PAVEMENT PERFORMANCE SURVEYS

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SYNOPSIS

The performance survey described in this report was made in an effort to determine the causes of premature failure, apparently due to lack of durability, of certain concrete pavements on the Ohio Highway system. The survey covered 375 projects totaling 1,115 lane miles of pavement.

Details of the method used in Ohio to obtain field data on each project are described in the paper, as are the methods for rating the pavements according to: (1) extent of surface scale, (2) degree of surface scale, and (3) progressive scale or disintegration. The method used in adjusting such ratings according to the age of the pavement is also described.

From such ratings the numerous variables present in the survey such as cements, fine aggregates, coarse aggregates, curing method, etc., were also rated. The ratings of these variables were then used by process of elimination to isolate questionable materials and practices.

Probably the best method of determining the suitability of materials and construction methods is to study their performance under field conditions. Data from existing pavements and structures can be utilized to good advantage in the preparation of specifications.

The method described was used by the Ohio Highway Department to evaluate the performance of all portland cement concrete pavements constructed during 1936 to 1942, inclusive. A total of 375 projects, amounting to 1,115 lane miles of pavement, were surveyed.

The procedure followed is essentially the same as that used in the surveys made in New York and Pennsylvania by the Portland Cement Association under the supervision of Prof. C. H. Scholer.

The survey in Ohio was made jointly by representatives of the Ohio Department of Highways and the Portland Cement Association. The Public Roads Administration furnished an observer. The Departments' representatives were from the Testing and Research Laboratory, Bureau of Construction and Bureau of Location and Design. On future surveys the Bureau of Maintenance will also be represented.

PREPARATION OF BASIC DATA

Preliminary work consisted primarily of examining laboratory and office records to obtain the necessary data on each project. This included the location of the project, the cross-section of the pavement, the specifications under which it was built, the dates of concrete placing, the materials used, the class of the concrete, whether or not the project was full-lane construction or merely widening, and whether it was full-depth or just resurfacing. This was entered upon one field sheet (see Fig 1). In cases where materials from different sources were used, or where the pavement was built in different years or seasons, a sketch was prepared showing the location of these variables by stations. A large amount of work and considerable time was required to collect and assemble these data.

FIELD OBSERVATIONS

Primary attention was directed to observing the type and extent of scaling of the pavements; and secondary attention was directed to other incidental and miscellaneous observations.

Scaling was classified into two types, surface and progressive.

Surface scale was considered to be the peeling or scaling of the surface mortar, where the concrete under the scale appeared to be sound, even though the scale extended into the mortar surrounding the coarse aggregate. Each slab (the area between successive trans-

verse joints) was considered individually. Those slabs having surface scale were placed in one of three groups: (1) those with scale covering up to 10 percent of the area of the slab; (2) those having surface scale from 10 to 50 percent; and (3) those having surface scale of more than 50 percent.

tar (see Fig 3), and third degree scale was where the coarse aggregate projected over ¼ in. above the mortar (see Fig 4).

Progressive scale (disintegration) was considered to be a condition of the pavement where the deterioration extended beyond the immediate pavement surface. Tapping or

T-2

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Salts Pr-1 Snow-2

Division 6 T/M, -198 County. Warren (1 comb)

FIELD DATA Date Inspected 9-13-43

Class S M Scale 03-100 Covered

Prog. 00 193 L M Abandoned

Remarks

3 3 0 173 joints
0 0 0 147 cracks
0 0 0 80 pumpers

Bit Premould Expansion Jt — Well Sealed.
Ribbon Contraction " — Edged & Good
Ribbon Longitudinal Jt — Deep & Chipped

Surface Scale — Not extensive

Drag Finish
Pumping — Very bad

Maintenance - Has been mudjacked — Need's

further mud jacking to check pumping

Cracks need to be sealed

Good except for pumping

OFFICE DATA 563-A (Re)

Hwy 10 T-1 (pt) & T-2 (pt.) FA 563-B un (1) US 22 SR 3

Contr W L Johnson Constr Co Engr Don Hatfield

Location

Sta 129+69.55 to 208+03.25
Equation - Sta 193+05.3 = 205+10.8
Bridge and Grade Crossing Elimination at Fosters

Lgth 0.967 mi Placed 6-14 to 7-7-38 Spec's Mix 1-5½

X-Sec 9-7-7-9 T-70 Jt Spacing 30 & 90 Width 20'

