THE PERFORMANCE OF CONCRETE RESURFACING IN INDIANA

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SYNOPSIS

The results of field performance surveys of portland cement concrete resurfacing projects in Indiana are reported in this paper. All concrete resurfacing projects built prior to 1943 were included in the surveys. Detailed data on both the design and the performance of the projects are presented. It is concluded that the concrete resurfacing used in Indiana has, in general, shown potentially long service life with better resistance to pumping than full-depth slabs, but has shown durability inferior to that of full-depth pavements constructed with the same materials and in the same project.

The use of portland cement concrete resurfacing in the United States dates back to the early part of the century. Fleming (*5*)[1] states that the oldest recorded concrete resurfacing was built in Schenectady, New York, in 1909. The next oldest projects were built in Iowa and Ohio in 1911 and 1912, respectively. The resurfacing in these projects was quite thin, varying from 1 to 4 in. in thickness.

During the past 40 years concrete resurfacing has been used in many states to strengthen pavements and to provide a new, smoother surface. It has been constructed over a variety of old pavements of both rigid and flexible types. Designs used have varied widely in many respects. Thicknesses used have ranged from 1 to 8 in. (*20*), reinforcement from none to heavy bar mats. In some cases the resurfacing has been bonded to the old pavement, in others bond has been prevented by the use of some separating material. The use of joints in the concrete resurfacing has also varied widely.

Numerous papers have been published on concrete resurfacing; however, the majority of them are concerned with the design and construction procedures used on particular projects. Except for some data on cracking reported by Fleming (*5*) in 1932, there appears to be little published information on the field performance of concrete resurfacing in actual use on state highway systems.

The first portland cement concrete resurfacing built on the state highway system in Indiana was constructed in 1923. Many other projects were built at intervals after that, but no extensive performance survey had ever been made of the resurfacing. However, a survey of several projects was made by Woods (*19*) in 1942. The unpublished results of this survey indicated that the resurfacing increased the supporting power of the slab but that it was more susceptible to cracking and blowups than adjacent, full-depth slabs.

Since the present need for extensive rehabilitation of pavements has caused increased interest in resurfacing, the performance of projects which have been in use for long periods of time should be evaluated. The performance survey reported in this paper was made in 1950, with particular emphasis placed upon the relative durability of resurfacing and regular pavement slabs. Several years are required for performance features of concrete to become evident; therefore, the survey was limited to the concrete resurfacing projects built prior to 1943 (eight or more years old).

DESIGN OF CONCRETE RESURFACING IN INDIANA

Data on the design of the concrete resurfacing built in Indiana prior to 1943 are shown in Table 1. Typical cross-sections used are illustrated in Figure 1. A variety of pavement types—brick, concrete and bituminous—have been resurfaced with portland cement concrete having a minimum thickness of either 5 or 6 in.

Bar mat reinforcement, consisting of ½-in. square deformed bars spaced about 3 ft. apart in both the longitudinal and transverse directions, was used in the four resurfacing projects built from 1923 to 1930, inclusive. The resurfacing built during the period from 1934 to 1940 contained wire fabric reinforcement of No. 6 gage wires with 6- and 12-in.

[1] Italicized figures in parentheses refer to the bibliography at the end of the paper.

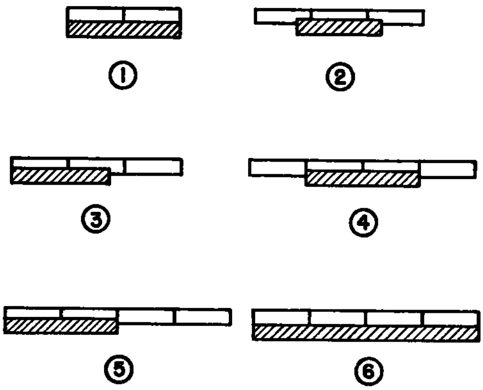
TABLE 1
LOCATION AND DESIGN DATA FOR CONCRETE RESURFACING PROJECTS

Road and Section	Contract No.	Project No.	Project Length	Year Built	Old Pavement Width	Old Pavement Type	Resurfacing Width	Resurfacing Net Length	Resurfacing Minimum Thickness	Resurfacing Reinforcement	Resurfacing Separation	Widening Thickness	Full-Depth Pavement Thickness	General Cross-Sections Used[a]
			mi.		*ft.*		*ft.*	*mi.*	*in.*			*in.*	*in.*	
40-B		FA61	1.278	1923	28	Brick[b]	28	1.125[c]	5	Bar Mat	None			1
37-L		125	1.896	1929	18	Brick[b]	18	0.522	5	Bar Mat	None		9–7–9	1
31-Y		207	4.567	1930	18	Bituminous[b]	40	4.567	5	Bar Mat	None	9	9–7–9	4[d]
40-L		201	5.816	1930	18	Concrete	30 & 40	5.816	5	Bar Mat	Asphalt Paint	7–9 & 9	9–7–9	2, 4[d]
9-OO	R-844	NRM412B	0.405	1934	21.5	Brick	34	0.301	6	Wire Fabric	1 in. Sand Cushion	9–7[e]	9–7–9	4
52-JJ	R-712	NRM40E	1.433	1934	30	Brick[b]	40	0.379	5	Wire Fabric	None	7–9	9–7–9–7–9	4
33-H	R-1098	NRM11D	1.525	1935	18	Concrete	30	1.131	5	Wire Fabric	Paper	7–9	9–7–9	2
33-H	R-1183	FA11F, A_1	5.484	1935	18	Concrete	30	3.593	5	Wire Fabric	Paper	7–9	9–7–9	2, 3[f]
67-L	R-1073	NRH263B, A_1	4.860	1935	20	Concrete	30	2.233	5	Wire Fabric	Paper	9 & 9–7–9	9–7–9	2, 3[f]
40-R	R-1128	NRHM5C, F	3.197	1935	18	Concrete	30, 40, & 48	2.665	5	Wire Fabric	Paper	9	9–7–9	3, 5[f]
40-R	R-1043	NRH5A_1	3.523	1935	18 & 20	Concrete	30 & 40	3.010	5	Wire Fabric	Felt	9	9–7–9	3, 5[f]
40-R	R-1044	NRHM5B	3.041	1935	18	Concrete	30 & 40	2.778	5	Wire Fabric	Paper	9	9–7–9	3, 5[f]
12-ZZ	R-1359	NRM367B, H	2 397	1936	24	Concrete	42	2.361	5	Wire Fabric	Paper	8–10	10–8–10–8–10	4
33-J	R-1450	FA420C	6.835	1936	18	Concrete & Brick	30	3.901	5	Wire Fabric	Paper	7–9	9–7–9	2, 3
29-J	R-1431	FA221F	2.246	1936	24	Concrete	22	0.690	5	Wire Fabric	Paper		9–7–9	1
40-M	R-1566	FA13F	5.357	1937	30	Concrete	58 & Dual 22	4.778	5	Wire Fabric	Paper	9–7[g]	7–9	5
24-P	R-1653	FA98G	2.291	1938	18	Concrete	Dual 20	0.563	5	Wire Fabric	Paper	9–7[g]	7–9	4
31-C	R-1968	FA21E_6	1.222	1940	18	Concrete	22	0.227	5	Wire Fabric	Paper	9	9–7–9	1
31-C, D	R-2038	SN-FA21A_4, E_3	1.078	1940	18	Concrete[h]	22	0.624	5	Wire Fabric	Paper	9	9–7–9	1
20-A	R-2326	193B_1,C_2	3 267	1942	40	Concrete[h]	40.25	3.141	6	None	Paper		9–8–9–8–9	6
20-A, B	R-2327	193C_2	2.802	1942	40	Concrete[h]	40.25	2.526	6	None	Paper		9–8–9–8–9	6
40-O	R-2251	SN-FA13B_2	5.951	1942	18	Concrete	22	0.346	6	None	Paper	9	9–8–9	1

