, surface treatments placed by design methods perform better than those not designed, and some aggregates perform poorly as a result of excess fines.

The following figures show samples of both gravel and crushed stone surface treatments several months after they were placed. Figure 3 shows a gravel surface treatment placed during the later part of September when the air temperature was 60°F. According to Runkle and Mahone(2) failures are apt to occur when surface treatments are placed at temperatures less than 70°F. Figures 4 and 5 show river gravel and crushed stone surface treatments that are performing well after six months. Even though both of these treatments look good, failure of the river gravel treatment is much more likely to occur than the treatment with the crushed stone. This statement is made as a result of observations of other river gravel surface treatments that performed well for six months and then failed. Normally, a failure such as this occurs during the winter months.

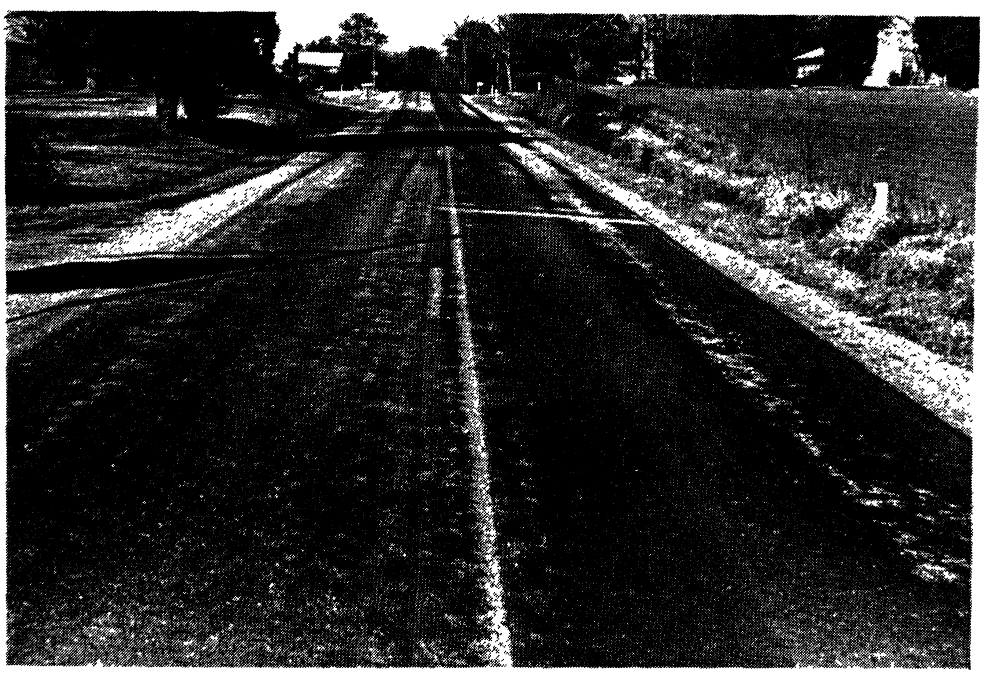

Figure 3. River gravel surface treatment that failed.

Figure 4. River gravel surface treatment performing well.

Figure 5. Crushed stone surface treatment performing well.

The vibratory roller that was tested in 1984 did a good job. Because of the design of the roller (with a steel drum in front covered with a 1 1/2-inch rubber sleeve and using large rubber wheels in the rear), the rolling effect was similar to using both a steel wheel and a rubber tired roller.

## 1985 EXPERIMENTS

Test sites placed in the Fredericksburg District in 1983 and 1984 focused mainly on river gravels. However, as stated earlier, some crushed stone test sites were placed for comparison.

The work in 1983 and 1984 indicated that crushed stones normally performed better than river gravels, but even crushed stones sometimes present problems during construction. It was observed that compatibility problems were often the result of dirty aggregates.

Even though the aggregates were often dirty or contained too many fines for successful surface treatments, the aggregates still passed VDOT specifications. When problems occurred, it was often observed that the amount of material passing the No. 4 sieve was in excess of 25 percent.

Because of the problems experienced using some crushed stones and complaints from districts other than Fredericksburg experiencing surface treatment problems, an addendum to the original working plan was added for work to be carried out during 1985 and 1986.

The addendum initially proposed that the researchers locate several quarries to furnish No. 8 aggregates with three unique gradations. The gradation would restrict the material passing the No. 4 sieve to 5 to 10 percent, 10 to 15 percent, and 15 to 20 percent. All of the six quarries contacted indicated that these ranges were too restrictive. However, five quarries agreed to furnish special No. 8 material with less than 20 percent passing the No. 4 sieve and with no more than 4 percent passing the No. 8 sieve. Two of the five quarries were river gravel quarries located in the Fredericksburg District. Of the remaining three, there was one each in the Richmond (crushed stone), Suffolk (crushed stone), and Staunton districts (river gravel).

In addition to placing test sections, the following tasks were included in the 1985-1986 plan:

1. Observe the placement of surface treatments in all districts.
2. Run gradation and design tests on as many aggregate sources as possible.
3. Place test sections with latex additives mixed with the emulsions.
4. Perform follow-up evaluations on surface treatments placed on as many different traffic group roads and employing as many different aggregate sources as possible.

## Materials

### Emulsions

The asphalt emulsions consisted of CRS-2 except for a test site on Rt. 601 in Louisa County where 3 percent latex additive was mixed with Chevron's CRS-2. The latex for one site was provided by Dow Chemical Company, and the latex for a second site was provided by USA and Textile Rubber and Chemical Company. A control section employing CRS-2 was also placed.

### Aggregates

The gradations for the No. 8 aggregate used can be found in Table 8. Even the regular graded aggregate had much less material passing the No. 4 sieve than some aggregates used in 1983 and 1984.

In addition, aggregates were obtained during 1985 and 1986 from all quarries that furnish No. 8 surface treatment aggregate to the state. Gradations and design tests were run on these aggregates and are shown in Appendices F, G, H, and I.

## 1985 Installations

The test sites were placed by Whitehurst Paving Co., Inc., and B. P. Short Co., Inc. Normal surface treatment practices were employed, and the special graded aggregates were placed on one side of the roadway, whereas the regular aggregates were placed on the opposite side.

Table 12 contains site locations and descriptive information on the 1985 test sites.

The 1985 plans included provisions for installations of surface treatments fabricated with emulsions containing latex. Because of various delays, these sites were not placed until May 1986. At that time, three test sites were placed by Payne Paving Co., Inc., on Rt. 601 in Louisa County. The test sites were approximately 2.0 miles in length, and two of these sites employed 3 percent latex additive. The third 2-mile site was a control section employing CRS-2.

The emulsions and aggregate were applied and treated in the same manner for all test sites. Each site was rolled with a pneumatic tire roller, and traffic was not allowed on the new treatments for 2 hours.

Table 13 provides the descriptive site information.

As stated earlier, gradations and design quantities were run on all surface treatment aggregates. Statewide, as many surface treatment installations were observed for as many aggregate sources and traffic groups as possible.

TABLE 12

1985 TEST SITE DATA

| ROUTE | COUNTY | LANE | LOCATION | AGGREGATE SOURCE | QUANTITIES AGGREGATE TYPE | AGGREGATE LB/YD² | EMULSION GAL/YD² |
|---|---|---|---|---|---|---|---|
| 620 | Spotsylvania | E | From Rt. 610 to 2.0 mi. W. Rt. 610 | M. A. Smith | *Gravel | 21 | .28 |
| 620 | Spotsylvania | W | From Rt. 610 to 2.0 mi. W. Rt. 610 | M. A. Smith | Gravel | 21 | .27 |
| 627 | Caroline | E | From Rt. 647 to K & Q Co. Line | Mattaponi | *Gravel | 18 | .32 |
| 627 | Caroline | W | From Rt. 647 to K & Q Co. Line | Mattaponi | Gravel | 20 | .31 |
| 634 | Brunswick | E | From Rt. 642 to Rt. 606 | Vulcan | *Crushed | 19 | .28 |
| 634 | Brunswick | W | From Rt. 642 to Rt. 606 | Vulcan | Crushed | 23 | .32 |
| 796 | Augusta | E | From Rt. 254 to Rt. 795 | West S & G | *Gravel | 18 | .26 |
| 796 | Augusta | W | From Rt. 254 to Rt. 795 | West S & G | Gravel | 18 | .26 |
| 730 | Greenville | E | From Rt. 666 to Rt. 629 | Trego | *Crushed stone | 18 | .28 |
| 730 | Greenville | W | From Rt. 666 to Rt. 629 | Trego | Crushed stone | 18 | .30 |

*Special graded aggregate.

TABLE 13

1986 TEST SITE DATA

| EMULSION TYPE | LOCATION | AGGREGATE SOURCE | QUANTITIES AGGREGATE | QUANTITIES EMULSION |
|---|---|---|---|---|
| Regular CRS-2 | From Rt. 522 to S. Anna R. Br. | Vulcan (crushed stone) | 20 lb/yd² | .30 gal/yd² |
| CRS-2 with Ultrapave Latex | From 0.6 mi. E. Rt. 522 to 2.4 mi. E. | Vulcan (crushed stone) | 18 lb/yd² | .28 gal/yd² |
| CRS-2 with Dupont Latex | From 2.4 mi. E. Rt. 522 to 4.1 mi. E. | Vulcan (crushed stone) | 18 lb/yd² | .28 gal/yd² |

## Evaluations

Evaluations were made periodically on the test sites and many regular surface treatments throughout the state in 1985 and 1986.

The 1985 test sites on the five routes that received both regular and special graded No. 8 aggregate have shown little difference except on one site of Route 634 in Brunswick County where about 4 pounds per square yard of excess stone were placed, which resulted in wind rows shortly after placement.

The test sites were evaluated during, shortly after, and up to 1 1/2 years after placement. During construction and shortly thereafter, the ratings on all sites were good to excellent. However, the aggregates furnished by the five quarries for both the regular and special graded material were very similar in gradation, and in no case did as much as 25 percent pass the No. 8 sieve (see Table 8).

