# HIGHWAY RESEARCH RECORD

**Number 173**

# Maintenance and Equipment

6 Reports

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Washington, D.C., 1967 Publication 1504

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# Foreword

The six papers in this RECORD offer practical solutions and helpful suggestions on a wide range of problems confronting the engineer or supervisor responsible for highway maintenance.

Linseed-oil based coatings showed excellent performance in test series reported in previous years by the Texas Transportation Institute and Battelle Memorial Institute. Yet, questions have been raised regarding long-term protection of such coatings and additional research by other agencies has provided a comparison of the life expectancy of linseed-oil based coatings with the life expectancy of substitute materials. Mr. Davis compares linseed-oil based coatings with three other concrete sealers.

Membrane waterproofing is a well-known and time-tested procedure for protecting bridge deck concrete. Unfortunately, the wearing course required to protect a membrane adds deadweight to the bridge without providing commensurate strength. Although no solution has been found to that problem a carefully designed membrane waterproofing and stable wearing surface system is described by Mr. Riley. At doubled cost the system provides crack resistance, waterproofing and skid resistant bridge deck protection which has performed satisfactorily for more than three years.

Pavement expansion at bridge ends has tipped bridge abutments, cracked backwalls and closed openings left for bridge deck expansion. Various devices have been inserted at the ends of bridge decks to overcome the problem. Pavement designers have not always provided for pressure release mechanisms of the sort mentioned and it has been common practice for maintenance forces to cut pressure relief joints 4 to 6 in. or wider through the concrete pavement. Mr. Smiley reports favorable experience utilizing urethane foam placed by normal maintenance crews to fill the relief joints. The foam provides a compressible material precluding intrusion of foreign matter into the relief joint.

Total sales of cutback asphalts, commonly used in maintenance seal coats, has remained constant or declined in recent years despite substantial increases in paving grade asphalt sales. One reason is the popularity of thin resurfacing as a substitute for conventional chip seal coats. Mr. Beagle compares performance of five alternate mixes in his paper.

Snowplow blade wear has increased as a problem because "bare pavement" snow removal policies have caused many public agencies to apply greater plow tip pressures in an effort to remove thin layers of snow from the pavement. Previously, it was common practice to carry most plow weight on shoes or casters. In some instances, built-in pavement "skid resistance" has accelerated blade wear. To overcome rapid wear, rubber, plastic and tungsten carbide tipped blades have been offered as substitute materials. In 1963 tungsten carbide tipped snowplow blade tests were initiated by the Ontario Department of Highways. Favorable experience and cost savings reported by a number of engineers is confirmed in the comprehensive study reported by Mr. Fitzpatrick.

Most states have created air pollution authorities and at least 70 major cities and counties have air pollution regulations affecting hot-mix asphalt plants. Widespread adoption of emission regulations has created a need for a dust monitoring system to provide aggregate producers with information on the dust pollution situation surrounding their operations.

A three-year research program conducted by the NCSA and reported by Mr. Renninger offers a practical measurement for aggregate producers.

# Contents

# A Discussion of Laboratory and Field Experience With Portland Cement Concrete Sealers

R. L. DAVIS, Technical Representative, Koppers Company, Inc., Pittsburgh

This investigation was conducted to evaluate the relative ability of a number of materials to protect portland cement concrete from the effects of deicing salts. The complexity of such an investigation was recognized from the beginning, and it was decided that only a carefully designed statistical experiment would be capable of separating the effect of the sealers from variation due to other causes.

•THE DESIGN of this experiment was approached with the knowledge that many factors influence the durability of concrete slabs other than the type of sealer used. Some of the factors considered were the quality and variability of (a) the aggregate used in the cement concrete, (b) the cement used, and (c) the deicing salts. Other factors included variation in (a) the severity of exposure among the concrete slabs during freeze-thaw cycles, (b) the application of the coating to the surfaces of the slabs, (c) the manufacture of the cement concrete within a batch, (d) the manufacture of the cement concrete between batches, (e) the finishing of the concrete slabs during manufacture, (f) the air-entrainment among slabs within a batch of concrete, (g) the surface of the slab due to different curing conditions, and (h) the rating of the condition of the slabs from rater to rater.

The approach which would give the most complete understanding of the resistance of the cement concrete slabs to deicing salts while covered with different sealers would be one in which all of these factors were varied at several different levels. The cost of such a program would be tremendous because many thousands of specimens would be required. Therefore, it was decided that the only variables investigated would be the effects of different sealers, different levels of air-entrainment, different raters, and the type of deicing salt.

The plan was to make slabs of good grade pavement concrete at three different levels of air-entrainment, curing them under controlled conditions, coating them with the various sealers, and subjecting them to up to one hundred 24-hr freeze-thaw cycles while covered with 4 percent solutions of rock salt (sodium chloride) and calcium chloride. Details of the manufacture, curing and treating, freeze-thaw cycling, and rating of the specimens are included in Appendixes A through D.

The effort to control each of the foregoing factors was made as follows.

1. Quality of the aggregate was controlled by selecting an aggregate with a history of good performance in cement concrete pavements. This was determined by a survey of interested agencies in the Pittsburgh area, including local Pennsylvania Department of Highways personnel and local ready-mix concrete suppliers. The variability of the aggregate was controlled by buying one load of gravel and one load of sand from the selected source. This aggregate was carefully graded and conditioned (Appendix A).

2. Quality and variability of cement were controlled by selecting a freshly blended batch of cement and by analyzing it to check its compliance with ASTM Specification, Type I (Appendix A).

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Paper sponsored by Committee on Effect of Ice Control and presented at the 46th Annual Meeting.

3. Quality and variability of the deicing chemicals were controlled by careful selection of these materials with the aid of recognized authorities in the field of highway deicer technology.

4. Variation in the severity of exposure among the concrete slabs during the freeze-thaw cycles was controlled by random placement of the slabs and by freezing the slabs in a large freezing plant capable of cooling all slabs at substantially the same rate.

5. Variation in coating was controlled on all but the first batch by covering the slab with the desired amount of sealer and then brushing the entire surface vigorously to insure that the whole surface was evenly coated. The first batch had the sealer applied in two coats (the usual field practice), but there was so little sealer applied with each coat that it was difficult to be sure that it was evenly applied. Therefore, after the first batch, the sealers were applied in one coat to reduce variability in coating.

6. Variation in the manufacture of the cement concrete within a batch was controlled by carefully following the prescribed procedure for combining and mixing the ingredients in a batch. A second precaution was to have the actual manufacture carried out by a firm of cement concrete specialists.

7. Variation in the manufacture between batches was controlled by carefully weighing and combining ingredients and by exact adherence to the prescribed procedure of manufacture. Again, variation was reduced by having specialists carry out the production of the concrete slabs.

8. Variation in the finishing of the slabs was reduced by setting up a precise procedure and by having one experienced man do all of the finishing.

9. Variation in air-entrainment within a batch was controlled by the same procedures as were other within-batch variations previously described. However, in drawing up the procedure for manufacturing the slabs, special attention was given to eliminating any unnecessary manipulation to reduce variation in the air-entrainment. This was especially true of the finishing operation.

10. Variation in the surface of the slab due to different curing conditions was controlled by curing the specimens in a fog room where the correct conditions were maintained uniformly for every specimen.

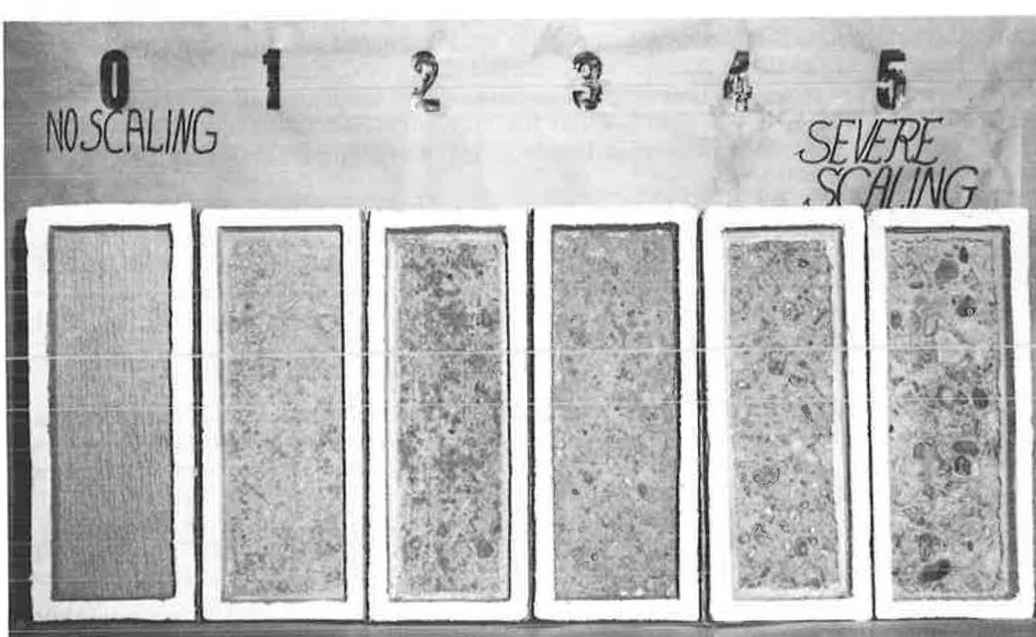


Figure 1. Rating of concrete slabs.

TABLE 1

DESIGN OF CONCRETE SEALER EVALUATION INVESTIGATION

| Treatment | Fog-Room Cured | | | | Membrane Cured |
|---|---|---|---|---|---|
| | Rock Salt | | | Calcium Chloride, Non-Air-Entrained | Rock Salt, Non-Air-Entrained |
| | Non-Air-Entrained | 4% Air-Entrained | 6% Air-Entrained | | |
| 1 | 7,3,8,5 | 2,7,10,10 | 7,3 | 8,7 | 1,2 |
| 2 | 3,9,4,6 | 10,3,6,9 | 9,7 | 5,2 | 7,5 |
| 3 | 2,5,1,7 | 6,2,2,2 | 5,9 | 3,5 | 3,6 |
| 4 | 4,2,10,10 | 9,1,9,8 | 6,6 | 7,8 | 5,7 |
| 5 | 6,10,6,1 | 5,4,3,1 | 2,5 | 4,10 | 2,4 |
| 6 | 10,6,2,2 | 7,9,8,3 | 8,8 | 10,1 | 4,3 |
| 7 | 9,1,7,8 | 8,8,5,4 | 10,1 | 6,4 | 9,8 |
| 8 | 8,8,5,3 | 4,10,7,6 | 3,4 | 1,9 | 10,1 |
| 9 | 1,7,9,4 | 3,5,4,5 | 1,10 | 9,3 | 8,10 |
| 10 | 5,4,3,9 | 1,6,1,7 | 4,2 | 2,6 | 6,9 |
| | 12,4,8,2 | 1,9,10,5 | 3,7 | 6,11 | 14,13 |

11. Variation in rating between raters was controlled through study and discussion of a photograph of slabs with different ratings (Fig. 1). The experiment was designed so that the effect of any differences between raters could be evaluated and removed from the analysis of the experiment mathematically.

There are many other sources of variation besides the foregoing major factors, and it was hoped that the remaining ones were small or chance causes. The variation due to the many small sources was controlled by carefully randomizing both the order in which the batches were made and the order in which the treatments were assigned to the slabs. This was done to reduce the probability of any effect due to chance or other factors appearing to be due to the effect of one of the variables of the experiment, i.e., the effect of different sealers, different levels of air-entrainment, different raters, or the type of deicing salt.

The general plan of the experimental design is given in Table 1. Two types of curing conditions (fog room and membrane curing), two types of chemical deicer (rock salt and calcium chloride), three levels of air-entrainment (non-air-entrained, 4% and 6%), and ten treatments or coatings were included in the experiment. Only five of the ten different treatments are reported here, as several of them represent such small variations in results as to be of little interest.

Numbers in the second through fifth columns represent the random order of making the specimens associated with each treatment. The second column indicates that treatment 9 was used to coat the first specimen made, and treatment 3 was used for the second specimen. The importance of randomization of the order of experimental units or specimens is often overlooked, but failure to randomize an experiment increases the likelihood of drawing false conclusions about the results. For example, suppose specimens had decreasing resistance to freeze-thaw cycles as time between mixing the batch and finishing the specimen increased. Then if the same treatment, for example treatment 1, were always put on the first specimen finished, it might be concluded that this treatment was superior, when the evidence showed only that the first specimen finished was the most resistant to the effects of freeze-thaw cycling in the presence of deicing salts. Randomization, or the absence of any system or pattern in variation, effectively insures that in the long run errors due to systematic disturbances, known or unknown, will be avoided. The last row of numbers gives the random order of making the batches.

The plan required 14 batches and 140 specimens. There were 2 specimens with black treatment, 7 with clear treatments, and 1 specimen with no treatment in each batch. All treatments were applied once in each batch. This enabled us to eliminate any batch-to-batch variation mathematically. It was necessary to have two black treatments in each batch so that the raters would not know which treatment they were rating. With only one black treatment the raters would have known which treatment they were rating, which might have resulted in some bias. By blind-coding and making it impossible for them to distinguish between the treatments, the chance of bias was decreased. Linseed oil was included in the experiment as a standard because it was the most widely used concrete sealer at the time the experiment started.

Each of the specimens in the experiment was rated independently by three different raters, at 5, 10, 15, 25, 50, 75, and 100 cycles. In the rating scale (Fig. 1) 0 represents no scaling and 5, severe scaling.

The main part of the experiment, representing 120 specimens, includes non-entrained air, 4 and 6 percent entrained air ( all with rock salt), and calcium chloride on slabs with non-entrained air. The other 20 specimens were membrane cured, and the treatment or coating was applied immediately after the shine of free water had disappeared from the surface. They then remained in the molds to cure for 14 days, after which they were removed from the molds and cured in air for 14 more days. From this point on they were treated like the specimens in the rest of the experiment.

The 20 specimens which were freeze-thawed with a 4 percent calcium chloride solution on them were included to determine if there was any unusual effect of calcium chloride solution on any of the coatings.

The other 100 specimens were fog-room cured and freeze-thawed with rock salt solution on them. There were 40 non-air-entrained specimens or four replications with each treatment, 40 specimens with 4 percent air-entrained or four replications of each treatment, and 20 specimens with 6 percent air-entrained or two replications of each treatment. The higher replications were used under conditions which were expected to yield the most information. The 6 percent air-entrained specimens were included in the experiment to check on any possibly adverse interactions between the coatings and higher air-entrainment, although this appeared unlikely.

## ANALYSIS OF TEST RESULTS

The test results from the main part of the experiment are summarized in Tables 2 through 5. Table 2 gives the averaged surface condition ratings for non-air-entrained, rock salt, fog-room cured specimens at 5, 10, 15, 25, 50, 75, and 100 cycles. Tables 3 and 4 give the averaged surface condition ratings for 4 and 6 percent air-entrained, rock salt, fog-room cured specimens at 5, 10, 15, 25, 50, 75, and 100 cycles. Table 5 gives the averaged surface condition ratings for the three levels of air-entrainment at 100 cycles. Each table also includes the sums of all ratings, which gives an idea of the total effect of the freeze-thaw cycles on the specimens. Some specimens have

TABLE 2

AVERAGED SURFACE CONDITION RATINGS FOR NON-AIR-ENTRAINED, ROCK SALT, FOG-ROOM CURED SPECIMENS[a]

| No. of Cycles | Treatments | | | | | Total Rating |
|---|---|---|---|---|---|---|
| | RCS | Clear | Linseed | Black | No Treatment | |
| 5 | 0.08 | 0.92 | 0.17 | 0.50 | 1.42 | 37 |
| 10 | 0.00 | 0.92 | 0.42 | 0.50 | 1.92 | 45 |
| 15 | 0.00 | 1.25 | 0.83 | 1.08 | 2.75 | 71 |
| 25 | 0.42 | 1.33 | 1.00 | 1.33 | 3.58 | 92 |
| 50 | 1.00 | 3.25 | 3.67 | 2.67 | 4.18 | 176 |
| 75 | 1.17 | 3.67 | 4.67 | 3.00 | 4.85 | 208.4 |
| 100 | 1.58 | 3.94 | 5.15 | 3.45 | 5.33 | 233.4 |

[a]Each value represents the average of one rating by each of three different raters on four different specimens, or an average of 12 ratings.

TABLE 3

AVERAGED SURFACE CONDITION RATINGS
FOR 4 PERCENT AIR-ENTRAINED, ROCK SALT,
FOG-ROOM CURED SPECIMENS[a]

| No. of Cycles | Treatments | | | | | Total Rating |
|---|---|---|---|---|---|---|
| | RCS | Clear | Linseed | Black | No Treatment | |
| 5 | 0.00 | 0.67 | 0.25 | 0.50 | 1.42 | 34 |
| 10 | 0.00 | 0.83 | 0.75 | 0.83 | 1.42 | 46 |
| 15 | 0.00 | 0.75 | 0.83 | 0.92 | 1.59 | 49 |
| 25 | 0.08 | 0.83 | 0.92 | 0.92 | 1.83 | 55 |
| 50 | 0.25 | 0.83 | 1.42 | 1.00 | 2.00 | 66 |
| 75 | 0.50 | 0.92 | 1.92 | 1.25 | 1.83 | 78 |
| 100 | 0.50 | 1.16 | 2.50 | 1.50 | 2.00 | 92 |

[a]Each value represents the average of one rating by each of three different raters on four different specimens, or an average of 12 ratings.

TABLE 4

AVERAGED SURFACE CONDITION RATINGS
FOR 6 PERCENT AIR-ENTRAINED, ROCK SALT,
FOG-ROOM CURED SPECIMENS[a]

| No. of Cycles | Treatments | | | | | Total Rating |
|---|---|---|---|---|---|---|
| | RCS | Clear | Linseed | Black | No Treatment | |
| 5 | 0.33 | 0.33 | 0.00 | 0.33 | 1.33 | 14 |
| 10 | 0.00 | 0.67 | 0.33 | 0.50 | 1.33 | 17 |
| 15 | 0.17 | 0.67 | 0.33 | 0.50 | 1.33 | 20 |
| 25 | 0.67 | 1.00 | 1.00 | 0.83 | 1.67 | 31 |
| 50 | 0.50 | 1.50 | 1.83 | 0.67 | 2.17 | 40 |
| 75 | 0.50 | 1.50 | 1.83 | 0.83 | 1.67 | 38 |
| 100 | 0.33 | 0.83 | 2.17 | 1.00 | 1.67 | 36 |

[a]Each value represents the average of one rating by each of three different raters on two different specimens, or the average of six ratings.

TABLE 5

AVERAGED SURFACE CONDITION RATINGS
FOR NON-AIR-ENTRAINED, 4 PERCENT AIR-ENTRAINED, AND
6 PERCENT AIR-ENTRAINED, ROCK SALT, FOG-ROOM CURED
SPECIMENS AT 100 CYCLES[a]

| Entrained Air | Treatments | | | | | Total Rating |
|---|---|---|---|---|---|---|
| | RCS | Clear | Linseed | Black | No Treatment | |
| Non | 1.58 | 3.94 | 5.15 | 3.45 | 5.33 | 233.4 |
| 4 | 0.50 | 1.16 | 2.50 | 1.50 | 2.00 | 92 |
| 6 | 0.33 | 0.83 | 2.17 | 1.00 | 1.67 | 72[b] |

[a]Each value represents the average of one rating by each of three raters on each specimen. In the case of non-air-entrainment and 4 percent air-entrainment there were four specimens or a total of 12 ratings averaged in each value, and in the case of the 6 percent air-entrainment there were two specimens or a total of six ratings averaged in each value.

[b]The totaled rating for 6 percent air-entrainment was doubled to give a value which was comparable to the totaled ratings for non-air-entrainment and 4 percent air-entrainment in which the totaled ratings are for twice as many specimens as in the case of 6 percent air-entrainment.

averaged ratings in excess of 5, the top value in the rating scale used. This was because after 50 cycles there were a few specimens which all three raters rated 5. If these were merely rated 5 at the 75 and 100 cycle level, our analysis would not differentiate between those specimens which reached the level of 5 at 50 cycles and those which barely reached it at 100 cycles. Therefore, it was considered desirable to develop a relationship which would properly rate those specimens which reached a rating of 5 earlier than 100 cycles. The following equation was developed:

$$\text{Rating at 100 cycles} = \frac{5 \times \log 100 \text{ cycles}}{\log \left( \begin{array}{c} \text{cycle at which} \\ \text{specimen reached} \\ \text{a rating of 5} \end{array} \right)}$$

The rating at 100 cycles was obtained by using this equation, and this accounts for the values over 5 at the 100 cycle level.

In the tables, RCS stands for regular (tar-based) concrete sealer. Clear stands for clear (resin-based) concrete sealer. Linseed stands for a 50-50 blend of boiled linseed oil and mineral spirits. The linseed oil was selected after consultation with experts and was included as a reference standard. Black stands for a black sealer of an entirely different type from RCS. The second black sealer was included, as previously explained, to reduce any possible tendency for bias which might have occurred with only one black sealer. Surface condition ratings are based on a scale of 0 to 5, as previously mentioned (Appendix D, Fig. 1).

In Tables 2, 3, and especially 4, the rated values do not always increase smoothly. Sometimes there is a reduction in rating at a higher number of cycles. This evident variation shows the effect of the chance or residual variation. This variation makes it important to analyze such experiments by statistical methods. The greatest variation is in Table 4 where each value is the average of only six ratings. An important statistical principle is that variation is reduced as the number of values averaged is increased. The values in Tables 2 and 3 are the average of 12 ratings and show less variation.

The treatments were applied as described in Appendix B. Although it is usually recommended that concrete sealers be applied in two coats for field applications, it was found in early trials of this experiment that better coating of the specimens was obtained if the treatment was applied in one application, then thoroughly brushed over the entire surface to obtain good wetting and coverage.

An analysis of variance was made of the data from the 80 specimens which were fog-room cured, covered with a 4 percent rock salt solution with no air-entrainment and with 4 percent air-entrainment at 100 freeze-thaw cycles. These are the 80 specimens indicated in Table 1. Table 6 gives the result of this analysis.

The analysis of variance is a method for separating the variation of the experimental results or variance. In Table 6 the variation was separated into the following categories: that due to air-entrainment (indicated as air), that indicated as treatment, that due to raters, that due to the interaction between raters and treatments (R × T), that due to the interaction between raters and air-entrainment (R × A), that due to the interaction between air-entrainment and treatments (A × T), that due to the interaction between raters, air-entrainment and treatments (R × A × T), and that due to residual or all other causes. The residual variation ideally represents the variation due to chance or many small factors. The significance of the various sources of variation is determined through the variance ratios. Significance here means that the estimated probability of one of the sources of variation being due to chance causes alone is less than some predetermined probability level. In this paper, as is most frequently the case, this level is 5 percent.

In every experiment, there are small uncontrolled sources of variation often termed chance causes. One of the major problems in interpreting experiments is determining whether an effect such as a shift from non-air-entrainment to 4 percent air-entrainment is a real difference or merely a chance variation. The analysis of variance technique not only separates the sources of variation, but also makes it possible to test the

TABLE 6

ANALYSIS OF VARIANCE—FOG-ROOM CURED, ROCK SALT, NON- AND 4 PERCENT AIR-ENTRAINED SPECIMENS AT 100 FREEZE-THAW CYCLES

| Source of Variance | Deg. of Freedom | Sum of Squares | Mean Squares | Variance Ratio |
|---|---|---|---|---|
| Between air | 2-1 = 1 | 211.68 | 211.68 | 263.94[a] |
| Between treatments | 10-1 = 9 | 146.22 | 16.25 | 20.26[b] |
| Between raters | 3-1 = 2 | 7.14 | 3.57 | 4.45 |
| R × T | 9 × 2 = 18 | 6.87 | 0.38 | 0.47 |
| R × A | 2 × 1 = 2 | 1.39 | 0.70 | 0.87 |
| A × T | 1 × 9 = 9 | 37.90 | 4.21 | 5.25[c] |
| R × A × T | 2 × 1 × 9 = 18 | 4.02 | 0.22 | 0.274 |
| Residual | 2 × 10 × 3 × 3 = 180 | 144.42 | 0.802 | |
| Total | 239 | 559.64 | | |

[a]Significant at the 5 percent probability level.
[b]Significant at the 0.1 percent probability level.
[c]Significant at the 1 percent probability level.

significance of these effects against the residual or chance variation underlying the experiment.

The analysis of variance in Table 6 is based on a fixed-effect, qualitative model. The variation between raters and the interactions of R × T, R × A, and R × A × T are small enough, when compared to the residual or chance variation, that they could reasonably be said to be due to chance causes. But there is less than one chance in 20 of the variation between levels of air-entrainment being due to chance, or the difference in air-entrainment is said to be significant at the 5 percent probability level. Likewise, there is less than one chance in 1000 that we would have the differences between treatments indicated in Table 6 through chance alone. There is less than one chance in 100 that an effect would occur as large as that shown for the interaction of air-entrainment and treatment through chance alone. Therefore, these three sources of variation are considered to exist. The interaction of air-entrainment and treatments causes a separate effect in addition to the sum of these two effects.

Having an estimate of the residual or chance variations under the conditions of fog-room cure, rock salt solution, 100 cycles at non-air-entrainment and 4 percent air-entrainment, let us examine Tables 2 and 3 using this estimate. Noting the mean square value of 0.802 for the residual with 180 deg of freedom, we will take the square root of this value to obtain a standard error of 0.895. The mean for the rating of each treatment at the 100-cycle level in Tables 2 and 3 then has a standard error of $0.895/\sqrt{12} = 0.259$ because each of these values is the mean of 12 ratings. This gives 95 percent confidence limits of $\pm 1.96 \times 0.259 = \pm 0.507$, where the value 1.96 was obtained from a table of the t distribution for the 95 percent probability level and 179 degrees of freedom. Thus, Table 2 indicates that the regular concrete sealer gave the best resistance to the effects of 100 freeze-thaw cycles on the non-entrained air specimens while covered with a rock salt solution. The other black sealer was second best and the clear sealer was next in effectiveness. Although there may be some question as to whether black sealer was significantly better than clear sealer, there was no significant difference between no treatment and the linseed oil at the 100 cycle level.

Linseed oil gave good protection up through 25 cycles. It is frequently recommended that linseed oil applications be renewed yearly or at least every two years. Furthermore, the freeze-thaw cycles used in this report are of a very severe nature where the specimens are completely covered by the solution at all times. It is estimated that deterioration is several times faster than it would be where the slab is allowed to dry during the freeze-thaw cycle.

In Table 3 with 4 percent air-entrainment and at the 100-cycle level, it can be stated with considerable confidence that the regular concrete sealer performed best, with some question as to whether the clear concrete sealer was significantly better than the black sealer. But again, with considerable confidence, it can be stated that the black sealer was better than no treatment and there was considerable evidence to support the idea that at the end of 100 cycles with 4 percent air-entrainment no treatment was better than the linseed oil treatment.

In the section of the experiment in which there were 20 specimens with 6 percent air-entrainment (Table 4) there was no apparent adverse effect on the ability of the sealers to protect the concrete under a condition of high air-entrainment, with the exception of linseed oil which had the highest rating after 100 freeze-thaw cycles.

The 20 specimens on which a 4 percent calcium chloride solution was used during the freeze-thaw cycles were considerably less affected by this deicer than were the specimens on which the rock salt solution was used. The averaged ratings at the end of 100 freeze-thaw cycles on the specimens covered with calcium chloride solution were as follows: RCS, 0.83; clear, 1.17; linseed, 3.56; black, 1.50; and no treatment, 2.34.

Most of the membrane cured specimens, on which sealers were applied to the fresh concrete, failed quite rapidly. All reached a rating of 5 in 40 cycles except for three specimens. Two of these specimens were coated with RCS and had a rating of less than 1 after 100 cycles of exposure. The other specimen was coated with one of the unreported sealers. In this case, there was one good specimen which was rated 1 after 100 cycles, and one bad specimen which reached a rating of 5 in 40 cycles.