[a] Generalized cross-sections are illustrated in Figure 1.
[b] Old pavement consisted of surfacing shown on a concrete base.
[c] Project consisted of 1.125 mi. of concrete resurfacing on brick and 0.153 mi. of concrete resurfacing on a concrete bridge floor.
[d] Outer full-depth lanes separated from resurfacing by longitudinal construction joint.
[e] 9–7-in. widening forms a 7-ft. parking lane on each side.
[f] Longitudinal butt joint between resurfacing and full-depth lanes.
[g] Widening and outer lanes integral, 9–7–9-in. section. Dual pavements separated by 4-ft. wide concrete median strip.
[h] Old pavement pumping badly when resurfaced with plain concrete in 1942.

spacings of the longitudinal and transverse wires, respectively. The outer four longitudinal wires at each side of the fabric sheets were of No. 0 gage.

Reinforcement was the same in the widening and in the full-depth pavement as in the resurfacing, except for the early projects with bar mat reinforcement. In these projects, the bar mat extended into the widening, but the reinforcement in the full-depth slabs consisted of a single $\frac{3}{4}$-inch round marginal bar a few inches from each edge.



CROSS-SECTIONS SHOWN ARE NOT TO SCALE, AND INDICATE ONLY THE RELATIVE POSITIONS OF THE RESURFACING AND THE OLD PAVEMENT. DATA ON PAVEMENT WIDTHS AND THICKNESSES ARE SHOWN IN TABLE I FOR EACH PROJECT.

Figure 1. Generalized Cross-Sections Used on Concrete Resurfacing Projects.

The concrete mixes used were the standard paving mixes used for all pavement construction. Prior to 1934, the cement content was 1.72 barrels per cubic yard. This was changed to 1.5 barrels in 1934, and this mix was used in all subsequent projects. Normal Type I portland cements and standard aggregate gradations for paving mixes were used.

The standard specifications for transverse joint spacing were generally followed in the concrete resurfacing projects. No expansion or contraction joints were used before 1934. In 1934, both expansion and contraction joints were adopted, with spacings of 105 and 35 ft. respectively. Later changes made the expansion joint spacings 80 ft. with one intermediate contraction joint, 100 ft. with two contraction joints at $33\frac{1}{3}$ ft. and 120 ft. with a 40-ft. contraction joint spacing. Contraction joints spaced at 20 ft. with an expansion joint spacing of 500 ft. or more were used in the plain concrete resurfacing built in 1942. In some projects no contraction joints were used, and the expansion joints were spaced 40 ft. apart.

In 18 of the 22 projects shown in Table 1, bond between the old pavement and the resurfacing was prevented by the use of a separating material. Materials used for this purpose included asphaltic paint, a sand cushion, subgrade felt, and subgrade paper; with the paper being used in a majority of the projects.

All except one of the concrete resurfacing projects reported here had some full-depth pavement included in the project. In some cases, the full-depth pavement was placed in new lanes beside the resurfacing; in others, it was constructed either at relocations of the highway or in sections where the old pavement was removed. Data on the full-depth sections and on widening built integrally with the resurfacing are also shown in Table 1. The full-depth pavement included in all of these projects was built under the same contract and with the same materials as the resurfacing.

PERFORMANCE OF CONCRETE RESURFACING IN INDIANA

During the summer and fall of 1950, each of the resurfacing projects was inspected and data were obtained on the transverse crack interval, number of blowups, and the prevalence of D-line cracking and scaling. In some of the short projects the entire length was checked carefully, in others the data were obtained from several short sections spaced throughout the project.

Crack-interval measurements were made by counting the cracks in a distance of several hundred feet as measured by a foot-odometer mounted in the car. Several such counts were made and averaged to obtain the value reported for the project. Estimates of the percentage of transverse cracks and (or) joints affected by D-lines were made on the basis of actual counts made in the same manner.

TABLE 2
PERFORMANCE DATA FOR CONCRETE RESURFACING PROJECTS

Project No.	Concrete Resurfacing					Full-Depth Pavement					Remarks
	Crack Interval[a]	Blow-Ups Per Mile	D-Line Cracking		Scaling[c]	Crack Interval[a]	Blow-Ups per Mile	D-Line Cracking		Scaling[c]	
			Severity[b]	Percentage of Cracks Affected				Severity[b]	Percentage of Cracks Affected		
	ft.					*ft.*					
FA61	11.8	3.1	Moderate	75+	Slight						No full-depth concrete
125	6.8		Slight	50	Moderate	12.3		Slight	20	Slight	
207	7.4	5 9	Slight	75+	Severe	15 4	1.1	Slight	50	Moderate	Some longitudinal cracking
201	7.0	16.0	Severe	75+	Severe	14.0	6.1	Slight	10	Slight	Longitudinal cracking common. Full-depth pavement pumping. Project resurfaced in 1950
NRM412B	17.0	0	None	0	Slight						Full-depth pavement (0.1 miles) resurfaced prior to survey
NRM40E		0	Slight	75	Severe		0	Slight	10	Slight	
NRM11D		0	Slight	20	Moderate		0	None	0	Slight	Some longitudinal cracking over edge of old pavement
FA11F, A_1	28.2	0	Moderate	75+	Severe	34.4	0	Slight	10	Slight	Data from part where cross-section 3 was used. Full-depth lane pumping
NRH263B, A_1	17.7	2 7	Moderate	75	Severe	18.2	0	None	0	Slight	Same as above
NRHM5C, F	11.7	0	Slight	50	Moderate	17.3	0	None	0	Slight	Corner breaks more common in resurfacing. Full-depth pavement pumping
NRH5A_1	10 3	0	Slight	50	Severe	13.0	0	None	0	Slight	Same as above
NRHM5B	12.4	0	Slight	50	Severe	15.2	0	Slight	10	Slight	Same as above
NRM367B, H		0	None	0	Slight		0	None	0	Slight	Small amount of longitudinal cracking over edge of old pavement. Resurfaced in 1950 because of dangerously slippery surface
FA420C		0	None	0	Slight		0	None	0	Slight	Small amount of longitudinal cracking over edge of old pavement
FA221F	15.1	0	Moderate	25	Slight	21.4	0	Slight	5	Slight	
FA13F	24.5	0	Slight	75	Moderate	22.1	0	Slight	10	Slight	Full-depth sections faulted
FA98G	28	0	Slight	5	None	28	0	Slight	5	None	Project was resurfaced in 1950 because of pumping
FA21E_6	35.4	0	Slight	75+	None	40.0	0	Slight	20	None	
SN-FA21A_4&E_5											Project resurfaced in 1948. No survey possible
193B_1,'C_2											Resurfaced in 1950, prior to detailed survey. Both resurfacing and full-depth pavement were cracked and faulted
193C_3	4 7[d] 7.7	0	None	0	Slight						Resurfacing in progress at time of survey in 1950. Insufficient full-depth pavement for survey. Small amount of pumping throughout the project
SN-FA13B_2		0	None	0	Slight		0	None	0	Slight	

