HIGHWAY RESEARCH BOARD
Bulletin 87

Concrete Resurfacing of Concrete Pavement in Various Stages of Deterioration

National Academy of Sciences—
National Research Council

publication 313

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2101 Constitution Avenue, Washington 25, D. C.

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PRESENTED AT THE
Thirty-Third Annual Meeting
January 12-15, 1954

1954
Washington, D. C.

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Concrete Resurfacing of Concrete Pavement in Various Stages of Disintegration

D. E. GOTHAM, Senior Engineer, and GEORGE W. LORD, Senior Engineer,
Missouri State Highway Department

● THERE are many miles of old concrete pavement in Missouri that might be made serviceable for an extended period of time by widening and resurfacing. Considerable information and experience are available regarding resurfaces of various types, but little is known regarding specific effects of the old pavement condition on the performance of resurfacing. Customarily when an old pavement is to be resurfaced, whatever reconstruction or maintenance considered necessary is done in preparation for resurfacing, but seldom has any attempt been made to record variations in the condition of the old pavement so as to study the effects of such variations. The experimental concrete resurfacing of an old pavement on Route 40, which had been under observation for a number of years, presented an opportunity to study not only the effects of wide variations in the old pavement condition on concrete resurfacing of different thickness, but also to analyze the influence of several other factors, such as the type and spacing of transverse joints, distributed reinforcement, and drainage conditions.

The original old concrete pavement was 9-6-9 Bates-type, 18 ft. wide, constructed in 1924 and 1925 with chert gravel coarse aggregate produced locally. No distributed reinforcement nor transverse joints (except construction joints) were used. After less than four years of service, it began to show serious distress in many places from a type of deterioration termed map cracking. Intensive studies were made to investigate the causes, rate, and mode of progression, and methods of treatment of this deterioration. In connection with the investigation, a strip map was made on which was sketched in detail the defects in the old pavement, drawn to scale and located by stationing. This provided an accurate record of the old pavement condition as observed at periodic intervals and permitted correlating the defects that developed in the resurfacing with those in the old pavement.

EXPERIMENTAL CONCRETE RESURFACES

There were two experimental concrete-resurfacing projects built on this road, the first in 1932 and the other in 1936. In the 1932 investigation, two sections of concrete resurface were built, one with 6-inch minimum thickness and the other 4-inch. Each section was about ¼-mile long and was purposely located so as to cover old pavement which contained subsections in all stages of deterioration. In the 1936 resurface, which totalled 11¾ miles in length, three thicknesses were used, 4 inches, 5 inches, and 6 inches, but the 4-inch resurface was put on old pavement in relatively good condition, the 6-inch resurface on old pavement in the worst condition, while the 5-inch resurface was laid on old pavement in intermediate stages of deterioration. Table 1 gives certain construction features that are distinctive to the resurfaces available for study.

The 2AA Summary Sheet (which follows Appendix C of this report) gives detailed construction data for Sections M52 & F. A. P. 144B, Callaway County. Since Projects 144C, Callaway County, and 273A, Montgomery County, which were constructed with 144B have similar construction features, summaries for these have been omitted.

Early in the investigation of the old-pavement disintegration, detailed subgrade-soil studies were made to ascertain whether or not inadequate subgrade support might have had an important influence on the cause and development of the map cracking. Following the subgrade studies, it was reported that the type of soil in the area traversed by the road was Putnam silt loam, one of the most difficult to drain and most-unmanageable soils encountered in Missouri highway construction. Four profile horizons were found which not only varied in thickness but also differed greatly in textural composition, physical proper-

TABLE 1

Features of the Various Resurfaces in the Investigation

Year Built	Thickness (Min.)	Width	Relative Condition of old Pavement	Widening Each Side (Monolithic)	Distributed Reinforcement	Transverse Joints			Longitudinal Joint	Length of Service (Years)
						Type	Spacing	Load Transfer		
1932	4"	20' Lip Type	Good to bad	1' wide x 9" thick	Bar Mat	¾" open	40'	None	Premolded Bituminous with tie bars @ 5' c-c.	12
"	6"	"	"	"	"	"	"	"	"	18½
1936	4"	22' Lip Type	Good	2' wide x 9" thick	43# wire mesh	1" premolded Bituminous	50'	¾" x 2'	"Marker-Seal" without tie-bars	15
"	4"	"	"	"	"	"	"	"	"Marker-Seal" with tie-bars @ 5' - c-c.	15
"	5"	"	Intermediate	"	"	"	"	"	"	15
"	6"	"	Bad	"	"	"	"	"	"	15

ties, and permeability. According to the AASHO Designation M 145-49 method of group classification, the soils in the various horizons were included either in Group A-4(8), A-7-5(19) or A-7-6(14).

The topography was level to undulating and the road grade varied from 0 to 5 percent through alternate cut and fill sections. In cut sections on different portions of the road the subgrade was composed of one or another of the horizons, and often an impervious layer of heavy clay was intercepted by the grade line. On fill sections the subgrade was generally composed of a mixture of soil from two or more horizons. As a result, wide variations in drainage conditions were encountered and the subgrade support was exceedingly non-uniform. It was concluded that the subgrade soil was not a primary factor in causing map cracking but that the disintegration developed more extensively and progressed to total failure more rapidly in areas of low subgrade support.

Route US 40, on which the experimental project was located, is the principal cross-state thoroughfare between St. Louis and Kansas City. As compared to other main routes in the state, US 40 carries a relatively large volume of heavy trucks. Table 2 indicates the annual average daily number of vehicles and heavy trucks that travelled the sections of pavement under observation. The section of old pavement that was resurfaced in 1932 carried 1,126 vehicles per day (based on annual averages) from 1926 until it was resurfaced. The minimum average daily traffic for one year was 996 and the maximum was 1,232. Of these total vehicles, the average number weighing over 10,000 lb. was 43; the maximum average daily volume for one year was 77 over 10,000 lb. and the minimum average daily number over 10,000 lb. was 14.

Table 2 shows similar values—minimum, maximum, and average daily volumes (computed on an annual basis) of all vehicles and of trucks over 10,000 lb.—for the old pavement resurfaced in 1936 and for the 1932 and 1936 resurfaces. The trend toward increasing volumes of heavy trucks can be seen from the tabulation; during 1951 the average daily volume of vehicles was 2,649 of which 475 weighed more than 10,000 lb. It should be kept in mind that all of the resurfaces were subjected to the same traffic since 1936 and that the volume of traffic and number of heavy loads increased annually.

Studies of the old pavement led to the conclusion that its early deterioration was due primarily to the use of an inferior coarse aggregate (chert gravel). It was also observed that deterioration ordinarily occurred first and progressed faster at points where the pavement was subjected to concentrations of water. Such concentrations of water caused loss of subgrade support and rapid disintegration of the concrete from excessive internal stresses due to

TABLE 2

Annual Average Daily Volume of Traffic to Which the Old Pavement and Resurfaces were Subjected

	Period of Time	Total Loads over 10,000 lbs.			Total Volume of Traffic		
		Min.	Max.	Avg.	Min.	Max.	Avg.
Old pavement before resurfacing in 1932	1926 to 1932	14	77	43	996	1232	1126
Old pavement before resurfacing in 1936	1926 to 1936	14	170	92	996	1232	1107
1932 Resurfaces	1932 to 1951	97	475	298	960	2649	1439
1936 Resurfaces	1936 to 1951	188	475	339	960	2649	1532

alternations of freezing and thawing. The heavy wheel loads on this route passing over the rough pavement caused excessive impact stresses, which hastened the progress of the disintegration.

GENERAL SERVICE RECORD

When concrete resurfacing was recommended, it was assumed to have certain advantages for use in reconstructing such a deteriorated old pavement. In the first place, it should prevent impact by presenting a smooth surface to traffic. Secondly, if joints and cracks were properly sealed with asphaltic material, it should protect the base from the surface water. Thirdly, being a rigid material, it should distribute load stresses over relatively large areas, preventing excessive concentrations of such stresses in small areas of the weakened base.

The performance of the concrete resurfacing on this road indicated that these assumptions were correct. The 1932 resurface gave satisfactory service for more than 12 years. When the 4-inch section was covered with a bituminous mat in 1944, it was still serviceable and, no doubt, could have been maintained satisfactorily for a longer period. It was covered primarily as a maintenance experiment to improve riding qualities and to see if such treatment might prolong its life. The 6-inch resurface built in 1932 gave excellent service for 18½ years and, when resurfaced in 1951, was apparently still good for several years of service without excessive maintenance.

The results obtained with the 1936 resurface sections during the 15 years they were in service varied considerably. The 6-inch sections gave good service and could have been used for several more years. A few of the 4-inch and 5-inch sections showed some deterioration after only 8 years of service, and in 1944 a length of 2,550 feet was covered with bituminous mat as part of the maintenance experiment mentioned above. After 15 years of service many of the 4-inch and 5-inch sections showed distress, largely from surface deterioration, but the road as a whole (the combined concrete base and resurface) still maintained its integrity and load-carrying ability. Because of the surface roughness and impending progressive surface disintegration, it was considered advisable in 1951 to cover the entire length of concrete resurface with 3 inches of asphaltic concrete.

OBSERVATIONS DURING SERVICE

In both the 1932 and 1936 resurfacing, some transverse cracking was noticed soon after the concrete was placed, but much more was observed in the 1936 construction. Early cracking in the 1932 pavement was not serious. However, 6 months after construction, 10 transverse cracks were found, all in the 4-inch resurface. Most of these had developed over old cracks at ends of long, unbroken slabs in the old pavement. No signs of deterioration were observed in the 6-inch resurface within the first 2 years.

The 1932 resurface was poured in December, when both the old pavement and the resurfacing concrete were cool and in relative contracted volume. Conditions were not conducive to much volume change in either the old pavement or the resurface. Furthermore, the open joints were spaced at 40-foot intervals with no load-transfer provisions and, consequently, no restraint to movement of the joints. These factors probably tended to prevent the occurrence of transverse cracking in the 1932 resurface during the first few months, and the subject was given little attention during the early ages of this resurface.

However, a different situation developed in the 1936 resurfacing. Soon after construction, numerous transverse cracks were noticed in the concrete resurface. When the resurface was about 4 months old, it was found that many of these cracks had opened wide enough to break the mesh and that some of them had developed close to expansion joints. It was evident that this cracking would have a detrimental effect on the ultimate performance of the resurfacing. Any cracks in a concrete pavement are points of weakness at which the forces of destruction may begin action. When the cracks develop at an early age, the destructive forces begin their action sooner and result in more-rapid deterioration. The development of such early cracking near transverse joints and their opening wide enough to break the reinforcement called for an investigation to determine the factors that were responsible.

Pursuant to investigating the causes for this cracking, a condition survey was made of the entire resurface on these projects and the following observations noted: (1) all cracks in the resurface were found to have occurred directly above or within a foot of a crack or joint in the old pavement; (2) many of the cracks were noticed within a few days and most of them were recorded within a month after pouring; (3) the resurfacing poured during hot weather showed much more cracking than that poured when the weather was relatively cool; (4) the resurfacing at the end of the job, poured when the temperature was below 75F., showed practically no cracking; (5) the resurfacing cracked more and the cracks were opened wider in areas where the unbroken slab length of the old pavement was relatively long, than where the old pavement was broken up into short lengths; (6) over areas where the old pavement was badly cracked, leaving no unbroken slabs longer than a few feet, practically no cracks were found in the resurface; (7) several instances were found where a crack had occurred within 3 feet of an expansion joint in the resurface; (8) in some cases the crack had opened as wide as ½ inch and broken mesh was found in several cracks; (9) where wide open cracks were found in the resurface at least one, and often both, of the adjacent expansion joints had apparently failed to open; (10) in areas where the resurface was not cracked the expansion joints showed evidence of having opened and, wherever consecutive expansion joints (at 50-foot intervals) had obviously opened, no cracking was found; and (11) no cracking was found in a short section of pavement built full depth on earth subgrade to replace rather than resurface the old pavement.

The excessive cracking found in the resurface and the occurrence of several cracks near expansion joints indicated that the joints had been restrained from moving freely. In the 1932 project where conditions were similar, except that expansion joints without dowels were used, no cracking near expansion joints and no wide open cracks had been found. This led to the assumption that the dowels might have furnished enough resistance to prevent the joint from functioning properly. On this project provisions were made for sliding of the dowels in the concrete by greasing one end of each dowel.

A detailed investigation of 50 dowels in four different expansion joints showed that all but two of the 50 dowels were bonded to the concrete sufficiently tight to furnish considerable resistance to the movement of the joint. Many of the dowels were found to be as tightly imbedded in the concrete on the end which was intended to slide as on the fixed end. In some cases the dowels were found to be out of line and not truly parallel to both the centerline and the surface of the pavement.

At one expansion joint all the dowels were sawed in two and the concrete for a width of 18 inches on both sides of the joint was cut out with a pavement breaker. The blocks of concrete in which the dowels were embedded were carefully removed without disturbing the dowels. Three of the blocks encasing dowels which were supposed to be free to slide were selected at random, brought into the laboratory, and the load necessary to move each dowel in the concrete determined by pulling it in the testing machine. The loads required to pull the steel from the concrete were found to be respectively 713, 656, and 545 lb. per linear inch of dowel embedded. There was generally about 10 inches of dowel embedded in the concrete and 20 dowels in each joint, so it was evident that, if all dowels were bonded as tight as the first one tested, a total load of over 140,000 lb. could be developed in the full width of the pavement. Since the mesh was designed to withstand a total load of only about 125,000 lb., it may be seen that the dowels alone could easily cause the accumulation of enough stress to break the mesh.

An attempt was made to study the movement of various expansion joints by setting points at opposite sides of the joint and measuring the change in distance between them. These measurements showed that joints over breaks in the old pavement moved more than joints over unbroken slabs. In some cases joints over unbroken slabs showed practically no movement, while supposedly comparable joints over breaks in the old pavement moved as much as two millimeters during the same time. Where the joint was over a break between two long, unbroken slabs, the movement was much greater than where the underlying slabs on both sides of the joint were relatively short. Joints over breaks in areas of badly broken pavement and joints in full-depth pavement replacement built upon earth subgrade showed less movement than joints over breaks between long slabs.

From the above observations it was deduced that the objectionable cracking in the 1936 resurface was initiated by shrinkage in the new concrete combined with movement in the old pavement and was aggravated by the fact that the dowels tended to tie the 50-foot panels together, thus preventing the relief of contraction stresses. Where the most-serious cracking was found (in the resurface poured on a hot day which was followed by a relatively cool night) the concrete was laid in an expanded condition on a concrete base which was also expanded. The subsequent natural shrinkage of the fresh concrete and the shrinkage of the old pavement as it cooled off tended to cause the two layers to move together, away from existing transverse breaks in the old pavement. This shrinkage occurred while the concrete was green and before it had developed sufficient tensile strength to offer much resistance to cracking. Obviously, where the unbroken slabs in the old pavement were long, the total movement would be greater, there would be greater stresses induced, and the crack would be wider after breaking through than where the underlying slabs were short. Where the underlying pavement was broken into short lengths, the shrinkage over any given length would be distributed among several transverse breaks and might not concentrate enough movement at any one break to cause a crack in the resurface, or if a break did occur, a fine crack would be sufficient to relieve the contraction stresses.

The fact that numerous dowels were found to be securely bonded in the concrete indicates that they provided enough resistance to restrain the movement of the joint, especially in keeping it from opening. Perhaps, if the first movement of the concrete had been due to expansion, which would have tended to close the joint, the concrete might have been strong enough in compression to break the bond on the dowels, thus permitting the joint to move satisfactorily thereafter. However, under the conditions existing on this project, the first movement apparently was caused by contraction forces, and the concrete was not strong enough in tension to break the dowels loose. Since the dowel resistance prevented the joints from opening and relieving the contraction stresses, the resurface cracked at points where these stresses were concentrated, i.e., above breaks in the old pavement.

The investigation of early transverse cracking as discussed above shows that where dowels are used across joints in resurfacing, methods of design and installation should be such that no misalignment nor bonding is possible. It also calls attention to the tendency for cracks in the old pavement to cause cracks in the resurface directly above them and suggests the desirability of locating joints above old cracks by means of variable joint spacing. Various aspects of this subject are discussed later in the report.

FINAL CONDITION-SURVEY DATA

In June of 1951, a final condition survey

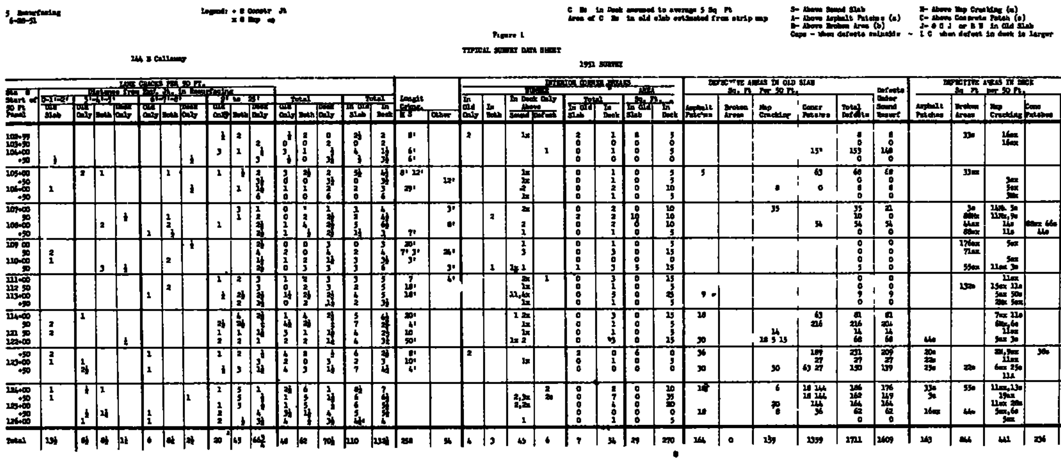


Figure 1

TYPICAL SURVEY DATA SHEET

was made of the concrete resurface just prior to the time it was scheduled to be resurfaced with asphaltic concrete. All transverse joints, surface defects, and repairs, as well as pertinent construction details, were located by stationing in the survey notes so that they could be studied in relation to similar features in the underlying old pavement, which had likewise been located by stationing and sketched on a strip map just before the concrete resurfacing was placed.

