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RESURFACING WITH PORTLAND CEMENT CONCRETE

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SYNOPSIS

Concrete is being widely used for resurfacing pavements which have proved inadequate for modern traffic, especially where additional width and greater strength are required The report summarizes the results of surveys of concrete resurfacing in various parts of the country, describing the effect of different types of joints, different thicknesses of resurfacing and of widening, cushion courses between new and old slab, base condition and aggregate size and reinforcement, on the service rendered by the pavement Designs for resurfacing are suggested and a discussion of cost as compared with removal and replacement is included "

No careful record has been kept of pavements resurfaced with concrete. The oldest recorded concrete resurfacing was a 10-foot strip in the center of Union Street at Schenectady, New York, built in 1909

This resurfacing was 1 to $1\frac{1}{2}$ inches thick along the edges and three inches in the center, but was grooved to secure traction, reducing its thickness at the groove by $\frac{1}{2}$ inch. When 12 years old it had broken up considerably and was removed. The next oldest concrete resurfacing is on East Main Street in Marshalltown, Iowa, where four inches of plain concrete was placed over a natural cement base in 1911. The next is Warsaw Street in Toledo, Ohio, resurfaced with 1 to 2 inches of reinforced concrete in 1912. Both of these pavements are still in service.

In California some years ago more than 200 miles of 4 to 7-inch concrete resurfacing was built on state and county highways.

Figure 1. East Main Street, Marshalltown, Iowa. Resurfaced in 1911. Photographed 1932. Four-inch plain concrete on a five-inch natural cement concrete base. The railway track was built later and the pavement had to be cut out in the track area, which is blamed for much of the cracking in this twenty-one-year-old pavement.

Both rigid and non-rigid pavements have been successfully resurfaced with concrete.

EXPERIMENTAL RESURFACING

Many of the earlier projects were considered experimental, but few of them were of more than local interest. Recently, however, four experimental resurfacing projects have been built by as many state highway departments. Some of these are too new to warrant conclusions concerning the different designs, but they are listed for future reference.

Figure 2. Market Street, Savannah, Mo. Resurfaced 1914. Photographed 1932—18 years old. Two-to-three-inch concrete over one year old concrete base. Light mesh reinforcement. Oil tracked onto pavement from oiled dirt streets. Cracked, but good for many years. Light traffic.

Figure 3. Water Street, Cape Girardeau, Mo. Resurfaced 1916. Photographed 1932—16 years old. Four inches of plain 1:1½:3 concrete on seven-year-old concrete base. In good condition except one broken area. Dray and truck traffic.

TABLE I

SUMMARY OF OCTOBER, 1932, SURVEY OF THE SYRACUSE TEST ROAD

Thickness		Reinforcement	Joint interval, Ft	Transverse joint and crack interval	Per cent of total possible internal corner breaks	Per cent of total possible external corner breaks	Per cent of total area shattered	Remarks
Edge	Center							
No center joint								
inches	*inches*		*feet*					
3½	2¾	Mesh	30	30	0	5	0	Bad condition due to double to quadruple longitudinal cracks entire length
Center construction joint								
3½	2¾	Mesh	30	26	30	11	0 3	
No center joint								
3	3	Bar Mat	30	29 2	13	10	0 07	
Center construction joint								
4	3	Mesh	30	27	24	3	20	
No center joint								
3½	3½	Bar Mat	30	27	12	6	0	All cracked longitudinally 25 per cent has double longitudinal
Center construction joint								
3½	3½	Bar Mat	60	36	35	16	0 5	
Center construction joint								
4½	3½	Mesh	30	29	18	2	0	
Center construction joint								
4	4	Bar Mat	7 at 60 6 at 30	52 5 30 0	14 46	10 12	0 5	Excessive interior corners at 3 consecutive joints No explanation
Center construction joint								
5	4	Mesh	30	30	0	2	0	Outstandingly the best sections

Syracuse Test Road

The Syracuse Test Road is approximately one mile in length, on the main route from Syracuse, New York to Watertown, and carries from 7,000 to 10,000 vehicles daily. The old pavement was concrete 16-feet wide and $4\frac{3}{4}$–$6\frac{3}{4}$–$4\frac{3}{4}$-inch cross section. The resurfacing was built in 1925 and is from 3–$2\frac{3}{4}$–3 inch to 5–4–5 inch in thickness, the additional edge thickness being secured by flattening the crown. Some sections

Figure 4. Syracuse Test Road. Section 92 in foreground, section 93 beyond joint. Photographed in 1926 when surfacing was one year old, with white lines indicating breakage since that time. Resurfacing three inches thick along center joint. Breakage due to lack of mortise or dovetail in the center joint, leaving the joint a free edge to carry loads without help from the adjacent slab.

had mesh reinforcement of different weights and others double or single mats of $\frac{3}{8}$-inch round bars. For 280-feet a bituminous mat $\frac{1}{2}$ to 2 inches in depth, separates new and old concrete. Except in 21 slabs which are 60 feet long, transverse joints were placed over those in the old pavement at 30-foot intervals. Most of the sections have a longitudinal construction joint which is, in effect, an interior edge, as adjacent slabs are neither mortised nor held together by tie bars.