[a] Crack interval reported is based on counts of both transverse cracks and joints in projects built in 1934 and later.
[b] Severity of D-line cracking was rated as follows:
Slight—areas only a few inches across affected at the intersection of transverse cracks and joints with the longitudinal joint.
Moderate—affected areas are from a few inches to a foot in size.
Severe—larger areas at crack or joint intersections, deterioration spreading along the joints and major cracks.
[c] Scaling was rated as follows:
Slight—Scaling found only in a few small, widely scattered spots.
Moderate—Scaling adjacent to 10–50 per cent of the transverse cracks or joints.
Severe—Scaling adjacent to higher percentages of the cracks and joints and/or extending appreciably into the centers of the slabs.
[d] Crack intervals shown are for outer and inner lanes, respectively, of 4-lane pavement.

Wherever possible, the performance of full-depth pavement in the same project was determined for comparison with the resurfacing.

On a few of the resurfacing projects which are subjected to heavy traffic, the concrete at the junction of cracks and joints is broken into small fragments. The performance resembles that observed on heavily traveled pavements in which known non-durable materials were used—definite D-line patterns are obscured by breakage of the weakened, deteriorated concrete under traffic. This similarity, and the fact that D-lines were found at some locations in these resurfacing projects, leads to the belief that the breakage is due to the effects of heavy traffic on deteriorated concrete. These broken areas were, therefore, included as D-lines in the survey.

The data obtained in the performance survey are shown in Table 2. No detailed evaluation of the prevalence or severity of pumping was made in the survey. However, the presence of pumping is noted in the "Remarks" column of the table for those projects in which it occurs.

For convenience in discussing the performance of the resurfacing projects, they will be divided into two groups: those 15 or more years old, and those that are 8 to 14 years old.

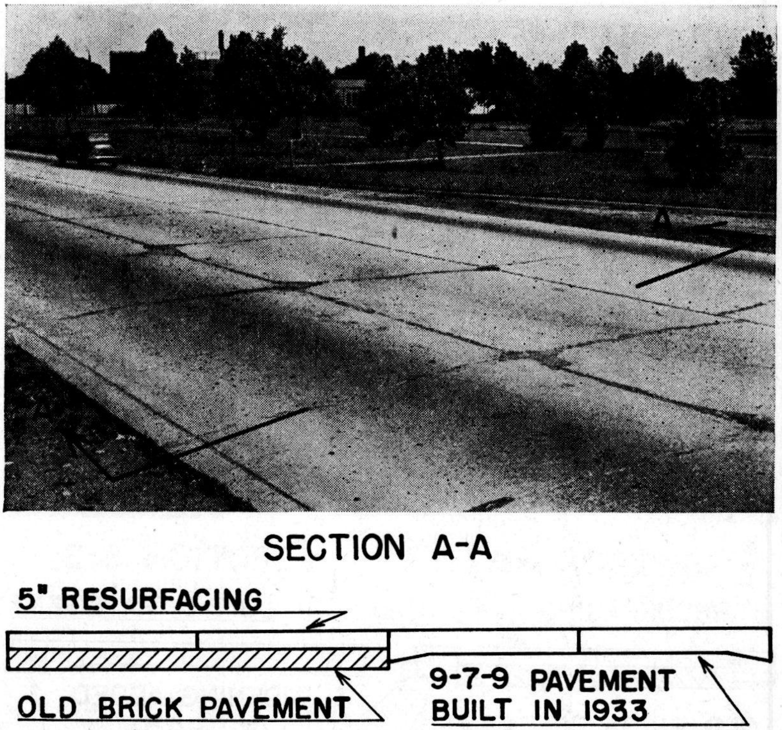


Figure 2. Indiana's First Concrete Resurfacing Project. This resurfacing (on the two lanes on the left) has carried the heavy traffic of U. S. 40 for 27 years.
Project FA61—U. S. 40, Sec. B
Date Built—1923

Performance of Resurfacing Projects 15 or More Years Old—The oldest concrete resurfacing project in the state, FA 61, contained no full-depth pavement. This 5 in. reinforced resurfacing, although it now has a moderate amount of D-line cracking and 3.1 blowups per mile, has carried the heavy traffic of US 40 for 27 years. It shows that concrete resurfacing is capable of an extensive service life. Figure 2 illustrates the appearance of this resurfacing.

The other project in this age group in which no comparison of full-depth pavement with resurfacing could be made was NRM 412 B.

In this case, the full-depth pavement was approximately 0.1 mi. in length at one end of the project and had been resurfaced prior to the 1950 survey along with an adjacent project, which accounts for the fact that comparisons could not be made. The concrete resurfacing in project NRM 412 B shows no deterioration after 16 years of use.

125, built in 1929, is shown in Figure 3. Even greater contrast in performance was found in projects 207 and 201 (both 20 years old), where deterioration of the resurfacing was pronounced. In both of these projects, several times as many blowups occurred in the resurfacing as in the full-depth pavement. Project 201 was patched extensively with con-