After 1 1/2 years, the sites employing the river gravel from M. A. Smith and Mattaponi began to fail, but the sites containing river gravel from West were still performing well. All of the crushed stone sites received good to excellent ratings except one side of Route 634 in the Richmond District where the regular graded aggregate was used. This failure was not the result of the aggregate but rather of the application of 0.04 gal/yd$^2$ more asphalt than indicated by design.

The initial evaluation of the latex test sites in Louisa County indicated that the aggregate/emulsion compatibility was better on the latex test sites than on the regular test site. Also, immediatly after construction, there was more loose aggregate on the regular treatment than on the latex treatments. This is attributed to too much stone being placed on the regular site, as can be seen in Table 13.

Excess aggregate was used on many regular surface treatments placed throughout the state in 1985 and 1986. In addition, it was noted that compatibility continued to create many problems, especially with those aggregates that had more than 25 percent passing the No. 4 sieve.

Even though dirty aggregates created major compatibility problems, there were some surface treatments placed with relatively clean agregates that did not do well. Such failures have been traced to the application of too much asphalt, too much stone, lack of traffic control, poor rolling procedures, cold asphalt, failure to adjust asphalt quantities for road and traffic conditions, and a number of other poor practices. In this study, it was found that most river gravels, even under the most controlled conditions, do not provide as high a quality surface treatment as those that employ crushed stone.

# CONCLUSIONS

The findings of this project are that construction techniques, the determination of material quantities by design, the type of aggregate and its gradation, aggregate and emulsion adhesion, and the cleanliness of aggregates significantly affect the performance of a surface treatment.

Based on the information obtained in this study, river gravels do not perform as well as crushed stones. River gravels from some sources perform better than those from other sources, but it is not advisable to use them on roads with high levels of traffic.

The steel wheel roller does a better job of embedding the aggregate than the rubber tire roller. Since many of Virginia's secondary roads do not have good cross sections, it was found advisable to use the rubber tire and steel wheel rollers together. Because the vibratory roller can employ a 1 1/2-inch rubber sleeve around the steel drum and has two pneumatic wheels, it could serve the purpose of both types of rollers.

## RECOMMENDATIONS

1. Tighten the gradation tolerance of the No. 8 aggregate to 10 percent + 12 percent passing the No. 4 screen, 2 percent + 2 percent passing the No. 8 screen and 1 percent + 1 percent passing the No. 16 screen.

2. Employ the U.S. Customary design method found in the Asphalt Institute's *Asphalt Emulsion Manual* (MS-19) for determining asphalt and aggregate quantities.

3. Require the use of a tandem steel wheel roller on roads where it will not bridge ruts or undulations.

4. Implement better construction practices.

   - Do not place surface treatments at surface temperatures below 70°.

   - Calibrate the distributor and chip spreader.

   - Make sure the screen that provides for dispersal of the large aggregate first is attached to the chip spreader.

   - Check frequently for quantities placed as well as the distribution pattern of the materials. Place the cover aggregate immediately after the application of asphalt (0 to 30 seconds).

   - Check the speed of the rollers to make sure the operators are complying with specifications.

   - Employ traffic control for a minimum of two hours.

   - Pay for aggregate by the square yard based on design quantities to eliminate excessive applications.

- Require that steel wheel rollers be used in conjunction with rubber tire rollers.
- Allow the use of the vibratory rollers with a 1 1/2-inch rubber sleeve on the compaction drum without the vibratory system turned on.
- Use materials that have good performance histories rather than those that have presented construction problems. If economics require that those which present problems be used, they should be used only on low traffic roads.
- Disallow the use of river gravels on roads with traffic groups greater than V.
- Perform daily checks with the one square foot metal plates to ensure proper quantities.
- Adjustments should be made to asphalt quantities based on traffic and road conditions.
- Adjust design quantities based on road and traffic conditions.
- Make frequent quantity checks to ensure that accurate quantities are being placed.
- Additional experimental surface treatments that have latex added to the binder should be placed.
- Make sure that the inspectors assigned to surface treatment placements are qualified in surface treatment techniques.
- Make sure the screen that provides for dispersal of the large aggregate first is attached to the chip spreader.

## REFERENCES


1. The Asphalt Institute, 1985. *Asphalt surface treatments.*
2. Runkle, Steven N. and Mahone, David C. 1967. *Study of bituminous surface treatments in Virginia*. Charlottesville, VA: Virginia Trasportation Research Council.
3. The Asphalt Institute. 1979. *A basic asphalt emulsion manual.*
4. Arnold, Eugene D., Jr. 1968. *Effect of moisture on typical Virginia surface treatment materials*.

## ACKNOWLEDGMENTS

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# APPENDIX A

# FLAKINESS INDEX DESIGN METHOD

# APPENDIX A

THIS METHOD IS EXCERPTED FROM APPENDIX C OF "ASPHALT SURFACE TREATMENTS AND ASPHALT PENETRATION MACADAM" PUBLISHED BY THE ASPHALT INSTITUTE.

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...The methods of design presented here are based on studies made by Mr. F. M. Hanson of New Zealand and modifications to his method by engineers in the United States, Canada, and Australia.

Hanson's method involves the following principles:

(1) When one size cover aggregate is dropped by a spreader on an asphalt film, the particles lie in unarranged positions and the voids between the particles are approximately 50 percent.

(2) Rolling shifts the aggregate particles and the voids are reduced to 30 percent.

(3) Finally, after considerable traffic, the particles become oriented into their densest positions, with all lying on their flattest sides, and the voids become approximately 20 percent.

(4) Since the particles lie on their flattest sides, the average thickness of a surface treatment is determined from the overall average smallest dimension of the aggregate particles. Hanson refers to this as the "average least dimension of the cover aggregate".

(5) The average least dimension of any approximately one-size cover aggregate can be determined by calipering a number of individual aggregate particles or by using slotted screens.

(6) As soon as the average least dimension of the aggregate particles is known, the number of square yards covered by each cubic yard can be calculated, and the quantity of cover aggregate to be ordered for any job can be determined quickly.

(7) The average least dimension of the aggregate also is the basis for the amount of asphalt binder to be used with any given aggregate cover.

(8) For good performance the quantity of asphalt binder used should fill about 70 percent of the 20 percent void space, (see (3) above) if the traffic volume is low. However, the asphalt binder should fill not more than 60 percent of the 20 percent void space if the traffic volume is high.

AVERAGE LEAST DIMENSION -- A rapid method for determining the average least dimension of surface treatment aggregate was developed in Australia. First, a grading analysis is made using sieves with square holes and the results are plotted on a grading chart. The 50 percent passing size, in inches, determined from the grading curve, is the median size of the aggregate.

Each size passing one sieve and retained on the next, down to the minimum size is then tested particle by particle on appropriate slotted sieves to determine the flakiness index. The median size and the flakiness index are then used to determine the average least dimension from the graph in Figure A-3.

Table A-1

Sizes to be Tested for Flakinesss Index

| Aggregate Size Designation | Nominal Range of Sizes U.S. Standard Sieves; Square Openings - Inches | | All Materials Larger than: |
|---|---|---|---|
| | Passing | Retained | |
| A | 3/4 | 1/2 | 1/2 inch |
| B | 1/2 | 3/8 | 3/8 inch |
| C | 3/8 | No. 4 | No. 4 Sieve |

TRAFFIC FACTOR -- Traffic volume is a variable that should be considered when determining the amount of emulsion needed for the surface treatment. Unless adjustments in the quantity of emulsion are made for traffic volume, flushing may result under heavy traffic or the voids may not be filled enough for best performance under light traffic. Studies have shown that the percent of voids filled with emulsion should be about as given in Table A-2. The traffic factors in this table are percentages expressed as decimals.

Table A-2

Traffic Factors for Surface Treatments

| | Traffic Factor = Percentage (expressed as a decimal) of 20 percent void space in cover aggregate to be filled with emulsion | | | | |
|---|---|---|---|---|---|
| | Traffic - Vehicles per Day | | | | |
| Aggregate | Under 100 | 100 to 500 | 500 to 1,000 | 1,000 to 2,000 | over 2,000 |
| Recognized Good Type of Aggregate | 0.85 | 0.75 | 0.70 | 0.65 | 0.60 |

Note: (1) the factors above do not make allowance for absorption by the road surface or by absorptive cover aggregate.
(2) Values shown in the table are from "Do's and Dont's of Seal Coating" Norman W. McLeod, presented at ARBA Conference for County Highway and officials, Gatlinburg, Tennessee, September 1963.

## Single Surface Treatment and Aggregate Seal Cost

DESIGN FORMULAS FOR ONE-SIZE AGGREGATE -- The formulas below for determining the amount of one-size aggregate and emulsion for single surface treatments and aggregate seal coats are based on the Australian work. To use them, the bulk specific gravity (AASHO Designation T-85 or ASTM Designation C-127), The Flakiness Index, and the Average Least Dimension of the aggregate must be determined. Also, the traffic volume and the percent of aggregate lost by whip-off and handling must be estimated. Table A-4 gives aggregate wastage factors for whip-off and handling. Then, the quantity of aggregate in pounds per square yard, and the quantity of emulsion, in gallons per square yard, can be found readily.

$$S = 37.4 G_m H_1 E \quad \ldots\ldots \quad (1)$$

$$A = 1.122\ TH_1 + V \quad \ldots\ldots \quad (2)$$

Where

| | | |
|---|---|---|
| $S$ | = | Aggregate Spread in pounds per square yard. |
| $G_m$ | = | Bulk Specific Gravity of Aggregate |
| $H_1$ | = | Average Least Dimension of Aggregate |
| $A$ | = | Asphalt Spread in gallons per square yard |
| $T$ | = | Traffic Factor (Table A-2) |
| $E$ | = | Average Wastage Factor (Table A-4) |
| $V$ | = | Variable in gallons per square yards, to cover absorption by pavement |

| | | | Gal/sq.yd |
|---|---|---|---|
| Smooth, nonporus surface . . . . . . . . . . . . | V | = | 0.00 |
| Slightly porous, slightly oxidized surface . . | V | = | 0.03 |
| Slightly pocked, porous oxidized surface . . . | V | = | 0.06 |

Badly pocked, porous oxidized surface . . . . V = -0.09

Flushed asphalt surface, . . . . . . . . . . . . V = -0.03

Example:

(From grading chart, Figure A-5*) Median size of aggregate = 0.42 inches

(From Flakiness Index test, Appendix A*) Flakiness Index = 25.0 percent

(From chart, Figure A-3), Average Least Dimension $H_1$ = 0.29 inch

(From Specific Gravity test AASHO Designation T 85) Bulk

Specific Gravity, $G_m$ = 2.70

(For traffic of 1,200 vehicles per day, from Table A-2)

Traffic Factor, T, = 0.65

Aggregate Wastage Factor, E = 1.05 (for wastage of 5 percent, Table A-4)

(Assuming a smooth, nonporous pavement surface) V = 0.00 gal/sq.yd.