Cure Burlap - Straw

F A Van Camp Sand & Gravel Co. S Lebanon, Ohio (N)

C A " " " " " " " " " (Gravel)

Cement Medusa Silica, 0

Remarks Concrete poured in one strip 20 wide

Bridge Sta 160+80.8 to 174+87.5
" " 189+45.11 to 190+64.89

Figure 1. Example of Data Sheet

In addition to the area, the depth of the scale was noted. This was recorded as first, second or third degree scale. First degree scale was merely a peeling of the surface mortar (see Fig 2); second degree scale was that condition where the coarse aggregate projected up to ¼ in. above the surrounding mortar (see Fig 3), and third degree scale was where the coarse aggregate projected over ¼ in. above the mortar (see Fig 4).

Progressive scale (disintegration) was considered to be a condition of the pavement where the deterioration extended beyond the immediate pavement surface. Tapping or drawing a hammer over such areas generally produces a hollow or "punky" sound much different from that of adjacent areas not so affected (see Fig 5). This scale is generally, but not necessarily, associated with "D" cracks.

The term "D" crack was applied to fine

cracks marked by a dark-colored deposit (see Figs 6 and 7). These "D" cracks are usually parallel to joints, cracks and pavement edges and generally extend for an appreciable depth into the concrete and may go through fissures in or around particles of aggregate. They are generally associated with progressive scale although sometimes they develop only in the surface mortar and when the affected surface mortar peels off, the remaining concrete is sound.

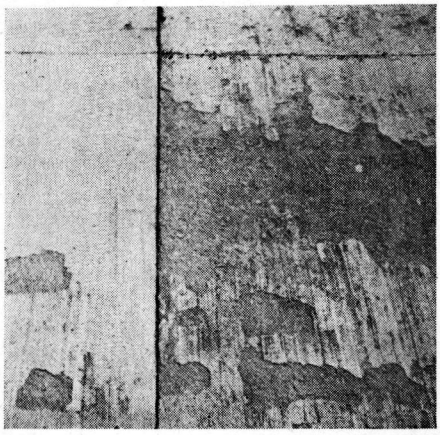

Figure 2. First Degree Scale, Surface Mortar Only Peeling, Concrete Under Scale Sound.

Figure 3. Second Degree Scale, Coarse Aggregate Projects up to $\frac{1}{4}$ in. Above the Mortar, Concrete Under Scale Sound.

Since the concrete along the joints, cracks and edges of the pavement is subjected to the severest exposure, it is to be expected that if progressive scale develops, it will be found at such locations (see Figs 6 and 8). On this assumption it was considered that the progressive scale along the transverse joints would be a relative measure of the progressive scale on each individual project. Therefore in this investigation the progressive scale was recorded along transverse joints only, and was divided into four groups. In the first

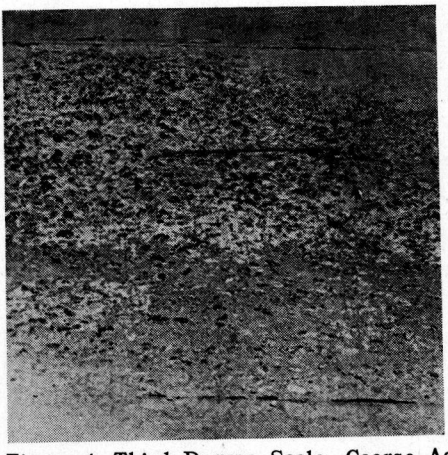

Figure 4. Third Degree Scale, Coarse Aggregate Projects Over $\frac{1}{4}$ in. Above the Mortar, Concrete Under Scale Sound.

Figure 5. Drawing Hammer Over Pavement Surface to Check for Progressive Scale (Disintegration). This generally produces a hollow or "punky" sound much different from that of unaffected areas.

group were placed those joints having "D" cracks only. In the second group were placed those joints where the deterioration (raveling) along the joint extended for a width up to 6 in. on one or both sides of the joint. In group three were placed the joints where the deterioration extended from 6 to 12 in. on one or both sides of the joint, while group four included all joints having deterioration exceeding 12 in. (see Fig 9). In addition to these recordings notes were made of "D" cracks or deterioration along the pavement edges, longitudinal joints or at any areas in the interior of any slab.