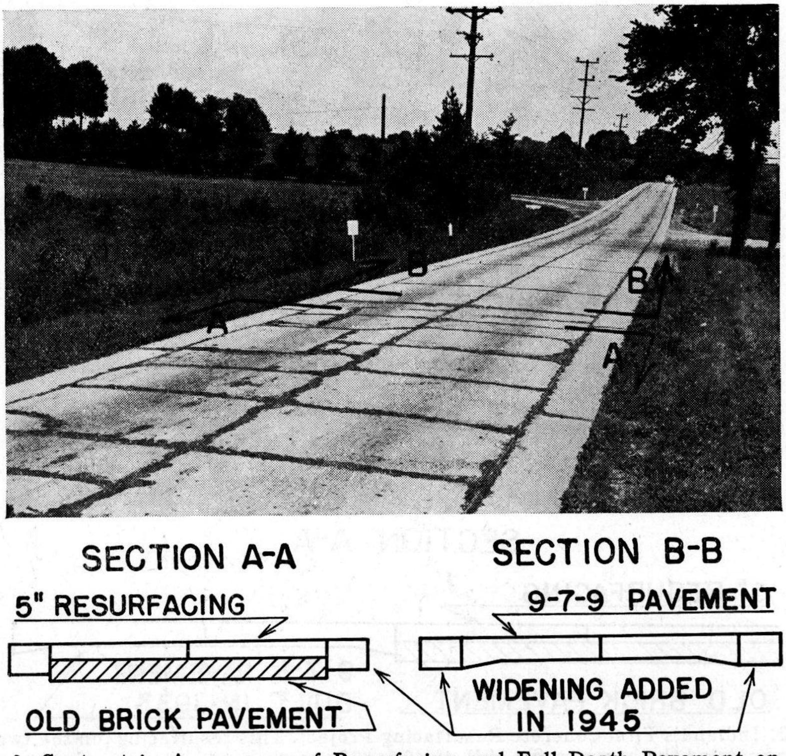


Figure 3. Contrast in Appearance of Resurfacing and Full-Depth Pavement on a 21-Year Old Project

Project 125—S. R. 37, Sec. L
Date Built—1929

The outstanding feature of the performance of the other 10 projects in this group is the poorer durability of the resurfacing as compared to the full-depth sections. In all of these projects the transverse crack interval was smaller in the resurfacing than in the standard slabs, and the resurfacing was much more susceptible to deterioration as evidenced by the greater prevalence of blowups, D-line cracking, and scaling.

The contrast in appearance of the resurfacing and full-depth pavement in project crete and resurfaced with a bituminous mix in 1950. In patching the badly deteriorated areas in the resurfacing, it was found that the old pavement underneath was still sound and it was left in place. A typical view of the four lane portion of this project is shown in Figure 4.

The appearance of FA 11 F, A_1, one of the 1935 projects, is shown in Figure 5. Six projects were built in 1935, and all of them show the same trends with respect to performance that are found in the older projects.

The pumping noted on several of the projects in this age group was confined almost entirely to the full-depth sections. Only a few isolated spots, where very extensive deterioration had taken place, showed any signs of pumping in the resurfacing. This indicates greater structural capacity in the resurfaced sections than in the standard pavement slabs on the natural subgrade.

were 193 B_1, C_2 and 193 C_3. Both of these projects had six inches of plain concrete on an old pavement that was pumping badly at the time it was resurfaced. Severe structural cracking and the beginning of pumping through the concrete resurfacing were the reasons for covering the projects with a bituminous surface course. No evidence of poor durability of the concrete was found in either the resurfacing or the full-depth sections. The fourth project resurfaced in 1950, FA 98 G, was also covered because of pumping in the outer full-depth lanes of the four-lane pavement. The concrete resurfacing, built in 1938 on the inside lanes, showed a small amount of deterioration, but no more than the same lanes where a 9-7-9-in. pavement section was employed.

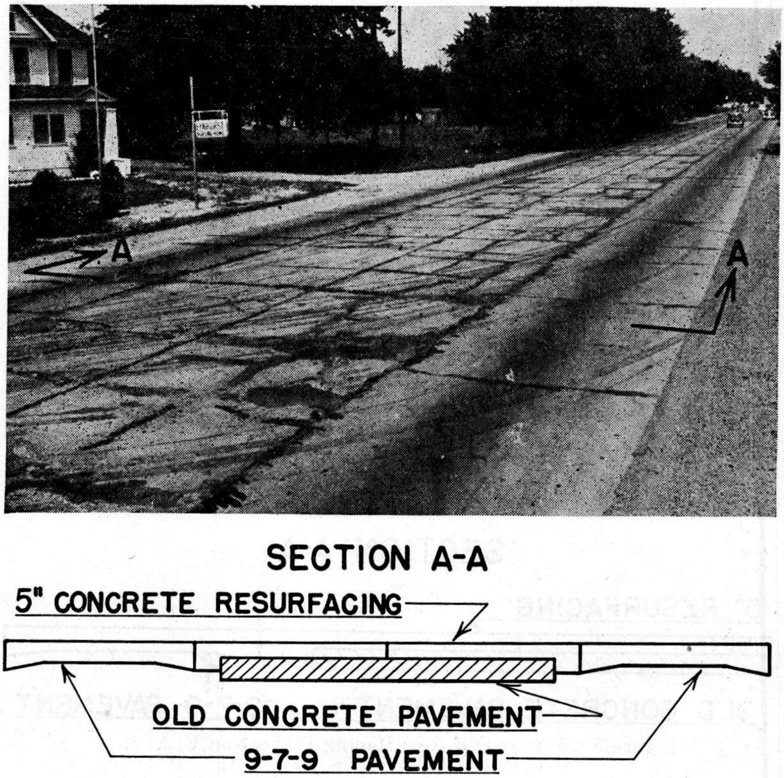


Figure 4. Typical Appearance of Project 201 After 20 Years
Project 201—U. S. 40, Sec. L
Date Built—1930

Performance of Resurfacing Projects 8 to 14 Years Old—One of the 10 concrete resurfacing projects 8 to 14 years old had been covered with a bituminous resurfacing prior to the survey. Four others were similarly covered during 1950. Of the latter four, project NRM 367 B, H showed excellent performance with respect to cracking and deterioration. The surface was dangerously slippery, however, necessitating construction of a new surface course. Two other projects covered in 1950

Three of the five projects in this age group which are still in service showed more severe deterioration from scaling and D-line cracking

in the concrete resurfacing than in the adjacent full-depth pavement. Figure 6 shows the appearance of one of the projects, FA 13 F, built in 1937. This difference was not as pronounced as in some of the older projects discussed above, probably because of the shorter time of exposure. Considering all of the projects inspected, one-third of those 8 to 14 years old show accelerated deterioration vice for 20 years at the time it was resurfaced; the 11 still in use range in age from 15 to 27 years. The relatively poor showing of the projects 8 to 14 years old with respect to the number still in service is due to resurfacing of slippery and pumping pavements. Only two projects had any significant amount of pumping in the concrete resurfacing; it was confined to the adjacent, full-depth pavement in