## CONCRETE SEALERS—FIELD APPLICATIONS

Regular concrete sealer (tar-based) and clear concrete sealer (resin-based) have been used experimentally by a large number of state highway departments and toll road authorities. These sealers have been marketed commercially in New York, Connecticut, Pennsylvania, Ohio, Massachusetts, Michigan, Iowa, and the District of Columbia. Regular (tar-based) concrete sealer has been used commercially since 1957. Clear (resin-based) concrete sealer has been used commercially since 1964.

These sealers have been used primarily to protect new portland cement concrete. However, they have also been employed to treat spalled portland cement concrete (and sometimes new PC pavement) before overlaying with hot plant mix or bituminous surface treatment. In general, these applications have been confined to bridge decks and bridge approaches. However, in several locations concrete sealer has been used to treat long stretches of new PC pavement before opening the completed projects to traffic. Some of these stretches have been as short as 2 miles and some as long as 15 miles.

On many of the earlier treatment projects, the bridge deck alone was treated, leaving the curbing, wheel guards and parapet walls unprotected. Experience indicated that these unprotected areas were attacked by the deicing chemicals applied to the bridge decks. In some cases damage occurred on top of the parapet wall, where apparently treated abrasives landed after being displaced by traffic. In no case where the regular (tar-based) concrete sealer was used was there any damage within 5 years after treatment. In some locations no damage occurred after 9 years.

Although the black color of the regular concrete sealer was objectionable to many for aesthetic reasons, some engineers began to prefer it because it tended to give the treated surface a uniform color or cast. In most cases, after a year or two under traffic the treated roadway did not (in the traffic lanes) appear much darker than untreated adjacent sections. Although variation in the finished concrete surface caused some areas to dry faster than others after treatment, the treated areas appeared quite uniform when finally dry.

On the other hand, application of the clear (resin-based) concrete sealer tends to accentuate any difference in surface density, porosity, or finish because the resin solution drys to a varnish-like surface, and "hot spots" or surface blemishes become more noticeable after treatment. However, after a few months, such differences are not readily noticeable.

In general, both concrete sealers are applied in the same manner, except that usually surfaces require or can absorb a greater amount of the regular (tar-based) concrete sealer. Before application, test areas are treated, beginning with an application rate of 0.05 gal/sq yd. The application rate selected is usually that amount which will be absorbed into the PC concrete surface within 3 hr—usually somewhere between 0.05 and 0.15 gal/sq yd for the regular concrete sealer and 0.03 to 0.08 gal/sq yd for the clear concrete sealer.

Although experience indicates that the regular (tar-based) concrete sealer affords effective protection for at least 5 years, it is expected that the clear (resin-based) concrete sealer may afford adequate protection for a 2 or 3-yr period before another application is needed.

## CONCLUSIONS

### Laboratory Evaluation

In the laboratory experiment reported in this paper the following conclusions appear warranted.

1. There was a significant difference in the ability of different sealers to protect portland cement concrete from deicing salts during 100 freeze-thaw cycles.
2. The increased ability to protect cement concrete from the effect of deicing salts of the combination of air-entrainment with sealer treatments was greater than the sum of their individual effects, except in the case of the linseed oil blend.
3. An increase in air-entrainment increases the protection of cement concrete from the effects of deicing salts.
4. The concrete sealers were put into the following order of efficacy by the experiment for 100 freeze-thaw cycles and non-entrained air specimens: regular concrete sealer, black concrete sealer, clear concrete sealer, linseed oil sealer, and no treatment. Up to 25 cycles the linseed oil sealer was second on the list, following regular concrete sealer in providing effective protection.
5. The concrete sealers were put into the following order of efficacy by the experiment for 100 freeze-thaw cycles and 4 percent air-entrainment: regular concrete sealer, clear concrete sealer, black concrete sealer, no treatment, and linseed oil sealer. It would appear that the ability of linseed oil sealer to protect concrete is adversely affected by higher levels of air-entrainment, whereas the other sealers are helped.
6. Although it is more difficult to draw definite conclusions from field installations due to the great number of variables involved, a study of the field installations indicates that both regular and clear concrete sealers have given good protection on PC concrete roads and structures over a period of years.

# *Appendix A*

## MANUFACTURE OF SPECIMENS

A sound, durable aggregate with a history of good performance in cement concrete pavement construction was selected and graded as indicated in Table 7. Aggregates were air dried and screened into six sizes for the sand and three sizes for the gravel. They were recombined during batching to yield the gradings given in Table 7.

The cement used in these tests met the requirements for ASTM, type I cement (Table 2). Aggregates were weighed in the air-dried condition (moisture content known) and, 18 to 20 hr before use, inundated with a known amount of water. Before mixing, excess water was drawn off and weighed to permit calculating the net water-cement ratios (Table 8).

Neutralized Vinsol resin solution was added at the mixer in the proper amounts to bring the air-entrainment to 4 ± 0.5 and 6 ± 0.5 percent.

The cement content of the concrete was held at not less than 6 bags of cement per cubic yard and the slump was held between 2 and 3 in. The water cement ratio was

TABLE 7

| Aggregate Type | Source | Fineness Modulus | Bulk Spec. Gravity | Grading | |
|---|---|---|---|---|---|
| | | | | Sieve Size | Retained (%) |
| Gravel | Dravo | — | 2.57 | $1\frac{1}{2}$ in. | 0 |
| | | | | $\frac{3}{4}$ in. | 50 |
| | | | | $\frac{3}{8}$ in. | 75 |
| | | | | No. 4 | 100 |
| Sand | Dravo | 290 | 2.62 | No. 4 | 0 |
| | | | | 8 | 18 |
| | | | | 16 | 33 |
| | | | | 30 | 57 |
| | | | | 50 | 87 |
| | | | | 100 | 95 |

TABLE 8

CEMENT TEST REPORT

| Chemical | Type I | Physical | Type I |
|---|---|---|---|
| $SiO_2$ | | Specific surface | 1870 |
| $Al_2O_3$ | | Autoclave soundness | 0.06 |
| $Fe_2O_3$ | | Vicat set | 1.35 |
| MgO | 1.3 | Air content | 8.5 |
| $SO_3$ | 2.5 | Comp. strength 3 day | 3120 |
| Ignition loss | 1.2 | 7 day | 4040 |
| Insolubles | 0.2 | | |
| $C_3S$ | | | |
| $C_3A$ | 10.7 | | |

TABLE 9

CONCRETE CHARACTERISTICS

| Batch No. | Cement Factor (sk/cu yd) | Net W/C (gal/sk) | Slump (in.) | Net Air Content (% pressure) | 28-Day Compressive Strength (psi) |
|---|---|---|---|---|---|
| 1 | 6.32 | 4.72 | 2 | 3.9 | — |
| 2 | 6.75 | 4.85 | $2\frac{3}{4}$ | 1.3 | — |
| 3 | 6.41 | 4.68 | $2\frac{1}{4}$ | 5.6 | — |
| 4 | 6.82 | 4.85 | $2\frac{1}{2}$ | 1.5 | — |
| 5 | 6.45 | 4.72 | $2\frac{1}{2}$ | 4.0 | — |
| 6 | 6.85 | 4.85 | 3 | 1.4 | 5660 |
| 7 | 6.75 | 4.74 | $2\frac{1}{4}$ | 5.7 | 4950 |
| 8 | 6.85 | 4.85 | 2 | 1.5 | 5620 |
| 9 | 6.64 | 4.86 | $2\frac{3}{4}$ | 4.1 | 4350 |
| 10 | 6.54 | 4.86 | $2\frac{3}{4}$ | 4.3 | 4350 |
| 11 | 6.78 | 4.85 | $2\frac{1}{4}$ | 1.8 | 5730 |
| 12 | 6.86 | 4.85 | $2\frac{1}{2}$ | 1.7 | 6370 |
| 13 | 6.82 | 4.85 | $2\frac{3}{4}$ | 1.7 | 6050, 5770 |
| 14 | 6.83 | 4.85 | $2\frac{1}{2}$ | 1.6 | — |

less than 5 gal water per bag of cement. Characteristics of the concrete are given in Table 9.

The laboratory was maintained at 70 to 77 F and at 50 percent relative humidity. Batches were mixed for 2½ min. A slump test and air-entrainment test were run on each batch made. Fourteen batches, two each day, were made. Each batch made ten specimens and one 6 by 12-in. cylinder for compression testing purposes. The specimens were 3 by 6 by 15 in., cast in watertight plastic molds. The mold was filled in two layers of equal depth, each layer rodded 50 times with a ⅝-in. bullet-nosed tamping rod. The top layer slightly overfilled the mold and on completion of the rodding of this layer, the top surface was leveled and consolidated by patting with the hand protected by a rubber glove. The surface was then finished by three or four passes with a cork float, using a sawing motion to produce a finished surface on a specimen similar to that obtained on a concrete pavement. Immediately before final set of the surface, a ½-in. width of the top surface bordering all four sides was scratched lightly to provide for better bond between the surface and a mortar dike. The mortar dike was placed around the perimeter of the top surface of the specimen with a cross section of approximately 1 by 1 in. For best results, the mortar used was one part of cement to two parts of sand (top size No. 16 mesh) by weight, sufficient air-entraining agent to produce approximately 20 percent entrained air and a consistency similar to damp sand (balling up under pressure between the hands). A steel mold was used to form the dike. The surface to which the dike was to be bonded was brushed with neat cement paste of a thin consistency. The dike mold was filled with mortar and compacted with vigorous finger pressure. After filling and striking off the top, the mold was carefully lifted vertically, and at the same time it was tapped to avoid lifting the dike with it.

# *Appendix B*

## CURING AND TREATING SPECIMENS

After 24 hours in the molds, during which time the specimens were protected from drying by damp burlap covers, the specimens were cured in a moist room at 100 percent relative humidity for 13 days, followed by 14 days at the same temperature and 50 percent relative humidity. The specimens were then stored in air for an additional three day period with a ¼-in. layer of water on the top surface. The cylinders for compression testing were cured continuously in the moist room for the full 28 days. On the seventh day of the 14-day drying period, the specimens were given an application of the prescribed treatment by flooding the surface and brushing. The specimens were at 73 F during treatment, and the materials were applied at the prescribed temperatures (Table 10).

TABLE 10

| Treatment | Coats | Application Temperature | Total Quantity (gal/yd$^2$) |
|---|---|---|---|
| Regular concrete sealer | 1 | 150 F | 0.08 |
| Clear concrete sealer | 1 | 73 F | 0.04 |
| Boiled linseed oil, U. S. P. | 1 | 73 F | 0.04 |
| Black sealer | 1 | 150 F | 0.08 |
| No treatment | | | |

# *Appendix C*

## FREEZE-THAW CYCLING OF TREATED SPECIMENS

At the completion of the curing period, the surface of the specimen was covered with 250 ml of a 4 percent solution of rock salt and water, by weight. Twenty of the specimens were covered with 250 ml of a 4 percent solution of $CaCl_2$. The specimen and solution were then alternately frozen and thawed, in a room maintained at -20 F, the specimen remaining in this room for approximately 18 hr. The specimen was thawed for approximately 6 hours at normal laboratory temperature (about 70 F). Once each week, the solution was replaced by a freshly prepared solution, thus correcting for possible changes in concentration during the week due to evaporation or spillage. This process was carried on for 100 cycles.

# *Appendix D*

## RATING SPECIMENS

Visual examination at regular periods was used to determine the amount of scaling and numerical ratings which were assigned on the following scale (Fig. 1).

0 = no scale
1 = slight scale
2 = slight to moderate scale
3 = moderate scale
4 = moderate to heavy scale
5 = heavy scale

Each specimen was rated independently by each of three different raters. The specimens were examined and rated at 5, 10, 15, 25, 50, 75, and 100 cycles. The specimens were also photographed at each rating time.

# Development of a Bridge Deck Protective System

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The continuing rise in the incidence of concrete bridge deck deterioration and the increasing cost, and patron inconvenience, of making repairs have caused many owning agencies to look for some effective means for protecting bridge decks.

Over the past five years a consulting engineering firm working with several major toll roads has sought to determine the nature and extent of the problem, evaluate numerous protective systems, survey the literature with an eye toward combining new products to offset potential difficulties in the system utilized, and maintain records of the cost of repairing the decks compared with the cost of constructing a protective system.

It was found that cracks in the concrete leading to spalls and eventually to failure were rampant and increasing despite constant, costly repair. One major toll road spent $6 million without arresting the cause of deterioration.

Waterproofing is the key to prevention and coal-tar epoxy resin is the most suitable protective membrane because of its history of satisfactory service, its strength and flexibility, ease of application and cost. But a wearing course is still essential, because no membrane is sufficiently wear-resistant.

The best wearing course is a dense asphaltic concrete (for impermeability) fortified with asbestos (for stability) and modified with latex (for flexibility). Such a wearing course doubles the cost of the system but increases its service life at least fivefold.

The total cost of a protective system is less than half the total cost of repair. Other factors such as design procedures, methods of construction, and skid resistance, are unimpaired.

•IT IS no secret to anyone responsible for maintenance of structures that surface deterioration on concrete bridge decks has become an enormous problem. The extent and similarities of the problem have received extensive attention (1, 2).

The engineering industry has made available, through papers and periodicals, its experience with making repairs, whether conventional (3), using epoxies (4), or other imaginative programs (5). This writer has also reported on bridge deck repair techniques (6).

But surely repair is only half the answer. In the first place, a hole in a bridge deck, whether a surface spall or a complete failure, is at least uncomfortable, if not actually dangerous, on a high-speed roadway. Second, there is the inconvenience of closing lanes to traffic to make the repairs and closing them on toll roads for patrons who have paid for a safe, swift ride. Finally, there is the cost. Between 1958 and 1965 six million dollars was spent on a major toll road solely for the patching and repair of concrete bridge decks.

All such repairs are really an expediency, treating the symptom rather than the disease. The world's best patch is, after all, only a palliative and not a vaccination.

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There is always the likelihood of recurrence, with the added uncertainty about when or where it will happen. Experience in the Northeast has shown that all decks may crack, most of them do, and some of them must. With cracks come spalls, and with spalls come deck failures. So it is manifest that some way must be found either to prevent cracks or to negate their destructive effect. Yet the prevention of cracks surely belongs in the original design and construction, and is not properly a part of maintenance. Therefore, a search was conducted for a superior protective system.

## FUNDAMENTAL CONCEPTS

The ideal bridge deck protective system must at least be waterproof, because water is both mechanically and chemically destructive to concrete. It is mechanically destructive because of its power to erode and because of its peculiar property of forming ice crystals which have a greater volume than the liquid. It is chemically destructive because it is rarely pure in an industrial environment and often carries high concentrations of ionic salts used for deicing. Numerous surveys, reports and papers have verified this beyond debate.

An ideal deck protective system should also be wear resistant. It should be capable of resisting abrasion both from traffic and from such punishments as tire chains and snowplow blades (7). Of course, to be effective, the protective system should be better able to resist the same forces that attack the concrete.

In addition, an effective system should be thin to avoid disturbing the design drainage patterns, to prevent the addition of excessive weight to the structure, and to avoid the high attendant costs in reconstructing joints, curbs, and other features which depend on the pavement elevations. It should also be inexpensive and easy to apply outdoors, and it should last for a long time to avoid continued lane closings for repairs every spring.

Unfortunately, such a product does not exist. There are many materials which can be applied relatively easily in a plastic state and which harden into a thin waterproof membrane. But when dealing in the range of mil thickness, a concrete bridge deck is not a mirror-smooth surface. Any material applied in a liquid state is thinner on hills and thicker in the valleys. Also, most liquid-applied products tend to have a slick surface, so aggregates must be cast into the membrane to provide suitable skid resistance. Any hard, sharp material penetrating through a membrane has the capacity to weaken the membrane. For these reasons, we know of no thin waterproof membrane which can stand up to, for instance, 30,000 axle applications per day for more than two years and still be considered waterproof.

One way around this would be to build up consecutive layers of a polymer material to increase its thickness (8, p. 23). This has been tried but, inevitably, the cost becomes prohibitive.

Thus, the best answer seems to be a thin polymerized type membrane with a suitable wearing course. Even the most carefully controlled and expensive asphaltic wearing courses, put down at a generous thickness and considering all attendant expenses of raised construction joints and inlets, still cost about the same as the membrane itself. But by doubling the cost to provide this wearing course, we increased the life of the system five to tenfold.

Therefore, the following three-step protective system was used: (a) apply a waterproof membrane to the deck, (b) raise the end dams and joints and drainage inlets, (c) place an asphaltic-concrete wearing surface.

## INTERLAYER MEMBRANE

There are, no doubt, many products that will serve the purpose of a waterproof membrane (8, pp. 20-26). We have tried four and finally settled on a coal-tar epoxy resin formulation for many reasons. Coal-tar has been used for hundreds of years as a waterproofing material on ships and marine facilities and has proved to be an effective barrier. The epoxy resin gives the added bonus of strength to help bridge the fine cracks and pinholes in the concrete surface. The product was one of the first to be widely test-marketed across the country with satisfactory results (7). Application and distribution equipment has been developed and is competitively available and relatively


Figure 1. Combination mixer and sprayer of epoxy membrane.

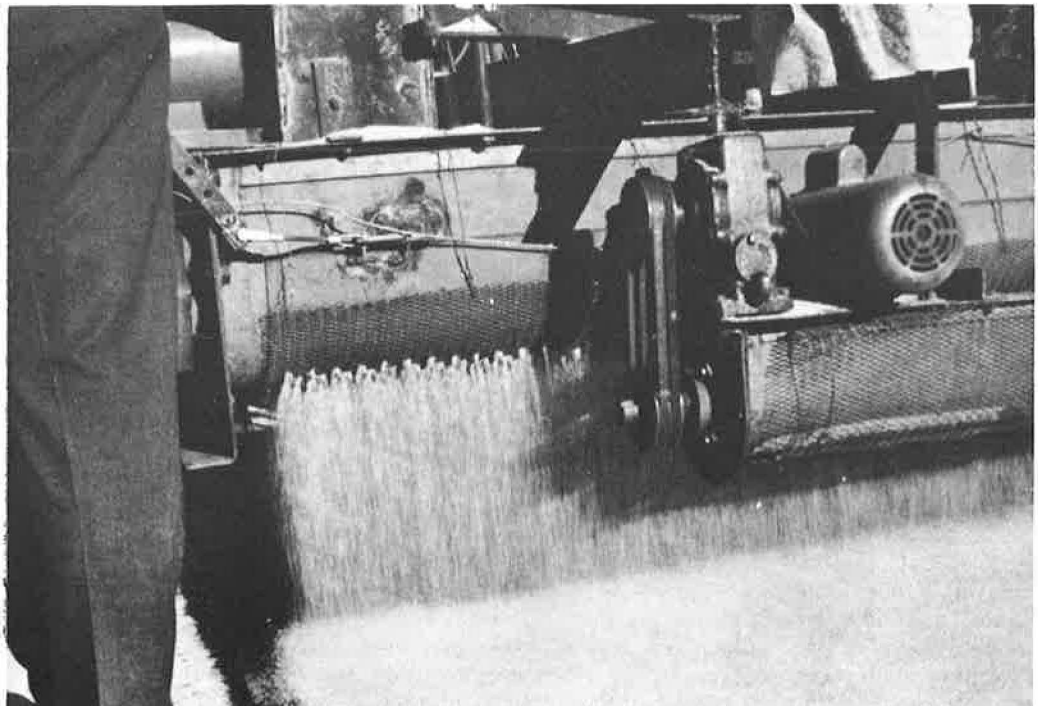

Figure 2. Distributor truck conveyor system.

TABLE 1

COST OF COAL-TAR EPOXY RESIN MEMBRANE AND ASPHALTIC CONCRETE

| Month | Year | Structure | Unit Price ($) | |
|---|---|---|---|---|
| | | | Coal-Tar Epoxy (sq yd) | Asphaltic Concrete[a] (sq yd) |
| Sept. | 1963 | Passaic River Bridge | 2.00 | 1.25 |
| Sept. | 1963 | Oak Island Viaduct | 2.00 | 1.25 |
| April | 1964 | Blacks Creek Bridge | 3.00 | 0.95 |
| May | 1964 | Belleville Turnpike | 3.00 | 1.85 |
| May | 1964 | Hackensack River Bridge | 2.40 | 1.85 |
| Sept. | 1964 | Southeast Viaduct | 2.54 | 1.75 |
| Oct. | 1964 | Cranbury Brook Bridge | 3.00 | 1.72 |
| Oct. | 1964 | Rocky Brook Bridge | 3.00 | 1.90 |
| May | 1965 | Crafts Creek Bridge | 6.00 | 1.72 |
| Sept. | 1965 | Newark Bay Bridge | 2.90 | 1.67 |
| Aug. | 1966 | Rancocas Creek Bridge | 3.50 | 1.98 |

[a]1½ in. thick.

simple to operate. The cost is at least competitive, and in many cases cheaper, than similar types of membrane materials.

As for methods of construction, the deck surface must first be carefully cleaned, as for any thin-bonded membrane. Acid cleaning is satisfactory but sandblasting is better. The application is made by a combination mixer and sprayer which works much like an ordinary asphalt distributor (Fig. 1). The material is usually put down at the rate of about 2 to 3 lb/sq yd. Then comes the one "touchy" operation, sand application. In planning the work, it should be kept in mind that a coal-tar epoxy resin membrane is really a three component system: the A and B components of the coal-tar epoxy and sand. The sand must, of course, be applied before the epoxy is cured, and this can create a serious access problem when only one lane can be closed to traffic. Fortunately, equipment is now available which spreads the sand simultaneously with the epoxy by means of a conveyor system mounted on the distributor truck (Fig. 2).

The rate of sand application and the selection of sand particle size have also proved more critical than was at first realized. The sand particles should be rounded rather than flat to avoid an interface of particles that might cause capillary action or the drawing up of the epoxy from the concrete surface (9). All the sand should be of a size between a 20 and 40 mesh sieve to provide sufficient voids between particles for the epoxy to be contiguous.

The cost of this membrane ranged from $2.25 to $4.50, with an average price of about $3.00 per sq yd being typical (Table 1). There are three things to watch for in a coal-tar epoxy application: adhesion, pinholing, and blistering. Adhesion is almost always a matter of careful deck cleaning. Pinholing and blistering can be largely controlled by proper sand application.

## WEARING COURSE

Inasmuch as some imperfections are bound to occur, it is sensible to design the asphalt wearing course with a thought toward correcting any deficiencies that might exist in the membrane. Ideally, the design of such a wearing course would be dense enough to hold in place the isolated unbonded areas of sealcoat, rich enough to avoid the formation of continuous capillaries which could lead to pinhole imperfections in the sealant, and thick enough to protect the sealing membrane from abrasion and wear.

The addition of asbestos fibers to a well-designed dense mix greatly improves the foregoing characteristics (10). This is brought about by the ability of the asbestos to absorb some of the fatty globules in the asphalt and thereby allow a higher asphalt content without creating surface flushing common to rich mixtures. Furthermore, the fibrous nature of the asbestos tends to bridge the interstices within the matrix of the mix and thus inhibit the formation of continuous capillaries.

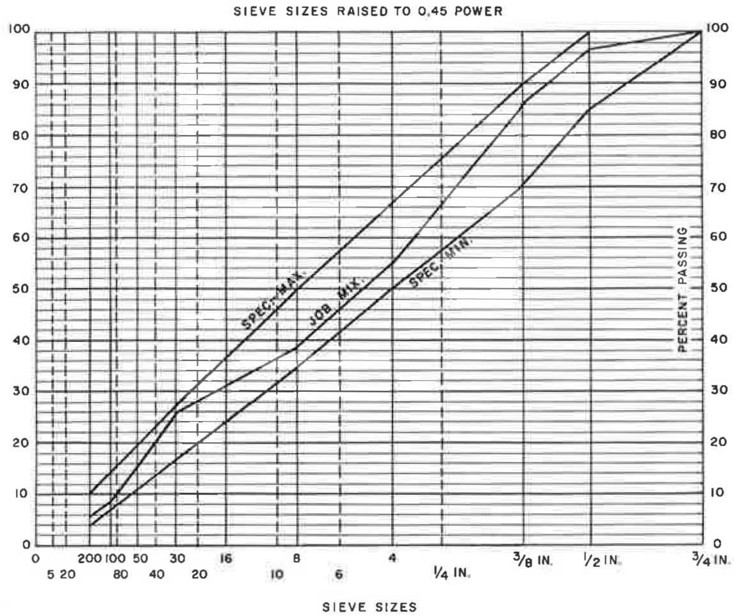


Figure 3. Aggregate gradation chart.

The determination of the most suitable thickness for the wearing course is somewhat arbitrary. We have found it impractical, however, to specify thicknesses of any less than 3/4 in. Lesser thicknesses are difficult to bond; reduce the maximum size of aggregate that can be used, thereby reducing stability; and increase the likelihood of damage and wear that would expose the seal coat. However, thicknesses in excess of 1½ in. become uneconomical and present dead-load problems on many structures.

Two things are necessary to insure a dense pavement: well-graded aggregate through all the sieve sizes, and a high asphalt content. A handy way to check for density of the aggregate mix is to plot the aggregate gradation on a chart showing sieve sizes raised to the 0.45 power (11). The curve which falls closest to a straight line is usually the densest mix (Fig. 3). With 2½ percent of asbestos added to the mix, it is possible to increase asphalt content to 8 percent without serious flushing. This combination of densely graded aggregate and 8 percent asphalt content has produced pavements which are virtually impermeable when measured by the California permeability test (12). As an added bonus, asbestos also has the ability to increase the stability of a mix far beyond the normal expectation for such high asphalt contents. Although the reasons for this are beyond the scope of this paper, Spear and Keitzman (13) showed that the addition of 2½ percent asbestos can cause a 90 percent reduction in rutting depth over that which would occur in a similar mix without asbestos.

Because of the density of the mix and the absolute necessity to prevent cracking in the overlay, we are also specifying an asphalt modified with rubberized materials. A continuing research program by the British Road Research Laboratory has shown that the addition of rubber considerably reduces the number and severity of cracks in a surfacing material and substantially increases the life of the asphalt when added to a bitumen macadam (14). Research in this country has shown that toughness, tenacity, and ductility are all improved by the addition of neoprene latex to the asphalt cement (17). And recent studies have shown that latex improves asphalt adhesion to aggregate, a property which tends to increase flexibility and decrease brittleness (16). These considerations are important because of the constant repetitive deflections in bridge decks and the density of the surface material. Both conditions may contribute to fatigue of the bituminous concrete mixture and allow the possibility of reflective cracking from

Figure 4. Neoprene-modified, asbestos-additive pavement construction.

Figure 5. Rolling operation.

the deck below. So we have added two varieties of latex to the asphalt-cement to insure retaining the more desirable properties.

In this regard, the relative long-term merits of reclaimed rubber compared with neoprene latex cannot yet be evaluated from our experience. We have used the neoprene for five years and have begun using the reclaimed rubber only this spring.

However, the reclaimed rubber is much cheaper, amounting to only one-third the cost; it is easier to handle as it can be dumped dry directly to the pug mill, whereas neoprene must be specially blended with the asphalt-cement; and it is more uniformly workable because the neoprene with such high asphalt contents sometimes shows a tendency to wave under compaction. Also, the neoprene is currently under limited production.

The methods of construction for the neoprene-modified, asbestos-additive pavement are the same as those used for any asphalt overlay (Fig. 4) with the exception that the mix is somewhat sensitive to rolling temperature. If the mixture is rolled when too hot, a mud wave may develop in front of the roller (Fig. 5). Also, hand-raking should be avoided because this disrupts the careful blending to achieve maximum density. Such an asphalt mix is, of course, expensive. Latex additives add from \$0.50 to about \$2.50 to the cost of a ton of asphaltic concrete, depending on the type and quantity involved, and the asbestos adds another \$1.50. So such a mixture adds about \$4.00 per ton to the cost of a conventional asphalt surface course mix. But bridge deck surfacing is usually extremely expensive anyway because of the low production rate that can be realized per day on a short span bridge. On one major turnpike, working under severely restricted conditions, the cost for the total job generally runs to about \$20.00 per ton, or about \$1.62 per sq yd, which, as noted previously, is about half the cost of the membrane we are trying to protect (see Table 1).