An accurate crack survey was made of the old pavement to determine whether or not these cracks were reproduced in the resurfacing

The New York Highway Department made its fifth crack survey of the resurfacing in October 1932, when it was seven years old. After a study of this crack survey, which is summarized in Table I and an inspection of the pavement, the following conclusions seem possible

1 A 30-foot spacing is satisfactory for transverse joints

2 Longitudinal center joints are desirable

3 A center joint which does not provide for transmission of load across the joint, weakens the resurfacing and should be avoided

4 Where resurfacing is not accompanied by monolithic widening, an edge thickness of five inches is the minimum desirable for resurfacing carrying heavy traffic

5 An asphalt carpet entirely covering an old base is not objectionable and need not be removed

6 Of the 21 slabs in which resurfacing was continuous over transverse joints in the old pavement 16, or 76 per cent, have cracked above the old joint

7 Cracks or shattered areas in the base are not reproduced in the resurfacing, except when the resurfacing is of inadequate thickness, as indicated by failures over sound base

Experimental Resurfacing in Missouri

Two experimental resurfacing projects have been constructed by the Missouri Highway Department, the first in 1930, the second in 1931 Both were built over old concrete pavement six inches thick at the edges, eight in the middle and 18 feet wide

The 1930 experimental section is on U S 71 adjoining the south city limits of Joplin It is two miles long, of which $\frac{1}{4}$ mile is concrete and $1\frac{3}{4}$ miles various bituminous surfaces The concrete is four inches thick, proportioned 1 2 $3\frac{1}{2}$ with a $1\frac{1}{4}$ inch maximum size crushed limestone as the coarse aggregate Possibility of a bond between new and old concrete was eliminated on half the work by applying a $\frac{1}{2}$ inch coating of asphalt to the old pavement On the other half, bonding was induced by scrubbing the old pavement and keeping it wet in advance of the resurfacing All the sections contained wire mesh weighing 59 lbs per 100 sq ft

The 1931 experimental resurfacing is on U S 66 from Joplin west to the Kansas line It is four miles long and two miles of it is concrete, the other half being various types of asphalt An accurate condition survey was made of the old pavement so that the effect on the resurfacing of broken areas and cracks can be determined.

The portion resurfaced with concrete was divided into 17 sections all 20 feet wide and having a minimum thickness of four inches, but differently reinforced, having a different arrangement of tie or dowel bars, and with the new slab laid directly on the old or separated from it by tar paper or mortar.

No special loads will be run over the experimental pavement Instead it will be allowed to carry the heavy traffic using this highway which in 1928 amounted to 6,000 vehicles daily

Neither experimental pavement is old enough to permit accurate conclusions concerning the effect of the various designs

Maryland Test Road

In the spring of 1930 the Maryland State Roads Commission constructed 4,200 feet of experimental resurfacing on Annapolis Boulevard between Baltimore and Annapolis A section 1,798 feet long was resurfaced with four inches of concrete reinforced with wire mesh weighing 54 lbs per 100 sq ft Two-foot concrete shoulders, nine inches thick, widen the pavement to 20 feet and were built monolithic with the resurfacing

Expansion joints one inch wide were placed at 105-foot intervals and transverse dummy joints at 35-foot intervals between them A longitudinal dummy joint was placed on the center line. The mesh reinforcement was run across both the transverse and longitudinal dummy joints and no tie bars were used across the longitudinal joint. There was no attempt to definitely bond the resurfacing to the old base

A crack survey made in October 1932, when the pavement was two years old, indicated that mesh was holding the dummy joints together, so they could not open and relieve tensile stresses. Consequently, transverse cracks were forming at about the intervals that would have been expected if no dummy joints had been used.

An accurate crack survey was made of the old pavement before it was resurfaced When the new crack survey is superimposed on this it is found that out of 50 cracks in the new surface, only 10 have formed over cracks in the old pavement The worst cracking in the new slab has occurred over areas in the old pavement that were covered by bituminous patches

The average daily traffic over this highway in 1931 was 3,587 vehicles of which 280 were trucks and buses

Illinois' Experimental Resurfacing

In 1931 the Illinois Division of Highways constructed a 512-foot experimental resurfacing section on route 42-A, the principal highway between Chicago and Milwaukee, carrying an average daily traffic of 8,000 vehicles The resurfacing replaces a bituminous surface. It is $2\frac{1}{8}$ to $3\frac{1}{8}$ inches thick on a seven-inch concrete base Mesh weighing 100 lb per 100 sq. ft. was used in the south 255 feet of the resurfacing while the north 257 feet is plain concrete A 75-foot section built with high early strength cement was also included. This section was proportioned 1:2:3½; the other sections 1:1½:2½. The pavement was opened to traffic when the oldest section was four days and the youngest section two days old. The subgrade is swampy black soil.

The resurfacing was built without longitudinal or transverse joints, except transverse construction joints. Cement grout was brushed over the concrete base just before the resurfacing was placed.

An inspection was made when the resurfacing was one year old. There were no corner breaks nor indications of failure of any kind. Transverse cracks had appeared at approximately 21-foot intervals in