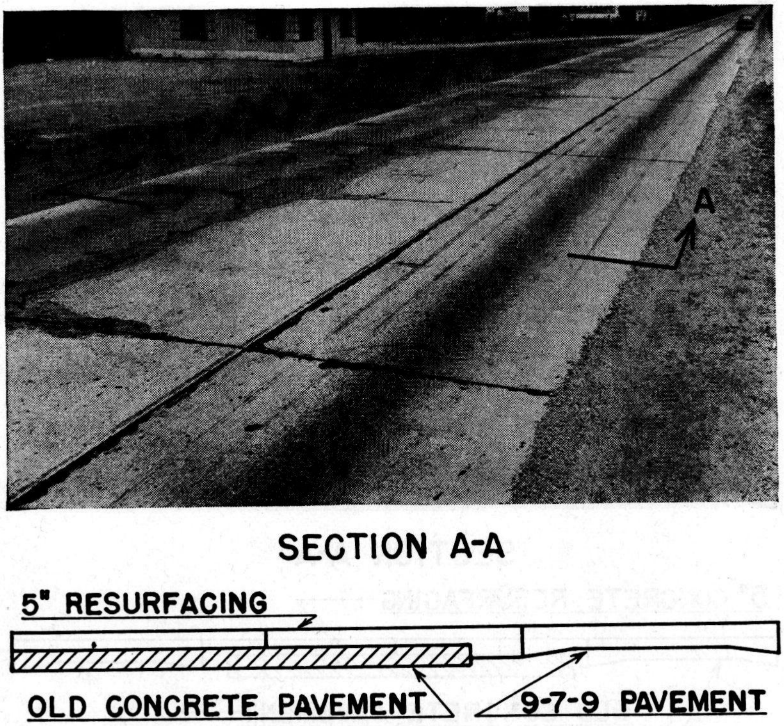


Figure 5. 15-Year Old Resurfacing Project on U. S. 33
Project $FA11A_1$—U. S. 33, Sec. H
Date Built—1935

of the resurfacing as compared to full-depth pavement sections built with the same materials.

GENERAL DISCUSSION

A brief summary of the performance of the concrete resurfacing projects built in Indiana prior to 1943 is shown in Table 3.

The potential service life of concrete resurfacing is shown by the number of projects 15 or more years old that were still in service at the end of 1950. The one project in this age group that was covered had been in ser-

all others. In both of these projects, the concrete resurfacing was not reinforced and was placed on a badly pumping old pavement. No undersealing or other treatment was used on the old pavement before the concrete resurfacing was built.

The outstanding performance feature revealed by the survey is the relatively poorer durability of the concrete resurfacing as compared to the adjacent, full-depth pavement. The comparison was made, in every case, between resurfacing and standard slabs that were both constructed on the same project,

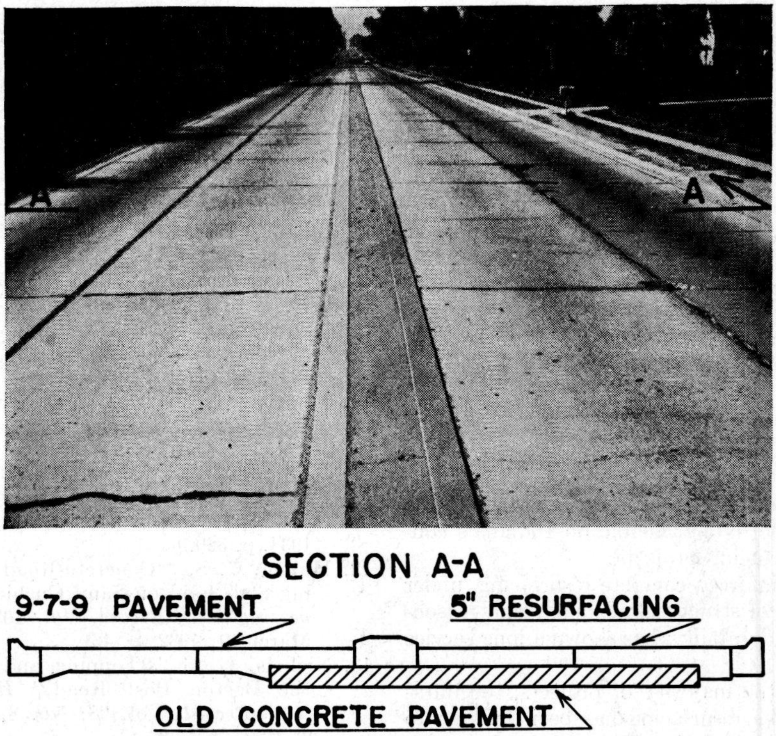


Figure 6. Typical Appearance of Project FA13F After 13 Years
Project FA13F—U. S. 40, Sec. M
Date Built—1937

TABLE 3

SUMMARY OF PERFORMANCE OF CONCRETE RESURFACING PROJECTS

Description	No. of Projects	
	15 or More Years Old	8–14 Years Old
Total resurfacing projects built	12	10
Total projects inspected	12	9
Relative durability of resurfacing and full-depth pavement:		
Resurfacing poorer	10	3
No difference or no comparison possible	2	6
Projects still in service at end of 1950	11	5
Projects covered with bituminous resurfacing in 1950	1[a]	4[b]
Projects covered with bituminous resurfacing before 1950		1[b]

[a] One project covered after 20 years service showed both inferior durability of the concrete resurfacing and pumping of the full-depth pavement.
[b] One project covered prior to survey (8 years service), one after 14 years service because of slippery surface, two after 8 years service because of pumping of the concrete resurfacing, one after 12 years service because of pumping in full-depth outer lanes of 4-lane pavement.

under the same contract, and with the same materials. The concrete placed in the resurfacing and in the adjacent, full-depth slabs should, therefore, be identical in any given project. Despite this fact, the poorer durability is shown by the resurfacing in 10 of the 12 projects 15 or more years old, and in three of the nine projects 8 to 14 years old that were inspected. In all of the other projects, there was no difference in durability or no comparison could be made between the resurfacing and full-depth slabs.

The deterioration that has taken place to a greater extent in the resurfacing than in the full-depth pavement includes scaling, D-line cracking, and blowups. The data available at the present time do not indicate any correlation that would explain the accelerated deterioration of the resurfacing noted in so many cases. However, it seems probable that the major factor causing the deterioration is the effect of freezing and thawing, which could be accelerated by the presence of more water in the resurfacing. The greater number of transverse cracks in the resurfacing, combined

with a relatively impermeable old pavement beneath, may result in increased infiltration and ponding of water under the resurfacing, thus subjecting it to more severe moisture conditions than the full-depth sections. The lesser thickness of the resurfacing may also contribute to more severe effects from temperature and moisture changes.

Any explanation advanced at the present time can be only a hypothesis, since substantiating data are lacking. The problem is believed to be worthy of further study and investigation, because any improvement that could be made in the durability of concrete resurfacing would be reflected directly in increased service life.

CONCLUSIONS

The following conclusions are drawn on the basis of the data available on Indiana's concrete resurfacing projects:

1. Reinforced concrete resurfacing, under conditions of structural adequacy and reasonably good durability, has shown a long service life.

2. In the majority of projects, the durability of the resurfacing has been inferior to that of full-depth slabs built of the same materials and under the same contract.

3. Old pavements resurfaced with 5 inches of reinforced concrete have been less susceptible to pumping than standard pavement slabs in the same project.

4. A need is indicated for additional investigation to make increased service life of concrete resurfacing possible by utilization of the full potential durability of the concrete mix used.