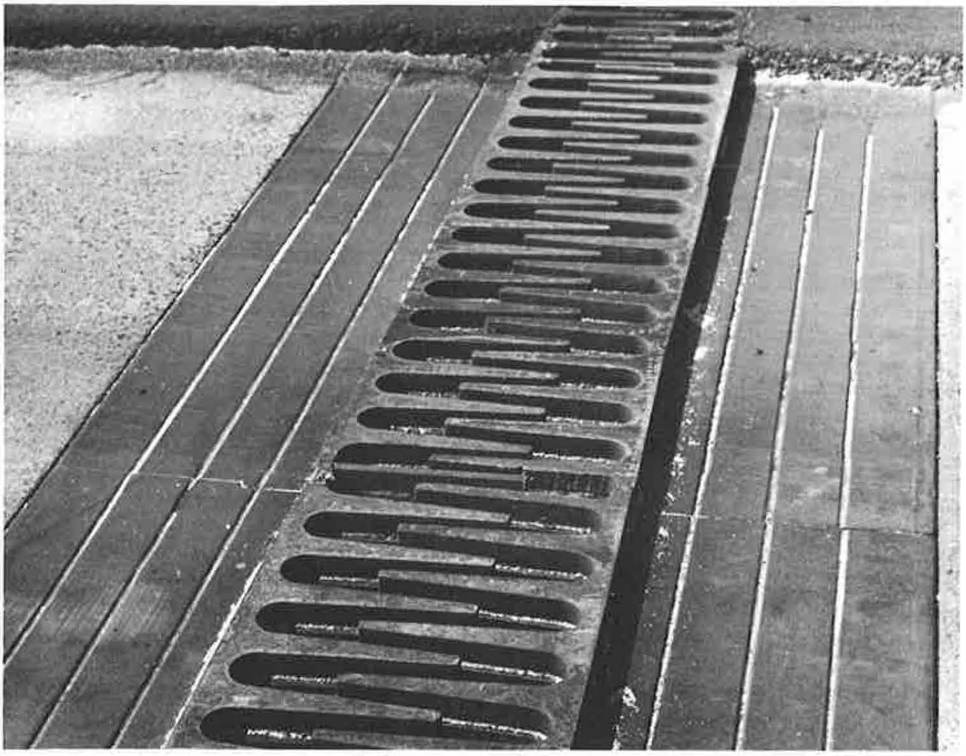

Figure 6. Large finger dam built up 1¼ in.


Figure 7. Welding of bar stock to top of old dam.

## EXPANSION JOINTS

There is nothing special about the raising of the end dams and inlets. For the most part, with finger dams a 1½-in. thick steel plate conforming to the configuration of the existing dam is cut out and welded directly to the old dam (Fig. 6). On straight bulb-angled type dams, 1½-in. bar stock is usually welded to the top of the old dam (Fig. 7). Lately, we have also experimented with 1-ft wide epoxy resin dams and with some success. However, I think the steel dams will prove far more durable.

On a few bridges we have experimented with sawn joints only at contraction joints. These were then filled with a hot-poured neoprene-modified joint filler. In at least one instance, nothing at all was placed in the joint. To date, there is no evidence of any failure in the joint edge (Figs. 8 and 9).

## SUMMARY

Our procedure is the following.

1. Patch and clean the deck and put down a coal-tar epoxy resin membrane for waterproofing.
2. Raise the expansion dams and inlet covers by 1½ in. to contain the overlay.
3. Place a 1½-in. thick mat of neoprene-modified asphalt-concrete with asbestos added to protect the membrane (Fig. 10).

The results have been most heartening. So far, over the past three years this treatment was used on 3 large bridges, 2 very large viaducts, and about 30 smaller overpasses. The total cost of the protective treatment has so far run to $3,000,000. On each bridge the treatment cost was about equal to the cost of the previous year's

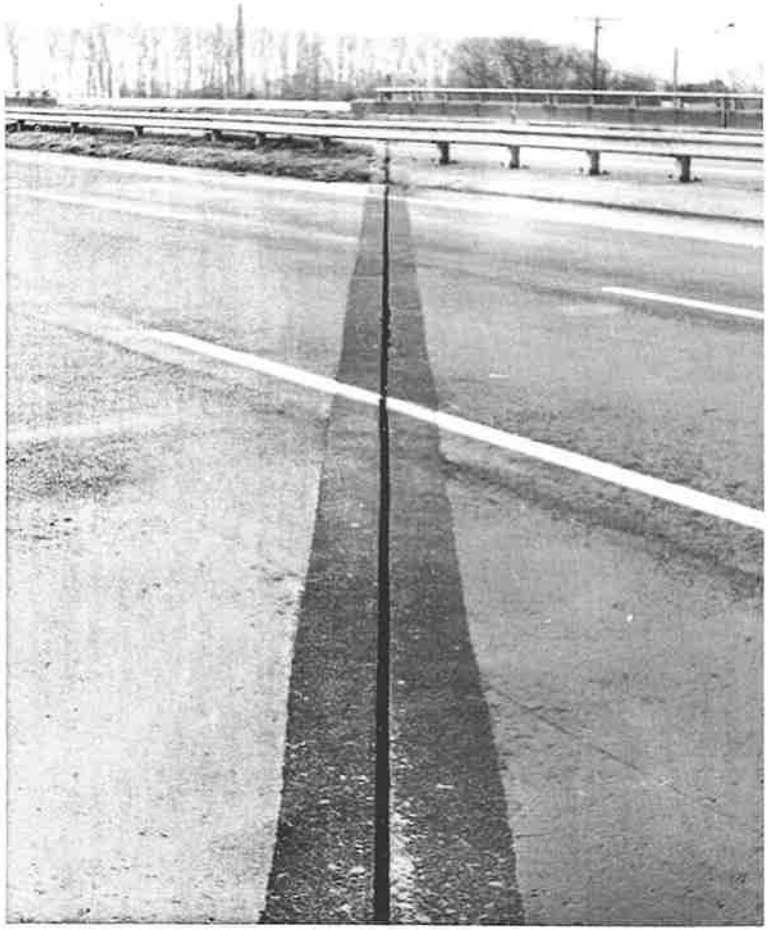

Figure 8.

Figure 9.

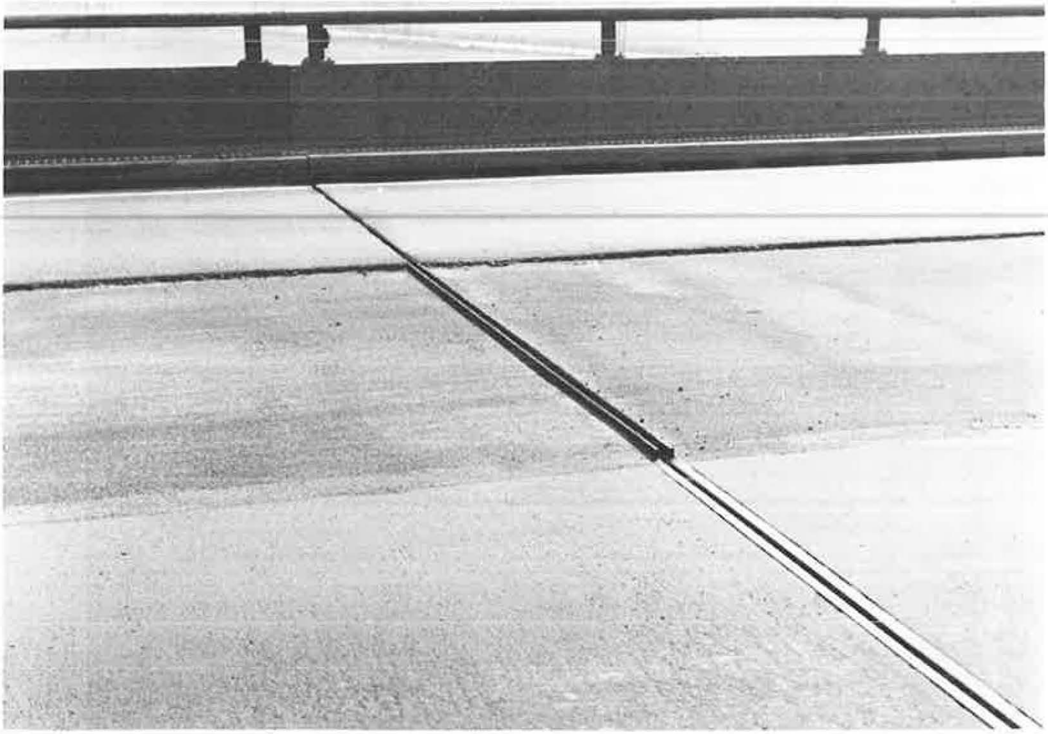

Figure 10. Mat of neoprene-modified asphalt-concrete with asbestos added to protect membrane.

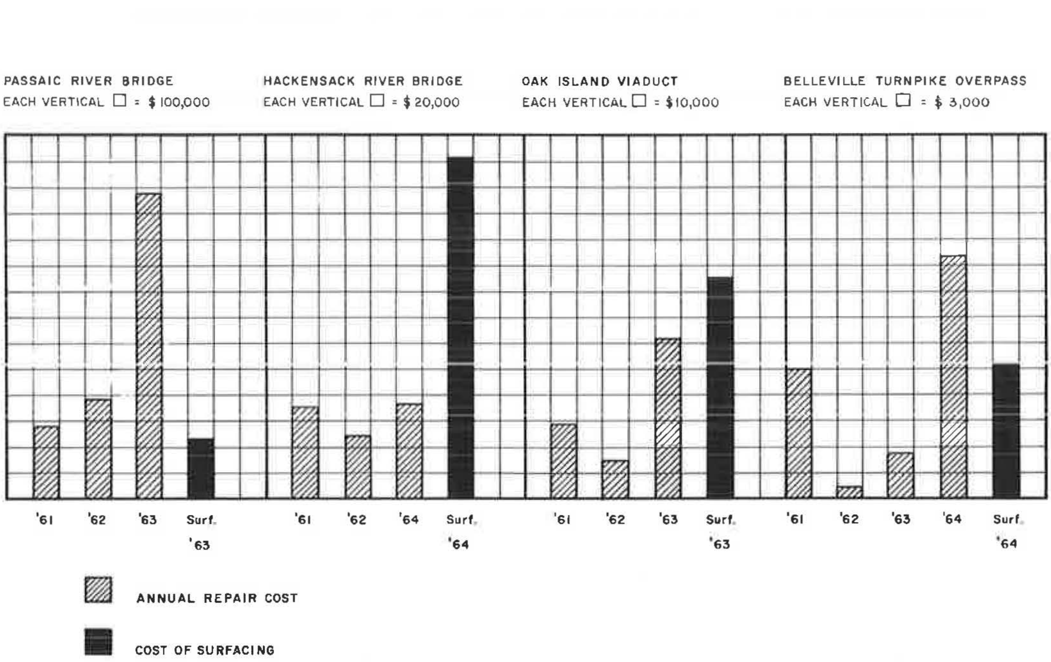


Figure 11. Cost of protective treatment.

TABLE 2

TYPICAL RESULTS OF SKID TEST ON NEW BRIDGE DECK SURFACING—ALLEGHENY AVENUE OVERPASS, NEW JERSEY TURNPIKE

| Location | Age | Left Lane | | Center Lane | | Right Lane | |
|---|---|---|---|---|---|---|---|
| | | f[a] | Skid Length | f | Skid Length | f | Skid Length |
| Area I + 2.6% grade | 49 mo | 0.51 | 48 | 0.47 | 51 | 0.49 | 58.5 |
| Area II + 2.4% grade | 3 mo | 0.45 | 42.5 | 0.42 | 56 | 0.42 | 59 |
| Area III + 1.8% grade | 49 mo | 0.43 | 41 | 0.40 | 45.5 | 0.43 | 48 |

[a]f is the coefficient of friction calculated from the following formula: $f = (V^2)/(30D)$, where V = velocity (in all cases corrected from the velocity to 30 mph) and D = total distance traveled from brake application to full stop. All areas were wetted before each test.

repair program on the old concrete deck. Thus, as far as we are concerned, the protective treatment has already paid for itself—$3 million invested to halt a rising $6 million repair bill (Fig. 11).

Furthermore, there is no evidence of cracking in the surface in any of the overlays, nor is there any sign of water leaking through the bridge deck either during, immediately after, or long after a rainfall.

This has been demonstrated rather convincingly by the removal of metal forms. For reasons beyond the scope of this paper, we often use left-in-place corrugated galvanized metal forms to replace a deteriorated bridge deck. Concern was expressed that these forms would prohibit us from evaluating the effectiveness of the surface systems, and some of the forms were removed. Although the forms had been in place for two years, there was no sign of moisture.

Also, because of the high asphalt content used, some clients were fearful of skidding problems. Over the years we have had several areas tested. In all cases the coefficients of friction on the bridge surface were at least as good as those on the roadway approach pavement (Table 2).

The program has been so successful that this method of construction has now been adopted as the standard policy for all new bridges constructed on the New Jersey Turnpike, including the proposed 30-mi widening program and the Delaware Memorial Bridge, and is the recommended procedure for at least three other major clients.

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# Use of Urethane Foam in Pavement Pressure Relief Joints at Bridges

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•A PROCEDURE for using "foamed-in-place" urethane foam in joints on bridge approach pavement has been adopted as a routine maintenance operation on primary roads in Iowa. This is related to the relief of pavement pressure against approximately 2700 bridges in the state.

Many costly bridge repairs are related directly to the tremendous pressure exerted on the structure from the ever expanding concrete pavement at each end of the bridge. The damage from pavement pressure is evidenced by cracked or crushed backwalls or cracked abutment faces. The pressure also results in tipped abutments or piers and skew bridges being pushed out of alignment.

Iowa design standards for many years have required two or three 2-in. expansion joints in the approach pavement at bridges. These joints were filled with either two 1-in. pieces of pre-formed bituminous joint filler or one piece of bituminous joint filler and a 1-in. redwood board. These were ineffective in preventing damage to backwalls and bridge ends; therefore, the Maintenance Department adopted a procedure of cutting an additional 4-in. joint the full depth and width of the pavement outside the heavily reinforced bridge approach sections. The joints were approximately 30 to 45 ft from the ends of the bridge and were filled with four pieces of 1-in. pre-formed bituminous expansion material. Damage to the bridges continued to occur.

Compression tests were made on the various combinations of wood-bituminous joint fillers used. To compress them half their thickness required pressures ranging from 650 to 1000 psi. Compression tests of four pieces of 1-in. pre-formed joint material (as would be used when four 1-in. strips were placed in a 4-in. relief joint) indicated why bridge damage continued to occur. To compress four thicknesses of 1-in. bituminous fiber joint material, ½ in. required 85-95 psi, 1 in. required 170-200 psi, 1½ in. required 350-400 psi, 2 in. required 795-835 psi, and 2½ in. required 1700-1900 psi. A more readily compressible material was necessary in these pressure relief joints if damage to bridges was to be prevented or at least substantially reduced. The alternative would require that joints be recut if they had closed more than ½ in. This would be a frequent chore in some locations inasmuch as there have been numerous instances reported of unfilled 4-in. joints closing 2 in. or more overnight.

A study of the problem indicated that a nearly ideal material would have to meet the following characteristics.

1. Compress to at least half its thickness at approximate pressure of 40 to 50 psi and recover to 90 percent of original size. (Later consideration and experience indicated recovery is not an important feature because the pavement, even in cold weather, retracts only insignificant amounts.)
2. Retain flexibility at minus 40 F and remain stable at plus 120 F.
3. Not extrude from the joint when compressed.
4. Be readily adaptable to various widths and depths of joints (joint widths would vary from 3 to 5 in. and pavement thickness could vary from 8 to 14 in.).
5. Reject objects such as stones, sticks or other incompressibles under traffic action.

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6. Be chemically inert, at least to those chemicals normally present on road surfaces, such as chlorides and petroleum derivatives.
7. Create minimum interference with traffic while being placed.
8. Have favorable cost benefit ratio.
9. Have an expected ten-year service life. (Current thinking is that five years would be sufficient because most relief joints need to be recut at least every five years.)

It was decided that urethane foam could be formulated and economically adapted for this use. Arrangements were made to begin field experiments in May 1964. A 2-pcf rigid type foam, because of its lower cost per volume, was used first, but it was evident within hours that it would not reject foreign objects. The material was also scuffing out in the wheel tracks. It was concluded that a flexible type foam would be necessary, at least for the top part of the joint.

During the following months various combinations of rigid and flexible type foams were tried, both as single materials and as combined materials.

As a result of laboratory tests and field observations, it was concluded that a relief joint with the bottom portion filled with rigid foam of 4-pcf density and the top 1 in. of the joint with flexible type foam of 18-pcf density would meet nearly all the desired physical characteristics. (Later, the thickness of flexible type foam was changed to 2 in.) Service life could be determined only by usage and time.

In an effort to determine whether the materials could be satisfactorily placed by local forces and to get exposure of the material to varying traffic conditions, foam joints were placed at both ends of five bridges in each of four counties in southeastern Iowa. On July 15, 1964, a demonstration of the mixing and placing of the foam was attended by the foreman from each of the counties involved in the test so he could supervise the work in his area. Written instructions and charts indicating quantities of the components comprising the two types of foam were distributed following the demonstration.

In the fall of 1964, pressure relief joints at 22 bridges were filled with the combination of rigid and flexible type urethane foam using local maintenance personnel. Several were put in during adverse weather. All joints were inspected in December 1964 (air temperature at 8:00 a.m. was 4 F), and again in June 1965. All joints were performing satisfactorily except at six bridges where they had closed over half their width. That is, joints at six bridges that were 4 in. wide when filled in the fall of 1964 had closed to approximately 2 in. by June 1965, and had lost the bond between the flexible and rigid foam where the depth of flexible foam was less than $^3\!/_4$ in. There did not appear to be any deterioration of the rigid type foam in those joints where bond had been broken. The loss of bond was not considered a failure of the material because it had performed its desired function during the useful life of the joint. Inasmuch as these joints had closed half their constructed width, it would be necessary to recut them and place new joint filler.

Inspection of the foam-filled joints at the original 22 bridges in the spring of 1966 revealed little, if any, deterioration. Where flexible foam was of adequate thickness (1 in. or more) and depressed below the surface $^1\!/_2$ to $^3\!/_4$ in., there was no loss of bond.

Our experience to date indicates that "pour-in-place" urethane foam joints are readily adaptable to our local maintenance operations. Local personnel are easily trained. The materials are not toxic in this open air operation, but the chlorothene used to clean the equipment must be used in a ventilated area. The few items of special equipment necessary are inexpensive. The materials cost very little more than the bituminous joint filler previously used and are generally conceded to be easier to install.

The joint preparation required some changes in our concrete saws. Previously we used 14-in. diameter diamond blades which permitted a $3^1\!/_2$ or 4-in. depth cut. Breaking out the concrete with jack hammers resulted in breakout in the bottom part of the joint being wider than the sawed width, and in effect, resulted in short cantilever section of pavement at the joint. By adapting the concrete saws to use 24-in. diameter diamond blades, a $9^1\!/_2$ in. depth of cut was possible and eliminated (except in extra thick pavement) this undesirable cantilever section. Relief joints are cut full width of

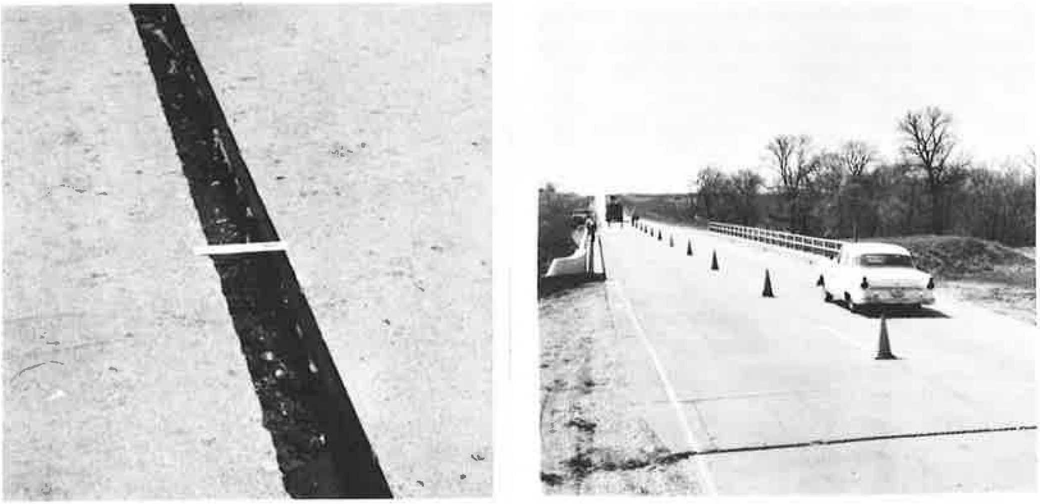


Figure 1. Prepared relief joint.

Figure 2. One-inch vent holes through form on 1-ft centers to allow entrapped air or excess foam to escape.

the pavement and a nominal 4 in. wide (Fig. 1). Joints over 5 in. wide may be objectionable to traffic.

Placing the urethane foam is usually accomplished one lane at a time, using a removable form at the centerline or lane line to prevent flow of liquid material into the unfilled portion of the joint.

For proportioning, mixing, and placing the materials after the relief joint is cut, the following special equipment items are necessary.

1. A container in which to weigh and mix the components. Our present practice is to use $2\frac{1}{2}$-gal paper ice cream cartons because it is impractical to attempt to clean a reusable container after the foam has set.

2. A scale or balance to weigh the components. The scale must be fairly accurate and easily read. A platform type household scale (the type usually seen at roadside vegetable stands) has proved suitable.

3. For mixing the foam, a $\frac{3}{8}$-in. or heavy duty $\frac{1}{4}$-in. drill with a speed of at least 1650 rpm is necessary. An even higher speed drill is desirable so that more thorough mixing can be secured in the normal 30-sec mixing time of the two components. Thorough mixing is necessary to develop a high quality foam.

4. Forms to control the height of rise of both the rigid and flexible type foams are easily constructed from lumber available at any local lumberyard. Both forms consist of a 1 by 8-in. board to which a "lug" or "key" is nailed, which projects into the joint the desired depth for the full length of the joint. To place approximately 2 in. of flexible foam in the top part of the joint, the key on the bottom of the form for the rigid foam should extend into the joint $2\frac{3}{8}$ or $2\frac{1}{2}$ in. The key on the forms we have constructed consists of 2 by 4-in. and 1 by 4-in. boards nailed together (Fig. 2). It is also necessary to keep the surface of the flexible foam approximately $\frac{1}{2}$ in. below the surface of the pavement to reduce traffic loads on the joint and to eliminate the possibility of the joint being damaged by snowplows. A form similar to that used for the rigid foam is adequate except that the key or lug projects into the joint a lesser distance. A few holes are bored through the form to relieve pressure and excess foam. The process of placing the joint material has presented no difficulties and can be accomplished by a three-man crew.

For convenience and to simplify the operation, the containers for the various foam components have been color coded, and charts have been prepared for various cross-sectional dimensions and widths of joints to provide a guide for the amounts of material needed to produce the correct amount of foam for a specific location.

The rigid foam prepolymer (color coded yellow) and the rigid foam crosslinker (color coded white) are stocked in 5-gal units. The flexible foam prepolymer (color coded red) is also stocked in 5-gal units. The flexible foam crosslinker (color coded blue) is stocked in 1-gal units. One of each of the units is usually sufficient to pour a joint in each end of a bridge on 24-ft pavement.

Instructions to the maintenance personnel on the use of the materials are given generally in the following form.

A $2\frac{1}{2}$-gal paper carton (such as is used for delivery of bulk ice cream) is placed on a scale, and the scale is adjusted to compensate for the weight of the empty carton. From the chart the amount of prepolymer (color coded yellow) is determined, and this material is then poured into the paper carton in the correct amount (Fig. 3). The prepolymer should then be stirred with an electric drill for not over 3 min to incorporate air. A definite color change from dark brown to tan will be noticed when mixed sufficiently. After stirring the prepolymer, the carton is placed back on the scales and the correct amount of crosslinker (color coded white) is then added. The crosslinker catalyst material must be added quickly and the two components must be thoroughly mixed with the electric drill. In normal weather conditions, 70 to 80 F, it is anticipated there will be approximately a 30-sec period in which the mixing of the two materials can be accomplished before they begin to react (Fig. 4). As the temperature rises the mixing time decreases. In hot weather it is desirable to keep containers of material stored in the shade. After thoroughly mixing the two components, the material is poured into the joint in a uniform layer for one-half the pavement width (Fig. 5). The form should then be placed over the top of the material (the form should have a projection into the joint of approximately $2\frac{3}{8}$ in. to control the height of the rise of the rigid foam, Fig. 6).

If the form is covered with thin plastic sheeting similar to that used in curing concrete pavement, a smooth clean surface can be maintained on top of the rigid foam. As soon as the chemical action of the foam material is completed and the foam becomes firm (a minimum of 5 min), the form may be removed and the flexible type urethane foam may be placed on top. Any of the rigid type foam that has squeezed up

Figure 3. Weighing material.

Figure 4. Timing mixing of foam components.

Figure 5. Pouring mixed material into prepared joint.

Figure 6. Man holding form down until foam has completed its rise.

Figure 7. Cleaning excess rigid foam from sides of joint.

Figure 8. Completed joint.

along the form or above the controlled height must be removed before placing the flexible foam (Fig. 7).

The flexible type foam is designed to weigh approximately 18 lb to the cubic foot. Here again the amount of materials needed for particular joints can be secured by checking the attached charts. The weighing and mixing of the materials will proceed the same as with the rigid foam. That is, the prepolymer (color coded red) will first be weighed in the correct amount and then the material mixed, for not over 3 min, to incorporate air. A definite color change from carmel to milk white will occur when properly mixed. The crosslinker or catalyst (color coded blue) is added in the correct amount, the materials mixed for approximately 30 sec and then poured in the joint over the rigid foam in a uniform layer. Here again, a form over the top of the material must be used to control the height of rise of material and to secure proper closure or seal at the sides of the joint.

A 1 by 6-in. or a 1 by 8-in. board with 1/2 or 3/4 by 4-in. strip tacked to the bottom is a satisfactory form for this operation. Here again, plastic sheeting placed over the form results in a smooth textured surface and also facilitates the removal of the form. The joint should remain closed to traffic for approximately 1 hr (Fig. 8).

In handling and storing these foam materials it is essential that the component materials do not come in contact with moisture. Materials should be stored inside where it is dry and temperature is reasonably cool. Containers must be kept closed except when actually pouring out materials.

Best results are obtained if foam material is placed when the air temperature is above 70 F. Material has been placed at temperatures as low as 45 F; however, this requires heating the material, heating the joint, and additional mixing of both the prepolymer and combined materials.

It is recommended in Iowa that relief joints be filled between May 1st and August 1st. Joints filled after late summer may not become compressed enough before cold weather to remain watertight due to slight contraction of the adjacent concrete slabs because of thermal change.

The mixing and placing process described is for the method presently used. (There is a machine available to proportion the components mechanically and spray the foam into the joint; however, we have not tried this method.)

The foregoing procedures and materials have proved satisfactory; however, consideration is presently being given to using 10-pcf flexible foam for the full depth of the joint rather than the combination of rigid and flexible types.