The data from the 1951 condition survey of the resurfacing and that from the condition surveys of the old pavement just prior to resurfacing were assembled on tabular sheets as shown in Figure 1. Each horizontal space was used to enter the data pertaining to one panel — the length of pavement between two transverse expansion joints. Since the joint interval was 40 feet in 1932 and 50 feet in 1936, for the resurfacing built in 1932 a panel length was 40 feet while for the 1936 resurfacing it was 50 feet.

TRANSVERSE CRACKING

Under the heading "Lane Cracks per 50 feet" were tabulated the number of transverse cracks grouped according to their distance from the expansion joints in the resurfacing. A lane crack was defined as one extending from one edge of the pavement to the centerline. Transverse cracks less than one lane in length were counted as fractional lane cracks expressed as ¼-, ½-, or ¾-lane crack. If two or more fractions were encountered in any tally, they were added and their sum treated statistically as a continuous crack of the same total length. The cracks in the 50-foot panels of the resurface and those in the underlying 50 feet of old pavement were tabulated in the columns as shown. A crack occurring in only the old pavement was entered in the column "Old Only"; if a crack developed in the surface within a foot of a crack in the old pavement, the entry was made in the column "Both" and, if a crack was found in the resurface above a point where no crack was recorded in the old pavement, it was entered under "Deck Only". For example, in Figure 1 the panel starting at Station 105+00 had two lane cracks in the underlying old pavement and one in both the old pavement and deck within 3 to 5 feet of one end of the panel; one lane crack came through the deck at a point 6 to 8 feet from a joint; and in the interior 32 feet of the panel (9 to 25 feet from each joint) one lane crack occurred in the old pavement but did not come through the deck, ½ lane each in the old pavement did come through the deck and two lane cracks developed in the deck over points where there were no cracks in the old pavement when it was resurfaced. The totals in each category of all cracks in the 50 feet of deck and old pavement between the joint at 105+00 and the one at 105+50 are shown in the next columns. In the example, there were three lane cracks that did not come through the deck; 2½ that did, and two lane cracks in the deck that developed above apparently sound old pavement, i. e., at points where there were no cracks when the old pavement was resurfaced. The next two columns show that there was a total of 5½ lane cracks in the old pavement and 4½ in the deck within the

50-foot length cited. The purpose of this tabulation was to permit study of the tendency for cracks in the old pavement to come through the deck, as well as to investigate the efficacy of the joints in controlling cracking in the deck.

CORNER BREAKS

The resurfacing design also specified widening the old pavement with a section of 9-inch-minimum thickness. Due to the widening section along each edge, exterior corner breaks were found to be practically nonexistent in the resurface so only interior corner breaks were considered.

Under the heading, "Interior Corner Breaks" were tallied the number of corner breaks in the old pavement when it was resurfaced; those found in the old pavement before resurfacing and in the deck above the same point; and those in the deck above old pavement which was apparently sound when resurfaced; and those above other defective areas in the old pavement. The total number of corner breaks in the old pavement and those in the deck for each 50-foot length were entered in their respective columns under "Total". The areas of corner breaks in the old pavement were scaled from the strip map made just prior to resurfacing and entered in square feet in the next column. Corner breaks in the deck were found to average about 5 sq. ft. each and, therefore, each corner break was arbitrarily given 5 sq. ft. in arriving at the values in the last column, which represent the total square feet of corner breaks per 50-foot resurface panel. The purpose of this tabulation was to determine whether corner breaks in the resurface tended to develop over old corner breaks, other old defects, or above sound concrete in the old pavement.

DEFECTS IN OLD PAVEMENT

Under the heading "Defective Areas in Old Slab" various types of defects were tabulated in individual columns as shown in Figure 1. The column headings should be self-explanatory. The area of each defect was determined in square feet from the strip map of the old pavement sketched just prior to resurfacing. The total defects of all types for each 50-foot length of old pavement lying under its 50-foot resurfacing panel are given in "Total Defects" column. In order to segregate data to indicate the degree to which the resurface effectively covered old defects and prevented them from coming through, the next column "Defects Under Sound Resurface" was provided. In this column are included all of the defective areas no part of which came through and, of those which partly came through, that portion which did not. In other words, when an overlying defective area was smaller than its underlying defect, the difference was included in this column with the area of those none of which came through.

DEFECTS IN RESURFACE

Areas of asphalt patches, broken pavement, map cracking and concrete patches in the resurface were tabulated in units of square feet in their respective columns. The sum of these areas plus the area of corner breaks were totalled in the last column to show total defects per 50-foot panel.

By comparing the location of each defective area in the resurface with the strip map showing the condition of the old pavement at time of resurfacing, information was obtained to show statistically the relation between defects in the resurface and those in the underlying old pavement when resurfaced. The symbols and letters at the top of the page of Figure 1 were used to indicate the old pavement condition under each defective area and also to show the location of the defects with respect to transverse joints.

SUMMARY OF DEFECTS

The columns of figures on the data sheets, as shown in Figure 1, were totalled for each sheet and the totals recapitualted so as to provide statistics for each type and thickness of resurface. These data and recapitulation sheets are too voluminous to be included in this report, but in the discussion of various features, excerpts will be taken from the data sheets and presented as required. Data from all of the recapitulation sheets have been summarized in Table 3.

DISCUSSION OF VARIABLES AND ANALYSIS OF DATA

In evaluating the performance of the

TABLE

SUMMA

1951 Survey

Number of 50' Panels	LANE CRACKS — Distance from Expansion joint in resurfacing: 0-2'	3 - 5 ft			6 - 8 Ft			9 - 25 ft.			Total			Total		INTERIOR CORN — Number: In		In Deck Only		Total	
	Old Slab	Old Only	Both	Deck Only	Old Only	Both	Deck Only	Old Only	Both	Deck Only	Old Only	Both	Deck Only	In Old Slab	In Deck	Old Only	In Both	Above Sound	Defect	In Old Slab	In Dec
																			- 4" RESURFACIN		
427	156¼	106¼			79¼			236¼			577			1368¼		140				167	
418	*152¼	103¼	48¼	20½	76¼	72¼	18¾	228¾	652¾	530½	559½	773¼	569¾	1333¾	1343	125	27	480	65	152	572
	(* 3 lane cracks in deck 0-2' from joint have not been included in totals)																				
																			- 5" RESURFACIN		
182	84¼	85			69			337¼			575½			895¼		28				37	
140	62¼	50½	18	3¾	40	27	6¾	192¾	205½	174½	345½	250½	185	596	435½	21	6	98	22	27	126
																			- 6" RESURFACIN		
	(Old Pavement under 7 panels is all sealed-cracks not counted)																				
184				1¾			4			108			113¾		329	52	5	16	18	57	39
	(Cracks in old pavement under 23 panels were estimated, but not located)																				
177				1¾			4			99½			105¼	1381	320½	52	5	16	16	57	37
	(Cracks in old pavement were located with respect to Exp. Jt. in Deck)																				
154	128½	93½	8	1¾	103	17	4	549¾	186¾	87¾	874¾	211¾	93½	1086½	305¼	51	5	15	16	56	36
																			- 4" RESURFACIN		
35														185½							
																			- 6" RESURFACIN		
Number of 40' Panels	0-2'	3 - 5 ft			6 - 6 ft.			9 - 20 ft.			Total										
33	21	28½	3½	4	23½	8½	3¾	83¼	42¼	55¼	156¼	54¼	63	210½	117¼	5	1	27	13	6	41
																			Full Depth Paveme		
Number of 50' Panels 8			Old Pavement Removed												8						0

concrete resurface on these projects, various criteria were available for consideration. Also various pertinent conditions, materials, and design features influenced the resurfacing behavior. The effects of all of these variables are interrelated and some cannot be uniquely isolated from others, but for practical purposes an attempt was made to identify and study the effects of the following: (1) thickness of resurface, (2) condition of old pavement, (3) drainage, (4) expansion joints, (5) cross-section design, and (6) "marker seal" center joint.

EFFECT OF THICKNESS ON CONCRETE RESURFACE

In order to gain a general idea of the performance of resurfaces of various thickness, the transverse cracking and total surface deterioration in all of the resurface under observation were summarized as shown in Table 4. When the

TABLE 4

Summary of Defects in Concrete Resurface of Various Thicknesses and Ages and in Full Depth Pavement

Transverse Cracking			Surface Deterioration	
Number of Panels	Avg. No. of Lane Cracks per panel	Avg. No. of Full Cracks & Jts. per 100 ft.	Avg. No. of Sq. Ft. of Defective Area per panel	Avg. % of Area Affected
1936 Construction - 50 ft. panels - Age 15 years				
4" Resurface				
418	3.2	5.21	102	9.25
5" Resurface				
140	3.1	5.11	59	5.37
6" Resurface				
154	2.0	3.81	26	2.36
Full Depth Pavement				
8	1.0	3.06	3.75	0.36
1932 Construction - 40 ft. panels - Age 18½ years				
4" Resurface				
	(Entire length sealed)		(Entire length sealed)	
35			800	100
6" Resurface				
33	3.5	6.94	19	2.41

Data

BREAKS Area (Sq. Ft.) In Old Slab	In Deck	DEFECTIVE AREAS IN OLD PAVEMENT (Square Feet) Asphalt Patches	Broken Areas	Map Cracking	Concrete Patches	Total Defects	Def per 50'	Defects under Sound Resurf.	DEFECTIVE AREA IN RESURFACE (Square Feet) Asphalt Patches	Broken Areas	Map Cracking	Concrete Patches	Total Defects	Per 50' Panel	Ratio Def. in Deck to Old Slab
1936 -															
585		1329	123	4976	9320	16,333	38		(9 panels covered with bit seal)				52,443	123	3.24
544	2857	1200	123	4891	8996	15,754	38	11,462	1575	4821	29,672	3618	42,543	102	2.70
1936 -															
137		992	7	8366	7276	16,778	92		(42 panels covered with bit. seal)				54,446	299	3 25
103	630	805	7	3859	6192	10,966	78	9,335	774	1588	4,650	626	8,268	59	0 75
1936 -															
296	195	21,412	33	18,827	14,586	55,154	300	52,469	214	254	4,112	0	4,775	26	0 081
296	185	15,256	33	18,827	14,586	48,998	277	46,435	201	245	4,022	0	4,653	26	0 094
292	180	2,160	33	16,326	11,260	30,071	195 Def per 40'	28,158	141	245	3,432	0	3,998	26 Per 40' Panel	0 133
1932 -															
		130		3,894	855	4,879	139		All covered with bit. seal				28,000	800	
1932 -															
39	205	20	35	3223	2,266	5,583	169	5,323	5	42	321	60	633	19 Per 50' Panel	0.113
- 1936 -															
	0								11	0	19	0	30	3.75	

final condition survey was made, the 1936 resurface built with 50-foot panels was 15 years old, and the resurface built in 1932 with 40-foot panels was 18½ years old. As explained previously, all of the 4-inch resurface built in 1932, and 2,550 feet of the 4-inch and 5-inch resurface built in 1936 had been given bituminous treatments and could not be observed in detail when the final condition survey was made in 1951.

It is logical to assume that the resurfacing sections, which required maintenance seal coats, had developed more surface deterioration than those not so treated, but of course, none of them was 100 percent defective. A few of the panels may have been in even better condition than some of those not covered, because it would not be expedient to break the continuity of a seal coat to omit a slab or two in good condition. For this reason it is difficult to estimate, with any degree of reliability, the percentage of deterioration in the sealed panels. In order to present the possible limits, Table 3, in addition to showing values for the unsealed panels, also shows values which include the sealed panels rated as 100 percent defective. Representative values would be somewhere between the values for these two sets of data. Because most of the 42 panels of 5-inch resurface were little worse when covered with seal coat than others not sealed but were given treatment in an attempt to retard anticipated deterioration, and since the surface of the 35 panels of 4-inch resurface was not nearly 100-percent defective when sealed, it is believed that the values representing the averages of panels still available for observation are much-more representative than those which include panels that have been given seal coat treatment.

As shown in Table 4, the 418 fifty-foot panels of 4-inch resurface built in 1936 that were available for study had developed on the average 3.2 lane cracks and 102 sq. ft. of surface defects per panel; the 140 fifty-foot panels of 5-inch resurface that could be observed showed 3.1 lane cracks and 59 sq. ft. of surface defects; and the 154 fifty-foot panels of 6-inch resurface had on the average 2.0 lane cracks and 26 sq. ft. of surface defects per 50-foot panel. None of the 4-inch resurface built in 1932 could be observed in detail, since it was all covered with bituminous seal coat, but the 33 forty-foot panels of 6-inch resurface had developed at the age of 18½ years 3.5 lane cracks and 19 sq. ft. of surface defects per average panel.

Further consideration of these data indicates very little difference between the 4- and 5-inch resurfaces at 15 years, insofar as the transverse-crack control resulting from the use of expansion joints at 50-foot intervals is concerned. Under the conditions of this particular road, each 50-foot panel of either 4- or 5-inch resurface developed on the average slightly more than 1½ full transverse cracks in 15 years of service. The comparable 6-inch resurface showed on the average only one full transverse crack per 50-foot panel. The 6-inch resurface built in 1932, with 40-foot joint spacing showed considerably more transverse cracking — 1¾ full cracks per 40-foot panel at 18½ years of age.

Transverse cracking in resurfacing of various thickness cannot be fully analyzed without considering the effects of other factors and distinguishing between cracking due to shrinkage and that due to load stresses. The early cracking mentioned above, which was attributed to faulty joint design and installation, no doubt affected all resurfaces, regardless of thickness, and the influence of other factors on cracking probably overshadowed the effects of variations in thickness. The subject of transverse cracking is discussed further in other parts of this report; these data are presented here to show that (1) the average degree of crack control was unsatisfactory in all of the resurfaces and (2) as would be expected, less cracking developed in the 6-inch resurface than in comparable resurfaces 4 or 5 inches thick.

The general effect of resurface thickness seems to be more consistent in regard to surface deterioration than to transverse cracking. As shown in the fourth column of Table 4, at 15 years of age the 4-inch resurface showed on the average nearly twice as much total surface deterioration per panel as the 5-inch, while the latter had developed about twice as much total defective area per panel as the 6-inch resurface. The 4-inch resurface built in 1932 was all covered before the 1951 condition survey, and the actual amount of surface defects at 19 years of age could not be determined. The 1932 six-inch resurface had developed on the average 19 sq. ft. of surface defects per 40-foot panel at the age of 18½ years.

If the surface deterioration is expressed as percentage of total pavement area affected, as shown in the fifth column of Table 4, the values for the 4-inch, 5-inch, and 6-inch resurface built in 1936 are respectively 9.25 percent, 5.37 percent, and 2.36 percent. The 6-in. deck constructed in 1932 was affected by various types of surface defects on 2.41 percent of its area after 18½ years of service.

These percentages seem relatively small to represent the total surface deterioration in a pavement which has reached a stage requiring resurfacing but, due to the characteristic development of defects in this pavement, from a practical standpoint the deterioration was more serious than these percentages indicate. The defects were generally concentrated in the vicinity of transverse joints and cracks with relatively large areas of sound concrete between. With such variable distribution and large variations between individual panels in a group, by the time all of the panels in a given classification were affected to a degree averaging 5 to 10 percent, many had developed relatively large areas of serious deterioration requiring patching or resurfacing. Figure 2, which shows examples of some of the more-serious deterioration, illustrates this situation; the 50-foot panel in the foreground showed about 7 percent of surface deterioration, the next panel about 27 percent, and the third panel about 60 percent. When these were averaged with other panels which had developed only 0 to 3 or 4 percent of surface deterioration, the average for the group was a relatively low figure. This subject will be discussed in detail below; the percentages are presented here to show statistically the variation in surface deterioration with changes in resurface thickness.

EFFECTS OF TRANSVERSE CRACKING IN OLD PAVEMENT ON CRACKING IN RESURFACES OF VARIOUS THICKNESSES

As explained above, in the 1932 investigation two sections of concrete resurface were constructed, one 6 inches thick and the other 4 inches. Each of these sections was purposely located so as to cover old pavement which contained subsections in all stages of deterioration. In the 1936 construction, three thicknesses of resurface were used, 4 inches, 5 inches, and 6 inches. Before resurfacing, the old pavement condition was evaluated throughout its entire length and where deterioration was severe, 6 inches of resurface was applied; where deterioration was relatively slight, 4 inches of resurface was used; and the old pavement in an intermediate stage of deterioration was resurfaced with 5 inches of concrete. Since it was not practical to change resurfacing thickness for each short, localized change in old pavement condition, the degree of transverse cracking in the old pavement under resurfacing sections of each specified thickness varied considerably. In other words, some 6-inch resurface was built on old pavement with very little transverse cracking, while some 4-inch resurface covered old pavement with a short transverse crack interval and practically all degrees of variation from one extreme to the other were present. Consequently, there are available for study numerous resurface panels of each thickness on old pavement that showed transverse cracking in various degrees when resurfaced.

Table 5 shows the transverse cracking in resurfacing panels of various thicknesses that have been grouped according to the degree of transverse cracking in the underlying old pavement. On the first line of the tabulation, for example, it can be seen that in the 4-inch resurface there were 45 fifty-foot panels with 98.5 transverse lane cracks over old pavement that had no cracks when resurfaced; 152 panels with 432 lane cracks over old pavement that had from $\frac{1}{4}$ to $2\frac{1}{2}$ lane cracks per 50 feet when resurfaced; and 10 resurfacing panels with 39.75 lane cracks over old pavement with $8\frac{3}{4}$ to $10\frac{1}{2}$ cracks per 50 feet when resurfaced. The number of panels of each thickness of resurface and the number of lane cracks in them are tabulated according to the number of lane cracks in the underlying old pavement at the time of resurfacing. In order to bring the cracking to a comparable basis, the total lane cracks were converted to average number of full cracks and joints per 100 feet and these values plotted in Figure 3 to show the relation between the transverse cracking in the resurface and that in the underlying old pavement for each type and thickness of resurface.

Figure 2.