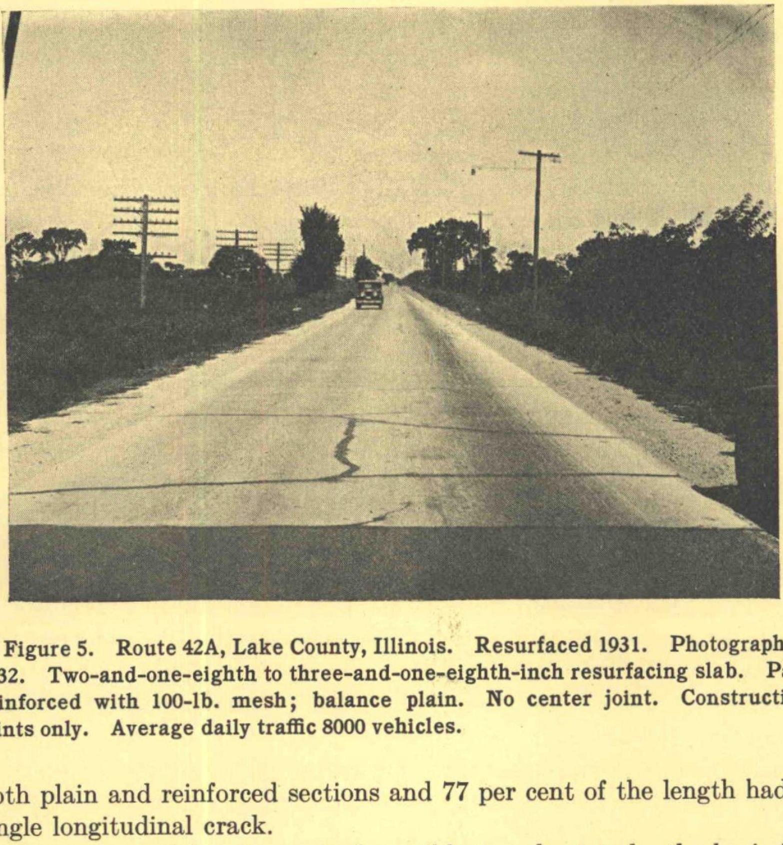

Figure 5. Route 42A, Lake County, Illinois. Resurfaced 1931. Photographed 1932. Two-and-one-eighth to three-and-one-eighth-inch resurfacing slab. Part reinforced with 100-lb. mesh; balance plain. No center joint. Construction joints only. Average daily traffic 8000 vehicles.

both plain and reinforced sections and 77 per cent of the length had a single longitudinal crack.

This pavement is too new and possibly too short to be the basis for definite conclusions. It is already evident however, that a longitudinal center joint is desirable, at least from the standpoint of appearance.

SURVEYS OF EXISTING CONCRETE RESURFACING

In 1930 the Portland Cement Association made a condition survey of 179.74 miles of concrete resurfacing in California. Of this, 21.10 miles were county built and maintained and the remainder were state projects. Streets were not included.

Faced with the necessity of completing the greatest possible mileage of paved highway with limited funds, the California Highway Department, beginning in 1912, built a large mileage of concrete bases These bases were to be surfaced with some material as soon as sufficient money could be raised, or as such surfacing was required. Until 1917 the bases were generally four inches thick, 15 feet wide and of 1 2½ 5 concrete In 1917 the proportions were changed to 1 2 4 and in 1920 the thickness was increased to five inches

Resurfacing of these bases with concrete commenced in 1919 The resurfaced bases covered in the survey were all built before 1917 and so were generally of the thin, narrow, lean mix type Most of the bases had been covered with a ⅜-inch oil mat which was left in place when resurfaced with concrete

Resurfacing surveyed included thicknesses ranging from 4 to 6½ inches, and ages from 1 to 11 years at the time of the survey (1930) The older pavements were reinforced with transverse ⅜-inch square bars extending the full width with a similar bar along each edge This was followed by a period when no reinforcement was used except short bars or mesh over the edge of the old slab During 1928 and 1929, reinforcement consisted of two ½-inch peripheral bars around each half slab, in addition to the reinforcement over the edge of the old pavement

County resurfacing surveyed consisted of thicknesses ranging from 4 to 6 inches, ages from 2 to 10 years at the time of the survey, and for reinforcement, mesh or bars over the edge of the old pavement, peripheral bars and mesh, or bar mats over the entire pavement

On most county projects surveyed a separating course of sand or disintegrated granite, usually one inch thick, was used beneath the resurfacing

As resurfacing was made necessary by structural failure of the thin, narrow bases, most of the resurfacing was placed on rather badly broken bases.

The survey recorded transverse and longitudinal cracking, edge, corner, and other breakage, joint imperfections and similar defects for each project In studying these data, projects of different ages, thicknesses, joint spacing, reinforcement, etc were grouped so that the effect of each variable could be studied

The more important conclusions from this study are

Bars ⅜-inch square, placed transversely only in 4- and 5-inch resurfacing, reduced slab lengths to below that of comparable resurfacing on which other types of reinforcing, or no reinforcing, was used This was apparently caused by the reduction in cross-sectional area of the concrete by the steel

A joint spacing of 20 feet is satisfactorily controlling transverse cracking, for all thicknesses of resurfacing This is the same spacing required to control cracking in California concrete pavements laid directly on the soil.

The dummy center joint will satisfactorily control longitudinal cracking when used on a slab of adequate cross-section.

An oil mat, or a sand cushion, separating the new and old concrete, has little effect on transverse cracking.

Dowels across transverse expansion joints materially strengthen slab ends and corners.

Special reinforcing adjacent to transverse joints, encountered on one project, materially strengthened slab ends and corners.

Tie bars across the center joint are necessary to assure continued mechanical bond.