When the 10-pcf flexible foam was first used, it was thought that it would not be suitable inasmuch as the cells in the top $\frac{1}{8}$ or $\frac{1}{4}$ in. seemed to break down under traffic within 1 mo. After a rain the surface of the joint absorbed water. It was concluded (perhaps too hastily) that this material would not withstand the freeze-thaw action which would take place; however, after two winters' experience there does not appear to be any further breakdown of the material, and it is considered to be functioning very satisfactorily. Further experimentation and study of this type of joint is intended in the future. Although the cost of 10-lb flexible foam for full depth would be greater (approximately $110 per bridge as compared to present cost of $75 per bridge), the savings realized in mixing time, in less waste material both from mixing operations and in partly used shipments, could result in comparable cost. The 10-lb flexible foam has the additional advantage of compressing to half its thickness at approximately 25 psi, further reducing the possibility of damage to bridges because of pavement pressure.

## ACKNOWLEDGMENTS

We wish to acknowledge the efforts of our Maintenance Special Services Engineer, E. J. O'Connor, in developing this procedure.

We also wish to acknowledge the assistance and wholeharted cooperation of the management and staff of Phelan's Resins & Plastics of Burlington, Iowa. Their technical assistance, both in the development of materials and the adaption for field application, contributed greatly to the results obtained.

# *Appendix*

AMOUNTS OF RIGID AND FLEXIBLE FOAM COMPONENTS REQUIRED FOR VARIOUS WIDTHS AND DEPTHS—12-FT JOINT LENGTH

RIGID FOAM

COLOR CODE
PP151-Yellow
XPA142B-White

| JOINT DEPTH | | JOINT WIDTH 2" | 3" | 4" | 5" | 6" |
|---|---|---|---|---|---|---|
| 4" | Cu. Ft. | 0.67 | 1.00 | 1.33 | 1.67 | 2.00 |
| | Yellow | 1 lb. - 9 oz. | 2 lb. - 5 oz. | 3 lb. - 2 oz. | 3 lb. - 14 oz. | 4 lb. - 10 oz. |
| | White | 1 lb. - 2 oz. | 1 lb. - 11 oz. | 2 lb. - 4 oz. | 2 lb. - 13 oz. | 3 lb. - 6 oz. |
| 5" | Cu. Ft. | 0.83 | 1.25 | 1.67 | 2.08 | 2.50 |
| | Yellow | 1 lb. - 15 oz. | 2 lb. - 15 oz. | 3 lb. - 14 oz. | 4 lb. - 13 oz. | 5 lb. - 13 oz. |
| | White | 1 lb. - 6 oz. | 2 lb. - 2 oz. | 2 lb. - 13 oz. | 3 lb. - 8 oz. | 4 lb. - 3 oz. |
| 6" | Cu. Ft. | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| | Yellow | 2 lb. - 5 oz. | 3 lb. - 8 oz. | 4 lb. - 10 oz. | 5 lb. - 13 oz. | 7 lb. - 0 oz. |
| | White | 1 lb. - 11 oz. | 2 lb. - 8 oz. | 3 lb. - 6 oz. | 4 lb. - 3 oz. | 5 lb. - 0 oz. |
| 7" | Cu. Ft. | 1.17 | 1.75 | 2.33 | 2.92 | 3.50 |
| | Yellow | 2 lb. - 12 oz. | 4 lb. - 1 oz. | 5 lb. - 7 oz. | 6 lb. - 13 oz. | 8 lb. - 2 oz. |
| | White | 1 lb. - 15 oz. | 2 lb. - 15 oz. | 3 lb. - 14 oz. | 4 lb. - 14 oz. | 5 lb. - 14 oz. |
| 8" | Cu. Ft. | 1.33 | 2.00 | 2.66 | 3.33 | 4.00 |
| | Yellow | 3 lb. - 2 oz. | 4 lb. - 10 oz. | 6 lb. - 3 oz. | 7 lb. - 12 oz. | 9 lb. - 5 oz. |
| | White | 2 lb. - 4 oz. | 3 lb. - 6 oz. | 4 lb. - 7 oz. | 5 lb. - 9 oz. | 6 lb. - 11 oz. |
| 9" | Cu. Ft. | 1.50 | 2.25 | 3.00 | 3.75 | 4.50 |
| | Yellow | 3 lb. - 8 oz. | 5 lb. - 4 oz. | 7 lb. - 0 oz. | 8 lb. - 12 oz. | 10 lb. - 8 oz. |
| | White | 2 lb. - 8 oz. | 3 lb. - 12 oz. | 5 lb. - 0 oz. | 6 lb. - 5 oz. | 7 lb. - 9 oz. |
| 10" | Cu. Ft. | 1.67 | 2.50 | 3.33 | 4.17 | 5.00 |
| | Yellow | 3 lb. - 14 oz. | 5 lb. - 13 oz. | 7 lb. - 12 oz. | 9 lb. - 11 oz. | 11 lb. - 10 oz. |
| | White | 2 lb. - 13 oz. | 4 lb. - 3 oz. | 5 lb. - 9 oz. | 7 lb. - 0 oz. | 8 lb. - 6 oz. |
| 11" | Cu. Ft. | 1.83 | 2.75 | 3.67 | 4.58 | 5.50 |
| | Yellow | 4 lb. - 4 oz. | 6 lb. - 6 oz. | 8 lb. - 9 oz. | 10 lb. - 10 oz. | 12 lb. - 13 oz. |
| | White | 3 lb. - 1 oz. | 4 lb. - 10 oz. | 6 lb. - 2 oz. | 7 lb. - 11 oz. | 9 lb. - 3 oz. |
| 12" | Cu. Ft. | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 |
| | Yellow | 4 lb. - 10 oz. | 7 lb. - 0 oz. | 9 lb. - 5 oz. | 11 lb. - 10 oz. | 13 lb. - 15 oz. |
| | White | 3 lb. - 6 oz. | 5 lb. - 0 oz. | 6 lb. - 11 oz. | 8 lb. - 6 oz. | 10 lb. - 1 oz. |

FLEXIBLE FOAM

COLOR CODE
PP111B-Red
FC24-Blue

| JOINT DEPTH | | JOINT WIDTH 2" | 3" | 4" | 5" | 6" |
|---|---|---|---|---|---|---|
| 1" | Cu. Ft. | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 |
| | Red | 2 lb. - 11 oz. | 3 lb. - 15 oz. | 5 lb. - 3 oz. | 6 lb. - 10 oz. | 7 lb. - 14 oz. |
| | Blue | 0 lb. - 6 oz. | 0 lb. - 9 oz. | 0 lb. - 12 oz. | 0 lb. - 15 oz. | 1 lb. - 2 oz. |
| 2" | Cu. Ft. | 0.33 | 0.50 | 0.67 | 0.83 | 1.00 |
| | Red | 5 lb. - 3 oz. | 7 lb. - 14 oz. | 10 lb. - 9 oz. | 13 lb. - 2 oz. | 15 lb. - 13 oz. |
| | Blue | 0 lb. - 12 oz. | 1 lb. - 2 oz. | 1 lb. - 8 oz. | 1 lb. - 14 oz. | 2 lb. - 3 oz. |
| 3" | Cu. Ft. | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 |
| | Red | 7 lb. - 14 oz. | 11 lb. - 13 oz. | 15 lb. - 13 oz. | 19 lb. - 12 oz. | 23 lb. - 11 oz. |
| | Blue | 1 lb. - 2 oz. | 1 lb. - 11 oz. | 2 lb. - 3 oz. | 2 lb. - 12 oz. | 3 lb. - 5 oz. |

# One-Half Inch Bituminous Concrete Surfaces

CHARLES W. BEAGLE, Director of Public Works, Woodbridge, New Jersey

Information is given on performance and experience of ½-in. bituminous concrete surfaces. A comparison of yield and cost of application on asphalt pavement and on old concrete pavement is made. Five mixes are compared as to mixing and application, and as to performance. Irregularities which occurred for each mix are recorded. The mixes include Perfect Dix Seal, rubberized sand asphalt, New Jersey SP-1 mix, emulsion hot mix and Maryland Smooth Seal.

These ½-in. surfaces provide a smooth, quiet riding surface. They can be used to protect old, spalled and cracked concrete surfaces, and can be used instead of liquid seal on asphalt pavement.

•THE Township of Woodbridge programmed $50,000 for the application of ½-in. bituminous concrete to approximately seven miles of municipal streets in 1962.

Concrete streets constructed during the 1930's and asphalt pavements of various types constructed during the 1940's and 1950's were selected. There were approximately the same number of miles of concrete and asphalt pavement in the program.

The objectives of this program were to ascertain the possibility of eliminating liquid seal coating on asphalt pavements, to extend the life of badly worn and cracked concrete pavements, and to provide a better shape and smoother surface to the streets. The work was to be done under a state aid maintenance and repair program.

There was no information on the performance and experience of ½-in. overlays for municipal work in New Jersey. It was known that many municipalities were using ½-in. bituminous concrete overlays in smaller quantities but records of comparison of the various mixes were not available. It was learned that in many other states ½-in. bituminous concrete overlays were being applied as a maintenance measure. The New Jersey Turnpike has applied test strips of ½-in. overlays to several sections. The Garden State Parkway has applied more than thirty such test strips.

The reported successes of such overlays in many of the eastern states raised the question of which mix would provide Woodbridge the most benefit for the least expense.

Woodbridge Township has many miles of streets requiring major improvement. Any program that would extend the life of existing streets at a low cost would enable the township to extend its construction and reconstruction programs.

On this premise, the State Highway Department approved the supplemental Specifications for Maintenance and Repair Materials on the basis of the mix designated as New Jersey SP-1 in the New Jersey State Highway Specifications and permitted the inclusion of the following mixes as alternates: (a) Perfect Dix Seal, (b) asphalt emulsion hot pre-mix, (c) hot-mix rubberized sand asphalt, and (d) Maryland Smooth Seal.

The lowest bids per ton received for the material delivered and laid in place were as follows:

Paper sponsored by Committee on Salvaging Old Pavements by Resurfacing and presented at the 46th Annual Meeting.

| | |
|---|---|
| Bituminous concrete type SP-1 | \$10.50 |
| Perfect Dix Seal | \$12.50 |
| Asphalt emulsion hot pre-mix | \$13.00 |
| Hot rubberized sand asphalt | \$18.00 |
| Maryland Smooth Seal | \$10.50 |

The engineer's estimate was \$16.00 per ton.

The fact that the prices were below the engineer's estimate brought about a meeting with officials from the State Aid Projects Division of the State Highway Department and the State Highway Testing Laboratories.

There were two options open to the award of bids: (a) to award the contract for SP-1, the lowest price bid; or (b) to provide for a comparison test program and award equal tonnage of all five mixes.

The officials from the State Highway Testing Laboratories agreed to cooperate with a test program, and Woodbridge Township then outlined the plans for pictures, records, maps and reports. It was agreed to award the contract on the basis of equal tonnage for each of the five mixes.

During the time required to prepare the contracts and receive the recommendation of award, the Woodbridge Township Engineering Department prepared a map of the streets to be surfaced.

The streets to be surfaced with each mix were selected so that the mix would be laid on approximately the same amount of asphalt pavement as on concrete pavement. Examples of the conditions of asphalt and concrete pavements before surfacing are shown in Figure 1. One concrete pavement was selected to be paved with all five mixes so that a comparison could be made under conditions as close to identical as possible. One asphalt pavement was also selected to be paved with all five mixes. The concrete street selected was one that is subjected to a high rate of residential and commercial traffic including school buses.

The asphalt street selected is the entrance to the yard and plants of the Middlesex Concrete Products & Excavating Company. This street is subjected to very heavy truck traffic. Ready mix concrete trucks, tandem rear dump trucks loaded with stone, sand and asphalt, and low bed trailers transporting equipment and machines use this street in large numbers every working day.

An inspection of all the streets in the program was made, and notes were taken concerning the surface condition, sunken trench patches, cracks, pot holes, joints and any other deformity or irregularity that might be a source of future failure or cracking.

A card file was prepared, using different colored cards to identify the different types of overlays. The face of the card carries the street name, type of construction, length, width and area in square yards and the application records. The back of the card lists the physical conditions of the road surface before treatment. These cards were used to record the data obtained during the laying of the ½-in. overlay and to record the results of inspections. It was desirable to keep the project as realistic as possible. The successful bidder produced all mixes except the Dix Seal. Preliminary surveys of the streets for cracks and surface condition were supplemented by facts and conditions produced or occurring during the course of the work and by periodic inspections.

The Jersey Testing Laboratories sampled all materials to be used and designed the mixes.

The preparation of the surfaces required the normal cleaning and minor repairs encountered in any normal resurfacing operation, and repairs were kept to a minimum. As the material was placed approximately ½ in. in depth, the need for raising many manholes, catch basins and other utility boxes was eliminated. The material was built up or feathered in as required to meet the various structures. If certain units were below the existing grade of the pavement, they were adjusted before the resurfacing work.

Application of the various tack coat materials did not present a problem.

The control, sampling and testing were done by the New Jersey State Highway Testing Laboratories and the Jersey Testing Laboratories. Inspection was performed

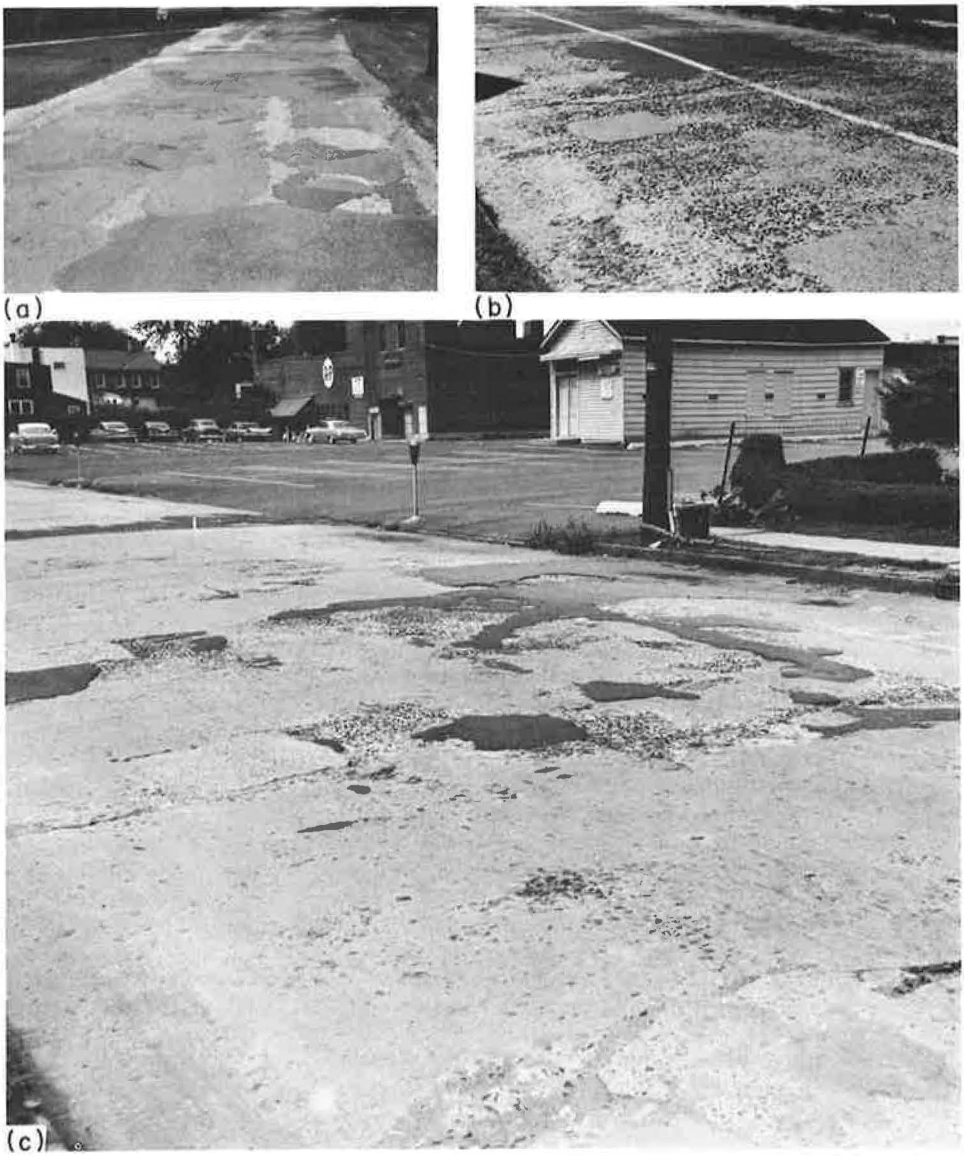


Figure 1. Condition of pavement before surfacing: (a) asphalt, (b) and (c) portland cement concrete.

by the New Jersey State Highway Department and the Woodbridge Engineering Department.

In several locations on asphalt streets extremely high spots were removed and repaired so that no bare spot would appear in the final surface.

Four different pavers were used on the project. The best work was done with a late model paver having temperature control on the screed. With the exception of Dix Seal, the initial rolling was done with a 12-ton 3-wheel roller, and for the smooth rolling a 10-ton tandem roller was used.

When handling thin overlays it is extremely important to maintain proper temperatures for the mix used. This is true for all operations at the plant and on the job.

Thin mixes are very difficult to lay if the pavement temperature is below 50 F.

Care must be taken in tack coating to prevent puddling. Fogging a tack coat was found to be very successful. The amount of tack coat to be applied is a matter of judgment. Worn concrete surfaces absorb more tacking material than asphalt surfaces.

Thin overlays do not hold heat, but cool rapidly. Low air temperature and low pavement temperature present a rolling problem. Constant attention was required in applying these thin overlays. Minimum coverage was set at 50 lb/sq yd and maximum coverage was set at 75 lb/sq yd for all mixes.

It is recognized that these mixes have no structure strength. They are not designed for applications in excess of 75 lb/sq yd. Experience in Woodbridge indicates that a yield of 60 to 70 lb/sq yd is easily obtained on old concrete pavement. The yield on asphalt pavement is slightly higher.

Any asphalt pavement surface that is so uneven as to require a yield of more than 75 lb/sq yd should either be prepared with a leveling course before application or be resurfaced with a bituminous concrete having a more stable mix than the mixes designed for ½-in. applications.

Mixes designed for ½-in. application are not successful on any asphalt pavement having a poor base. Movement in an unstable base is always reflected on the surface. The ½-in. applications do not prevent surface failure due to an unstable base condition.

The use of ½-in. bituminous concrete applications in lieu of liquid seal coating does produce a quiet, smooth ride which is usually not achieved with a broken stone cover on freshly applied asphalt or tar seal coat.

This same ½-in. application on old spalled and worn concrete pavement provides the same quiet, smooth ride and protects the porous concrete from the weather, thus preventing rapid deterioration and extending the useful life of the pavement.

During the application of the mixes, samples were taken and analyses were made. A record of the date and location was kept so that streets laid could be checked against a particular analysis if desired. Samples were taken of the bitumens used in each of the mixes so that their actual characteristics were known.

The gradation analysis for each mix was averaged and a gradation chart drawn for comparison with the maximum and minimum required for each mix.

The average gradation for two of the mixes was on a percent passing and percent retained basis. For these two mixes the average gradation of samples taken was converted to percent passing so that a gradation chart showing the comparison of the average gradations of the five mixes could be drawn. This same chart shows the comparison of the bitumens analyzed.

Over the past three years, periodic inspections of the streets were made, and pictures were taken of any faults that occurred in the surfaces. The causes of these faults were determined.

A chart was made showing the comparison of yield and cost on both concrete and asphalt pavement for each of the mixes.

Rating charts were made for the mixing and application of the mixes, and for the performance of the mixes.

## PERFECT DIX SEAL

The first day Dix Seal was applied a Trac-Paver was used (see Tables 1 and 2; Fig. 2). The work was not as good as was expected, and the top finish was poor. The Trac-Paver was replaced with a Cedar Rapids paver which did much better work. The finish was very smooth. At the start, a 3-wheel roller was used for the initial rolling. After the first few hours this practice was stopped and only a tandem roller was used to smooth the overlay. Dix Seal cannot stand much rolling, the mix has a tendency to push. A tack coat is not used with Dix Seal. The speed of application for the Dix Seal was 16 ft/min. A faster speed caused the mix to creep or push and tear. The roller pushed the mix during the rolling operation. The Dix Seal was mixed at the Barrett Plant in Bound Brook. The length of haul was 19 miles. The daily average laid was 215 tons.

The Dix Seal Company does not specify a tack coat of any kind, saying that Dix Seal is tacky enough, which may be true if the surface is clean and free from dust. If not,

TABLE 1

APPLICATION RECORD FOR PERFECT DIX SEAL MIX

| STREET TYPE OF CONST | SURFACE CONDITION | DATE | WEATHER | TEMPERTURE 8 AM. | NOON | 4 PM | SQ YDS | TONS | YIELD LBS/SQ YDS | UNIT COST PER SQ YDS |
|---|---|---|---|---|---|---|---|---|---|---|
| NORTH PARK DR. | PATCHES | 9.7.62 | PARTLY CLOUDY | 63 | 72 | 71 | | 221.4 | | |
| CONST 6" PEN | SHALLOW HOLES | 9.10.62 | PARTLY CLOUDY | 72 | 86 | 82 | | 99.95 | | |
| ASPHALT | & CRACKES | 9.11.62 | PARTLY CLOUDY | 70 | 83 | 76 | | | | |
| | | | | | | | 8866 | 321.35 | 72.6 | .4512 |
| CROCUS ST | PATCHES & | 9.10.62 | PARTLY CLOUDY | 72 | 86 | 82 | | 80.72 | | |
| CONST 6" PEN | VERY ROUGH | 9.11.62 | PARTLY CLOUDY | 70 | 83 | 76 | | | | |
| ASPHALT | SURFACE | | | | | | 2333 | 80.72 | 69.0 | .4312 |
| LINDEN AVE | CRACKS BAD | 9.11.62 | PARTLY CLOUDY | 70 | 83 | 76 | | 100 | | |
| CONST CONCRETE | JOINTS. WIDE | 9.12.62 | CLEAR | 73 | 84 | 81 | | 187.4 | | |
| | CENTER JOINTS | 9.13.62 | CLEAR | 74 | 86 | 82 | | | | |
| | PATCHES | | | | | | 8222 | 287.4 | 69.8 | .4362 |
| HIGH STREET | BAD JOINTS | 9.11.62 | PARTLY CLOUDY | 70 | 83 | 76 | | 90.43 | | |
| CONST CONCRETE | MANY PATCHES | 9.12.62 | CLEAR | 73 | 84 | 81 | | | | |
| | | | | | | | 2547 | 90.43 | 71.0 | .4437 |
| BARRON AVE | WIDE JOINTS | 9.11.62 | PARTLY CLOUDY | 70 | 83 | 76 | | 50.00 | | |
| CONST CONCRETE | & BAD CRACKS | 9.12.62 | CLEAR | 73 | 84 | 81 | | | | |
| TEST STREET | | | | | | | 1430 | 50.00 | 69.9 | .4369 |
| ELEANOR ST | POT HOLES | 9.12.62 | CLEAR | 73 | 84 | 81 | | 30.09 | | |
| CONST ASPHALT | & PATCHES | 9.13.62 | CLEAR | 74 | 86 | 82 | | | | |
| PAVEMENT TEST STREET | | | | | | | 836 | 30.09 | 71.8 | .4487 |
| | | | | TOTALS | | | 24.234 | 85999 | | |
| | | | | AVERAGE | | | | | 70.9 | .4481 |

a lot of sweeping is required to obtain a clean surface so that the mix will bond. It is believed that a tack coat of RS-1 would have been beneficial. When the Dix Seal is dumped into the receiving hopper of the paving machine, a heavy cloud of smoke and kerosine fumes envelopes the equipment, and the operator, rakers and shovelers are exposed to those fumes. They find them unpleasant to breathe all day long. The rollers are able to roll up to the paving machine with only a few passes of the roller being required. Creeping, shoving and displacement occur when it is over-rolled.

When traffic is allowed on the Dix Seal immediately after it has been laid, it seems tacky and tire marks are evident for a short time. However, after a day or so, the mix "irons" out and marks from power steering and braking are gradually eliminated, leaving the mix smooth and dense.

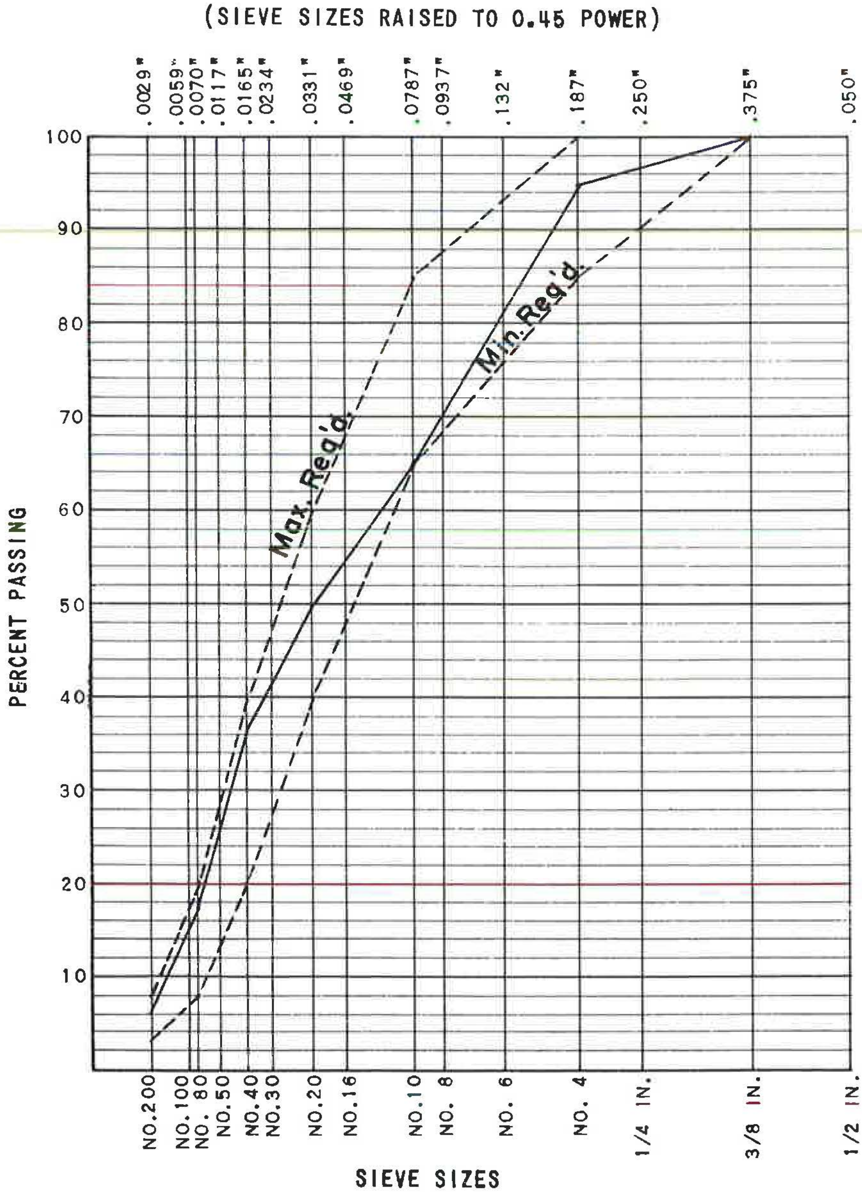
TABLE 2

PERFECT DIX SEAL

(Gradation Analysis)

| | New Jersey State Highway Testing Laboratories | | | | | | | | | | Jersey Testing Lab. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | 123-B | 124-B | 1 | 2 | 1-BS | 2-TM | 3-TM | 3 | 4 | 4-TM | J-1 | J-2 | J-3 | J-4 | | | |
| Date | 9/7/62 | 9/7/62 | 9/7/62 | 9/10/62 | 9/10/62 | 9/10/62 | 9/11/62 | 9/11/62 | 9/12/62 | 9/12/62 | 9/7/62 | 9/10/62 | 9/11/62 | 9/12/62 | | | |
| Street Laid | No. Park Dr. | No. Park Dr. | No. Park Dr. | No. Park Dr. | Crocus St. | Crocus St. | Barron Ave. | Linden Ave. | Linden Ave. | High St. | No. Park Dr. | Crocus St. | High St. | Eleanor St. | AVERAGE | Required % Min. | Required % Max. |
| Sieves & Screens Passing | Percent | | | | | | | | | | | | | | | | |
| 3/8" | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |
| No.4 | 95 | 93 | 93 | 94 | 94 | 96 | 94 | 94 | 94 | 95 | 95.6 | 97.0 | 96.7 | 97.0 | 94.9 | 85 | 100 |
| No.10 | 64 | 61 | 66 | 62 | 61 | 63 | 65 | 63 | 65 | 65 | 68.8 | 65.0 | 67.0 | 65.8 | 64.4 | 65 | 85 |
| No.20 | 52 | 46 | 55 | 50 | 50 | 46 | 50 | 48 | 52 | 55 | 53.5 | 44.6 | 45.2 | 45.4 | 49.5 | 40 | 60 |
| No.40 | 39 | 34 | 42 | 38 | 38 | 34 | 36 | 36 | 38 | 41 | 39.8 | 37.0 | 31.3 | 34.4 | 36.7 | 20 | 40 |
| No.80 | 18 | 16 | 19 | 17 | 18 | 17 | 17 | 17 | 19 | 19 | 18.6 | 15.8 | 17.2 | 17.2 | 17.5 | 8 | 20 |
| No.200 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 5 | 4.9 | 5.9 | 5.3 | 5.4 | 6.1 | 3 | 8 |
| Bitumen | 6.6 | 6.4 | 6.6 | 6.3 | 6.6 | 7.0 | 6.8 | 6.4 | 6.6 | 6.7 | 7.0 | 7.0 | 7.0 | 7.0 | 6.7 | 6.5 | 7.0 |

Stone (T.R.) 27%; stone sand (T.R., W.S.) 66%; A.C. (MC 5) 7%, pen. 136.




| MATERIALS: | TYPE |
|---|---|
| 1 27% Stone | Trap Rock |
| 2 66% Stone Sand | (Trap Rock) |
| 3 | (Washed Sand) |
| 4 7% A.C. | MC 5 Pen. 136 |

Figure 2. Gradation chart—Perfect Dix Seal, average of samples taken.