It should be kept in mind that the counts of transverse cracks in the old pavement were made prior to resurfacing and no data

TABLE 5

Transverse Cracks in Resurface Panels Grouped According to Degree of Transverse Cracking in Underlying Old Pavement

Number of Transverse Lane Cracks & Joints per Panel in Underlying Old Pavement — Limits	0		¼-2½		2¾-4½		4¾-6½		6¾-8½		8¾-10½		10¾-12½		12¾-14¾		14¾+			
Number of Transverse Full Crack & Joints per 100' in Underlying Old Pavement — Average	0		1 375		3 625		5 625		7 625		9 625		11 625		13 625		14 75+		Total	
							Transverse Cracking in Resurface Panels													
	No of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking	No of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking	No. of Panels	Cracking
							4 Resurface - 1936 Construction - 50 Foot Panels													
*Number of Resurface Panels & Total Number Lane Cracks in them	45	98 50	152	432.00	125	433 25	58	213 75	28	125 75	10	39 75	0		0		0		418	1343 00
Average Number of Lane Cracks per Panel		2 19		2 84		3 47		3 69		4 49		3 98								3 21
Average Number of Lane Cracks per 100 ft.		4 38		5 68		6 94		7 38		8.98		7 96								6 42
Average Number of Full Cracks per 100 ft		2 19		2 84		3 47		3 69		4 49		3 98								3 21
Average Number of Full Cracks & Joints per 100 ft		4 19		4 84		5 47		5 69		6 49		5 98								
							5" Resurface - 1936 Construction - 50 Foot Panels													
*Number of Resurface Panels & Total Number of Lane Cracks in them	8	25 50	34	89 25	38	131 75	34	116 00	20	64 75	6	8 25	0		0		0		140	435 50
Average Number of Lane Cracks per Panel		3 19		2 63		3 47		3 41		3 24		1 37								3 11
Average Number of Lane Cracks per 100 ft		6 38		5 26		6 94		6 82		6 48		2.74								6 22
Average Number of Full Cracks per 100 ft		3 19		2 63		3 47		3 41		3 24		1 37								3 11
Average Number of Full Cracks & Joints per 100 ft		5 19		4 63		5 47		5 41		5 24		3 37								
							6" Resurface - 1936 Construction - 50 Foot Panels													
*Number of Resurface Panels & Total Number of Lane Cracks in them	4	8 50	18	41 25	27	61 50	30	66 50	23	42 50	21	48 75	25	27 75	11	7 25	18	16 50	177	320 50
Average Number of Lane Cracks per Panel		2 12		2.29		2 28		2 22		1 85		2 32		1 11		0 66		0 92		1 81
Average Number of Lane Cracks per 100 ft.		4 24		4 58		4 56		4 44		3 70		4 64		2 22		1 32		1 84		3 62
Average Number of Full Cracks per 100 ft		2 12		2 29		2.28		2 22		1 85		2.32		1 11		0 66		0 92		1 81
Average Number of Full Cracks & Joints per 100 ft		4 12		4 29		4 28		4 23		3 85		4 32		3 11		2 66		2.92		
Number of Transverse Full Crack & Joints per 100' in Underlying Old Pavement — Average	0		1 72		4 53		7 03		9 53		12 03		14 53		17 03					
							6' Resurface - 1932 Construction - 40 Foot Panels													
*Number of Resurface Panels & Total Number Lane Cracks in them	1	4 50	2	6 50	10	41 00	5	20 25	8	25 00	3	10 50	3	9 00	1	0 50	0		33	117 25
Average Number of Lane Cracks per Panel		4 50		3 25		4 10		4 05		3 12		3 50		3 00		0 50				3 55
Average Number of Lane Cracks per 100 ft.		11 25		8 13		10 25		10 13		7 80		8 75		7 50		1 25				8 88
Average Number of Full Cracks per 100 ft.		5 63		4 07		5 13		5 07		3 90		4 38		3 75		0 63				4 44
Average Number of Full Cracks & Joints per 100 ft		8.13		6 57		7 63		7 57		6 40		6 88		6 25		3 13				

* In this line are shown the number of panels and the total number of lane cracks in the resurface panels lying over corresponding lengths of old pavement that had cracks within the limits shown in the column headings

TABLE 6

Surface Defects in Resurface Panels Grouped According to Degree of Surface Deterioration in Underlying Old Pavement

Surface defects in Underlying Old Pavement — Sq Ft. per panel length	0		1-25		26-50		51-100		101-200		201-400		401-600		601-750		751+		Total — In resurface		In Old Pvmt	Ratio Defects Resurface to Old Pavement
Avg % of Area affected	0		1 4		4 2		8.4		16 7		33 4		55 6		75 0		83 3+					
									Surface Defects in Resurface Panels (Areas in Sq Ft.)													
	No. of Panels	Area	No. of Panels	Area	No. of Panels	Area	No. of Panels	Area	No of Panels	Area	No. of Panels	Area	No of Panels	Area	No. of Panels	Area	No. of Panels	Area	No. of Panels	Area of Defects		
									4 Resurface 1936 Construction - 50 - Foot Panels													
*Number of Resurface Panels & Total Area of Defects in them - Sq Ft.	162	14581	118	9800	62	7677	34	4318	24	2682	12	2829	5	607	0		1	49	418	42,543	15,784	2.70
Avg Area of Defects per panel - sq ft.		90		83		124		127		112		236		122				49		102	38	
Average Percent of Surface Affected		8.2		7 5		11 3		11 5		10 2		21 4						4 5		9 3	4 2	
									5 Resurface 1936 Construction -50- Foot Panels													
*Number of Resurface Panels & Total Area of Defects in them - Sq. Ft	36	2046	21	1361	19	675	25	1451	24	1825	10	657	2	124	2	129	0		140	8,268	10,966	0 75
Avg Area of Defects per panel - sq ft.		57		65		36		55		76		66		62		65				59	78	
Average Percent of Surface Affected		5 2		5 9		3 3		5 0		6 9		6 0		5 6		5 9				5 4	8 7	
									6' Resurface 1936 Construction -50- Foot Panels													
*Number of Resurface Panels & Total Area of Defects in them - Sq Ft.	17	473	19	632	21	612	18	337	23	453	26	569	23	735	9	214	21	628	177	4,653	48,988	0 005
Avg Area of Defects per panel - Sq. Ft.		28		33		29		19		20		22		32		24		30		26	277	
Average Percent of Surface Affected		2 5		3 0		2 6		1 7		1 6		2.0		2 9		2 2		2 7		2.4	30 8	
Surface Defects in Underlying Old Pavement — Sq Ft. per panel length	0		1-25		26-50		51-100		101-200		201-400		401-600									
Avg % of area affected	0		1 6		5 3		10 5		20 9		41 7		69 5									
									6" Resurface 1932 Construction -40- Foot Panels													
*Number of Resurface Panels & Total Area of Defects in them - Sq Ft.	6	92	5	156	3	34	3	65	4	30	7	142	5	115	0		0		33	633	5,583	0 113
Avg Area of Defects per panel - Sq Ft		15		31		11		22		6 5		20		23						19	169	
Average Percent of Surface Affected		1 9		3 9		1 4		2 8		0 9		2 5		2 9						2 4	23 5	

* In this line are shown the number of panels and the total Sq Ft of surface defects in the resurface panels lying over corresponding length of old pavement that had defects within the limits shown in the column headings

are available to show the cracking which has developed in the old pavement since it was covered. Probably some cracking has occurred under the various resurfaces, and their development may have influenced cracking in the resurfaces. However, since the old pavement could not be inspected after resurfacing, when reference is made to the old pavement condition it should be understood that the observations were made prior to resurfacing.

The values from Table 5, plotted in Figure 3, do not produce smooth curves showing consistent influence of the old pavement cracking, but they do show trends which indicate that the transverse cracking in the resurfaces was affected by that in the underlying old pavement. Apparently all of the 1936 resurfaces with expansion joints at 50-foot intervals tended to develop transverse cracking at about the same rate when laid on uncracked old pavement. According to the curves, the 4-inch, 5-inch, and 6-inch resurfaces each show about four or five cracks and joints per 100 feet where laid on sound old pavement. This indicates a tendency for these resurfaces to crack into slabs about 20 to 25 feet long on old pavement that was uncracked when resurfaced in 1936.

Where the 1936 resurfaces were laid on cracked old pavement, the various thicknesses showed divergent trends as the rate of cracking in the underlying old pavement increased. Cracking in the 4-inch resurface increased with increased cracking in the underlying old pavement. Cracking in the 6-inch resurface apparently did not increase with increased cracking in the old pavement but tended to crack at about the same rate until the old pavement reached a relatively high rate of cracking. Where the underlying old pavement was broken up into slabs 10 feet or less in length, the 6-inch resurface developed on the average less cracking than where laid on sound old pavement.

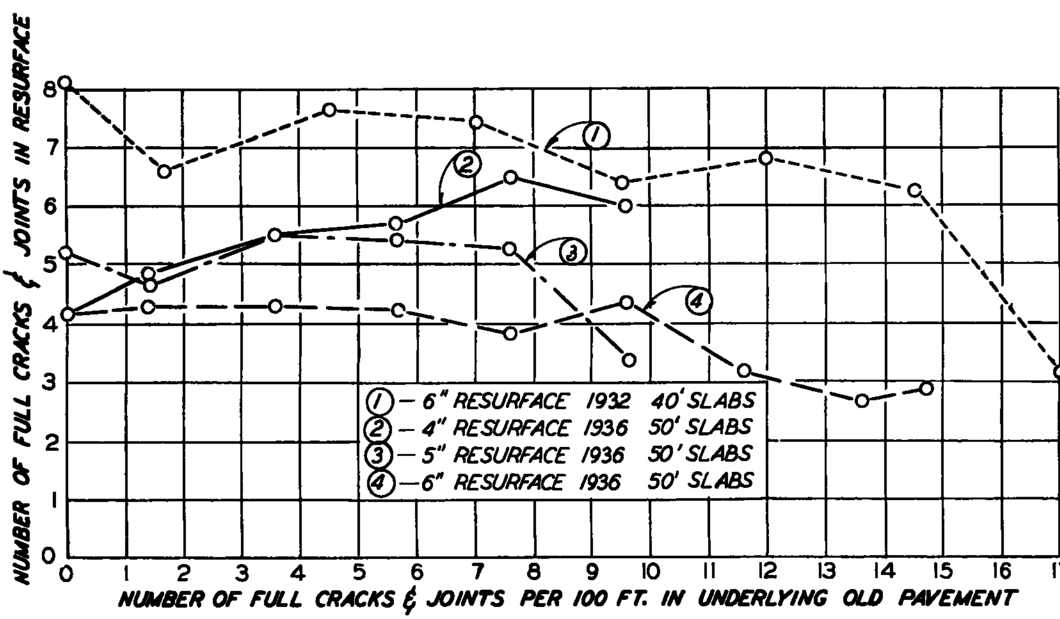


Figure 3. Transverse cracking in resurfaces of various thickness as influenced by transverse cracking in underlying old pavement.

The curve representing the 5-inch resurface built in 1936 is somewhat erratic but, in general, lies between the curve representing the 4-inch resurface and that of the 6-inch resurface. The relationships shown indicate that for a given rate of cracking in the underlying old pavement the 4-inch resurface developed the greatest amount of cracking, the 5-inch resurface somewhat less, and the 6-inch resurface the least cracking.

The curve representing the number of cracks and joints in the 6-inch resurface built in 1932 with expansion joints at 40-foot intervals was derived from observations on only 33 panels. These data may be inadequate for reliable comparisons, but indicate that this resurface developed considerably more cracking than the 1936 resurfaces. Since the 1932 resurface is $3\frac{1}{2}$ years older and has joints at 40 feet rather than 50 feet, it might be expected to show more joints and cracks per 100 feet. The curve indicates that this resurface exhibits a tendency similar to that of the 6-inch resurface built in 1936, i. e., less cracking when it lies on old pavement broken into relatively short slabs.

Transverse cracking in the various resurfaces was no doubt affected by the failure of some of the expansion joints to function and, also, by other factors whose influence could not be segregated from that of the cracking intensity in the old pavement. However, it appears that the 4-inch resurface tended to develop increased cracking when laid on badly cracked old pavement, while the 6-inch resurface was not affected in the same way by increased cracking in the old pavement.

The tendency for the 6-inch resurfaces to develop less cracking when laid on old pavement with increased cracking might indicate that, where the underlying slabs were short, the movements at individual cracks were small and produced less cracking in the resurface than where the movements were greater at cracks separating long, underlying slabs. The cracking in the thinner resurfaces may have been due more to load failures, and where the old pavement is broken into short slab lengths, the resurface thickness was insufficient to overcome the uneven support. Consideration should be given to these relationships in deciding upon the thickness, type, and spacing of joints to be used in resurface design.

EFFECTS OF SURFACE DETERIORATION IN OLD PAVEMENT ON SURFACE DETERIORATION IN RESURFACES OF VARIOUS THICKNESSES

Because of the specified variation in resurface thickness of both the 1932 and 1936 construction, as explained above, there was available for study resurfacing of each thickness on old pavement in varying degree of deterioration. There were sections of old pavement under each thickness of resurface which varied from "no" surface deterioration to more than 50 percent of the surface affected by defects of one type or another when resurfaced.

Table 6 shows the surface deterioration in resurface panels of various thickness grouped according to the surface deterioration in the underlying old pavement at the time of resurfacing. As shown by the column headings, nine degrees of old pavement surface deterioration were selected varying from 0 to 751+ sq. ft. of surface affected or, expressed as percentages, from 0 to 83.3+ percent. Under each heading were tabulated the number of resurface panels laid on old pavement in the corresponding degree of deterioration and the total square feet of defects that had developed in these panels since constructed. For example, there were 162 panels of 4-inch resurface built on sound old pavement and when surveyed these had developed 14,581 sq. ft. of surface defects. Likewise, there were 5 panels of 4-inch resurface laid on old pavement with between 401 and 600 sq. ft. of surface defects (on the average 55.6 percent of the surface affected) and when surveyed these had developed a total of 607 sq. ft. of surface deterioration. In order to bring these values to a comparable basis, the square feet of deterioration was divided by the number of panels in each case and the average percent of surface affected by defects computed by dividing the average area of defects per panel by the panel surface area.

The values from Table 6 are plotted in Figure 4 to show the relationships between the surface deterioration in the various resurfaces and that in the underlying old pavement. The data regarding deterioration in the old pavement were obtained just prior to resurfacing while observations of deterioration in the resurfaces were made $18\frac{1}{2}$ years later on the 1932 construction and 15 years later in the case of the resurfaces built in 1936. No doubt some deterioration developed in the old pavement after resurfacing but, since it could not be inspected after resurfacing, when reference is made to deterioration in the old pavement it should be understood that the observations were made prior to resurfacing.

Although the curves of Figure 4 are erratic, they appear to indicate some general relationships. As shown by comparison of the ordinates at zero abscissae, some deterioration developed in each of the various resurfaces when laid on sound old pavement, but the percentage of area affected varied inversely with the thickness of the resurface. In the 1936 construction laid on sound old pavement, at the age of 15 years approximately 8 percent of the 4-inch resurface was affected by deterioration; 5 percent of the 5-inch resurface and 2½ percent of the 6-inch resurface. The 6-inch built in 1932 on sound old pavement showed about 2 percent of its surface affected by deterioration at the age of 18½ years.

When laid on defective old pavement, the 4-inch, 1936 resurface showed a tendency toward increased surface deterioration as the deterioration in the old pavement increased, but deterioration in the 5-inch and 6-inch resurfaces tended to remain fairly uniform for all degrees of deterioration in the old pavement.

The percentage of deterioration in the 4-inch resurface continued to increase to about 21 percent, which occurred when the surface of the underlying old slab was about 33 percent affected by deterioration. The 5-inch resurface fluctuated between about 3 percent and 7 percent of its surface affected by defects, although laid on old pavement that varied from 0 to 75 percent deteriorated. The deterioration in both the 1932 and the 1936 6-inch resurfaces seemed to be influenced very little by the deterioration in the underlying old pavement. Variation from 0 to more than 83 in the percent of old pavement surface affected by deterioration apparently had no effect upon the deterioration in the 1936 resurface, since it averaged between about 2 and 3 percent regardless of the condition of the old pavement. In the case of the 1932 construction, the deterioration in the 6-inch resurface also varied only slightly as the percent of surface deterioration in the old pavement increased from 0 to 70 percent.

The essential points to be derived from this analysis, based on average deterioration per panel length, are: (1) apparently the degree of deterioration in the underlying old pavement had practically no effect upon the deterioration that developed in the 6 inch resurfaces; (2) the 5-inch resurface developed more deterioration than the 6-inch but did not show increased deterioration when laid upon old pavement in more advanced stages of deterioration; and (3) the 4-inch resurface developed more deterioration than the 5-inch and showed increased deterioration when laid on old pavement in more advanced stages of deterioration.

Since the data indicate that thin resurfaces tend to develop more deterioration and to be more susceptible to increased deterioration in the underlying old pavement than thicker resurfaces, provision should be made in resurface design to obtain adequate thickness.

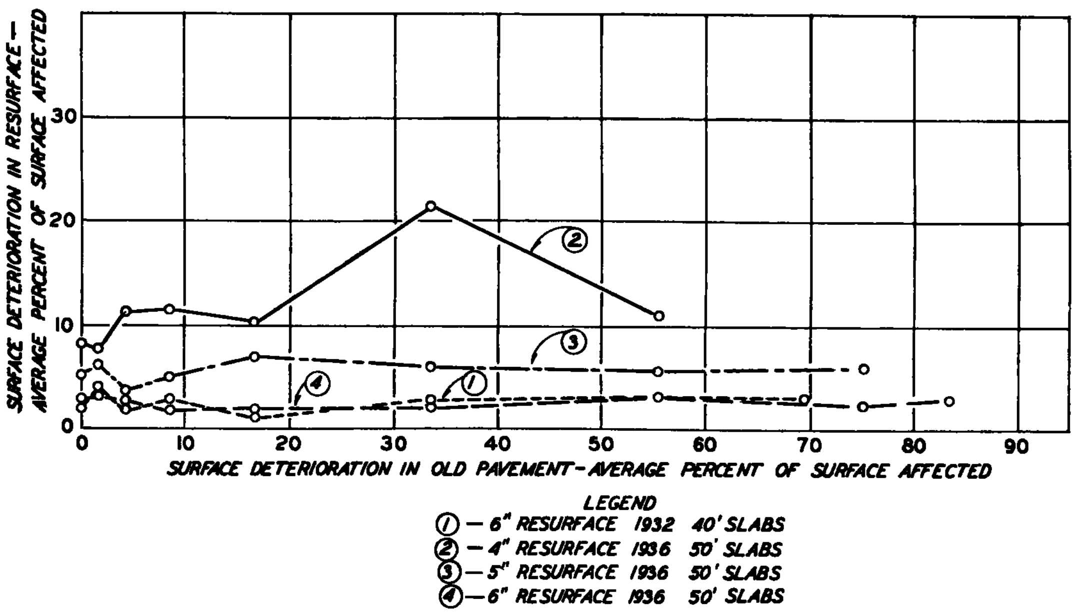


Figure 4. Surface deterioration in resurfaces of various thickness as influenced by surface deterioration in underlying old pavement.