-----

* refer to "Asphalt Surface Treatments and Asphalt Penetration Macadam"

(1) $S = 37.4\ G_m H_1 E$

$S = 37.4 \times 2.70 \times 0.29 \times 1.05$

$S = 30.7$ pounds per square yard

(2) $A = 1.122\ TH_1 + V$

$A = 1.122 \times 0.65 \times 0.29 \times 0.00$

$A = 0.211$ gallons per square yard

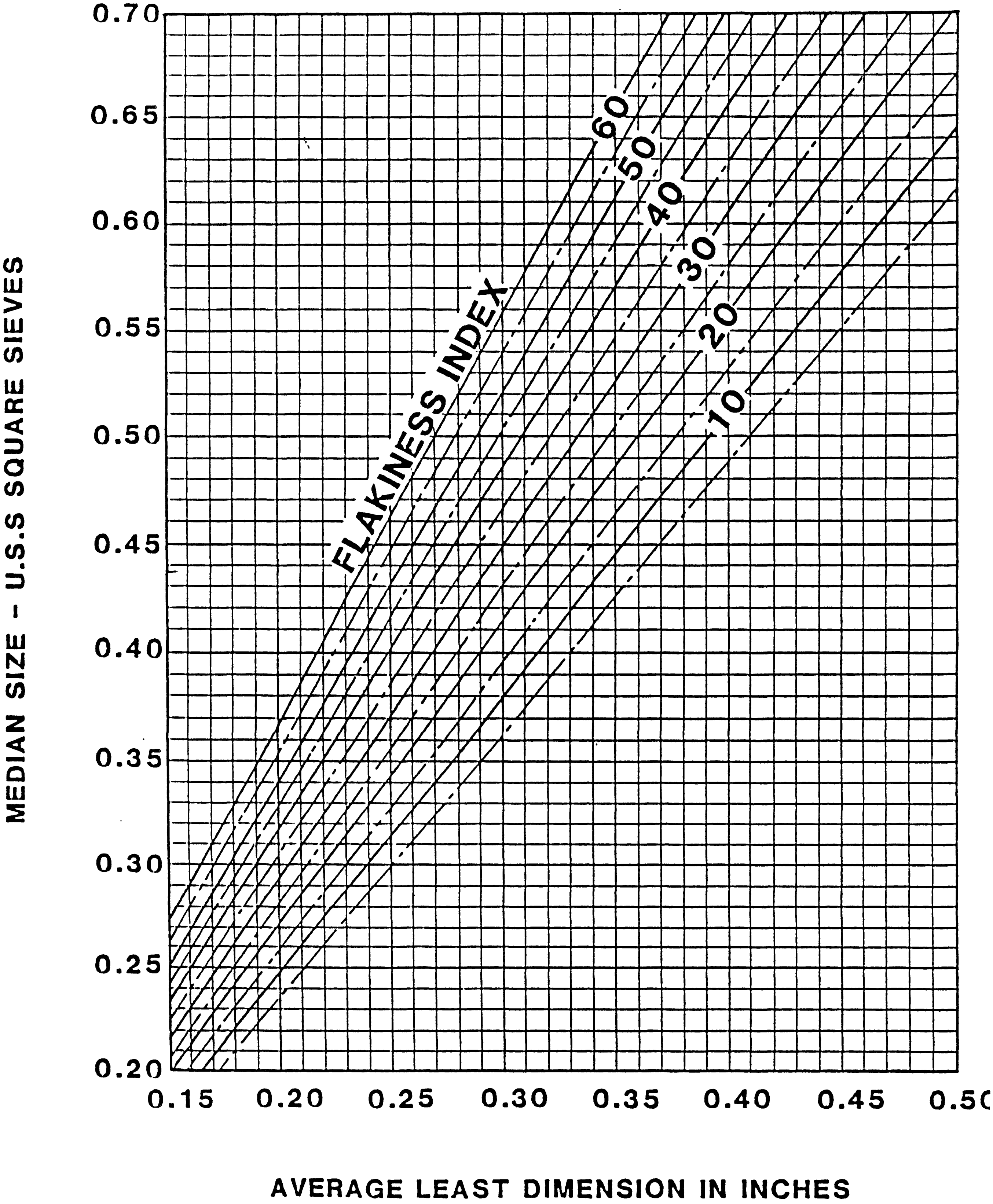
FLAKINESS INDEX
60
50
40
30
20
10
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
MEDIAN SIZE - U.S.S SQUARE SIEVES
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
AVERAGE LEAST DIMENSION IN INCHES

Table A-4

Aggregate Wastage Factors

| Percentage Waste* Allowed For | Wastage Factor, E |
|---|---|
| 1 | 1.01 |
| 2 | 1.02 |
| 3 | 1.03 |
| 4 | 1.04 |
| 5 | 1.05 |
| 6 | 1.06 |
| 7 | 1.07 |
| 8 | 1.08 |
| 9 | 1.09 |
| 10 | 1.10 |
| 11 | 1.11 |
| 12 | 1.12 |
| 13 | 1.13 |
| 14 | 1.14 |
| 15 | 1.15 |

* Due to whip-off and handling

Rather than designing the required quantities each time a surface treatment is placed, it is proposed that the sources and sizes of stone which are to be used in surface treatment schedules be evaluated (perform gradation and flakiness index information) once or twice per year and that this information be used to design the individual surface treatments. Engineering judgment will still have to be exercised in such matters as increasing or decreasing those materials placed due to traffic and pavement conditions.

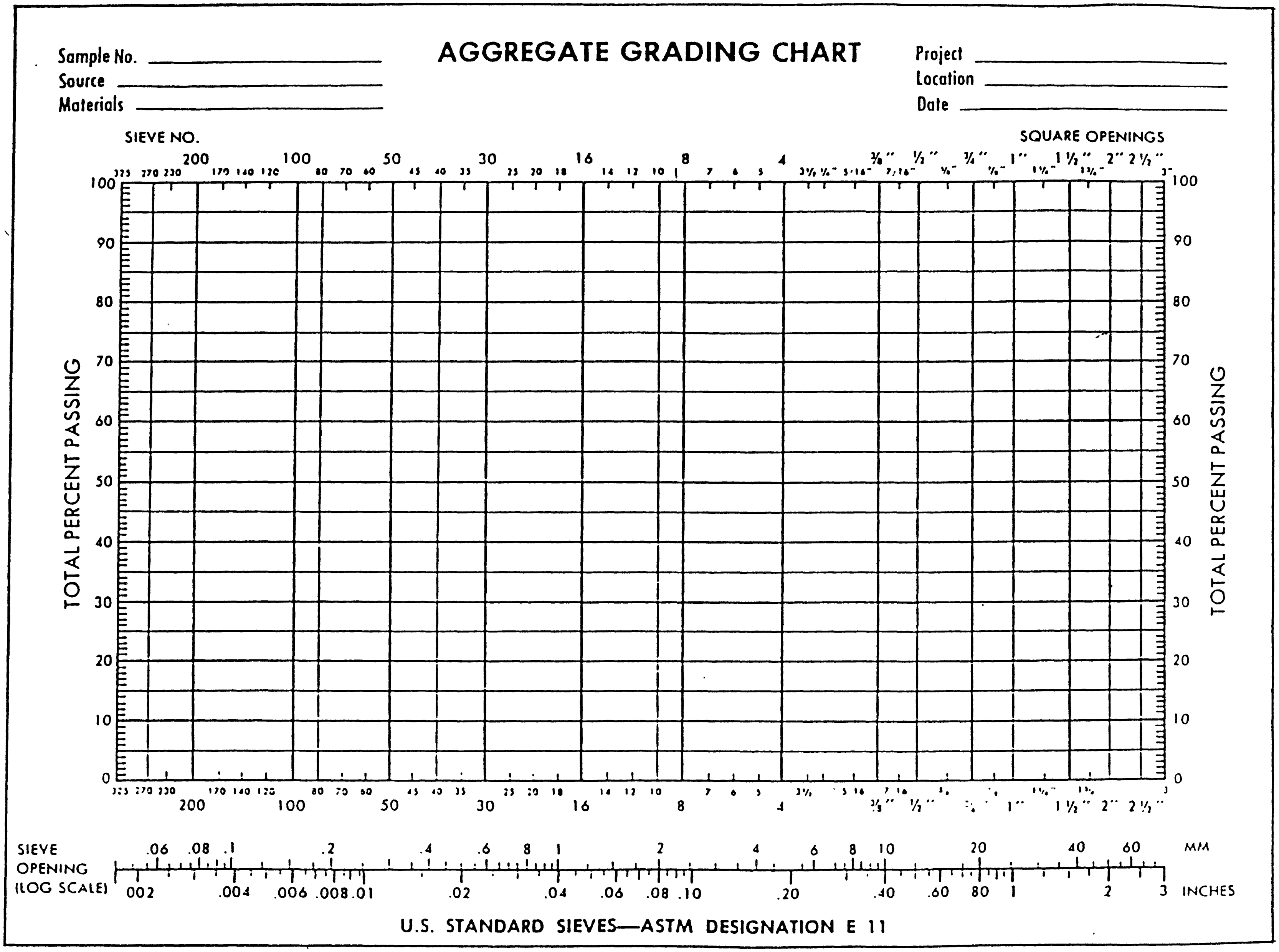


Figure A-5. Sample aggregate grading chart.

# APPENDIX B

## DESIGN FORMULAS USING GRADED AGGREGATE

## Appendix B

### Design Formulas for graded aggregate

Formulas have been derived for finding the amount of graded aggregate and asphalt needed for a single surface treatment or aggregate seal coat. Before they are used, a sieve analysis and a loose unit weight (AASHO Design T 19) of the aggregate must be made.