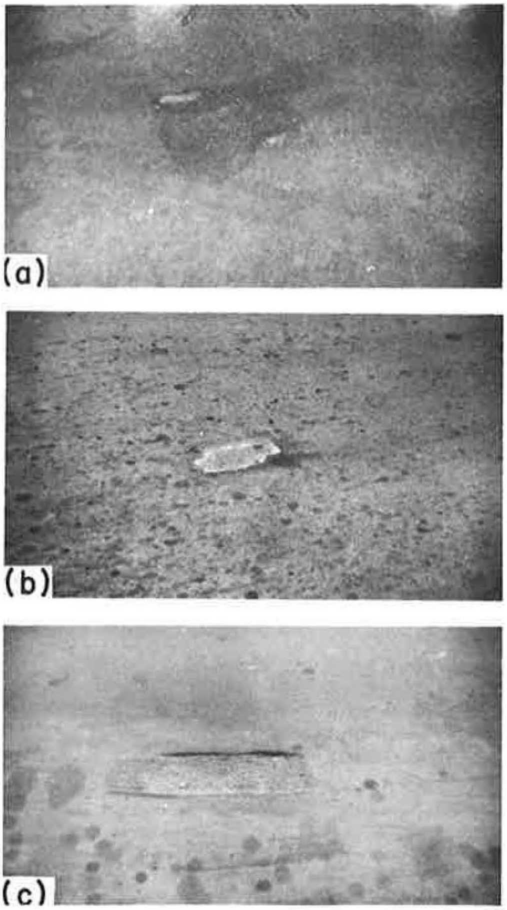


Figure 3. Perfect Dix Seal mix: (a) pushing or shoving, (b) and (c) cutting caused by rapid acceleration.

The joints between each pass of the paving machine are neat and smooth and traffic will correct most of the roughness and openness of the mix. The Perfect Dix Seal mix proved to be the most tender of the five mixes. The texture was good and equal to the texture of the SP-1 mix and the Maryland Smooth Seal mix.

The Perfect Dix Seal has a poor resistance to reflection cracking, shoving and scaling. Pushing or shoving occurs when a car is backed out of a driveway, then shifted into drive to go forward. Shoving also occurred where sanitation trucks stopped. The sudden application of brakes caused the rear wheels to push the Dix Seal (Fig. 3a).

As many as 14 such incidents were found on one street (Fig. 3b). The shoving occurred only where the Dix Seal was applied to asphalt pavement. There was no shoving where the Dix Seal was applied to concrete pavement.

There are several locations where rapid acceleration of a car has caused the rear wheel to cut a piece out of the Dix Seal. This occurred on asphalt pavement at an intersection within three weeks after application (Figs. 3b and c). It has also occurred where Dix Seal was applied to concrete pavement. To surface 24,234 sq yd of pavement, 860 tons were used. The yield was 70.9 lb/sq yd at a unit cost of $0.448 per sq yd.

## BITUMINOUS CONCRETE—TYPE NEW JERSEY SP-1

A Cedar Rapids paver was used for laying the New Jersey SP-1 (Tables 3 and 4; Fig. 4). The top finish was very good. The rolling was done with a 12-ton three-wheel roller initially and smooth rolled with a 10-ton tandem roller. The average daily tonnage laid was 172 tons.

This mix is easily made at the plant, requiring only a storage tank for 200-300 penetration asphalt. At first, the mix tore, honeycombed and cracked due to a higher percentage of asphalt cement in the mix and also because it was spread so thin (½ to ¾ in.). After the State Highway Department's laboratory reduced the asphalt content and slowed the speed of the Cedar Rapids paving machine to 14 to 15 ft/min from 25 to 26 ft/min, the tearing was reduced considerably. Before this, it was necessary to broadcast continuously behind the paving machine and to rake and lute so that honeycombs and tearing would not be noticed. A tack coat of RS-1 was used and appeared effective.

This was applied approximately ½ to ¾ hr before paving to permit the RS-1 to set. Rolling was close to the machine, and the first roller was a 3-wheel, 10-ton roller followed by an 8-ton tandem. The operation was clean and uniform with no smoke or fumes—or complaints. This mix sets much quicker than the Dix Seal and no evidence of tires, power steering or rutting was noticed. Except for the slower speed of the paving machine, 14 ft/min, the mix handles well at the plant and at the paving machine.

TABLE 3

APPLICATION RECORD FOR "SP-1" MIX

| STREET TYPE OF CONST | SURFACE CONDITION | DATE | WEATHER | TEMPERTURE 8 AM | NOON | 4 P.M. | SQ YDS | TONS | YIELD LBS/SQ YDS | UNIT COST PER SQ YD |
|---|---|---|---|---|---|---|---|---|---|---|
| CLINTON ST. ASPHALT PAVEMENT | ROUGH WITH POT HOLES. | 9.13.62 | CLEAR | 74 | 86 | 82 | | 118.8 | | |
| | | 9.14.62 | CLOUDY | 71 | 83 | 74 | | 93.65 | | |
| | | 9.15.62 | | | | | | | | |
| | | | | | | | 6417 | 212.45 | 67.7 | .3553 |
| GRENVILLE ST ASPHALT PAVEMENT | CRACKS, PATCHES, POT HOLES. | 9.14.62 | CLOUDY | 71 | 83 | 74 | | 82.5 | | |
| | | 9.15.62 | | | | | | | | |
| | | | | | | | 2500 | 82.5 | 66.0 | .3465 |
| PEARL ST. CONST CONCRETE | BAD JOINTS, HOLES, CRACKS, & PATCHES. | 9.18.62 | PARTLY CLOUDY | 71 | 75 | 66 | | 116.7 | | |
| | | 9.19.62 | CLOUDY | 61 | 66 | 62 | | | | |
| | | | | | | | 3666 | 116.7 | 63.6 | .3339 |
| FULTON ST SO. OF TURNPIKE CONCRETE. | CRACKS, PATCHES & BAD JOINTS. | 9.18.62 | PARTLY CLOUDY | 71 | 75 | 66 | | 82.4 | | |
| | | 9.19.62 | CLOUDY | 61 | 66 | 62 | | 135.95 | | |
| | | 9.20.62 | PARTLY CLOUDY | 66 | 71 | 65 | | | | |
| | | | | | | | 6830 | 218.35 | 63.9 | .3354 |
| ELEANOR PL. ASPHALT PAVEMENT TEST STREET | POT HOLES & PATCHES. | 9.13.62 | CLEAR | 74 | 86 | 82 | | 60.5 | | |
| | | 9.14.62 | CLOUDY | 71 | 83 | 74 | 1830 | | | |
| | | | | | | | | 60.5 | 66.0 | .3465 |
| BARRON AVE CONCRETE TEST STREET | WIDE JOINTS & BAD CRACKS | 9.17.62 | SHOWER | 70 | 76 | 72 | | 59.25 | | |
| | | 9.18.62 | PARTY CLOUDY | 71 | 75 | 66 | | | | |
| | | | | | | | 1872 | 59.25 | 63.3 | .3323 |
| | | | | | TOTALS | | 23,115 | 749.75 | | |
| | | | | | AVERAGE | | | | 64.4 | .3381 |

It appeared to be richer than any of the other types observed. The overlay immediately following the paver had a sheen. It had the appearance of being too rich or having too high a bitumen content.

The sheen disappeared 5 feet behind the paver. It was generally agreed that this was probably due to the 200-300 penetration asphalt. The SP-1 mix proved to be one of the three best mixes for performance. The only fault found with it occurred on

**TABLE 4**

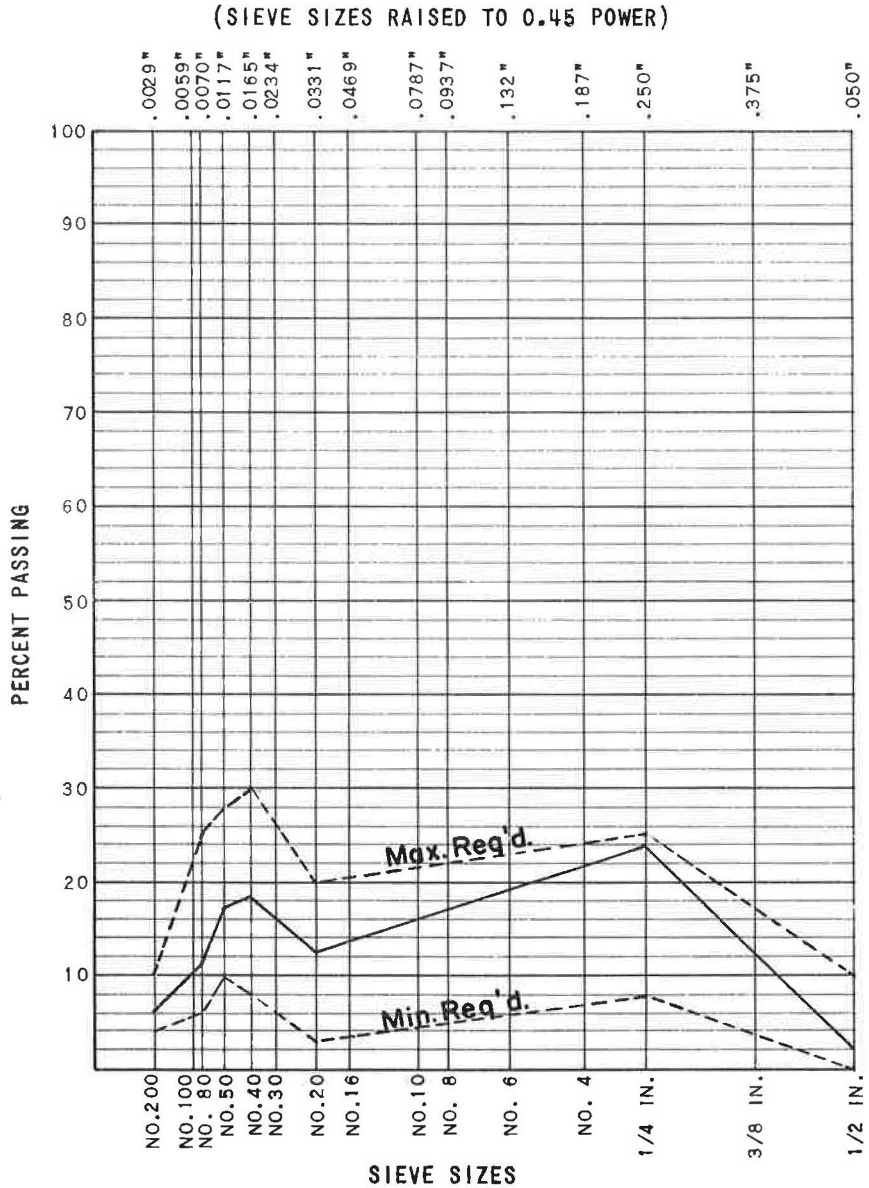
SP-1

(Gradation Analysis)

| Sample No. | | New Jersey State Highway Testing Laboratories | | | | | | | | | | | | Jersey Testing Lab. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1TM | SP1-2 | 1-SB | 5 | 6 | 2TM | 3TM | 7 | 8 | 4TM | 5TM | 5TM | J-1 | J-2 | J-3 | J-4 | J-5 | | | |
| Date | | 9/13/62 | 9/13/62 | 9/13/62 | 9/13/62 | 9/14/62 | 9/14/62 | 9/17/62 | 9/17/62 | 9/18/62 | 9/18/62 | 9/19/62 | 9/19/62 | 9/13/62 | 9/14/62 | 9/17/62 | 9/18/62 | 9/19/62 | | | |
| Street Laid | | Eleanor Pl. | Clinton St. | Clinton St. | Clinton St. | Clinton St. | Grenville St. | Barron Ave. | Barron Ave. | Pearl St. | Pearl St. | Fulton St. | Fulton St. | Clinton St. | Grenville St. | Barron Ave. | Pearl St. | Fulton St. | | Required % | |
| Sieves & Screens | | | | | | | | | | | | | | | | | | | AVERAGE | Min. | Max. |
| Pass. | Ret. | Percent | | | | | | | | | | | | | | | | | | | |
| 1/2 | 1/4 | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 5 | 2 | 2 | 4 | 0.5 | 0.7 | 1.1 | 0.9 | 6.3 | 2.2 | 0 | 10 |
| 3/8 | 1/4 | | | | | | | | | | | | | | | | | | | | |
| 1/4 | 10 | 24 | 24 | 23 | 25 | 21 | 25 | 22 | 26 | 17 | 20 | 20 | 19 | 21.3 | 24.3 | 20.7 | 21.3 | 15.9 | 24.0 | 8 | 25 |
| 4 | 10 | | | | | | | | | | | | | | | | | | | | |
| 10 | 20 | | | | | | | | | | | | | 10.6 | 13.2 | 12.7 | 5.8 | 12.3 | | | |
| 20 | 30 | 12 | 12 | 12 | 12 | 14 | | | 13 | | | | | | | | | | 12.5 | 3 | 20 |
| 30 | 40 | | | | | | | | | | | | | 20.8 | 21.3 | 22.5 | 23.4 | 25.4 | | | |
| 40 | 50 | 18 | 17 | 17 | 19 | 22 | | | 17 | | | | | | | | | | 18.3 | 8 | 30 |
| 50 | 80 | 17 | 19 | 19 | 17 | 14 | | | 17 | | | | | 20.8 | 17.9 | 17.4 | 22.6 | 17.7 | 17.2 | 10 | 28 |
| 80 | 200 | 12 | 11 | 11 | 11 | 12 | | | 11 | | | | | 12.2 | 9.3 | 10.7 | 12.2 | 8.9 | 11.3 | 6 | 25 |
| 200 | | 7 | 7 | 7 | 5 | 5 | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 5.8 | 5.3 | 6.9 | 5.8 | 5.5 | 6.1 | 4 | 10 |
| Bitumen | | 8.5 | 8.2 | 8.3 | 9.0 | 8.5 | 7.9 | 8.2 | 8.1 | 8.3 | 8.1 | 8.3 | 8.4 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.4 | 8.0 | 8.3 |
| RET ON NO 10 | | 25 | 26 | 25 | 27 | 24 | 27 | 24 | 28 | 22 | 22 | 22 | 23 | | | | | | 24.6 | 18 | 26 |

**Remarks:** Sample 1TM & Sample No. 5 Were Mixed At 8.5 % A.C.
Average Does Not Include Jersey Testing Laboratory Samples.

Stone (T.R.) 22%; sand (B.S.) 65%; filler (L.D.) 5%; A.C. (O.A. 200-300 pen.), pen. 235, duct. 110 at 57 pen.




| MATERIALS: | | TYPE |
|---|---|---|
| 1 | 22 % Stone | Trap Rock |
| 2 | 65 % Sand | Bituminous Sand |
| 3 | 5 % Filler | Limestone Dust |
| 4 | 8 % A.C. | O.A. (200-300 Pen.) Pen. 235 |

Figure 4. Gradation chart—SP-1, average of samples taken.

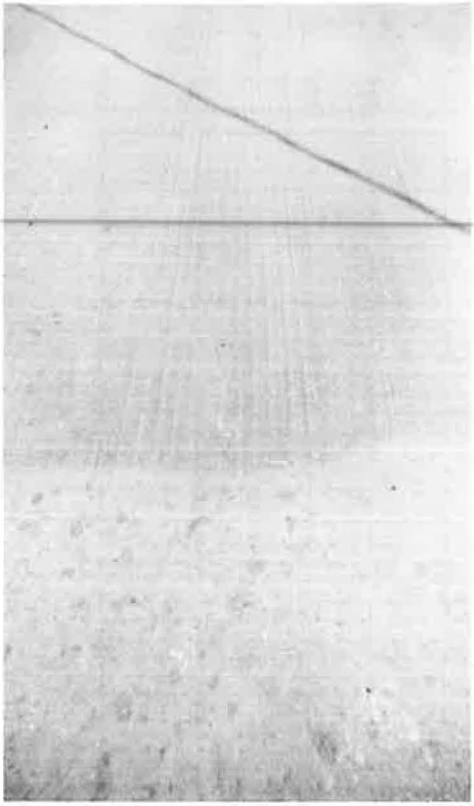


Figure 5. Pavement surfaced with SP-1 mix, showing tire marks.

asphalt pavement. When the air temperature went above 90 F, the surface became soft and left tire marks (Fig. 5). Tire impressions occurred only at two different locations on asphalt pavement, and both were under heavy traffic conditions. This could have been caused by an excess of asphalt on the original pavement. It is recommended that a lower penetration asphalt be used in the SP-1 mix when it is to be applied to asphalt pavement. To surface 23,115 sq yd of pavement 750 tons were used. The yield was 64.4 lb/sq yd at a unit cost of $0.338 per sq yd.

Figure 4 was drawn on the basis of percent passing and percent retained as required by the specifications. These values were converted to percent passing for comparison (see Fig. 12).

## RUBBERIZED SAND ASPHALT

A Cedar Rapids paver was also used for laying 400 tons of rubberized sand asphalt (Tables 5 and 6; Fig. 6). Two Barber-Greene pavers, one of them a new machine with an improved tamping bar, laid 350 tons. The new paver gave the best results. The rolling was accomplished with a 12-ton 3-wheel roller for the initial rolling and a 10-ton tandem roller for smooth rolling.

This mix is difficult to handle. The rubber in the mix resists raking and casting. The material pulls strands of rubber and does not spread when raked. It tends to "ball up." In spite of this it rolls out very smooth. The workmen do not like this material because of the difficulty in hand raking.

The paving speed was 16 ft/min. The average daily production with the rubberized sand asphalt was 160 tons.

The surface has a good smooth finish, but joints are difficult to make because of the balling of the material and "pancakes" are in evidence in the finished surface.

This mix was the densest of all, because it was 100 percent sand mixed with 85-100 penetration asphalt cement and rubber latex additive. At the plant, the drums of rubber were on the ground, and a pump was used to get the latex through a 1-in. hose to a measuring tank on the mixing platform where it was measured for each batch. As soon as the sand and asphalt cement were mixed, the rubber was added into the pugmill.

The mix on the job was the hottest of all the mixes, with temperatures of 360 to 375 F. Therefore, there was some blistering and wrinkling of the mix when it was being rolled. However, after several passes of the roller, the mix was uniform in appearance with no apparent evidence of wrinkling.

The rubber made the mix stiff and not as workable when it was being raked, luted and shoveled in place. Small balls of rubber $^1/_4$ to $^3/_8$ in. in diameter formed in the mix, possibly because the rubber was not uniformly distributed throughout the pugmill. The diluted 1:1 SS-1 tack coat also contained some latex rubber, but it appeared too thin and watery because it ran down into the gutters and marked the gutters and curbs. The runniness of the tack coat was attributed to the dilution rate.

TABLE 5

APPLICATION RECORD FOR "RUBBERIZED SAND ASPHALT" MIX.

| STREET TYPE OF CONST | SURFACE CONDITION | DATE | WEATHER | TEMPERATURE 8 PM | 12 N | 4 PM | SQ YDS | TONS | YIELD LBS/SQ YDS | UNIT COST PER SQ YDS |
|---|---|---|---|---|---|---|---|---|---|---|
| DIXON DRIVE, SOUTH CIRCLE & CENTER CIRCLE CONST. 6" PEN ASPHALT | POT HOLES, DEPRESSED, PATCHES & ROUGH TEXTURE 1/2 STONE SHOWING | 10.2.62 | CLEAR | 64 | 73 | 70 | | 120.35 | | |
| | | 10.3.62 | CLOUDY | 62 | 69 | 71 | | 20.00 | | |
| | | 10.4.62 | CLOUDY | 60 | 72 | 64 | | | | |
| | | | | | | | 4300 | 140.35 | 65.3 | .5877 |
| FLEET WOOD ROAD CONST ASPHALT | PATCHES, DEPRESSIONS | 10.3.62 | CLOUDY | 62 | 69 | 71 | | 74.35 | | |
| | | 10.4.62 | CLOUDY | 60 | 72 | 64 | | 103.0 | | |
| | | 10.5.62 | RAIN | 63 | 67 | 59 | | | | |
| | | | | | | | 4500 | 177.35 | 78.8 | .7092 |
| HUNTER LANE CONST ASPHALT | CRACKS BADLY WORN IRREGULAR SURFACE | 10.3.62 | CLOUDY | 62 | 69 | 71 | | 88.5 | | |
| | | 10.4.62 | CLOUDY | 60 | 72 | 64 | | | | |
| | | | | | | | 2416 | 88.5 | 77.8 | .7002 |
| ALBERT ST CONST CONCRETE | CRACKS & BAD JOINTS | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 64 | | |
| | | 10.14.62 | | 59 | 72 | 69 | | | | |
| | | | | | | | 2133 | 64 | 60 | .5400 |
| WILLIAM ST CONST CONCRETE | BAD JOINTS, CRACKS, PATCHES VERY ROUGH | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 52.0 | | |
| | | 10.14.62 | | 59 | 72 | 69 | | | | |
| | | | | | | | 1600 | 52.0 | 65 | .5850 |
| SECOND ST CONST CONCRETE | CRACKS, PATCHES, HOLES, BAD JOINTS | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 78.0 | | |
| | | 10.14.62 | | 59 | 72 | 69 | | | | |
| | | | | | | | 2611 | 78.0 | 59.8 | .5382 |
| COLEY ST. CONST CONCRETE | CRACKES, BAD JOINTS PATCHES | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 66.0 | | |
| | | 10.13.62 | CLEAR | 59 | 72 | 69 | | | | |
| | | | | | | | 1933 | 66.0 | 68.3 | .6147 |
| PART OF NEW STREET CONST CONCRETE | POT HOLES, CRACKS, BAD JOINTS DETERIORATED | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 20.0 | | |
| | | 10.14.62 | CLEAR | 59 | 72 | 69 | | | | |
| | | | | | | | 670 | 20.0 | 59.7 | .5373 |
| BARRON AVE CONCRETE TEST STREET | WIDE JOINTS BAD CRACKS | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 37.0 | | |
| | | 10.14.62 | CLEAR | 59 | 72 | 69 | | | | |
| | | | | | | | 1080 | 37.0 | 68.5 | .6165 |
| ELEANOR ST ASPHALT TEST STREET | POT HOLES & PATCHES | 10.13.62 | PARTLY CLOUDY | 63 | 74 | 64 | | 23.0 | | |
| | | 10.14.62 | CLEAR | 59 | 72 | 69 | | | | |
| | | | | | | | 660 | 23.0 | 69.7 | .6273 |
| | | | | TOTALS | | | 21.903 | 746.20 | | |
| | | | | AVERAGE | | | | | 67.6 | .6084 |

TABLE 6

HOT-LAID RUBBERIZED SAND ASPHALT

(Gradation Analysis)

| Sample No. | 1TM | 11 | 1RSA | 12 | 2TM | 13 | 3TM | 4TM | 14-1P | 15-1P2 | 16-1P3 | J-1 | J-2 | J-3 | J-4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | New Jersey State Highway Testing Laboratories | | | | | | | | | | | Jersey Testing Lab. | | | | | | |
| Date | 10/2/62 | 10/2/62 | 10/3/62 | 10/3/62 | 10/3/62 | 10/4/62 | 10/13/62 | 10/13/62 | 10/13/62 | 10/13/62 | 10/13/62 | 10/2/62 | 10/3/62 | 10/4/62 | 10/13/62 | | | |
| Street Laid | Dixon Dr. | Dixon Dr. | Center Circle | Fleetwood Rd. | Hunter Lane | Fleetwood Rd. | Albert St. & William St. | Second St. & Coley St. | New St. | Barron Ave. | Eleanor Pl. | South Circle | Fleetwood Rd. | Fleetwood Rd. | Second St. | | Required % | |
| Sieves & Screens | | | | | | | | | | | | | | | | AVERAGE | Min. | Max. |
| Passing | Percent | | | | | | | | | | | | | | | | | |
| No.4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |
| No.8 | 95 | 95 | 97 | 96 | 97 | 93 | 96 | 97 | 98 | 98 | 98 | 99.2 | 99.5 | 98.8 | 97.9 | 97 | 95 | 100 |
| No.16 | 90 | 89 | 89 | 90 | 92 | 87 | 90 | 92 | 91 | 90 | 92 | 96.0 | 94.4 | 93.8 | 92.7 | 91.3 | 85 | 100 |
| No.30 | 74 | 72 | 73 | 78 | 76 | 68 | 73 | 78 | 77 | 70 | 71 | 85.7 | 78.4 | 84.5 | 83.9 | 76.2 | 65 | 90 |
| No.50 | 44 | 40 | 45 | 51 | 45 | 37 | 43 | 52 | 48 | 37 | 39 | 55.7 | 45.1 | 51.5 | 50.2 | 46.2 | 35 | 65 |
| No.100 | 19 | 17 | 21 | 22 | 20 | 16 | 19 | 24 | 24 | 14 | 14 | 23.7 | 19.8 | 11.9 | 10.9 | 17.7 | 10 | 30 |
| No.200 | 6 | 5 | 8 | 4 | 7 | 5 | 6 | 9 | 7 | 5 | 4 | 8.2 | 7.4 | 5.3 | 5.5 | 6.2 | 5 | 10 |
| Bitumen | 9.0 | 8.7 | 8.6 | 8.9 | 8.8 | 8.7 | 8.7 | 9.1 | 9.4 | 8.9 | 8.8 | 9.4 | 9.4 | 9.4 | 9.4 | 9.0 | 8.7 | 9.3 |

Sand (W.S.) 87%; filler (L.D.) 4%; rubber (R 504) 0.90%; A.C. (O.A.) 8.55%, pen. 97, duct. 110 at 54 pen.