TABLE 7

Defects in Resurfaces Grouped According to Drainage Conditions

Classification of Drainage From good to poor*	I	II	III	IV	V	Totals
4" Resurface - 1936 Construction - 50 ft. Panels						
Total Area of Surface Defects, Sq. Ft.	351	10,863	3,066	21,887	6,376	42,543
Number of Panels	8	178	34	171	27	418
Defective Area per panel, Sq. Ft.	44	61	90	128	236	102
5" Resurface - 1936 Construction - 50 ft. Panels						
Total Area of Surface Defects, Sq. Ft.	196	1,897	1,405	3,617	1,153	8,268
Number of Panels	3	31	20	74	12	140
Defective Area per Panel Sq. Ft.	65	61	70	49	96	59
6" Resurface - 1936 Construction - 50 ft. Panels						
Total Area of Surface Defects, Sq. Ft.	100	343	-	3,123	432	3,998
Number of Panels	5	16	0	117	16	154
Defective Area per Panel Sq. Ft.	20	21	-	26.7	27	26
6" Resurface - 1932 Construction - 40 ft. Panels						
Total Area of Surface Defects, Sq. Ft.	5	-	-	628	-	633
Number of Panels	4	0	0	29	0	33
Defective Area per Panel, Sq. Ft.	1+	-	-	21.7	-	19

EFFECTS OF DRAINAGE CONDITIONS UPON DETERIORATION OF RESURFACES OF VARIOUS THICKNESSES

Throughout the length of the investigational project there are numerous variations in drainage conditions. Some of the resurfacing lies on well-drained sections of road, while other resurfacing is in poorly drained locations, so that there are available for study resurface panels of each thickness that have been subjected to various conditions of drainage. In order to investigate the effects of this variable, five classes of drainage conditions were arbitrarily established and the entire pavement length surveyed to locate the changes from one to the other of the five classifications of drainage. The five classifications, arranged in order from what was considered would provide the best drainage to that which included conditions thought to be conducive to poorest drainage, were as follows: (1) over crest of sharp vertical curves with good longitudinal and side drainage, best drainage conditions; (2) on prairie, level, or slight grades, good side drainage; (3) over long, flat crests where water could stand on pavement, no discharge to pavement from shoulders nor accumulation from grades but little drainage away from pavement; (4) on grades and depressions with shoulders sloping toward pavement where both longitudinal and shoulder drainage could add water to pavement; and (5) in cuts with drainage from shoulders, side hills, back slopes, etc., as well as longitudinal drainage, discharging water onto pavement, worst drainage conditions.

The area of surface deterioration in each resurface panel was tabulated according to the drainage conditions which apparently affected it. The totals for each classification are summarized by resurface thicknesses in Table 7 which also shows the average defective area per panel in each category. The latter values have been plotted in Figure 5 to show graphically the relationships between the average surface deterioration in resurface panel of various thickness that have been subjected to the different drainage conditions.

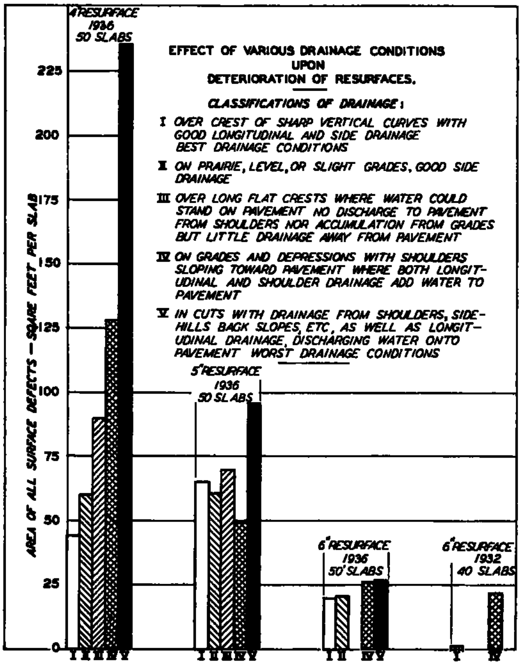


Figure 5

Study of Figure 5 shows that drainage apparently influenced the deterioration in resurfacing of each thickness. In each case, the average deterioration in panels under Classes 4 and 5, those subjected to the most-unsatisfactory drainage conditions, is greater than the deterioration in panels that have been subjected to the better drainage conditions (Classes 1 and 2). The 4-inch resurface appears to have been much more susceptible to the influence of variations in drainage than 5-inch or 6-inch resurface. Four-inch resurface panels under the best drainage conditions (1) showed on the average only 44 sq. ft. of surface deterioration per panel those in locations where drainage was the worst (5) averaged more than five times as much (236 sq. ft. per panel); while panels subjected to intermediate conditions of drainage (2, 3, 4) showed intermediate deterioration which increased in each case (respectively 61, 90, and 128 sq. ft. per panel) as the drainage conditions became worse.

The relatively small differences in deterioration in the 6-inch resurfaces under the various classifications indicate that they are not as susceptible to the influence of drainage as the 4-inch resurfaces. In the case of the 6-inch resurface built in 1932 the change from Class 4 drainage to Class 1 drainage affected a reduction in surface deterioration of about 21 sq. ft. per panel; in the case of the 1936 6-inch resurface a similar change resulted in a reduction in surface deterioration of about 7 sq. ft. per panel, but in the 4-inch 1936 resurface a change in drainage from Class 4 to Class 1 effected a reduction in defective area of 84 sq. ft. per panel. This would indicate that, insofar as prevention of surface deterioration is concerned, more percentage benefit could be derived from improving drainage conditions in the 4-inch resurface than in the 6-inch resurface. It is apparent, however, that when poor conditions of drainage are encountered, the 6-inch resurface is affected to a much-less degree than the 4-inch resurface, in fact, the 6-inch resurfaces under the worst drainage conditions show considerably less deterioration than 4-inch resurface where drainage conditions are best.

This analysis illustrates the importance of drainage on the deterioration of concrete resurfaces and calls attention to two significant factors that should be considered in resurfacing design: (1) a thicker resurface might overcome the destructive effects of poor drainage and (2) improvement in drainage conditions might permit the use of a thinner resurface.

RESURFACING AS COMPARED TO FULL-DEPTH PAVEMENT

Although most of the pavement in the investigational project was resurfacing, there are a few sections of full-depth pavement available for study. At two locations it was necessary to remove the full 18-foot width of the old concrete and replace it with full-depth pavement as thick as the combined depths of the old pavement and the resurface. At three locations where the alignment was changed slightly, some yardage of old concrete on the inside of curves was removed and replaced with full-depth pavement. The concrete widening which was built monolithic with the resurfacing provided a strip resembling full-depth pavement along the edge of the old pavement. In the 1932 construction, the widening strip was a foot

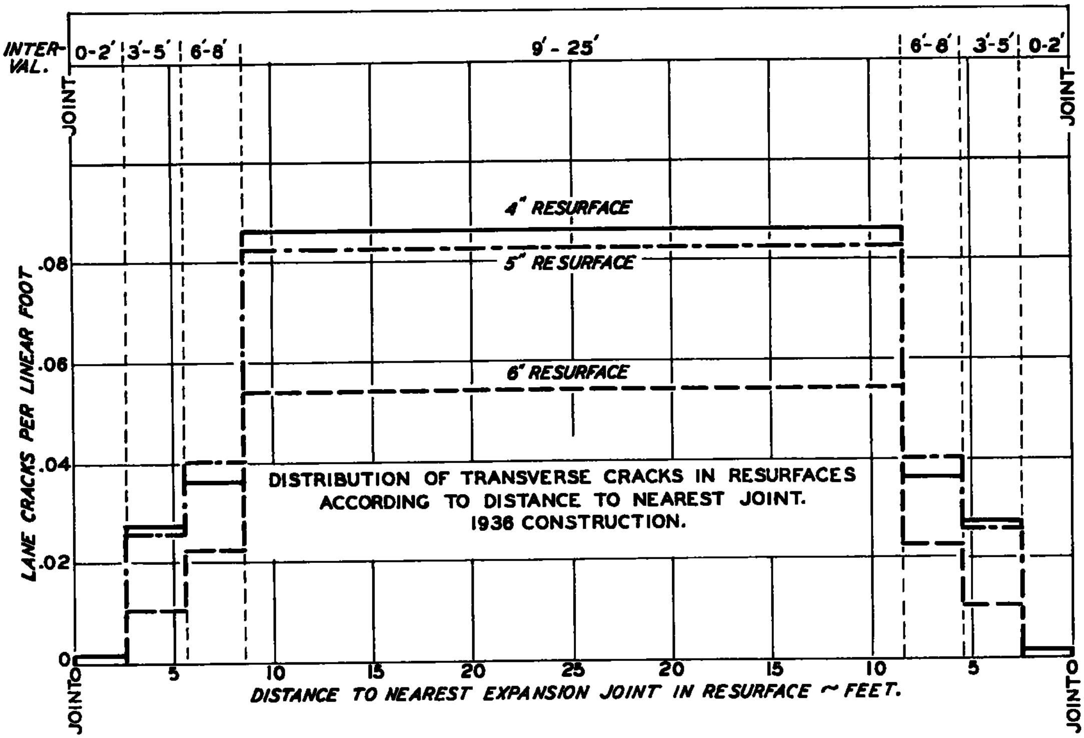


Figure 6.

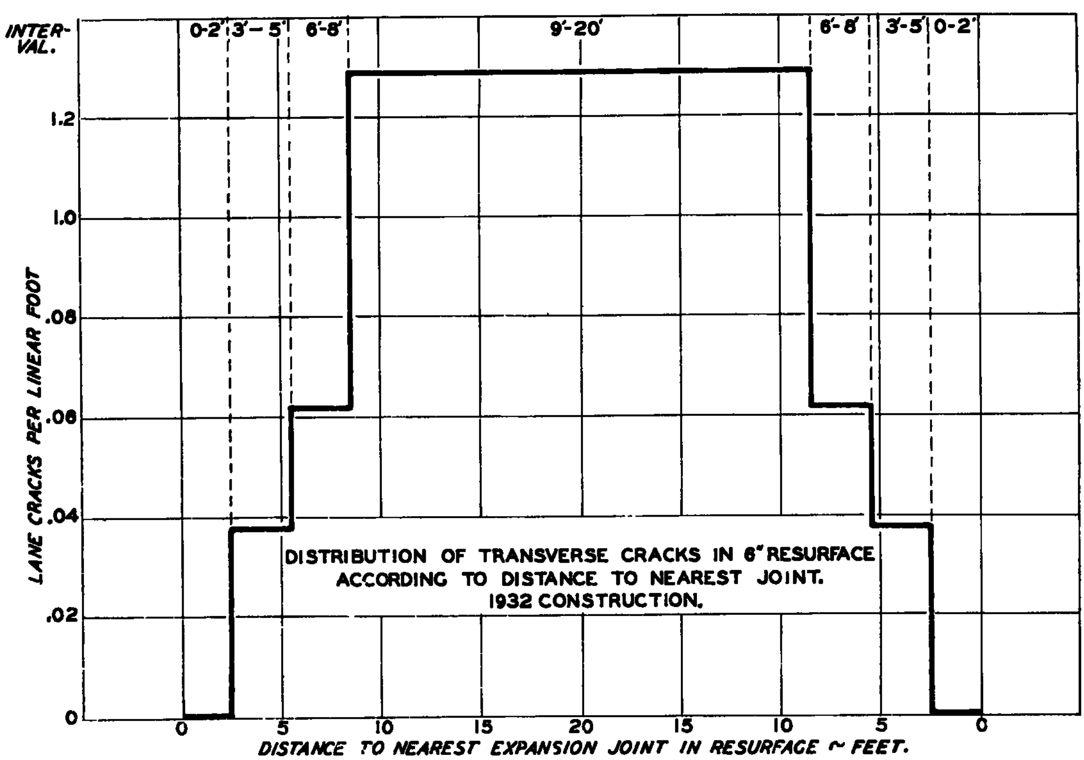


Figure 7.

wide along each edge and its depth was 9 inches plus the lip which was 3 inches thick at the edge and feathered out to zero thickness at 9 inches. The 1936 construction had a widening section of the same depth but a width of 2 feet.

Although these sections of full-depth pavement cannot be considered adequate for evaluating the performance of full-depth pavement as compared to that of concrete resurfacing, they do afford an opportunity to make certain comparisons.

The length of full-depth replacement pavement provided eight panels totaling approximately 375 linear feet of pavement 22 feet wide and 10 to 11 inches thick. There were 8 transverse lane cracks and 30 sq. ft. of surface defects in these 8 panels or, on the average, transverse cracking at the rate of one full crack per 100 feet and surface deterioration at the rate of less than 0.4 percent of the area affected. As shown in Table 4, cracking in the resurfacing averaged from 3.81 to 6.94 full cracks and joints per 100 feet and deterioration from 2.36 to 9.25 percent of surface affected by defects. From this it is apparent that the transverse cracking and surface deterioration were much less in full-depth pavement than in any of the various resurfaces.

Although separate data were not kept which would permit statistical comparisons between the resurfaces and the widening strip along each edge or the full depth replacement sections on curves, the observers noted that both the widening and the full-depth replacements showed decidedly better appearance and, in general, were less affected by surface deterioration than any of the resurfaces. The surface defects were generally concentrated in the interior 18 feet of the resurface (in the part lying directly above the old pavement), while the concrete along each edge for a width of about 1 foot in the 1932 construction and about 2 feet in the 1936 construction, was relatively free of surface deterioration.

These observations indicate the possibility that pavement laid directly on the subgrade with a thickness of either 10 to 11 inches as a full-width pavement or 9 inches plus a 3-inch lip as widening, may give better performance than 12 inches of pavement consisting of a 6-inch old pavement covered with 6 inches of concrete resurfacing. In the latter, water entering through cracks and joints in the resurface, when ponded between the two layers and subjected to freezing and thawing, increases the rate of deterioration in the resurfacing. The relatively thin layer of resurfacing apparently is subjected to more severe conditions of exposure, greater variations in moisture content, and more destructive action from freezing and thawing than full-depth pavement. Furthermore, the underlying old pavement acts as a rigid base and when inequalities of support develop, such as result from curling of the resurface or settlement of broken sections of old pavement, the destructive effects of heavy loads are undoubtedly intensified.

EFFECTS OF "MARKER SEAL" CENTER JOINT

The presence of an unusual amount of longitudinal cracking in the 1936 resurfacing has been attributed to the use of "marker seal" longitudinal joint. This joint is designed to provide a weakend plane along the centerline through which a longitudinal crack will develop but, as experienced on numerous other pavements where this type of joint was used, especially when tie bars are used in conjunction with the marker-seal, the plane of weakness is ineffective and the longitudinal crack tends to develop outside the zone of influence of the tie bars in an irregular line 2½ feet or more away from the centerline. Even without tie bars the use of marker-seal joint is believed to be conducive to the development of longitudinal cracking.

The following tabulation shows the amount of longitudinal cracking attributed to the marker-seal joint that was observed in each thickness of the 1936 construction:

TABLE 8

No. of 50 ft. Panels Observed	Length of Pavement Observed (Feet)	Linear Feet of Longitudinal Cracking	% of Length Affected by Longitudinal Cracking
	4" Resurface		
418	20,900	2,287	11
	5" Resurface		
140	1,057	7,000	15
	6" Resurface		
184	9,200	551	6
	10"-11" Full Depth Pavement		
8	400	336	84

As an experiment to investigate the effect of tie bars in the marker-seal joint, they were omitted in a ½-mile length of 4-inch resurface. Within this ½ mile there were thirty-eight 50-foot panels of 4-inch resurface which on the average, showed 2.7 ft. of longitudinal cracking. This represents 5.4 percent of the pavement length. The thirty-eight 50-foot panels built with tie bars and lying immediately east of the section wherein the tie bars were omitted, had longitudinal cracking averaging 10 ft. per panel or 20 percent of their total length. The 38 comparable panels with tie bars adjoining the experimental panels on the west showed the average 9.8 ft. of longitudinal cracking per panel or 19.6 percent of their length. Thus it can be seen that where tie bars were used the longitudinal cracking was more than 3½ times as much as in comparable lengths where they were omitted. When compared with the average for all the 4-inch resurface (i.e., 11 percent) the use of tie bars apparently caused more than twice as much longitudinal cracking.

The use of marker-seal longitudinal joint has been discontinued and the principal purpose of presenting the data is to corroborate the observations noted on other projects. However, the excessive length of longitudinal cracking resulting from its use on this job contributed to the deterioration in the resurfaces and should be considered in evaluating their performance.

CONSIDERATION OF INDIVIDUAL DEFECTS RATHER THAN DEFECTS PER PANEL IN ANALYZING SURVEY DATA

It is generally convenient and satisfactory in the study of jointed pavements to assemble and analyze the condition survey data on the basis of panel lengths or units of pavement between two consecutive transverse joints. Such procedure develops the data in terms of defects per panel. This method was followed in much of the investigation and in the foregoing discussion the resurfacing panel length (40 feet in the 1932 and 50 feet in the 1936 construction) was employed as a unit. The underlying old pavement was considered in corresponding units of length and the data analyzed on the basis of the condition of the resurface panel and that of the corresponding length of old pavement lying directly below. Consequently, the foregoing discussion is based upon the average condition of the resurface panels in each category and the average condition of the underlying corresponding lengths of old pavement with no consideration being given to the actual location within the panel of the various defects. No account is taken as to whether defects in the resurface are actually directly over defects in the old pavement or are over sound areas of old pavement nor whether transverse cracks tend to develop close to transverse joints or near the center of the panels.