The first determination is the spread modulus. The following formula, using information taken from the grading curves for the aggregate is used to find it:

$$M = 0.20 \frac{(b + a)}{2} + 0.60 \frac{(c + b)}{2} + 0.20 \frac{(d + c)}{2}$$

or simplifying:

$$M = 0.10 (b + a) + 0.30 (c + b) + 0.10 (d + c) \qquad (3)$$

Where --

M = Spread modulus

a = 100% passing aggregate size in inches

b = 80% passing aggregate size in inches

c = 20% passing aggregate size in inches

d = 0% passing aggregate size in inches

After the spread modulus is determined, the quantity of aggregate, in pounds per square yard, and the quantity of asphalt, in gallons per square yard, can be found.

$$S = 0.80\ MW \qquad (4)$$

$$A = 1.122\ MT + V \qquad (5)$$

Where --

S = Aggregate spread in pounds per square yard

M = Spread modulus

W = Loose unit weight of aggregate in pounds per cubic foot

V = Variable, in gallons per square yard, to cover absorption by aggregate and pavement.

| | |
|---|---|
| Smooth, nonporous surface | V = 0.00 |
| Slightly porous, oxidized surface | V = 0.05 |
| Slightly pocked, porous, oxidized surface | V = 0.10 |
| Badly pocked, porous, oxidized surface | V = 0.15 |

A = Asphalt spread in gallons per square yard

T = Traffic Factor (Table A-2)

Example:

From grading chart, Figure A-5 (crushed stone aggregate)

a = 0.500 inches

b = 0.330 inches

c = 0.187 inches

d = 0.039 inches

Then --

$$M = 0.10\ (0.330 + 0.500) + 0.30\ (0.187 + 0.330) + 0.10\ (0.039 + 0.187)$$

$$M = 0.083 + 0.155 + 0.023$$

$$M = 0.261$$

Loose unit weight, W = 95 pounds per cubic foot (AASHO Designation T 19)

Assuming: V = 0.000 gallon per square yard absorption by pavement

$T = 0.70$ (750 vehicles per day. Table A-2)

(1) $S = 0.80\ MW$

$S = 0.80 \times 0.261 \times 95$

$S = 19.8$ pounds per square yard

(2) $A = 1.122\ MT + V$

$A = 1.122 \times 0.261 \times 0.70 + 0.00$

$A = 0.205$ gallon per square yard

The use of flat and elongated aggregate should be avoided, but if it becomes necessary to use such aggregate the average least dimension should be determined as described in Article C.04. The average least dimension should then be substituted for "M" in the design formulas so that the correct spread of asphalt and aggregate can be determined.

# APPENDIX C

## U. S. CUSTOMARY DESIGN PROCEDURE

U.S. Customary | S.I. Metric*

$C = M[46.8\ (1-(0.4V)\ HGE]$ $\qquad$ $C = M[(1-0.4V)\ HGE]$

where

C = cover aggregate applications, $lb/yd^2$ ($kg/m^2$)

V = voids in the cover aggregate in loose weight condition,

$V = 1: \frac{W}{62.4G}$ or metric ($V = 1 - \frac{W}{1000G}$) percent, expressed as

as a decimal

W = loose unit weight of cover aggregate lb/ft ($kg/m^3$), AASHTO Method T19 (ASTM Method C29).

G = bulk specific gravity of cover aggregate, AASHTO Method T 85 (ASTM Method C127)

H = average least dimension (ALD) of cover aggregate, in. (mm) (Appendix D)

E = wastage factor to allow for cover stone loss, due to whip-off and unevenness of spread.

M = a multiplying factor that must be evaluated by experience with local conditions of climate, traffic, cover aggregate, etc., and may have a value greater or less than 1.0 which is its normal value.

700 The quantity of emulsified asphalt to be applied is found by the following equation:

| U.S Customary | S.I. Metric |
|---|---|
| $B = K \left[\frac{2.244\ HTV + S + A}{R}\right]$ | $B = K \left[\frac{0.40\ HTV + S + A}{R}\right]$ |

where

B = emulsified asphalt application, $gal/yd^2$ ($litre/m^2$)

H = average least dimension of cover aggregate, in. (mm), T = traffic factor

V = voids in cover aggregate, loose weight condition (see equation for cover aggregate application above), percent expressed as a decimal

S = correction, $gal/yd^2$ ($litre/m^2$), for texture of surface on which surface treatment is to be placed

| | Correction, S | |
|---|---|---|
| Texture | $gal/yd^2$ | $litre/m^2$ |
| Black, flushed asphalt .......... | -0.01 to -0.06 | (-0.04 to -0.27) |
| Smooth, non-porous .............. | 0.00 | (0.00) |
| Absorbent -- slightly porous, oxidized.. | 0.03 | (0.14) |
| -- slightly pocked, porous, oxidized .................. | 0.06 | (0.27) |
| -- badly pocked, porous, oxidized .................. | 0.09 | (0.40) |

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* International System of Units (S.I.) being adopted throughout the world.

# APPENDIX D

## DESIGN RESULTS FOR 1984 AND 1985

# APPENDIX D

1984 AND 1985 DESIGN RESULTS
EMULSION GAL./SQ. YD. AGGREGATE LBS./SQ. YD.

| YEAR | SOURCE AND TYPE | ASPHALT UNDER 100 VPD FI | GA | US | 100-500 VPD FI | GA | US | 500-1000 VPD FI | GA | US | AVERAGE VPD UNDER 100 | 100-500 | 500-1000 | AGGREGATE | | | AVER LBS/ SQ.YD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984 | Dogue S&G (round gravel) | .25 | .37 | .20 | .22 | .32 | .17 | .20 | .31 | .16 | .27 | .24 | .22 | 17 | 20 | 18 | 18 |
| 1984 | Fredericksburg S&G (round gravel) | .29 | .42 | .21 | .26 | .37 | .19 | .25 | .34 | .18 | .31 | .27 | .26 | 20 | 23 | 21 | 21 |
| 1984 | Massaponax S&G (round gravel) | .28 | .28 | .36 | .21 | .25 | .31 | .19 | .23 | .29 | .31 | .26 | .24 | 19 | 19 | 20 | 19 |
| 1984 | Massaponax S&G (crushed gravel) | .28 | .43 | .23 | .25 | .37 | .20 | .23 | .35 | .19 | .31 | .27 | .26 | 19 | 23 | 20 | 21 |
| 1984 | Mattaponi S&G (crushed gravel) | .32 | .28 | .25 | .29 | .25 | .22 | .26 | .23 | .21 | .28 | .25 | .23 | 22 | 15 | 23 | 20 |
| 1985 | Mattaponi S&G (round gravel) | .23 | .35 | .17 | .22 | .31 | .16 | .20 | .29 | .14 | .25 | .23 | .21 | 17 | 20 | 18 | 18 |
| 1985 | Mattaponi S&G (round gravel special gradation) | .32 | .45 | .26 | .29 | .40 | .23 | .27 | .37 | .21 | .29 | .41 | .23 | 23 | 24 | 24 | 24 |
| 1984 | M. A. Smith (round gravel) | .26 | .36 | .22 | .23 | .32 | .15 | .22 | .32 | .30 | .28 | .23 | .28 | 17 | 21 | 19 | 19 |
| 1985 | M. A. Smith (round gravel) | .32 | .42 | .27 | .28 | .37 | .24 | .26 | .34 | .22 | .34 | .30 | .27 | 23 | 22 | 24 | 23 |
| 1985 | M. A. Smith (round gravel special gradation) | .32 | .42 | .26 | .28 | .37 | .23 | .26 | .34 | .22 | .34 | .38 | .24 | 22 | 22 | 23 | 22 |
| 1984 | General-Verdon (crushed stone) | .26 | .42 | .24 | .23 | .37 | .21 | .22 | .34 | .19 | .31 | .27 | .25 | 19 | 21 | 15 | 18 |
| 1984 | Vulcan-Garrisonville (crushed stone) | .28 | .42 | .20 | .25 | .37 | .18 | .23 | .34 | .17 | .30 | .27 | .25 | 19 | 24 | 20 | 21 |
| 1985 | Vulcan-Lawrenceville (crushed stone) | .29 | .40 | .28 | .26 | .35 | .25 | .24 | .33 | .23 | .32 | .29 | .27 | 20 | 19 | 20 | 20 |
| 1985 | Vulcan-Lawrenceville (crushed stone special gradation) | .23 | .37 | .34 | .20 | .34 | .30 | .19 | .31 | .28 | .31 | .28 | .26 | 24 | 17 | 24 | 22 |
| 1985 | Trego-Skippers (crushed stone) | .22 | .32 | .45 | .19 | .28 | .40 | .17 | .20 | .37 | .34 | .29 | .27 | 15 | 15 | 15 | 15 |
| 1985 | Trego-Skippers (crushed stone special gradation) | .29 | .40 | .27 | .25 | .35 | .24 | .23 | .32 | .23 | .32 | .28 | .26 | 15 | 15 | 15 | 15 |
| 1985 | West S&G (round gravel) | .28 | .38 | .27 | .24 | .34 | .24 | .23 | .32 | .32 | .31 | .27 | .29 | 20 | 17 | 20 | 19 |
| 1985 | West S&G (round gravel special gradation) | .29 | .42 | .32 | .25 | .35 | .28 | .24 | .34 | .26 | .34 | .29 | .28 | 20 | 16 | 20 | 19 |
| 1985 | Solite (lightweight aggregate) | .25 | .24 | .30 | .22 | .21 | .26 | .21 | .20 | .25 | .26 | .23 | .22 | 12 | 9 | 11 | 11 |