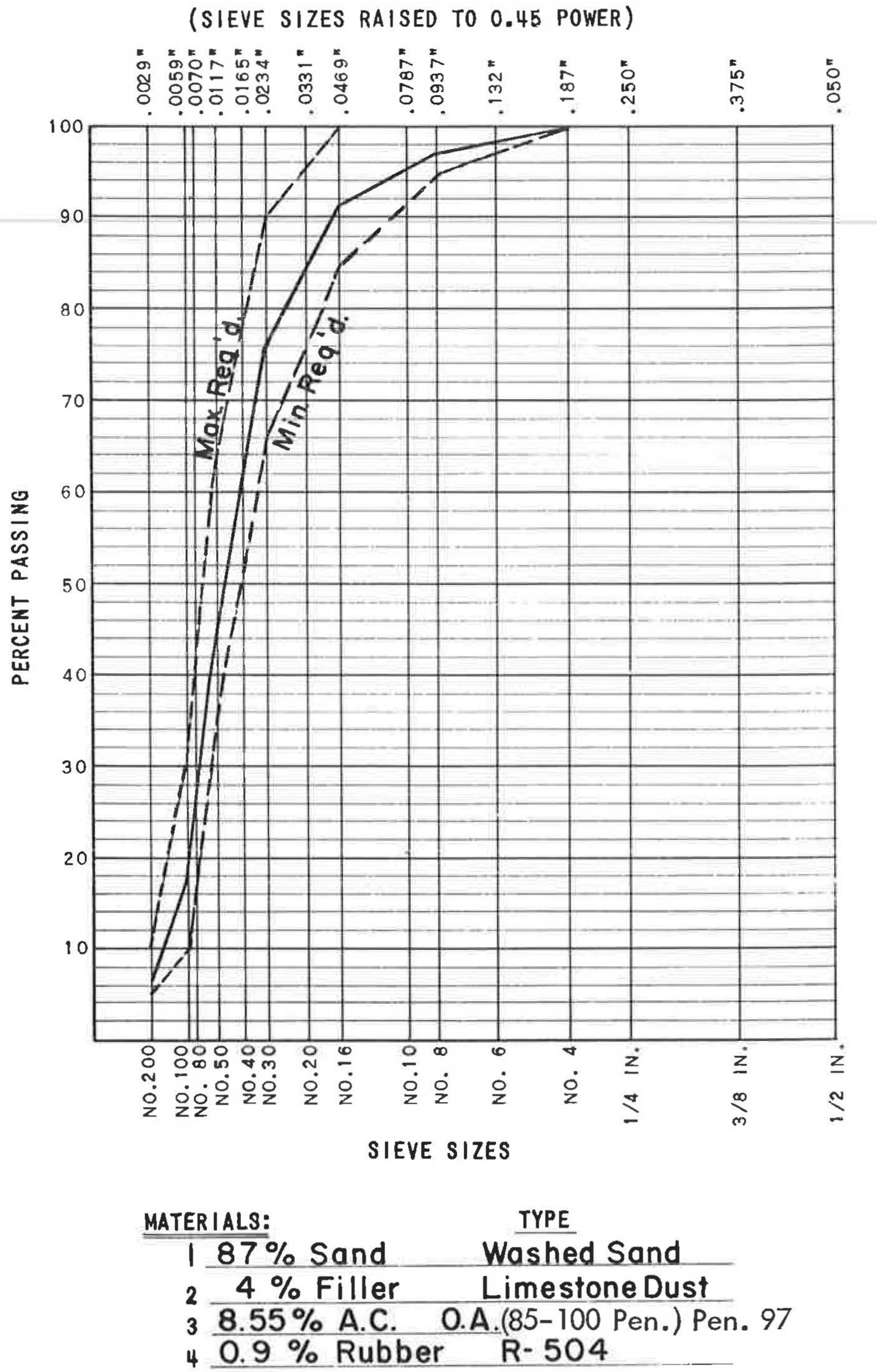



Figure 6. Gradation chart—Hot-laid rubberized sand asphalt, average of samples taken.

Figure 7. Rubberized sand asphalt surface, showing bare spots where thickness was less than $^3/_{16}$ in.

Rolling followed the machine closely, and the mix set quickly with no evidence of tire marking. The joints were good on most streets, although on several locations the joints and handwork made the mix look rough and uneven. Traffic ironed out these unsightly areas in time, making a uniform appearance.

The rubberized sand asphalt mix will stand a lot of rolling. It makes a very good surface under proper conditions, but is very hard to handle.

The addition of the rubber emulsion to the mix at the plant presents a problem. If the rubber emulsion touches the hot sides of the pugmill it will form balls.

Rubberized sand asphalt proved to be the best for performance, although it is the most difficult to mix and apply and is the most expensive mix. One failure occurred: a worn spot on a concrete pavement caused by a high spot in the original surface (Fig. 4). The thickness of the application measured $^1/_8$ in. at the worn spot. The rubberized sand asphalt proved the most resistant to reflection cracking, shoving and scaling. It was the least tender of the five mixes.

To surface 21,900 sq yd of pavement 746 tons were used. The yield was 67.6 lb/sq yd at a unit cost of $0.608 per sq yd.

## ASPHALT EMULSION HOT PRE-MIX

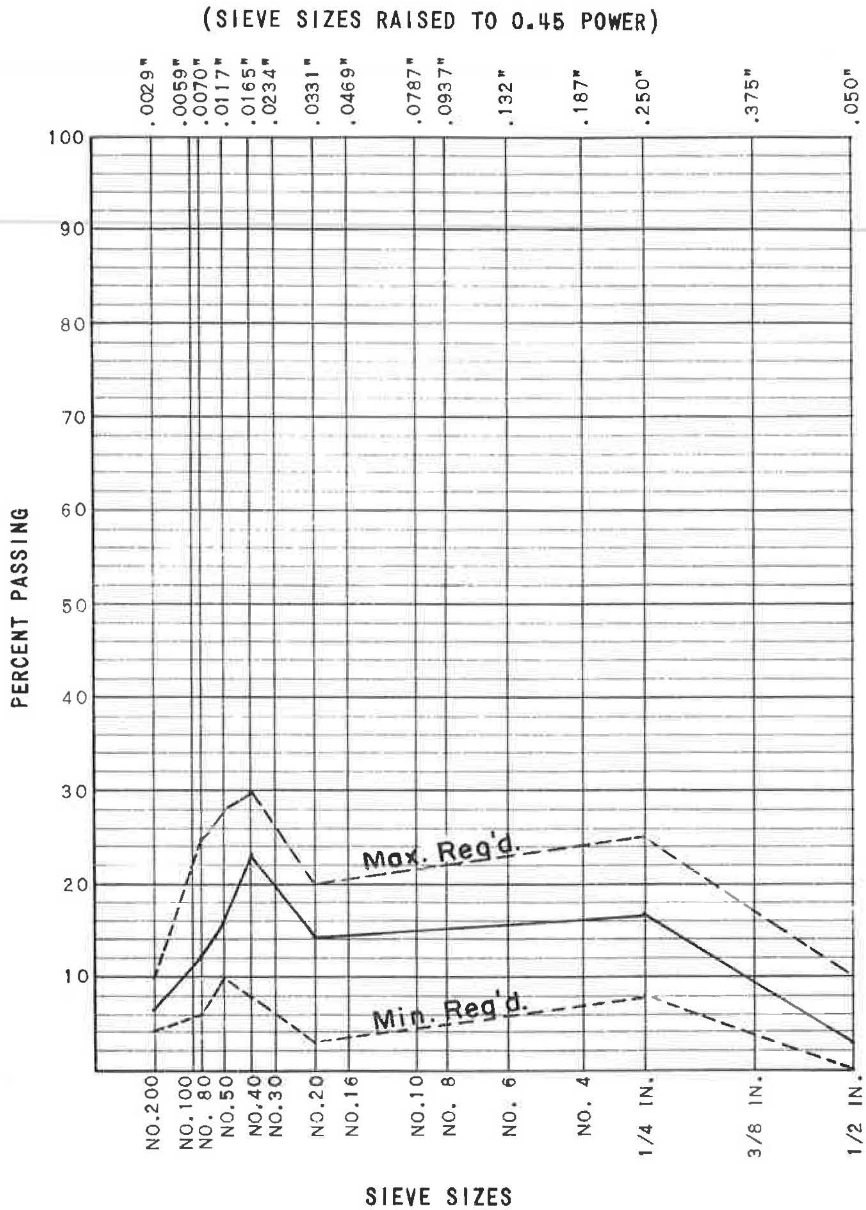
The emulsion mix presented no problem as to material source, mixing or paving (Tables 7 and 8; Fig. 8). The material was easy to handle, both for the paver operator and the rakers. The finished surface is very good.

TABLE 7

APPLICATION RECORD FOR "HOT PRE-MIX EMULSION"

| STREET TYPE CONST | SURFACE CONDITION | DATE | WEATHER | TEMPERATURE 8 AM | 12 N | 4 PM | SQ YDS | TON | YIELD LBS/SY | UNIT COST PER SQ YD. |
|---|---|---|---|---|---|---|---|---|---|---|
| IRIS PLACE CONST. ASPHALT | POOR SURFACE CRACKS, HOLES | 10-16-62 | PARTLY CLOUDY | 64 | 78 | 71 | | 43.13 | | |
| | | 10-17-62 | PARTLY CLOUDY | 65 | 76 | 73 | | | | |
| | | | | | | | 1150 | 43.13 | 75 | .4875 |
| SOUTH PARK DR. & NORTH CIRCLE CONST ASPHALT. | PATCHES. POT HOLES. CRACKES | 10-16-62 | PARTLY CLOUDY | 64 | 78 | 71 | | 84.12 | | |
| | | 10-17-62 | PARTLY CLOUDY | 65 | 76 | 73 | | 140.35 | | |
| | | 10.18.62 | CLEAR | 54 | 68 | 62 | | 122.75 | | |
| | | 10.19.62 | CLEAR | 58 | 67 | 61 | | | | |
| | | | | | | | 11.738 | 347.22 | 59.2 | .3848 |
| SCHOOL ST. CONST CONCRETE | CRACKS PATCHES BAD JOINTS POOR SURFACE | 10.18.62 | CLEAR | 54 | 68 | 62 | | 80.3 | | |
| | | 10.19.62 | CLEAR | 58 | 67 | 61 | | 124.35 | | |
| | | 10.20.62 | CLEAR | 63 | 71 | 68 | | | | |
| | | | | | | | 6222 | 204.65 | 65.8 | .4277 |
| NEW STREET CONST CONCRETE | HOLES, CRACKS. PATCHES. DETERIOERATION | 10.19.62 | CLEAR | 58 | 67 | 61 | | 92.5 | | |
| | | 10.20.62 | CLEAR | 63 | 71 | 68 | | | | |
| | | | | | | | 3580 | 92.5 | 51.7 | .3360 |
| BARRON AVE CONST CONCRETE TEST STREET | WIDE JOINTS BAD CRACKS. | 9.20.62 | PARTLY CLOUDY | 66 | 71 | 65 | | 49.55 | | |
| | | 9.21.62 | PARTLY CLOUDY | 68 | 73 | 64 | | | | |
| | | | | | | | 1430 | 49.55 | 69.3 | .4504 |
| ELEANOR PL. CONST ASPHALT. TEST STREET | POT HOLES PATCHES. | 9.20.62 | PARTLY CLOUDY | 66 | 71 | 65 | | 29.15 | | |
| | | 9.21.62 | PARTLY CLOUDY | 68 | 73 | 64 | | | | |
| | | | | | | | 832 | 29.15 | 70.1 | .4556 |
| | | | | TOTALS | | | 24.952 | 766.20 | | |
| | | | | AVERAGE | | | | | 61.4 | .3991 |

– NOTE –
THE 29.15 TONS ON ELEANOR PLACE CONTAINED 40% 1/4 AGGREGATE
ALL THE REST OF THE MIX CONTAINS 20% TO 22%. 1/4 AGGREGATE.




| MATERIALS: | | TYPE |
|---|---|---|
| 1 | 22 % Stone | Trap Rock |
| 2 | 63.5 % Sand | Bituminous Sand |
| 3 | 5 % Filler | Limstone Dust |
| 4 | 9.5 % A.C. | R.S.3 K Pen. 178 |

Figure 8. Gradation chart—Asphalt emulsion hot mix, average of samples taken.

## TABLE 8

# ASPHALT EMULSION HOT-MIX

(Gradation Analysis)

| | | New Jersey State Highway Testing Laboratories | | | | | | | | | | | | | | | | Jersey Testing Lab. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | | 1TM | 1TM2 | 1TM3 | 1TM4 | 10 | 17 | 18 | 2TM | 3TM | 19 | 20 | 21 | 4TM | 5TM | 22 | 1 | J-2 | J-3 | J-4 | J-5 | | | |
| Date | | 9/20/62 | 9/20/62 | 9/20/62 | 9/20/62 | 9/20/62 | 10/16/62 | 10/16/62 | 10/16/62 | 10/17/62 | 10/17/62 | 10/18/62 | 10/18/62 | 10/18/62 | 10/19/62 | 10/19/62 | 10/19/62 | 10/16/62 | 10/17/62 | 10/18/62 | 10/19/62 | | | |
| Street Laid | | Eleanor Pl. | Eleanor Pl. | Eleanor Pl. | Barron Ave. | Barron Ave. | Iris Pl. | So. Park Dr. | So. Park Dr. | So. Park Dr. | So. Park Dr. | So. Park Dr. | So. Park Dr. | No. Circle | School St. | School St. | New St. | So. Park Dr. | So. Park Dr. | So. Park Dr. | School St. | | | |
| Sieves & Screens | | | | | | | | | | | | | | | | | | | | | | Average | Required % | |
| Pass | Ret. | Percent | | | | | | | | | | | | | | | | | | | | | Min. | Max. |
| 1/2 | 1/4 | 2 | 1 | 5 | 2 | 2 | 3 | 4 | 2 | 1 | 3 | 2 | 4 | 2 | 3 | 5 | 5 | 1.0 | 2.1 | 2.5 | 2.0 | 2.8 | 0 | 10 |
| 3/8 | 1/4 | | | | | | | | | | | | | | | | | | | | | | | |
| 1/4 | 10 | 28 | 29 | 42 | 29 | 28 | 18 | 18 | 18 | 18 | 17 | 19 | 19 | 20 | 18 | 17 | 15 | 19.7 | 20.0 | 19.7 | 19.9 | 18.4 | 8 | 25 |
| 4 | 10 | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 20 | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 30 | 16 | 19 | 15 | 16 | 17 | 18 | 20 | 16 | 11 | 11 | 9 | 17 | 10 | 13 | 19 | 21 | 13.2 | 12.0 | 12.3 | 11.2 | 14.2 | 3 | 20 |
| 30 | 40 | | | | | | | | | | | | | | | | | | | | | | | |
| 40 | 50 | 16 | 12 | 9 | 15 | 15 | 24 | 23 | 21 | 23 | 23 | 20 | 22 | 20 | 23 | 23 | 23 | 23.5 | 21.6 | 22.8 | 26.0 | 22.6 | 8 | 30 |
| 50 | 80 | 16 | 10 | 8 | 14 | 14 | 10 | 10 | 15 | 23 | 22 | 26 | 16 | 24 | 20 | 11 | 8 | 11.1 | 15.8 | 13.3 | 15.3 | 16.0 | 10 | 28 |
| 80 | 200 | 11 | 9 | 5 | 10 | 11 | 12 | 12 | 13 | 11 | 11 | 12 | 9 | 12 | 10 | 13 | 14 | 15.5 | 14.0 | 13.5 | 10.4 | 12.2 | 6 | 25 |
| 200 | | 6 | 15 | 11 | 8 | 7 | 8 | 7 | 8 | 6 | 7 | 5 | 7 | 6 | 7 | 6 | 8 | 6.5 | 6.1 | 6.4 | 5.7 | 6.6 | 4 | 10 |
| Bitumen | | 5.1 | 4.8 | 4.8 | 5.4 | 5.4 | 6.2 | 6.3 | 6.5 | 6.3 | 6.3 | 6.1 | 5.9 | 6.1 | 6.1 | 5.9 | 6.0 | | | | | 6.2 | | |
| Ret. on No. 10 | | 30 | 30 | 47 | 31 | 30 | 21 | 22 | 20 | 19 | 20 | 21 | 23 | 22 | 21 | 22 | 20 | | | | | 21.0 | 18 | 26 |
| Emulsion | | 7.5 | 7.1 | 7.1 | 7.9 | 7.9 | 9.1 | 9.3 | 9.8 | 9.3 | 9.3 | 9.0 | 8.7 | 9.0 | 9.0 | 8.7 | 8.8 | 9.5 | 9.5 | 9.5 | 9.5 | 9.2 | 9.0 | 9.5 |

Remarks: 1. Samples No. 1TM, 1TM2, & No. 10 Were Mixed At 7.5 % Emulsion.
2. Sample No. 1TM3 Mixed At 40 % Stone And 7.5 % Emulsion.
3. Sample No. 1TM 4 Mixed At 8.5 % Emulsion.
4. Mix Was Redesigned Sept. 21, 1962. The Minimum And Maximum Required And The Average Do Not Include The Samples Of Sept. 20, 1962.

Stone (T.R.) 22%; sand (B.S.) 63.5%; filler (L.D.) 5%; A.C. (R.S.3K) 9.5%, pen. 178, duct. 110.

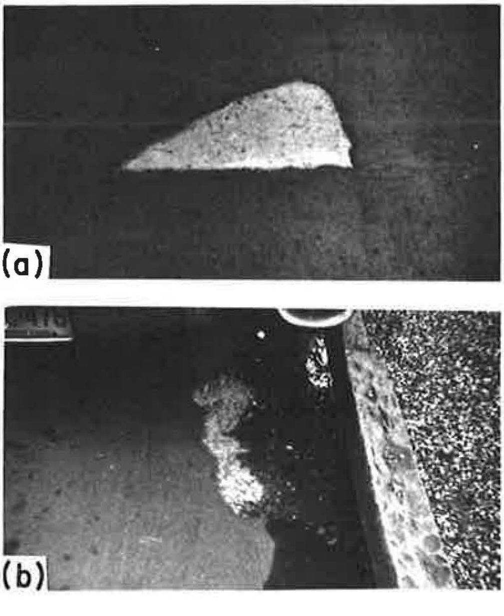


Figure 9. Faults on concrete pavement surfaced with emulsion hot mix: (a) in the crown at a transverse joint where reflection cracking occurred; and (b) on gutter line, caused by improper sweeping.

A Barber-Greene paver was used for paving, a 12-ton 3-wheel roller for initial rolling and a 10-ton tandem roller for the smooth rolling. The paver was operated at a speed of 26 ft/min. The daily average tonnage was 172 tons. The tacking material used was asphalt emulsion grade RS-1. No difficulties were encountered in handling this material.

At the mixing plant, introduction of the RS-3K, cationic emulsion, into the hot aggregates created steam and dust, especially when aggregate temperatures were in excess of 300 F. There is no danger of fire or explosion with RS-3K, but dust and vapor can be bothersome. If the operator added the emulsion slowly rather than all at once, the dust and steam were greatly reduced and not too objectionable. Transportation of the mix, spreading and rolling were easy with no fumes, smoke, or objectionable handling properties. The workmen found that even at 185 F the mix handled easily, was not stiff or sticky, and rollers were able to compact the mix uniformly; joints were neat and smooth. The texture of the mix and stability were good;

traffic did not rut or mark it. The tack coat of RS-1 was spread ½ to ¾ hr before paving, and its effectiveness was apparent.

Emulsion hot mix is rated second best in mixing and application and is given a quite satisfactory performance rating. The cost of this mix is also reasonable.

Two faults occurred with the emulsion mix, both on concrete pavement. One occurred in the crown of the pavement at a transverse joint adjacent to a reflection crack. It is believed that there was insufficient tack coat at this point and water got under the surface through the reflection crack. Freezing and thawing ruptured the ½-in. surface and traffic kicked out the material (Fig. 9a). The size of the failure was 12 by 18 in. and has remained so for the past two years. The second fault occurred along the gutter line on concrete pavement (Fig. 9b). This was caused by improper sweeping. The area was 18 in. wide and 72 in. long. This has been static for the past two years. There was loose sand and organic matter on the original pavement, thus the overlay did not become bonded to the concrete surface; moisture, freezing and thawing caused failure.

To surface 24,950 sq yd of pavement, 766 tons were used. The yield was 61.4 lb/sq yd at a unit cost of $0.399 per sq yd.

The gradation chart (Fig. 8) is drawn on the basis of percent passing and percent retained as required by the specifications. These values were converted to percent passing for comparison (see Fig. 12).

## MARYLAND SMOOTH SEAL

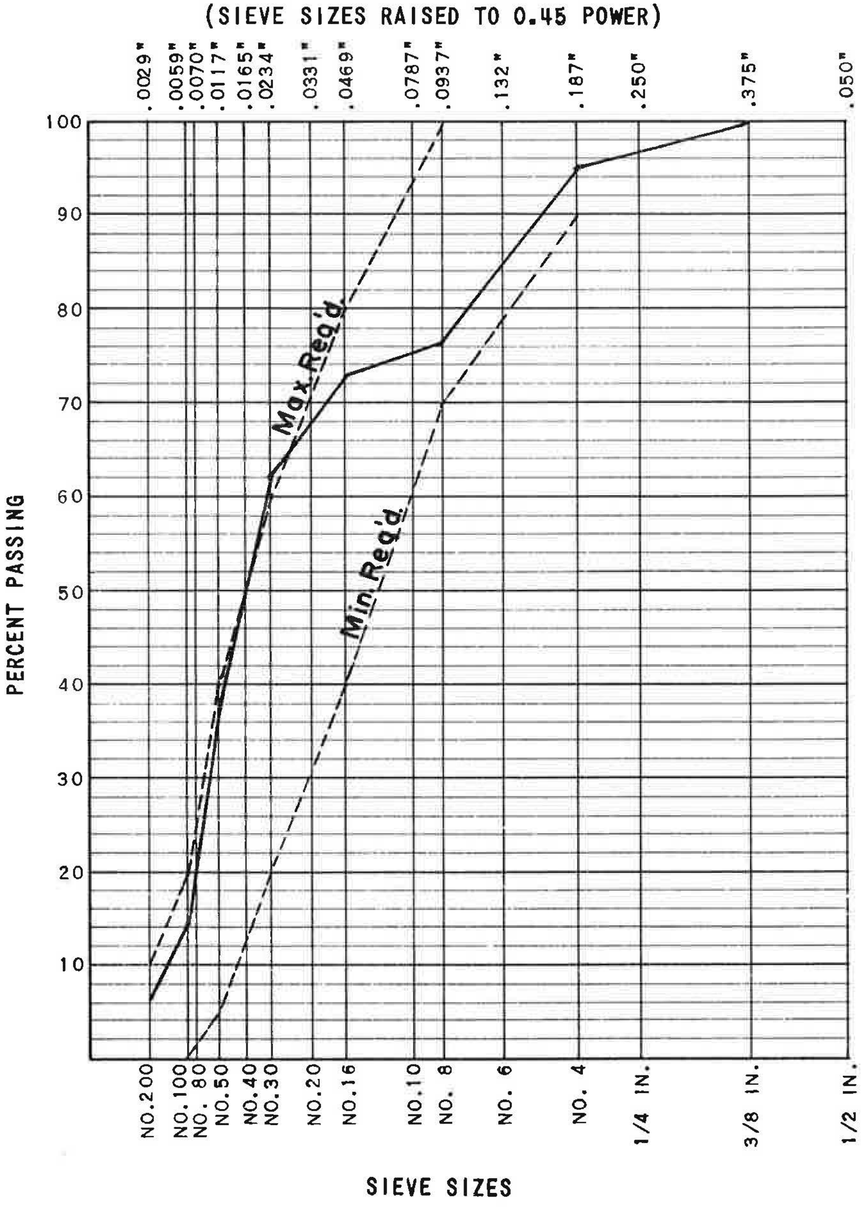
Maryland Smooth Seal had the same characteristics as far as paving and handling as the New Jersey SP-1 mix (Tables 9 and 10; Fig. 10). The surface was very good. A Barber-Greene paver was used. The initial rolling was done with a 12-ton 3-wheel roller, and the final rolling with a 10-ton tandem roller. The maximum paving speed was 18 ft/min. The tack coat used was asphalt emulsion grade RS-1.

The first two loads of smooth seal received had a percentage of large stone in the mix. A hole in the screen found at the mixing plant was patched, and the mix was quite satisfactory thereafter. The average daily tonnage laid was 198.

TABLE 9

APPLICATION RECORD FOR "SMOOTH SEAL" MIX

| Street Type of Const | Surface Condition | Date | Weather | Temperature 8 AM | 12N | 4 PM | Sq Yds | Tons | Yield Lbs/SY | Unit Cost Per SY |
|---|---|---|---|---|---|---|---|---|---|---|
| New Street Const Concrete | Pot Holes Cracks Patches Deterioration | 10.22.62 | Clear | 51 | 67 | 54 | | 20 | | |
| | | 10.23.62 | Cloudy Rain | 55 | 63 | 58 | | | | |
| | | | | | | | 650 | 20 | 65.5 | .3438 |
| Fulton St Const Concrete | Bad Joints Bad Cracks Pot Holes Patches | 10.22.62 | Clear | 51 | 67 | 54 | | 20.05 | | |
| | | 10.23.62 | Cloudy Rain | 55 | 63 | 58 | | 100.25 | | |
| | | 10.24.62 | Partly Cloudy | 45 | 48 | 51 | | 85.1 | | |
| | | 10.25.62 | Partly Cloudy | 36 | | | | | | |
| | | | | | | | 5865 | 205.40 | 70.0 | .3675 |
| Legion Pl Const Asphalt | Cracks Patches Poor Surface | 10.24.62 | Partly Cloudy | 45 | 48 | 51 | | 137.6 | | |
| | | 10.25.62 | Partly Cloudy | 36 | | | | | | |
| | | | | | | | 3670 | 137.6 | 75.0 | .3937 |
| High Street Const Concrete | Bad Joints Patches | 10.24.62 | Partly Cloudy | 45 | 48 | 51 | | 56.9 | | |
| | | 10.25.62 | Partly Cloudy | 36 | | | | | | |
| | | | | | | | 1460 | 56.9 | 77.9 | .4089. |
| Barron Ave Const Concrete Test Street | Wide Center Joints Depressions Cracks, Bad Joints | 10.24.62 | Partly Cloudy | 45 | 48 | 51 | | 41.6 | | |
| | | 10.25.62 | Partly Cloudy | 36 | | | | | | |
| | | | | | | | 1080 | 41.6 | 77.0 | .4042 |
| Eleanor Pl Const Asphalt. Test Street | Pot Holes, Poorly Patched, Ditch, Cracks. | 10.24.62 | Partly Cloudy | 45 | 48 | 51 | | 42.4 | | |
| | | 10.25.62 | Partly Cloudy | 36 | | | | | | |
| | | | | | | | 1100 | 42.4 | 77.1 | .4047. |
| | | | | Totals | | | 13,825 | 503.9 | | |
| | | | | Average | | | | | 72.9 | .3827. |




| MATERIALS: | | TYPE |
|---|---|---|
| 1 | 20 % Stone | Trap Rock |
| 2 | 68.5 % Sand | Bituminous Sand |
| 3 | 4 % Filler | Limestone Dust |
| 4 | 7.5 % A.C. | O.A.(100-120 Pen.) Pen. 110 |

Figure 10. Gradation chart—Maryland Smooth Seal, average of samples taken.