In addition to these data, the following information was taken and recorded on the field sheet for each individual project:

1. Type and spacing of expansion joints.
2. Type and spacing of contraction joints.
3. Type of longitudinal joints.
4. Type of surface finish.
5. Number of joints, cracks, spalled joints, pumping joints and cracks.
6. Sealing of the joints.

Figure 6. D Cracks Parallel to Joints and Pavement Edges. These cracks are generally associated with progressive scale.

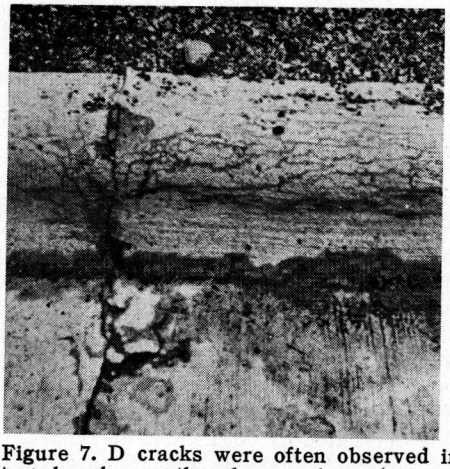

Figure 7. D cracks were often observed in integral curb even though no such cracks were found in the adjoining pavement.

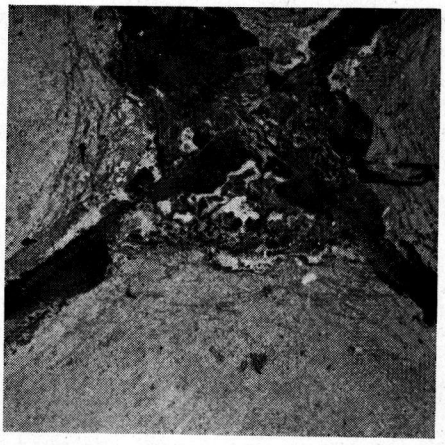

Figure 8. Progressive Scale at a Joint Intersection. The maintenance here was fair. However, the scale has now progressed beyond the stage at which it was when last maintained.

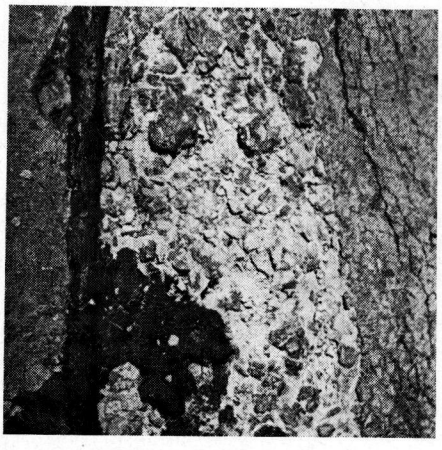

Figure 9. Progressive Scale, Group 4. The scale along this joint extends more than 12 in.

7. General maintenance of the concrete pavement.
8. Indications of the use of salts for ice removal.

General notes were also made of any obvious defects in construction procedure which might have affected the quality of the concrete pavement.

All of the data were obtained for each combination of materials used on each project on the basis of each year of construction and for summer and winter work during each year, and so taken that they could be converted readily to a lane mile basis.

METHOD OF TAKING OBSERVATIONS

The operations of the survey were divided among the party as follows:

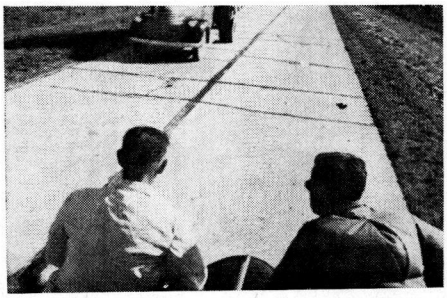

Figure 10. Scale data, were taken by observers riding on the front fenders of a car travelling at 5 to 10 miles per hour.

One man recording surface scale.
One man recording progressive scale.
One man counting joints and spalled joints, cracks and corner breaks.
One man checking stations, mileages and keeping notes, etc. (driver).
One man counting pumping joints (driver).

Two passenger cars were used. The driver of the lead car was generally not required to do any counting or recording, but was responsible for keeping and writing up the notes. The driver of the rear car was assigned to counting pumping joints.