FI - Flakiness Index
GA - Graded Aggregate Design
US - U.S. Customary Design

# APPENDIX E

# AGGREGATE TYPES AND SOURCES IN 1984

## APPENDIX E

| Site No. | Aggregate Soure & Type | Placement Date | Air Temperature | Precipitation Date | Precipitation (in) Amount |
|---|---|---|---|---|---|
| 33,42,59,60,69,86 | Dogue (Round Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 34,43,58,61,70,85 | Fredericksburg (Round Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 35,44,56,62,71,83 | Massaponax (Round Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 36,45,57,63,72,84 | Massaponax (Crushed Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 37,46,54,64,73,81 | Mattaponi (Crushed Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 87-90,93,94 | Mattaponi (Crushed Gravel) | 9/6-7/84 | 72 | 9/12/84 | 0.01 |
| 38,47,55,65,74,82 | Mattaponi (Round Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 39,48,53,66,75,80 | M.A. Smith (Round Gravel) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 40,49,51,52,67,76,79 | General (Crushed Stone) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |
| 91 | General (Crushed Stone) | 9/7/84 | 70 | 9/12/84 | 0.01 |
| 41,50,68,77,78 | Vulcan (Crushed Stone) | 8/20-23/84 | 75-80 | 8/29/84 | 1.43 |

# APPENDIX F

## GRADATION RESULTS FOR 1985 AND 1986

# APPENDIX F

## GRADATION RESULTS FOR 1985 AND 1986

| AGGREGATE SOURCE | | % PASSING NO. AGGREGATE 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
|---|---|---|---|---|---|---|
| Acme Stone Co. | Fort Springs, WV | 100.0 | 94.1 | 19.4 | 0.7 | 0.5 |
| Acco Stone | Blacksburg, VA | 100.0 | 94.5 | 20.5 | 2.6 | 1.1 |
| Aylett S & G | Aylett, VA | 99.5 | 86.2 | 14.1 | 0.2 | 0.1 |
| Blue Ridge | Blue Ridge, VA | 100.0 | 98.5 | 27.8 | 1.1 | 0.8 |
| Cardinal Stone | Galax, VA | 93.9 | 89.6 | 22.0 | 1.4 | 0.6 |
| Caroline Stone | Ruther Glen, VA | 99.6 | 89.7 | 6.2 | 0.4 | 0.3 |
| Chantilly | Chantilly, VA | 100.0 | 94.3 | 23.7 | 3.3 | 1.9 |
| Culpeper | Culpeper, VA | 100.0 | 83.9 | 23.2 | 2.1 | 1.1 |
| C. W. Barger | Lexington, VA | 100.0 | 95.6 | 21.8 | 0.2 | 0.4 |
| E. Dillon & Co. | Swords Creek, VA | 100.0 | 79.1 | 6.2 | 0.2 | 0.2 |
| F & M Construction Co. | Poplar Camp, VA | 100.0 | 92.6 | 28.6 | 5.8 | 1.5 |
| Frazier's N. Quarry | Harrisonburg, VA | 100.0 | 89.3 | 15.8 | 1.1 | 0.5 |
| Fredericksburg S & G | Fredericksburg, VA | 99.5 | 82.8 | 23.4 | 0.8 | 0.2 |
| W. S. Frey | Clear Brook, VA | 100.0 | 96.6 | 20.0 | 2.4 | 1.0 |
| General | Doswell, VA | 100.0 | 91.0 | 18.1 | 1.9 | 0.5 |
| Haymarket | Haymarket, VA | 100.0 | 89.1 | 20.6 | 0.5 | 0.1 |
| Holston | Dublin, VA | 100.0 | 93.0 | 21.1 | 4.2 | 1.8 |
| Lone Star | Chester, VA | 100.0 | 95.8 | 20.4 | 1.9 | 0.9 |
| Lone Star | Petersburg, VA | 99.6 | 88.6 | 17.0 | 2.7 | 1.0 |
| Loudoun | Herndon, VA | 100.0 | 86.8 | 26.9 | 2.6 | 1.3 |
| Luck | Boscobel, VA | 100.0 | 85.3 | 20.4 | 1.4 | 0.5 |
| Luck | Burkeville, VA | 100.0 | 90.1 | 25.0 | 2.3 | 1.2 |
| Luck | Charlottesville, VA | 100.0 | 86.5 | 21.2 | 1.5 | 0.8 |
| Luck | Elkton, VA | 100.0 | 82.7 | 10.8 | 0.5 | 0.3 |
| Luck | Leesburg, VA | 100.0 | 89.3 | 26.9 | 1.3 | 0.8 |
| Luck | Manassas, VA | 100.0 | 93.6 | 18.0 | 1.8 | 1.2 |

*continues*

## APPENDIX F (CONT.)

| AGGREGATE SOURCE | | % PASSING NO. AGGREGATE | | | | |
|---|---|---|---|---|---|---|
| | | 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
| Luck | Rockville, VA | 99.9 | 87.3 | 20.5 | 3.5 | 1.6 |
| Luck | Ruckersville, VA | 100.0 | 82.5 | 18.9 | 1.0 | 0.4 |
| Luck | Staunton, VA | 100.0 | 92.9 | 22.0 | 1.5 | 0.6 |
| M.A. Smith | Fredericksburg, VA | 100.0 | 85.1 | 11.0 | 0.3 | 0.1 |
| Martin Marietta | Red Hill, VA | 100.0 | 99.0 | 30.7 | 1.9 | 0.8 |
| Martinsville Stone | Martinsville, VA | 100.0 | 95.0 | 25.8 | 3.2 | 2.0 |
| Massaponax S & G | Fredericksburg, VA | 100.0 | 97.9 | 23.2 | 0.3 | 0.2 |
| Mattaponi | Fredericksburg, VA | 100.0 | 90.1 | 30.6 | 1.9 | 0.3 |
| Maymead | Mt. City, TN | 100.0 | 93.5 | 22.2 | 1.5 | 0.7 |
| Maymead | Boone, NC | 100.0 | 90.9 | 24.3 | 5.8 | 1.9 |
| C. S. Mundy | Singers Glen, VA | 100.0 | 89.7 | 28.5 | 2.4 | 1.2 |
| Natural Tunnel Stone | Natural Tunnel, VA | 100.0 | 98.4 | 34.4 | 1.9 | 0.6 |
| Nolichucky Sand Co. | Greenville, TN | 100.0 | 92.2 | 33.1 | 6.3 | 2.8 |
| Pendleton Construction | Poplar Camp, VA | 100.0 | 96.9 | 14.3 | 0.4 | 0.3 |
| S. M. Perry | Winchester, VA | 100.0 | 97.1 | 24.5 | 1.1 | 0.5 |
| Pounding Mill Quarry | Pounding Mill, VA | 100.0 | 82.0 | 21.9 | 1.4 | 0.5 |
| Pounding Mill #2 | Bluefield, VA | 100.0 | 87.1 | 10.5 | 0.6 | 0.4 |
| Powell Valley | Dot, VA | 100.0 | 93.8 | 9.7 | 1.2 | 0.6 |
| Radford Limestone | Newbern, VA | 100.0 | 93.8 | 18.5 | 2.0 | 1.3 |
| Rim Rock Quarry #1 | Norton, VA | 100.0 | 90.7 | 6.9 | 1.3 | 0.8 |
| Rim Rock Quarry #2 | Norton, VA | 100.0 | 97.3 | 11.9 | 1.2 | 0.6 |
| Rockydale Quarries | Roanoke, VA | 100.0 | 92.2 | 8.4 | 0.8 | 0.7 |
| Salem Stone Corporation | Sylvatus, VA | 100.0 | 94.1 | 30.6 | 0.6 | 0.2 |
| Sanders Quarry | Warrenton, VA | 99.7 | 82.9 | 24.0 | 1.6 | 0.4 |
| Sisson & Ryan | Shawsville, VA | 100.0 | 88.2 | 11.4 | 1.2 | 0.6 |
| A. H. Smith | Mitchells, VA | 100.0 | 77.6 | 15.2 | 1.0 | 0.4 |
| Solite | Arvonia, VA | 100.0 | 88.2 | 18.4 | 6.4 | 4.2 |
| Stuart Perry | Winchester, VA | 100.0 | 97.1 | 21.7 | 0.5 | 0.1 |

*continues*

## APPENDIX F (CONT.)

| AGGREGATE SOURCE | | % PASSING NO. AGGREGATE 1/2 | 3/8 | NO. 4 | NO. 8 | NO. 16 |
|---|---|---|---|---|---|---|
| Trego | Skippers, VA | 100.0 | 89.6 | 23.8 | 2.1 | 0.4 |
| VA Trap Rock | Leesburg, VA | 100.0 | 97.0 | 12.0 | 1.5 | 0.9 |
| Vulcan Materials | Bristol, VA | 100.0 | 98.6 | 20.7 | 1.6 | 0.6 |
| Vulcan Materials | Hylas, VA | 100.0 | 89.1 | 28.4 | 1.0 | 0.1 |
| Vulcan Materials | Kingsport, TN | 100.0 | 88.6 | 9.6 | 1.8 | 0.9 |
| Vulcan Materials | Manassas, VA | 100.0 | 90.8 | 25.3 | 3.0 | 0.7 |
| Vulcan Materials | Occoquan, VA | 100.0 | 88.6 | 16.5 | 0.4 | 0.2 |
| Washington County Stone | Glade Spring, VA | 100.0 | 89.6 | 20.1 | 0.6 | 0.4 |
| West S & G | Grottoes, VA | 100.0 | 86.5 | 18.8 | 2.5 | 1.1 |
| West S & G | Richmond, VA | 100.0 | 97.0 | 31.8 | 1.0 | 0.2 |
| White Stone | Castlewood, VA | 100.0 | 93.4 | 4.9 | 0.5 | 0.5 |
| Wilson Quarries | Horse Pasture, VA | 100.0 | 93.6 | 32.4 | 3.0 | 0.4 |
| Woodway Stone | Woodway, VA | 100.0 | 98.2 | 19.1 | 0.3 | 0.2 |