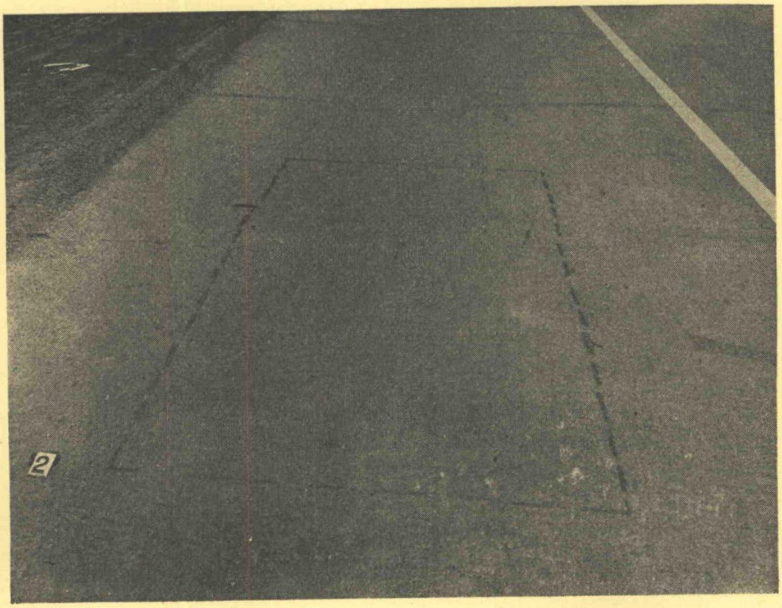

Figure 6. Route 2AB, Los Angeles County, California. Uniform four-inch resurfacing slab on four-inch base with 2½ feet by 8-inch widening shoulder. Patch in old base, as indicated by dash lines, concreted monolithic with the resurfacing, has not caused cracking in the resurfacing.

The use of reinforcement consisting of small members distributed over the width and length of the pavement is desirable.

Resurfacing four-inches thick is inadequate for moderately heavy traffic when placed on broken bases only 4 or 5 inches thick. Resurfacing five-inches thick, without a center joint, is adequate for moderately heavy traffic.

Resurfacing five-inches thick, having a center joint without provision for transfer of load across the joint, is not adequate for moderately heavy traffic when placed on thin, broken bases.

Resurfacing five inches thick, having dowels across transverse expansion joints and mechanical bond across the center joint, is adequate for moderately heavy traffic. A 6-inch thickness may be necessary for extremely heavy loads or over badly broken base.

A widening section of eight-inch uniform thickness, or one having a nine-inch edge with a 6 or 7-inch thickness at the edge of the old base, is adequate for moderately heavy vehicles. A widening section with a 6-inch edge and 4-inch thickness at the edge of the old base proved inadequate.

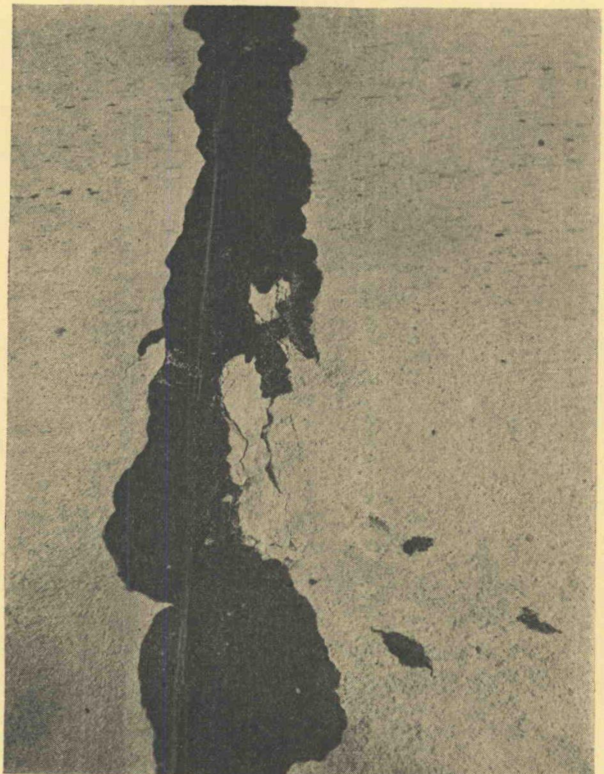

Figure 7. A transverse dummy joint in resurfacing which does not have expansion joints. Concrete at the joint is crushed by expansion stresses. Photographed in 1932. Pavement near Fort Story, Princess Anne County, Virginia.

Differential movement between the resurfacing slab and the old base is negligible and need not be provided for in design. Patches in the base pavement, constructed monolithic with the resurfacing, are not detrimental.

A less detailed survey was also made of concrete resurfacing in Washington, Idaho and Utah. In Washington, streets were studied as well as roads. Resurfacing thicknesses ranged from 3 to 6 inches, reinforcement from none to $\frac{3}{8}$-inch square bars, 18 inches apart, and ages from 1 to 9 years.

Besides confirming the important conclusions from the California survey, especially the need of mechanical bond across the center joint, the following additional conclusions were made possible

A three-inch edge thickness is not enough for resurfacing on roads carrying moderately heavy traffic

Resurfacing of thin cross-section should include widening built monolithic with the resurfacing to avoid edge weakness, and longitudinal joints should be avoided over the edge of the old pavement

Welded wire mesh weighing 28 pounds per 100 sq ft held together cracks in three-inch resurfacing

Four miles of four-inch concrete resurfacing in Virginia, built on a sand cushion, is in very fine condition after carrying light traffic for one year A short section, laid directly on the old concrete, and another in which new and old concrete were separated by a bituminous paint coat, are in equally good condition

Transverse joints are of the dummy type only Lack of expansion space has resulted in six joints which have been raised or crushed by expansion stresses Apparently relief of expansion stresses is even more important in the thin slabs used for resurfacing than in ordinary concrete pavements

SURVEY OF CONCRETE STREET RESURFACING

A survey was also made of resurfacing on streets Since the Syracuse Test Road and the California survey both indicate that 4 inches is the critical thickness, the older street resurfacing of that or less thickness was selected for study, though some thicker pavements were also included

Resurfacing 5 to 6 years old having a minimum thickness of two inches, reinforced with 42 pound mesh, was inspected in Battle Creek, Mich , 20-year old slabs having a thickness of 1 to 2 inches, reinforced with light mesh, in Toledo, Ohio, 2 to 3-inch slabs, five years old, reinforced with 40-pound mesh in Lexington, Ky , 2 to 3-inch slabs, 18 years old, reinforced with light mesh in Savannah, Mo , 2 to 3-inch plain slabs 9 to 11 years old in Des Moines, Ia , 3 to 4½-inch, 14 year old resurface in Terre Haute, Ind , containing 48-pound mesh and 3 to 4-inch slabs 30 feet long, containing 42-pound mesh on the main business street of Oswego, N Y were inspected Reports were also secured on resurfacing in Atlanta and Rome, Ga , where 2 to 8 year old resurfacing without reinforcement and from ¼ to 7 inches thick, averaging 2½ inches, was constructed by the Vibrolithic process The Des Moines and Georgia resurfacing was done as repair to pavements damaged during construction and was placed when the base pavement was only a few days old.