Two of the remaining three men rode on the fenders of the lead car, one man recording surface scale and the other recording progressive scale (see Fig 10). The third man rode on the fender of the rear car and counted joints, spalled joints, cracks, and corner breaks.

The recording of joints, cracks, spalled joints, pumping joints, and corner breaks, was accomplished by punching counters and making tallies at the end of each section or partial section surveyed.

The recording of the surface scale and progressive scale was also accomplished by the use of counters. Several of these counters were mounted on conveniently sized boards. In the case of surface scale, six counters were used (see Fig 11). The first three were used for recording the extent of surface scale into the three groups and the second three counters for recording the degree of the surface scale. Similarly, the observations relative to progressive scale were recorded into four groups, by the use of four additional counters.

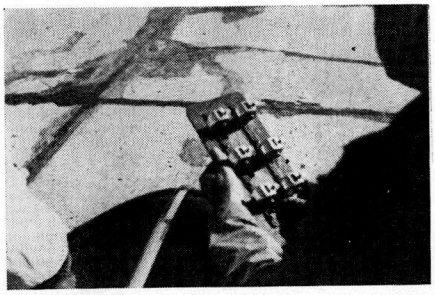

Figure 11. Recording Surface Scale Data. The three left hand counters were used to record the extent of the scale and the three on the right the degree of the scale.

The cars were driven very slowly in order to afford the members of the survey party full opportunity to make detailed observations of the pavement conditions. Stops were made frequently for the purpose of examining deterioration, joint installations, pumping and other features. Considerable use was made of sledge hammers, picks and other tools in examining the concrete. Photographs were taken to illustrate typical conditions and any unusual features.

It was the practice at the completion of each project or portion thereof, to tally the information, record it on the field sheets and prepare a brief description with pertinent comments and discussion (see Fig 1), before moving to the next project.

COMPILATION AND ANALYSIS OF FIELD DATA

Computation of Scale Ratings

From the field data average ratings for surface and progressive scale were computed for each project or for each part of a project built within the same calendar year and using cement, fine aggregate and coarse aggregate, each from one source only. There were, in all, 375 such single-year-material projects or parts of projects.

The average scale ratings were computed as follows:

Average Rating for Extent of Surface Scale

$$= \frac{(A + 3B + 5C)100}{5S} \quad (1)$$

Where A = Number of slabs having some scale, up to 10 percent of their areas,
B = Number of slabs having 10 to 50 percent of their areas scaled,
C = Number of slabs having 50 to 100 percent of their areas scaled,
and S = Total number of slabs

Average Rating for Degree of Surface Scale

$$= \frac{D + 3E + 5F}{D + E + F} \quad (2)$$

Where D = Number of the slabs having first degree scale,
E = Number of the slabs having second degree scale,
and F = Number of the slabs having third degree scale,
and where $D + E + F = A + B + C$ in Formula (1)

Average Rating for Progressive Scale

$$\frac{(K + 3L + 4M + 5N)100}{5J} \quad (3)$$

Where K = Number of joints showing "D" cracks adjacent,
L = Number of joints with progressive scale extending up to 6 in. on one or both sides of the joint,
M = Number of joints with progressive scale extending from 6 to 12 in. on one or both sides of the joint,
N = Number of joints with progressive scale extending over 12 inches,
and J = Total number of joints.

These average ratings computed as indicated and carefully rechecked, were entered upon the original sheets used in the survey.

Preparation of Project Record Cards

Following computation of the ratings, these were entered, along with various other items, on International Business Machine cards, for sorting, tabulation and analysis.

The items as entered on I.B.M. cards (see Fig 12), were secured from the field sheets, from testing laboratory records, from the divisions, from the Bureau of Maintenance, from the Planning Survey, and from the Ohio Agricultural Experiment Station at Wooster. These items were:

1. An identification number, given to each project or part of a project in the survey.
2. The division and county.
3. The plants furnishing the portland cement, the fine aggregate, and the coarse aggregate, respectively; the type of coarse aggregate, whether gravel, limestone or slag; and the type of fine aggregate, whether natural or limestone.
4. The type of construction: whether new; full width; resurface; widening; reinforced or not; and the cross section.
5. The lane-miles.
6. The type and spacing of the expansion and contraction joints and the type of longitudinal joint.
7. Whether a vibratory machine was used or not; and the type of finish and curing method.
8. The year in which the concrete was placed and whether in the spring or summer, or both; or in the fall or winter, or both; or whether placed partly in spring or summer, or both, and partly in fall or winter, or both.
9. The contractor and the project engineer.
10. The average rating for surface scale