# APPENDIX G

## DESIGN RESULTS FOR 1985 AND 1986

## APPENDIX G

### DESIGN RESULTS FOR 1985 AND 1986

| AGGREGATE SOURCE | | U.S. CUSTOMARY DESIGN UNDER 100 VPD AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) | 100–500 VPD AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) | 500–1000 VPD AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Acme Stone Company | Fort Springs, WV | 21 | 0.26 | 21 | 0.23 | 21 | 0.22 |
| Acco Stone | Blacksburg, VA | 19 | 0.24 | 19 | 0.21 | 19 | 0.19 |
| Cardinal Stone | Galax, VA | 18 | 0.23 | 18 | 0.20 | 18 | 0.19 |
| Culpeper | Culpeper, VA | 18 | 0.24 | 18 | 0.21 | 18 | 0.20 |
| E. Dillon & Co. | Swords Creek, VA | 24 | 0.30 | 24 | 0.27 | 24 | 0.25 |
| F & M Construction Co. | Poplar Camp, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.20 |
| Frazier's N. Quarry | Harrisonburg, VA | 21 | 0.26 | 21 | 0.23 | 21 | 0.21 |
| W. S. Frey | Clear Brook, VA | 20 | 0.24 | 20 | 0.21 | 20 | 0.20 |
| W. S. Frey | Clear Brook, VA | 20 | 0.24 | 20 | 0.21 | 20 | 0.20 |
| General | Doswell, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.22 |
| Lone Star | Chester, VA | 19 | 0.27 | 19 | 0.24 | 19 | 0.22 |
| Lone Star | Petersburg, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.22 |
| Lone Star | Petersburg, VA | 19 | 0.24 | 19 | 0.21 | 19 | 0.20 |
| Loudoun | Herndon, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Luck | Boscobel, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Luck | Burkeville, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.20 |
| Luck | Charlotesville, VA | 24 | 0.28 | 24 | 0.25 | 24 | 0.23 |
| Luck | Leesburg, VA | 22 | 0.26 | 22 | 0.23 | 22 | 0.21 |
| M. A. Smith (special) | Fredericksburg, VA | 23 | 0.26 | 23 | 0.23 | 23 | 0.22 |
| Martin Marietta | Red Hill, VA | 20 | 0.28 | 20 | 0.24 | 20 | 0.23 |
| Martinsville Stone | Martinsville, VA | 21 | 0.26 | 21 | 0.23 | 21 | 0.21 |
| Mattaponi (regular) | Fredericksburg, VA | 20 | 0.22 | 20 | 0.19 | 20 | 0.18 |
| Mattaponi (special) | Fredericksburg, VA | 24 | 0.26 | 24 | 0.23 | 24 | 0.21) |
| Maymead | Mt. City, TN | 18 | 0.22 | 18 | 0.20 | 18 | 0.18 |

*continues*

APPENDIX G (CONT.)

| AGGREGATE SOURCE | | U.S. CUSTOMARY DESIGN UNDER 100 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 100–500 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 500–1000 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Maymead | Boone, NC | 19 | 0.24 | 19 | 0.21 | 19 | 0.20 |
| C. S. Mundy | Singers Glen, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.21 |
| Natural Tunnel Stone | Natural Tunnel, VA | | | | | | |
| Pendleton Const. | Poplar Camp, VA | | | | | | |
| S.M. Perry | Winchester, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Pounding Mill Quarry | Pounding Mill, VA | 21 | 0.27 | 21 | 0.24 | 21 | 0.22 |
| Pounding Mill #2 | Bluefield, VA | 22 | 0.28 | 22 | 0.24 | 22 | 0.23 |
| Powell Valley | Dot, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Radford Limestone | Newbern, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.20 |
| Rim Rock Quarry #1 | Norton, VA | 22 | 0.28 | 22 | 0.24 | 22 | 0.23 |
| Rim Rock Quarry #2 | Norton, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.20 |
| Rockydale Quarries | Roanoke, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.20 |
| Salem Stone Corporation | Sylvatus, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Sanders Quarry | Warrenton, VA | 20 | 0.25 | 20 | 0.22 | 25 | 0.20 |
| Sanders Quarry | Warrenton, VA | 22 | 0.28 | 22 | 0.25 | 22 | 0.23 |
| Sisson & Ryan | Shawsville, VA | 20 | 0.25 | 20 | 0.24 | 20 | 0.21 |
| A. H. Smith | Mitchells, VA | 25 | 0.30 | 25 | 0.26 | 25 | 0.25 |
| Solite | Arvonia, VA | 19 | 0.23 | 19 | 0.21 | 19 | 0.19 |
| Stuart Perry | Winchester, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Trego (special) | Skippers, VA | 19 | 0.27 | 19 | 0.24 | 19 | 0.23 |
| VA Trap Rock | Leesburg, VA | 21 | 0.27 | 21 | 0.24 | 21 | 0.23 |
| Vulcan Materials | Bristol, VA | 21 | 0.26 | 21 | 0.23 | 21 | 0.21 |
| Vulcan Materials | Hylas, VA | 18 | 0.25 | 18 | 0.22 | 18 | 0.21 |
| Vulcan Materials | Kingsport, TN | 21 | 0.27 | 21 | 0.23 | 21 | 0.22 |
| Vulcan Materials (special) | Lawrenceville, VA | 24 | 0.34 | 24 | 0.30 | 24 | 0.28 |
| Vulcan Materials | Manassas, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.21 |

*continues*

## APPENDIX G (CONT.)

| AGGREGATE SOURCE | | U.S. CUSTOMARY DESIGN UNDER 100 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 100–500 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 500–1000 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Wash. County Stone | Glade Spring, VA | 18 | 0.23 | 18 | 0.20 | 18 | 0.19 |
| West S & G | Grottoes, VA | 20 | 0.24 | 20 | 0.21 | 20 | 0.20 |
| West S & G (special) | Grottoes, VA | 20 | 0.32 | 20 | 0.28 | 20 | 0.26 |
| West S & G | Grottoes, VA | 23 | 0.33 | 23 | 0.29 | 23 | 0.27 |
| West S & G (Stkd 84, used 85) | Grottoes, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| West S & G | Richmond, VA | 19 | 0.22 | 19 | 0.20 | 19 | 0.18 |
| Wilson Quarries | Horse Pasture, VA | 20 | 0.25 | 20 | 0.22 | 20 | 0.21 |
| Woodway Stone | Woodway, VA | 21 | 0.26 | 21 | 0.23 | 21 | 0.21 |
| White Stone | Castlewood, VA | 24 | 0.33 | 24 | 0.29 | 24 | 0.27 |
| Aylett S & G | Aylett, VA | 21 | 0.24 | 21 | 0.22 | 21 | 0.20 |
| Mattiponi (regular) | Fredericksburg, VA | 23 | 0.22 | 23 | 0.19 | 23 | 0.18 |
| Mattiponi (special) | Fredericksburg, VA | | | | | | |
| Holston River | Dublin, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| Luck Stone | Ruckersville, VA | | | | | | |
| Haymarket Quarry | Haymarket, VA | | | | | | |
| M. A. Smith S & G | Fredericksburg, VA | | | | | | |
| Caroline Stone | Ruther Glen, VA | | | | | | |
| C. S. Mundy | Singers Glen, VA | | | | | | |
| Chantilly Cr. Stone | Chantilly, VA | | | | | | |
| Vulcan | Occoquan, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.22 |
| Trego (regular) | Skippers, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.22 |
| Trego | Skippers, VA | | | | | | |
| General Cr. Stone | Doswell, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.21 |
| Massaponax S & G | Fredericksburg, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.21 |
| Vulcan Materials | Occoquan, VA | 18 | 0.24 | 18 | 0.21 | 18 | 0.19 |

*continues*

## APPENDIX G (CONT.)

| AGGREGATE SOURCE | | U.S. CUSTOMARY DESIGN | | | | | |
|---|---|---|---|---|---|---|---|
| | | UNDER 100 VPD | | 100-500 VPD | | 500-1000 VPD | |
| | | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) |
| Fredericksburg S & G | Fredericksburg, VA | 22 | 0.25 | 22 | 0.23 | 22 | 0.21 |
| Luck Stone | Elkton, VA | 22 | 0.31 | 22 | 0.27 | 22 | 0.25 |
| C. W. Barger | Lexington, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| Vulcan Materials | Lawrenceville, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Blue Ridge St. Corporation | Blue Ridge, VA | 19 | 0.25 | 19 | 0.22 | 19 | 0.21 |
| Luck Stone | Staunton, VA | 16 | 0.24 | 16 | 0.21 | 16 | 0.20 |
| Culpeper Stone | Manassas, VA | 20 | 0.33 | 20 | 0.29 | 20 | 0.27 |
| Luck Stone Corporation | Manassas, VA | 22 | 0.28 | 22 | 0.25 | 22 | 0.23 |
| Nolichuckey Sand Co. | Greenville, TN | 19 | 0.22 | 19 | 0.19 | 19 | 0.18 |
| Maymead Lime Co. | Mountain City, TN | 18 | 0.23 | 18 | 0.20 | 18 | 0.19 |
| Radford Limestone | Newbern, VA | 18 | 0.32 | 18 | 0.24 | 18 | 0.22 |
| Luck | Rockville, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| M. A. Smith | Fredericksburg, VA | 24 | 0.27 | 24 | 0.24 | 24 | 0.22 |