Resurfacing four or more inches thick, plain or reinforced with mesh or bars, and from 1 to 20 years old was surveyed at Lexington, Ky , Terre Haute, Ind , Champaign, Urbana and Granite City, Ill , Cape Girardeau and Kirksville, Mo , and Marshalltown, Iowa

Conclusions from the survey of street resurfacing are as follows

Resurfacing thinner than four inches is only satisfactory for strictly residential streets carrying vehicles of light-weight, or where the base pavement is new and unbroken

Over flexible or badly broken base pavements, a thickness of five inches is desirable At longitudinal joints along which loads can run and which are not aided in carrying load by mechanical bond with an adjacent slab, greater slab thickness should be obtained, even at the expense of chipping off or removing part of the base Such joints frequently are encountered along street railway tracks

Very thin resurfacing may be satisfactory over pavements only a few days old For very thin resurfacing, bond with the base is essential Bonding is aided by thoroughly ramming or vibrating the fresh concrete

Reinforcement is desirable, provided transverse joints are not over 50-feet apart and reinforcement does not extend across them

Longitudinal joints are necessary to control longitudinal cracking

SPECIAL TYPES OF RESURFACING

In Kansas City, in 1930, resurfacing from 0 to 1-inch but largely $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, was placed on scaled concrete pavement in the car track area and is still in good condition The old pavement was cleaned by a wet sand blast from a cement gun The cement gun then applied the resurfacing mortar

Experimental resurfacing averaging $\frac{1}{2}$-inch thick has also been built in car track areas in Cleveland and Cincinnati The concrete topping contained $7\frac{1}{2}$ sacks of cement per cubic yard and was obtained with an International tamper

The work is too new to warrant conclusions concerning its success although after one year it is in good condition

DESIGN OF RESURFACING

The features to be determined in designing resurfacing are

- Thickness of resurfacing
- Thickness of widening
- Joints—type, location and spacing
- Reinforcement—type, size, location
- Maximum size of coarse aggregate
- Proportions for the concrete
- Bond with or separation from the old pavement

Thickness

Recommended thicknesses for various classes of support and traffic are indicated in Table II As a rational theoretical calculation of

Figure 8. Five-inch resurfacing increasing to seven inches over edge of old base. Center joint having no mechanical bond nor tie bars. Mesh in outer 4 feet of old slab only. Longitudinal cracking 2 to 3 feet from center joint because of lack of bond across joint. Badly broken base.

Figure 9. Five-inch resurfacing (along center line). No reinforcement. Three corner breaks at intersection of joints having neither dowels nor tie bars. Center joint a butt construction joint without tie bars. No dowels across transverse joint.

such thicknesses has never been accepted the thicknesses given are based on the conclusions of the surveys already described.

Widening

When the pavement is resurfaced and widened by the addition of concrete shoulders, the shoulders should be built monolithic with the resurfacing, to provide extra edge strength for the resurfacing. If full traffic lanes are added to the width a narrow concrete shoulder (say one foot wide) should be built monolithic with the resurfacing. The thickness of the widening section should be the same as for a standard concrete pavement laid on an earth subgrade, i.e., the edge should have

Figure 10. Three-and-one-half-inch resurface on four-inch base with widening section eight inches deep. Joint space not cut through to old base. Resulting underspall faulted joint and caused joint breakage under loads.

the thickness $D = \sqrt{\frac{3W}{S}}$ which should taper to a minimum thickness of $0.7D$ not less than two feet from the edge. Or if a uniform thickness is preferred for the widening, it may be made D 1. In the formula D is edge thickness in inches, W the expected wheel load in pounds and S the allowable modulus of rupture, usually assumed to be 300 lb. per sq. in. for normal paving concrete.

Joints

Longitudinal joints should divide the slab into strips not more than 15-feet wide. For economy, transfer of part of the load across the joint should be assured by providing a mortised or dovetailed joint, held together by tie bars, or by making reinforcement continuous across it Since deformed metal plate is difficult to hold upright on old pavement, the dummy type of joint seems best adapted to resurfacing This should have a depth from $\frac{1}{4}$ to $\frac{1}{3}$ the depth of the resurfacing

Where part-at-a-time construction is used the joint may be mortised by providing a groove in the edge build first, with the usual tie bars

If no transfer of load by the joint is provided for, additional slab thickness at the joint is needed for a balanced design

Expansion joints are needed in resurfacing Since they are a point of weakness, it seems wise to space them as far apart as possible A one-inch joint at 100-foot intervals is recommended