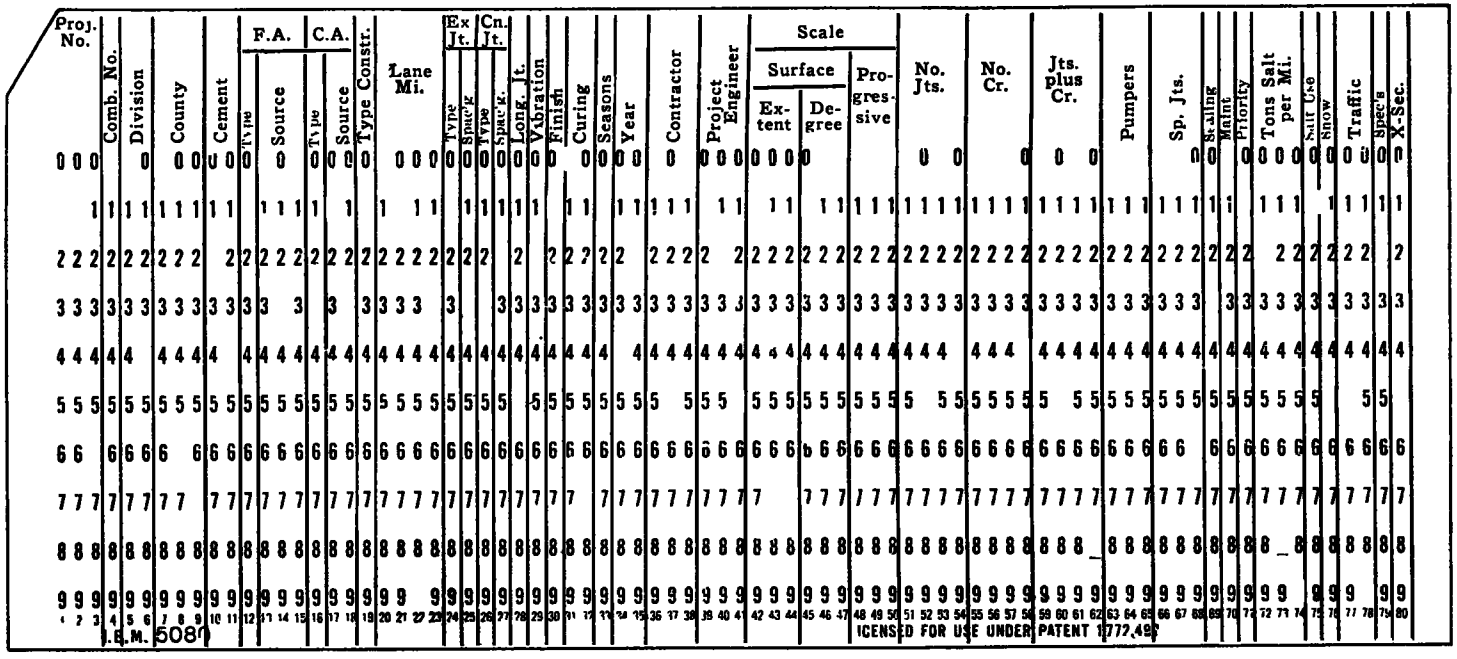

Figure 12. International Business Machine Card, Showing Column Headings Used

extent and degree, and for progressive scale.

11. The number of joints, cracks, pumping joints and spalled joints.
12. Observations on pavement maintenance, joint sealing and probable use of salt.
13. The average tons of salts per mile used in a winter in the county of the project, and the priority given to the highway by the Maintenance Bureau for purposes of employment of snow and ice removal agents.
14. The average annual snowfall at the location of each project.
15. The average daily number of all vehicles on the highway and the average daily number of commercial vehicles alone, for 1941.

Most of the foregoing items, though not all, were entered upon the I.B.M. cards in code. Through the cooperation of the Planning Survey, 375 cards were prepared, one for each project or part of project, and a tabulation by years was made.