# APPENDIX H

## GRADED AGGREGATE DESIGN FOR 1985 AND 1986

# APPENDIX H

## DESIGN RESULTS FOR 1985 AND 1986

| AGGREGATE SOURCE | | MS-13 GRADED AGGREGATE DESIGN UNDER 100 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 100–500 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) | 500–1000 VPD AGGR. (LB/YD²) | EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Fort Springs, WV | 19 | 0.38 | 19 | 0.33 | 19 | 0.31 | |
| Acco Stone | Blacksburg, VA | 19 | 0.38 | 19 | 0.34 | 19 | 0.32 |
| Cardinal Stone | Galax, VA | 19 | 0.38 | 19 | 0.34 | 19 | 0.32 |
| Culpeper | Culpeper, VA | 16 | 0.34 | 16 | 0.31 | 16 | 0.28 |
| E. Dillon & Co. | Swords Creek, VA | 21 | 0.43 | 21 | 0.38 | 21 | 0.35 |
| F & M Construction Co. | Poplar Camp, VA | 17 | 0.35 | 17 | 0.31 | 17 | 0.29 |
| Fraziers' N. Quarry | Harrisonburg, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.33 |
| W. S. Frey | Clearbrook, VA | 18 | 0.37 | 18 | 0.33 | 18 | 0.31 |
| W. S. Frey | Clearbrook, VA | 17 | 0.35 | 17 | 0.30 | 17 | 0.28 |
| General | Doswell, VA | 18 | 0.25 | 18 | 0.22 | 18 | 0.21 |
| Lone Star | Chester, VA | 16 | 0.37 | 16 | 0.32 | 16 | 0.31 |
| Lone Star | Petersburg, VA | 17 | 0.37 | 17 | 0.32 | 17 | 0.31 |
| Lone Star | Petersburg, VA | 18 | 0.37 | 18 | 0.32 | 18 | 0.30 |
| Loudoun | Herndon, VA | 18 | 0.37 | 18 | 0.32 | 18 | 0.31 |
| Luck | Boscobel, VA | 17 | 0.38 | 17 | 0.34 | 17 | 0.32 |
| Luck | Burkeville, VA | 18 | 0.37 | 18 | 0.32 | 18 | 0.31 |
| Luck | Charlottesville, VA | 20 | 0.38 | 20 | 0.34 | 20 | 0.31 |
| Luck | Leesburg, VA | 19 | 0.37 | 19 | 0.32 | 19 | 0.31 |
| M. A. Smith (special) | Fredericksburg, VA | 22 | 0.42 | 22 | 0.37 | 22 | 0.34 |
| Martin Marietta | Red Hill, VA | 16 | 0.34 | 16 | 0.31 | 16 | 0.28 |
| Martinsville Stone | Martinsville, VA | 18 | 0.37 | 18 | 0.32 | 18 | 0.30 |
| Mattaponi (regular) | Fredericksburg, VA | 20 | 0.37 | 20 | 0.32 | 20 | 0.31 |
| Mattaponi (special) | Fredericksburg, VA | 24 | 0.45 | 24 | 0.40 | 24 | 0.37 |
| Maymead | Mt. City, TN | 18 | 0.36 | 18 | 0.32 | 18 | 0.30 |

*continues*

# APPENDIX H (CONT.)

| AGGREGATE SOURCE | | MS-13 GRADED AGGREGATE DESIGN | | | | | |
|---|---|---|---|---|---|---|---|
| | | UNDER 100 VPD | | 100–500 VPD | | 500–1000 VPD | |
| | | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) |
| Maymead | Boone, NC | 19 | 0.38 | 19 | 0.33 | 19 | 0.31 |
| C. S. Mundy | Singers Glen, VA | 17 | 0.35 | 17 | 0.31 | 17 | 0.29 |
| Natural Tunnel Stone | Natural Tunnel, VA | | | | | | |
| Pendleton Construction | Poplar Camp, VA | | | | | | |
| S. M. Perry | Winchester, VA | 18 | 0.36 | 18 | 0.32 | 18 | 0.30 |
| Pounding Mill Quarry | Pounding Mill, VA | 19 | 0.39 | 19 | 0.35 | 19 | 0.32 |
| Pounding Mill #2 | Bluefield, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.33 |
| Powell Valley | Dot, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.33 |
| Radford Limestone | Newbern, VA | 19 | 0.39 | 19 | 0.35 | 19 | 0.32 |
| Rim Rock Quarry #1 | Norton, VA | 20 | 0.40 | 20 | 0.36 | 20 | 0.33 |
| Rim Rock Quarry #2 | Norton, VA | 19 | 0.39 | 19 | 0.35 | 19 | 0.32 |
| Rockydale Quarries | Roanoke, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.33 |
| Salem Stone Corporation | Sylvatus, VA | 17 | 0.35 | 17 | 0.31 | 17 | 0.29 |
| Sanders Quarry | Warrenton, VA | 19 | 0.37 | 19 | 0.32 | 19 | 0.31 |
| Sanders Quarry | Warrenton, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.34 |
| Sisson & Ryan | Shawsville, VA | 20 | 0.40 | 20 | 0.35 | 20 | 0.33 |
| A. H. Smith | Mitchell, VA | 22 | 0.43 | 22 | 0.37 | 22 | 0.35 |
| Solite | Arvonia, VA | 19 | 0.39 | 19 | 0.35 | 19 | 0.32 |
| Stuart Perry | Winchester, VA | 18 | 0.36 | 18 | 0.32 | 18 | 0.30 |
| Trego (speical) | Skippers, VA | 17 | 0.40 | 17 | 0.35 | 17 | 0.32 |
| VA Trap Rock | Leesburg, VA | 18 | 0.38 | 18 | 0.34 | 18 | 0.32 |
| Vulcan Materials | Bristol, VA | 18 | 0.36 | 18 | 0.32 | 18 | 0.30V |
| ulcan Materials | Hylas, VA | 17 | 0.38 | 17 | 0.34 | 17 | 0.31 |
| Vulcan Materials | Kings Port, TN | 20 | 0.41 | 20 | 0.36 | 20 | 0.34 |
| Vulcan Materials (special) | Lawrenceville, VA | 17 | 0.37 | 17 | 0.34 | 17 | 0.31 |
| Vulcan Materials | Manassas, VA | 18 | 0.37 | 18 | 0.32 | 18 | 0.31 |

*continues*

APPENDIX H (CONT.)

| AGGREGATE SOURCE | | MS-13 GRADED AGGREGATE DESIGN | | | | | |
|---|---|---|---|---|---|---|---|
| | | UNDER 100 VPD | | 100–500 VPD | | 500–1000 VPD | |
| | | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) | AGGR. (LB/YD²) | EMUL. (LB/GAL) |
| Washington County Stone | Glade Spring, VA | 19 | 0.38 | 19 | 0.33 | 19 | 0.31 |
| West S & G | Grottoes, VA | 20 | 0.40 | 20 | 0.36 | 20 | 0.33 |
| West S & G (Special) | Grottoes, VA | 16 | 0.42 | 16 | 0.35 | 16 | 0.34 |
| West S & G | Grottoes, VA | 18 | 0.40 | 18 | 0.35 | 18 | 0.32 |
| West S & G (Stkd 84, used 85) | Grottoes, VA | 17 | 0.38 | 17 | 0.34 | 17 | 0.32 |
| West S & G | Richmond, VA | 16 | 0.32 | 16 | 0.28 | 16 | 0.26 |
| Wilson Quarries | Horse Pasture, VA | 17 | 0.34 | 17 | 0.30 | 17 | 0.28 |
| Woodway Stone | Woodway, VA | 18 | 0.37 | 18 | 0.33 | 18 | 0.31 |
| White Stone | Castlewood, VA | 21 | 0.43 | 21 | 0.38 | 21 | 0.36 |
| Aylett S & G | Aylett, VA | 22 | 0.41 | 22 | 0.36 | 22 | 0.34 |
| Mattiponi (regular) | Fredericksburg, VA | 20 | 0.38 | 20 | 0.34 | 20 | 0.32 |
| Mattiponi (special) | Fredericksburg, VA | | | | | | |
| Holston River | Dublin, VA | 19 | 0.38 | 19 | 0.33 | 19 | 0.31 |
| Luck Stone | Ruckersville, VA | | | | | | |
| Haymarket Quarry | Haymarket, VA | | | | | | |
| M. A. Smith S&G | Fredericksburg, VA | | | | | | |
| Caroline Stone | Ruther Glen, VA | | | | | | |
| C. S. Mundy | Singers Glen, VA | | | | | | |
| Chantilly Cr. Stone | Chantilly, VA | | | | | | |
| Vulcan Materials | Occoquan, VA | 17 | 0.37 | 17 | 0.32 | 17 | 0.31 |
| Trego (regular) | Skippers, VA | 16 | 0.37 | 16 | 0.32 | 16 | 0.29 |
| Trego | Skippers, VA | | | | | | |
| General Cr. Stone | Doswell, VA | 18 | 0.36 | 18 | 0.31 | 18 | 0.29 |
| Massaponax S & G | Fredericksburg, VA | 19 | 0.38 | 19 | 0.34 | 19 | 0.32 |
| Vulcan Materials | Occoquan, VA | 20 | 0.41 | 20 | 0.36 | 20 | 0.34 |
| Fredericksburg S & G | Fredericksburg, VA | 21 | 0.40 | 21 | 0.36 | 21 | 0.33 |

*continues*

## APPENDIX H (CONT.)

| AGGREGATE SOURCE | | MS-13 GRADED AGGREGATE DESIGN UNDER 100 VPD AGGR. (LB/YD$^2$) | UNDER 100 VPD EMUL. (LB/GAL) | 100-500 VPD AGGR. (LB/YD$^2$) | 100-500 VPD EMUL. (LB/GAL) | 500-1000 VPD AGGR. (LB/YD$^2$) | 500-1000 VPD EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Luck Stone | Elkton, VA | 19 | 0.40 | 19 | 0.35 | 19 | 0.33 |
| C. W. Barger | Lexington, VA | 17 | 0.34 | 17 | 0.30 | 17 | 0.28 |
| Vulcan Materials | Lawrenceville, VA | 19 | 0.40 | 19 | 0.35 | 19 | 0.33 |
| Blue Ridge St. Corporation | Blue Ridge, VA | 18 | 0.36 | 18 | 0.32 | 18 | 0.30 |
| Luck Stone | Staunton, VA | 17 | 0.38 | 17 | 0.34 | 17 | 0.32 |
| Culpeper Stone | Manassas, VA | 21 | 0.42 | 21 | 0.37 | 21 | 0.35 |
| Luck Stone Corporation | Manassas, VA | 19 | 0.37 | 19 | 0.33 | 19 | 0.31 |
| Nolichuckey Sand Co. | Greenville, TN | 19 | 0.36 | 19 | 0.32 | 19 | 0.29 |
| Maymead Lime Co. | Mountain City, TN | 19 | 0.39 | 19 | 0.34 | 19 | 0.32 |
| Radford Limestone | Newbern, VA | 18 | 0.40 | 18 | 0.36 | 18 | 0.33 |
| Luck | Rockville, VA | 18 | 0.40 | 18 | 0.35 | 18 | 0.32 |
| M. A. Smith | Fredericksburg, VA | 22 | 0.42 | 22 | 0.37 | 22 | 0.34 |