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DISCUSSION

M. P. BROKAW, *Regional Highway Engineer, Portland Cement Association*—During the past 20 years the Portland Cement Association has surveyed the condition of concrete resurfacing in many locations throughout the United States. The data collected have been used to formulate suggestions for design and construction practices which would improve resurfacing performance. Fleming's paper in Highway Research Board *Proceedings*, Vol. 12, and subsequent bulletins issued from time to time were based in part on observations made in Indiana.

As shown by Mr. Lewis, there is ample opportunity to compare resurfacing and full-depth pavement constructed in contiguous locations. However, the significance of a comparison of this kind depends on several factors which are known to control the performance of resurfacing, yet have little effect on full-depth pavement placed on a soil subgrade. When resurfacings become inadequate in thickness for traffic or when certain beneficial design and construction practices, such as those suggested by Fleming, are not followed, cracking, shattering, ravelling and exfoliation will become more severe than in full-depth slabs. Where less durable materials are used, especially without air-entrainment, these defects create conditions conducive to deterioration because of increased exposure.

A study of the traffic, designs and conditions in the field has led to the conclusion that the majority of the manifestations of lower durability in the Indiana resurfacings are secondary distress induced by excessive cracking and ravelling followed by accelerated weathering. This conclusion is different from that suggested by Mr. Lewis since he has included the imperfections in the tabulation of deterioration due to D-line cracking. Several factors preclude this procedure.

Traffic on the resurfacings ranges from 1,300 to over 20,000 vehicles per day with an average of about 9,000. All except one are on routes where loadometer surveys show from 60 to more than 200 axles per day in excess of 18,000 lb. New pavements now being designed for some of these highways are 9 in. thick. This indicates that structural breakage should be expected on many of the 5-in. resurfacings which have served from 10 to 25 yr. and were placed on bases of unknown quality and strength.

A survey of the condition of resurfacing projects, constructed in 1945 and 1946 but not covered in the present study, shows the same pattern of cracks, broken areas and ravelling. In comparison with the full-depth slabs these could be interpreted as symptoms of inferior durability. However, lack of substantial age and the use of air-entrained concrete eliminates the possibility that deterioration of the concrete preceded the breakage.

Likewise, an examination of 3-lane pavements (those designated as cross-section number 3) shows the major distress in the outside resurfaced lane carrying the heaviest traffic and having a minimum 5-in thickness. The interior resurfaced lane, varying in thickness from 5 to 8 inches, and the 9-in. widening is far superior and in many cases surpasses the adjacent full-depth lane. Of further significance is the inferior performance of the integral longitudinal joint in the 5-in. resurfacing when compared with the adjacent longitudinal construction joint in the 9-in. widening. Where the resurfacing has thicknesses sufficient to prevent breakage and the longitudinal joint is adequate, there is no evidence of deteriora-

tion. If D-line cracking preceded breakage, it would as likely be present along both of the joints.

Another example is the performance of project NRM 412B. Other than intermediate

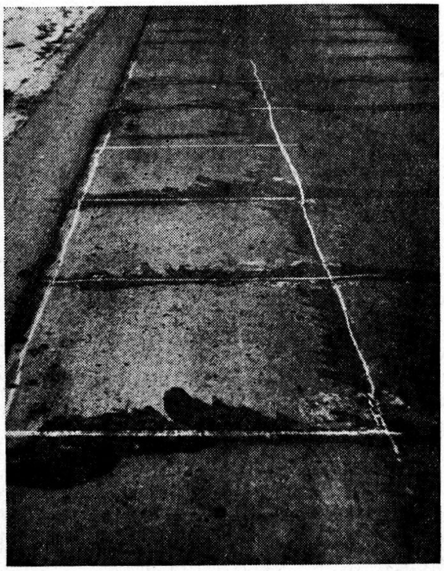

Figure A. Transverse Cracks Over Bar Mat Reinforcing—White lines show planned location of bars. Project 125

Figure B. Deterioration Around Bar Placed Within ½ in. of Surface—Cracks Over Bonded Edge Bars Shown Next to Pavement Widening—Project 125

cracking in the 35-ft. reinforced panels there is no evidence, after 16 years, of unusual breakage, ravelling or deterioration. The absence of conditions favoring lower durability may be attributed to the light traffic which now is about 1,300 vpd.

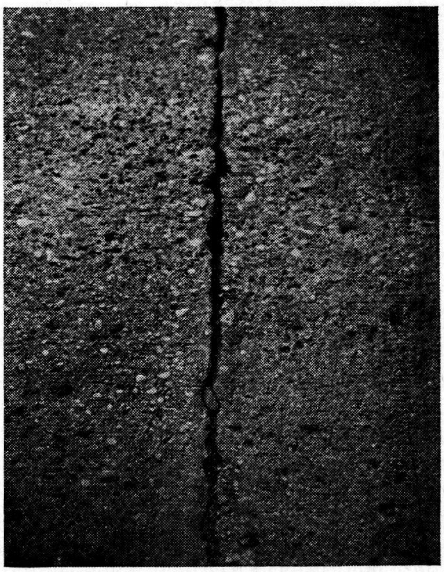

Figure C. Construction Joint in 27-Year Old Resurfacing, Showing Excellent Durability and Freedom from 'D'-Cracks—Project FA-61

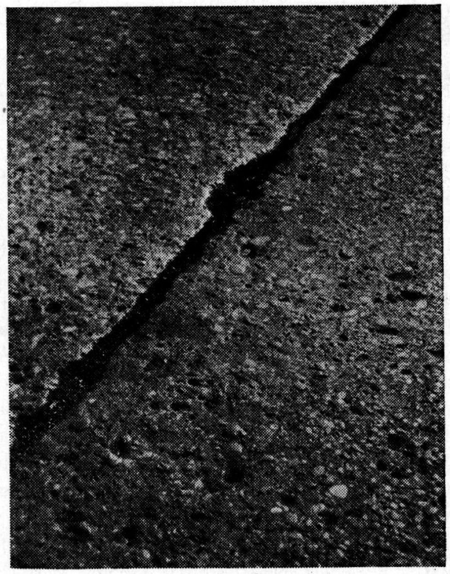

Figure D. Expansion Joint in 27-Year Old Resurfacing—Excellent durability has accompanied freedom from structural defects. Project FA-61

Some of the projects show the relative effect of material durability on performance. Projects NRM 367B, H and FA42OC have excellent records although both were subjected

to heavy traffic and have some abnormal cracking. The fact that subsequent deterioration has not been observed may be due to the use of excellent coarse aggregates of proven quality. While these examples are not particularly significant individually, they are cited to show the effect of quality of material on performance where weathering has been accelerated by physical conditions.

Several design details peculiar to resurfacings have greatly affected long-time performance and relative durability.