The information developed by this method in the foregoing discussion is believed to be indicative of the influence of the variables studied on the general performance of the different resurfaces. However, additional information should be available by further study of the individual defects. Such an analysis has been made in which each defect is considered separately rather than on the basis of defects per panel (see Appendix A).

EXPANSION JOINTS IN CONCRETE RESURFACES

With the exception of construction joints installed at the gaps left for insertion of drop inlets or at points where cessation of paving necessitated a joint, the only transverse joints used in the resurfacing were expansion type. In the 1932 construction ¾-inch open joints were installed at 40-foot intervals; 1-inch premolded bituminous joints spaced at 50-foot intervals were used in 1936. Since no blowups nor evidence of compression were found in any of the resurfacing, it is assumed that the expansion provisions were adequate. Certain effects of the expansion joints which were observed at an early age have been discussed earlier. Other observations which are believed indicative of the effects of the expansion joints are discussed in the following paragraphs.

EFFECTS OF EXPANSION JOINTS ON TRANSVERSE CRACKING

Data from the 1951 condition survey have been analyzed in the following discussion to present statistically the effect of expansion joints on transverse cracking in the various resurfaces. In Table 9 have been assembled data from Table 3 to show the intensity of cracking in each of the resurfaces for intervals at various distances from the joints. Figures 6 and 7 show the same data in graphical form. The transverse cracks were tabulated into groups according to their distances from the nearest joint. The four intervals selected were 0 to 2 feet, 3 to 5 feet, 6 to 8 feet, and 9 feet or more from the joint. The cracking further than 9 feet from a joint was not further subdivided because previous studies indicated that, although cracking varied with the distance from a joint up to about 9 feet, beyond that point the intensity of cracking showed no trend relative to the proximity of the joint.

In the surveys the stationing of each crack was recorded to the nearest integral foot. Therefore, as grouped in the various interval classifications according to distance from the nearest joint, the actual limits were 0 to 2½ feet, 2½ to 5½ feet, 5½ to 8½ feet, and 8½ feet plus. It was assumed that the decrease in the rate of cracking in the intervals closer to joints could be taken as a measure of the effectiveness of the joints in controlling cracking. Table 10 shows, for each interval classification given in Table 9, the actual limits (distance included each side of joint) and the length of pavement considered in computing the average rate of cracking per linear foot.

TABLE 9

Transverse Cracks in Resurfaces of Various Thicknesses Classified According to Distance from Nearest Joint

	Location of Cracks Distance to Nearest Joint (Feet)				
	0-2	3-5	6 to 8	9+	Total
4" Resurface - 1936					
No of Lane Cracks in 418 panels	3	68¾	91	1183¼	1346
Avg No of Lane Cracks, per panel	0072	1644	2177	2 8307	3 220
Avg No of Lane Cracks, per linear foot	0014	0274	0363	0858	0644
5" Resurface - 1936					
No of Lane Cracks in 140 panels	0	21¾	33-¾	380	435½
Avg No of Lane Cracks, per panel	0	1554	2411	2 7143	3 111
Avg No of Lane Cracks per linear foot	0	0259	0402	0 0823	0 0622
6" Resurface - 1936					
No of Lane Cracks in 154 panels	0	9¾	21	274½	305¼
Avg No of Lane Cracks, per panel	0	0633	1364	1 7825	1 982
Avg No of Lane Cracks, per linear foot	0	0106	0227	0 0540	0 0396
6" Resurface - 1932					
No of Lane Cracks in 33 panels	0	7½	12¼	97½	117¼
Avg No of Lane Cracks, per panel	0	227	371	2 955	3 553
Avg No of Lane Cracks, per linear foot	0	0378	0618	1284	0 0888

In order to present the relative cracking in the various intervals on a comparable basis, the values of lane cracks per linear foot in Table 6 were expressed in terms of

TABLE 10

Distance from Nearest Joint

Interval Classification	Actual Limits (Feet)	Linear feet of Pavement Included
0-2	0-2½	5
3-5	2½-5½	6
6-8	5½-8½	6
9+	8½+	33 for 1936 construction
9+	8½+	23 for 1932 construction
Total	0-25	50 for 1936 construction
Total	0-20	40 for 1932 construction

percentages of the intensity of cracking in the interval beyond the influence of the joints (9 ft. or more away) and tabulated in Table 11.

As would be expected, the percentages in Table 11 show for each resurface less intensity of cracking near the joints than that 9 feet or more away from them and also, that within the 9-foot interval the rate decreases closer to the joint. In the 0-to-2-foot interval there was no cracking except in the 4-inch resurface where the intensity was only 1.6 percent of that beyond the influence of the joints. Cracking intensity in the interval from 3 to 5 feet from the joint as compared to that 9 feet and more away, varied from 20 percent in the 1936 6-inch resurface to 32 percent in the 1936 4-inch resurface. The percentage of cracking in the 6-to-8-foot interval, as compared to that in the 9-foot-plus interval, varies from 42 percent in the 4-inch and 6-inch 1936 resurfaces to 48 percent and 49 percent respectively in the 1932 6-inch and the 1936 5-inch resurfaces.

The expansion joints in the 1932 construction had no load-transfer features and, therefore, no dowels to restrain joint opening and thereby cause transverse contraction cracks to develop near joints. The percentages shown in Table 11 indicate the intensity of cracking near joints in the 6-inch resurface built in 1932 to be comparable with that in the 4-inch and 5-inch 1936 resurfaces with dowels and considerably greater than that in the 1936 6-inch resurface with dowelled joints (29 percent as compared with 20 percent).

TABLE 11

Transverse Cracking in Resurfaces Classified According to Distance to Nearest Expansion Joint, Expressed as Percentage of Cracking Intensity 9 Ft. or More Away From Joint

	% of Cracking Intensity 9 Ft. or More Away from Joint			
Distance from Nearest Joint (Feet)	0-2	3-5	6-8	9+
4" Resurface, 1936	1 6	32	42	100
5" Resurface, 1936	0	32	49	100
6" Resurface, 1936	0	20	42	100
6" Resurface, 1932	0	29	48	100

This would indicate that the restraint to joint movement ascribed to the dowels in the 1936 construction was probably not as prevalent or serious as was suspected or else there are other factors which have increased the cracking near the joints in the 1932 construction. The 1932 resurface is 3½ years older, but it seems improbable that this increased cracking near the joints could be attributed entirely to the difference in age.

If not due to greater age, the increased cracking might be structural failures in the 1932 construction resulting from lack of load transfer across the expansion joints. As discussed later, a study of faulting at the expansion joints indicates that this may be a factor since 46 percent of the joints in the 1932 construction were faulted as compared to less than 3 percent in the 6-inch resurface built in 1936.

EFFECTS OF EXPANSION JOINTS IN CONTROLLING TENDENCY FOR CRACKS IN RESURFACING TO DEVELOP OVER CRACKS IN OLD PAVEMENT

The preceding study did not analyze the effects which might be due to the influence of cracking in the underlying old pavement. Many cracks in the resurfacing developed directly above a crack in the old pavement so the following analysis was made to investigate whether the expansion joints in the resurfacing were effective in overcoming the tendency for cracks in the old pavement to cause cracks in the resurface above them.

In this study the cracks that developed in the resurface above cracks in the old pavement, as given in Table 3, were classified as to distance from the nearest joint and expressed as percentage of the cracking in the corresponding classification of old pavement. These data are given in Table 12. The same explanation, regarding the limits of the interval classifications given above applies in this discussion. The percentages from Table 12 are plotted in Figures 8 and 9 to show for each resurface the effectiveness of expansion joints in controlling the tendency of cracks in the old pavement to come through the resurfacing.

Figure 8 shows that in the 1936 construction, through the interior of the slabs where the joints theoretically had little influence, 74 percent of the cracks under the 4-inch resurface came through, 51.6 percent of those under the 5-inch resurface came through and 25.4 percent of those under the 6-inch resurface came through. In the intervals assumed to be within the influence of the joints, the percentage of cracks coming through decreased as the distance to the nearest joint decreased for all thicknesses of resurface. In the 4-inch resurface 2 percent of the cracks came through in the interval closest to the joint, whereas, in the 5-inch and 6-inch resurfaces none came through within 2 feet of the joint. This is an indication of the effectiveness of the joints in controlling cracking in the 4-, 5-, and 6-inch resurfaces.

As shown graphically in Figure 9, the 6-inch resurface built in 1932 has a somewhat greater percentage of cracks coming through than the comparable thickness of 1936 construction. At least part of this difference might be attributed to the greater length of service of the 1932 construction.

From Figures 8 and 9 it can be seen that for any distance from the nearest joint, the percentage of cracks that came through is smaller as the resurfacing thickness increases. It is also evident that in all resurfaces the expansion joints had an effect in controlling the tendency for cracks in the old pavement to come through the resurfacing within a distance of 9 feet from joints. It should be kept in mind that joint spacings were uniform in each of these resurfaces and no attempt was made to locate joints over cracks in the old pavement. The results of this study indicate that design methods to provide for locating transverse joints over well-defined cracks by varying the joint spacing would be worth trying. Theoretical studies of this subject have been reported previously and a method is presented in Appendix B.

EFFECTS OF EXPANSION JOINTS ON SURFACE DETERIORATION

As mentioned previously, deterioration characteristically started at interior corners or along joints and cracks. With the exception of some defects scattered along the longitudinal joint, practically all the defective areas were located at transverse joints and cracks. Whenever pavement observations were made, it was evident that, in general, deterioration was worse at expansion joints than at transverse cracks.

TABLE 12

Transverse Cracks in Resurfaces of Various Thicknesses Above Cracks in Old Pavement

Classified According to Distance From Nearest Joint

	Location of Cracks Distance to Nearest Joint (Feet)				
	0 to 2	3 to 5	6 to 8	9+	Total
418 Panels - 4" Resurface - 1936					
No. of Lane Cracks in Both Old Pavement and Resurface	3	48¼	72¼	652¾	776¼
No. of Lane Cracks in Old Pavement under 418 panels	152¼	151½	148½	881½	1333¾
% of Total Old Cracks that came through Resurface	2.0	31.8	48.7	74.0	58.2
140 Panels - 5" Resurface - 1936					
No. of Lane Cracks in Both Old Pavement and Resurface	0	18	27	205½	250½
No. of Lane Cracks in Old Pavement under 140 panels	62¼	68½	67	398¼	596
% of Total Old Cracks that came through Resurface	0	26.3	40.3	51.6	42.0
154 Panels - 6" Resurface - 1936					
No. of Lane Cracks in Both Old Pavement and Resurface	0	8	17	186¾	211¾
No. of Lane Cracks in Old Pavement under 154 panels	128½	101½	120	736½	1086½
% of Total Old Cracks that came through Resurface	0	7.9	14.2	25.4	19.5
33 Panels - 6" Resurface - 1932					
No. of Lane Cracks in Both Old Pavement and Resurface	0	3½	8½	42¼	54¼
No. of Lane Cracks in Old Pavement under 33 panels	21	32	32	125½	210½
% of Total Old Cracks that came through Resurface	0	10.9	26.6	33.7	25.8

The use of expansion joints in any concrete pavement introduces points of weakness at which deterioration tends to start. The expansion joints in this resurfacing, in addition to disrupting the continuity of the resurface and breaking it up into panels (at the ends of which destructive forces naturally concentrate), provided reservoirs for entrapping surface water. The presence of the impervious old pavement under the resurface helped retain water in the joint reservoirs from which it could permeate into the resurfacing concrete and intensify the destructive effects of freezing. Other objectionable features associated with the use of these expansion joints, such as defective installation and the placement of inferior quality concrete at the joints due to the difficulty of obtaining satisfactory compaction and finishing close to the joint members, were responsible in varying degrees for the development of increased deterioration at the expansion joints.

Table 13 shows that in the 1936 construction 41.5 percent of the total defective area in the 4-inch resurface was located at expansion joints, in the 5-inch resurface 47.2 percent was at expansion joints, and in the 6-inch resurface 69.4 percent of the defects were at expansion joints; in the 6-inch resurface built in 1932 55.1 percent of the defects were at expansion joints. The table also shows that the average area of deterioration per joint varied inversely with the resurface thickness.

If it is assumed that all of the defects not at transverse joints had developed at transverse cracks (which is erroneous in favor of the joints, since considerable map cracking developed along the center joint away from either joints or cracks), and the area of defects in each resurface not at joints is divided by the corresponding number of transverse cracks, the average area of defects per crack would be respectively 38, 20, 9, and 5 sq. ft. for the 4, 5, 6-inch 1936 resurfaces and the 6-inch 1932 resurface. When those values are compared to the average defective area at expansion joints as tabulated above, it can be seen that, in each case, the joints were more disadvantageous than the cracks insofar as their influence on the development of defects was concerned.

In Table 14 data regarding faulting have been tabulated for each of the resurfaces. The number of faulted joints or cracks divided by the total number indicates the relative rate of faulting in each design. As shown in the table, in the 1936 construction 2.4 percent of the joints in the 4-inch resurface were faulted, 5.7 percent in the 5-inch resurface and 2.7 percent in the 6-inch. Faulting at cracks in these were, respectively, 4.0 percent, 4.1 percent and 3.0 percent. The relatively high percentage of faulting at joints in the 5-inch resurface is not readily explainable but, in general, the proportion of joints or cracks that show faulting is not great in any of the 1936 resurfaces.

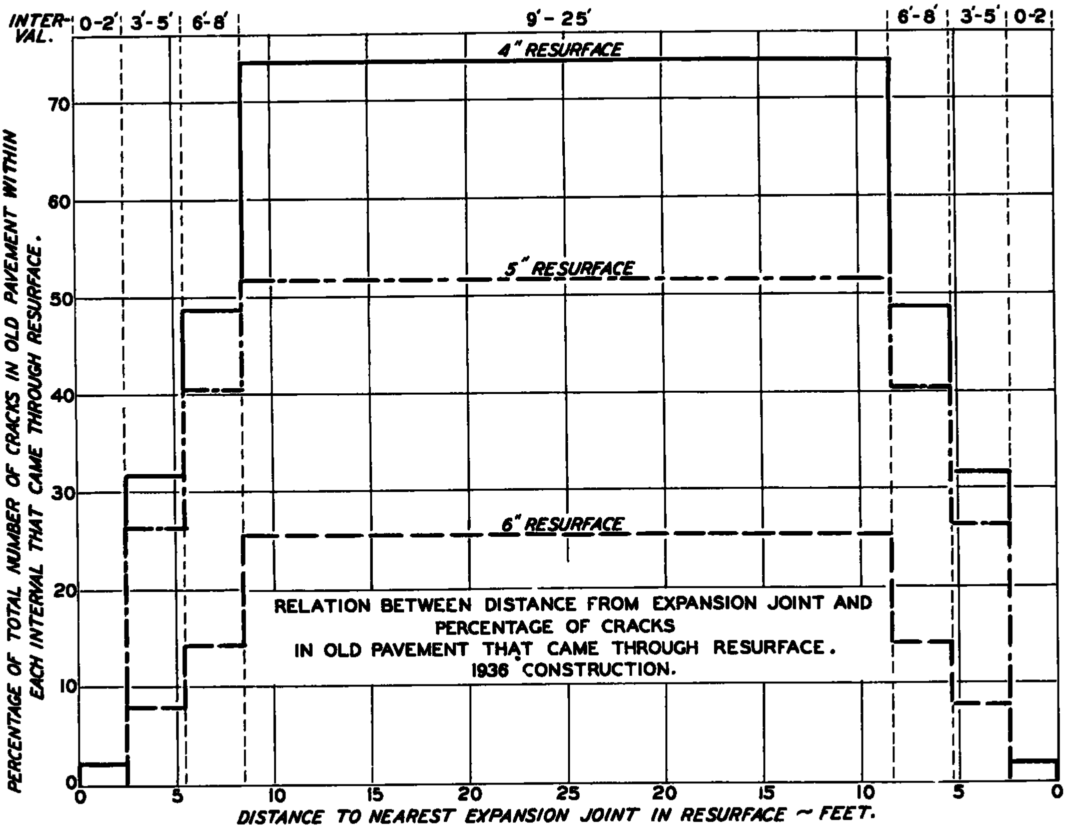


Figure 8.

FAULTING OF EXPANSION JOINTS IN RESURFACING

Any faulting observed in the resurfacing, whether at joints or cracks, was recorded in the condition survey notes. Practically all of the faulting was found to have occurred above full transverse cracks, joints, or defective areas in the old pavement, and in most cases, the surface was depressed on the forward side of the joint or crack, with reference to the direction of traffic. Several instances were found at a single joint or crack where the surface was depressed on the west side of the joint or crack in one lane and on the east side in the opposite lane. This indicates that traffic loads were a major factor in the faulting.

In the 6-inch resurface built in 1932, nearly 46 percent of the joints were faulted but only 1.7 percent of the cracks showed faulting. As stated above, the 1932 resurface included bar-mat reinforcement but no load-transfer device in the joints. The difference between the

TABLE 13

Surface Deterioration Observed at Expansion Joints

Resurface Thickness	Panels	Total Area of Defects at Expansion Joints (Sq. Ft.)	Total Area of Defects at Expansion Joints (Sq. Ft.)	Percent of Defective Area at Exp. Jts.	Ave. Area of Defects per Exp. Jt. (Sq. Ft.)
in.	no.				
		1936 Construction			
4	418	42,543	17,661	41.5	42
5	140	8,268	3,905	47.2	28
6	184	4,775	3,314	69.4	18
		1932 Construction			
6	33	633	349	55.1	11

joints and cracks in the percentage faulted (45.5 percent versus 1.7 percent), as compared to the relationship shown in the 1936 construction (2.7 percent versus 3.0 percent), apparently can be attributed to these design differences. The use of bar-mat reinforcing in 1932 proved effective in maintaining surface alignment at cracks since only 1 of 58 showed faulting, whereas, the omission of dowels in the joints was probably the major factor in permitting 46 percent of the joints to develop faulting.