TABLE II

RECOMMENDED THICKNESS FOR RESURFACING

Traffic	Rigid old pavement not badly broken		Rigid pavement badly broken	
	No free* joints or edges	Free joints or edges along which wheels can run	Joints or edges not free	Joints or edges free
Strictly local traffic of light-weight vehicles on residential street	3 inch thickness	4-inch or 3-inch thickened to 4 at joints and edges	4-inch	5-inch or 4-inch thickened to 5 at joints and edges
Business or Through Streets or County Roads Carrying Moderately Heavy Vehicles	4-inch	5-inch or 4-inch thickened to 5 at joints and edges	5-inch	6-inch or 5-inch thickened to 6 at joints and edges
Road or street carrying a large volume of heavy vehicles	5-inch	6-inch or 5-inch thickened to 6 at joints and edges	6-inch	7-inch or 6-inch thickened to 7-inch at joints and edges

* Free joints are those without tie bars, dowels or mechanical bond to assure the adjacent slab carrying part of the load Free edges are those far enough from curbs to permit wheels to travel along them or edges not monolithic with a widening section

The slab length required to control transverse cracking depends upon the condition of the old pavement, maximum size of coarse aggregate and type of coarse aggregate In general the economic joint interval for resurfacing is 25 feet This should be decreased to 20-foot for glassy, siliceous aggregates and for coarse aggregate of less than one-inch maximum size, and may be increased to 30 or 35-feet for rough surfaced crushed stone, such as granite and limestone Survey data also indicate that a shorter joint spacing is required to control cracking in resurfacing placed over badly cracked old base

Joint layout in intersections is the same as for standard concrete; a square or rectangle formed by expansion joints in line with the straight curb of the intersecting streets, with diagonal expansion joints from the corners of the rectangle to the return curb, and the rectangle quadrated by the center joints of the intersecting streets. Acute angled or offset intersections are made to approach this design as closely as possible, avoiding the intersection of joints at angles of less than 60 degrees.

Expansion joints in resurfacing need not extend through the old pavement. Transverse joints should either be exactly over any old joints, or not less than 6 or 8 feet from them.

Figure 11. Longitudinal crack (marked by pencil) over a dowel not placed parallel to surface of slab. Corner crack also starts over dowel. Joint itself is properly placed. Old base not broken.

It is extremely important that construction defects be eliminated from transverse joints in resurfacing, else expansion stresses will damage the thin slabs. Joint faces must be accurately perpendicular to the subgrade, the full depth of expansion joints be unobstructed by concrete or other solid material and dowels accurately parallel to surface and center line.

Dowels and Tie Bars

Dowels are desirable across all transverse joints. The $\frac{3}{4}$-inch round bar, 3 to 4 feet long, spaced two-feet center to center, is recommended for slab thicknesses of four inches or greater. For slabs less than four

Figure 12. Breakage at an expansion joint which had faulted one-inch

Figure 13. Above joint (Fig. 12) with broken concrete removed. Note sloping face, which caused the faulting. In this case, as in others noted, dowels did not prevent faulting.

inches thick, ½-inch round bars 30-inches long, spaced 18-inches center to center are recommended. The usual provision should be made for slippage and clearance. Sleeves should be of metal and fit so tightly they can barely be forced on by hand. Dowels must be installed parallel to the center line and surface of the slab else they will damage the slab.

Tie bars of sufficient cross-sectional area to sustain twice the weight of the slab on one side of the joint, should hold slabs together across all longitudinal joints designed to transmit load. They should bond with the concrete in both slabs and be embedded 40 diameters in each slab.

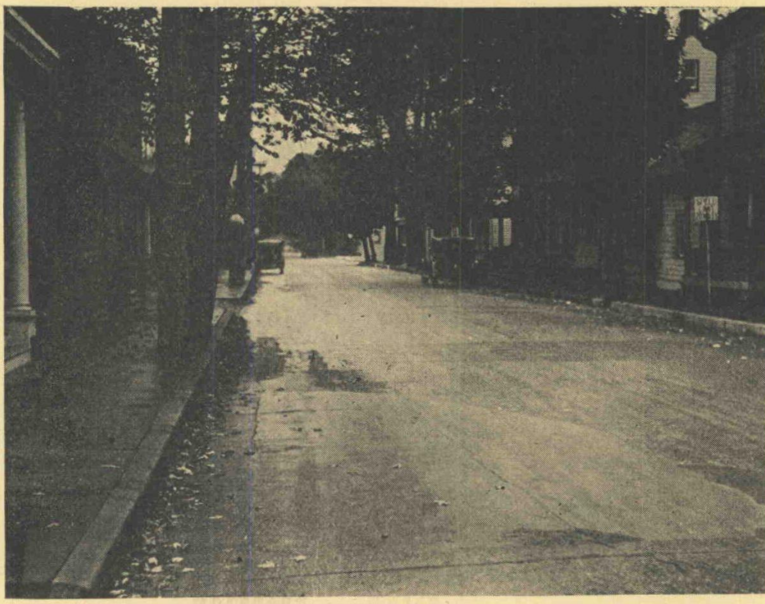

Figure 14. A concrete patch 0 to ¾-inch thick and seven years old. Patch is in Mannheim, Penn. and was put in because the contractor had left a low spot in the pavement. The pavement was one year old when patch was put in. Patch in perfect condition with no scaling of thin portion.

Reinforcement

No conclusive tests have been made to determine the friction of concrete being pulled over concrete, so the common formula for reinforcement cannot be applied to resurfacing, laid directly on the old pavement. Experience indicates, however, that mesh or small diameter bars weighing from 40 to 50 lbs. per 100 sq. ft. are satisfactory. In some cases lighter reinforcement has been almost equally satisfactory.

For the thinner resurfacing slabs large reinforcing members seem undesirable, first because they reduce the cross-sectional area of the pavement and so cut down the tensile strength of the slab and second, because if designed for too long a slab, additional cracking may occur.

Reinforcement should not extend across transverse joints nor should reinforced slabs be longer than 40 or 50 feet, because then the tensile stresses carried across cracks by the steel will tend to cause additional transverse cracks.