Reinforcement.—The four oldest projects, reinforced with bar-mats, have shown unusual transverse and longitudinal cracking. Many of the bars, placed at or near the surface, induced cracking and accelerated ravelling and deterioration. The difference in crack interval between the resurfacing and the full-depth pavement, which had only smooth longitudinal edge bars, is caused by the bar-mats. Severe deterioration at many of these cracks is represented by the unusual number of blow-ups reported. Similar performance was observed by Fleming in California. Figures A and B show the cracking induced by this type of reinforcement in Project 125. Figures C and D illustrate excellent durability in Project FA-61, now 27 years old, where exposure has not been increased.

Joints.—The spacing of joints in projects constructed after 1930 has not contributed to inferior durability. The joint-crack intervals are slightly smaller for the resurfacings in some projects but not more than should be expected from the differences in subgrade characteristics.

Transverse joints have shown average performance. Exceptions exist, however, in most of the projects constructed in 1935. These have many expansion and contraction joints which are inoperative because of misaligned or frozen dowels. This has resulted in mid-panel cracks with fracture of the mesh reinforcement in both the resurfacing and full-depth pavements. Wide opening of the cracks disengaged aggregate interlock which resulted in severe pumping of the full-depth slabs placed on soil subgrades or additional structural breakage of the weakened resurfacing. Figure E illustrates an open mid-panel tension crack which has caused shattering at the longitudinal joint of a 5-in. resurfacing. Figure F is a push-up at an expansion joint in Project NRH 263B,A1 resulting from restraint due to

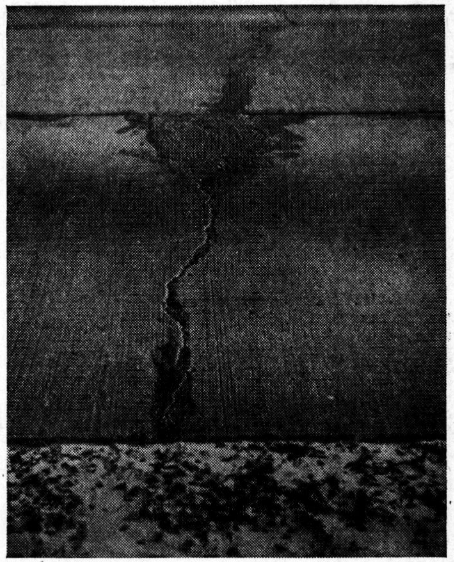

Figure E. Open Mid-Panel Tension Crack, Caused by Frozen Dowels, Which has Created Weakness at the Longitudinal Joint of a Five-Inch Resurfacing—Project NRH 263B, A1

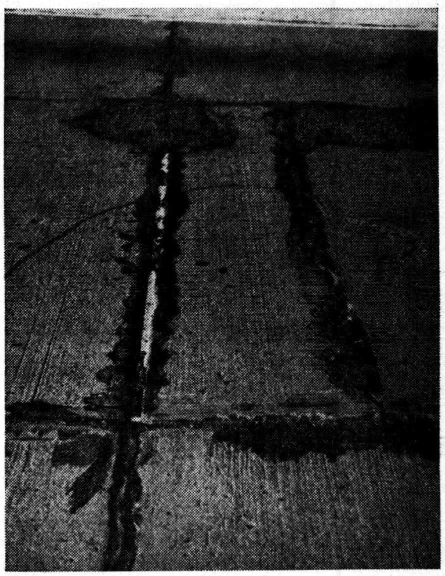

Figure F. Push-Up Caused by Frozen Dowels and Horizontal Splitting in the Plane of the Reinforcing—The concrete is in excellent condition and free from 'D'-cracks. This defect is not related to inferior durability. Project NRH 263B, A1

misaligned dowels. This defect is reported as a blow-up, although it is not caused by inferior durability. Damage resulting from misaligned and frozen dowels can be prevented by careful installation of a stable dowel support of the type now generally employed.

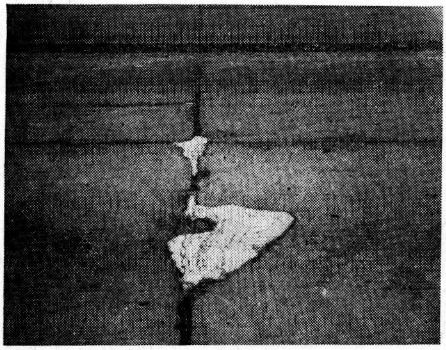

Figure G. Ice Frozen from Water Ejected Through Open Transverse Joint in Unbonded Resurfacing—Note exfoliation at point of ejection. Project FA13F

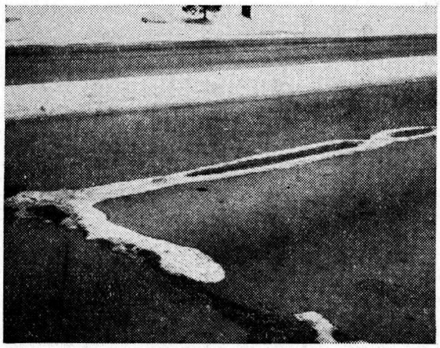

Figure H. Ice Forming Along Longitudinal Joint in Unbonded Resurfacing—Water is ejected from separation plane under resurfacing. Project FA13F

The design of longitudinal joints constructed integrally with resurfacings has had an important bearing on both structural and durability performance. The need for a strong longitudinal joint has been demonstrated in Figure 8 of Fleming's paper. This should consist of a groove, with a poured or premolded filler, one-fourth the thickness of the resurfacing. The adjacent lanes should be tied across the joint with bars of appropriate size spaced not over 30 in. center to center. Nearly all of the Indiana projects have 2-in. or 2½-in. poured grooves or premolded fillers in the 5-in. resurfacings. In many locations it is possible to observe that the actual installation, especially of premolded filler, is made to a greater depth. Likewise, tie-bars are generally spaced at 60-in. centers. The weakness of the joint has resulted in many interior corner breaks and shattered areas, and spalling and ravelling at the intersections with transverse joints and cracks. The same design is employed for some 7- and 8-in. full-depth slabs and performance is satisfactory because the effective depth under the groove is not re-

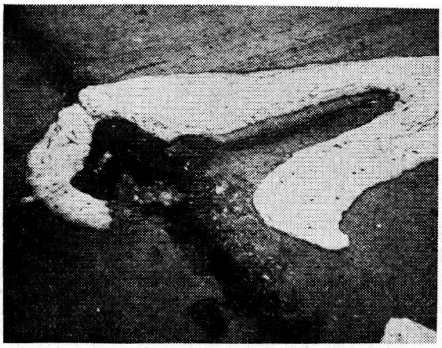

Figure I. Ice Forming at Intersection of Transverse and Longitudinal Joints in Unbonded Resurfacing—Mechanical breakage due to freezing is in progress. Project FA13F

duced below a safe level. Where untied longitudinal construction joints are used in resurfacings with depths of eight inches, excellent results have been observed. Figures 5 and 6 in Mr. Lewis' paper illustrate the comparative performance of longitudinal joints.