Adjustment of Scale Ratings to Equivalent Age Basis

Averages, weighed according to lane-miles, were worked out for each year for extent of surface scale, degree of surface scale, and progressive scale, and the curves of these average ratings plotted. Study of these curves failed to indicate a relationship between extent and degree of surface scale and age of pavement. Other factors such as climatic condition and location probably had more influence. It was not considered feasible, in this survey, to apply age factors to surface scale. However, when pavements to be surveyed are of a greater age than those included in this survey (1 to 7 years) and as a result are less likely to be influenced by one or more severe winters, it is quite probable that age factors might be determined for surface scale. In the case of progressive scale, however, age seemed to be a factor in the severity of scaling, and so it was decided to apply age factors to the progressive scale ratings, in order to place the various projects on a comparable age basis. A five-year basis was selected as the most applicable. These age factors were secured by using a uniform empirical curve $\left(y = \frac{10x}{13 - x}\right)$ which approximated the plotted curve (see Fig 13). Throughout these operations the years were plotted along the "x" axis, and the average ratings along the "y" axis.

Curve "C" (Fig 13) was obtained by applying to the original data (Curve A) the factors based on Curve "B". Theoretically Curve "C" would be a horizontal line, if age were the only factor involved. As a matter of fact, examination of Figure 13 reveals that, leaving out of consideration the somewhat exceptional

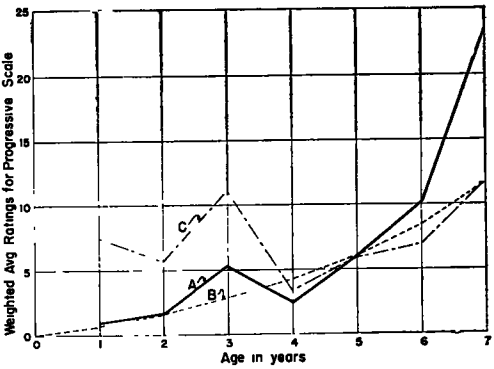

Figure 13. Graph Showing:
A—Curve of the Weighted Averages of the Original Ratings for Progressive Scale—For this one graph, the averages were weighted in terms of the lane miles only in those projects with some progressive scale.
B—Uniform Curve, Based Upon the Empirical Equation, $y = \frac{10x}{13-x}$ which Corresponds, in a General Way, to Curve A
C—Curve of the Equivalent 5-Year Average Ratings for Progressive Scale, Secured by Multiplying the Original Weighted Averages (Curve A) by Factors Based Upon Curve B

years 3 and 7, the Curve "C" does follow the horizontal quite closely.

The age factors as determined were·

Age in Years	*Factor*
1	7.5
2	3.4
3	2.1
4	1.4
5	1.0
6	0.7
7	0.5

Multiplication by these factors reduced all the average progressive scale ratings to equivalent five-year age.

Ratings Weighted on Lane Mile Basis

The revised ratings were entered on a new set of I.B.M. cards, containing also the other data as entered upon the original cards, with the exception that the space used on the original card for number of joints, cracks, pumpers and spalled joints was now used for certain products which would facilitate computation of averages. These products were:

1. Average rating for extent of surface scale times lane-miles.
2. The product of surface scale and lane-miles times the average rating for degree of surface scale.
3. The average rating for five-year equivalent progressive scale times lane-miles.

Thereafter, in order to obtain the weighted average ratings for progressive scale of any given group of projects, it was necessary, merely, to divide the sum of the products of progressive scale and lane-miles by the sum of lane-miles of the group; likewise, the sum of the products of surface scale and lane-miles divided by the sum of lane-miles gave the weighted average rating for extent of surface scale; and the sum of the products of surface scale, lane-miles and degree divided by the sum of the products of surface scale and lane-miles gave the weighted average rating for degree of surface scale.

Statistical Arrangement of Data

Tabulations were then run and weighted averages computed on the basis of all 375 projects or parts of projects in the survey, grouping them in turn according to each of the items entered upon the cards, except those items pertaining to joints, cracks, spalled joints and pumpers.

Straight averages for some of the items were also computed. These averages were compiled for comparative purposes only, as the weighted averages were the ones used in the analysis of the data. Maps, based on weighted averages, were made showing statewide distribution of surface and progressive scale.