# TABLE 10

## MARYLAND SMOOTH SEAL

(Gradation Analysis)

| Sample No. | N. J. State Highway Laboratories | | | | | | | | Jersey Test. Lab. | | | | Required % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1TM | 22 | 2TM | 23 | 24 | 25 | 26 | 3TM | J-1 | J-2 | J-3 | | | |
| Date | 10/22/62 | 10/22/62 | 10/23/62 | 10/23/62 | 10/24/62 | 10/24/62 | 10/24/62 | 10/24/62 | 10/22/62 | 10/23/62 | 10/24/62 | | | |
| Street Laid | New St. | New St. | Fulton St. | Fulton St. | Legion Pl. | High St. | Barron Ave. | Eleanor Pl. | New St. | Fulton St. | Eleanor Pl. | | | |
| Sieves & Screens Passing | Percent | | | | | | | | | | | Average | Min. | Max. |
| 3/8" | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | 100 |
| No. 4 | 92 | 95 | 94 | 94 | 95 | 96 | 95 | 96 | 96.8 | 97.3 | 97.6 | 95.3 | 90 | 100 |
| No. 8 | 75 | 76 | 74 | 76 | 77 | 77 | 77 | 75 | 78.4 | 78.3 | 79.0 | 76.6 | 70 | 100 |
| No. 16 | 72 | 70 | 71 | 73 | 74 | 73 | 72 | 73 | 74.5 | 74.6 | 75.0 | 73.0 | 40 | 80 |
| No. 30 | 58 | 54 | 58 | 66 | 66 | 65 | 63 | 65 | 61.3 | 63.1 | 63.6 | 62.1 | 20 | 60 |
| No. 50 | 33 | 32 | 36 | 43 | 43 | 41 | 40 | 41 | 33.8 | 37.1 | 36.1 | 37.6 | 5 | 40 |
| No. 100 | 18 | 16 | 18 | 13 | 12 | 15 | 14 | 12 | 13.1 | 15.2 | 13.4 | 14.5 | 0 | 20 |
| No. 200 | 8 | 7 | 9 | 5 | 5 | 7 | 9 | 5 | 5.4 | 6.0 | 5.3 | 6.5 | 0 | 10 |
| Bitumen | 7.6 | 7.3 | 7.4 | 7.1 | 7.2 | 7.3 | 7.4 | 7.0 | 7.5 | 7.5 | 7.5 | 7.3 | 7.2 | 7.8 |

Stone (T.R.) 22%; sand (B.S.) 68.5%; filler (L.D.) 4%; A.C. (O.A.) 7.5%, pen. 110, duct. 110 at 56 pen.

Figure 11. Maryland Smooth Seal surface showing an example of worn spots which occurred at four intersections.

This mix was laid when the temperature of the concrete pavement was approximately 40 F. The mix cooled rapidly and did not provide the fine texture and smooth joints which can be achieved when the pavement is warmer. The tack coat used was asphalt emulsion grade RS-1, uniformly applied; it appeared to be very effective. Because the ambient temperature was about 40 to 45 F, the mix tore behind the paving machine, making it necessary to hand broadcast behind the paver, accompanied by raking and luting. The 3-wheel and tandem roller were right behind the paving machine; the mix compacted well but cooled rapidly. The rough-textured areas were smoothed out by traffic action. The temperature of the mix was about 310 F on the job, and it was handled through the paving machine satisfactorily, except for the tearing caused by the cold pavement temperature.

This mix was applied late in October and at an air temperature 10 degrees colder than when the other mixes were applied. Four intersections developed worn spots (Fig. 11). These intersections, having been done by hand, cooled before the rolling was done. The worn spots are a result of improper compaction caused by the low air and pavement temperatures and the unevenness of the handwork.

TABLE 11

| RATING CHART MIXING AND APPLICATION | DIX SEAL | SP-1 | RUBBERIZED SAND ASPHALT | EMULSION HOT MIX | SMOOTH SEAL |
|---|---|---|---|---|---|
| AVAILABILITY OF MATERIAL | 4.0 | 1.7 | 4.0 | 2.5 | 1.7 |
| MIXING PROCEDURE | 3.5 | 1.3 | 3.7 | 2.3 | 1.3 |
| MIXING | 3.7 | 1.5 | 3.2 | 2.8 | 1.3 |
| TEMPERATURE | 4.0 | 1.8 | 3.8 | 2.3 | 1.6 |
| PAVING-MACHINE | 3.0 | 3.2 | 3.8 | 1.8 | 2.0 |
| HANDWORK | 1.8 | 2.2 | 3.8 | 1.7 | 2.0 |
| ROLLING | 2.3 | 2.3 | 3.2 | 1.5 | 1.8 |
| APPLICATION SPEED | 2.3 | 3.2 | 4.0 | 1.8 | 2.0 |
| TOTAL | 24.6 | 17.2 | 29.5 | 16.7 | 13.7 |

TABLE 12

| RATING CHART PERFORMANCE | DIX SEAL | SP-1 | RUBBERIZED SAND ASPHALT | EMULSION HOT MIX | SMOOTH SEAL |
|---|---|---|---|---|---|
| TENDERNESS | 3.7 | 1.8 | 1.5 | 2.8 | 2.2 |
| TEXTURE | 2.2 | 2.2 | 3.3 | 2.8 | 2.3 |
| Resistance To: REFLECTION CRACKS | 3.0 | 3.0 | 2.5 | 2.7 | 3.0 |
| Resistance To: SHOVING & PUSHING | 3.7 | 2.2 | 1.3 | 2.3 | 1.8 |
| Resistance To: SCALING & SPAWLING | 2.7 | 1.2 | 1.5 | 1.5 | 1.8 |
| TOTAL | 15.3 | 10.4 | 10.1 | 12.1 | 11.1 |

Smooth Seal is rated first in mixing and application, third in performance, and second in cost.

To surface 13,800 sq yd of pavement, 500 tons were used. The yield was 72.9 lb/sq yd at a unit cost of $0.383 per sq yd.

## RATINGS

Two rating charts were drawn; one for mixing and application (Table 11) and one for the first year's performance (Table 12). Copies of these charts were mailed to six persons who worked closely with the program. They were asked to rate the different mixes on the various items, using numbers 1 to 5. Number 1 was to be used for the mix that was best for the particular item rated, and number 5 for the worst. In case it was felt that there was no difference in the mixes for any item, the same number was to be used for those mixes considered equal. When the rating charts were returned, the averages of the ratings were entered in the respective charts. These ratings are not reflective of individual opinions but are a numerical average. The best possible rating for mixing and application is 8, the worst 40. The best possible rating for performance is 5, the worst 25.

## CONCLUSIONS

The following comments are based on the observations of those concerned with this program.

Large stones in the mixes for thin overlays create long scars. The general appearance immediately after completion is only fair. Joints, high spots, pancaking and sometimes backcasting are in evidence. After three to four weeks of use, traffic smooths out these blemishes.

The asphalt emulsion mix was the easiest to lay and could be laid faster than the other mixes.

The rubberized sand asphalt mix was the most difficult to handle for the rakers, and was the most expensive to produce (Table 13).

The New Jersey SP-1 mix, the asphalt emulsion mix and the smooth seal mix cost less than $0.40 per sq yd to lay (Table 13).

## TABLE 13
## COMPARISON OF YIELD AND COST

| MIX | Cost/Ton In Place | ON OLD CONCRETE S.Y. | ON OLD CONCRETE Tons | ON OLD CONCRETE Yield lbs/S.Y. | ON OLD CONCRETE Cost Per S.Y. | ON OLD ASPHALT S.Y. | ON OLD ASPHALT Tons | ON OLD ASPHALT Yield lbs/S.Y. | ON OLD ASPHALT Cost S.Y. | TOTAL S.Y. | TOTAL Tons | TOTAL Yield lbs/S.Y. | TOTAL Cost S.Y. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perfect Dix Seal | 12.50 | 12,199 | 427.83 | 70.1 | .4381 | 12,035 | 432.16 | 71.7 | .4481 | 24,234 | 859.99 | 70.9 | .4431 |
| SP-1 | 10.50 | 12,368 | 394.30 | 63.7 | .3344 | 10,747 | 355.45 | 66.1 | .3470 | 23,115 | 749.75 | 64.4 | .3381 |
| Asphalt Emulsion Hot Mix | 13.00 | 11,232 | 346.70 | 61.6 | .4004 | 13,720 | 419.50 | 61.2 | .3978 | 24,952 | 766.20 | 61.4 | .3991 |
| Hot Laid Rubberized Sand Asphalt | 18.00 | 10,027 | 317.00 | 63.3 | .5697 | 11,876 | 429.20 | 72.2 | .6498 | 21,903 | 746.20 | 67.6 | .6084 |
| Maryland Smooth Seal | 10.50 | 9,055 | 323.90 | 71.6 | .3760 | 4,770 | 180.00 | 75.4 | .3958 | 13,825 | 503.90 | 72.9 | .3827 |

The average daily tonnage laid is not representative of a good day's run for any mix. All of the figures given can be improved with experience.

In laying thin pavements (½ in.), it should be recognized that thinness makes these pavements cool much more rapidly than thicker pavements. Therefore, factors such as pavement temperature, air temperature, and relative humidity become increasingly important.

When the hot rubberized sand asphalt was mixed, a means was devised for pumping the latex from drums to a container located at the upper level of the mill. The amount of latex was regulated by a float in this container and the latex was injected into the mix by opening a quick-opening valve. This injection took approximately 8 sec. The system worked very well provided that care was taken to avoid pumping in rubber solids which occurred in skin formations in the tops of drums. The latex should have been filtered before its introduction into the pugmill. A ¼-in. wire mesh screen is adequate for this work. The mix design called for the inclusion of 2.1 gal of latex per ton of mix. It was introduced into the pugmill after the aggregates had been coated with asphalt. This procedure added about 20 seconds to the mixing time.

For each type of asphaltic concrete used, there was a slight but significant variation of the screen or sieve sizes required to establish the blended mixture within a given grading range (Fig. 12). Because of this lack of uniformity, it was necessary to investigate many sources of fine aggregate before a material or blend of materials could be found to conform to a particular mixture grading range under a recommended specification.

It is felt that a uniform or standardized specification for each of the mixtures, as to screens and sieves used and the requirements of aggregate conformation, would greatly enhance these pavements to other buyers and producers of bituminous materials. For example, if the New Jersey State Highway Department, Standard Specifications (1961) were used to establish aggregate, screen and sieve size requirements and the manufacturer's general or extreme range of grading limits were adapted under a code of uniformity, then any asphalt plant complying with the New Jersey requirements could produce one or all the pavements from stock materials while still supplying other customers' needs and attaining a maximum plant efficiency.

After three years observation of the five ½-in. surfaces used, it seems apparent that, had any one of these mixes been used for the entire program, the program would have been considered a success.

Perfect Dix Seal is considered less desirable because of shoving or pushing, higher cost, and the difficulty in mixing. The paving crews do not like to handle this mix because of the fumes. However, the performance of this mix is good.

The rubberized sand asphalt is rated excellent on performance, but due to its cost and the difficulty in mixing and application, it would have to have an expected life of at least twice that of the other mixes to be economical.

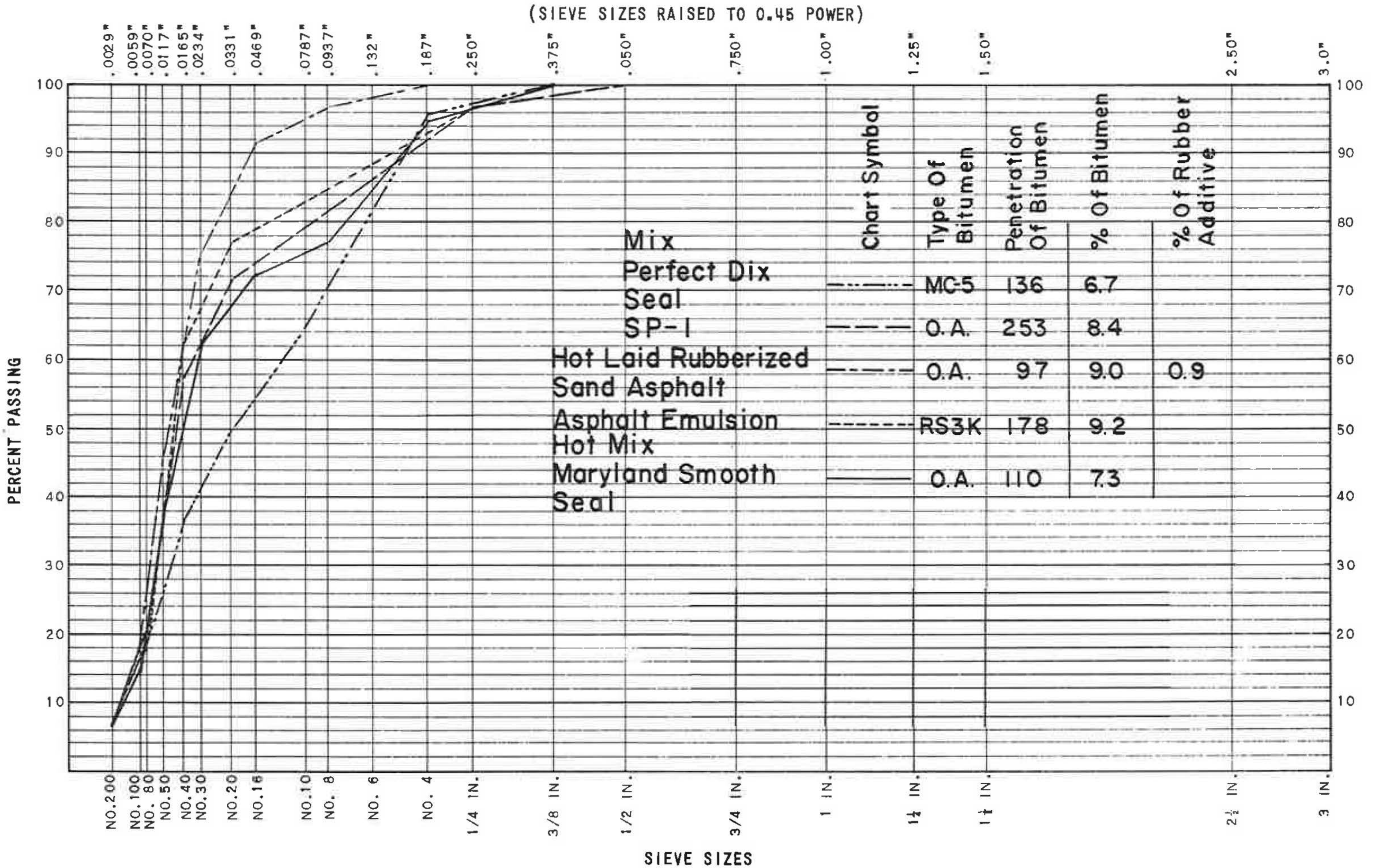



Figure 12. Comparison of gradations and bitumen.

The SP-1 mix, the emulsion hot mix, and the Maryland Smooth Seal proved to be the easiest to mix and apply; they cost less and have provided more than satisfactory performance. These mixes can be used instead of the conventional liquid seal on asphalt pavement and to protect old, spalled, and cracked concrete surfaces. The wearing surface of these mixes provides a smooth quiet ride whether applied to concrete or asphalt pavement. After three years of service, it is anticipated that these mixes will last from four to six years.

The economics of the use of these ½-in. applications cannot be determined until the useful life is determined. The citizens of Woodbridge Township apparently feel that the benefits of ½-in. surfaces far outweigh the lower cost of liquid seal coats.

# Tungsten Carbide for Snowplow Blades

J. R. FITZPATRICK, Department of Highways, Ontario, Canada

In this investigation tungsten carbide tips were inductively welded to steel plow blades, and their use and the amount of wear were compared with conventional plow blades.

Early findings during the experimental use of the modified blades showed such encouraging results, both in the effectiveness of the blades for snowplowing and in the minimal amount of wear, that 40 percent of a large fleet was equipped with tungsten carbide tips and further tests were conducted.

The results of the tests fully confirmed that tungsten carbide tipping of plow blades effects considerable savings and that the tipped blades outperform conventional steel blades. Advantages and disadvantages of the modified blade are discussed, and changes in design to improve the life-span of the blade are detailed.

•THIS investigation into the use of tungsten carbide tipped plow blades by the Equipment Division of the Department of Highways, Ontario, began in 1963. Its purpose was to determine if tungsten carbide tipping of plow blades would prolong the life of the conventional steel blades used, and if the savings afforded in the number of blades required for the removal of snow from the highways of the Province would exceed the extra costs involved.

There are 85,462 miles of roads in Ontario, of which the Department maintains 12,785 miles of major and secondary highways. To keep these roads clear in the winter, the Department's maintenance equipment includes 772 one-way plows (Fig. 1). Thus, a large savings potential exists if the useful life-span of plow blades can be extended.

## EXPERIMENTAL BLADE

The tungsten carbide selected for the first experimental blade consisted of standard rock-bit carbide, $\frac{1}{2}$ in. wide, which was induction welded into a $\frac{7}{8}$-in. blade of 1018 steel. The grade of tungsten carbide was comparable with that used in rock drilling bits, with 11 to 12 percent cobalt and a nominal Rockwell "A" hardness of 88.5.

The blade was designed to fit a 132-in. moldboard, and the tungsten carbide inserts were 1 in. in length. The blade was constructed in three sections, primarily to overcome machining problems, and because the induction welding equipment available could not handle a full-length blade. The cold-rolled steel sections of the blade were machined to take the 1-in. inserts, which were inductively welded to the steel with silver solder. Great care was taken during this operation to insure that no voids were left under the inserts (Fig. 2).

## METHOD OF TESTING

To compare the performance of the blades, two similar plows were operated in tandem on one of the major highways (Highway 400) of the Province (Fig. 3).

One plow was equipped with the experimental blade, and the other with a steel blade. The steel of the conventional blades used conformed to the requirements of the AISI

Paper sponsored by Committee on Maintenance Equipment and presented at the 46th Annual Meeting.

Figure 1. One-way plow.

Specification No. C. 1090. It had a chemical composition of 0.85521 percent carbon, 0.8602 percent manganese, 0.04 percent phosphorus and 0.05 percent sulfur. The Brinell hardness was 250.

The two plows were operated in tandem throughout the winter season and each plow was alternately used in the lead position so that both blades were exposed to leading and trailing positions and covered equal mileages. During this test over the full plowing season, the plow fitted with the conventional steel blade used a total of 8 blades, whereas it was not necessary to replace the experimental blade, which suffered only a minor amount of wear. The wear that occurred was fairly uniform across the length of the blade, practically nil at the leading edge, and only $\frac{1}{32}$ in. at the trailing edge. Figure 4 shows this blade after 3 winters' use.

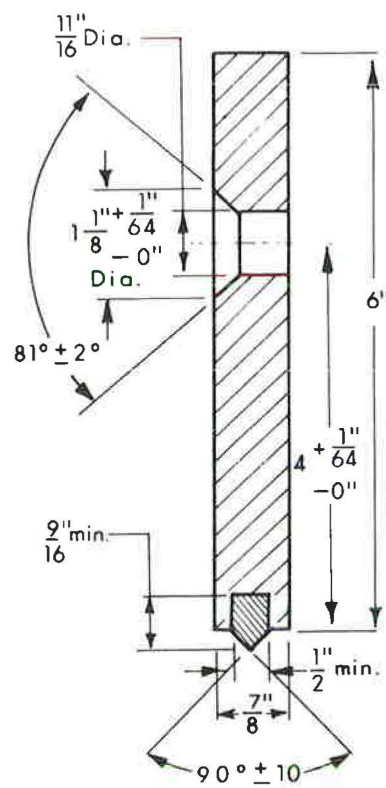




Figure 2. Original blade design.

## FURTHER TESTS WITH FIVE EXPERIMENTAL BLADES

In the summer of 1964, 5 additional tungsten carbide tipped blades were obtained for experimental use and fitted to plows in several districts in southern Ontario. The original experimental procedure was conducted during the 1964-1965 winter with all 5 blades. The tungsten carbide tips used were $\frac{3}{8}$ in. wide, $\frac{9}{16}$ in. high, $1\frac{1}{4}$ in. long, and of standard rock-drill design; the tips were attached to $\frac{3}{4}$-in. thick steel blades. The blades were constructed in three 44-in. sections, and the tips were silver soldered into the steel blades by induction welding.

Experience during the winter of 1964-1965 confirmed the original findings. The tungsten carbide tipped blades showed negligible wear—from no perceptible wear to less than $\frac{1}{4}$ of the carbide—whereas the companion plows had used from 3 to 9 steel blades each. The original experimental blade had outlasted 15 steel blades by the end of this second winter of use, and yet only about 20 percent of the carbide tip was worn away. On the strength of these results, the Department proceeded to equip 40 percent of the one-way plows with tungsten carbide tips for the 1965-1966 winter season.

Figure 3. Highway 400, Ontario.

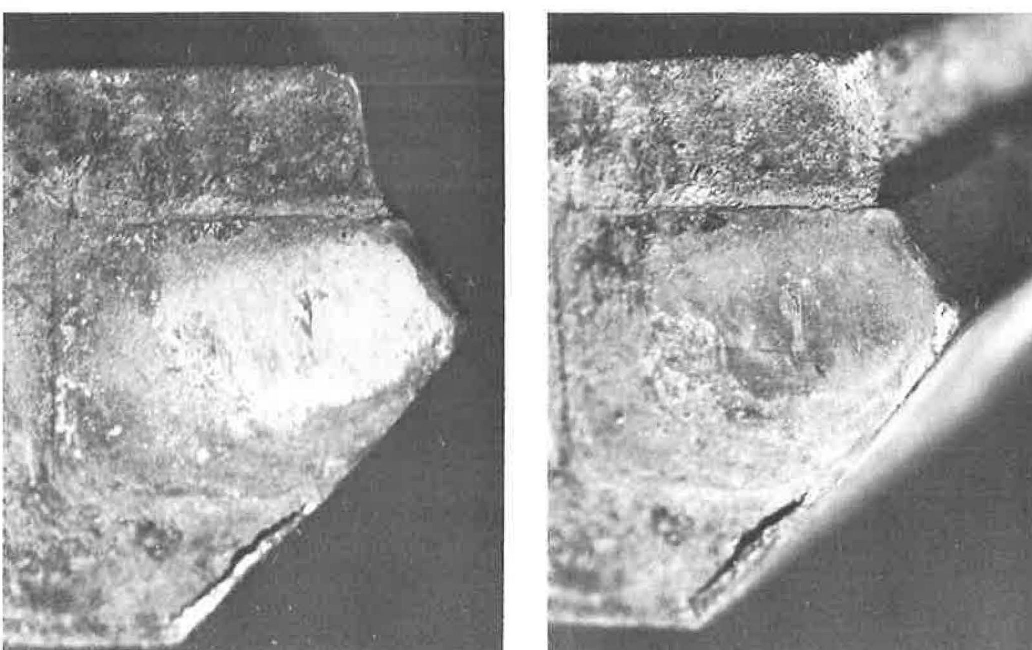


Figure 4. Original blade after three winters' use.

## BLADE DESIGN AND USE

The new blades were constructed to the Department's design by two manufacturers and distributed to all 18 districts in the Province. They were installed on both 116 and 132-in. plows. All blades were constructed in three sections; 28-in. center sections were provided for the 116-in. plows, and the original design length of 44 in. per section was retained for the 132-in. plows.

## TEST RESULTS ON 40 PERCENT OF FLEET

A total of 281 plows, equipped with 116-in. tungsten carbide tipped blades were used during the 1965-1966 winter season. Examination of the blades at the end of the winter indicated that: (a) 47.4 percent exhibited less than 25 percent wear, (b) 29.1 percent exhibited between 25 and 50 percent wear, (c) 10.0 percent exhibited between 50 and 75 percent wear, and (d) 13.5 percent were considered 100 percent worn or unfit for further use (some sections of the worn-out blades were still usable, however, when matched with other sections of worn blades).

Experience during the 1964-1965 winter, when plows were required less frequently than during the 1965-1966 season, suggests that 1,628 more ordinary steel blades would have been used if the 281 plows had not been fitted with tungsten blades. The percentage wear results further suggest that by the time the 281 tipped blades are completely worn-out, they will have outlasted 4,467 ordinary steel blades: a ratio of 15.9 to 1. This potential saving of the 116-in. steel blades is shown in Figure 5.

Fifty-five large plows were fitted with 132-in. blades, and the percentage of wear results were as follows: (a) 56 percent less than 25 percent wear, (b) 26 percent between 25 and 50 percent wear, (c) 2 percent between 50 and 75 percent wear, and (d) 16 percent were 100 percent worn. Estimates based on the previous year's experience indicate that 757 ordinary blades would have been used on these plows, and if an estimate is made of how many ordinary blades would be used by the time all 55 tipped blades are worn out, a saving of 2,333 blades is indicated. On this basis, one 132-in. tungsten tipped blade is equivalent to 44 ordinary blades (Fig. 6).

Actual mileage data are available for 205 of the 116-in. blades and 51 of the 132-in. blades (Table 1).

TABLE 1

MILEAGE DATA

| No. of Blades | Avg. Mileage | Wear % |
|---|---|---|
| | 116-in. blade | |
| 113 | 4,150 | Less than 25 |
| 48 | 5,850 | Between 25 and 50 |
| 23 | 5,760 | Between 50 and 75 |
| 21[a] | 6,150 | 100 |
| | 132-in. blade | |
| 26 | 4,150 | Less than 25 |
| 18 | 4,350 | Between 25 and 50 |
| 3 | 6,600 | Between 50 and 75 |
| 4[a] | 4,120 | 100 |

[a]These blades were considered worn-out and unfit for further use; two of them had been involved in accidents.

Projected mileage for the blades is 13,400 mi. for each 116-in. blade and 12,400 mi. for each 132-in. blade (Figs. 7 and 8), indicating that the two sizes of blades give approximately the same mileages.

## ADVANTAGES AND DISADVANTAGES OF NEW BLADE

The major advantage of the new blade is the saving in material cost (blades, nose points, hardware, and shoes), but other savings include idle time, or "down-time," which is particularly important during a heavy snow storm because the time required to change blades can sometimes be the difference between keeping ahead of the storm or falling behind. In the one to two hours often required to change a blade, roads can become blocked with snow and create increasing difficulties for the plowman. The tungsten carbide tipped blade obviates the need for frequent changing of blades.

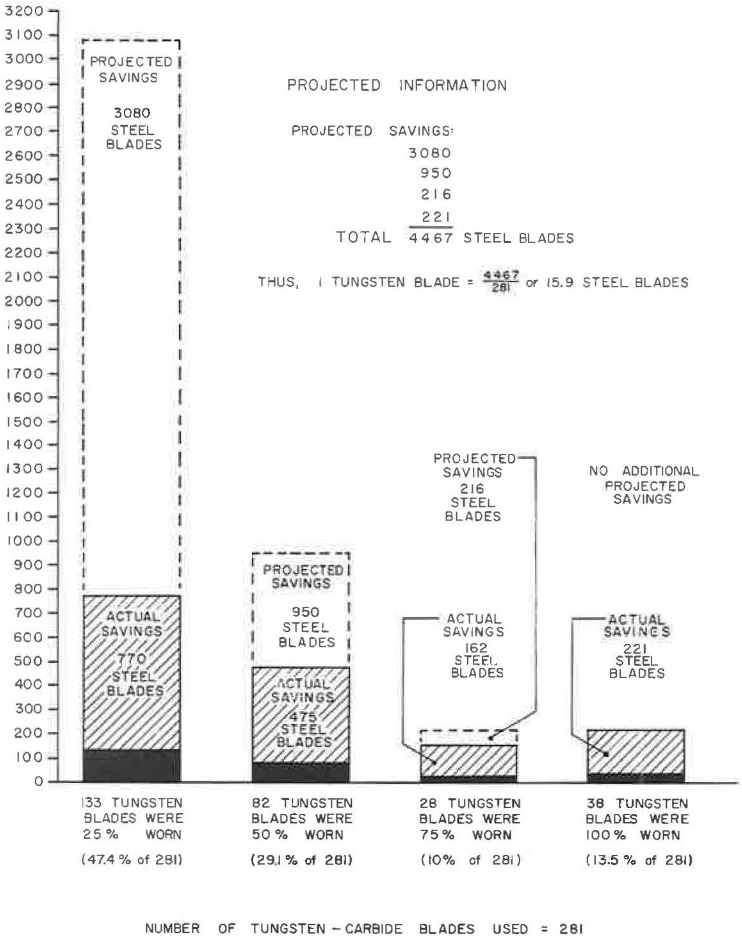



Figure 5. Actual savings in steel blades and projected savings (116-in. blade).