The effects of load transfer across joints and cracks may be further illustrated by comparisons between the 1936 and 1932 6-inch resurfaces. Of the dowelled joints in the 1936 resurface, only 2.7 percent have faulted, whereas, 46 percent of the joints in the 1932 resurface without dowels show faulting. In the 1936 resurface with mesh reinforcing, 3.0 percent of the cracks have faulted, whereas, in the 1932 resurface, built with bar mat, only 1.7 percent of the cracks have faulted, even though the latter has been subjected to 3½ years

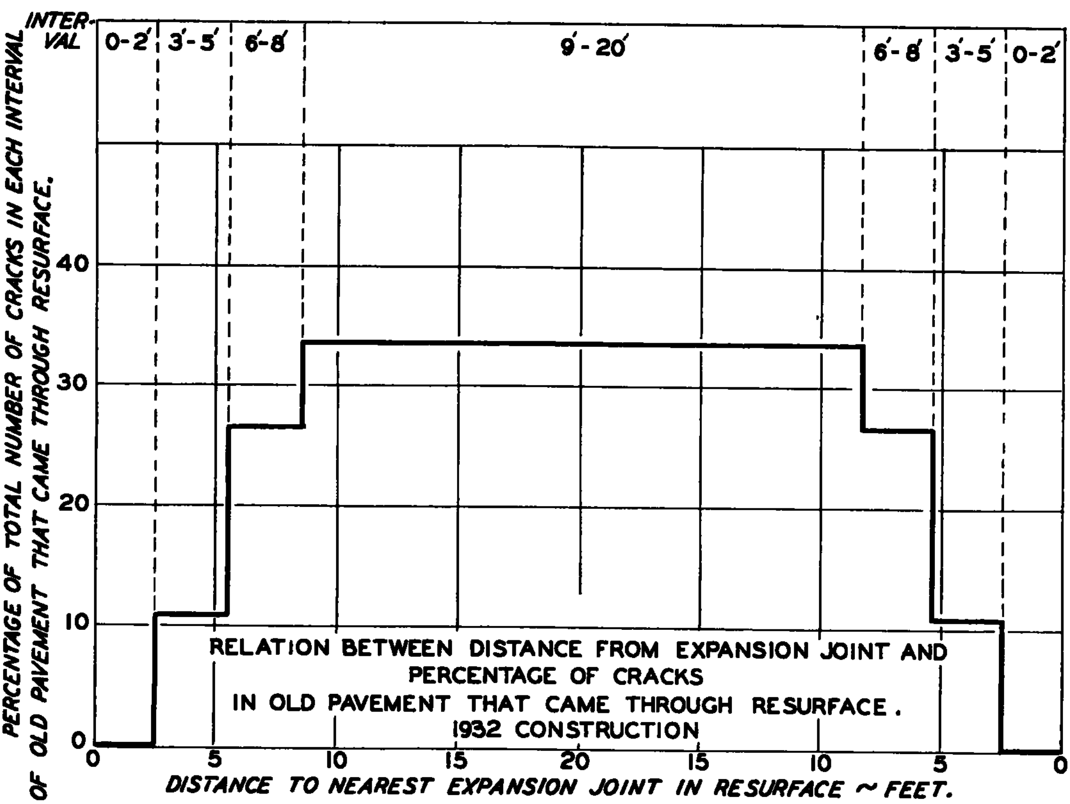


Figure 9.

more service. These relationships indicate the value of load-transfer provisions in resurface design.

OBSERVATIONS OF OLD PAVEMENT AFTER REMOVAL OF SECTIONS OF RESURFACING

When the 1936 resurfacing was laid, a 40-ft. panel of the 4-inch resurface built in 1932 was removed to permit relocating a drain basin and to provide a smooth junction between the 1932 and 1936 resurfaces. The old pavement within this 40-foot length was in good condition when resurfaced in 1932, and when the resurface was removed less than 4 years later, no deterioration of consequence was visible in either the old pavement or the 4-inch resurface. There was one full transverse crack in the old pavement, and it had come through the resurface in both lanes prior to January 1935.

The 40-foot panel removed was located near the foot of a slight grade and drainage conditions appeared conducive to deterioration but the concrete in both the resurfacing and the old pavement was found to be sound and in good condition. As the resurfacing was removed a film of water was observed between the two layers of concrete. This water was of sufficient volume that its movement flowing down the grade could be detected.

The principal deductions from these observations are: (1) the 4-inch resurface laid in 1932 over a 40-ft. section of old pavement in good condition was satisfactory for a period of about 4 years and, within that period, no deterioration developed in the underlying old pavement; (2) the film of water between the two layers of concrete showed that the resurface was not bonded to the old pavement; and (3) the presence of this water demonstrates that it is possible for water to accumulate between the two layers and calls attention to the probability that soaking combined with freezing and thawing may be a major factor in the resurface deterioration.

In May 1951 some of the most-seriously disintegrated areas in the concrete resurface were removed and replaced with concrete patches preparatory to resurfacing with asphaltic concrete. This afforded an opportunity not only to inspect the concrete being removed, but also, to ascertain the condition of the old pavement underlying the areas removed. Following are pertinent observations made during the removal of 33 disintegrated areas of lane width or less, located at 19 different stations.

The resurfacing disintegration appeared in general to result from material failure evidenced by a scaly type of map cracking that covered considerable area before progressing to complete disintegration in the most-severely affected portion of the area, probably its area of inception.

TABLE 14

Faulting of Joints and Cracks in Resurfaces of Various Thicknesses

	Thickness of Resurface							
	1936 Construction						1932 Construction	
	4"		5"		6"		6"	
	At Joints	At Cracks	At Joints	At Cracks	At Joints	At Cracks	At Joints	At Cracks
Number Faulted	10	27	8	9	5	5	15	1
Total Number	418	671	140	218	184	164	33	58
% Faulted	2.4	4.0	5.7	4.1	2.7	3.0	45.5	1.7

The most-severely affected areas were found at the interior corners and along the expansion joints. Sixty-four percent of the number of patched areas were at joints. Apparently the expansion joints provided a reservoir into which water could accumulate and permeate between the old pavement and the resurface as well as into the adjacent concrete. The location and characteristics of the failures indicate that freezing and thawing was a major factor in their inception and development.

A large percentage (79%) of the failures that were patched occurred over old pavement in apparently good condition wherein the only defects observed were slight map cracking or transverse cracks (some of which had developed since resurfacing).

At 21 percent of the 33 patched areas the underlying old pavement, as well as the resurfacing, was removed; in these cases the failure of the resurface was attributed to defective old pavement.

Several construction joints in the old pavement were found to have faulted due to expansion having caused one side of the joint to slide up over the other. Where this occurred, part of the resurface was lifted out of contact with the old pavement and the consequent lack of uniform support caused cracking in the resurface.

The concrete in the widening section, 9 inches thick along each edge of the old pavement, was in decidedly better condition than the resurfacing concrete and was generally free from map cracking.

In all cases observed, the extrusion chambers of expansion joints in the resurfacing were filled with bituminous mastic and the filler above and below was compressed down to ⅛ to ¼ inch, demonstrating that the extrusion chamber functioned in the manner intended.

Tie bars across the center joint were generally in good condition and only slightly rusted at the centerline in the resurfacing. Tie bars seen in the old pavement were also in good condition, and both these and the resurfacing tie bars were still functioning.

In 1952 a section of the road was relocated, and the work included excavating both the resurface and the old pavement for several stations. Arrangements were made to remove the resurface separately from the old pavement for a distance of about 200 feet, so as to observe the old pavement condition. After the resurface was removed, the old pavement surface was cleaned and its defects sketched to scale on transparent sheets superimposed on the strip map made in 1936 just before the old pavement was covered with the concrete resurface.

Unfortunately, all of the pavement in this stretch was located on a curve, and the outer edge of the old pavement was superelevated 9 or 10 inches. When the resurface was built, it was superelevated even more, and its outer edge was up to 18 inches above its lower edge on the curve. As a result, drainage was toward the right (lower) side of the pavement and moisture conditions were more conducive to deterioration on that side than on the left side of the pavement.

The resurfacing design specified that, on superelevated curves, such as this, the minimum thickness should be measured directly above the lower edge of the old pavement. Due to the fact that the superelevation built into the resurface was greater than that in the old pavement, the thickness of the resurface on the high side of the curve was more than that on the low side. Specifically, above the section of old pavement observed, the thickness of the resurface cross-section varied from 4 inches at the lower edge of the old pavement to about 12 inches at the upper edge.

The old pavement deterioration that developed during the 16 years it lay under the resurface reflects the effects of the situation described above. The lower lane throughout showed more deterioration than the upper lane. In the upper lane there were apparently only four new lane cracks and merely slight progression of map cracking and checking that had developed during the 16 years the old pavement had been resurfaced with concrete which averaged about 9½ inches thick. However, in the lower lane there were about 12 cracks that appeared to have developed since the pavement was resurfaced, and disintegration had progressed greatly in both extent and severity in most of the lower lane. The resurface thickness over this lane was only 4 or 5 inches at the edge and averaged only about 6 inches over the 9-foot width.

SUMMARY

The effects of certain factors, peculiar to this and a few other jobs, influenced the results. For instance, the use of marker-seal center joint and the resistance to joint movement caused by "frozen" dowels undoubtedly contributed to surface deterioration. Had these factors been absent, the results might have been somethat different. The information derived from the analyses of factors whose effects could be evaluated should prove valuable in designing concrete resurfacing but does not provide all the answers. The results of this investigation should be corroborated by observations of other resurfacing projects before accepting all of the findings as a basis for standards of design.

1. An old concrete pavement in advanced stages of deterioration was made

serviceable for heavy traffic over an extended period of time by resurfacing with portland-cement concrete.

2. A thickness of 6 inches was more durable and theoretically more economic than 5 or 4 inches (see Appendix B).

3. The condition of the underlying old pavement affected the deterioration of resurfaces 4 or 5 inches thick but had practically no effect on the 6-inch resurface. One significance of this is that, if resurfacing with 4 or 5 inches were contemplated, it might be necessary to advance the date of resurfacing for the purpose of preserving the old pavement in suitable condition for a base.

4. The evidence that movements of the underlying slabs tended to cause transverse cracking in the concrete resurfacing, and the indications that transverse joints, at uniform intervals were effective in reducing cracking within 9 feet of the joints, indicate the further possibility of gaining better crack control by the use of variable joint spacing wherein the joints are placed, insofar as possible, over transverse cracks which show evidence of movement (see Appendix C).

5. The 6-inch resurface built in 1932 gave excellent service for 18½ years, and when resurfaced in 1951, apparently could still have been used for many years without excessive maintenance.

6. The 4-inch resurface built in 1932 gave satisfactory service until 1944, but by then was showing distress and had developed several failures requiring patching. The application of bituminous treatment in an attempt to prolong the life of this section obviated any further observations. Consequently, the service life of this 4-inch resurface was considered to have been 12 years.

7. The 1936 6-inch sections which overlay old pavement in relatively poor condition, gave very good service for 15 years and apparently would have been serviceable for many more years.

8. The 4- and 5-inch resurfaces built in 1936, on old pavement in relatively good and in intermediate condition, showed considerable distress after 15 years of service; these, especially the 4-inch, would have required extensive maintenance for further service.

9. In each resurface some transverse cracking was apparently caused by so-called frozen dowels and some by the fact that joints were spaced uniformly without regard to the location of transverse cracks in the underlying old pavement. This cracking, which occurred at an early age, undoubtedly contributed to subsequent increased deterioration in the resurfaces.

10. All of the resurfacing was cracked into slabs which appeared unusually short in comparison with the average length of uncracked slab commonly found in full-depth pavement with similar joint spacing. Considering the entire lengths of each of the 1936 resurfaces of different thickness, the intensity of transverse cracking was more severe in the 4-inch than in the 5-inch resurface; and more severe in the 5-inch than in the 6-inch resurface.

11. On the other hand, considering only those resurfacing slabs which lay on uncracked old pavement, a tendency was noted for such slabs to crack into lengths averaging 20 to 25 feet, regardless of the thickness of resurfacing.

12. In the 1936 construction, a rough relationship apparently existed between transverse cracking in the 4-inch resurface and the cracking in the underlying old pavement. The greater the cracking in the old pavement, the greater was the cracking in the 4-inch resurface.

13. However, in neither the 1932 nor the 1936 construction was there any apparent relation between transverse cracking in the 6-inch resurface and that in its underlying old pavement; in fact, when laid on old pavement with very short crack intervals, the 6-inch resurfaces tended to crack less than where laid on sound old pavement.

14. For a given intensity of transverse cracking in the underlying old pavement, the 4-inch resurface built in 1936 developed the most transverse cracking, the 5-inch somewhat less, and the 6-inch, the least.

15. Considering only those transverse cracks which developed in the resurfacing above cracks in the underlying old pavement, studies of the statistical distribution of such cracks with respect to their distance from resurfacing joints indicate that the joints had an effect in controlling cracking within a distance of 9 feet each side of the joints; and further indicate that the closer the cracks in the old slab were to the joint, the better was the degree of control. This indicates that, even though a number of joints had frozen dowels, there remained some which still functioned.

16. Surface deterioration developed to

some degree in each of the various resurfaces, but the percentage of area affected varied inversely with the thickness of the resurface; on the average in the 1936 resurfacing, the 5-inch resurface developed more than twice as much surface deterioration as the 6-inch, and the 4-inch developed 1¾ times as much surface deterioration as the 5-inch resurface.

17. When averages per panel length were considered, the percentage of surface affected by deterioration (other than transverse and longitudinal cracking) in the 5- and 6-inch resurfaces on defective old pavement remained fairly uniform for all degrees of deterioration in the old pavement, i. e., variations in the intensity of deterioration in the old pavement had little apparent effect upon the degree of deterioration in the 5- and 6-inch resurfaces. However, in the 4-inch resurface there was noted a well-defined trend toward more-intense deterioration over defective areas of underlying old pavement.

18. When individual defective areas were considered, a close association was discerned between deterioration in the resurface and that in the old pavement as evidenced by the tendency for defects to occur over defects.

19. Drainage conditions influenced the deterioration in all resurfaces; where drainage was obviously poor, deterioration was greater.

20. The 4-inch resurface was much-more susceptible to the effects of poor drainage than the 5- or 6-inch resurfaces.

21. Full-depth pavement built in 1936 appeared to be more durable and gave evidence of being more serviceable than appreciably greater thicknesses of comparable pavement consisting of the old pavement covered with concrete resurfacing.

22. The behavior of the marker-seal center joint corroborated experience on other projects, i. e., that its use was conducive to the development of longitudinal cracking. The excessive longitudinal cracking resulting from its use contributed to deterioration in the resurfaces and should be discounted in evaluating their performance.

23. Since no blowups nor evidence of compression were found in any of the resurfacing, it is assumed that adequate expansion space was provided. The apparent absence of extruded bituminous joint filler on the pavement surface and the observation that extrusion chambers in all expansion joints inspected were filled with mastic, indicated that this feature of design functioned as intended.

24. Dowels across transverse joints were effective in preventing faulting and apparently reduced the development of cracking due to loads passing over the joints.

25. During the years from 1932 to 1952, numerous opportunities were presented to inspect the old pavement while sections of resurfacing were being removed for maintenance or reconstruction, but no evidence was found of any bond between any of the resurfacing and the old pavement. A flowing film of water, which was found between the two layers of concrete at a number of places, precluded the possibility of bond at these points and revealed the presence of a void into which water could flow and be trapped.

26. Evidence was noted of expansion developing in the underlying old pavement of sufficient amount to cause failures in the resurfacing.

27. Although conditions of soil, moisture, and traffic were conducive to pumping development and although, in fact, pumping was prevalent and severe throughout the old pavement length before it was resurfaced, practically no instances of pumping were found on any of the resurfaces.

Appendix A

EFFECTS OF OLD-PAVEMENT CONDITION ON THE CONDITION OF RESURFACES, BASED ON STUDY OF INDIVIDUAL DEFECTS

In the following analysis each defect in the resurfacing and the condition of the old pavement directly below it are considered separately rather than by panels as units. This permits further study of the influence of old-pavement condition on the development of defects in the resurfaces.

From the data sheets, (a sample of which is shown in Figure 1), each defective area in the resurface was tabulated by type and according to the condition of the old pavement directly below it. The values were taken from the columns under "Defective Areas in Resurface" and classified according to the letter legend which identified the condition of the underlying old pavement. This tabulation was summarized as shown in Table A grouping the resurface defects according to the condition of the old pavement but without regard to the relative areas of defects below. Usually the area of a defect in the resurface was either larger or smaller than the area of the underlying defect.

In Line 1 under the 4-inch resurface, the summary shows there were 1222 sq. ft. of asphalt patches, 3104 sq. ft. of broken pavement, 25,162 sq. ft. of map cracking. etc., totalling 34,278 sq. ft. of all types of defects which developed over old pavement that was sound when resurfaced. Of the total defects in the resurface 80.6 percent were over sound old pavement. In Column 2 it can be seen that 78 percent of the asphalt patches in the 4 inch resurface were over sound old pavement while 22 percent were found over various types of defects in the old pavement — all of the asphalt patches in the resurface were only 3.7 percent of the total defective area. Although figures representing numerous relationships between the development of the various types of defects in the resurfaces and the influence of different conditions of underlying old pavement may be extracted from Table A, the chief reason for presenting it is to summarize the data for further analysis.

In Table C are assembled data and computations to analyze the effects of the underlying old pavement condition upon the deterioration of each of the resurfaces. The various surface areas are tabulated in square feet and expressed as percentages of the total surface area of the resurface for each thickness. Values to show the relationships between the defective areas in resurfaces and those in the underlying old pavement were taken from Table C and plotted in Figure A.

The letters A, B, B', B", C, D, and E, were used to designate the surface areas as identified diagrammatically in the legend of Figure A and described in Table C. To clarify the relationships of the various surface areas and to assemble them for convenient reference, the following table was arranged showing in alphabetical order the letters used to designate each area, the numerical values as percentages of the resurface area, the source or derivation of the data, and the significance or description of the area. Actually each area designated by a letter is the summation of all the areas in that category.

Where defects developed in a resurface above defects in the old pavement, the defective areas were seldom the same size. When the underlying defect was equal to, or larger than, that in the resurface, the defective area in the resurface was included in B (defective resurface under all or part of which are defects). That portion of the old pavement defect lying directly below and equal in area to the resurface defect was classified as B' (defects that came through). The remaining portion of the underlying defective area, when it was larger than that in the resurface, was included in A, (defects that did not come through).