# APPENDIX I

## FLAKINESS INDEX RESULTS FOR 1985 AND 1986

## APPENDIX I

## DESIGN RESULTS FOR 1985 AND 1986

| AGGREGATE SOURCE | | FLAKINESS INDEX RESULTS: UNDER 100 VPD AGGR. ($LB/YD^2$) | UNDER 100 VPD EMUL. (LB/GAL) | 100–500 VPD AGGR. ($LB/YD^2$) | 100–500 VPD EMUL. (LB/GAL) | 500–1000 VPD AGGR. ($LB/YD^2$) | 500–1000 VPD EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| Acme Stone Co. | Fort Springs, WV | 21 | 0.29 | 21 | 0.26 | 21 | 0.25 |
| Acco Stone | Blacksburg, VA | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Cardinal Stone | Galax, VA | 18 | 0.25 | 18 | 0.22 | 18 | 0.20 |
| Culpeper | Culpeper, VA | 18 | 0.25 | 18 | 0.22 | 18 | 0.20 |
| E. Dillon & Co. | Swords Creek, VA | 24 | 0.32 | 24 | 0.29 | 24 | 0.28 |
| F & M Construction Co. | Poplar Camp, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| Frazier's N. Quarry | Harrisonburg, VA | 20 | 0.29 | 20 | 0.26 | 20 | 0.25 |
| W. S. Frey | Clearbrook, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| W. S. Frey | Clearbrook, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| General | Doswell, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| Lone Star | Chester, VA | 19 | 0.27 | 19 | 0.23 | 19 | 0.22 |
| Lone Star | Petersburg, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.21 |
| Lone Star | Petersburg, VA | 19 | 0.27 | 19 | 0.25 | 19 | 0.23 |
| Loudoun | Herndon, VA | 20 | 0.24 | 20 | 0.22 | 20 | 0.20 |
| Luck | Boscobel, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Luck | Burkeville, VA | 18 | 0.28 | 18 | 0.23 | 18 | 0.21 |
| Luck | Charlottesville, VA | 23 | 0.30 | 23 | 0.26 | 23 | 0.24 |
| Luck | Leesburg, VA | 22 | 0.27 | 22 | 0.24 | 22 | 0.22 |
| M. A. Smith (special) | Fredericksburg, VA | 22 | 0.32 | 22 | 0.28 | 22 | 0.26 |
| Martin Marietta | Red Hill, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.22 |
| Martinsville Stone | Martinsville, VA | 16 | 0.29 | 16 | 0.25 | 16 | 0.23 |
| Mattaponi (regular) | Fredericksburg, VA | 19 | 0.27 | 19 | 0.24 | 19 | 0.23 |
| Mattaponi (special) | Fredericksburg, VA | 23 | 0.32 | 23 | 0.29 | 23 | 0.27 |
| Maymead | Mt. City, TN | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Maymead | Boone, NC | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |

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## APPENDIX I (CONT.)

| AGGREGATE SOURCE | | FLAKINESS INDEX RESULTS UNDER 100 VPD AGGR. ($LB/YD^2$) | UNDER 100 VPD EMUL. (LB/GAL) | 100–500 VPD AGGR. ($LB/YD^2$) | 100–500 VPD EMUL. (LB/GAL) | 500–1000 VPD AGGR. ($LB/YD^2$) | 500–1000 VPD EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| C. S. Mundy | Singers Glen, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.21 |
| Natural Tunnel Stone | Natural Tunnel, VA | | | | | | |
| Pendleton Construction | Poplar Camp, VA | | | | | | |
| S. M. Perry | Winchester, VA | 20 | 0.29 | 20 | 0.25 | 20 | 0.23 |
| Pounding Mill Quarry | Pounding Mill, VA | 21 | 0.31 | 21 | 0.28 | 21 | 0.25 |
| Pounding Mill #2 | Bluefield, VA | 21 | 0.31 | 21 | 0.28 | 21 | 0.26 |
| Powell Valley | Dot, VA | 20 | 0.29 | 20 | 0.25 | 20 | 0.23 |
| Radford Limestone | Newbern, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| Rim Rock Quarry #1 | Norton, VA | 21 | 0.31 | 21 | 0.28 | 21 | 0.26 |
| Rim Rock Quarry #2 | Norton, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| Rockydale Quarries | Roanoke, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| Salem Stone Corporation | Sylvatus, VA | 19 | 0.29 | 19 | 0.25 | 19 | 0.23 |
| Sanders Quarry | Warrenton, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.22 |
| Sanders Quarry | Warrenton, VA | 22 | 0.28 | 22 | 0.25 | 22 | 0.23 |
| Sisson & Ryan | Shawsville, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| A. H. Smith | Mitchells, VA | 25 | 0.32 | 25 | 0.29 | 25 | 0.26 |
| Solite | Arvonia, VA | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Stuart Perry | Winchester, VA | 20 | 0.29 | 20 | 0.25 | 20 | 0.23 |
| Trego (special) | Skippers, VA | 19 | 0.29 | 19 | 0.25 | 19 | 0.23 |
| VA Trap Rock | Leesburg, VA | 21 | 0.26 | 21 | 0.23 | 21 | 0.21 |
| Vulcan Materials | Bristol, VA | 20 | 0.29 | 20 | 0.26 | 20 | 0.25 |
| Vulcan Materials | Hylas, VA | 18 | 0.25 | 18 | 0.22 | 18 | 0.21 |
| Vulcan Materials | Kings Port, TN | 21 | 0.29 | 21 | 0.26 | 21 | 0.25 |
| Vulcan Materials (special) | Lawrenceville, VA | 24 | 0.35 | 24 | 0.31 | 24 | 0.29 |
| Vulcan Materials | Manassas, VA | 20 | 0.26 | 20 | 0.23 | 20 | 0.21 |
| Washington County Stone | Glade Spring, VA | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |

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## APPENDIX I (CONT.)

| AGGREGATE SOURCE | | FLAKINESS INDEX RESULTS UNDER 100 VPD AGGR. (LB/YD²) | UNDER 100 VPD EMUL. (LB/GAL) | 100–500 VPD AGGR. (LB/YD²) | 100–500 VPD EMUL. (LB/GAL) | 500–1000 VPD AGGR. (LB/YD²) | 500–1000 VPD EMUL. (LB/GAL) |
|---|---|---|---|---|---|---|---|
| West S & G | Grottoes, VA | 19 | 0.29 | 19 | 0.25 | 19 | 0.23 |
| West S & G (special) | Grottoes, VA | 20 | 0.29 | 20 | 0.25 | 20 | 0.24 |
| West S & G | Grottoes, VA | 23 | 0.33 | 23 | 0.29 | 23 | 0.27 |
| West S & G (Stkd 84 used 85) | Grottoes, VA | 20 | 0.28 | 20 | 0.24 | 20 | 0.23 |
| West S & G | Richmond, VA | 18 | 0.28 | 18 | 0.25 | 18 | 0.23 |
| Wilson Quarries | Horse Pasture, VA | 19 | 0.26 | 19 | 0.23 | 19 | 0.22 |
| Woodway Stone | Woodway, VA | 20 | 0.29 | 20 | 0.26 | 20 | 0.25 |
| White Stone | Castlewood, VA | 24 | 0.34 | 24 | 0.30 | 24 | 0.28 |
| Aylett S & G | Aylett, VA | 20 | 0.30 | 20 | 0.26 | 20 | 0.25 |
| Mattiponi (regular) | Fredericksburg, VA | 22 | 0.33 | 22 | 0.29 | 22 | 0.27 |
| Mattiponi (special) | Fredericksburg, VA | 23 | 0.32 | 23 | 0.29 | 23 | 0.27 |
| Holston River | Dublin, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Luck Stone | Ruckersville, VA | | | | | | |
| Haymarket Quarry | Haymarket, VA | | | | | | |
| M. A. Smith S&G | Fredericksburg, VA | | | | | | |
| Caroline Stone | Ruther Glen, VA | | | | | | |
| C. S. Mundy | Singers Glen, VA | | | | | | |
| Chantilly Cr. Stone | Chantilly, VA | | | | | | |
| Vulcan | Occoquan, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Trego (regular) | Skippers, VA | 18 | 0.28 | 18 | 0.25 | 18 | 0.23 |
| Trego | Skippers, VA | | | | | | |
| General Cr. Stone | Doswell, VA | 19 | 0.27 | 19 | 0.24 | 19 | 0.23 |
| Massaponax S & G | Fredericksburg, VA | 19 | 0.28 | 19 | 0.25 | 19 | 0.23 |
| Vulcan Materials | Occoquan, VA | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Fredericksburg S & G | Fredericksburg, VA | 21 | 0.32 | 21 | 0.29 | 21 | 0.27 |
| Luck Stone | Elkton, VA | 22 | 0.31 | 22 | 0.27 | 22 | 0.25 |

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## APPENDIX I (CONT.)

| AGGREGATE SOURCE | | FLAKINESS INDEX RESULTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | UNDER 100 VPD | | 100-500 VPD | | 500-1000 VPD | |
| | | AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) | AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) | AGGR. ($LB/YD^2$) | EMUL. (LB/GAL) |
| C. W. Barger | Lexington, VA | 20 | 0.28 | 20 | 0.25 | 20 | 0.23 |
| Vulcan Materials | Lawrenceville, VA | 20 | 0.29 | 20 | 0.26 | 20 | 0.24 |
| Blue Ridge St. Corporation | Blue Ridge, VA | 19 | 0.27 | 19 | 0.24 | 19 | 0.22 |
| Luck Stone | Staunton, VA | 16 | 0.24 | 18 | 0.21 | 16 | 0.19 |
| Culpeper Stone | Manassas, VA | 21 | 0.30 | 32 | 0.27 | 21 | 0.25 |
| Luck Stone Corporation | Manassas, VA | 22 | 0.29 | 22 | 0.26 | 22 | 0.24 |
| Nolichuckey Sand Co. | Greenville, TN | 18 | 0.28 | 18 | 0.25 | 18 | 0.23 |
| Maymead Lime Co. | Mountain City, TN | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Radford Limestone | Newbern, VA | 18 | 0.26 | 18 | 0.23 | 18 | 0.22 |
| Luck | Rockville, VA | 20 | 0.27 | 20 | 0.24 | 20 | 0.22 |
| M. A. Smith | Fredericksburg, VA | 23 | 0.32 | 23 | 0.28 | 23 | 0.26 |