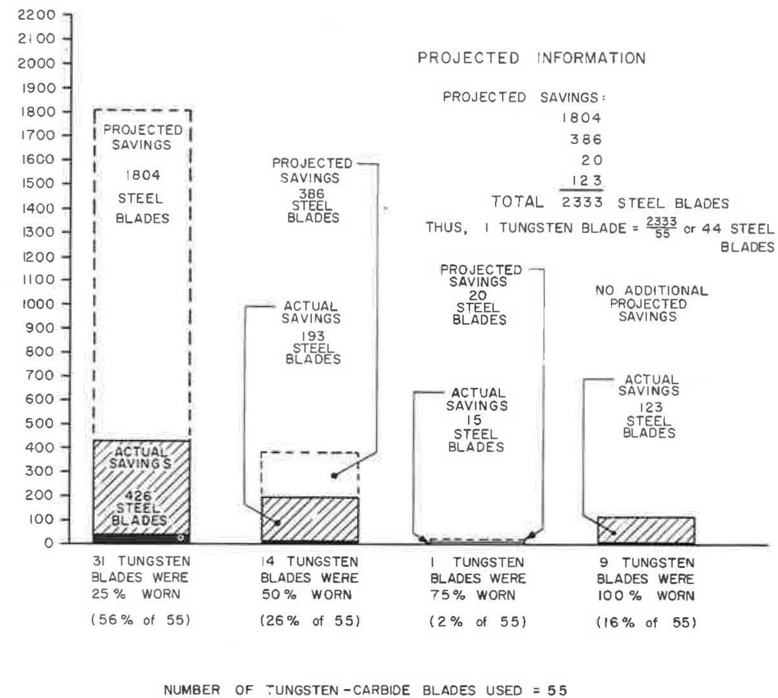



Figure 6. Actual savings in steel blades and projected savings (132-in. blade).

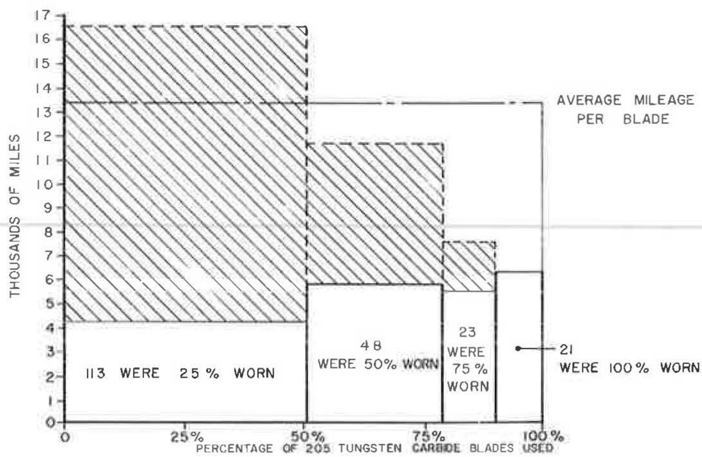



Figure 7. Actual mileage for 1965-1966 season and projected mileages for 116-in. tungsten carbide blades.

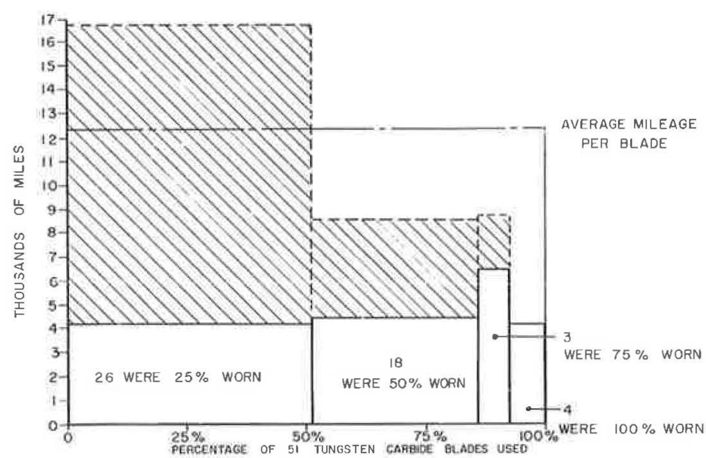



Figure 8. Actual mileage for 1965-1966 season and projected mileages for 132-in. tungsten carbide blades.

On one particular patrol investigated by the author, the patrolman was very enthusiastic about the new blade. It was necessary on this patrol to plow 30 mi to the end of the run, return to the yard, "flip" the blade, and make one more round trip before discarding the steel blade normally used. Thus, one steel blade was consumed every 120 miles plowed on this concrete highway. Over 2,879 miles had already been logged with the new tungsten carbide tipped blade, supplied to the patrol, with no downtime. Examination of the blade revealed less than 33 percent wear.

Other operators reported favorably on the clearing capabilities of the new blade. They reported that roads could be kept clear of ice and snow more easily, and in some cases much less salt was required to keep the highways clear.

Throughout the testing period, operators were instructed to use the new blades in the same manner that they had used the steel blades. Blade angles of 45 to 55 deg to the road were adopted. The steeper angle is generally preferred in the northern parts of the Province, and attempts are being made to standardize the blade angle at 50 deg.

Some undesirable characteristics were experienced with the new blades. Until the steel behind the tungsten carbide wears down to the desired angle, snow and slush can be thrown up in front of the moldboard and be deposited on the hood or windshield of the vehicle. When the steel behind the tungsten carbide wears and sand scours part of steel away from the front of the tungsten carbide insert, this effect diminishes.

Reports were received from some districts that the new blade had a tendency to wear at either the leading or the trailing end, or both. This may be due to the type and condition of road surface, or to incorrect adjustment of the plow. On the trailing end of the blade where it overhangs the surfaced part of the road onto the shoulder a high pressure point is created which may cause that part of the blade to wear quickly. Attempts to use the new blades for gravel shoulder plowing have not been too successful; the blades have a tendency to dig in. This is a desirable feature when clearing ice and snow, but undesirable for shoulder leveling. It is also suspected that small pebbles and blade chattering are causing the tungsten carbide to become chipped. This may be overcome by improved flotation, possibly by fitting shoes behind the blades.

## NEW BLADE DESIGN

The original design of the blade has been changed (Fig. 9). In the original design (blade angle 50 deg to the road), the area of tungsten carbide in contact with the road surface first increased, and later decreased as the wear continued. The tungsten carbide became wedge-shaped at one point in the wear pattern, and was then susceptible to shattering along a longitudinal plane (Fig. 10).

A new design (Fig. 11) was adopted which avoids the tendency to wear to a wedge-shaped section throughout the life of the tungsten carbide tip. The height of the tip was also increased from 0.535 to 0.735 in. This should increase the usable life of the blade by 60 percent, while only adding 10 percent to the cost.

The new blades are in five sections. The 132-in. blade consists of two end sections 16 in. long, two intermediate sections 28 in. long, and one center section 44 in. long. The 116-in. blade consists of two end sections 16 in. long, two intermediate sections 28 in. long, and a center section also 28 in. long. The 16-in. end sections and the 28-in. intermediate sections are interchangeable on both sizes of plows, to allow more latitude in section interchangeability, and thereby effect further economies. The sections may be tack-welded to keep them properly aligned.

The 5-sectioned blade is less rigid than the 3-sectioned blade, but new rails with increased rigidity will be mounted on the moldboards. Until these are actually available, old steel blades will be mounted behind the tungsten carbide blades to provide the required rigidity. The new design also includes countersunk plow bolts with square shoulders to facilitate tightening. Although the present grade of tungsten carbide has proved satisfactory, experiments with a more abrasive resistant type are being considered with a view to improving the life-span of plow blades even further.

Next winter (1966-1967), 100 percent of the Department's one-way plows will be equipped, so that more data on the use of tungsten carbide tipped blades will be available

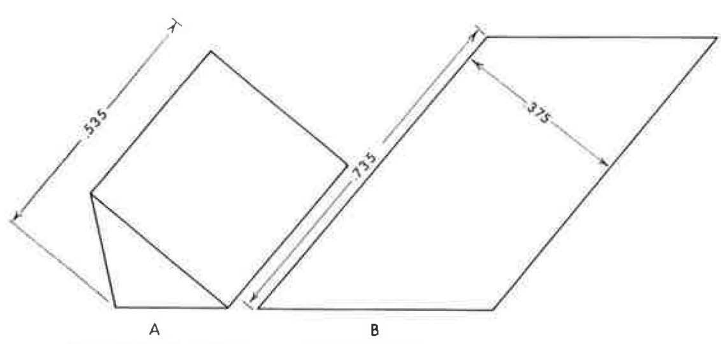



Figure 9. Original and new blade design.

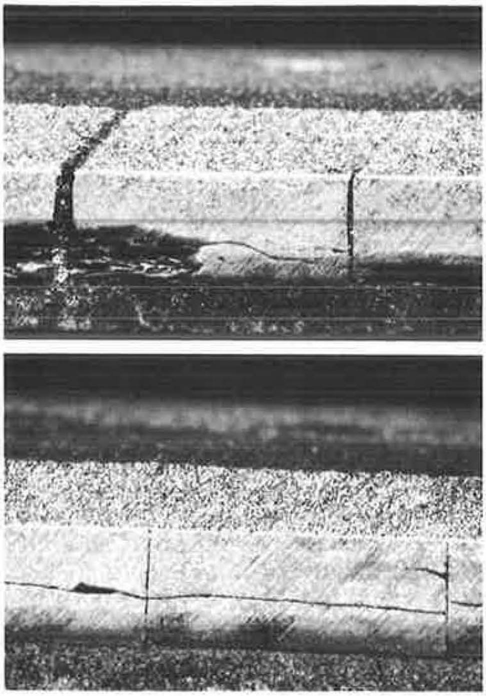


Figure 10. Blade shattering along the longitudinal plane.

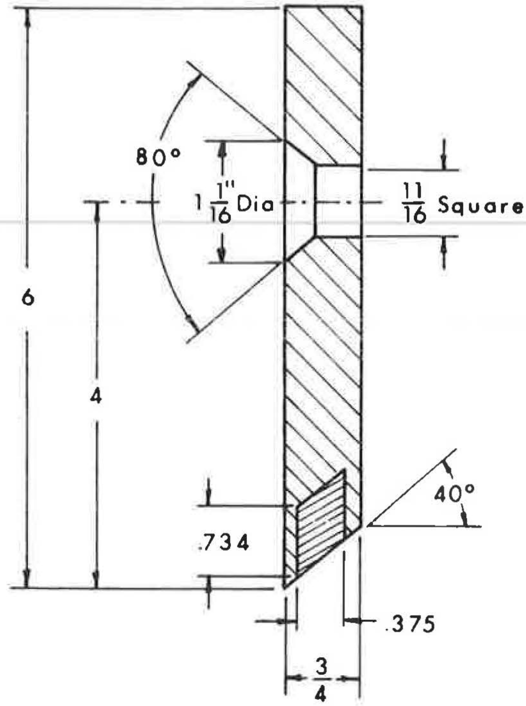



Figure 11. New design of blade.

at the end of the plowing season. On the basis of the results obtained from the 40 percent of the fleet covered in this paper, it is anticipated that the extra cost of the tungsten carbide tipped blades will be eliminated within $1\frac{1}{2}$ to 2 yr. It is then expected that the Department will be able to effect considerable saving and at the same time provide better snowplowing service.

# The Problem of Fugitive Dust in the Highway Construction Industry

F. A. RENNINGER, Geologist, National Crushed Stone Association, Washington, D. C.

The passage of the Clean Air Act in December 1963 and the amendments to it in 1965 have provided the necessary impetus to focus public attention toward the matter of community air pollution. In light of this new awareness, the increased research efforts being expended, and the appearance of many new state and local codes and regulations, the problem of community air pollution is rapidly becoming both a legal and a public relations problem for the highway contractor and his materials suppliers. This paper highlights the current trends and developments in this field and abstracts the results of a 3-yr research program conducted by the National Crushed Stone Association relative to the development of an adequate dust monitoring system designed to provide the crushed stone producer with information concerning the dust pollution situation surrounding his operations. It is proposed that this system may be applicable to other segments of the highway construction industry as well.

•THE passage of the Clean Air Act in December 1963 and its amendments in 1965 served to focus public attention on the matter of air pollution. The bill also put "teeth" in the Federal Government's drive for clean air. By providing the funds to finance needed research and technical assistance through the Public Health Service to train competent personnel, the Clean Air Act is rapidly paving the way for the various states and municipalities to strengthen their air pollution control boards and to establish air quality standards.

As a result of increased newspaper, radio, and television presentations of the perils of polluted air, the general public is demanding remedial action. Many large urban areas now include in their daily weather reports an "air pollution index" which presumably is an integrated measure of the relative concentrations of selected contaminants. This increased publicity has aroused and created a public less willing to tolerate conditions previously accepted without complaint. The following excerpt from The Wall Street Journal (Nov. 10, 1965) is an example of such publicity:

> The annual damage air pollution does to crops, buildings, equipment, and other property is estimated at $11 billion—without even calculating the health hazards. Pollutants such as sulfur dioxide and suspended particles can aggravate asthma and other chronic respiratory diseases, and in large enough concentrations can even cause death.

Industry is the natural target of the initial efforts to purify the air. A plant stack emitting large quantities of dense smoke, obnoxious odors, or injurious fumes is the prime target. However, airborne dust is also an air pollutant, although not toxic,

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certainly nuisance enough to warrant control. This is where the highway construction industry, in all its phases from the quarrying of rock and manufacturing of the cement to the removal of the last truck from the construction site, is affected by air pollution control measures. Quarrying and processing stone, batching bituminous or portland cement paving mixtures, cutting and sculpturing the grade, scarifying the subgrade and in general the moving and hauling of equipment and supplies are dusty operations. There are many sources of escapable dust associated with a normal highway construction job. Unfortunately, one cannot put a hood over the tops of these operations and channel the dust to common-collector equipped outlets. Many plant-type operations have some form of dust collecting equipment functioning at the more troublesome points, and dust control, through the use of water or "dust laying" chemicals is becoming more prevalent at construction sites. Despite these efforts, complaints about dust have probably increased during the past two or three years.

Dust and dust pollution problems are not new items of concern in the highway construction industry. In the absence of specific codes or regulations, the tendency was to convince the public of the temporary nature of the situation and the impracticability of exercising adequate control over such transient operations. This course of action was often viewed as an alternative to meeting and dealing with the dust pollution problem directly. The air the average individual breathes is now viewed as an irreplaceable natural resource which must be protected from increasing pollution, whether permanent or temporary. Action is being taken to control emission into the atmosphere of all known pollutants. Airborne dust is considered a primary air contaminant and it may be well to examine some standards relative to its control recently imposed in certain areas of the country.

## EXAMPLES OF CONTROL REGULATIONS

Before considering some existing dust control regulations, the general definitions applied to airborne dust should be thoroughly understood. Airborne dusts are generally separated into two broad categories: settled dusts and suspended dusts. Settled dusts are the coarser, heavier particles which settle rapidly and contribute to the dusting and soiling of property. Suspended dusts are the smaller, lighter particles which can be transported considerable distances by the air stream; they can be inhaled and affect atmospheric visibility. Air quality standards may be written about either or both types of dust. Settled dusts are generally measured in terms of tons per square mile per month or per year, simply by locating a suitable container to collect the settled material over a given period of time. Suspended dust concentrations are measured in terms of micrograms of dust per cubic meter ($\mu g/m^3$) of air sampled and require much more refined sampling equipment.

In October 1964, New Jersey added a new chapter to its Air Pollution Control Code designed to control the emissions of both coarse and fine solid particles from industrial processes (1). While it is true that the control limits imposed are related to particulate emissions from individual plant stacks, the values chosen may serve to indicate the control authorities' thinking with respect to pollutant concentrations.

The settled dust originating from any one given stack is limited to 200 tons per square mile per year when measured off the premises of the emitter. This value of 200 tons per square mile per year was derived from the examination of dustfall data which indicated that such a concentration represented a reasonably clean environment. The dustfall criteria are related to permissible stack emissions in the present code by considering such items as stack height, distance from the stack to the nearest property line, wind velocity, and particle free-fall velocity.

The same chapter of the New Jersey Code limits the concentration, during normal weather conditions, of suspended dusts to 615 $\mu g/m^3$ when measured off the premises of the emitter. This value compared with values obtained from outdoor air samples ranging from 50 $\mu g/m^3$ in rural areas to 1000 $\mu g/m^3$ in cities and up to 5000 $\mu g/m^3$ in heavy industrial areas. Like the settled dust criteria, the suspended dust concentrations measured off the premises of the emitter are related back to the permissible stack emissions through the use of such factors as the average wind speed, stack height, and the ratio of the vertical and horizontal diffusion (taken as 0.63).

Of somewhat more specific interest to the highway construction industry is part of the Florida Air Pollution Code. The Florida State Board of Health conducted a suspended dust survey (2) relative to portable asphalt plant operations and developed guides currently incorporated in the State Sanitary Code defining the permissible concentrations of fine particulate matter in areas adjacent to the operation. The results indicated that a buffer zone with a one-mile radius would provide adequate protection from unduly high concentrations of suspended dust. A concentration of 100 $\mu g/m^3$ was chosen as the limiting value, as this was the usual concentration found in Florida urban areas and any value greater than this is considered by the State Board of Health indicative of a "dirty atmosphere." Permanent asphalt batching plants are exempt from the buffer zone and suspended dust concept but are required to control their discharge to 0.3 grains of particulate emission per cubic foot of dry gas (68 F, 1 atm). The limiting of the weight of particulate emission per cubic foot of stack gas (or per hour of operation, etc.) is a third way in which control standards have been written. It is the oldest method and the most empirical from the standpoint of community air quality.

Of even greater interest and somewhat more direct concern to the heavy construction industry in general is the recent addition to the Pennsylvania Air Pollution Control Act (3) designed to control the emission of "fugitive dust." This document, Regulation IV (To Control Local Air Pollution From Sources of Particulate or Gaseous Matter Emissions) released in March 1966 defines fugitive dust as "solid air-borne particulate matter emitted at or near ground level from any source other than a flue." Regulation IV in its Section 1.3 on Limits for Particulate Matter Emissions sets forth the criteria applicable to fugitive dusts. These criteria are reproduced here as they are the first, to our knowledge, establishing quantitative limits applicable to fugitive dusts. Under the Pennsylvania Code, a local air pollution problem shall be deemed to exist "if any person causes, suffers, allows or permits fugitive dust to be emitted into the outdoor atmosphere from any air contamination source in such a manner that the ground level concentration of fugitive dust from the air contamination source at any point outside the person's property exceeds a concentration of 2.0 milligrams per cubic meter of air above background concentration, for any 10 minute period." Compliance is judged by taking companion samples, one upwind (taken as the background level) and one downwind of the alleged source, with a portable electrostatic precipitator. A control code such as this might readily be applied to a highway construction site, the prime contractor being deemed the responsible party and the limits of the right-of-way the point of compliance.

The foregoing descriptions are illustrative of the forms dust pollution control standards and codes may take. Most standards in current use generally apply to specific pollution sources and not to the control of dust emanating from such multiple source areas as crushed stone quarries or highway construction sites. Pennsylvania's Regulation IV represents the first real effort to control the emission of fugitive dust. In other areas, fugitive dusts are viewed simply as nuisances; however, legal definitions of a nuisance do exist. Even in the absence of specific codes or regulations, simple complaints about fugitive dust, if left unanswered, may be resolved in the courts. The funds are available and the research is being conducted in some areas to develop ambient air quality standards. The day of the controlled quality atmosphere is in the making and the problem of community air pollution, fugitive dust pollution in particular, is rapidly becoming both a legal and a public relations problem to those industries either directly or indirectly involved in highway construction.

## AMBIENT AIR QUALITY STANDARDS

The terms "ambient air quality standard" and "ambient air quality objective" have been introduced. It might be advisable to examine the meaning of these expressions and to cite an example of how ambient air quality standards or objectives might be employed.

The New York State Air Pollution Control Board (4, 5) has issued ambient air quality objectives which find their statutory authority in New York Public Health Law #1271 and #1276. Quoting the New York Control Board, ambient air quality objectives are defined as describing "a level of air quality designed to protect people from the adverse effects of air pollution; and they are intended further to promote maximum comfort, and enjoyment and use of property consistent with the economic and social well-being of the community." Ambient air quality standards, then, would be the specific regulations imposed to accomplish the desired objective.

The New York Board has recognized that it would be impossible and impractical to demand uniform standards for all areas of the state. They have, therefore, devised a scheme composed of four different "regional objectives," each one subdivided into subregions based on normal land uses (agricultural, single and two family residences, commercial, industrial, etc.). Each subregion under each regional objective will have separate and distinct ambient air quality standards or regulations. The regulations governing each subregion, theoretically, will attempt to balance the cost of obtaining the desired level of air quality with the benefits attained from a health as well as an economic and aesthetic standpoint. Supposedly, as technology improves and the cost of providing cleaner air is reduced, the regional objective and hence the ambient air quality standards governing a given subregion will be tightened. The community air pollution problem and the control requirements necessary are being viewed in New York as a series of progressive and continuing efforts. The present ambient air quality objectives, now being put into effect, will limit both the concentrations of suspended and settleable particulate matter or dust. Under such a system it is conceivable that a highway contractor might be subjected to varying control standards, depending on the subregional and regional objectives relative to the construction site.

## What Can the Contractor and Materials Supplier Do?

With the enforcement of air quality regulations, regardless of which form they take, highway contractors and materials suppliers must be familiar with the contribution their operations make to the overall local air pollution problem. From both a legal and a community relations standpoint the producer of pollutants must be aware of and ready to act on causes of complaint. With more knowledge of the situation surrounding their operations, the operators will be able to assess the impact of proposed regulations and effectively participate in the development of fair and adequate control standards.

The National Crushed Stone Association, anticipating the current trends and developments in the field of community air pollution and recognizing the crushed stone industry as a potential polluter of local atmospheres, began working in this area about four years ago. The engineering staff has developed an automatic monitoring system which, when properly designed and located, is capable of providing a permanent and continuous record of particulate concentration about a given plant area. The system is intended to function as a means to provide the records necessary to investigate and validate any complaints, and also to serve as a means for policing the operation to insure compliance with any existing or proposed codes or regulations. Development work was conducted during the period August 1964 to September 1965 with the aid of an NCSA member company. Admittedly, the present system will probably be refined and improved with time; however, in its present state it does function and does provide the desired information.

## NCSA's Airborne Dust Monitoring System

The airborne dust monitoring system involves measuring both settled and suspended dusts in areas immediately surrounding a crushed stone operation. Basically, it is designed to determine compliance with dust regulations similar to those mentioned previously. Before initiating such a system it is necessary to develop reliable information as to local wind speeds and direction. Member companies faced with a potential dust pollution problem have been encouraged to install a suitable windscope and to keep records of measurements taken during operating hours. Information of this type is the first step toward a thorough understanding of local dust movements and is often in itself a powerful tool in combatting specific complaints.

Monitoring is accomplished by locating throughout the area surrounding the operations a series of "dustfall buckets" which collect dust settlement during 30-day periods. The results are usually recorded and reported in terms of tons per square mile per

Figure 1. Typical dustfall bucket.

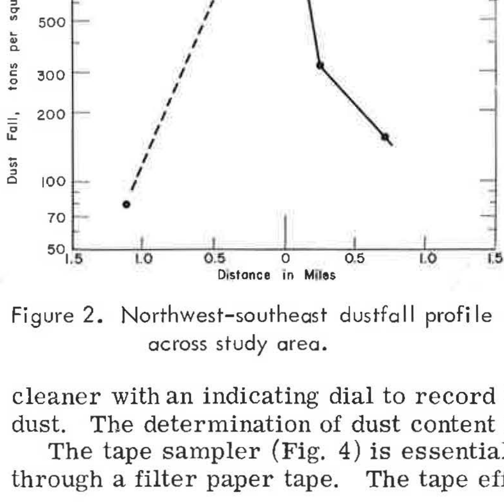


Figure 2. Northwest-southeast dustfall profile across study area.

month. Figure 1 shows one of these dustfall buckets; it is nothing more than an ordinary plastic waste basket. Figure 2 shows typical dustfall data taken across a line traversing the quarry property and indicates how rapidly the heavier settleable dusts deposit themselves. In the case illustrated, over 90 percent was dropped within a half mile of the source.

The high-volume and the papertape methods for measuring suspended particulates also have a place in the NCSA monitoring system.

The high-volume technique which gives results directly in micrograms of dust per cubic meter of air sampled is the method usually cited in control codes. It has the disadvantage, however, of requiring an individual's attention to change filters and recycle the unit, making it unsuitable as an automatic monitoring tool. The device (Fig. 3) is basically a vacuum cleaner with an indicating dial to record the air flow rate and a filter paper to trap the dust. The determination of dust content is a simple gravimetric measurement.

The tape sampler (Fig. 4) is essentially a small vacuum pump which draws air through a filter paper tape. The tape effectively removes the suspended dust from the

Figure 3. High-volume sampler.


Figure 4. Automatic tape sampler.


Figure 5. Papertape analyzing unit (densitometer).

air stream leaving a spot on the paper. The sampler can be preset to sample for a given period and then recycle itself automatically. This feature is unique to the tape sampler and is the feature around which the suspended dust portion of the NCSA monitoring system is developed. The paper tape spots are analyzed photoelectrically and reported in semiquantitative units based on the principle of light reflectance. The device used for this determination is called a densitometer (Fig. 5).

The assumption made and the principle proved by the NCSA studies were that the semiquantitative results obtained using the automatic tape sampler could be satisfactorily correlated with the standard quantitative measurements made using the high-volume technique. This correlation enables the crushed stone producer to monitor his operations automatically with a minimum of human attention. The records produced may be used to (a) police the dust emissions from the quarry area, either as a matter of record or for compliance with a specific code or regulation; (b) establish the validity of any complaints received; and (c) form the basis for a sound defense in the event of litigation. Technical details concerning the monitoring system and its development were previously presented (6). However, it should be emphasized that it is still necessary to correlate the high-volume and papertape techniques at each sample site.

Such a monitoring system would be equally applicable for other permanent-type installations. Modifications of the basic concepts might be made to accommodate other situations in the highway construction industry. The approach is felt to be sound and the investment involved amply justified by the knowledge developed and the protection afforded.

From a practical standpoint it might be well to consider the cost of initiating a similar program. The capital outlay is relatively small; the required equipment and its approximate cost (about $750) is given in Table 1. There are more elaborate automatic tape samplers which incorporate the sampler and analyzer into one unit.

TABLE 1

APPROXIMATE INITIAL COST OF MONITORING SYSTEM

| Item | No. | Cost |
|---|---|---|
| Automatic tape sampler | 1 | $345.00 |
| Tape analyzing unit | 1 | 175.00 |
| Windscope with desk indicator | 1 | 90.00 |
| Dustfall buckets (6 at $1.00) | 6 | 6.00 |
| Metal frames for buckets | 6 | 30.00[a] |
| Papertape filters | _b | 12.50 |
| Construction of enclosure[c] | _ | 50.00[a] |
| Filtering equipment | _ | 30.00 |
| Filter papers | _d | 6.00 |
| Total | | $744.50 |

[a]Estimated cost.
[b]Supply for operating 3 to 4 months.
[c]Includes electricity to tape sampler.
[d]Supply for 16 months.

Results are recorded on a strip chart. Samplers can also be equipped with a built-in alarm circuit which functions whenever contamination exceeds the established operating level. These units cost from $1100 to $1200, approximately, and increase the total cost by about $600. Continuing operating expenses are limited to the cost of filter paper and filter tape, with approximately 30 man-hours of time per month for tending the equipment and keeping records.

## SUMMARY

It is necessary for industries producing contaminants to become familiar with the circumstances surrounding their operations. Airborne dust is viewed as a primary air contaminant and building highways, from production of the raw materials to grading of the finished road, is a dusty operation. This paper has attempted to summarize some of the current codes and regulations and to emphasize the need for awareness on the part of industry. The NCSA's airborne dust monitoring system was reviewed as an example of what has been accomplished by one segment of the highway-oriented industry. This monitoring system may be directly applicable to other situations in the construction industry.

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