When the underlying defect was smaller than that above, the entire defective area in the resurface was included in B, (defects under all or part of which are defects). The underlying sound old pavement, equal in area to the difference between the larger resurface defect and the smaller underlying defect, was classified as B" which represented sound old pavement under

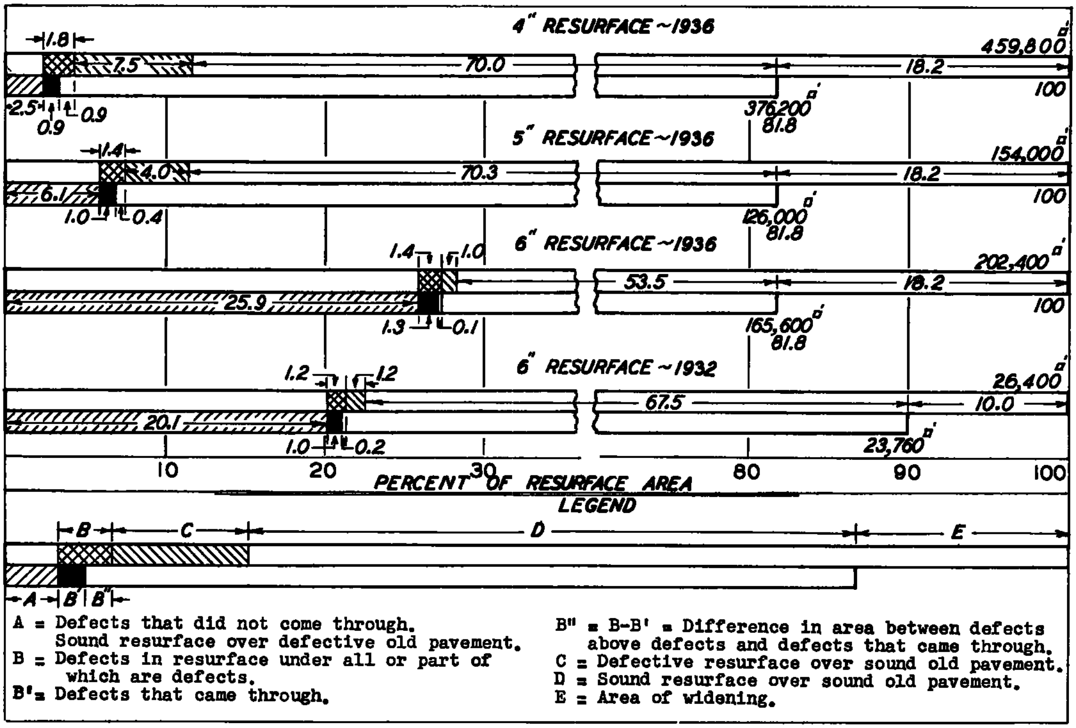
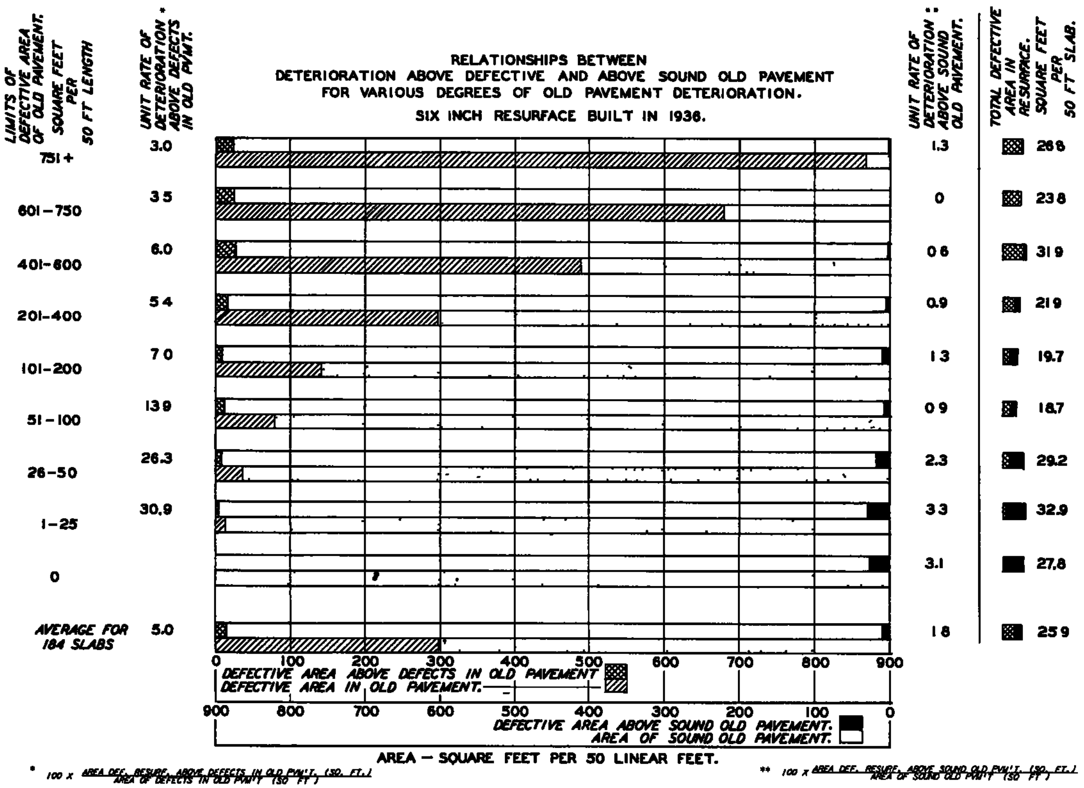


Figure A. Relationships between defective areas in resurfaces and those in the underlying old pavement (areas as percentages of resurface area).



Limits of defective area of old pavement, sq ft per 50 ft length	Unit rate of deterioration* above defects in old pvmt.	Unit rate of deterioration** above sound old pavement	Total defective area in resurface, sq ft per 50 ft slab
751 +	3.0	1.3	26.8
601 – 750	3.5	0	23.8
401 – 600	6.0	0.6	31.9
201 – 400	5.4	0.9	21.9
101 – 200	7.0	1.3	19.7
51 – 100	13.9	0.9	18.7
26 – 50	26.3	2.3	29.2
1 – 25	30.9	3.3	32.9
0		3.1	27.8
Average for 184 slabs	5.0	1.8	25.9

* 100 x (Area def. resurf. above defects in old pvm't. (sq. ft.)) / (Area of defects in old pvm't (sq. ft.))

** 100 x (Area def. resurf. above sound old pvm't. (sq. ft.)) / (Area of sound old pvm't (sq. ft.))

Figure B.

TABLE A

Areas of Defects in Resurface Grouped According to Type of Defect in Underlying Old Pavement

Type of Defect in Resurface	Asphalt Patches		Broken Areas		Map Cracking		Concrete Patches		Corner Breaks		Total Defective Area in Resurface	
	Area in Sq Ft.	% of Total	Area in Sq. Ft.	% of Total	Area in Sq. Ft.	% of Total	Area in Sq Ft.	% of Total	Area in Sq Ft.	% of Total	Area in Sq. Ft.	% of Total
Type of defect in underlying Old Pavement					-4" Resurface 1936 Construction-							
None—Sound Old Pavement	'222	78	3104	65	25,162	85	2393	66	2397	85	34,278	80 6
Asphalt Patches	104	6	434	9	481	2	275	7			1,294	3 0
Broken Areas	17	1	66	1	23	+	0	0			106	0 3
Map Cracking	154	10	744	15	2,097	7	236	7			3,231	7 6
Concrete Patches	33	2	275	6	1,306	4	220	6			1,834	4 3
Construction Joints	45	3	198	4	603	2	494	14			1,340	3.1
Any of the above defects									325	11	325	0 8
Corner Breaks									135	4	135	0.3
Total Area and % of Total Area of Defects in Resurfacing	1575	3 7	4821	11.3	29,672	69 8	3618	8 5	2857	6.7	42,543	100
					-5" Resurface 1936 Construction-							
None—Sound Old Pavement	622	80	1113	70	3,495	75	423	68	490	78	6,143	74.3
Asphalt Patches	6	1	105	7	23	1	44	7			178	2 2
Broken Areas	0	0	0	0	0	0	0	0			0	0
Map Cracking	63	8	225	14	740	16	159	25			1,187	14.4
Concrete Patches	83	11	143	9	329	7	0	0			555	6.7
Construction Joints	0	0	2	+	63	1	0	0			65	0 8
Any of the Above defects									110	17	110	1 3
Corner Breaks									30	5	30	0 3
Total Area and % of Total Area of Defects in Resurfacing	774	9 4	1588	19.1	4,650	56 3	626	7 6	630	7 6	8,268	100
					-6" Resurface 1936 Construction-							
None—Sound Old Pavement	119	56	0	0	1,828	45	0	0	80	41	2,027	42.5
Asphalt Patches	73	34	9	4	798	19	0	0			880	18.4
Broken Areas	0	0	0	0	0	0	0	0			0	0
Map Cracking	19	9	242	95	1,348	33	0	0			1,609	33.7
Concrete patches	0	0	3	1	134	3	0	0			137	2 9
Construction Joints	3	1	0	0	4	+	0	0			7	0.1
Any of the above defects									90	46	90	1.9
Corner Breaks									25	13	25	0.5
Total Area and % of Total Area of Defects in Resurfacing	214	4 5	254	5 3	4,112	86.1	0	0	195	4.1	4,775	100
					-6" Resurface 1932 Construction-							
None—Sound Old Pavement	0	0	42	100	89	28	60	100	135	66	326	51.5
Asphalt Patches	0	0	0	0	0	0	0	0			0	0
Broken Areas	0	0	0	0	0	0	0	0			0	0
Map Cracking	0	0	0	0	160	50	0	0			160	25 2
Concrete Patches	0	0	0	0	72	22	0	0			72	11.4
Construction Joints	5	100	0	0	0	0	0	0			5	0.8
Any of the above defects									65	32	65	10.3
Corner Breaks									5	2	5	0 8
Total Area and % of Total Area of Defects in Resurfacing	5	0.8	42	6.6	321	50.7	60	9.5	205	32.4	633	100

defective resurface and which surrounded a defect, part of which came through. It was realized that this method of classifying and grouping areas had a tendency to make the computed values of B and B' higher than actually existed but no other method was available and it was thought that this would suffice.

In analyzing the effects of defects in the old pavement on defects that occur in Table B, there are two viewpoints or two methods of procedure available: (1) To consider the defective areas of the old pavement which have defects directly above them — those which actually came through — (B') and (2) to consider the defective areas in the resurface under all or part of which there are defects in the old pavement (B).

The ratio of B' to (A+B') expresses the area of defects in the old pavement that came through as a proportion of the total defective area of the old pavement.

The ratio of B to (A + B') expresses the area of defects in the resurface that might be attributable to defects below as a proportion of the total defective area of the old pavement. This ratio will be termed the unit rate of deterioration over defective old pavement. This latter ratio appears more applicable to our analysis since it can be compared with C/ ÷ (B"+C+D) which can be termed the unit rate of deterioration over sound old pavement.

Line 11 shows B ÷ (A+B'), the unit rate of deterioration over defective old pavement for each thickness of resurface, 52.5% for the 4-inch, 19.4% for the 5-inch, 5.0% for the 6-inch. These figures indicate that in the 4-inch resurface the defective areas attributable to the effect of defects below is 10.5 times that in the 6-inch resurface, per unit area of defects below.

Line 12 shows the unit rate of deterioration over sound old pavement. These values are respectively 9.5, 5.3 and 1.8 for the 4-inch, 5-inch, and 6 inch 1936 resurfaces and 1.8 for the 1932, six inch resurface. These values indicate the relative tendencies of the various resurfaces to develop defective areas over sound old pavement and show that defects in the 4-inch resurface above sound old pavement developed at 9.5 ÷ 1.8, or 5.3 times the rate that they did in comparable 6-inch resurface above sound old pavement.

Each area value in Table C was derived from the summation of all areas of that thickness and, therefore, should be regarded as an average which included all conditions encountered on the road. The values from Table C, representing averages for all of one resurface, would not necessarily be applicable to any one specific part of the resurface nor to the condition of any particular section of old pavement.

The following example illustrates this point:

If it were erroneously assumed that the values for average rates of deterioration above defective and sound old pavement as given in lines 11 and 12 were applicable to all conditions of the old pavement, then in 5 inch resurface over old pavement having 75 percent deterioration, a deterioration of about 13 percent would be expected, derived as follows:

Defective area (%) x average unit rate of deterioration above defects - - - - - -
75% x 19.4% = 14.55%

Sound area (%) x average rate of deterioration above sound old pavement - - -
25% x 5.3% = 1.32%

Expected deterioration in Resurface expressed as % area of old pavement
= 15.87%

Expected deterioration in Resurface expressed as % area of Resurface
$= 15.87\% \times \frac{18}{22} = 12.98\%$

In Figure 4 and Table 4 it is seen that the 5 inch resurface over old pavement with 75% deterioration had only 5.9% surface deterioration.

This indicates that the deductions based on data and computations from Table C and Figure A are in apparent conflict with some of the deductions derived from the relationships shown in Figure 4. This figure is based on averages per panel, i. e., the average degree of deterioration that developed in each panel length of the resurface was compared to the average degree of deterioration in the corresponding length of old pavement on which it was placed. This showed that, on the average, greater deterioration developed in the 4-inch resurfacing panels when they were placed on old pavement in more advanced stages of deterioration, but practically no increased deterioration in the 5-inch or 6-inch resurfacing panels when placed on more severely deteriorated old pavement. From this the apparently incontrovertible deduction was made that the average degree of deterioration in the old pavement had practically no effect on the average degree of deterioration in the 5- or 6-inch resurfaces.

The data in Figure A and Table C were based on relationships between individual areas of sound or defective old pavement and the condition of the corresponding areas in the resurface above them. Deductions from these indicated considerable more deterioration in all resurfaces with increased deterioration in the underlying pavement because, as shown in line 13 of Table C, the unit rate of deterioration was greater above defects than above sound pavement. This appeared to be irreconcilable with the deductions from Figure 4 and presented a paradox which demanded further study.

Pursuant to this, an additional analysis was made of the 6 inch resurface built in 1936 to study the unit rate of deterioration above defective old pavement as compared to the unit rate of deterioration above sound old pavement when computed for particular, rather than average, old pavement conditions. The data for this analysis are presented in Table D. The 6-inch resurface was selected because it showed (in Figure 4), on the average, the least influence of variations in the average old pavement condition, and also, because of the wide variations in the old pavement deterioration existing under this resurface.

As shown in Table D, each 50-foot length of old pavement underlying a 50-foot resurface panel was tabulated according to its degree of deterioration and the square feet of defective areas in the corresponding resurfacing panels above were totalled for each degree of deterioration. From this, the unit rates of deterioration in the resurfacing above sound old pavement and in that above defective old pavement were determined for various degrees of old pavement deterioration (ranging from 1.4 percent to more than 83 percent of the area affected).

TABLE B
Tabulation of Areas Plotted in Figure A

Area Denoted by Letter	Numerical Value as % of Resurface Area 1936 4"	1936 5"	1936 6"	1932 6"	Source or Derivation of Data	Significance or Description of Area (Summation of Areas)
A	2.5	6.1	25.9	20.1	Table 1	Defects that did not come through = Sound resurface over defective old pavements.
B	1.8	1.4	1.4	1.2	Table A	Defects in resurface under all or part of which are defects.
B'	0.9	1.0	1.3	1.0	(A+B')-A	Defects that came through = Defects in old pavement under defects in resurface.
B"	0.9	0.4	0.1	0.2	B-B'	Difference in area between defects above defects and defects that came through.
C	7.5	4.0	1.0	1.2	Table A	Defective resurface above sound old pavement.
D	70.0	70.3	53.5	67.5	(A+B+C+D)-(A+B+C)	Sound resurface above sound old pavement.
E	18.2	18.2	18.2	10.0	(A+B+C+D+E)-(A+B+C+D)	Area of Widening.
A+B'	3.4	7.1	27.2	21.1	Table 1	Defects in old pavement.
B+C	9.3	5.4	2.4	2.4	Table 1	Defects in resurface.
A+B+C+D	81.8	81.8	81.8	90.0	Table C	Area of old pavement.
A+B+C+D+E	100	100	100	100	Table C	Area of resurface.
B"+C+D	78.4	74.7	54.6	68.9	A+B+C+D-(A+B)	Sound old pavement.