It should be pointed out that the method used in recording the degree of surface scale did not afford a subsequent correlation between the degree and the extent of surface scale for any particular slab. Therefore, the degree of surface scale is not a quantitative average measure of the depth of scale of any project. For this reason it was not used in the analysis of the data.

It was found to be impracticable to compile comparative data by divisions or counties for the cement, fine aggregate and coarse aggregate plants, because of limited mileage.

Isolation of Materials Appearing Questionable

A primary objective of the survey was to isolate, if possible, questionable cements, fine aggregates and coarse aggregates. The first approach to this problem was to list cement plants, fine aggregate plants, coarse aggregate plants, contractors, curing methods and concrete placing methods (use of vibrating machine or not) which appeared questionable, on the basis of a progressive scale average rating of 5.0 or over, or a progressive scale plus extent of surface scale average rating of 15.0 or over.

New sets of averages for cements, sands, coarse aggregates, contractors, curing methods, and placing methods were then compiled, after eliminating from the total list of projects, in turn: all those projects using any questionable cements, then all those using any questionable sands (and so forth with the questionable coarse aggregates, contractors, curing methods and placing methods).

These new averages were then examined, giving major weight to the averages resulting from the elimination of questionable cements, sands and coarse aggregates. This led to the revision of the original list of questionables. For example, in the case of any sand on the original questionable list, if eliminating either the questionable cements or the questionable coarse aggregates resulted in a new average rating for that sand lower than 5.0 for progressive scale or 15.0 for progressive plus surface scale, then this sand was no longer considered in the questionable category, unless the elimination resulted in leaving no mileage for this material.

Next, additional sets of averages for cements, sands and coarse aggregates were compiled by means of a second series of eliminations based upon the lists of questionable cements, sands and coarse aggregates resulting from the first elimination and using the same procedure as was used in the first elimination.

A study was made also of the averages of all

fine aggregates in projects using questionable cements only, and of all cements in projects using questionable fine aggregates only. The resulting mileages were small and the projects scattered, therefore no conclusions were drawn.

SUPPLEMENTAL FIELD OBSERVATIONS

Upon study of the last elimination, it was revealed that a number of these questionable materials were used on relatively short mileages. Therefore, it was decided to investigate the service records of these materials over a longer period. A list of projects constructed in the years 1930 to 1935, inclusive, in which these questionable materials were used, was obtained from testing laboratory records. In making up this list an attempt was made, insofar as possible, to select those projects in which some given questionable material had been used along with other materials that were not questionable. (For example, where questionable fine aggregate "X" had been used along with non-questionable cement "Y" and non-questionable coarse aggregate "Z".) Unfortunately a number of the questionable materials were not used from 1930 to 1935. In fact, a number of them were materials which had been obtained from recently opened deposits.

The committee inspected the jobs on this list and took such data as would enable them to obtain ratings for surface and progressive scale. These data were not averaged with previous data on these materials but were used as supplementary evidence only.

DEPARTMENT OF MAINTENANCE

W. H. ROOT, *Chairman*

SOME OBSERVATIONS ON RESURFACING PORTLAND CEMENT CONCRETE PAVEMENTS WITH BITUMINOUS MIXTURES

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SYNOPSIS

In order to secure information to indicate the most desirable construction practices for resurfacing old portland cement concrete pavements with bituminous concrete, regular inspections over a three-year period were made of a number of previously constructed bituminous resurfacing projects on which pertinent construction data were available.

Bituminous resurfacing of old concrete provides a waterproof roof over the subgrade and forms a smooth riding surface which reduces impact on the concrete base. By these means the load-carrying capacity of the old surface is preserved and perhaps increased.

The practices which seem to be giving the best service for the money expended are these:

Old concrete pavements in the area of the study having reasonably satisfactory grades and alignments may be economically resurfaced with about a two-inch thickness of relatively rich dense graded bituminous concrete laid in two layers. The most economical time to apply a bituminous surface is when it is anticipated that, as an annual average, 1 to 1.7 percent of the area would need to be patched with concrete if the road were to be maintained as a concrete pavement. Very little patching immediately prior to resurfacing is justified. Removal of fat bituminous patches and the use of a light tack coat is considered good practice.

The resurfacing of pavements subject to pumping cannot be depended upon to stop pumping permanently. Covering pumping concrete with a layer of dense graded granular material prior to resurfacing has been effective in stopping