Proportions and Aggregate Size

The proportions used in standard concrete pavement are suitable for resurfacing, regardless of the proportions used in the pavement being resurfaced.

Figure 15. Close-up of edge of above patch (Fig. 14) where it is zero inch thick. No scaling after seven years of "Main Street" traffic.

The maximum size of coarse aggregate should not exceed one-third the depth of the resurfacing. If small sized coarse aggregate is used, the concrete should be proportioned accordingly.

Bond Between New and Old Concrete

Special measures to prevent bond do not seem justified, nor removal of a coating of oil or asphalt to secure bond, except in the case of very thin resurfacing.

Where concrete is placed on the concrete of an old base, where some bond is bound to occur, due to the roughness of the base, it seems wise to get the best possible bond so that stresses due to bond will be evenly distributed.

Thorough washing of the old concrete with brooms and water, followed by a fairly wet "butter coat" of cement mortar, applied a few minutes ahead of the resurfacing, and thorough compaction to assure good contact of old and new concrete, are the means usually employed to secure bond.

Cost

Except for finishing, form setting and curing, which are the same per square yard, regardless of slab thickness, concrete pavement cost is directly proportional to thickness.

For resurfacing, the effect of the constant cost of these items is more than offset by the entire elimination of subgrading. It is, therefore, conservative to say that, exclusive of reinforcement, the cost of resurfacing bears the same relation to the cost of new concrete pavement as its thickness bears to the thickness of equivalent concrete pavement.

It is therefore economical to resurface with concrete whenever the resurfacing slab required would be thinner than the new concrete pavement for the same location.

There is such a wide range of costs for different parts of the country, and for recent years, that no attempt is made to include actual cost data.

In one case (Lexington, Ky.) 2 to 3 inches of concrete base was chipped off with pneumatic tools to permit use of a 5-inch resurfacing slab. This chipping cost $0.40 per sq. yd. in 1927.

DISCUSSION
ON
RESURFACING WITH PORTLAND CEMENT CONCRETE

Mr. R. D. Bradbury, *Director, Wire Reinforcement Institute.* As a member of the resurfacing subcommittee the writer, through the staff of the Wire Reinforcement Institute, has conducted during the past year an independent survey and study of concrete resurfacing.

In selecting examples for study, it seemed desirable to choose projects which had served for several years under traffic, which contained some experimental feature, or which included several variables in design features. Some fifteen rural highway projects were thus selected, analyzed and studied in an effort to determine the most desirable features of design. Projects studied are located in 11 states, are of ages from 1 to 10 years, are of various designs, and were built under various procedures.

In general, the findings of our investigation are in close agreement with the statements and conclusions presented in the report. Many of these observations are in remarkably close agreement, when it is realized that the surveys and studies were independently made on data obtained largely from separate sources. While it is my opinion that the report presents a very creditable discussion of this timely subject and also a most comprehensive outline of suggested design procedure, still I feel that certain general conclusions are open to question and that other phases of the problem are of more importance than the report would indicate

The Syracuse Test Road, known as New York Project No 5470, has served as a most excellent specimen for making direct comparison of certain features, since it was built as an experimental resurfacing project and accordingly contains a variety of design variables, all subjected to the same subgrade, climatic and traffic conditions The committee report presents certain conclusions drawn from a study of this project While I am in full accord with these conclusions, I am of the strong opinion, as based upon our analysis, that a definite conclusion can and should be drawn as to the very evident behavior of the resurfacing as influenced by distribution of the reinforcement Excellent opportunity for making this direct comparison is offered by this particular project, since it contains numerous sections reinforced either with small members closely spaced or larger members widely spaced and with other conditions substantially the same

In our analysis of this project attempt was made to classify old pavement condition by an arbitrary rating based upon the number of pieces into which an original 30 by 16-ft slab had become broken Four such groupings were made and considered as indicating excellent to poor condition of the old slab Thus three important variables were considered, (1) condition of old pavement, (2) resurface thickness, and (3) distribution of reinforcement

Analysis of resurface behavior on this project, as gauged by total lineal footage of crack in a given slab section, indicates very clearly that small reinforcing members closely spaced are more effective in resisting progressive crack formation than are large members wider spaced This is apparent in every comparison and in every group where more than one or two specimens are available for study Disregarding the several groupings as to old pavement condition and resurface thickness, 35 per cent of the slabs reinforced with closely spaced members are in perfect condition at seven years, while no slab reinforced with larger members more widely spaced is in perfect condition ("Perfect condition" indicates a 30 by 16-ft slab with no cracking except one longitudinal crack or joint)

This same relative effectiveness of the two types of steel distribution was noted at the two year age, as reported by H E Breed in the procedings of the Fourth Annual Meeting of the Highway Officials of the North Atlantic States, in which the following conclusion on the Syracuse Project was drawn "The evidence of the entire survey extending over the two year period indicates that reinforcement gains effectiveness by distribution throughout the pavement " (A survey made at the age of 5 years confirms the above conclusion)

Continuing, Mr Breed stated that in the case of the four-inch slabs reinforced with widely spaced members, 25 per cent of the old pavement cracks had appeared through the resurfacing, while in the case of four-inch slabs reinforced with closely spaced members, less than 2 per cent of the cracks had so appeared In the case of the 3½-inch slabs these respective percentages were 46 and 6 He added further that, "No matter how you scrutinize the evidence behind these figures, the result is favorable to small members closely spaced with an equal distribution of steel (except at edges and corners) for the work or resurfacing "

Thus at the ages of 2, 3, 5 and 7 years, there is definite evidence, as developed by totally independent investigations, to the effect that small members closely spaced have proved more effective in this resurfacing project than have larger members at wider spacings