Values from Table D were presented in Figure B to show graphically the deterioration that developed in resurface panels lying above old pavement in various degrees of deterioration. The values from line 3, representing average areas of defects per 50 linear feet, were plotted from the left origin in the lower spaces to show the variation in old pavement deterioration from 0 to 869.9 sq. ft. of defective area. The values from Line 5 were plotted from the left origin in the upper spaces to show the average area of defects per 50-foot panel of resurface lying above defective old pavement. Values from line 4 were plotted from the right origin to show the average area of defects per 50-foot resurface panel lying above sound old pavement. The percentage values from line 6 and line 9 which give, respectively, the unit rate of deterioration above defective old pavement and the unit rate of deterioration above sound old pavement, were tabulated to the left and right of the graph. The values shown in the last column of the chart represent the total defective areas in the resurface, i. e., the sum of the defects

TABLE C
Analysis of the Effects of the Condition of the Underlying Old Pavement upon the Deterioration in Resurfaces of Various Thicknesses

	Resurface 1936 4" Area Sq Ft.	4" % of Total Resurf Area	5" Area Sq Ft	5" % of Total Resurf Area	6" Area Sq Ft	6" % of Total Resurf Area	1932 6" Area Sq Ft	6" % of Total Resurf Area	Identification with Respect to Legend of Fig A
(1) Number of Resurface panels included (Table 3)	418		140		184		33		
(2) Area of Resurface panels ((1) x slab length x width)	459,800	100	154,000	100	202,400	100	26,400	100	A+B+C+D+E
(3) Area of Underlying Old Pavement ((1) x panel length x 18)	376,200	81.8	126,000	81.8	165,600	81.8	23,760	90	A+B+C+D
(4) Defective Area in Resurface (Table 3)	42,543	9.3	8,268	5.4	4,775	2.4	633	2.4	B+C
(5) Area of Defects in Resurface over Defects in old pavement (Table A)	8,265	1.8	2,125	1.4	2,748	1.4	307	1.2	B
(6) Area of Defects in Resurface over Sound Old Pavement (Table A)	34,278	7.5	6,143	4.0	2,027	1.0	326	1.2	C
(7) Area of Defective Old Pavement under Resurface (Table 3)	15,754	3.4	10,966	7.1	55,154	27.2	5,583	21.1	A+B'
(8) Area of Sound Old Pavement under Resurface (3) - (7)	360,446	78.4	115,034	74.7	110,446	54.6	18,177	68.9	B"+C+D
(9) Area of Defective Old Pavement under Sound Resurface (Table 3)	11,462	2.5	9,335	6.1	52,469	25.9	5,323	20.1	A
(10) Area of Defective Old Pavement under Defective Resurface (7) - (9)	4,292	0.9	1,631	1.0	2,685	1.3	260	1.0	B'
	Ratio	Percent	Ratio	Percent	Ratio	Percent	Ratio	Percent	
(11) Unit rate of deterioration over defective Old Pavement expressed as a percentage (5)/(7)	8,265 / 15,754	52.5	2,125 / 10,966	19.4	2,748 / 55,154	5.0	307 / 5,583	5.5	B x 100 / A+B'
(12) Unit rate of deterioration over Sound Old Pavement expressed as a percentage (6)/(8)	34,278 / 360,446	9.5	6,143 / 115,034	5.3	2,027 / 110,446	1.8	326 / 18,177	1.8	C x 100 / B"+C+D
(13) Relative Deterioration in Resurface Attributable to the Effect of Underlying Defects as Compared to that over Sound Old Pavement (11)/(12)	52.5 / 9.5	5.5	19.4 / 5.3	3.7	5.0 / 1.8	2.8	5.5 / 1.8	3.1	(B / A+B') / (C / B"+C+D)

TABLE D

Analysis of 6" Resurface Built in 1936 to Show Rate of Deterioration Above Defective and Above Sound Old Pavement - Classified According to the Degree of Deterioration Per 50 Ft Length of Old Pavement

Line No	Surface Defects in Underlying Old Pavement	0	1-25	26-50	51-100	101-200	201-400	401-600	601-750	751+	Total or Average
	Average Percent of Area Affected	0	1.4	4.2	8.4	16.7	33.4	55.6	75.0	83.3+	
				All areas are expressed in square feet							
1	No. of panels of resurfacing above old pavement having defects within limits of column headings	17	19	21	18	23	26	23	9	28	184
2	Total area of defects in old pavement (from tabular sheets)	0	223	764	1420	3233	7765	11,267	6,126	24,356	55,154
3.	Area of defects per 50 ft length of old pavement (Line 2 + Line 1)	0	11.7	36.4	78.9	140.6	298.7	489.8	680.7	869.9	299.8
4	Total area of defects over defective old pavement (from tabular sheets)	0	69	201	198	225	420	681	214	740	2748
5.	Area of defects over defective old pavement per 50 ft panel (Line 4 + Line 1)	0	3.6	9.6	11.0	9.8	16.2	29.6	23.8	26.4	14.9
6	Unit rate of deterioration above defective old pavement expressed as a percentage $\frac{(\text{Line 4})}{(\text{Line 2})} \times 100$	-	30.9	26.3	13.9	7.0	5.4	6.0	3.5	3.0	5.0
7	Defects in resurface over sound old pavement (from tabular sheets)	473	563	411	139	228	149	54	0	10	2027
8	Defects in resurface over sound old pavement, Avg per 50' panel $\frac{(\text{Line 7})}{(\text{Line 1})}$	27.8	29.3	19.6	7.7	9.9	5.7	2.3	0	0.4	11.0
9	Unit rate of deterioration over sound old pavement, expressed as percentage $\frac{(\text{Line 8})}{(900-\text{Line 3})} \times 100$	3.1	3.3	2.3	0.9	1.3	0.9	0.6	0	1.3	1.8

above defective old pavement and those above sound old pavement or the values in line 5 plus those in line 8 of Table D.

From the graph or a comparison of the values in Line 6 of Table D, a well defined trend may be seen for the unit rate of deterioration above defects to be greater above old pavement in better than average condition. The rate of deterioration above defective old pavement averaged 5. 0 percent for all 184 resurface panels but for those above old pavement with relatively little deterioration, (those having between 1 and 25 sq. ft. or an average of 11. 7 sq. ft. per 50 feet of pavement length) the unit rate of deterioration was 30. 9 percent, whereas, for panels above old pavement having more than 751 sq. ft. of deterioration per 50-foot length, the unit rate of deterioration was only 3. 0 percent. Between these two extremes, in general, the greater the deterioration in the underlying old pavement, the smaller was the unit rate of deterioration in the resurface.

Also, as shown in the graph and the values from Line 9 of Table D, there is a trend toward greater unit rate of deterioration above the sound portions of the old pavement in the classifications containing the lesser amounts of defective old pavement. The unit rate of deterioration above sound old pavement averaged 1. 8 % for all 184 resurface panels but above old pavement in the classifications of "no defects" and above that having between 1 and 25 sq. ft. per 50-foot length, the amount of defective resurface above sound old pavement was 3. 1 percent and 3. 3 percent respectively. When these are compared with the unit rate of deterioration above sound old pavement in the classifications having over 200 sq. ft. of defects per 50 feet (which is about 1% or less) the tendency for a greater unit rate of deterioration above sound old pavement, where the degree of deterioration in the underlying old pavement was less, can be readily discerned.

There are three outstanding observations to be derived from Figure B, (1) the unit rate of deterioration above defective old pavement was greater than that above sound old pavement, not only on the average (5. 0% as compared to 1. 8%) but also, for each category of old pavement condition, (2) the unit rate of deterioration above defective old pavement decreased as the rate of deterioration in the underlying old pavement increased; and (3) the unit rate of deterioration in the resurface above sound old pavement increased with increase in the proportion of sound old pavement.

The first observation is apparently in-consistent with the fact that no trend is apparent from the values of total defective resurface areas as plotted and tabulated in the graph or as shown in Figure 4. In the following paragraph an explanation of this paradox is given, but it cannot be proved or disproved statistically because of the manner of recording survey data.

All surface deterioration in the resurface except map cracking along the center joint developed at transverse cracks and joints. Likewise, the defects in the old pavement were concentrated at transverse cracks and joints. The pronounced tendency for the transverse cracks to develop above underlying transverse cracks and joints, especially above those that were open and generally surrounded by deterioration, would result in defects at cracks in the resurface being located above defects at underlying cracks. As shown in Figure 3 and Table 5, the frequency of cracks in the resurface was no less above underlying pavement with few cracks than above pavement with average cracking; and, in fact, the frequency of cracks in the resurface was even less over closely cracked old pavement where, in general, the percentage of defective area was high. Therefore, defects in the resurface occurring at cracks tended to develop to about the same area per panel regardless of the frequency of defects below, and yet the defects that did occur tended to be over defects. Also, the defective areas at expansion joints were due principally to the existence of joints rather than to the condition of the underlying old pavement, and consequently, tended to occur at a uniform rate. If this explanation is correct, the paradox is resolved and it would appear that the degree of deterioration that developed in the 6-inch resurface was independent of that in the old pavement.

Appendix B

A STUDY OF ECONOMIC CONSIDERATIONS IN THE SELECTION OF RESURFACE THICKNESS

Although the 6-inch resurface performed better under service than the 5- or the 4-inch thicknesses, it does not necessarily follow that the 6-inch would be the most economical resurface. However, because the 4- and 5-inch resurfaces developed such relatively high percentages of defective area as compared to the 6-inch, it would seem that the thicker resurface should have the lowest yearly cost. To determine which would actually be the most economical, the following factors must be taken into account:

A. Yearly amortization cost of the construction, which is computed from:

1. Cost of constructing resurface.
2. Rate of interest.
3. Life expectancy.

B. Yearly maintenance cost.

C. A measure of the annual value of the disadvantage to the travelling public of a poor riding surface caused by defects and of interruption of traffic during repairs.

All of these factors are not readily determinable. However, relative estimates can be made, which undoubtedly favor the lesser thicknesses and a result obtained which still shows the 6-inch thickness to be the most economical.

The values used in estimating life expectancies in this study were based on actual pavement condition. As a matter of practice, pavements are sometimes retired before the end of their useful lives because of obsolescence from the standpoint of alinement, width or grades, etc. Such cases would tend to favor the use of lesser thicknesses and might have considerable weight in the design of thickness when a pavement below the current standards in alinement, etc. is considered for resurfacing. If the possibility of obsolescence is great then the problem will also become one of whether to resurface or discard the old pavement. Then other factors enter such as value of improved design, available detours, etc.

A. 1. - The relative cost of construction of each thickness.

The bid prices by contractors on 4-, 5-, and 6-inch thicknesses would probably be approximately proportional to the thickness plus a constant to cover overhead, finishing, curing, etc. For example if this constant represented only 20 percent of the bid price of a 6-inch pavement, the relative bid prices would be 4.3, 5.2 and 6 respectively. If this constant is reduced to 0, making the relative construction costs 4, 5, and 6 respectively, this will undoubtedly favor the lesser thicknesses.

A. 2. - The interest rate.

The Missouri Highway bonds are now selling to yield 1¾ percent to maturity on the issue that matures the latest (1957). If new 20-year bonds were issued at this time, it is estimated by a financial house that the rate would be between 1.80 and 1.85 percent yield. To give the lesser thicknesses the advantage, a rate of 3 percent will be used.

A. 3. - Life expectancies

It is assumed that:

a. The 4-inch resurface reached the end of its service life at the age 16 in 1952.

b. The 5- and 6-inch resurfaces would have reached the end of their lives when they had the same percentage area of deterioration as did the 4-inch when it was retired.

c. Deterioration in any thickness of resurface progresses in such a manner that the area of deterioration is proportional to the cube of the age. (In this study this assumption is not used for percentages of deterioration over 16 percent.) To express this algebraically:

$$D = Ky^3$$

Where D = % Area of defects
K = A constant applicable to a given thickness of resurface
y = Service age in years

A lower exponent of y in this equation would have given greater life expectancies for the 5- and 6-inch resurfaces and would have been more favorable to the 6-inch resurface. Therefore this exponent was set at 3 as our observations over a period of years lead us to believe that deterioration in a given pavement will not progress faster than the cube of the age.

To compute relative life expectancies, values plotted in Figure 4 at a value of 25 percent deterioration of the old pavement will be used. These are as follows:

Thickness of Resurface	Deterioration of Resurface
inches	%
4	15.8
5	6.45
6	1.9

These values give, by the above formula, life expectancies of 32.4 years for the 6-inch thickness and 21.6 years for the 5-inch and 16 years for the 4-inch resurface.

The yearly amortization costs (A) are now computed as follows:

(1) Thickness	(2) Assumed Relative Construction Cost	(3) Life Expectancy	(4) At 3% Annuity Whose Present Value is 1 for years in Column 3	(5) Yearly Construction Cost (2) x (4)
in		yr		
6	6	32 4	0 04869	0 292
5	5	21 6	06360	381
4	4	16	07961	318

(Column 4 is obtained from an annuity table using values in Column 3 and 3-percent interest rate)

The total yearly cost of pavement=A+B+C

Items B and C were undoubtedly less for the greater thicknesses and since, as shown in the table, A was least for the 6-inch thickness, it follows that this was the most-economical installation of the three.

Appendix C

A METHOD OF SPACING TRANSVERSE JOINTS IN CONCRETE RESURFACING

Because of the fact that certain transverse cracks in the underlying old pavement tended to cause cracks to form in the resurface directly above them and this tendency decreased when uniformly spaced joints in the resurface happened to be placed near these cracks in the old pavement, it is logical to expect that a substantial amount of transverse cracking could be eliminated by a method allowing variable joint spacing so as to provide joints in the resurface over as many of the prominent cracks in the old pavement as possible.

To provide for all spacings of cracks in the old pavement, the allowable tolerance in spacing must permit the maximum to be twice the minimum. For example, if the standard design called for a spacing of 50 feet and it was desired to have an average of 50 feet in the variable joint spacing, then the limits should probably be set at 34'-68' or 35'-70'.

The joints should be located as follows:

1. When the spacing of transverse cracks in the old pavement is between the minimum and maximum designated joint spacings, a joint should be located over every crack.

2. When the spacing between adjacent cracks is in excess of the maximum spacing, then a joint should be located over each crack and one or more intermediate joints spaced uniformly, the minimum number possible being used.

3. When the spacing between adjacent cracks is less than the minimum spacing, then joints should be located over well defined cracks spaced between the limits.

There may occur rare instances where it would be advisable to allow spacing outside of the designated limits. An empirical set of rules for spacing joints could be established for any desired limits, which would include treatment of one lane and offset cracks.

Fed. Road Dist. No.	State	Federal Project No.	Fiscal Year	Sheet No.	Total Sheets
5	MO.	144B	36	2 M	
3	CALLAWAY		40		
	also				
5	CALLAWAY	32	40	M52	

SUMMARY SHEET FOR CONCRETE PAVING PROJECT

	PROJ 144B	SEC. M-52
CONTRACTOR / PAVED BY	Davis Construction Co	Deering & Davidson Inc
PROJECT ENGINEER	W F Boone	R J Kunder
SLAB INSPECTORS	G G Grant, C E Moore, H S Duncan, G Riles	G G Grant
PLANT INSPECTOR	L C White, J H Woolery	L F Lynes

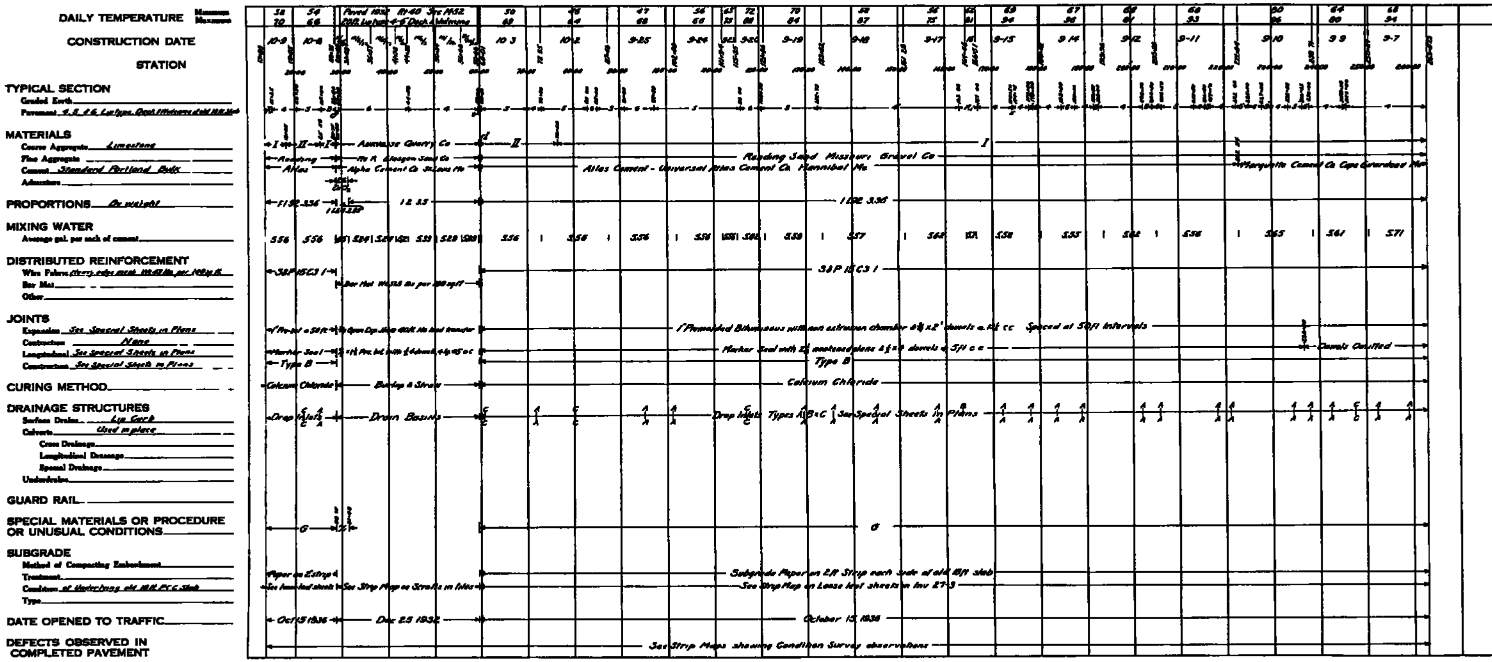
EQUIPMENT	PROJ. 144B	SEC. M-52
	27E Koehring Paver	27E Koehring Paver
	Ord Finisher	Lakewood Finisher
	Flexible Shaft Vibrator	Johnson Bins & Batcher
	Creason Form Tamper	
	Johnson Cement Scales & Kenekerts	
	Blaw Knox Batcher	

	PROJ 144B	SEC M-52
TYPE OF CONSTRUCTION	22 ft PCC Deck on Old 18 ft Slab	20 ft PCC Deck on Old 18 ft Slab
TOTAL LENGTH	4.123 miles	0.378 miles
EXCEPTIONS	28 75 to 59 66 - 3091 ft	None
EQUATIONS	168+05.1 = 168+06.9 - 1.8 ft	None

LOCATION OF PROJECT
From Rt Z Junction East to Williamsburg

DATE OF CONSTRUCTION
144B Sept 7 to Oct 9, 1936
M52 Nov 30 to Dec 21 1932

GRAPHIC RECORD OF CONSTRUCTION FEATURES



MATERIAL KEY
I Burlington Limestone Auxvasse Quarry Co
II St Louis Limestone Rock Hill Quarry Co

SPECIAL PROCEDURE KEY
X - Rich mix with 2% $CaCl_2$ admix Wet batched from paver at Auxvasse Creek
G - 27 - 20 ft Gaps left at Drop Inlets & Paved later with 2 bag mixer

PAVEMENT THICKNESS KEY
A - Removed old slab & replaced with pavement 7" thick @ 13+60 to 11 @ 15+25
4-5-6 - Thickness of Resurfacing on old slab Transitions included with section of lesser thickness
B - Transition from 5 of new resurfacing @ 26+80 to 3 of old resurfacing @ 28+60
C - Transition from 3 @ 28+75 to 6 @ 29+30
E - Removed 40 ft of old 4 resurfacing & replaced with 4 to 3 new
R - Removed old slab & replaced with 11 pavement

PREPARED BY Don E. Gotham June 8 1939
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