Separation of Resurfacing and Base.—The variety of separating treatments is limited, yet there is a definite indication that the incidence of interior corner breaks is higher with paper or felt separation. An exception is NRM-412B which employs a 1-in. sand cushion, shows excellent performance but has relatively low traffic.

A field check of performance has shown that water may accumulate in the separation plane between resurfacing and base. The water is ejected intermittently by the passage of heavy wheel loads. This action increases the winter exposure and has accelerated the rate of deterioration along the longitudinal and trans-

verse joints in the resurfacing. Similar action was not observed on adjacent full-depth pavements where the soil subgrade afforded more positive drainage, or where paper separation was not used with the resurfacing. Figures G, H, and I show ice accumulations on Project FA13F formed from water originating in the separation plane under a 5-in. resurfacing. It can be concluded that thin separating courses are detrimental and should be avoided in the interest of providing greater slab strength and of reducing exposure.

Proportions and Aggregate Size.—The maximum size of coarse aggregate has considerable influence on long-time performance. Fleming recommended a maximum of one-third the depth of resurfacing. This would be less than 1¾ in. for a 5-in. pavement. Records of the Indiana projects show that those constructed after 1930 had a maximum aggregate of 2¼ in. for both resurfacing and full-depth slabs. Difficulty in handling and placing this mix in 5-in. pavements with distributed reinforcement and dowelled joints is reflected in defects observed in several projects. These include segregation of the concrete under dowels and at interior joint corners and insufficient cover over distributed reinforcement.

Adjustments in the mix to accommodate smaller aggregate would have improved workability and made unnecessary the addition of extra water to facilitate placement. The later condition described in the construction record, prevailed on at least one project, NRM 40E.

Summary.—The performance of concrete-resurfacing in Indiana, and elsewhere, can be improved by continued selection of durable material, the use of air-entrainment and the adoption of design and construction practices which have been found beneficial. The condition survey and presentation of pertinent data by Mr. Lewis are valuable contributions which again call attention to the importance of these factors.

D. W. Lewis, *Closure*—The discussion by Mr. Brokaw contains several items of particular interest in developing an explanation of the causes of poorer durability in the concrete resurfacing as compared to adjacent full-depth slabs. It is possible, as he points out, that extra water was added to the concrete mix in the resurface slab to facilitate placement in the thinner sections. The use of more water would, in all probability, decrease the durability of the concrete.

Of even greater significance is the observation of water accumulation in the separation plane between resurfacing and base. Figures G, H and I of Mr. Brokaw's discussion are excellent examples of a condition in which the resurfacing is subjected to more severe conditions of exposure than those of the adjacent full-depth slabs. This increased exposure would accelerate the deterioration of any concrete that was at all susceptible to damage by freezing and thawing.

The author is not in agreement with Mr. Brokaw's opinion that the lower durability shown by Indiana's concrete resurfacing is a secondary distress which follows structural failure. In several of the projects which show severe deterioration, there can be no doubt that the durability of the concrete in the resurfacing is very much inferior to that in the full-depth slabs. This condition is shown by the occurrence of D-lines and progressive scaling in locations where there is little or no structural breakage.

In comparing the performance of the longitudinal joints in Figures 5 and 6 of the original paper, a comparison is being made of a joint in 5-in. concrete subjected to severe exposure by accumulation of water under it with a joint in 7-in. or 9-in. concrete that is exposed to less water. Accelerated weathering along the joint in the resurfacing would logically be expected from the factors of thinner thinner section and more severe exposure. D-line cracking should not be expected to occur along both joints at the same time and to the same degree. It is unnecessary to assume that structural defects exist in one of the joints in order to account for the differences in performance.

With regard to the cracking of the early projects in which bar mat reinforcement was used, a major portion of the cracks did form over the bars, resulting in a very short transverse crack interval. However, the relative durability of the resurfacing and full-depth concrete was studied on the basis of the percentage of cracks affected and the severity of the deterioration, and not on the total amount present. It is believed that such a rating method gives a true picture of the relative

durability regardless of the crack intervals involved.

The projects which have the best performance records are NRM 412 B, FA 420 C and NRM 367 B, H. Of these, NRM 412 has a sand cushion which may have prevented the accumulation of water under the resurfacing; the other two projects, as pointed out in the discussion, were constructed with a coarse aggregate that has a very good field performance record, which may have resulted in more durable concrete. In addition, the oldest projects still in service were built without separating courses, which would probably result in some bond to the base and at least partial elimination of the water accumulation noted by Mr. Brokaw. Although positive conclusions cannot be drawn from so few projects, it seems probable that their better performance is due to either the use of more durable concrete or to a decreased severity of exposure, without regard to their structural adequacy as compared to other projects.

An inspection was recently made of the concrete resurfacing projects constructed in Indiana during 1945 and 1946. The project built in 1945 has numerous large corner breaks and some longitudinal cracking. In more than two miles of resurfacing, however, only one break was noted that showed the disintegration so common in the older projects, and some D-line cracking was evident at this location. No defects were found in the full-depth sections. In the 1946 project, only one structural failure was found—a transverse break that occurred between two and three feet from a joint. Close inspection of this project revealed minor D-line cracking at 50 percent of the transverse joints in the resurfacing as compared to less than 10 percent of the joints in the full-depth sections. Whether or not these defects will progress to the severity found in the older pavements can only be determined by time.

Several worthwhile design and construction practices have been discussed by Mr. Brokaw. It is the author's opinion that the adoption of any such practices that will result in either concrete that is less susceptible to deterioration from weathering, or in reduced severity of exposure, will extend the service life of concrete resurfacing.

THE OVERLAY OF RIGID PAVEMENTS

Robert R. Philippe, *Engineer, Director,* and Carl H. Christiansen, *Head, Field Development Section, Ohio River Division Laboratories, Corps of Engineers*

SYNOPSIS

Some airfield pavements designed for the lesser loads of World War II aircraft now have insufficient bearing capacity for present use. The Corps of Engineers has completed many investigations to indicate the best method of increasing the bearing capacity of such pavements. The most interesting of these are three parallel full-scale traffic tests conducted at MacDill Field, Florida; Maxwell Field, Alabama; and Lockbourne Air Force Base, Ohio. The tests at the three sites were conducted with a 60,000-lb. load on dual wheels of the B-29 aircraft configuration, with a rigid base pavement 6 in. thick, uncovered, covered with flexible types of overlay 3 to 12 in. thick, and rigid type overlays 6 to 9 in. thick. The success of flexible type overlays was pronounced; indicating that this type of treatment appears to be the most successful method to increase the bearing capacity of an existing rigid pavement.

Many of the airfield pavements of portland cement concrete built during World War II were not designed for the increased loads of modern military aircraft. This has created the general problem of making these pavements adequate for present day operations. The only solution, other than complete reconstruction, is to reinforce the existing pavements by means of an overlay. This method of increasing the wheel load capacity of airfield pavements appears to be the more economical solution, and in most cases will fit into the overall expansion program of an air base. Other problems, such as the effect of