The general principle of increased effectiveness resulting from a closer spacing of reinforcing members is neither new nor is it peculiar to resurfacing slabs This conclusion was developed with reference to concrete pavements some years ago by the extensive investigation of "The Economic Value of Reinforcement in Concrete Roads" reported at the Fifth Annual Meeting of the Highway Research Board by C A Hogentogler It is, however, pertinent to the discussion at hand to observe that two independent surveys of the Syracuse Project corroborate the conclusion in its application to resurfacing slabs as well It would thus appear that this particular project, wherein direct comparisons are possible, has developed nothing to refute that conclusion but on the contrary gives definite indication that a close spacing of reinforcing members is particularly beneficial in resurfacing where relatively thin slab sections are encountered

In presenting conclusions on the California Resurfacing Survey, the report states that, "An oil mat or sand cushion, separating the new and old concrete, has little effect on concrete cracking " In view of the fact that this reference pertains to resurfacing laid over a very thin original pavement, in most cases, no thicker than 4 inches, it could hardly be construed as being applicable as a general statement where thicker bases are involved The question of whether or not a surface evener and bond breaker is beneficial in resurfacing is open to question Instances were noted in our survey of projects laid directly on the old base without any attempt to break bond between the old and new work that were in entirely satisfactory condition On the other hand several projects indicated that a bond-breaker and surface-evener on the old slab were definitely beneficial These indications were revealed by the Lynnhaven Project in Virginia, the Clio Road Project in Michigan, Grand Avenue, Wayne County, Michigan, Mt Morris to Clio Road, Michigan; Biltmore, North Carolina, Syracuse, New York, and Iowa 306.

In the Lynnhaven Project particularly, although this project is scarcely a year old, strong indications are presented to the effect that a bond-breaker is beneficial It is realized, of course, that if the bond-breaker consists of a comparatively thick layer of compressible material adequate support for the thin resurfacing slab under the action of heavy traffic loads may not be obtained On the other hand if the bond-breaker is of such a character and thin enough to not introduce this element of intermediate yielding support, breaking of the bond would seem logical as a means of relieving the otherwise high friction between the old and the new work This must necessarily have some effect upon the transverse cracking of the slab as developed by contraction

The Lynnhaven Project offers comparison on this feature as sections were built both with and without breaking the bond between the new and old work In the 500 foot length constructed over a mastic cushion and with transverse joints at 45 feet, no cracks had appeared at the age of three months, and at the age of seven months the pavement was reported to be in excellent condition In this same project the 200-foot section laid directly on the old concrete developed nine visible transverse cracks and several longitudinal cracks at the age of three months, and at the age of seven months was reported as cracking progressively with many of the old slab cracks appearing in the resurfacing This project, wherein a direct comparison is possible, would thus seem to indicate that some form of bond breaker is desirable, even where relatively short (33 ft) slab lengths are employed

Our independent survey and analysis of the projects herein mentioned lead to the following general conclusions

Condition of Old Pavement The extent of cracking, breakage and unevenness of surface of the old pavement exerts a general influence on the ultimate structural condition of the resurfacing slab

This influence is strongly resisted and often overcome through the use of increased thickness, properly designed steel reinforcement, a "bond breaker" between slabs, and the use of frequent joints (Syracuse, N Y 5470, Mt Morris, Michigan, Lynnhaven, Va , Clio U S 23 Michigan, N Y 5382 Oswego)

Surface Treatment of Old Slab Although several of the projects in satisfactory condition have been built by laying the new slab directly on the old pavement surface, the practice of covering the old slab first with a thin layer of material such as asphalt, tar, paper or sand is shown to be definitely beneficial (Lynnhaven, Va , Wayne County, Michigan, Clio U S 23 Michigan, Mt Morris, Michigan, Biltmore, North Carolina, Iowa 306)

Thickness. Increasing resurface slab thickness up to some indefinite point near 5 or 6 inches is effective in decreasing the amount of cracks appearing in a given resurfacing slab (Syracuse N Y. 5470, Mt. Morris, Michigan, Pennsylvania 221)

Increasing thickness is more effective on badly cracked old pavement than on pavement in relatively good condition (Syracuse N Y. 5470)

A four inch minimum thickness properly reinforced with small members at close spacings has proved fully adequate in projects of various ages Even 3-inch and 3½-inch mesh reinforced projects have given satisfactory service (Conn 29A, Mo 32, Mo 71, Syracuse, N. Y 5470, Penna 221, Wayne County, Mich , Lynnhaven, Va)

Reinforcement The use of reinforcement composed of small members at close spacing is especially desirable in resurfacing slabs (Conn 29A, Syracuse, N Y , Mt Morris, Michigan, Clio U S 23 Michigan, Iowa 306. Wayne County, Michigan, Missouri 32, Missouri 71, Lynnhaven, Va , Ohio 245, and prevalent use in current practice)

Small members at close spacing are more beneficial than similar amounts of larger members at wider spacing (Syracuse, N Y. 5470)

The 42 to 50 lb per 100 sq ft weights of well distributed reinforcement appear to be as beneficial as heavier weights, in slabs up to 60 feet long (Syracuse, N Y 5470)

Reinforcement should not extend through transverse joints

Transverse Joints The use of transverse joints at spacings of 30 to 50 feet appears advisable Transverse joint spacing may be increased where the old slab is given a thin bituminous surface treatment or where paper or sand is used With such treatments and mesh reinforcement, slabs up to 100 feet spacing have proved satisfactory, at least at early ages (Clio U S 23 Mich , Lynnhaven, Va)